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Contents

The Investigations of Heating Process in Solar Air Heating Collector

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Abstract. The aim of the research is to find the optimal technical solutions, utilized materials as absorbers, operation parameters and power possibilities for a solar collector. Different absorbers of sun radiation, the absorbers' ability and efficiency in air heating solar collector are compared.
0.1 x 0.5 x 1.0 meters long equipment for experimental research into the materials of solar air heating collector was built. The experimental data were measured and recorded in the electronic equipment REG. The investigations are devoted to the sun following collectors, which guarantee perpendicular location for all experimental time of the plane of absorber to the flow of the sun radiation. The collector covered material was a polystyrol plate and absorbers were: a) black colored steel tinplate and b) slices of black colored beer cans.
The use experimental data received expressions of heating degree of air in collector depending on sun radiation and distance from absorber (steel tinplate) at 35 cm and 60 cm from inlet.
In favorable weather conditions the heating degree of the ambient air with absorber black colored slices of beer cans reaches more than $\Delta T = 10^{o}$ C at the air velocity 0.9 m s^{-1}.

Key words: Solar collector, air, temperature, absorber

INTRODUCTION

The greatest advantage of solar energy compared to other forms of energy is that it is clean and can be supplied without environmental pollution. Over the past century, fossil fuels provided most of our energy, because they were much cheaper and more convenient than energy from alternative energy sources, and until recently, environmental pollution has been of little concern. The limited reserves of fossil fuels cause a situation in which the price of fuels will accelerate as the reserves are diminishing.

Solar energy is used to heat and cool buildings (both actively and passively), to dry production, to heat water for domestic and industry use, to heat swimming pools, to generate electricity, for chemistry applications, and many more operations (Kalogirou, 2009).

The application of solar energy is completely dependent on solar radiation, a low-grade and fluctuating energy source. An intrinsic difficulty in the use of solar energy lies in the wide variation of solar radiation intensity. The availability of solar radiation depends not only on location, but also on the season. Extreme differences are experienced between summer and winter, and from day to day.

In general, solar water and solar air heaters are flat-plate collectors (FPCs), consisting of an absorber, a transparent cover, and backward insulation. Despite the similarity in design, the different modes of operations and different properties of the heat transfer medium greatly affect the thermal performance and electric energy consumption for forcing the heat transfer medium though the collector. Solar water heaters are operated as a closed-loop system whereas, in most cases, solar air heaters are operated in the open-loop mode.

The performance of solar air heaters is mainly influenced by meteorological parameters (direct and diffuse radiation, ambient temperature, and wind speed), design parameters (type of collector, collector materials) and flow parameters (air flow rate, mode of flow). The principal requirement of these designs is a large contact area between the absorbing surface and the air.

The efficiency of a solar collector depending on collector covering materials (polyvinylchloride film, cell polycarbonate PC, translucent roofing slate), the absorber (black colored wood, steel-thin plate, etc.), together with different air velocities in the collector has been investigated (Lauva et al., 2006; Aboltins et al., 2007; Palabinskis et al., 2008; Aboltins et al., 2009). The main efficiency parameter of a solar collector is the air heating degree which we choose as criterion of efficiency.

The FPC absorber plane is perpendicular to the flow of sun radiation at the sun following collector; therefore, this type is more powerful than a stationary collector. The sun rays fall at an angle to the collector plane (i.e. they fall at an angle to the covered material), which gives more reflection.

MATERIALS AND METHODS

The aim of our investigations was to specify the air heating degree of solar collector at distance from the absorber’s steel-thin plate.

Experimental results and statistical processing data were used to find connectedness between collector length, sun radiation to absorber plate and air temperature exchange in FPC with absorber steel-thin plate. Expressions were got for air temperature over and under the steel-thin plate absorber in the solar collector (Aboltins et al., 2009).

In this article we are studying the influence of collector thickness on air heating degree at 35 cm and 60 cm length from input. In the laboratory a 0.1 x 0.5 x 1.0 meter long experimental solar collector was constructed for investigation into the properties of absorber materials. Air velocity in the experiments was $v = 0.9$ m s^{-1}. Our investigations concerned the sun following collectors, which guarantee perpendicular location of the absorber plane from the flow of sun irradiance.

In the experiments, the collector covering material was a polystyrol plate. This material has gained immense popularity due to such properties as safety, mechanical crashworthiness, translucence and high UV radiation stability. The covering material – polystyrol plate – reduced irradiance by 12-15%.

We studied a situation when the absorber (a black steel-thin plate) was put at the bottom of the collector (Figs. 1-2)

Experimental data are recorded by means of an electronic metering and recording equipment for temperature, radiation and lighting REG (REG, 2004). It is equipped with 16 temperature transducers and metering sensors for solar irradiance and lighting. Reading time of data can be programmed from 1 to 99 minutes (1 minute in our case).

Fig. 1. Sun following collector with steel-thin plate absorber.

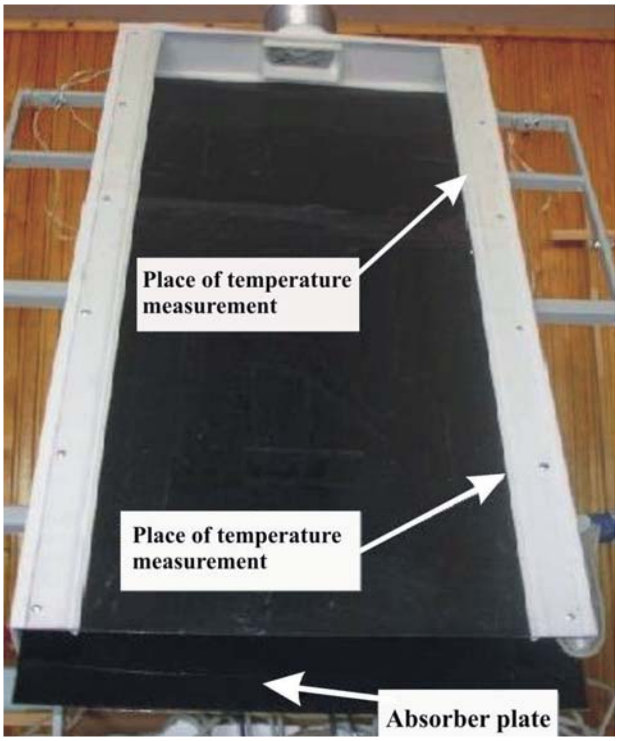

Fig. 2. View of solar collector with steel-tinplate absorber.

The recorded data are stored in the REG memory (there is place for 16,384 records) and in case of need it is transferred to a computer for archiving with further processing. For evaluation and analysis of results, the software REG-01 has been developed, which is meant for transferring to the computer and processing the recorded data. Information is stored in the form of a table and in case of need it is depicted as a graph.

RESULTS AND DISCUSSION

Using experimental results and statistical processing data we received connectedness between distance from absorber, sun radiation to absorber plate and air temperature exchange in collector. We got expressions for air temperature exchange over steel-thin plate absorber in FPC at 35 cm and 60 cm from inlet.

Temperature exchange ΔT over absorber at 35 cm distance from input can be expressed with the following equation:

$$\Delta T = 0.00385 \cdot R + 0.213 \cdot y - 0.032 \cdot y^2 - 4.6 \cdot 10^{-5} \cdot R \cdot y - 0.8 , \quad (1)$$

where y - distance from absorber, (cm), R - sun radiation (W m^{-2}).

Close connection of this expression shows coefficient of determination $\eta^2 = 0.804$ in temperature increase domain $\Delta T \in (0; 3)\,^{O}C$. The graphical interpretation of this expression is shown in Fig. 3.

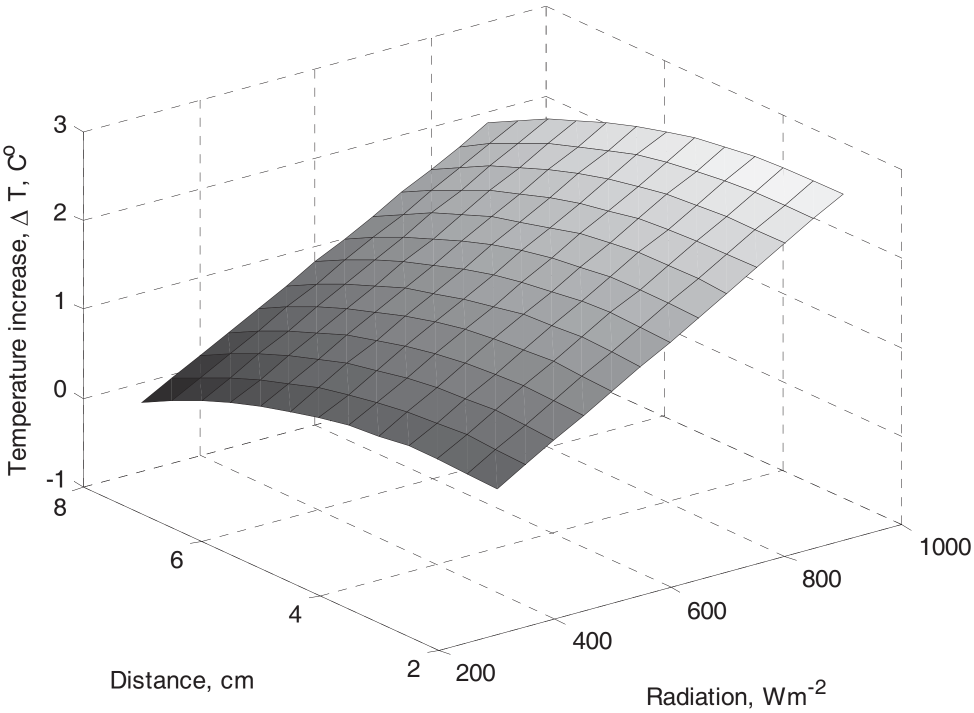

Fig. 3. Plot of air temperature increase ΔT depending on distance over absorber y (cm) and radiation R (W m^{-2}) at 35 cm from inlet.

Temperature exchange ΔT over absorber at 60 cm from inlet can be expressed with the following equation:

$$\Delta T = 1.57 + 0.011 \cdot R - 4.15 \cdot 10^{-6} \cdot R^2 - \\ - 0.348 \cdot y + 0.037 \cdot y^2 - 2.06 \cdot 10^{-4} \cdot R \cdot y \quad (2)$$

with coefficient of determination $\eta^2 = 0.855$.

The visual interpretation of expression (2) is shown in Fig. 4 as contour plot.

The efficiency of solar air collectors is influenced both by the design and air circulation and by the properties of the material used for cover, absorber and insulation. Considering its short useful life, the material and the production costs are the main selection criteria. The influence of air circulation on the efficiency is relatively low for a low temperature rise, while solar air heaters with air flow underneath or above the absorber show significantly higher value of efficiency in a higher temperature range.

We tested new absorber materials which can be used in hand made air heated solar collectors. These materials must be cheap, light and simple to use. We made a panel of colored 3 cm wide slices of beer cans, which was attached to the pressboard with 9 rows perpendicular to the airflow (Fig. 5-6).

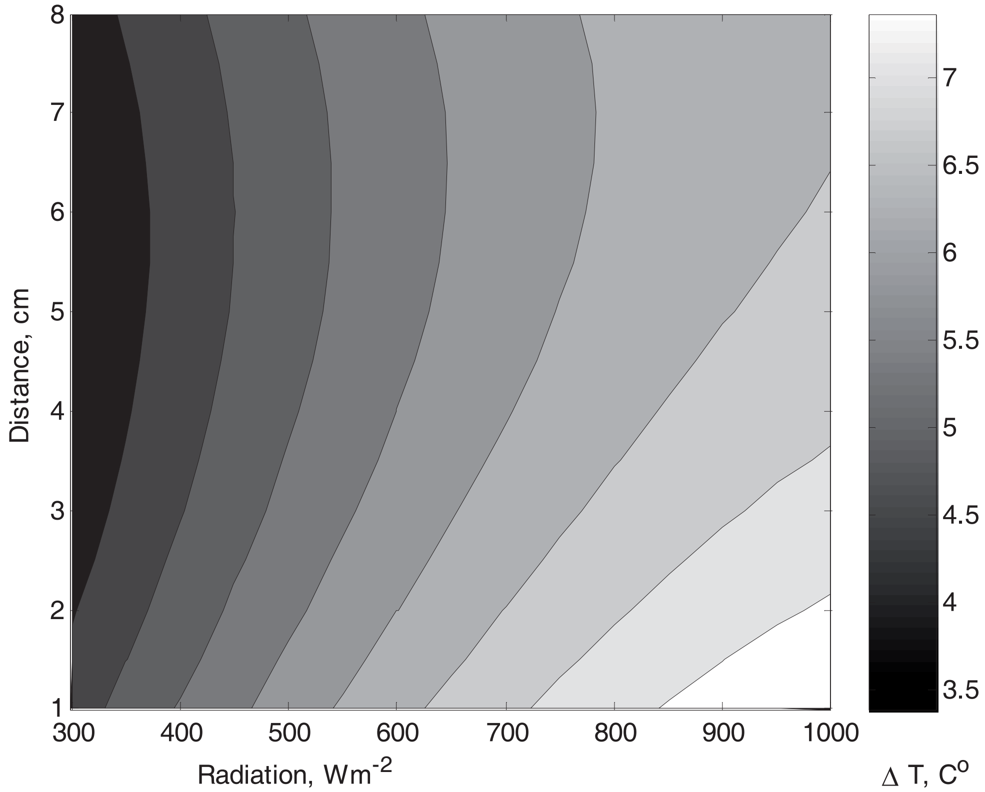

Fig. 4. Contour plot of air temperature increase ΔT depending on distance y (cm) over absorber and radiation of the sun R (W m^{-2}) at 60 cm from inlet.

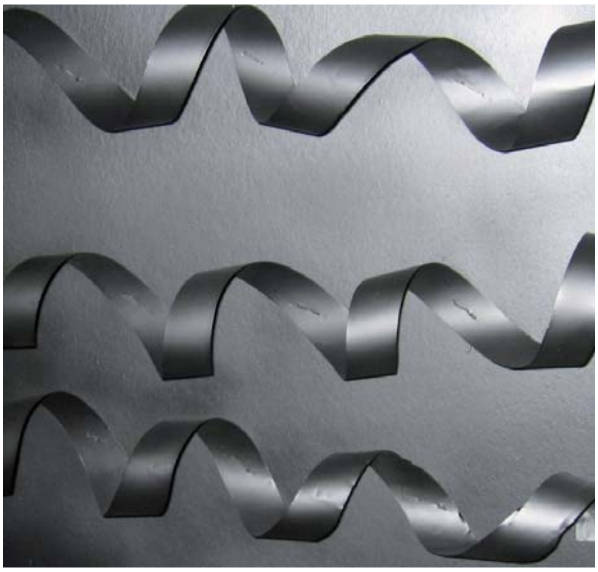

Fig. 5. Black colored slices of beer cans as absorbers of air collector.

Fig. 6. Air heating solar collector with absorber black colored slices of beer cans.

The area of the slices was 0.26 m^2. These slices help to mix air flow in collector and rise outlet air temperature.

The air heating experiments with this collector were made in different weather conditions. The instrument for measuring solar radiation is a pyranometer. The data on sun radiation depend on the clouds and shadows, and we aligned the experimental data with the method of least squares, using the following function (Vedenjapin, 1967):

$$\overline{y_i} = \frac{1}{35}[17y_i + 12(y_{i-1} + y_{i+1}) - 3(y_{i-2} + y_{i+2})]$$

where $\overline{y_i}$ - aligned data, y_i - experimental data, i - ordinal number.

Experimental data show that temperature difference in outlet of collector reaches up to 9-11 degree with sun radiation 1,000 W m^{-2} in different weather conditions. One of experimental (31 July 2009) data graph we can see in Fig. 7.

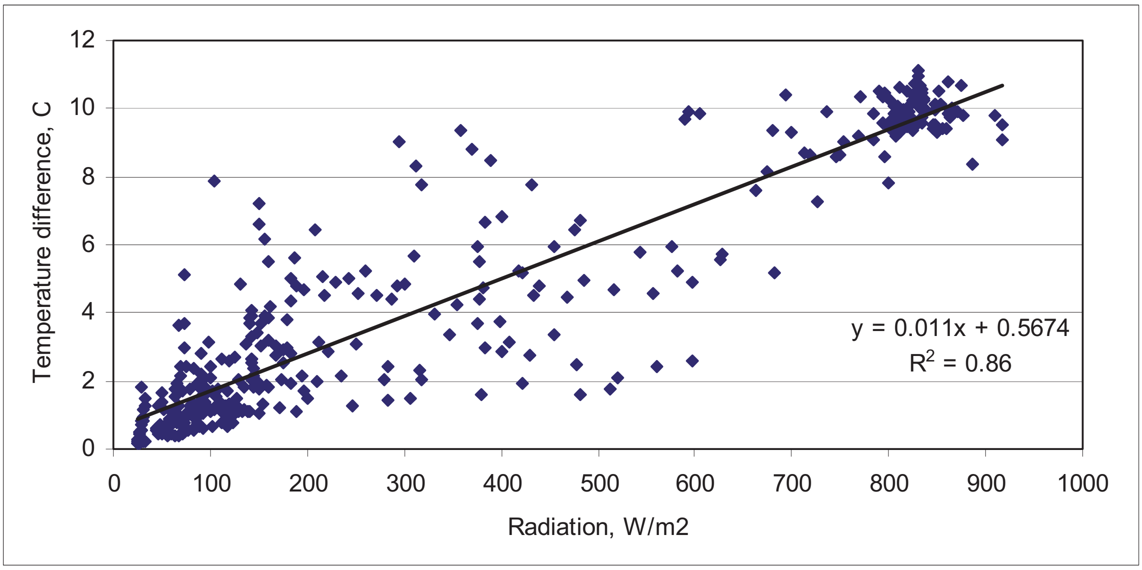

Fig. 7. Air heating temperature difference in case of black coloured slices of beer cans absorber depending upon solar radiation in a sun following collector (11:00 to 20:00 o'clock).

The slope of connection between sun radiation and ambient air temperature increase in collector outlet is in the range [0.009; 0.012].

This type of absorber gives better results than other types of absorbers (black colored wood, steel thin plate). Sun following collector's efficiency (air temperature grows) is closely dependent on sun radiation. The plate of this collector was perpendicular to the flow of sun radiation. The ambient air temperature grows in stationary collector outlet in case of a similar absorbent (slices of cans) and the location of absorbent is three, four degree less than that of the sun following collector.

The efficiency of this absorber material can be explained with the type of absorber which mixes air flow in the thickness and width of the collector area. It is important because without air mix, air exchange at corners and near sides of collector will not take place.

CONCLUSIONS

1. Theoretical expressions for air temperature which exchanging over steel-thin plate absorber in FPC at 35 cm and 60 cm from inlet are obtained. These expressions show temperature decrease depending on distance,
2. Absorber black colored slices of beer cans can use solar collectors for air heating. Experimental data show the temperature difference in the outlet of a sun following collector which reaches up to 9-11 degrees with sun radiation 1,000 W m^{-2}at different weather conditions.
3. When comparing a sun following and a stationary collector's temperature heating degree, then in the former it is 3-4 degrees higher (with sun radiation 1,000 W m^{-2}) than in the latter with absorber black colored slices of cans.
4. An air solar collector is due to its physical and mechanical properties suitable for heating the air in Latvia. In favorable weather conditions, heating degree of ambient air reaches over 10 degrees at exit with absorber length 1m and air velocity v = 0.9 m s^{-1}.

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New Method for Stabilization of Wind Power Generation Using Energy Storage Technology

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Abstract. Wind power appears to be one of the most perspective and widespread renewable energy sources in Estonia. However, wind is difficult to forecast. This complicates production planning and parallel operation with compensating power plants, allowing periods of excess energy and lack of energy to occur. This paper proposes a new energy storage technology to compensate unstable operation of windmills. This is based on a hydrogen buffer, which accumulates excess energy from windmills and transfers it to the DC-link of windmills converter. As all components of the hydrogen buffer are electrically connected to the DC-link, there are three main stages. The first stage is hydrogen production, which is realized with the help of water electrolysis in periods of excess energy. Interfacing is carried out with electrical components, such as DC/DC converter with a step-down isolation transformer. The second stage is hydrogen storage and delivery. The produced hydrogen is accumulated in a tank locally or in industrial gas storage. Hydrogen may be mixed with natural gas and distributed to natural gas pipelines. The third stage is electricity production. The stored energy is used to produce electrical energy during the absence of wind or in conditions of a weak wind. Hydrogen is converted into electricity by a fuel cell. Interfacing is carried out using electrical components with the help of DC/DC converter with a step-up isolation transformer. The paper represents the structure of the proposed hydrogen-based energy buffer and reviews its main elements.

Key words: Renewable energy storage, electrolysis, hydrogen buffer, fuel cell

INTRODUCTION

Sustainability and efficient use of energy resources is an urgent issue today. Reasons lie not only in the growth of demand and production, but also in the present level of resource exploitation leading to exhaustion of energy resources and related environmental impacts. The sustainable use of energy requires applications and methods that could increase efficiency. This is especially important in converter applications.

Traditional methods of energy conversion in power plants have some disadvantages, such as impact on the environment. Some new unconventional methods of energy generation have less impact on the environment. The cost of power generation is one of the main criteria when choosing a method for its production. Today, traditional technologies seem to be cheaper than the alternative ones. Energy produced from renewable sources lacks the cost of fuel, however, it has higher capital costs.

The predicted costs and cost price of electricity production based on renewable sources have been given in Table 1 (Solovjev, 2006). The use of renewable energy and storage offers prospects of significant decrease in fossil fuel extraction and accompanying environmental pollution (Andrijanovitš, 2009).

Table 1. Prediction costs and cost price of electricity production

Renewable source	Specific capital cost, $ kW^{-1}			Cost of production, cent kWh^{-1}		
	2005	2030	2050	2005	2030	2050
Onshore wind farm	900–1,100	800–900	750–900	4.2–2.2	3.6–2.1	3.5–2.1
Offshore wind farm	1,500–2,500	1,500–,1900	1,400–1,800	6.6–21.7	6.2–18.4	6–18
Solar power	3750–3850	1,400–1,500	1,000–1,100	17.8–54.2	7–32.5	6–29
Fuel cell	3,000–10,000	500–1,000	300–500	2–3	2–3	2–3

The use of wind energy can be considered technically and economically feasible only at average wind speed 4.5 m s^{-1} (Risthein, 2007). Average annual wind speed and large wind parks in Estonia, (Fig. 1), (Risthein, 2007).

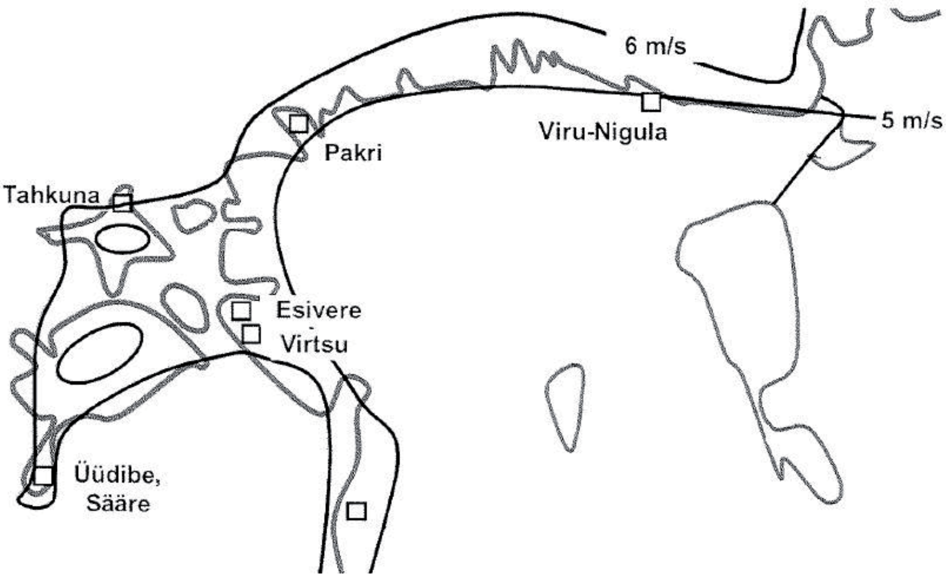

Fig. 1. Average annual wind speed in Estonia.

Unpredictable winds make it difficult to plan production (Fig. 2), complicating parallel operation with other power plants, intended for compensating the instability of wind power production. Due to unpredictable wind the difficulty in forecasting periods of excess energy as well as lack of energy occur (Andrijanovitš et al., 2010).

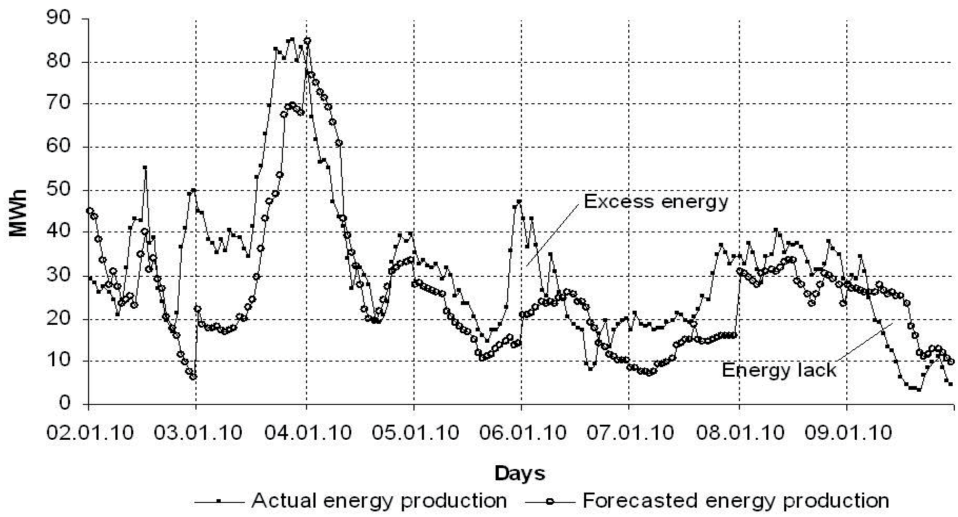

Fig. 2. An example of unpredictable energy production by Estonian wind farms.

HYDROGEN TECHNOLOGY AS A BUFFER FOR STABILIZATION OF WIND POWER GENERATION

The Department of Electrical Drives and Power Electronics has introduced the concept of using hydrogen for compensating the instability of wind production. A typical configuration of a wind farm connected to the transmission grid is formed by the set of wind generators, electrically connected through a medium voltage network, sharing one single infrastructure for access and control. A block diagram of the hydrogen buffer system for the stabilization of wind power generation is presented in Fig. 3 (Andrijanovitš et al., 2010).

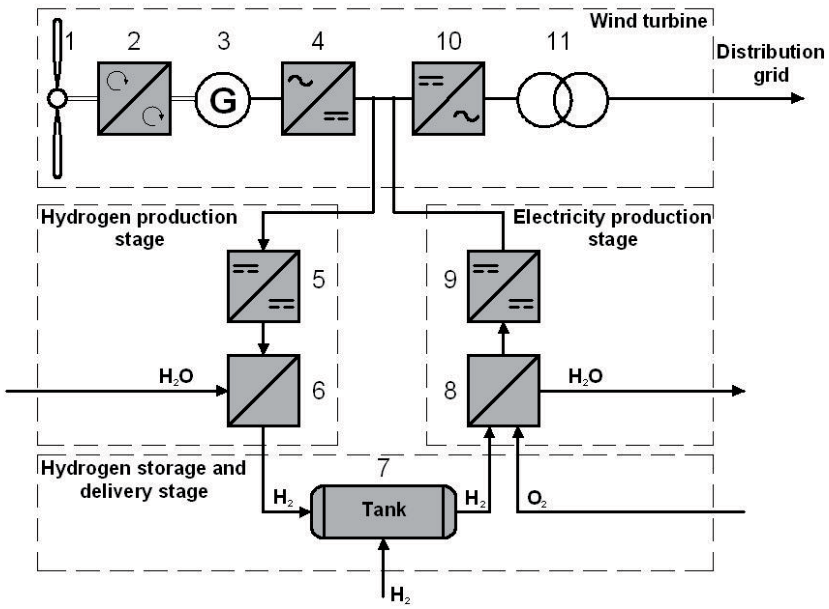

Fig. 3. Block diagram of the proposed hydrogen buffer: 1 – Blades; 2 - Gearbox; 3 - Generator; 4 – Rectifier; 5 - Interface DC/DC converter, 6 – Electrolyser; 7 - Storage tank; 8 - Fuel cell; 9 - Interface DC/DC converter; 10 – Inverter; 11 - Transformer.

Because of unregulated energy production (Fig. 2), the fluctuation of wind speed leads to a fluctuating output. It means that at some moments excess energy and energy lack appear. As mentioned above, a hydrogen buffer is used to stabilize unregulated energy production, consisting of the following main components:

1. Hydrogen production stage,
2. Hydrogen storage and delivery stage,
3. Electricity production stage.

HYDROGEN PRODUCTION STAGE

In periods of excess energy, the hydrogen generation system is connected to the internal grid. In this stage, electrical energy from the wind generator is converted into chemical energy by using water electrolysis. Because of low input voltage of an electrolyser it is necessary to decrease high output voltage of the grid with the help of interface DC/DC converter with a step-down isolation transformer.

The hydrogen generation system consists of two main parts:

1. Interface DC/DC converter with a step-down isolation transformer, which allows interfacing the high voltage DC output of converter with a low voltage input of the electrolyser,

2. Electrolyser, allowing electrical energy storage and producing hydrogen from water electrolysis using excess electricity from the wind generator.

There are three basic types of electrolysers: alkaline, proton exchange membrane (PEM) and high-temperature solid oxide (Fig. 4). Common characteristics of electrolysers are shown in Table 2 (Gamburg et al., 1989, Eg & G technical services Inc., 2004, Egorov et al., 2008). Advantages and disadvantages of different types of electrolysers are shown in Table 3.

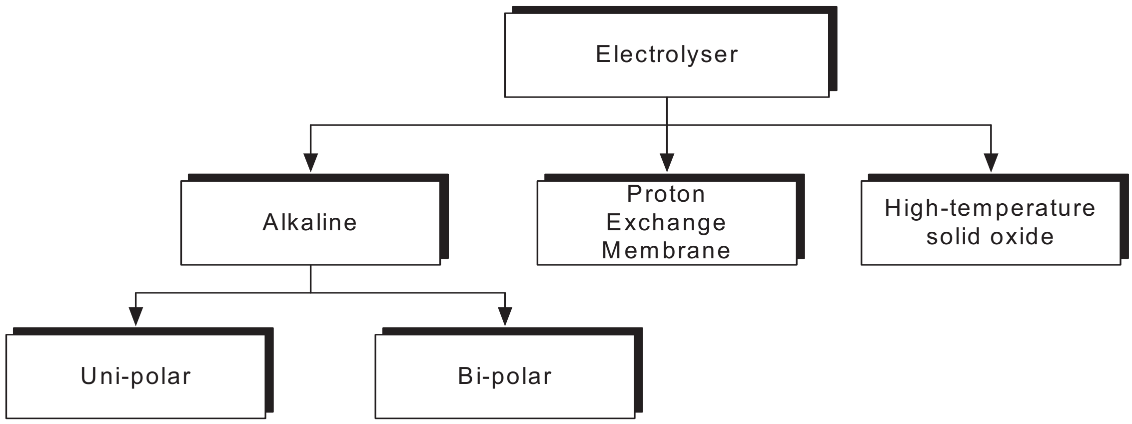

Fig. 4. General classification of electrolysers.

Alkaline electrolysers could be subdivided into unipolar or bipolar electrolysers (Fig. 4). The unipolar design is composed of a series of electrodes, anodes and cathodes alternatively suspended in a tank, filled with a 20–30% solution of electrolyte. In this design, each of the cells is connected in parallel. The bipolar electrolysers have alternating layers of electrodes and separation diaphragms, which are clamped together. The cells are connected in series and can result in higher stack voltages. Since the cells are relatively thin, the overall stack can be considerably smaller in size than the unipolar design (Kroposki et al., 2006).

Table 2. Common characteristics of electrolysers

Characteristic	Uni–polar	Bi–polar	Proton Exchange membrane	High–temperature solid oxide
Current density, A $(cm^2)^{-1}$	0.1–0.2	0.2–0.4	0.4	1.1–2.0
Voltage cell, V	2.04–2.14	1.87–2.10	1.65–1.85	1.78–1.85
Production, $(m^3\ H_2)\ h^{-1}$	Up to 80,000	Up to 200,000	Up to 25,000	Up to 25,000
Energy demand, $(кW \cdot h^{-1})\ (m^3)^{-1}$	5.0	4.3–4.6	4.5	3.9–4.0
Temperature, °C	50–100	50–100	80–100	120
Pressure, MPa	0.01–0.10	0.01–0.10	Up to 3.0	0.2–6.0
Efficiency, %	75–90	75–90	80–90	80–90

In the PEM electrolysers the electrolyte is contained in a thin, solid ion conducting membrane as opposed to the aqueous solution in the alkaline electrolysers. This allows the H+ ion to transfer from the anode side of the membrane to the cathode side and serves to separate the hydrogen and oxygen gasses. Oxygen is produced on the anode side and hydrogen is produced on the cathode side. PEM electrolysers use the bipolar design and can be made to operate at high differential pressure across the membrane (Kroposki et al., 2006).

High-temperature electrolysis (HTE) is different from the conventional electrolytic process. Some of the energy needed to split water is provided as thermal energy instead of electricity. It occurs because conventional electrolysis usually operates at temperatures below 100ºC. HTE generally refers to an electrolytic process operating at temperatures above 100ºC. As HTE curtails the relatively inefficient step of conversion of heat to electricity, it is more efficient than the conventional electrolysis (Sadhankar et al., 2006). In a HTE system using nuclear energy, a nuclear reactor supplies thermal energy that both generates electricity and heats up the steam needed for electrolysis. The HTE system is supported by nuclear process heat and electricity has the potential to produce hydrogen with overall system efficiency near that of the thermochemical processes. HTE cells consist of two porous electrodes separated by a dense ceramic electrolyte. HTE cells with oxygen ion conducting ceramic as electrolyte are often called solid oxide electrolysis cells (SOECs).

Table 3. Advantages and disadvantages of electrolysis

Type of electrolysis	Advantages	Disadvantages
Alkaline unipolar	this design is extremely simple to manufacture and repair	usually operates at lower current densities and lower temperatures
Alkaline bipolar	reduced stack footprints and higher current densities as well as the ability to produce higher pressure gas	can not be repaired without servicing the entire stack although this is rare
Proton exchange membrane	requires no liquid electrolyte, which simplifies the design significantly, the electrolyte is an acidic polymer membrane. PEM electrolysers can potentially be designed for operating pressures up to several hundred bar, and are suited for both stationary and mobile applications, increased safety due to the absence of KOH electrolytes, a more compact design due to higher densities, and higher operating pressures	limited lifetime of the membranes, membranes must use very pure deionized water, otherwise, they will accumulate cations that displace protons and increase cell resistance over time
High-temperature solid oxide	can operate at significantly higher overall process efficiencies than regular low-temperature electrolysers	requires large amounts of energy and heat, it is working with a nuclear power plant

Today's most widespread industrial electrolysers are alkaline and proton exchange membrane. These two types of electrolysers allow higher operating pressures, higher current density and low applied voltage to the cell.

ELECTRICITY PRODUCTION STAGE

In order to stabilize energy production, during the absence of wind or in conditions of a light wind, stored hydrogen could be reused. In this stage, hydrogen is converted into electrical energy by using a fuel cell (FC). The fuel cell takes the hydrogen from the tanks to generate electricity, plus water and heat as byproducts. The produced electrical energy is in DC form, thus a power converter is required to change DC voltage level required by the grid. Because of low output voltage of a fuel cell it is necessary to boost it with the help of the interface DC/DC converter with a step-up isolation transformer. A hydrogen-powered fuel cell system consists of two main parts:

1. Interface DC/DC converter with a step-up isolation transformer, which allows interfacing a low voltage DC output of fuel cell with a high voltage DC-link of the converter,
2. Fuel cell allows producing chemical energy into electrical energy in order to stabilize energy production of wind generator.

General classification of modern fuel cells (Fig. 5).

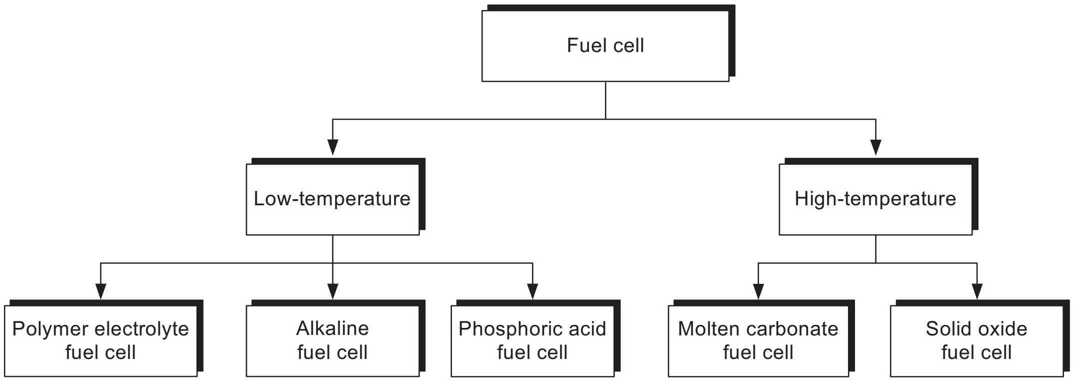

Fig. 5. General classification of fuel cells.

The electrolyte in polymer electrolyte fuel cell is an ion exchange membrane (fluorinated sulfonic acid polymer or other similar polymer), which is an excellent proton conductor. The only liquid in this fuel cell is water, thus the corrosion problems are minimal. Typically, carbon electrodes with platinum electrocatalyst are used for both anode and cathode and with either carbon or metal interconnects. Water management in the membrane is critical for efficient performance, the fuel cell must operate under conditions where the byproduct water does not evaporate faster than it is produced because the membrane must be hydrated. Higher catalyst loading than used in phosphoric acid fuel cell is required for both the anode and the cathode (Eg & G technical services Inc., 2004).

Alkaline fuel cells are one of the most developed technologies and have been used to provide power and drinking water in space missions, including the US Space Shuttle. The design of an alkaline fuel cell is similar to a proton exchange membrane (PEM) cell but with an aqueous solution or stabilized matrix of potassium hydroxide as the electrolyte. Alkaline cells operate at a similar temperature to PEM cells (around 80°C) and therefore start quickly, but their power density is around ten times lower than the power density of a PEM cell. As a result they are too bulky for using in car engines. Nevertheless, they are the cheapest type of a fuel cell to manufacture, so it is possible that they could be used in small stationary power generation units. Like the PEM cell, alkaline fuel cells are extremely sensitive to carbon monoxide and other impurities that would contaminate the catalyst (Eg & G technical services Inc., 2004).

In the phosphoric acid fuel cells, typically operating at 150 to 220°C, the concentrated phosphoric acid (close to 100%) is used as the electrolyte. The relative stability of the concentrated phosphoric acid is high compared to other common acids. Consequently the phosphoric acid fuel cell (PAFC) is capable of operating at the high end of the acid temperature range (100 to 220°C). The anode and cathode reactions are the same as in the PEM fuel cell with the cathode reaction occurring at a faster rate due to the higher operating temperature (Eg & G technical services Inc., 2004).

The electrolyte in the molten carbonate fuel cells is usually a combination of alkali carbonates, which is retained in a ceramic matrix. The fuel cell operates at 600 to 700°C where the alkaline carbonates form a highly conductive molten salt, with carbonate ions providing ionic conduction. At the high operating temperatures in MCFCs, Ni (anode) and nickel oxide (cathode) are adequate to promote a reaction. Noble metals are not required for operation, and many common hydrocarbon fuels can be reformed internally. The focus of MCFC development has been on larger stationary and marine applications, where the relatively large size and weight of MCFC and slow start-up time are not an issue (Eg & G technical services Inc., 2004).

In the solid oxide fuel cells, the electrolyte is a solid, nonporous metal oxide. The cell operates at 600-1,000°C where ionic conduction by oxygen ions takes place. The limited conductivity of solid electrolytes required cell operation at around 1,000°C, but more recently thin electrolyte cells with improved cathodes have allowed the reduction of operating temperatures to 650-850°C. SOFCs are considered for a wide range of applications, including stationary power generation, mobile power, auxiliary power for vehicles, and specialty applications (Eg & G technical services Inc., 2004).

In accordance with the classification of fuel cells (Fig. 5), common characteristics of fuel cells are shown in Table 4, their advantages and disadvantages (Eg & G technical services Inc., 2004, Matthew M., 2008) are given in Table 5.

Table 4. Common characteristics of fuel cells

Type of fuel cell	Electrolyte	Qualified power	Operating temperature	Electrical efficiency
Proton exchange membrane	polymer membrane	100 W to 500 kW	30–100°C	cell: 50–70% system: 30–50%
Alkaline	aqueous alkaline solution	10 kW to 100 kW	under 80°C	cell: 60–70% system: 62%
Phosphoric acid	molten phosphoric acid	up to 10 MW	150–200°C	cell: 55% system: 40%
Molten carbonate	molten alkaline carbonate	100 MW	600–700°C	cell: 55% system: 47%
Solid oxide	O_2–conducting ceramic oxide	up to 100 MW	850–1,100°C	cell: 60–65% system: 55–60%

Table 5. Advantages and disadvantages of a fuel cell

Type of FC	Application	Advantages	Limitations
Proton exchange membrane	cars, buses, portable power supplies, medium to large-scale stationary power generation	compact design; relatively long operating life; adapted by major automakers; offers quick start-up, low temperature operation	high manufacturing costs, needs pure hydrogen; heavy auxiliary equipment and complex heat and water management
Alkaline	space (NASA), terrestrial transport	low manufacturing and operation costs; does not need heavy compressor, fast cathode kinetics	large size; needs pure hydrogen and oxygen; use of corrosive liquid electrolyte
Phosphoric acid	medium to large-scale power generation	commercially available; heat for co-generation	low efficiency, limited service life, expensive catalyst

Molten carbonate	large-scale power generation	highly efficient; utilizes heat for co-generation	electrolyte instability; limited service life
Solid oxide	medium to large-scale power generation	high efficiency, takes natural gas directly, no reformer needed. Operates at 60% efficiency; co-generation	high operating temp; rare metals, high manufacturing costs, oxidation issues; low specific power

Technical properties of fuel cell (Table 6).

Table 6. Fuel cell technical properties

Characteristics of fuel cell	Polymer electrolyte	Alkaline	Phosphoric acid	Molten carbonate	Solid oxide
Current density, A $(cm^2)^{-1}$	0.1–0.9	0.1–0.9	0.1–0.9	0.1–0.9	0.1–0.9
Voltage cell, V	0.8–0.6	0.8–0.6	0.8–0.6	0.8–0.6	0.8–0.6
Power density, W $(cm^2)^{-1}$	0.35–0.7	0.1–0.3	~0.14	0.1–0.12	0.15–0.7
H_2 consumption, $(cm^3\ H_2)\ (min\ A)^{-1}$	7.0	7.0	7.0	7.0	7.0
O_2 consumption, $(cm^3\ O_2)\ (min\ A)^{-1}$	3.5	3.5	3.5	3.5	3.5
Pressure, bar	1–2	1	1	1–10	1

Having considered all the fuel cells explained the authors conclude that there are several perspective types of fuel cells that can be used. First a low-temperature fuel cell that is an alkaline fuel cell with a high efficiency and low oxygen reduction reaction losses. Second, a high-temperature fuel cell, a solid oxide and molten carbonate fuel cell.

HYDROGEN STORAGE

In an ideal system, supply will match demand. Energy storage enables the supply to be shifted to meet the demand. Electricity can be drawn from the primary supply during periods of excess availability, stored and then returned during periods of excess demand. Correct sizing of the storage should allow the generation plant to operate closer to its optimal efficiency, making thus better economic use of the existing assets. According to the International Energy Agency classification (Yartys & Lototsky, 2004), hydrogen storage methods can be divided into two groups:

The first group includes physical methods which use physical processes (compression or liquefaction) to compact hydrogen gas. Hydrogen being stored by physical methods contains H_2 molecules, which do not interact with the storage medium. The following physical methods of hydrogen storage are available:

1. Compressed hydrogen gas,
2. Liquid hydrogen: stationary and mobile cryogenic reservoirs.

The second group includes chemical (or physical-chemical) methods that provide hydrogen storage using physical chemical processes of its interaction with some materials. The methods are characterized by an essential interaction of molecular or atomic hydrogen with the storage environment. The chemical methods of hydrogen storage include:

1. Adsorption,
2. Bulk absorption in solids (metal hydrides),
3. Chemical interaction.

Comparison of hydrogen storage methods in accordance with the above mentioned methods (Tables 7, 8), (Yartys & Lototsky, 2004).

Table 7. Comparison of physical hydrogen storage methods

Group	Subgroup	Method	Storage conditions		Storage performances	
			P, bar	T,°C	Volume density, g $(dm^3)^{-1}$	Energy consumption, %
Physical	compressed gas storage	steel cylinders	200	20	17.8	9
		commercial composite cylinders	250	20	22.3	10
		advanced composite cylinders	690	20	29.7	12.5
		glass micro–spheres	350–630	200–400	20	25
	cryogenic (LH_2)		1	–252	71	27.9

Table 8. Comparison of chemical hydrogen storage methods

Group	Subgroup	Method	Storage conditions		Storage performances	
			P, bar	T,°C	Volume density, g $(dm^3)^{-1}$	Energy consumption, %
Chemical	cryo–adsorption		2–40	–208…–195	15–30	8.1
	metal hydrides	'low–temperature' (20–100°C)	0.01–20	20–100	90–100 60–70	10.4
		'high–temperature' (250–400°C)	1–20	250–350	90–100 60–70	20.6

		complex hydrides (alanates)	1–20	125–165	30	13.4
	organic hydrides		10–100	300–400	70–100	28

From the data (Tables 7, 8), it can be concluded that each method has its advantages and disadvantages and none of the specific hydrogen storage methods is superior to the remaining alternative ones. Cost, volume, weight and performance should be considered together in selecting an optimal storage method that suits the specific requirements.

HYDROGEN DELIVERY

Between the two ends of the economic chain, hydrogen has to be packaged by compression or liquefaction to become a commodity. In the transportation, hydrogen has to be produced, packaged, transported, stored, transferred to cars, then stored and transported again before it is finally admitted to fuel cells.

There are two possibilities of hydrogen delivery (Leighty, 2006):

1. Road delivery,
2. Pipeline delivery.

Because of the low density of the gaseous energy carrier, transport of pressurized or liquid hydrogen is extremely inefficient. Forty-ton trucks can carry only 350 kg of hydrogen at 200 bars in the gaseous or 3,500 kg in the liquid state (Leighty et al., 2006).

The energy required to deliver the gas is part of the production costs. Parasitic energy losses reduce the amount of available energy. Hydrogen transport by pipelines has to compete with electricity transport by wires.

Design and construction of large, long-distance, high pressure gaseous hydrogen pipelines and conventional natural gas (NG) transmission lines are similar. Four technological aspects differentiate the gaseous hydrogen (GH_2) line from the NG line and need to be addressed for the concept to be attractive to industry (Leighty et al., 2006):

1. The volumetric energy density of hydrogen is one third of that of methane,
2. High pipeline utilization is critical for economic feasibility,
3. Hydrogen embrittlement of pipeline steel must be prevented and controlled,
4. Compression is very costly.

Most of the analyses show that pipelining GH_2 costs approximately 1.3 to 1.8 times more per unit energy-distance than NG, because of these four factors. Pipelines are very expensive to design and construct, which is why they must have high utilization to justify the initial capital cost.

CONCLUSIONS AND FUTURE WORK

This paper is devoted to study of a new concept of using hydrogen for compensating the instability of wind power production. This concept has been considered in three main stages:

1. Hydrogen production stage allows excess energy of a wind power plant to be stored,

2. Hydrogen storage technologies, safety, automation and transportation system have to be developed in the future,

3. At moments when wind is low or absent the stage of electricity production allows wind power operation to be stabilized. Because all of the components of hydrogen buffer require DC power supply, interface converters were implemented.

In terms of ecology, the proposed method provides perspectives of significant decrease in fossil fuel extraction and accompanying environmental pollution. As Estonia depends on foreign energy supplies, the use of our own considerable wind potential will promote the promising field of energy development.

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Possibilities for Correcting Forecast Errors by Cutting off Production Chart Peaks

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Abstract. In this paper we describe a conception for the mitigation of wind power fluctuations by cutting off production chart peaks.
The rapid growth of wind energetics has been induced by several factors. Although the government support may be the main incentive, other important motives include the increasing network access fees and strict requirements set for ensuring the balancing capacity of production.
However, such capacity has the tendency of being underdeveloped. The possibilities of the operating oil-shale plants for providing the capacity to balance the wind parks are running out. Sudden changes in the oil-shale plant output contribute to additional CO_2 emissions, increased fuel consumption and decreased boiler efficiency. Under the circumstances, the transmission system operator (TSO) can face the need to reduce the power output of the wind parks. The operators of the wind parks integrated into the transmission network are responsible for presenting to TSO a 24 h forecast of their output power.
The forecast error is mainly specified in terms of Mean Absolute Percentage Error (MAPE), which for Estonian wind parks is about 20% on average. For forecast error estimation we have also applied the notion of Mean Percentage Error (MPE). Estimation of Pakri wind park data shows divergent actual forecast errors for different values of output power. For the values approximating the rated power of the wind park, the actual output power is larger than predicted. This situation clearly arises when the proportional output power is over 80% and MAPE is quite evenly distributed around 19.2%. In good wind conditions, for the relative output power value of 80%, the share of energy lost by cutting off production chart peaks amounts to 8.6% of the total energy production. The share is rapidly decreasing with declining wind conditions. Nevertheless, the average share of energy lost does not exceed 5%. The cut off energy might be applicable for heat production in boiler houses, although it is cheaper than the energy supplied to the electrical network.

Key words: Wind park, wind power, forecast error, production charts

INTRODUCTION

The development of wind energetics is speeding up. Favourable governmental regulations and new possibilities opened up in economy to construct wind parks enhance the development of this field. At the end of 2006, the European Union (EU) set its renewable energy target at 20% of overall energy consumption by year 2020 and at least 20% reduction in greenhouse gases (GHG) (A renew..., 2007). According to European Wind Energy Association (EWEA), by year 2020 the proportion of wind energy could be as high as 14.3% of EU electricity demand, 180 GW capacity of installed wind turbines (Pure..., 2009), while by the end of year 2008 the total in EU was 65 GW and it met 4.2% of EU electricity demand (Wind..., 2008). Thus, the triple increase is expected to take place within the next 11 years. All this capacity will be integrated into the grid that already includes conventional power plants like coal, oil-shale, gas or nuclear power plants.

The targets in Estonia for renewable electricity supply have been set at 5,1% (ca 400 GW h^{-1}) of gross inland consumption by 2010 and 25% by 2020, while the current share of wind power in Estonia is 115 MW (as of October 2009) (Eesti..., 2009). As onshore wind power production development in Estonia is quite limited, the offshore wind park projects will have a huge role to play in the near future if the targets set are aimed at. Also, the new Estonian Electricity Sector Development Plan of up to 2018 (Estonian..., 2009), where a 30% share of wind generation in total installed capacity has been foreseen by 2018, means a substantial share of power being generated onshore and offshore in the near future.

Different EU support schemes have rendered wind energetics economically attractive and have instigated a competition between the many wind park developers to establish new facilities. The faster the project is implemented, the more advantage is gained over the competing agents. An extra large increase in wind capacity is foreseen in offshore wind parks. The growing demand for wind generators has induced a rise in their price.

Today, in addition to the economic profitability, there is another major factor contributing to the fast growth of wind power development – that of the looming increase in the electric transmission network access fee. Meanwhile, the number of plots with good wind conditions is decreasing, and the availability of sufficient network transmission capacity has become crucial. The cost of establishing electrical networks may be of the same range as that of a wind park itself (Landsberg et al., 2005). In addition to the network related expenses, Estonian TSO requires fast-start generating units to be installed together with new connections of wind power, i.e. all new wind parks connected to the grid after 1st of July 2007, are obliged to have fast regulated power plants in Estonian territory. Up to now, the installation of wind parks meant very few additional expenses beside the initial capital costs. The later the project is started, the larger are the additional expenses involved. Although there is a theoretical possibility that one will be able to buy the balancing capacity required, its price and availability is undefined today.

Fluctuations in wind capacity are balanced by power plants of fast regulated output such as gas turbines and hydro power plants, or storage facilities such as pumped-storage hydro power plants and compressed air power plants. The conventional fossil fuel based thermal power plants are not easy to use for balancing large capacities of wind power, and nuclear power plants are totally unsuitable in this respect. In the territory of Estonia, the resources available for balancing the wind power by oil-shale power plants are becoming exhausted, and the same is true about the hydro power plants in Latvia. The fastest way to provide for the additional fast regulated capacity is to establish gas turbine plants and a pumped-storage hydro power plant in the further future.

TSOs are authorised to reduce wind park production peaks, which they occasionally also resort to in extreme conditions, when the balancing required cannot be achieved by other measures (Lepa et al., 2009). It can be presumed that the need for cutting off peak loads is increasing fast. In Estonia, the first reserve plant of 120 MW in capacity will be erected as late as 2013, and by this time, even the most conservative forecast suggests that the capacity of wind parks will have been increased to about 590 MW (Eesti..., 2009).

The method of cutting off production chart peaks could be applied systematically to correct forecast errors, whereas the energy cut-off might be applicable for heat energy production in boiler houses.

MATERIALS AND METHODS

The capacity produced by power plants at any given moment of time must be equal to the consumption capacity. With conventional fossil fuel based energy system the power balance is well maintained. The accuracy of consumption capacity forecast is high enough and it is by these charts that the output of thermal power plants is adjusted. On the contrary, the stochastic fluctuations in the wind park output power may have the amplitude as large as tens of megawatts per minute and this may result in emergency situations for the network if the need for forecast is neglected.

As a rule, wind park capacity is predicted for 24 h ahead. The time span of 24 hours enables to plan necessary changes to the reserve capacities. Nevertheless, the wind power forecast is bound to involve some error. The forecast error is estimated by 2 main methods: Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) (1) (Rosen et al., 2007). In this paper we also report on the use of Mean Percentage Error (MPE) (2).

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{P_a - P_f}{P_a}\right| \cdot 100, \qquad (1)$$

$$MPE = \frac{1}{n}\sum_{t=1}^{n}\frac{P_a - P_f}{P_a} \cdot 100, \qquad (2)$$

where P_a – actual wind park output power and P_f – predicted wind park output power.

While MPE shows the polarity of error, MAPE expresses the range of it. It is reasonable to use MPE for estimating the polarity of forecast error in the short time intervals of data-series. The MAPE values may vary significantly, but an average of 20% can be achieved (Agabus & Tammoja, 2009).

For the estimation of the forecast error of wind generators' output power we used the production chart of Pakri wind park as of 2008 and the forecast data chart of average power data for 1-hour time intervals. The Pakri wind park includes 8

Nordex N-90 2.3 MW wind generators with the total capacity of 18.4 MW. For the purpose of generalization we use the proportional unit of power, p.u.

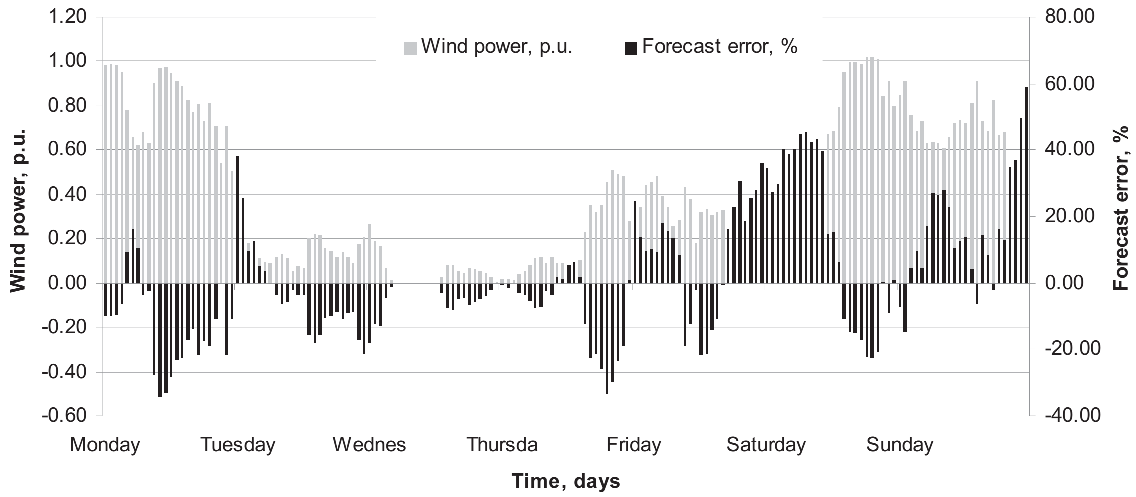

Fig. 1. Pakri wind park production chart with forecast error chart (6/10/2008-12/10/2008).

Fig. 1 presents the production chart of Pakri wind park in proportional units of power and the corresponding forecast errors in percentages. The average MAPE for the particular week is 14.5%. When processing the data we took into account the situations where a generator had stopped working for some technical reason. For the estimation of the forecast errors we used data of two weeks, each of which describing different wind conditions in the October and November of 2008. The negative forecast error values show that the actual wind park output power was higher than predicted, i.e. the case of so-called over forecast.

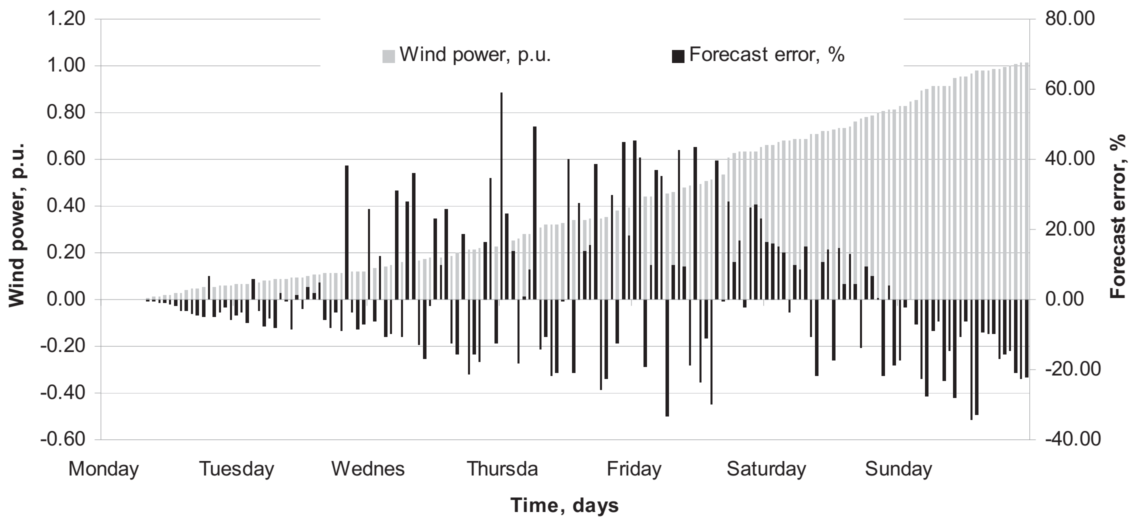

Fig. 2. Sorted data of Pakri wind park production chart with forecast errors (6/10/2008-12/10/2008).

As Fig. 2 well demonstrates, the tendency for over forecast is characteristic of the higher value range of the wind park output power. The increasing wind park capacities are bound to lead to a situation where the cheapest balancing option, i.e. the oil-shale plants will for technical reasons fail to adjust the capacities with sufficient speed.
In oil-shale power plants, the ramp-up speed of one single oil-shale generating unit is 2.5 $MW \cdot min^{-1}$, and the ramp-down speed is 7 $MW \cdot min^{-1}$ (Keel et al., 2009). Even though the regulating capacity of oil-shale power plants is in the range of 50-100% of the rated power, the actual free changeable capacity falls within the range of 10-15% after the regulation by consumption is performed (Keel et al., 2009). The total regulating capacity supply is proportional to the number of generators in operation and although today the oil-shale plants are able to balance the existing wind capacities, the rapid changes in production capacities decrease the efficiency of the plants, increase the CO_2 emissions, add to environmentally hazardous wastes, raise specific fuel consumption and cost price (Palu et al., 2009).

One option for compensating for the forecast error is cutting off wind park production chart peaks.

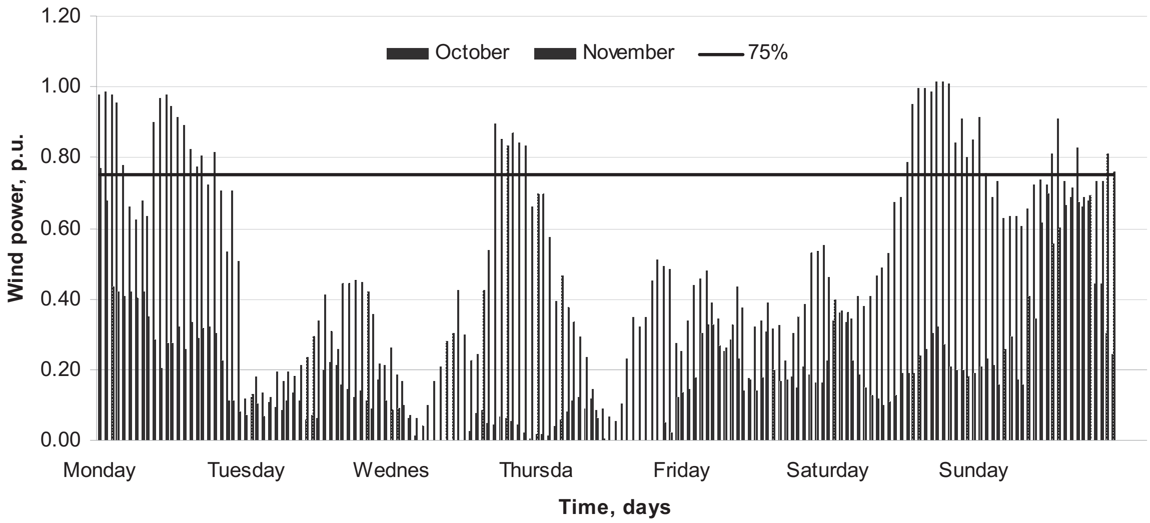

Fig. 3. Production charts of Pakri wind park (6/10/2008-12/10/2008 and 3/11/2008-9/11/2008). Horizontal line reflects the 75% capacity.

In the analysis of the performance of wind turbines it is feasible to apply the concept of coefficient of maximum (or nominal) power usage that may be described as

$$k_m = \frac{W_m}{P_m \cdot t_n} \cdot 100, \quad (3)$$

where W_m is energy produced by the wind turbine in the time period t_n, and P_m is maximum power (sum of the nominal power of the wind turbines). Here, $P_m t_n$ is the energy amount that would have been produced by all the generators working at nominal power for time t_n.

The data presented in the charts of Fig. 3 are based on rather different wind conditions, with the coefficient of maximum power usage being 42% and 33%, respectively. Fig. 2 shows that the prevailing over forecast is over 75% of the rated power. When cutting the chart peaks in Fig. 3 at the level of 75% rated power, the remaining amount of energy is 89.6% in the former and 96.4% in the latter case. With the higher coefficient of maximum power usage the energy losses after cutting the chart peaks are more significant.

RESULTS AND DISCUSSION

To make more substantial general conclusions in the estimation of forecast errors, we observed Pakri wind park data of 2 periods, those of 6/10/2008-12/10/2008 and 3/11/2008-9/11/2008 together. The data is classified and sorted in the ascending order, and the capacity interval of 0-1 is divided into four subsections. Fig. 4 presents the proportional power by step 0.25 on the horizontal axis and the MPE and MAPE values on the vertical axis. The value of MAPE in the given interval of 0-1 is 14.4%.

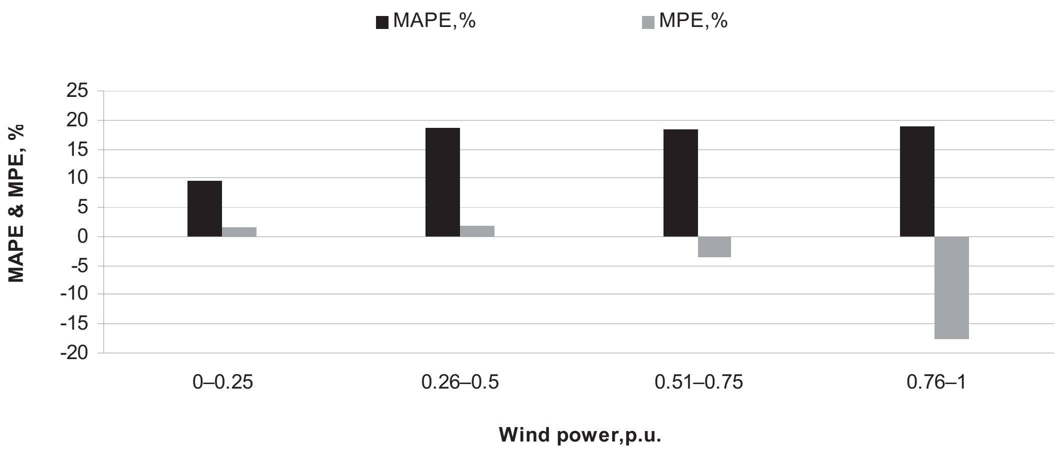

Fig. 4. MAPE and MPE of proportional power in Pakri wind park (6/10/2008-12/10/2008 and 3/11/2008-9/11/2008).

As Fig. 4 shows, MPE is negative in the proportional power range of 0.75-1. The MPE is 1.6%, 1.8%, -3.6%, and -17.4% for the wind park proportional power ranges of 0-0.25, 0.26-0.5, 0,50-0.75, 0.76-1.0, respectively. The values of MAPE are thereby 9.5%, 18.5%, 18.4%, 18.8%. In the last three quarters, the MAPE values approximate 18.5%. The low value of MPE in the two middle quarters suggests that in these quarters the prediction error features a changeable sign.

For more detailed analysis we can observe the interval 0.77-1 in Fig. 5. Fig. 5 makes it obvious that in the 0.8-1 range of proportional power, MPE is steadily negative and approximates the value of -18.0%, while MAPE is 19.2%. It thus provides statistical proof for over forecast in the interval of 0.8-1.

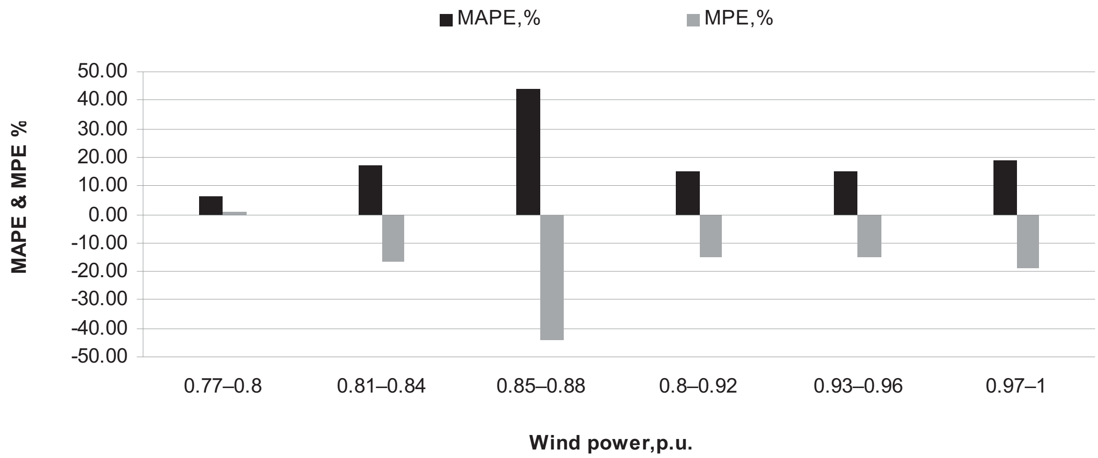

Fig. 5. MAPE and MPE of proportional power in Pakri wind park (6/10/2008-12/10/2008 and 3/11/2008-9/11/2008) in interval 0.77-1 by step 0.04.

After cutting production chart peaks at the level of 80% rated power, the MAPE decreased from 14.4% to 13.7%. Although it is quite a small change, it eliminates the production chart range of 0-0.8, where MAPE is higher than the average of the whole chart.

Table 1. Results of cutting Pakri wind park production chart peaks by 80% rated power in different months

Period	Average wind speed v, $m \cdot s^{-1}$	$k_{m100\%}$	Remained energy $W_{80\%}$, %	$k_{m80\%}$
November 2008	8.36	47.4	91.4	43.3
October 2008	8.27	46.7	93.3	43.6
September 2008	6.63	28.5	96.7	27.5
June 2006	5.64	19.0	97.6	18.5
July 2006	5.58	14.0	99.9	14.0
August 2006	6.72	24.2	96.0	23.2
June 2005	5.48	17.0	97.3	16.6

Table 1 shows that in November 2008 with extraordinarily high coefficient of maximum power usage, the share of the cut-off energy is 8.6%. However, by the 80% value of rated power the share of cut-off energy approximates 5% on the average.

CONCLUSIONS

1. All along the power range of the whole wind park, MPE and its sign feature divergent values. Comparing the MPE and MAPE values of some narrow interval of power of the production chart, it is possible to estimate the stability of forecast

error. The larger the difference between the absolute MPE and MAPE values, the more frequent is a change in the forecast error sign in the given interval.

2. In the 0.8-1 range of proportional power, the actual capacity of wind park is larger than the forecast one, whereas MAPE is 19.2% in this interval and MPE is -18.0%. Cutting the production chart peaks by the 80% proportional power, the value of MAPE in the interval 0.8-1 approaches zero.

3. By very good wind conditions, it is reasonable to cut the wind park production chart at the 80% level of rated power, whereas the share of the cut-off energy is 8.6% of the total energy produced and with less favourable wind conditions, it is decreasing fast. In Pakri wind park, the average share of cut-off energy should not exceed 5% of the total energy production.

4. The energy from cutting off the wind park production chart peaks could be used for the production of heat energy in boiler houses.

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Cleaner Production of Biomass and Biofuels

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Abstract. Ukrainian agriculture is an industry which produces a huge quantity of biomass. The main part of the biomass potential is made up by straw. By moderate estimations only 20% of the total amount of straw can be used for energy production. All plant growing and biomass processing technologies can be based on cleaner production methodology. Only a few ecological options in corn growing technology gave real profit, which was ca 220 UAH per hectare. The main steps for rearing Trichogramma insects are technical services in laboratory conditions and soft implementation of them on agricultural plants by special aircraft. The most important result of the research is an overview of the possibilities of Ukraine to cover up to 12% of the total primary biomass energy demand for cleaner biofuel production.

Key words: Biomass, biofuels, technology, cleaner production

INTRODUCTION

Agricultural and environmental machinery are both going to change in a number of modern ways. One of them is the service development of technology for the production & use of biomass for energy production. The market analysis of agricultural products testifies the necessity of transformation of agricultural product in the form of raw material into power setting and production of high-grade fertilizers [1, 2]. But sometimes new bioenergy technologies in rural areas stimulate the heaping up of agricultural wastes. Last years we had such experience in cleaner bioenergy production as a result of growing plants and processing biofuels.

OBJECTS AND METHODS

The objects of research are agricultural technologies of biomass and biofuels production. Implementation of cleaner production (CP) program by UNIDO method provides conditions for increase in income by means of rational use of natural resources [3]. Our practice based on UNIDO Cleaner Production Project in Ukraine covered product development in agriculture and introduced ecologically more sustainable means of production relating to the use of energy, chemicals and other inputs. The main criteria for motivating and stimulating agricultural workers are the following: timely and effective harvesting; minimum losses; minimum wastes and pollution; higher yield of agricultural and other production. All the options are tested by technological, ecological and economical indicators. Implementation of the abovementioned options into winter rape and corn cultivation technologies turned out to be economically efficient.

RESULTS AND DISCUSSION

We used UNIDO methodology [3] in developing CP technologies in the field of bioenergy, the algorithms of which are very flexible and can sometimes give a positive result. Our University realized the CP project in an agricultural research station near Kiev in years 2007-2009. A thorough analysis of rape and corn production technologies points at a necessity to implement new energy and material saving processes in crop cultivation.

Taking into account the impact of chemical pest control on farm production and using integral methods of plant control gain more and more ground [4, 5]. Introduction of biological methods of plant protection together with the chemical ones for grain crops will enable to reduce the market production cost by ca 30%. Ecological and biotechnological possibilities of biomass production for energetic purposes are a new way in the development of technologies in rural areas. The modern technology for growing and processing energy plants is based on multistep quality management. The production of special equipment at industrial enterprises seems to be the most promising strategy for the development of the same modern biotechnologies. One of the positive results in our practice was the use of biological methods for plant protection (Fig. 1).

Fig. 1. The use of Trichogramma insects for corn protection during plant growth.

Only a few ecological options in the technology for growing corn gave real profit (Fig. 2), which was ca 220 UAH per hectare.

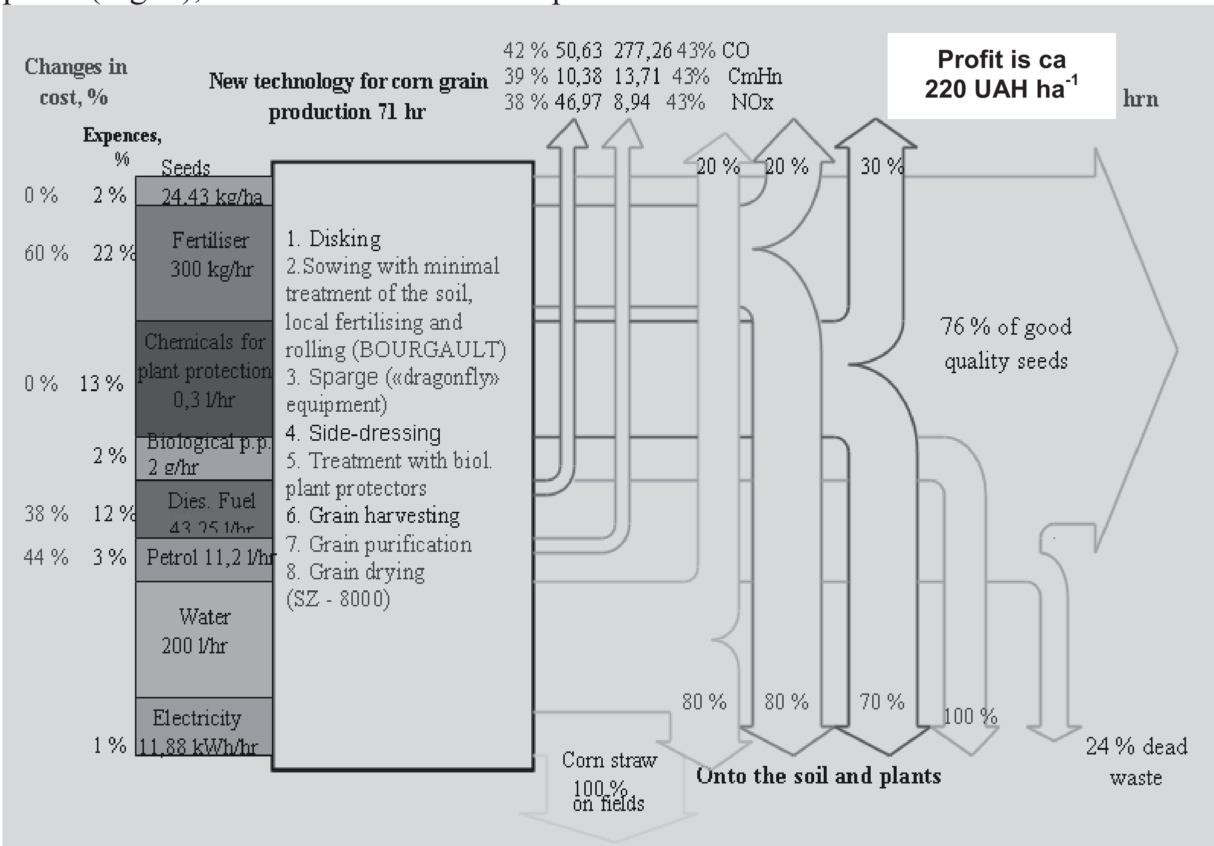

Fig. 2. Material flows after implementation of CP options in corn production and processing.

On the way of developing non-food crops and producing energy sources, agricultural and environmental engineering can create a new technique for the production of biofuels from energy crops, building materials, genetically modified organisms and plant cloning. Agricultural and environmental engineering have to transform agricultural production into analogues of energy or industrial engineering. The main part of biomass potential is made up by straw. According to moderate estimations only 20% of the total amount of straw can be used for energy production. Straw is burnt as briquettes, pellets, pressed rolls or bales [4]. Today we develop technologies for processing and using all kinds of solid biofuels. According to our conception some types of biomass will be used in our country. These are straw from cereal crops, stems from maize, sunflower, manure, wood wastes, and so on. There is a huge potential of straw for energy tests amounting from 7 to 12 million tons per year. The results of power use of biofuels from biomass have created a new generation of heating devices which have an output-input ratio in a scope from 85 to 90%.

There is strong interest in liquid biofuel production in the field of agriculture. The potential area to be used for growing oil plants is approximately 6 million hectares. Ca 3 million of them may be squares for rape cultivation. Our University in cooperation with VUZT (Prague) has launched a demonstration project for manufacturing methyl ether from rape and for the production of other oil seeds amounting to 1,000 tons per year (Fig. 3).

Fig. 3. A pilot plant for methyl ether production from oil seeds.

Domestic practice shows us that it is possible to get 1,200 liters of biodiesel, 2 tons of mill cake and more than 2 tons of solid biofuels in granules or briquettes from one hectare of energy crops.

The CP technologies can be introduced applying the tillage-sowing machine Bourgault, the Dragonfly sprayer, the Biomasser briquette line, the ECO-BIO 100 granulation line, partial replacement of common diesel fuel by biodiesel, the use of new automatic boilers P6-KOBA-25, a grain dryer, a rolling press and biological methods for plant protection. Implementation of the above mentioned options into a technology of winter rape cultivation proved economically very efficient. Energy saving options gave real profit due to new bioenergy technologies [5]. It was ca 200 USD per hectare (Fig. 4).

For example, positive ecological effect was achieved due to the reduction of soil damage, decrease in the use of chemicals and fertilizers, replacement of common diesel by its mixture with biodiesel (emissions of CO_2 were reduced by 50.5 kg) and introduction of granules and briquettes.

As a result of the implementation of CP project, the company actively develops a new ecological policy and is open to dialogue and cooperation in fields of environmental protection with community representatives, authorities and other interested parties in the agricultural complex of Ukraine.

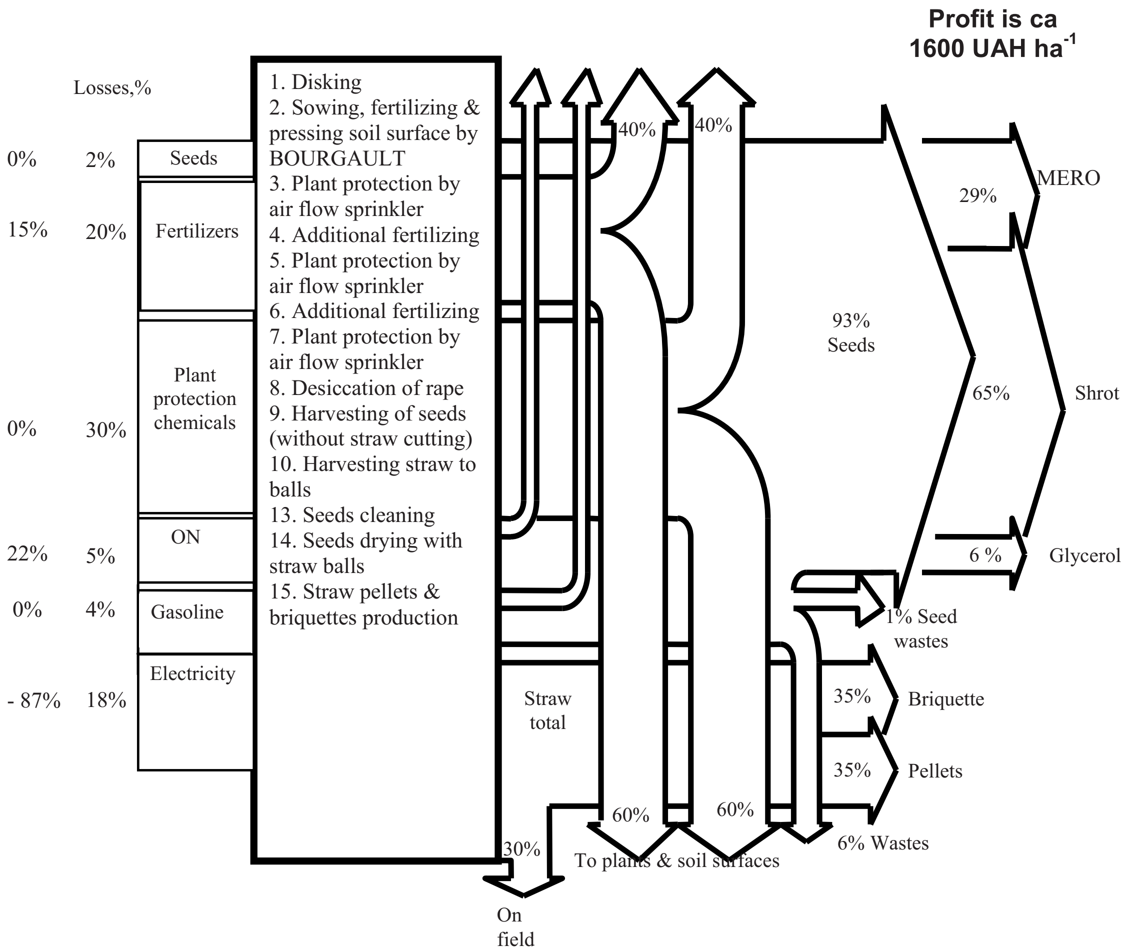

Fig. 4. Material flows after implementation of CP options in rape production and processing.

The development of CP bioenergy technologies would reduce Ukraine's dependence on imported energy carriers, enhance its energy security at the expense of organizing energy supply based on local renewable sources, create a lot of new jobs and contribute greatly to the improvement of the ecological situation.

CONCLUSIONS

Ukraine has high potential of biomass available for energy production. Biomass (excluding the share that is used by other sectors of economy) can cover up to 12% of the total primary energy demand.

Every type of biomass in real conditions has several new effective complex technologies for biofuel production. A few ecological options in the technology of corn growing gave ca 220 UAH profit per hectare. The use of rape for energy purposes based on new technology raised its efficiency to more than 1,600 UAH per hectare.

There is possibility to grow up energetic plants on 10-20% of arable lands in Ukraine. Taking into account the European requirements, in 2010 we have to be ready to produce about 250 thousands tons of biodiesel.

All projects in bioenergy sphere are designed better, when we use the modern strategy for cleaner production, which is promoted by UNIDO.

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Exhaust Emissions from Vehicles Operating on Rapeseed Oil Fuel

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Abstract. One of the primary incentives for expanding the production and use of biofuels worldwide is the potential environmental benefit that can be obtained from replacing petroleum fuels with fuels derived from renewable biomass resources. The use of straight vegetable oil (SVO) in diesel engines is one of the available alternatives, but its use in existing vehicles usually requires modification of engine or fuel system components. In order to find out the trends in changes of different exhaust emission components using fossil diesel and pure rapeseed oil fuel, the car VW GOLF and the truck MAN 19,464 were modified using one-tank and two-tank conversion kits respectively. To ensure stable driving characteristics, a Mustang Chassis Dynamometer MD-1750 was used and for the determination of the content of different exhaust gas components, the AVL SESAM multicomponent exhaust gas measurement system was used. The analyses of obtained results show that the content of NO_x and SO_2 using rapeseed oil fuel in comparison with fossil diesel decreased with both one-tank and two-tank systems. The content of CO and mechanical particles was higher using rapeseed fuel, but the content of unburned hydrocarbons differs depending on the used engine modification system. Since in the one-tank system original engine nozzles were replaced, the pilot studies of the influence of ignition timing on vehicle power characteristics and exhaust emissions were carried out. It was found out that changing the ignition timing from 10.5 to 18.5 degrees decreases the content of CO, mechanical particles and unburned hydrocarbons by up to 70% without losses in power and torque.

Key words: biofuels, straight vegetable oil, rapeseed oil, exhaust emissions, one-tank system, two-tank system

INTRODUCTION

One of the primary incentives for expanding the worldwide production and use of biofuels is the potential environmental benefit that can be obtained from replacing petroleum fuels with fuels derived from renewable biomass resources.

According to the results of the European Commission supported project 'Clean Views on Clean Fuels', conventional biofuels, primarily straight vegetable oil (SVO), remain the lowest cost options until 2020 with a gradually increasing market share for future biofuels based on lignocelluloses (Wakker et al., 2005).

The use of SVO in diesel engines usually requires modification of engine or fuel system components. If SVO is to be used in conjunction with diesel in a dual-fuel mode, necessary modifications include additional fuel tank, a system for switching between the two fuels, and a heating system. Another alternative is to use SVO exclusively. Modifications would include an electric pre-heating system for the fuel, an upgraded injection system, and the addition of glow plugs in the combustion chamber as the vegetable oil is not highly flammable.

Examples of investigations in the field of SVO use are researches carried out in Turkey to evaluate the potential of using vegetable oil fuels as a fuel for diesel engines (Altin et al., 2001), emission tests performed on the test bench with rapeseed oil fuelled tractor Deutz-Fahr in Germany (Thuneke, 2006). Comparative bench testing of a direct injection unmodified diesel engine operating on neat rapeseed oil and its blend with petrol was performed in Lithuania (Labeckas & Slavinskas, 2009).

Most of these studies are carried out by testing engines on the bench, but not the entire vehicle. Besides, the results provided by different publications regarding power, fuel consumption and, especially, exhaust gas composition changes are very different. Therefore, an automobile VW GOLF was adapted for using pure rapeseed oil as a fuel at the Scientific Laboratory of Biofuels (Latvia University of Agriculture). The car was modified using ELSBETT one-tank conversion kit (Dukulis et al., 2009a). Methodology for testing automobiles operating on biofuels was developed (Dukulis et al., 2009b). Tests were performed using three different fuels – fossil diesel, biodiesel and pure rapeseed oil, but the first analysis of exhaust emissions using rapeseed oil was not as good as expected (Dukulis et al., 2009c). As one of the most reliable explanations was the use of special oil nozzles (no adjustments were made to the engine during the tests), then one of the tasks for this study is to determine whether the exhaust gas content cannot be improved by changing the ignition timing. To determine whether the previously obtained results were not solely caused by the use of the one-tank system, another vehicle was equipped for using pure rapeseed oil, but this time with a two-tank system.

MATERIALS AND METHODS

Vehicles VW Golf 1.9TDi (rebuilt to run on rapeseed oil with a one-tank system) and MAN 19,464 (rebuilt to run on rapeseed oil with a two-tank system) were used as the study objects in these experiments (Fig. 1).

Fig. 1. Vehicles used in the experiments (VW Golf 1.9TDI and MAN 19,464).

For comparison of exhaust emission content arctic fossil diesel fuel (density at 15° C 826.1 kg m^{-3}, viscosity at 15° C 1.81 m s^{-1}) and pure rapeseed oil (density at 15° C 920.3 kg m^{-3}, viscosity at 15° C 33.63 m s^{-1}) were used in these experiments.

The following measuring systems were chosen for tests (Fig. 2):

- Laboratory Chassis Dynamometer Mustang MD-1750 with Control Platform MDSP-7000;
- Multicomponent Exhaust Gas Measurement System AVL SESAM FTIR (Fourier Transform Infrared Spectroscopy).

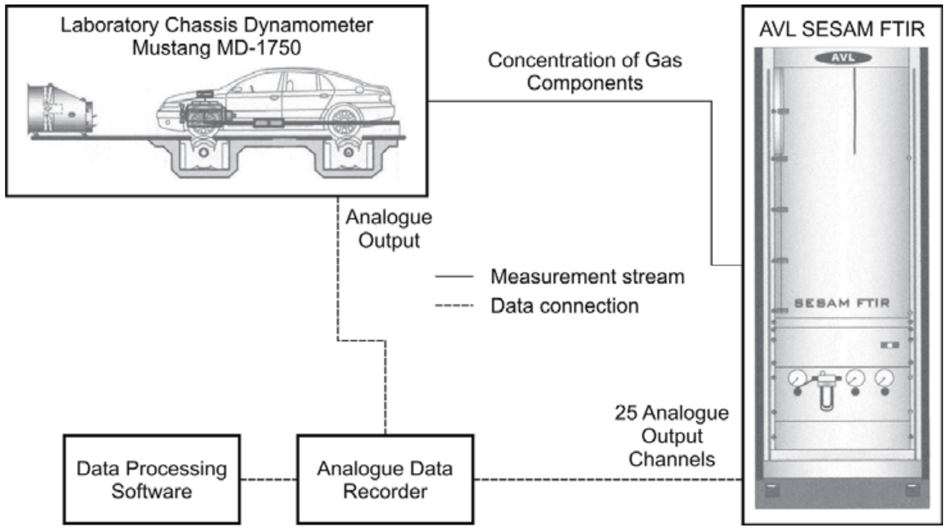

Fig. 2. Block diagram of the emission test routines.

A Mustang Chassis Dynamometer MD-1750 provides the ability to simulate actual road loads while the tested vehicle remains in the safe and controlled confines of a test centre. During Vehicle Simulation test the bench loading motor maintains the load, which corresponds to the real mass of the car and the road and air resistance at a certain speed. This test is typically used for fuel consumption and exhaust component determination at constant speeds. The chosen transmission gear at different speeds for cars equipped with mechanical gearboxes may vary (most often it is 4th or 5th gear), but cars equipped with automatic transmissions must have to have their gear lever put in position 'D' during testing. In these investigations the tests were conducted in idle running and at speeds of 50 and 90 km h^{-1}. They correspond to the maximum allowed speeds in Latvian urban areas and suburbs. Measurements were performed for 60 seconds with the reading step of 1 second. Three repetitions were made in each testing mode.

AVL SESAM (System for Emission Sampling and Measurement) is a multicomponent exhaust gas measurement system that is used particularly in the development of modern engines and vehicles in order to achieve compliance with current and future exhaust gas legislation. By means of absorption of infrared light by the individual gas components, up to 25 gases can be measured simultaneously. In addition, some collective components can be calculated from this process. In these investigations the content of NO_x, CO, CO_2, SO_2, mechanical particles (MP) and unburned hydrocarbons (HC) were analyzed.

RESULTS AND DISCUSSION

The results of exhaust emission analysis for automobile VW Golf 1.9TD are shown in Fig. 3.

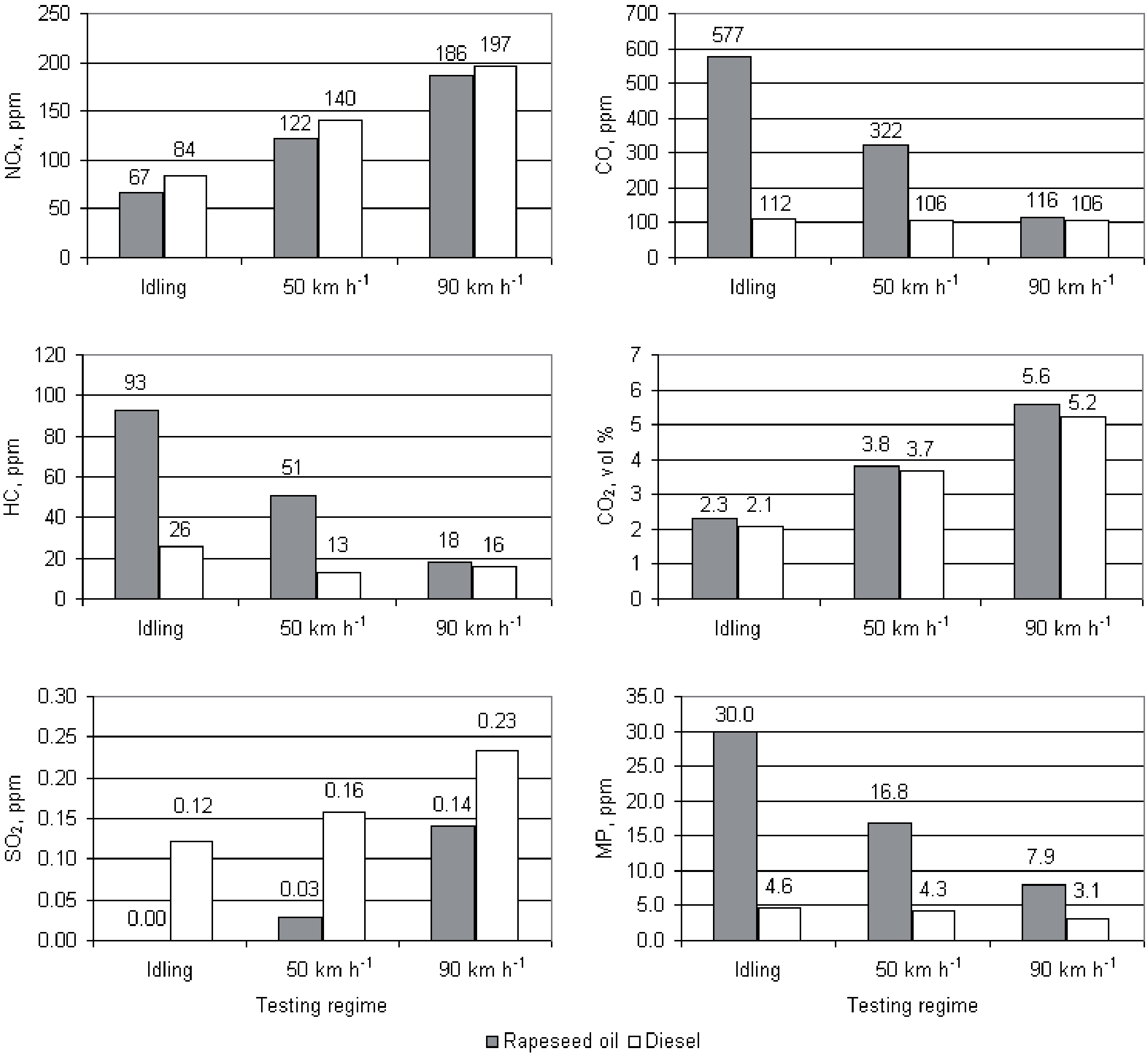

Fig. 3. Exhaust emission comparison of performed VW Golf 1.9TD simulation tests.

In comparison with fossil diesel, the average reduction of NO_x when running on rapeseed oil was 13%. The amount of SO_2 in exhaust gases was also lower by an average of 74%. The CO, HC, CO_2 and mechanical particle (MP) emissions were higher with pure rapeseed oil fuel, compared to fossil diesel fuel. If the CO_2 increase (an average of 7% compared to fossil diesel fuel) is irrelevant, because the plants (in this case, rape) take it back from the atmosphere and consume in growth process providing a neutral carbon circulation in nature, the mechanical particle amount, compared to fossil diesel fuel, increased approximately 3-fold, CO – approximately 2-fold, but the unburned hydrocarbons – nearly 2-fold. The ignition timing in these tests was set as required by the vehicle specification, i.e., 10.5°. As in the publications of other researchers it is mentioned that when using vegetable oil fuels, more complete combustion can be reached by increasing ignition timing, the experiments to determine the ignition timing impact on exhaust gas content were carried out, at the same time measuring the car's dynamic characteristics, i.e., the power and torque. The results of the experiment are given in Table 1. Ignition timing was changed in the range of 10.5° to 21.0°, when, based on the dynamometer readings, the torque and power reduction was observable. The tests were performed in idle running, because the scattering of measured components in this mode was the lowest. In addition to the previously mentioned components the content of methane (CH_4) was also analyzed.

Table 1. The results of optimal ignition timing studies

Ignition timing, degrees	NO_X, ppm	CO, ppm	HC, ppm	CO_2, %	SO_2, ppm	CH_4, ppm	PM, ppm	N_{max}, kW	M, N m
10.5	67.02	577.30	93.84	2.31	0.00	4.39	30.14	38.5	106.0
13.0	70.05	561.23	90.54	2.26	0.00	3.93	28.56	39.0	106.0
15.0	84.66	528.12	75.34	2.28	0.01	3.44	24.12	39.0	106.0
16.5	90.29	515.26	68.53	2.33	0.01	3.10	22.62	39.5	107.5
17.5	131.47	445.63	48.65	2.32	0.02	2.06	14.44	39.5	108.0
18.5	152.20	376.98	33.65	2.36	0.02	1.81	11.00	39.5	108.5
19.5	173.30	418.42	31.88	2.35	0.05	1.64	10.93	39.5	108.5
20.5	189.88	485.12	30.97	2.33	0.07	1.34	8.26	39.0	108.0
21.0	194.90	499.13	28.83	2.40	0.07	1.38	7.67	39.0	107.5

Hence, the optimal ignition timing while running the car VW Golf 1.9TD on rapeseed oil fuel is 18.5°, because here is the peak of power and torque and the minimum of CO content in exhaust gases (reduced about 35% comparing with the 10.5° ignition timing), significantly reduced unburned hydrocarbon (about 66%), methane (59%) and mechanical particle (68%) content. Further increase in ignition timing is not desirable because, as seen from the table, at 19.5° and beyond, the amount of CO and SO_2 is significantly increased, moreover, the more ignition timing is increased; the greater is the NO_x content.

Since in the adapted car, if necessary (for example in winter when operating cars on pure rapeseed oil can be problematic), fossil diesel fuel can also be used, power and torque measurements at fossil diesel fuel and rapeseed oil optimum ignition timings were performed. The results are given in Table 2.

Table 2. The power and torque measurements at different ignition timings

Ignition timing, degrees	N_{max}, kW			M, N m		
	Rapeseed oil after modifying the car	Fossil diesel fuel		Rapeseed oil after modifying the car	Fossil diesel fuel	
		before modifying the car	after modifying the car		before modifying the car	after modifying the car
10.5	38.5	42.0	41.5	106.0	108.0	107.0
18.5	39.5	N/A	42.0	108.5	N/A	107.0

As the table data shows, engine operation with fossil diesel at rapeseed oil optimum ignition timing is not a problem from the viewpoint of power and torque and it even slightly increases power.

The results of exhaust emission analysis for automobile MAN 19,464, rebuilt to run on rapeseed oil with a two-tank system, are shown in Fig. 4.

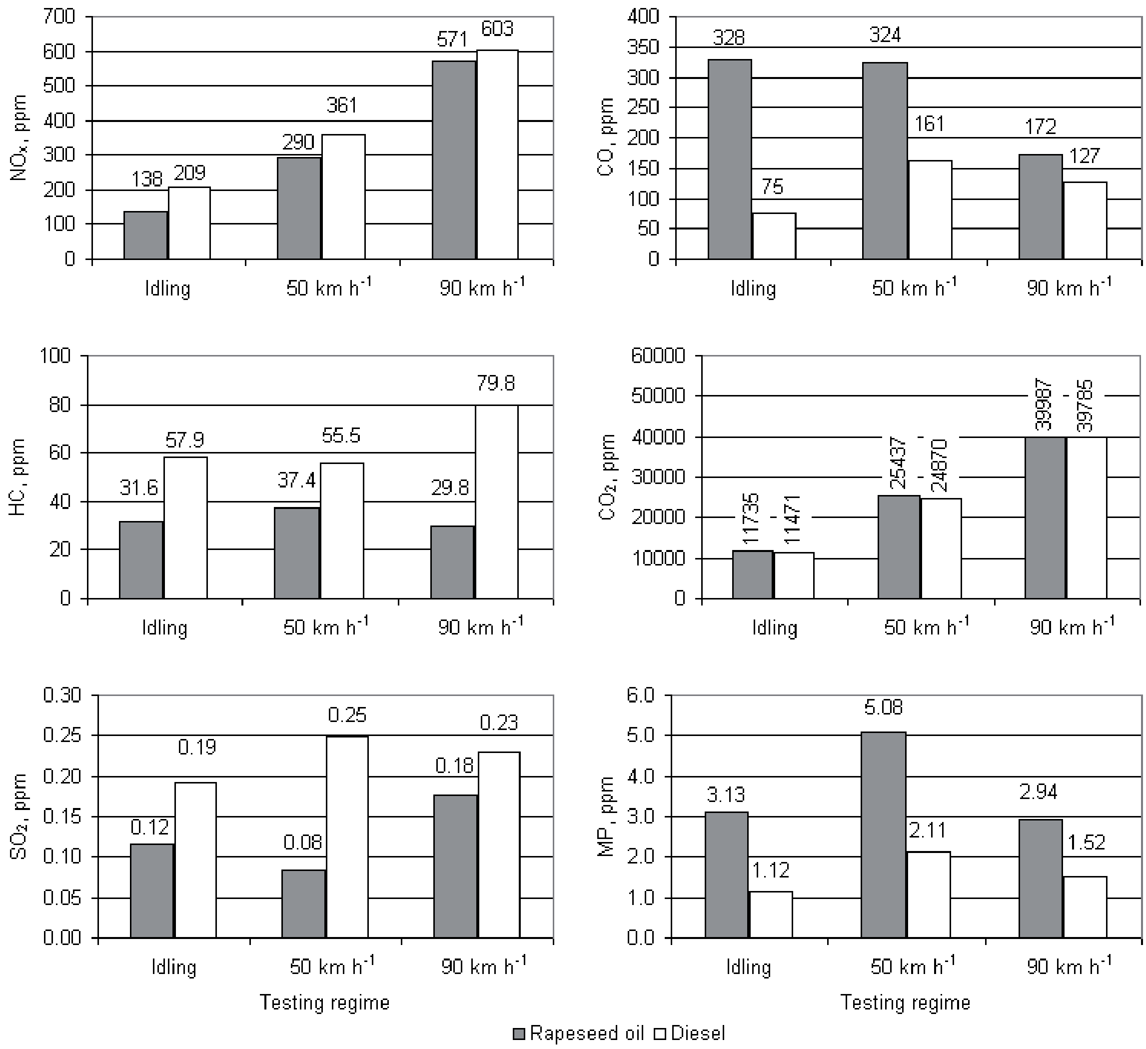

Fig. 4. Exhaust emission comparison of performed MAN 19,464 simulation tests.

Comparing the obtained data with the one-tank system investigations, it can be concluded that the average trends of exhaust component changes are similar:

- NO_x content, using rapeseed oil fuel and the two-tank system compared to fossil diesel fuel, is reduced by 20% (by 13% when using one-tank system);
- SO_2 content decreases by 43% (by 74% when using one-tank system);
- CO_2 content increases by 2% (by 7% when using one-tank system);
- CO content increases 1.6-fold (2-fold when using one-tank system);
- mechanical particle content increases 1.4-fold (almost 3-fold when using one-tank system).

The only exhaust gas component, which changes differently is unburned hydrocarbons. If using one-tank system and rapeseed oil a 2-fold increase compared with fossil diesel was observed, then with two-tank system the content of the unburned hydrocarbons was reduced by 47%.

CONCLUSIONS

1. The trends of different exhaust gas component changes, using rapeseed oil compared with fossil diesel, are similar using both one-tank and two-tank systems.
2. Using a one-tank system the content of different exhaust gas components can be improved by changing ignition timing. However, the reduction of certain components may increase the content of others, such as NO_x.
3. Since not all the contents of harmful components, using SVO fuels, decrease, in order to evaluate the effectiveness of its use, more detailed studies of engine construction and conversion kit impact on exhaust gases have to be carried out.

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Potentials for Savings by Implementing RFID and Telematic Technologies in the Timber and Biomass Supply Chain

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Abstract. While RFID and telematic technologies already enjoy wide implementation among retailers and logistics providers, their use in timber and biomass logistics is still in a phase of initial testing and pilot projects. Implementable technologies provide cross-organizational functionalities and facilitate the optimization of the supply chain 'from the forest to the factory'. Naturally, timber and biomass supply processes confront logistics with special challenges. Moreover, there are constraints and a need for further developments. Nonetheless, these technologies have been effectively and successfully implemented in a number of projects. The standardization of information technology will be a fundamental prerequisite for the acceptance of RFID and telematic technologies.

Key words: Biomass and timber logistics, marking technologies, telematics & RFID

INTRODUCTION

Among other factors, the diverse types, quantities and numbers of potential sources and sinks and means of transportation employed complicate any description of the numerous logistics processes related to the development of raw materials from forest and field, especially for the wood processing industry or renewable energy recovery. Conventional methods of logistics control and measurement only capture these processes in part. Innovative developments in the field of electronic information technologies are opening tremendous potentials for the improvement of logistics processes (Von Bodelschwing, E. et al., 2001; Fraunhofer IFF, 2005).

Innovative telematic technologies furnish potential to cut timber logistics costs. Cost pressure and structural modifications are 'drivers' intensifying the use of telematic technologies, especially among public forestry operations. Telematic technologies cut costs substantially by minimizing duplicated data acquisition, the time spent on searching for or being guided to a site, inspection work and the period of roundwood and biomass storage. Mobile services such as deck and job order management, off-road navigation and condition monitoring are particularly helpful.

Marking timber assortments with RFID holds forth further potential for rationalization. Electronic marking and identification make the timber supply chain more efficient up to the mill. RF marking could be used to reliably identify individual logs and correlate data relevant to the wood processing industry, e.g. quantity, quality and owner data. Mobile terminals could transmit the data to central databases and internal systems where it would be immediately available to others involved in the process.

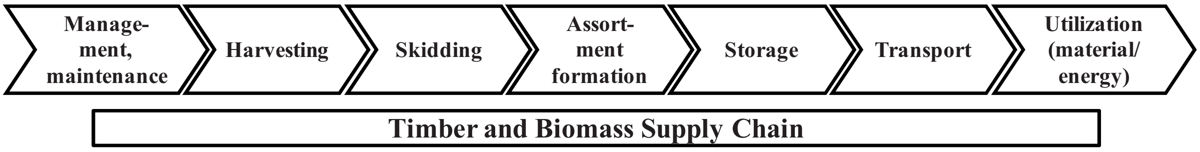

Fig. 1. Stages of timber and biomass supply.

However, format changes and non-standardized interfaces still frequently typify information exchange between Central European actors involved in timber logistics. Data is often exchanged on paper. This regularly forces subsequent actors who intend to process or save communicated data electronically to recapture or re-enter it.

The Logistics and Factory Systems Business Unit of the Fraunhofer Institute for Factory Operation and Automation IFF has been working on processes of the timber supply chain from the forest to the factory since 1999 and additionally on problems of biomass logistics since 2005. The unit specializes in research and development of logistics supporting information systems and services that organize the planning, control, monitoring and controlling of material and information flows in complex supply chains more efficiently. Its work includes both research projects and industrial development projects in which potential and process analyses are performed and systems, e.g. telematics and RFID, are implemented in the field.

This paper provides an overview of the Fraunhofer IFF's current projects, development work and solutions in the context of approaches to research and development for timber and biomass logistics.

The necessity of research of timber and biomass logistics as well as a multitude of potential approaches and the challenges of their practical implementation can only be appreciated when one is familiar with the distinctive features of timber and biomass logistics in general and in Germany in particular.

THE TIMBER AND BIOMASS SUPPLY CHAIN

Timber logistics processes proceed in an open and dynamic system with a plethora of immediate relationships and unclearly specified system boundaries. Timber supply chains are comprised of a combination of humans and equipment, i.e. they are socio-technical systems, and their complexity makes them impossible to capture as a whole. Hence, only certain aspects are mappable and traceable, and only when a particular viewpoint has been adopted. The viewpoint selected here incorporates peripheral factors, processes, information flows, material flows, actors, their roles, technical systems and technologies.

Timber logistics processes cover every operation from harvesting through delivery to a mill. Processes such as forest stand planning and maintenance or mill operations are not considered direct elements and thus are only analyzed secondarily (see Fig. 1). The large number of actors, their types of interaction and the great diversity of products define the specifics of the timber logistics processes.

Timber type and quality define timber assortment specifications, which require different methods of processing in the timber industry

The overall timber supply chain from the 'forest to the factory" encompasses the individual processes of harvesting, skidding, assortment formation, storage and transport.

Harvesting involves the felling, delimbing, debarking and cutting of marked trees. Different harvesting technologies (e.g. power saws or harvesters) are employed.

Skidding entails hauling individual logs to a skid road whence several logs are simultaneously skidded to the truck road.

Assortment formation subsumes all processes that supply customers individually based on their respective intended uses of the timber. Timber collected in decks may be separated into industrial timber and sawmill wood. Chiefly longwood, logs and industrial timber are used in the timber supply chain. Biomass chips are also frequently transported. Since this requires on site timber processing, such assortments tend to be formed in piles.

Storage and intermediate storage denote the deposition of timber in decks at the edge of the truck road. More finely structured woody biomass (brushwood, branch material, etc.) is stored in stacks, piles or bundles instead of decks.

Transport involves hauling assortments or decks away from a storage site by truck, rail or even ship to the mills where they are processed or to other buyers.

Individual stakeholders usually organize timber and biomass supply processes based on business decisions. The costs incurred are influenced by the

- number and structure of biomass assortments,
- current demand for biomass,
- potential for available biomass,
- methods and technologies for processing biomass,
- means of transport,
- hauling distances,
- storage technologies,
- storage requirements,
- buyer locations and
- infrastructure.

HIGH GRADE TIMBER, INDUSTRIAL TIMBER AND ENERGY WOOD

The high grade timber, industrial timber and energy wood process chains are important (see Fig. 2).

The high grade timber process chain is highly individualized. Every single veneering and sawmill wood log is marked. The marking contains information on quality or origin. Since timber quantities are small and their monetary value is high, usually every log is recorded and marked with its dimensions and quality characteristics.

Industrial timber is produced during logging or forest thinning. Poor dimensions or quality characteristics make it unsuitable for use as a higher grade in sawmills or veneer mills. Industrial timber is normally mechanically or chemically pulped and subsequently processed into composite wood panels, groundwood, woodchips, pellets or pulp. Industrial timber is normally delivered directly from the forest in the form of long logs or precut cordwood with typical lengths of one or two meters. Marking every log is not cost effective since the sales units are large (decks or bulk). Hence, only information on supplier, quantity, quality, etc. is captured from truck loads arriving at a mill. This information facilitates delivery and dispatch inspection as well as invoicing. Hence, industrial timber is only marked on the deck or bulk level for reasons of labour and cost.

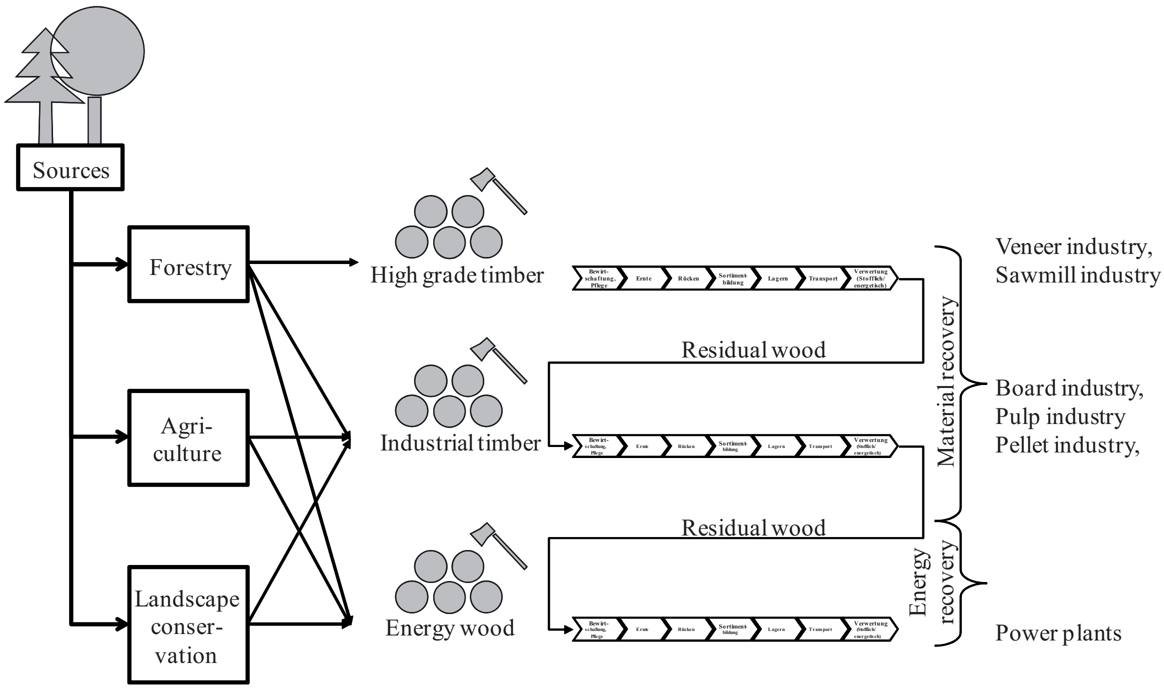

Fig. 2. The three basic process chains.

Marking is least advanced in the energy wood process chain because the biomass structures impede attachment and feasibility. Since quality and assortment characteristics constitute important information for the organization of logistics, researchers are also starting to work on energy wood marking.

SPECIFIC CHALLENGES OF THE TIMBER SUPPLY CHAIN

The German timber supply chain from the forest to the factory differs from the Scandinavian chain inasmuch as a large number of actors (forest owners, forestry operations, private forestry contractors, carriers, trucking companies, timber buyers and retailers, wood processing industry, etc.) interact. Various partners in this inhomogeneous and complex network collaborate in different processes and exchange information at a multitude of interfaces.

In addition to technical problems at the interfaces between individual actors in the timber supply chain, organizational and informational deficits in particular have an adverse effect on the economically optimized and ecologically sustainable value added of timber. Forestry operations, wood processing industry and other actors involved in the process chain plan and control their activities according to internal and normally functional criteria and individual spheres of responsibility (e.g. purchasing, logistics and marketing). Interactions and influencing factors among actors and their impact on the cost effectiveness and efficiency of internal and cross-organizational processes are often disregarded (Ehrhardt et al., 2006; Wäsche, 2007; Ehrhardt et al., 2008).

Forestry logistics often faces special challenges:

- Timber and biomass properties (shape, weight and volume) as commodities,
- Harvesting with manual, semiautomatic and fully automatic methods at dispersed and constantly changing locations,
- Harvesting of heterogeneous quantities and assortments for different methods of further processing at individual locations,
- Impact of weather (harsh environment) and
- Cyclical changes of infrastructure (road restrictions, protected areas, weather).

Primary challenges for a large number of different actors involved in the process are:

- Locating (intermediate) storage sites, i.e. search times in forest and field,
- Identifying assortments for producers and buyers,
- Reconciling discrepancies in quality and quantity between data captured at the site of production and at a buyer's facilities,
- Dealing with remainders during transport,
- Minimizing losses by unauthorized transport or theft,
- Eliminating format changes in complex communication and
- Working with non-standardized interfaces.

LOGISTICS COSTS

In Germany, the timber supply chain from the forest to processing into material and energy is highly complex (Von Bodelschwing et al., 2001). The process and information flows generated by a multitude of actors and service relationships in the chain increase indirect supply costs which are usually not transparent and hence neither qualifiable nor quantifiable. As a result, indirect supply costs are frequently not entered in costing and pricing. Thus, while timber providers may be aware of the (procurement) costs of services, e.g. harvesting, skidding or transport, during their planning, they usually lack an overview of the total process costs that offset the 'value' of the timber supplied.

Consequently, decisions on timber marketing and assortment are usually only incorporate direct costs of supply and obtainable market prices but disregard other criteria and influencing factors. Hence, a holistic analysis of the expenses and costs incurred in the forest-factory supply chain in conjunction with a determination of the 'timber value' would have to incorporate direct as well as indirect costs of supply and logistics. Otherwise, it would be impossible to already optimize timber's value added economically and ecologically during harvesting.

Supply chain management methods and tools provide bases and options to analyze aspects of value added and organize the timber supply chain with emphasis on logistics. The ultimate goal is to organize the supply chain so that organizations and companies no longer reach decisions based on overall cross-organizational value added rather than on individual business interests. Supply chain management hinges on cross-organizational coordination of the material and information flows throughout the entire value added process with the goal of optimally organizing the overall process in terms of time and cost. Logistics interfaces influence the smoothness of a supply chain's operation most. The goal must be to optimize the interfaces by eliminating unnecessary activities and resource consumption at system transitions in order to optimize costs.

This is precisely where the current research at the Fraunhofer IFF in Magdeburg is eliminating the existing gaps[1]. Researchers are performing extended analyses of the actual state of the timber supply factors in Germany in correlations between actors and their expenditures, costs and logistics processes as well as related information flows with the intention of compiling a survey of influencing factors and interactions. Initial isolated cost analyses have already established that indirect costs constitute 9-13% of the total costs.

SOLUTIONS IN FORESTRY

The term ´material Internet' denotes a trend in logistics towards monitoring and evaluating the condition of mobile logistics assets in conjunction with their surroundings. Distinct marking, time-based localization and condition monitoring of goods, load carriers and handling, transport and transportation equipment as well as personnel are the prerequisites for the identification of motion sequences and local concentrations of logistics assets as the basis for internal and cross-organizational analyses of logistics processes.

Telematic and RF technologies are driving the innovation behind the development of the material Internet. Telematics combine telecommunication and computer technologies. Radio frequency identification (RFID) employs radio technologies to automatically identify and localize objects.

Information on the type, quantity, current position and condition of identifiable logistics assets and the near real-time availability of this data in expediting systems are assuming a central role in logistics. Accompanied by trends towards miniaturisation and mobility in electronic information exchange and continually dropping costs, new markets are opening for autonomous logistics assets equipped with communication modules and sensor systems which optimize company and logistics processes.

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[1] The transnational, interdisciplinary research project ´WOODVALUE Tailor-made Wood Supply´ is being supported with fund from the Federal Ministry of Education and Research as part of the ERA-Net WOODWISDOM-Net initiative (Ref. No.: 0330835B). In addition to the German partners, the FVA and the Fraunhofer IFF, other organizations from four European countries are involved in the project.

As in other industries, the use of RF and telematic technologies in cross-organizational timber development, supply and processing facilitates and benefits logistics by:

- Detecting the quality and condition of logistics assets (e.g. timber and biomass) and related job orders (harvested – stored – transported),
- Representing the secure supply chain beyond organizational and national borders (chain of custody),
- Clearly identifying logistics assets (assortments, units, staff, tools, etc.) at any point in the logistics process,
- Determining the position of logistics assets (localizability) and tracking (and tracing) them and
- Providing route guidance to logistics assets down to the last meter, even off the public roads.

These capabilities are augmented by aspects that benefit users with special needs in forestry and wood processing industries. The use of telematic and RF technologies generates the following improvements in information exchange between individual actors:

- Reliable execution of processes through:
- Increased process efficiency (eliminating format changes and multiple data acquisition),
- Invoicing reliability,
- Completeness (complete transport),
- Condition monitoring (statuses),
- Situational control (weather, protected seasons, etc.).
- Clear identification of assets (e.g. chain of custody for certification and qualification and quantification of types of ownership and lands),
- Definite localization of assets (e.g. locations, logs, storage sites, equipment, staff and transport units).

Telematic and RF success stories from retailers, logistics providers and the automotive industry have had an impact on the industry despite isolated doubts about the technologies' applicability under the conditions in forestry and wood processing industry. Reports of increased sales, reduced losses by theft, minimized search times and material losses and reliable invoicing have helped establish RFID in timber logistics processes.

RFID IN FORESTRY

In theory at least, RFID is well suited for the harsh operating conditions in forestry (Knehr, 2005; Fleisch et al., 2003; Ehrhardt et al., 2006). Since reading does not require a visual connection between the transponder and reader, dirt, ice and snow do not interfere with RFID identification. Transponder technology enables easy tracking of the whereabouts of timber in the supply chain and thus controlling the rate of loss. It should become possible to individually identify logs from a small private forest and allocate them to suppliers for bulk timber marketing. Extracting data automatically when reading RFID tags would save time and costs for data entry and thus ensure that the data is of high quality. Near real-time transmission of information on the delivery status and geographic position of lots would provide expediters in mills an effective tool to control timber flows.

Such considerations have delivered impetus for various research projects with different objectives and focuses on specific aspects of RF use in roundwood logistics. Different projects have employed different RF transponder frequency ranges depending on the stated objectives and the desired improvements.2

RFID TECHNOLOGIES IN THE HIGH GRADE TIMBER PROCESS CHAIN

Prompted by the potentials of RF technology many projects have demonstrated in many domains of logistics, Cambium Forstbetriebe and the Forstliche Versuchs- und Forschungsanstalt FVA among others have initiated and completed numerous roundwood logistics projects focusing on single log marking (see Table 1).

Log Tracking System LTS

Cambium Forstbetriebe and DABAC GmbH jointly created a commercial tracking system based on Progress software for the forestry and wood processing industry's value added process. It facilitates continuous timber tracking from its original location to processing. Data is documented and supplied to the organizations involved in the process for control and invoicing. The distinctive feature of this effective solution is the high number of partners, which enabled a 1:1 distribution between providers and buyers. Processes entailing several providers and buyers or even service providers were disregarded.

Freiburg Transponder Cycle

The Forstliche Versuchs- und Forschungsanstalt FVA collaborated with the engineering firm Föller & Partner to develop an innovative marking system for roundwood based on commercial RFID systems. Their goal was transponder reusability. The RFID tags are either mechanically or manually attached to the end faces of logs with the aid of a specially developed nail. Paper making industry endorsed the practicability of this transponder mount since it is a biotech material produced from renewable raw materials. Thus, production offcuts can be marketed without sacrificing quality. The transponder itself is retrieved and, thus available again for marking.

[2] The frequency range depends on the intended purpose (single log marking or commercial timber identification) as well as on the given boundary conditions in the process, e.g. possible or desired read ranges. In addition, the selected frequency range also co-determines transponder costs and thus becomes a factor in business decisions.

Table 1. Selected projects on RF in roundwood logistics (2008)

Project	Project emphasis	Marking method	Tag	Information system	Read method	Focus
Log Tracking System	Data manage-ment	Single log/ manual Sawmill wood	Nail (plastic)	Web-based Stand alone	Single log/ manual (terminal)	Integrated identification in every process step but 1:1 ratio between timber providers and buyers ('simple' IT solution)
Freiburg Transpon-der Cycle	RFID application and shearing device	Single log/ manual sawmill wood	Disc on timber carrier (timber and plastic)	None	Single log/ manual (terminal)	Complete removal of the tags at the mill and potential reuse
Optimization of the Flow of Goods in the Timber Harves-ting Chain	Mechanical tag application (har-vester)	Single log/ harvester Industrial timber, sawmill wood	Smart-card (plastic)	None	Single log	Mechanical application of tags during harvesting
Wilwer-ding data Cargo GmbH	Data manage ment	One tag per deck/ manual	Smart-card (plastic)	Web-based Stand alone	Deck/ manual	Cost reduction by minimizing the number of tags on 1 deck
Indispu-table Key	System based on IAD concepts	RFID/bar code/ LNP Sawmill wood			Single log, board	Integrated identification from forest to sawmill

Indisputable Key[3]

Twenty-nine partners from five countries are collaborating on the Indisputable Key project which is developing a methodology, advanced technologies and systems for complete traceability, including standards for information transfer: The goal is to improve the use of timber and optimize forest production through the chain of transformation while minimizing environmental impacts.

[3] For more information, see http://www.indisputablekey.com/

Although the logistical problems are identical for low grade (industrial timber) and high grade assortments, RFID technology is presently only used to mark single high grade roundwood logs.

Here, too, the plastic carrier materials of the transponders in use diminish the acceptance of RF technology, particularly when they remain in the timber and thus potentially cause damage in subsequent processing in paper and pulp or MDF and particleboard industry (e.g. machine jams). A process has been developed to automatically remove tags from high grade roundwood but it is too complex and expensive for industrial timber assortments.

Since they are geared towards individual logs, all processes that identify timber in a factory (tag reading) are unsuited for low grade timber logistics (see Sect. 2.2). Single log identification is fundamentally required for industrial timber and it is ultimately too expensive as well. Buyers need to be able to identify timber on a truck at the mill to allocate a delivery of roundwood assortments to different orders and thus owners. This necessitates automatic, simultaneous bulk reading of any logs marked with RF tags. Automatic single log reading is impossible (without separating the logs) and manual methods are too labour and time consuming.

The number of logs that have to be marked during harvesting to effectively identify the origin of industrial timber at a mill (gate-based bulk reading of timber on a truck) has not yet been established. No studies have been conducted to determine the minimum detectable electronic marking per truck load for every site of origin (i.e. whether every second, fifth or tenth log has to be marked during harvesting) or the costs incurred in the process. Additionally, bulk timber marking raises another important issue: How are the quantities of data generated to be handled, i.e. who will manage the information and how? Put differently, how should the ‘intelligence in timber’ be managed in the process? Data processing and management that supports broad implementation of RF technology in low grade timber logistics has not been developed. Issues of integration, e.g. in internal order management systems, are unresolved and there are no methods and standards to integrate extensive RF transponder data in information systems and transmission routes, e.g. to utilize the information flow and content for machine harvesting and mill acceptance. One open issue is whether to transmit every individual RF transponder ID or an origin ID stored on several tags, e.g. an order number or a plot or subplot key. While the former entails the transmission of large quantities of data and potentially longer computing times during identification when received at a mill, the latter requires write methods to export origin ID to the tag.

The project ‘Intelligent Wood’ is addressing open questions related to commercial roundwood assortments in particular[4]. The project is running from 2008 through 2010 and the results, specifically their integration in IT, manufacturing and

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[4] The research project ´Intelligent Wood: RFID in Roundwood Logistics’ is being supported by the Federal Ministry of Food, Agriculture and Consumer Protection as part of its innovation support program (Ref. No.: PGI-06.01-28-1-53.F11-07).

logistics systems as well as formulated standards, shall be transferrable to higher grade assortments.

In a partner consortium including the Fraunhofer IZM, Thüringer Landesanstalt für Wald, Jagd und Fischerei (TLWJF), metraTag GmbH, Gicon GmbH, Wahlers Forsttechnik GmbH and the Kuratorium für Waldarbeit und Forsttechnik (KWF), the Fraunhofer IFF is working in the project 'Intelligent Wood" on developing tags with (carrier) materials, which do not interfere with buyers' production processes when they remain in the timber and are simultaneously suitable for bulk reading (for roundwood identification on a truck at a mill). In addition, equipment compatible with the tags is being developed to identify the origin of roundwood on a truck at a mill by means of bulk reading (gate). The project is also researching software for the acquisition, management and exchange of RF identification data as an integral part of job order and invoice management in the timber supply chain from the forest to the factory.

The newly developed transponder and gate have so far delivered extremely promising results in the field tests for their future usability in the field. Consensus on the design of an IT solution implementable cross-industrially in Germany, including an IT infrastructure with standardized IT processes, has been more difficult to reach. One challenge of designing an IT infrastructure is the analysis of pros and cons of transponders with a unique internal ID and writeable transponders, i.e. tags that store individual data for various application scenarios and their comparison from the perspective of cost effectiveness, IT security and organization. While not yet final, the latest results of the project work have thoroughly demonstrated the expediency of the different approaches in various scenarios of timber logistics. However, transponders with a unique internal ID have proven preferable for commercial timber logistics for reasons of work, costs and organization.

The results of the project will be documented in a final report at the end of 2010.

IT TECHNOLOGIES IN THE ENERGY WOOD SUPPLY CHAIN

The depletion of such fossil fuels as coal and crude oil is making new approaches to energy recovery imperative. However, the substitution of coal and crude oil with biomass may also generate new problems. More intensive utilization could lastingly damage forests. Competition between agriculture and forestry is also critical. The utilization of residual biomass provides a promising alternative. Residual biomass logistics are challenging, though, and entail high costs. IT, telematic and marking technologies may well be implementable much as they are in the high grade and industrial timber industry. An international consortium, lead-managed by the Fraunhofer IFF has been assembled in the project Best4VarioUse to research pressing issues in the energy wood sector related to IT technologies.

Among other things, the project is:

- Piloting methods and services that build upon regionally specific and comprehensive site and supply strategies while utilizing and adapting existing IT solutions, e.g. to optimize storage sites and transport,

- Testing and piloting solutions and methods to plan, control and monitor material flows and eliminate specific barriers to action,
- Developing ICT that identify biomass, capture it on site and attribute to logistically relevant site, quality and condition information and developing support services to plan, control and monitor the overall process chain.

OUTLOOK: THE NEED FOR STANDARDS

Information exchange between actors in forestry timber logistics is plagued by non-standardized formats and interfaces (Dietz, 2009). Deficits in information logistics largely caused by absent standards for data exchange and communication would be a prime starting point for applied research and development. Efficient IT aided supply chains could ensure that interfaces and formats are compatible and thus facilitate a smooth process flow. Ideally, all the actors involved in the supply chain would have the information relevant to them at their disposal to optimize their process flows.

No single solution in Germany let alone in Europe will be able to optimize every supply chain. A multitude of actors and different business processes demand the standardization of data exchange and communication at interfaces with the goal of developing efficient information logistics to optimize timber logistics. The achievement of this goal will entail analyzing information requirements, optimizing information flows and standardizing data exchange formats while simultaneously assuring high technical and organizational flexibility.

To this end, the Fraunhofer Institute IFF in Magdeburg is cooperating with industry partners and multipliers to develop standards for data exchange and communication. Their long-term goal is to advance standardization, keep standards up-to-date and adapt standards to the changing technical and organizational requirements.

So far, projects related to other important European standards have focused on data and exchange formats. Forestry continues to lack IT standards, e.g. for mobile equipment, interfaces or supply systems. This situation is increasingly threatening to obstruct the dissemination of IT standards. Basically caused by IT providers' market strategies, these problems will only be eliminated when the actors in timber logistics define the minimum requirements, i.e. implement technical standardization. Hence, not only data standards but also technical standards and specifications or guidelines are needed.

Not only the optimization of the material flow throughout the forestry timber supply chain but, above all, the optimization of the related information flows will also open substantial potentials for rationalization. This will necessitate extending standardization from products to information technology. Initial approaches to standardization have been devised and now have to replace the existing isolated solutions. Data formats have to be standardized for the existing basic data structures. Then, they will be transferrable to attached EDP systems and adapted for specific companies or organizations. Numerous completed projects clearly demonstrate that the standardization of information flows and related data formats will satisfy a demand and is feasible. In the future, importance will be increasingly attached to international collaboration in the domain of logistics in general and information logistics in particular. The challenges of globalization will not be mastered in Germany or Switzerland alone. They require systems solutions that bundle resources and synergy potentials. These will only be implementable with international collaboration and the development of standards.

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Measurement and Modelling of Circumstances in Animal Houses: What, Why and How

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Abstract. The indoor air of the animal house has to be of such quality that the animal, the human being and the building should feel well. It means suitable temperature without moisture and gas, microbe and dust contents which should be low enough. The objective of our studies is to create general physical-chemical models for the ventilation and temperature of animal houses as the function of factors which affect micro climate (temperature, moisture, gases, dust, microbes, mould) and the heat balance of the animals. The optimal climate given by the models is achieved by the right ventilation. A system which is automatic or gives alarms and can be used to carry out the optimum conditions of the animal buildings in as stable a way as possible is needed. For this purpose reasonable and reliable sensors which measure the right factors are needed. So the results of sensors can be used for model based control of the ventilation in which case one can switch to the modelling adjustment in which more quantities can be simultaneously used and in such a way the quality of the indoor air of animal houses can be improved by the adjustment of only one quantity (temperature or moisture or carbon dioxide or other gas).

Key words: Ventilation, modelling, animal houses, sensors, balance

INTRODUCTION

Ventilation is needed in animal buildings for removing harmful gases in order to ensure acceptable indoor microclimate. Microclimate parameters such as the concentration of gases, temperature, air velocity, dust and humidity affect the welfare of animals, humans and buildings themselves. On the other hand, ventilation rates are required to estimate the amount of gases emitted from animal houses. The rate of production (P in $m^3\ h^{-1}$) of a specific gas in an animal building is given by the mass balance:

$$P = q_V \left(C_{in} - C_{out}\right) = q_V\ \Delta C \qquad (1)$$

where q_V ($m^3\ h^{-1}$) is the ventilation rate, and C_{in} ($m^3\ m^{-3}$) and C_{out} ($m^3\ m^{-3}$) are the concentrations of the gas inside and outside the animal building, respectively. If P is known, ventilation rate may be calculated from Eq. 1. Suitable gases the production of which P is known are CO_2, water vapour and methane.

Animal buildings may either be mechanically or naturally ventilated, or a combination of these two. There may also be possibilities to regulate the rate of ventilation in the buildings by adjusting fan flow rates (mechanically ventilated), closing windows or rolling up curtain walls (naturally-ventilated curtain-wall barns). Air exchange in mechanically ventilated buildings is usually done by fans, and the ventilation rates are then:

$$q_V = v \cdot A \tag{2}$$

where A (m^2) is the cross-sectional area of the fan and v ($m\ s^{-1}$) is the average air flow through the fan.

To evaluate their practical usefulness, four methods of estimating ventilation in dairy buildings were compared by Teye & Hautala (2007): heat balance, moisture balance, carbon dioxide balance and direct air flow measurements in a naturally ventilated dairy barn. Rather big differences were observed.

In this paper, first of all, we express the theoretical considerations concerning ventilation in section 2. Various balances together with recommendations for the microclimate in cow houses are used to calculate the minimum ventilation per cow. Ammonia emission model is presented that gives ammonia emission as a factor of T, RH, v and pH. Thus, the microclimate in cow houses can easily be calculated and automatic ventilation should function. In section 3, we describe the apparatus that can be used for the automatic measurement of microclimate in animal buildings. In section 4, we give some results of the measurements performed in cow houses, piggery and poultry houses. In section 5, we describe what is most important in determining the ventilation in animal houses in various circumstances.

THEORY

Carbon dioxide and methane balance

Assuming ideal mixing, the ventilation rate, q_V of a animal building (as used in Equation 1) can be estimated by measuring the rate of production, P of a tracer gas in the building and the differences in the tracer gas' concentration in and outside the building, ΔC as:

$$q_V = \frac{P}{\Delta C} \tag{3}$$

The gas involved (tracer gas) could be an artificially produced gas if the rate of production is known. Methane (CH_4) and carbon dioxide (CO_2) in solid floor dairy buildings with regular manure removal are considered to be produced mainly from the dairy animals' metabolism and therefore could be used as a tracer gas. If the production of CO_2 and CH_4 from other sources in a dairy barn is negligible, then 330 g h^{-1} of CO_2 per cow (CIGR, 1999), and 10 g h^{-1} of CH_4 per cow is produced in a dairy building (Amon et al., 2001; Hindrichsen et al., 2005; Johnson & Johnson., 1995; Jungbluth et al., 2001). Measurements have indicated (Teye and Hautala, 2008) that less than 10% of the total emission of CH_4 and CO_2 emerge from dairy building floors, confirming the assumption of cows being the main source of production to be fairly good.

Estimated from Equation (3), the minimum ventilation rate per cow to keep CO_2 concentrations below recommended harmful limits (3,000 ppm according to CIGR, 1984) is 100 $m^3\ h^{-1}$. For a typical dairy building with 100 m^3 space per cow, the minimum exchange rate of air is about once an hour to keep CO_2 concentration below the recommended harmful limit.

Water balance

The amount of water or moisture produced per cow is well documented (CIGR, 1984). In dairy buildings, ventilation rate is calculated from moisture balance as:

$$q_V = \frac{P_{H_2O}}{\left(C_g - C_{out}\right)} = \frac{P_{H_2O}}{\rho_{air}\left(x_{in} - x_{out}\right)} = \frac{P_{H_2O}}{\rho_{air} \cdot \Delta x} \qquad (4)$$

where x is the water content (kg kg^{-1}), ρ_{air} is the air density (kg m^{-3}), P_{H_2O} is the total production of water vapour, i.e. from cows and from the building floors.

Similarly as in the section discussing CO_2 and CH_4 balances, the minimum ventilation using water balance can be estimated based on Equation (4). The problems of moisture in dairy buildings occur during winter when relative humidity (RH) ranges between 80 and 100%. During a winter with inside and outside air RH of 80 and 100% respectively, if the inside and outside temperatures are 10 and 0° C respectively, Δx will be 0.003. Furthermore, if the inside and outside temperatures are 0 and -10° C respectively, Δx will be 0.002, and if the inside and outside temperatures are 0 and -20° *C* respectively, Δx will be 0.003. Hence, if winter average water production, P_{H_2O} is 500 g h^{-1} per cow (CIGR, 1984), then the minimum ventilation rates according to equation (4) will be between 150 and 250 m^3 h^{-1} per cow, assuming the water emission from other sources to be negligible.

Heat balance

Ventilation according to heat balance is expressed as:

$$q_V = \frac{P_{heat} - P_{loss}}{\rho \ c_s \left(T_{in} - T_{out}\right)} \qquad (5)$$

where P_{heat} is the heat produced indoors by animals, heat system, illumination etc. (W), P_{loss} is the heat lost through the floor, walls and ceilings (kW), T_{out} is the temperature of the outdoor air (°C), c_s is the specific heat of air (J kg^{-1} K^{-1}) and ρ is the air density (kg m^{-3}).

The required ventilation rate for a fully insulated building (no losses, no heating) estimated from Equation (5) is 360 m^3 h^{-1} per cow if the difference between inside and outside temperature is 10° C, and the heat production per cow is 1 kW (CIGR, 1984). In winter ventilation is minimized in order to keep temperature indoors as high as possible. Neglecting heat losses, even temperature difference 40° C allows ventilation to be 100 m^3 h^{-1} per cow. Thus, a suitably insulated cow house does not need a heating system.

Comparing the ventilation rates from Equations (3), (4) and (5), it can be deduced that, to ensure safe and comfortable microclimates for human dairy workers (indoor temperature above zero and CO_2 less than 3,000 ppm), the minimum ventilation rate should be 100 m^3 h^{-1} per cow, i.e. an exchange rate of about once an hour.

Ammonia emission model

The NH_3 emission from manure can be separated into different processes. NH_3 molecules are first created in the manure in various chemical and microbiological processes. Then the molecules diffuse to the surface of the manure. From the surface they further diffuse in the air through the laminar boundary layer and finally by turbulent convective motion into all parts of the building. Turbulent motion is assumed to be fast enough to yield space independent concentrations. This is the so-called ideal mixing model.

NH_3 emission rate is theoretically modelled using information from literature. First, the surface concentration of NH_3 is calculated using equations adopted from Zhao and Chen (2003): the amount of NH_3 dissociation in the manure, the fraction of NH_4-N concentration in the total ammoniacal nitrogen C_{TAN} (kg m^{-3}) and the ratio of the NH_3 concentration at the manure side of the interface between the manure and the air and the NH_3 concentration at the air side of the interface between the liquid manure and the air. This comes from chemistry and microbiology. Then physics, i.e. Fick's law of diffusion and boundary layer theory are used for mass flux calculation from the manure surface. The final approximate equation (deviates less than 50% from exact calculations) is (Hautala, 2007; Teye and Hautala, 2008)

$$emission\ flux\,(g\ m^{-2}\ h^{-1}) = 0.02 \cdot 10^{T(^{o}C)/20+pH-8} \cdot C_{TAN}(kg\ m^{-3})\,/\,\delta(mm) \quad (6)$$

where δ (in mm) is the thickness of the laminar boundary air layer and presents the physics part of the equation in addition to the fact that emission rate is strictly proportional to emitting area, when diffusion plays a role. δ varies from 2 to 20 mm depending on the wind. 20 mm calm, 2 mm strong wind. If necessary, δ may be measured as explained by Teye and Hautala (2010). Neither of these assumptions is strictly valid in practical cases. Equation (6) is valid for any cover. For a porous cover, δ is the thickness of the cover. For liquid or solid cover, flux should be divided by at least 10^4 since diffusion coefficient is so much smaller in a liquid than in the air. If the manure is put into soil, δ is the relevant depth of soil above the NH_3 level. This is so according to the rules of physics.

METHODS

The stationary telemetry air quality monitoring and measurement system consisted of a central measurement unit and additional wired sensors located at different positions in and outside the animal buildings (Teye et al., 2009). The central measurement unit for telemetric transmission of air quality data was a 1m by 1m flat wooden board on which a General Packet Radio Service (GPRS) transmitter (a-Lab Oy's AWS-Core) and a set of air quality sensors were fitted. The sensors attached to the board of the central measurement unit continuously measured air temperature, manure temperature (infrared), radiation, relative humidity, air velocity, ammonia, and carbon dioxide concentrations in the building.

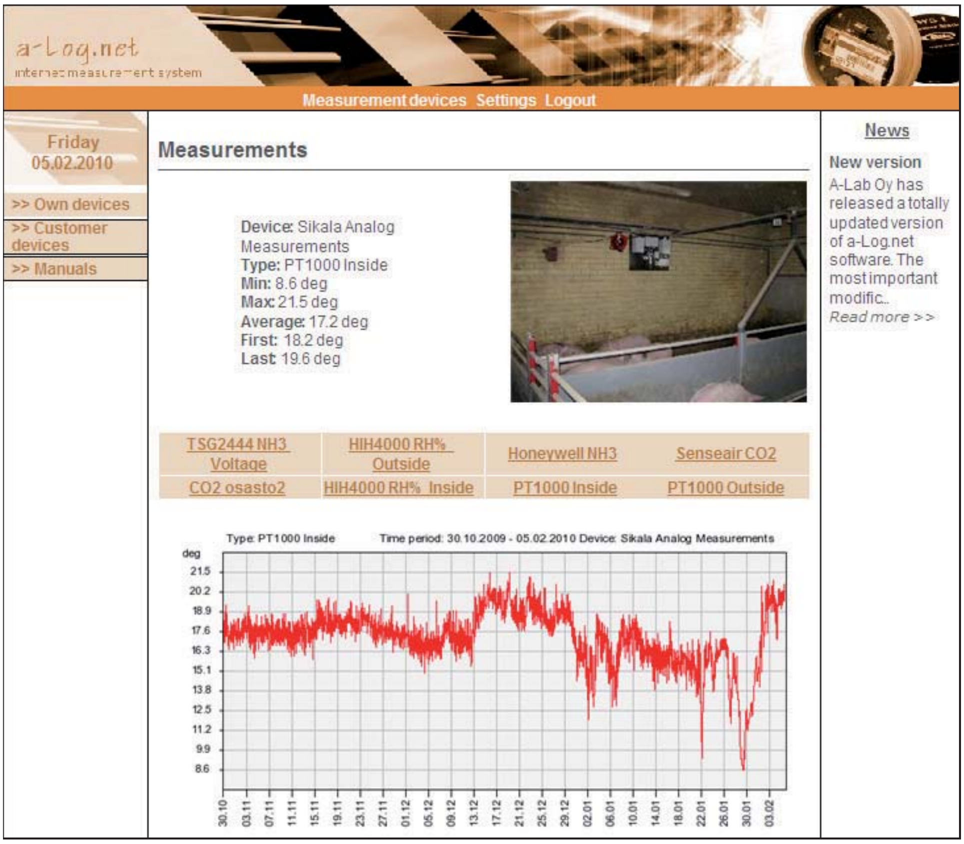

Fig. 1. An internet page showing the implementation of wireless data transmission of indoor air in piggery. The equipment is seen hanging on the wall in the inset.

All wiring connections and sensitive electronics were shielded from dust and moisture. Measurements were performed at a 30-minute interval and the data was sent through GPRS to a database server to be viewed or downloaded over a World Wide Web (WWW) interface. Fig. 1. shows a preview of the measurements taken with the wireless measurement system as viewed from the internet.

RESULTS

In Fig. 2 the CO_2 concentrations in two different kinds of dairy barns are shown. In the semi-insulated dairy barn the CO_2 concentrations are much higher in winter than in the uninsulated one. The farmer has obviously closed the curtains to keep the air warm inside. In the uninsulated barn the concentration stays all year round at a low level, 500-1,000 ppm.

Figs. 3-5 show measurements in other animal buildings. It can be clearly seen that the concentrations in winter are most of the time above the recommendations (3,000 ppm) but also that there is strong variation as a function of animal size (broilers) and time of the day.

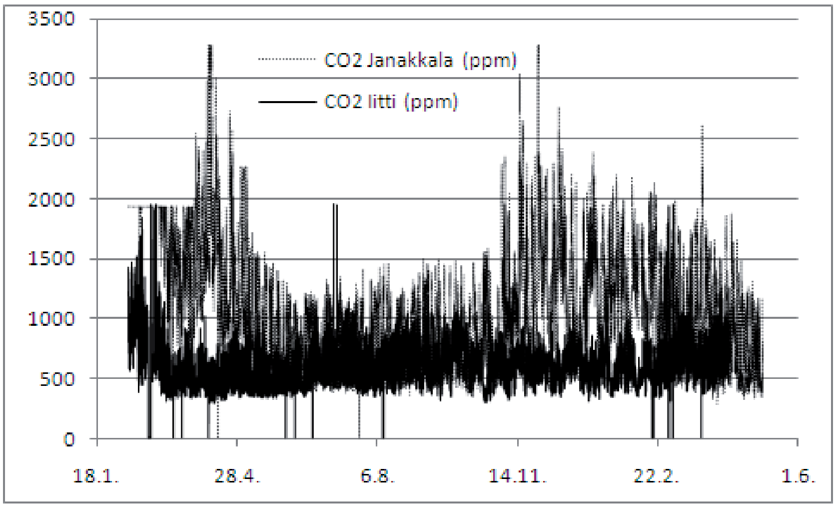

Fig. 2. CO_2 concentrations in a semi-insulated (Janakkala) and an uninsulated (Iitti) dairy barn.

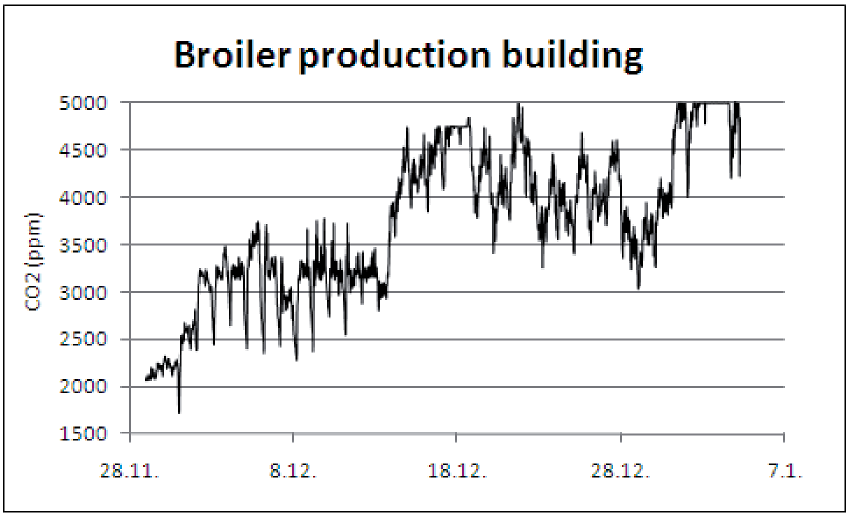

Fig. 3. CO_2- concentration development during the growth of broilers.

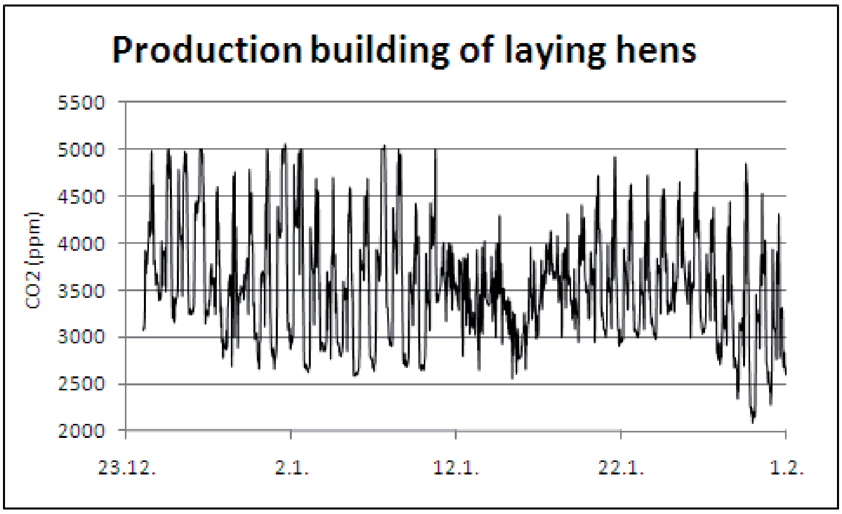

Fig. 4. Daily variation of CO_2-concentration in a hen house.

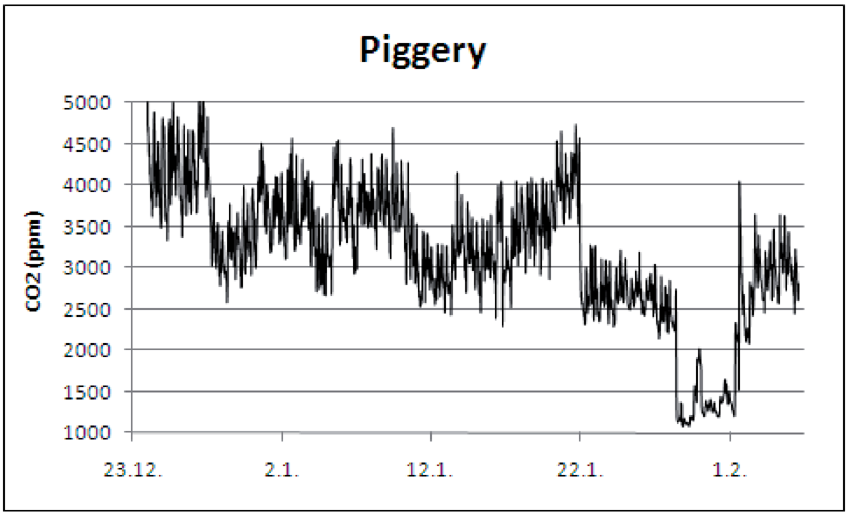

Fig. 5. CO_2-concentration in a piggery. The pigs were removed 26.1 and new ones came 2.2.

DISCUSSION AND CONCLUSIONS

Methods given in section 2 give adequate theoretical background concerning T, RH, CO_2, CH_4 and NH_3 in most situations, especially in dairy barns, where no heating is needed, if the house is suitably insulated. Ventilation can adequately be regulated by CO_2-sensors, which are cheap and have turned out to be reliable. Poultry houses as well as piggeries are different. They need heating in winter and this may be costly. One may roughly calculate the cost e.g. in a piggery. The ventilation per pig must be about 20 m^3 h^{-1}. If the outdoor temperature is -20^o C and indoor +10^o C, heating of this air in one day needs energy

q_V time ρ c_s ΔT = 20 m^3 h^{-1} 24 h 1 kg m^{-3} 30 K 1 k J kg K = 14 MJ = 4 kWh.

If the weight increases 1 kg day^{-1}, the cost is 40 cents pig kg in Finland. This noticeable cost means that the regulation of ventilation is of utter importance, as well as it would be very useful to know the lowest temperature the pig can stand in various conditions, e.g. in case the floor is heated. A simple heat balance model that gives the lower critical temperature is given in Hautala et al. (2008). We clearly need reliable sensors to regulate ventilation. When the activity in the night time is small, water evaporation and CO_2 emission are smaller and less ventilation is needed. Probably a good combination of sensors for automatic control of ventilation is T and CO_2. Both are cheap and reliable.

We have totally neglected here dust and microbes. Our preliminary measurements in Finland indicate very alarming concentrations of both dust and microbes especially in broiler and hen houses. The primary reason evidently is the use of peat.

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A Novel Manipulator for a Stone Protector of Stony Soil Tillage Implement

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Abstract. This paper studies a novel manipulator for a stone protector of stony soil tillage implement. According to the virtual reality technology based method, the composition technology of the virtual model of the novel manipulator is described in detail. This virtual model is used for the compilation of a video clip which simulates the motion of the model. The obtained results and a special computer program, realizing the virtual reality technology based study of the working process of the novel manipulator, can be useful for real time manipulator designers.

Key words: Agricultural machinery, field tillage machines, virtual reality technology, modelling, manipulator, stone protector

INTRODUCTION

Olt, Heinloo (2009) have studied a virtual model of a stone protector with safety device DEICLG (Fig. 1). They have examined the process of switching on the safety device DEICLG, when the point M meets an obstacle and cannot move to the left, as in Fig. 1.

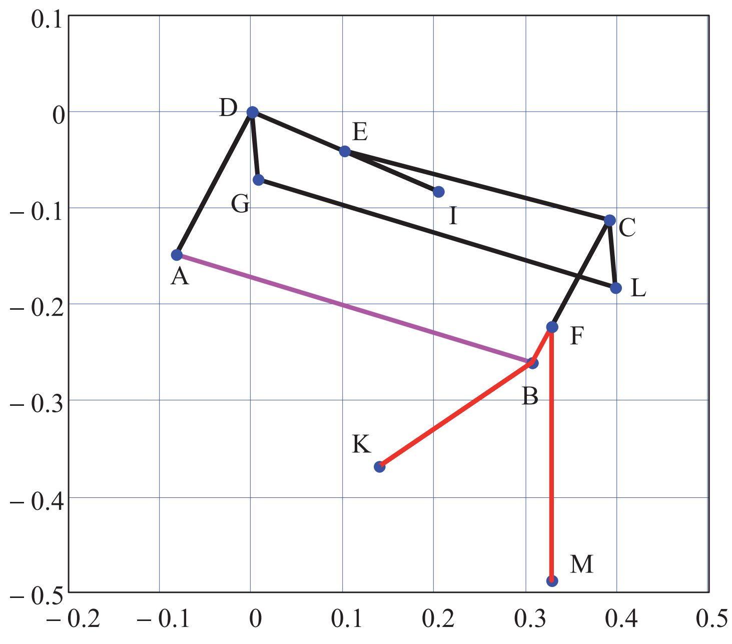

Fig. 1. Manipulator with the safety device DEICLG for a stone protector.

The virtual reality technology based method, used in the paper by (Olt & Heinloo, 2009), has earlier been used in studies on the working processes of elements of agricultural machinery by (Heinloo et al., 2005), (Heinloo & Olt, 2006), (Heinloo, 2006), (Heinloo & Leola, 2007) and reviewed by (Heinloo & Leola, 2008).

This paper presents the results of studying the motion of the novel virtual manipulator (Fig. 2) for a Stone Protector of Stony Soil Tillage Implement. In Fig. 2 the points A and K are moving in a straight line and the point M in a prescribed curve.

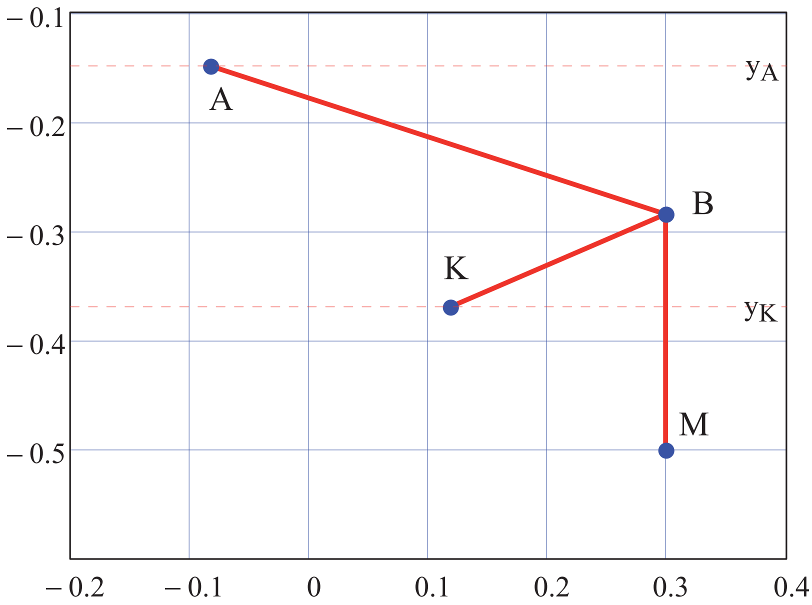

Fig. 2. Virtual model of the novel manipulator for stone protector.

CREATION OF VIRTUAL MANIPULATOR

To create a virtual model of a special manipulator ABKBM, let us suppose that the links AB and KBM (Fig. 2) have the following dimensions: l_{AB} = 0.405 m, l_{KB} = 0.200 m, l_{BM} = 0.216 m, l_{KM} = 0.223 m and at the initial position, the co-ordinates of the pivots A, B and points K, M have the following co-ordinates: A(-0.082 m, -0.149 m), B(0.299 m, -0.284 m), K(0.118 m, -0.369 m), M(0.299 m, -0.500 m). The vectors

$$x = \begin{pmatrix} A_{x0} \\ B_{x0} \end{pmatrix}, \qquad y = \begin{pmatrix} A_{y0} \\ B_{y0} \end{pmatrix}, \qquad x' = \begin{pmatrix} K_{x0} \\ B_{x0} \\ M_{x0} \end{pmatrix}, \qquad y' = \begin{pmatrix} K_{y0} \\ B_{y0} \\ M_{y0} \end{pmatrix},$$

where A_{x0}, B_{x0}, K_{x0}, M_{x0} are initial x-co-ordinates and A_{y0}, B_{y0}, K_{y0}, M_{y0} – initial y-co-ordinates of points A, B, K, M, drawn in the worksheet of the Computer Package Mathcad novel virtual manipulator at the initial position (Fig. 2).

Let us suppose that the trajectory of the point M is given by the equations

$$X_M(\tau) = M_{x0} - a\tau\,,\;\; g(\tau) = h\sin(10\tau - 1) - b\,,$$

$$Y_M(\tau) = g(\tau),\text{ if } g(\tau) \geq -b\,,\text{ else } g(\tau) = -b\,, \tag{1}$$

where

$$g(\tau) = h\sin(10\tau - 1) - b\,.$$

Here M_{x0} is the initial x-co-ordinate of the point M (Fig. 2), τ – a no dimensional parameter of this trajectory, $a = 2$ – constant with the dimension m, $h = 0.12$ m – the height of the virtual stone, $b = 0.5$ m – the parameter that determines the position of the virtual stone underground. The trajectory of point M, determined by the formulas (1), is modeling the profile of a virtual field with a stone (Fig. 3).

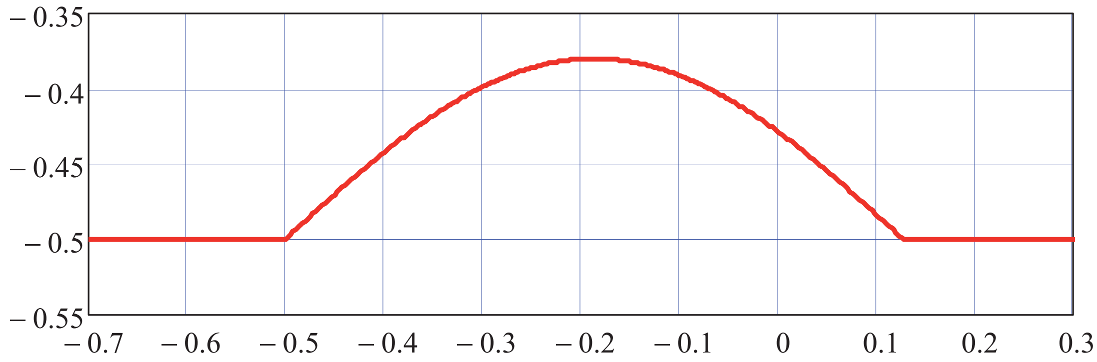

Fig. 3. Supposed trajectory of the point M (Fig. 2), modelling the profile of a virtual field with a stone.

The co-ordinates B_x, K_x, B_y, and the parameter τ at the moment of the time t can be found out from the following system of nonlinear equations:

$$(B_x - A_{x0} + vt)^2 + (B_y - A_y)^2 = l_{AB}{}^2\,,$$
$$[K_x - M_x(\tau)]^2 + [K_y - M_y(\tau)]^2 = l_{kM}{}^2\,,$$
$$(K_x - B_x)^2 + (K_y - B_y)^2 = l_{KB}{}^2\,,$$
$$[B_x - M_x(\tau)]^2 + [B_y - M_y(\tau)]^2 = l_{BM}{}^2\,, \tag{2}$$

where $v = 2$ m s^{-1} is the given velocity of the point A, supposed to be connected to the tractor. To simulate the motion of the virtual stone protector let us define the new vectors

$$x(t) = \begin{pmatrix} A_{x0} - vt \\ B_x(t) \end{pmatrix}, \quad y(t) = \begin{pmatrix} A_y \\ B_y(t) \end{pmatrix}, \quad x'(t) = \begin{pmatrix} B_x(t) \\ K_x(t) \\ B_x(t) \\ F_x(t) \\ M_x(t) \\ F_x(t) \end{pmatrix} - s(t), \; y'(t) = \begin{pmatrix} B_y(t) \\ K_y \\ B_y(t) \\ F_y(t) \\ M_y(t) \\ F_y(t) \end{pmatrix},$$

By the use of these vectors the video clip, showing the motion of the virtual stone protector (Fig. 2), was created. To show several frames from this video clip in the worksheet of the Computer Package Mathcad, we have defined the following vectors:

$$X = augment(x(0), x(0.1), x(0.2), x(0.3)),$$
$$X' = augment(x'(0), x'(0.1), x'(0.2), x'(0.3)),$$
$$Y = augment(y(0), y(0.1), y(0.2), y(0.3)),$$
$$Y' = augment(y'(0), y'(0.1), y'(0.2), y'(0.3)).$$

Here the function *augment* (A, B, C…) returns the matrix, formed by placing vectors A, B, C... from left to right in the worksheet of the Computer Package Mathcad. Fig. 2 shows the created virtual model at the moment of the time t at $t = 0$ s. Fig. 4 shows the positions of the virtual manipulator in the process of overcoming a virtual stone. At that the arrows show the velocities of the points A, K, M and the pivot B (To see the motion simulation of the virtual manipulator, click on Fig. 4 in the online version of this paper).

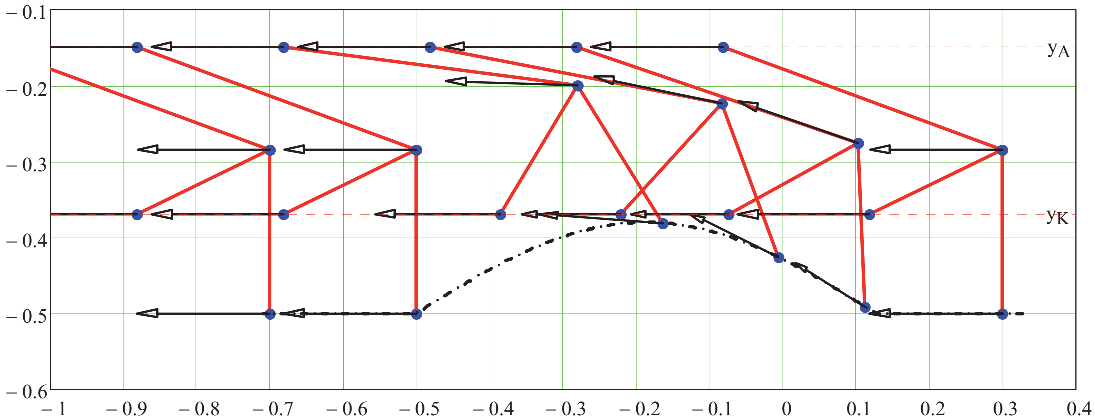

Fig. 4. Positions of the virtual manipulator while overcoming a virtual stone.

Let us now consider a case where the point M (Fig. 2) cannot move to the left. In this case instead of the system (2) the co-ordinates B_x, K_x, B_y, M_y in dependence of the time t must be found out from the following system of equations:

$$(B_x - A_{x0} + vt)^2 + (B_y - A_y)^2 = l_{AB}{}^2,\ [K_x - M_{x0}]^2 + [K_y - M_y]^2 = l_{kM}{}^2,$$
$$(K_x - B_x)^2 + (K_y - B_y)^2 = l_{KB}{}^2,\ [B_x - M_{x0}]^2 + [B_y - M_y]^2 = l_{BM}{}^2,$$

(3)

Fig. 5 shows that in this case the manipulator lifts the point M up (To see the motion simulation of the virtual manipulator, click on Fig. 5 in the online version of this paper). At that the arrows show the velocities of the points A, K, M and the pivot B (To see the motion simulation of the virtual manipulator, click on Fig. 5 in the online version of this paper).

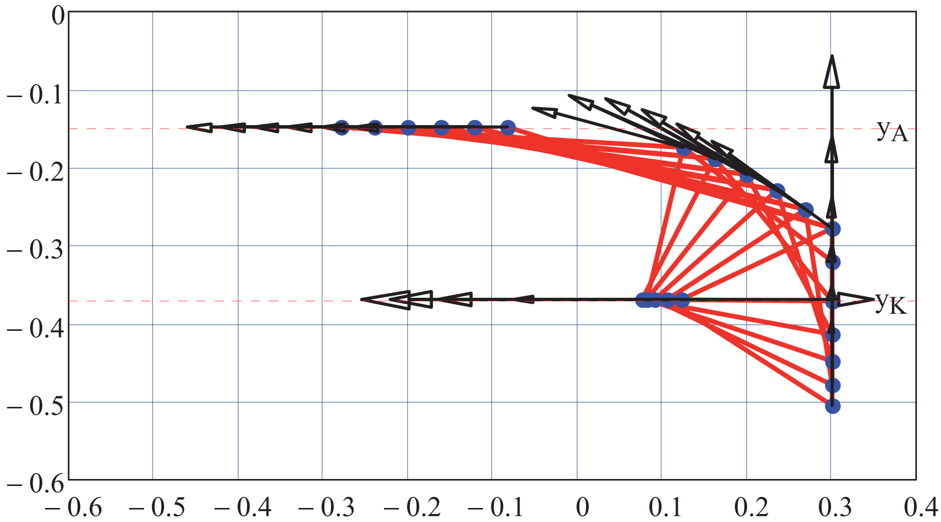

Fig. 5. Positions on the virtual manipulator when the point M (Fig. 2) cannot move to the left.

CONCLUSIONS

The paper concludes that the manipulator in Fig. 2 can be used as a stone protector for stony soil tillage implement. It is able to free a working tool from behind an obstacle and protect the working tool from damage.

The paper has also demonstrated the possibility of creating the manipulator in Fig. 2, three points of which are moving along the prescribed lines.

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Common Rail Diesel Feed System Diagnosing Technology

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Abstract: For testing common rail diesel feed systems, the company responsible for the production has issued test plans that include cycle values and repair technology. This particular article provides the reader with an overview of the common rail diesel feed systems' changes in cycle value due to control parameters and diagnosing technology that does not use test plans.

Keywords: Combustion engine, common rail, diagnosing, characteristics

INTRODUCTION

In Estonia, several companies deal with the technical maintenance, diagnostics and repair of diesel feed systems. The particular software and hardware used in these operations is rather expensive, thus limiting business in this field. The technical condition of a mechanical high-pressure pump is evaluated on a test stand. In addition to the test stand, electronic feed systems require a control unit. Different feed systems require different control units. In addition, test plans describing the productivity of the feed system on fixed control characteristic values are necessary for diagnosing the feed systems (Bosch EsiTronic). This kind of software and hardware can be purchased from the manufacturer of the feed system; however, it could be argued whether the diagnostic method described in this article is more effective. The common rail diesel feed systems used nowadays can be diagnosed without test plans. For doing so, it is crucial to know the principles of changes in the characteristics that are required for an engine's work.

MATERIALS AND METHODS

There are specific standard requirements for testing feed systems. Test liquid temperature should be 40° C during the test. The measurement of glass accuracy when using a 500 cm^3 measuring glass is ± 0.5 cm^3. When measuring a liquid, the dimensional error could be ± 1° C and in case of a fuel ± 1% of the measured quantity (Standard, ISO 4008/2).

Ten measurements were carried out during every test, the average of which was calculated. The regression equation was worked out on the basis of the data received. Microsoft Excel was used to process the data.

When dealing with high-pressure pumps, the fuel supply is regulated by turning the plunger and regulating the active gear. The regulation of the compression spring of the injector changes injection pressure. In case of common rail feed system, the electronic control system simplifies the equipment and the previously mentioned change in control parameters is electronic (Heisler, 2001).

When diagnosing a common rail feed system, the extent of cycle value released by it is measured. The cycle value describes the amount of fuel injected into the cylinder in mm^3 during one working cycle. The cycle value of common rail feed systems can be measured with three characteristics: injection pressure, opening time of the injector and rotational speed of the high-pressure pump (Mikita, 2008).

Injection pressure

In the common rail system, injection pressure is regulated by the pressure controller, which is in turn regulated by the control unit of the engine (Fig. 1). The injection pressure is regulated according to the rotational speed of the high-pressure pump and the opening time of the injector (Bosch, 2002; Bosch, R. 2002, Autoelektronik). Moreover, the extent of the cycle value is influenced by the productivity of the high-pressure pump. If the amount of fuel running through the injectors exceeds the maximum productivity of the pump, injection pressure will remain on a certain level and will stop increasing.

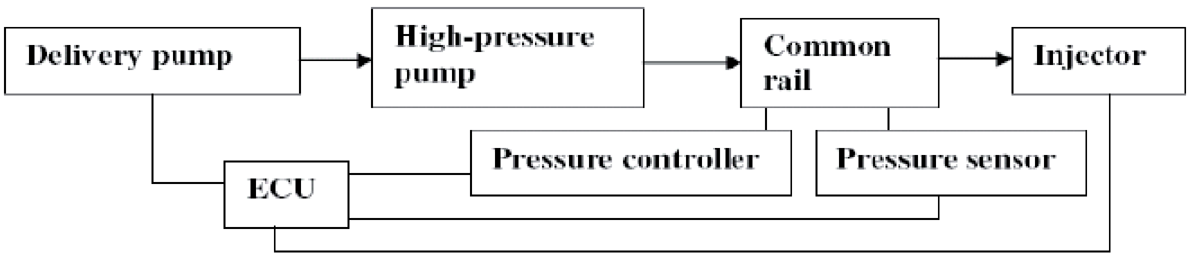

Fig. 1. Functional schema of common rail (Reif, 2007).

Injection pressure influences the extent of the cycle value and injection quality. The greater the injection pressure, the better its productivity. Fig. 2 demonstrates the increase in cycle value due to injection pressure.

As can be seen from the graph, with the injection pressure of $p_f = 750$ bar and opening time of $t_o = 1$ m s^{-1}, the cycle value released by the injector is $V_f = 40$ mm^3 $cycle^{-1}$. If the injection pressure is doubled, the cycle value doubles as well. Therefore, the same feed system can be used with different engines by regulating the necessary amount of fuel electronically.

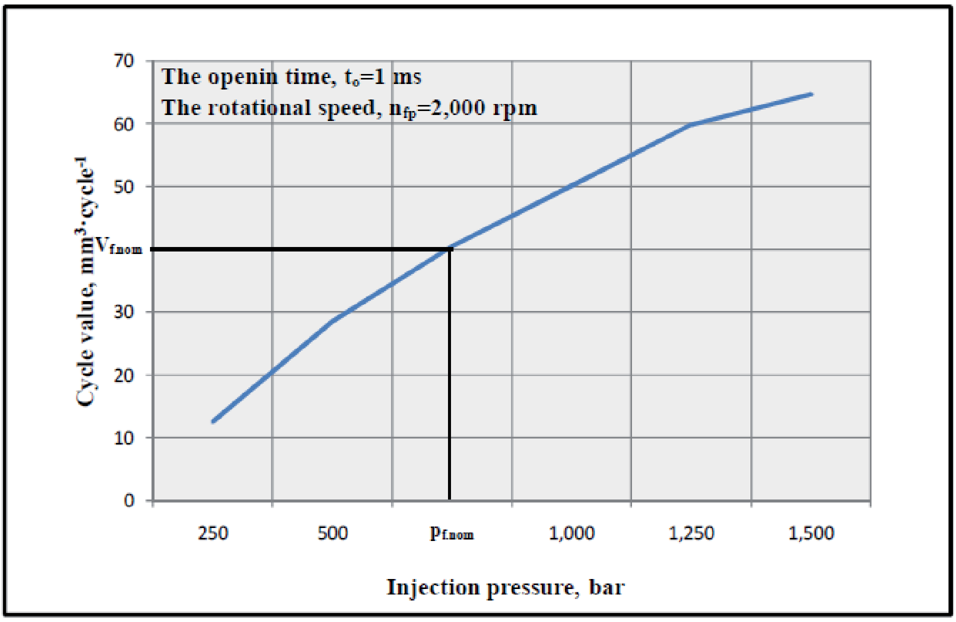

Fig. 2. The increase in the cycle value due to injection pressure.

The opening time of the injector

The productivity of the injector is regulated by changing its opening time. The opening time of the injector influences the extent of the cycle value, namely, the longer the opening time, the greater the cycle value. Fig. 3 describes the relation between the cycle value and the opening time of the injector.

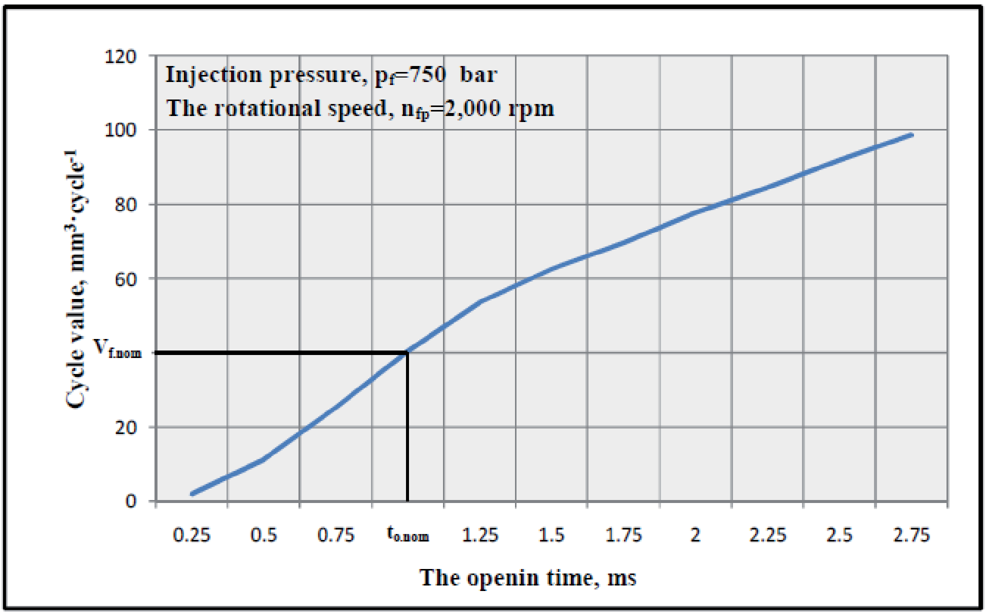

Fig. 3. The relation between cycle value and the opening time of the injector.

The rotational speed of the high-pressure pump

The rotational speed of the high-pressure pump influences the productivity of the pump and the maximum pressure in the feed system. Fig. 4 characterizes the dependence of system control characteristics on the rotational speed of the high-pressure pump. As can be seen from the graph, in case of longer opening times of the injector, the pump is not able to keep the pressure in the system at a slower rotational speed which starts to fall. In this way, the boundary conditions of the feed system's work, or, in other words, the conditions allowing the use of the feed system at a certain rotational speed of the pump, are fixed.

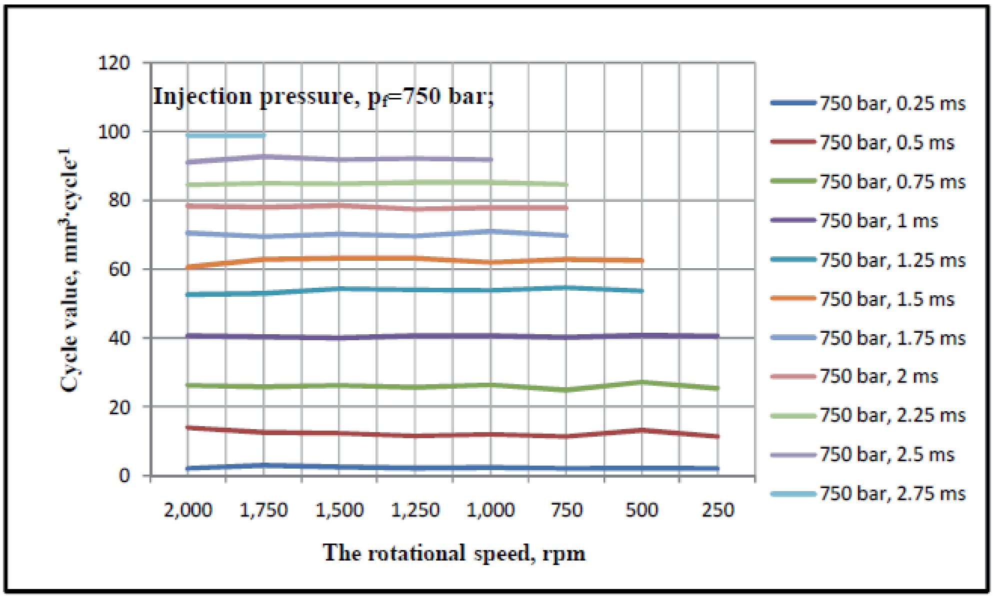

Fig. 4. The relation between cycle value and the rotational speed of the high-pressure pump.

As a part of the research, a three-dimensional characteristic has been designed (Fig. 5), taking into account the previously mentioned control parameters. It characterizes the cycle values of the feed systems.

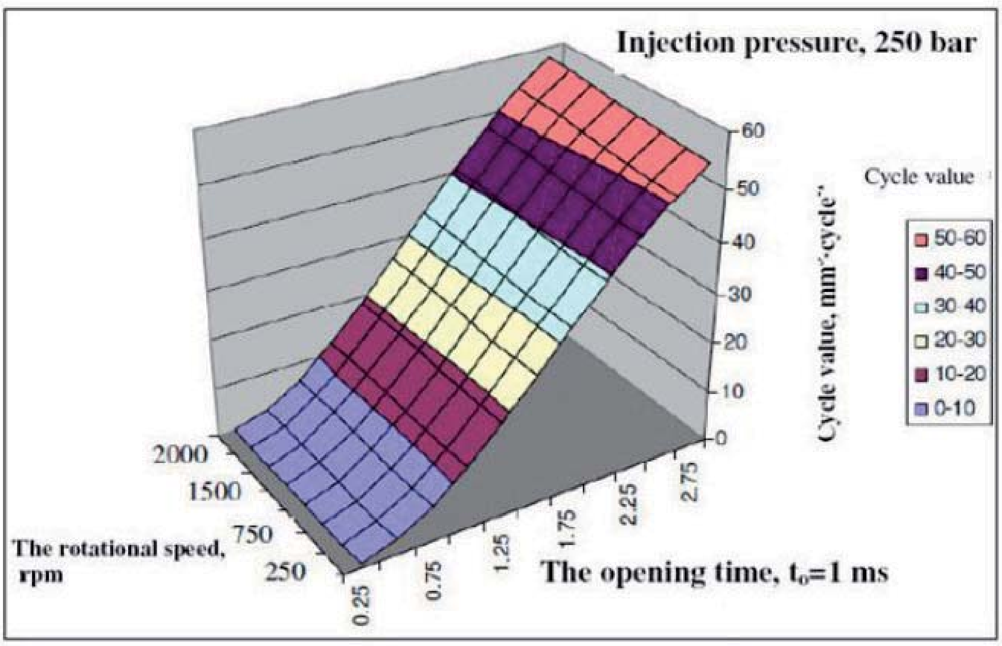

Fig. 5. The characteristic describing the common rail feed systems work.

DISCUSSION

Fig. 5 can be perceived as a test plan, which gives the cycle values of the feed system on the pressure 250 bar. When diagnosing the feed systems, the cycle values ought to be compared with the ones on the characteristic to decide whether the feed system is in good order. Comparative measurements such as these should be conducted on at least two pressure values, 250 bar and 1,000 bar. In the first case, the value would represent the ignition mode, and in the second one – the working mode of the engine. If the diagnostics reveals that the received cycle values of these particular pressures are smaller than permitted, the injector tip is clogged up or the backflow valve is worn-out, respectively.

The necessary characteristic and the corresponding database for diagnosing the common rail diesel feed system has been designed as a result of research which involved stand tests without the engine. The three-dimensional characteristic can be described with the following mathematical expression:

$$y(x_1, x_2) = \left| \begin{matrix} 1{,}7718 - 4{,}57 \cdot 10^{-3} \cdot x_1 - 4{,}5902 x_2 + 3{,}66 \cdot 10^{-6} \cdot x_1^2 + 19{,}7507 \cdot x_2^2 - \\ -1{,}04 \cdot 10^{-9} \cdot x_1^3 - 3{,}9913 x_2^3 + 9{,}98 \cdot 10^{-4} \cdot x_1 \cdot x_2 \end{matrix} \right|$$

where $250 \le x_1 \le 2{,}000$ min^{-1} and $0{,}25 \le x_2 \le 2{,}75$ m s^{-1}.

CONCLUSION

The particular example deals with the common rail feed system diagnosing technology where the necessary cycle value test results are obtained through the mathematical expression on the pressure 250 bar. Characteristics such as these and the corresponding characterizing mathematical expressions can replace the test plans of the feed system manufacturers.

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Neuromuscular Fatigue Characteristics in Female Painters Following the Working Day

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Abstract. The aim of this study was to evaluate changes in neuromuscular fatigue characteristics in painters following the working day. The subjects (n = 10) were female painters aged 22-60 years. First the subjects completed a questionnaire and thereafter they performed before and after the working day a 3-minute test of wall painting, in the course of which the electromyographical (EMG) power spectral median frequency (MF) for biceps brachii, trapezius, deltoideus and infraspinatus muscles was measured. The results indicated an increase in subjectively evaluated muscle fatigue compared to the beginning of the working day, whereas the most burdened regions were the arms and shoulders. Objectively estimated muscle fatigue emerged before and after the working day when comparing EMG power spectral MF measured at the beginning and end of the wall painting test. However, this muscle fatigue, evaluated objectively by EMG power spectrum MF slope from biceps brachii, trapezius, deltoideus and infraspinatus muscles, did not differ significantly before and after the working day. This study revealed that painters used different manners of work, whereas the working tool was the same for everyone and no-one had customized it for herself. It is also important to emphasize that 82% of the workers had not been guided in terms of ergonomics. The results of this study can be used by specialists of ergonomics.

Key words: Electromyography, muscle fatigue, neuromuscular function

INTRODUCTION

Epidemiological studies indicated that in shoulder joint, various disorders and injuries occur in the first place in case of working with arms elevated above the level of shoulders, as in such a position, the burden on the joint structure increases abruptly (Bjelle et al., 1973; Dan et al., 2001). The typical ailments of the shoulder joint are calcific tendinitis, tenosynovitis, arthritis and periarthritis. Each disease has a distinctive pathology and treatment regime (Neviaser, 1983). Garg et al. (2005) studied shoulder girdle muscle strength of one hand in women when working with hands elevated above the head. It was found that women, especially in those professions that require working with hands elevated above the head, have little strength in their shoulder muscles. Chow & Dickerson (2008) investigated shoulder strength as a function of hand location and force direction while sitting and standing. They found that there is a significant decrease in shoulder strength of females compared to males.

Muscle fatigue has been defined as a reduction in the force-generation capacity of a muscle due to previous activity (Edwards 1981; Bigland-Ritchie et al., 1986). It is associated with changes in amplitude as well as the power spectrum parameters of the electromyogram (EMG) over time. During sustained submaximal isometric contractions typical changes in surface EMG occur including an increase in root mean square and a spectral shift towards low frequency (spectral compression) (Löscher et al., 1994). Musculoskeletal discomfort can manifest itself as tension, muscle fatigue, soreness, etc. in and around active and passive structures, i.e. muscles, tendons and joints (Van der Grinten, 1992). Perceived musculoskeletal discomfort as subjective sensation of muscle fatigue can be measured by self-reports using the Borg Category Ratio (SR-10) Scale (Borg, 1990; Hamberg-van Reenan et al., 2009).

The aim of this study was to evaluate the changes in neuromuscular fatigue characteristics in painters following the working day. Measurements were carried out at the place of work at the beginning of and after the working day.

MATERIAL AND METHODS

Subjects

Ten females working as painters at (mean ±SE) age of 45.5±3.2 years participated in this study. The height, body mass and body mass index of the subjects were 162.4±2.6 cm, 80.1±4.8 kg and 30.3±1.4 kg m^{-2}, respectively, and their length of employment as painter was 21.3±4 years. The subjects were randomly selected and participated in this study voluntarily. The questionnaires and the measurements were completed in May and June, 2008. Larger facilities were chosen as the site of the measurements. Eight subjects were surveyed at the 1st stage of construction at the Tartu University Maarjamõisa centre of medical facilities and two subjects at the fashion and entertainment centre in downtown Tartu. The measurements were conducted at the beginning and at the end of the working day at the site where the workers were employed. The subjects did not have to leave the site and the working rhythm was disturbed as little as possible, thus yielding more reliable results. The height and body mass of the subjects were measured at the site with metal anthropometer and electronic scales, respectively. The subjects were familiarized with the essence and the aims of the survey.

Data collection

The measurements were conducted at the beginning and at the end of the working day at the site where the workers were employed. So the subjects did not have to leave the site and the working rhythm was disturbed as little as possible, thus yielding more reliable results. The height and body mass of the subjects were measured at the site with metal anthropometer and electronic scales, respectively. The body mass index (kg m^{-2}) of the subjects was also calculated. In the course of the research, subjects completed the questionnaire first. Subjective muscle fatigue sensation in hands, trunk, back and lower limbs was estimated with a psychophysical rating scale (Borg CR-10 Scale). The scale included numbers from 0 to 10. Perceived exertion was estimated in the following way: 0-2 weak, 3-4 moderate, 5-7 strong, 8-10 extremely strong fatigue. During the wall painting test, the EMG power spectrum MF (Hz) was recorded from deltoideus, trapezius, infraspinatus and biceps brachii using 8 channel electromyograph ME 6000 (Mega Electronics, Finland). The data gained were processed with the computer application MegaWin (2007). When processing the data, the following intervals were taken out of the three-minute segment: from the beginning of the test a 10-20 s interval and from the end of test a 160-170 s interval. The same intervals were taken before and after the working day. EMG power spectrum MF slope ($\%\bullet\text{min kg}^{-1}$) was calculated according to the formula:

$$MF_{slope} = \frac{(MF_b - MF_a) \cdot t}{MF_b \cdot P \cdot 60} \cdot 100,$$

whereas *MFb* is a EMG power spectrum median frequency at the beginning of the working day, *MFa* is a median frequency after the working day, *t* is a test time (3-minutes) and *P* is the weight of the extension pole (3.2 kg). The selection of the muscles depended on the nature of the wall painting exercise. The single-used surface EMG electrodes (Leonhard Long GmbH) were attached on the subjects by a female assistant who had been instructed correspondingly.

Statistical analysis

Data are expressed as means and standard errors (±SE). One-way analysis of variance (ANOVA) was used to test the differences in measured parameters before and after the working day and at the beginning and at the end of the wall painting test. When the significant main effect was found with ANOVA´, the Bonferroni post hoc procedure tested for establishing differences among mean values. A level of $p<0.05$ was selected to indicate statistical significance.

RESULTS AND DISCUSSION

During the 3-minute wall colouring test (Fig. 1), EMG power spectral activity MF slope did not change significantly but there was objectively estimated muscle fatigue when comparing the beginning of the working day and the end of the working day (Fig. 2). This can be related to the fact that at the beginning of the working day, the muscles have not yet reached their working capacity. EMG power spectrum median frequency (MF) slope (Fig. 3) of the measured muscle groups did not differ significantly ($p>0.05$) at the beginning and after the working day.

Fig. 1. Performing a 3-minute wall painting test.

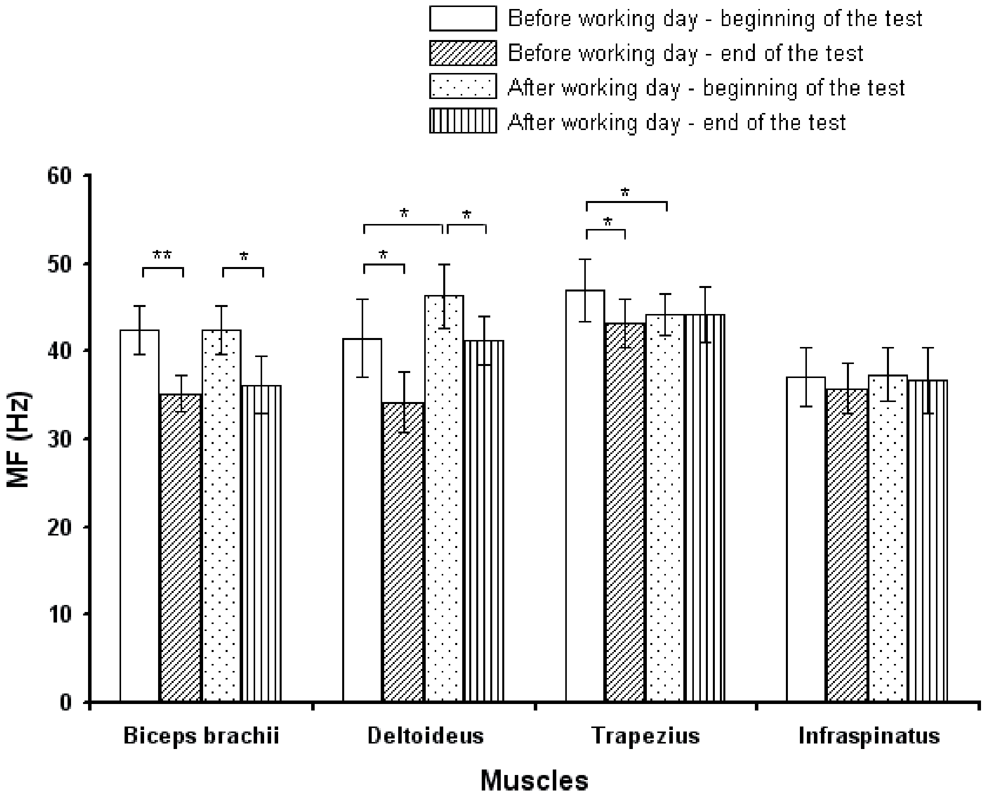

Fig. 2. The electromyogram power spectrum median frequency (MF) at the beginning and end of a 3-minute wall painting test before and after the working day (mean ± SE). * $p<0.05$.

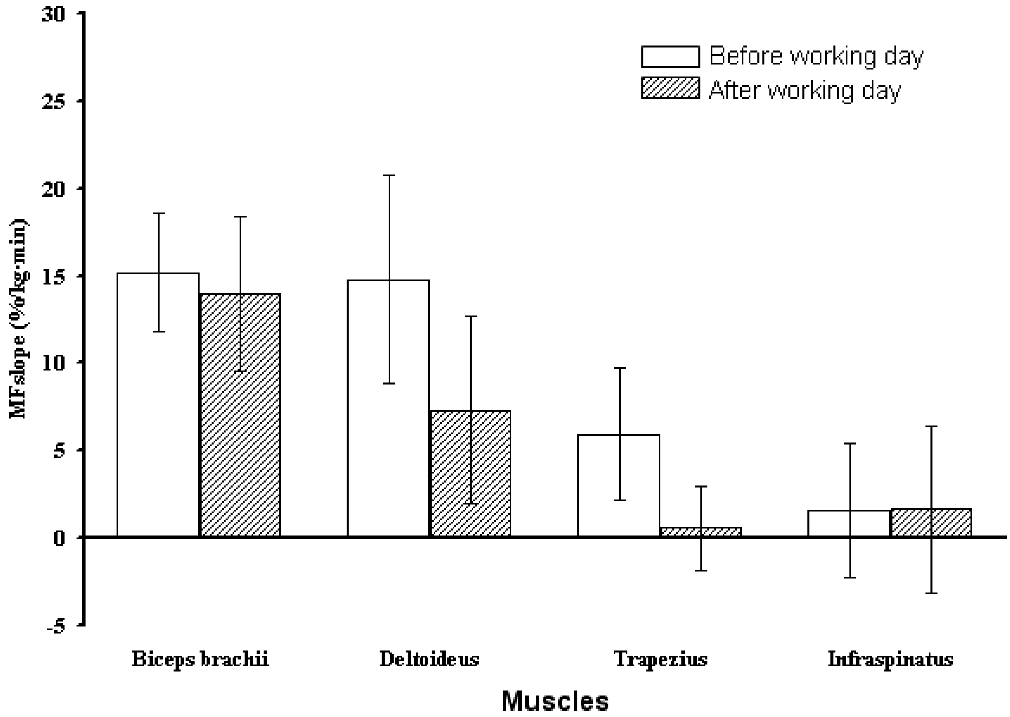

Fig. 3. The electromyogram power spectrum median frequency (MF) slope during a 3-minute wall painting test before and after the working day (mean ± SE).

The MF slope of the EMG power spectrum of the observed group revealed that in case of biceps brachii, deltoideus and trapezius, this indicator was moderately lower ($p>0.05$) at the end of the working day. But in case of infraspinatus MF slope it was moderately higher ($p>0.05$) at the beginning of the working day than it was at the end of the working day. This fact indicates that female painters tend to be more overloaded in the hands and shoulder region and less in the back.

The results indicated a significant subjective muscle fatigue sensation evaluated according to the Borg (CR-10) Scale in hands ($p<0.05$), lower limbs ($p<0.01$) and trunk ($p<0.05$) before and after working day (Fig. 4).

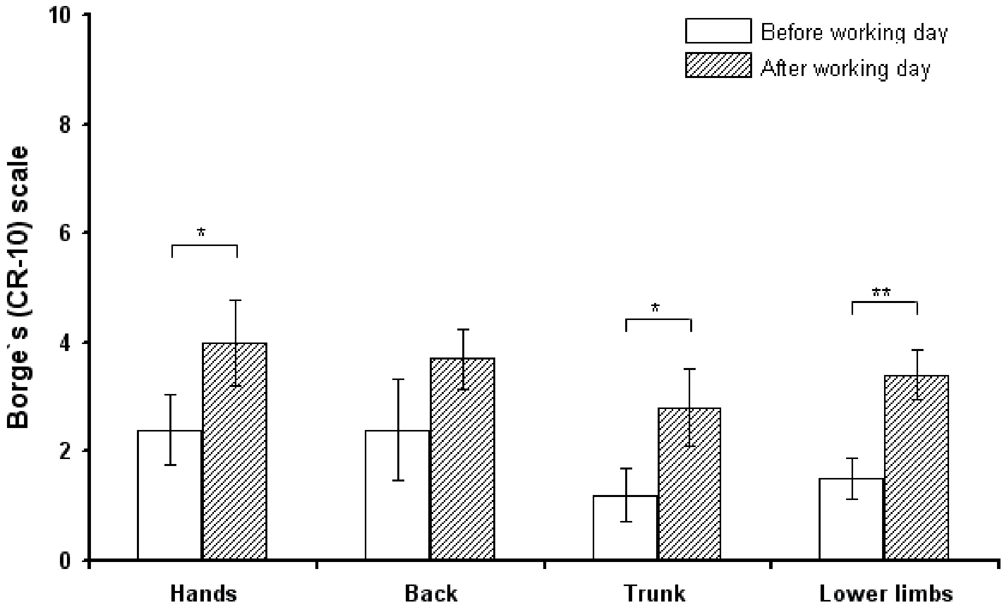

Fig. 4. Subjective muscle fatigue sensation estimated by the Borg Category Ratio (CR-10) Scale before and after the working day (mean ± SE). * $p<0.05$; **$p<0.01$.

A change in the subjective muscle fatigue sensation of hands, lower limbs and trunk before and after work was evident and this result deserves attention. It is known that physical stress and musculoskeletal discomfort while working can be alleviated and prevented by selecting the right tool that reduces the physical stress in the worker's fingers and hands to a minimum, and he or she needs to use less energy for working. A correctly selected tool also reduces jolting, repulse, and vibration (Marras & Karwowski, 2005).

The subjective muscle fatigue sensation of lower limbs may be due to the fact that painters have to stand throughout the working day mostly on concrete floor, which lacks amortization that would reduce jolting. Comfortable good quality working shoes are of great help for reducing such overload in case of workers (including painters), who have to work standing all day long. A pair of shoes which does not suit one's feet can cause problems lasting for years (Kane, 1987).

Proceeding from the data gained in the course of the research concerning the fact that the painters mostly had shoulder girdle and hands overload, it is recommended that they perform stretching exercises before and during the working day. A worker should customize the tools proceeding from his/her own anthropometrical measures and use suitable means of protection. This requires corresponding instructive materials and instructing the workers by a trained specialist. In case of physical work, it is advisable to make short breaks (5…10 minutes) every hour to avoid the problems caused by overload.

CONCLUSION

In conclusion, this study indicated that muscle fatigue, evaluated objectively by EMG power spectrum MF slope from biceps brachii, trapezius, deltoideus and infraspinatus muscles was not evident during a 3-minute wall colouring test before and after the working day. However, subjective muscle fatigue sensation in female painters was higher after the working day in hands, lower limbs and trunk, less pronounced in the back.

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Evaluation of Physical-Mechanical Properties of Energy Plant Stems and Their Chaff

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Abstract. In this article characteristics of willow and topinambour stems used for energy generation are presented. The potential of energy plants grown in Lithuania is reviewed, the methods of plant converting to energy are presented, and different chopping mechanisms are reviewed. The article presents a methodology for evaluation of willow and topinambour stems, their bio-metrical properties and physical-mechanical properties of stem chaff. The experiment results were discussed. Experiments were made on manually cut willow and topinambour stems, which were chopped by drum, disc and screw type choppers. Bio-metrical properties of non-chopped willows and topinambour stems were determined, and the stem chaff physical-mechanical properties such as moisture content, density, angles of natural crumble and fall were evaluated and the investigation of chaff thinness was fulfilled.

Key words: Willow, topinambour stem, chopper, chaff, bio-metrical property, physical-mechanical property

INTRODUCTION

One of the most important renewable energy sources is the plant biomass used for power purposes. Plant biomass makes up about half of the alternative energy in the countries of the European Union (Communication from the commission, 2005). At present plant biomass used for power makes up approximately 90% of all the renewable energy used in Lithuania (Jasinskas, 2006). Growing of energy plants and their use as a fuel is important in Lithuania, because there are vast areas of unused land in Lithuania, in addition to poor land and that unsuitable for agriculture, where energy plantations could be established. Up to 10-15% of the agricultural land could be used for energy crops (Jasinskas et al., 2008 a, b).

Different kinds of grasses, such as reed fescue grass (*Festuca arundinacea Schreb*), awnless brome grass (*Bromus inermis Leyss*), reed canary grass (*Typhoides arundinacea* L.), flax (*Linum*), hemp (*Cannabis* L.), topinambour (*Helianthus tuberosus* L.), sunflower (*Helianthus* L.), etc. can be used for energy purposes (Jasinskas et al., 2008 b). Non-traditional grasses, such as elephant grass (*Miscanthus sinensis*) and sorgo (*Sorghum bicolor*) are grown in Scandinavian countries, Germany, Czech Republic and other countries (Jasinskas et al., 2008 a, b). Topinambour is popular in many countries, their roots can be used as food or for pharmaceuticals, and the stems can be utilized for the energy. The stems of these plants are similar to those of sunflowers, but the yield is greater. Topinambour is widely grown in Austria, France and USA, with 2.5 million ha grown (Jasinskas et al., 2008 a). These plants are grown in Lithuania, too.

Test data from Lithuania showed that topinambours have good perspectives for being used for energy purposes – for combustion and heat production. The stems of topinambours can reach 4m height and have approximately 15 t ha^{-1} of dry matter. The change in moisture content during their growth was determined as well as the uncut stems left in the field. In spring the moisture content of uncut stems is less than 20%, thus they need no additional drying. The bulk density of the chaff of topinambour stems ranged from 40 to 77 kg m^{-3}. The lower heating value of the dry mass ranged from 17,0 to 18,8 MJ kg^{-1} (Jasinskas, 2006). Self-propelled forage harvesting technique can be used for the harvesting and chopping of topinambour stems.

As the most important renewable energy sources, willow and other sorts of rotation energy plants – poplar, fast growing aspen, etc. can be used for energy purposes. Willows are widely used energy plants that offer great potential as a source of renewable energy, not adding to the production of greenhouse gases or acid rain.

Willows (*Salix viminalis*) can grow in the soil of different composition, in poor land and land unsuitable for agriculture, by the roadsides, on the slopes, etc. (Jasinskas, 2006; João Carlos et al., 2007). Producing willow as an energy crop contributes to sustainable development in:

- putting the land, and the farmers' skills and equipment, to good use;
- retaining jobs in rural areas;
- helping rural communities to remain viable.

Willow grows throughout the northern hemisphere, mainly in cold and wet areas, and a few species are native to the southern hemisphere. Willows:

- produce a lot of biomass in a short period, and are among the fastest growing woody species in northern Europe;
- can be grown with low inputs of agro-chemicals;
- are easily established from un-rooted cuttings;
- re-sprout vigorously after each harvest;
- offer large potential for genetic improvement;
- have an energy balance in the region of 20:1 (i.e., the energy obtained can be 20 times as much as the energy used to grow the crop);
- can be used as a vegetation filter during "bio-remediation" of waste water or contaminated land.

One hectare of a well-managed willow plantation can yield 10-12 tonnes of dry matter per year, with energy equivalent to about 5,000 liters of oil. As a rough guide, 1 kg of willow will yield about 1 kW h^{-1} of electrical output. A district heating scheme for the development of 100 houses would require about 25 hectares of willow coppice. A combined heat and power system with a 100 kW electrical output will use 50 ha of willow coppice harvested on a three year cycle. A power station generating 5 MW of electricity would need around 2,500 ha of willow (Jasinskas, 2006; Jasinskas & Scholz, 2008).

Willow for energy is normally grown as coppice. The plants are cut back at intervals near ground level, and allowed to re-grow as multiple shoots rather than a single stem. Willow coppice might be harvested up to six times, typically at intervals of 3-5 years. At the end of that time (perhaps 25 years), the stumps can be removed, and the land re-planted with agricultural crops or more coppice (Jasinskas & Scholz, 2008).

Most of the chopped material is used for energy needs. It is easy to chop willow during harvesting, but freshly-harvested chops tend to decompose in a store unless a drying system is installed. Alternatively, the crop can be harvested as long stalks and chopped shortly before use. The main types of short-rotation plant harvesting systems are able to (Jasinskas & Scholz, 2008):

- harvest and chop in one operation;
- harvest full length stalks or gather stalks into bundles or bales during harvest, to be chopped later.

Willow harvesting is normally restricted to the winter months (November -February in northern Europe) in the period after leaf fall and before leaf set. An extended harvest period from late September to June is possible, but may lead to:

- higher moisture content at harvest;
- lockage of harvesters by leaf material;
- eduction in long-term yield, as nutrients in leaves are not returned to the soil.

Willow for energy production has generally been harvested on a three-year cycle. Harvesting on a 2-year, 4-year or 5-year cycle can be considered, depending on the rate of crop growth and the demand for fuel. Stem thickness influences the type and quality of fuel produced: shorter harvesting cycles will produce thinner stems, with a high proportion of bark. Delayed harvesting results in stems with larger diameter, which need robust machinery (Jasinskas & Scholz, 2008).

Willow can be used to produce heat or electricity. Electricity is either used on site, or sold through a distribution grid. An engine or turbine driving a generator converts only 25-33% of the energy content of the fuel into electricity, the remainder is emitted as heat. Where this heat energy can be utilized in a combined-heat-and-power (CHP) system, the total efficiency can be increased to 85% or more (Jasinskas, 2006; Jasinskas & Scholz, 2008).

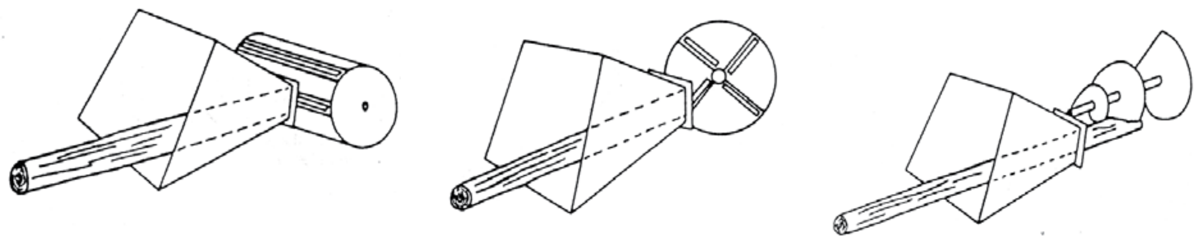
Willow is converted to energy using *thermo-chemical* processes (i.e., they involve both heat and chemical reactions). There are three methods for converting willow into energy:

- *combustion* is used for heating water or for raising steam for a turbine (Nadziakiewicz & Micha, 2003; Lund & Münster, 2003; Chagger et al., 1998);
- *gasification* produces a combustible gas that can be burned in a boiler, or used as a fuel for an engine or gas turbine (Schaumann, 2007; Marbe & Harvey, 2006; Jong et al., 2003; Bram et al., 2009);
- *pyrolysis* can be used to convert the crop into gas, oil or charcoal fuels (Sand et al., 2008).

Combustion technology is already well established. Gasification and pyrolisis are not new methods, but their utilization for energy generation from willows is still in the development stage. In the future Lithuania is going to carry out research in this field (Jasinskas & Scholz, 2008; Jasinskas & Zvicevičius, 2008).

In Lithuania, there are more than 70 larger wood waste fired boilers which can use willow chaff without major reconstruction of their design. According to their energy characteristics, wet (not dried) 50% moisture content willow chaff is not different from the chopped wood waste, which is already used in the regional boiler houses for heat production. If expressed in calorific value, one ton of willow chaff gives about 9 GJ, almost as much as one ton of peat briquettes. Thus, the yield per one hectare of willows is enough to produce approximately 40 MW h^{-1} of heat. It was calculated, that in order to provide bio-fuel for a 10 MW power boiler for a 6 month burning period (for one heating season), 18,720 tons of willow chaff must be prepared. To produce such a quantity of bio-fuel, willows should annually be planted on approximately 930 hectares (Jasinskas & Zvicevičius, 2008).

There are three basic chopper types, which can be used for willow stem chopping: a) the drum chopper, b) the disc chopper and c) the screw chopper (Fig. 1). The only difference is the way they produce the chips. All the choppers are equipped with a blower which conveys the chips into the container through a duct (Handbook for Energy Forestry, 1986; Olsson, 1993; Scholz et al., 2006).



a) b) c)

Fig. 1. Various types of energy plant chopping mechanisms: a) the drum chopper; b) the disc chopper; c) the screw chopper.

The drum chopper consists of a rotating drum with knives embedded in 2-4 longitudinal grooves in the curved surface. Like in the disc chopper, the knives pass a fixed anvil and the chip size is modified in the same way. As a result of the circular movement of the drum chopper, the cutting angle in relation to the fibre direction of the tree changes with the diameter of the stem. Consequently, the chips produced are less uniform than those from a disc chopper. These choppers are generally used for wood chopping, and they are best suited for chopping willow stems, too (Jasinskas & Scholz, 2008).

The disc chopper consists of a heavy rotating disc with rectangular grooves provided with knives running radially on the shaft. Normally, a disc chopper for fuel chips has 2-4 knives. When the disc is rotating, the knives pass an anvil. The chip size can be modified by adjusting the knives and the anvil. The chips produced by a disc chopper are fairly uniform as the cutting angle in relation to the fibre direction of the tree remains unchanged regardless of the thickness of the stem.

In a screw chopper, the chips are cut by a conical screw with a sharp peripheral edge. When the screw is rotated, it cuts into the tree while pulling the tree stem into the chopper. However, feed rollers are needed, too. The shape of the screw determines the size of the chips. Screw choppers can produce larger chips than disc choppers and drum choppers. Some types cut down the wood into chunks of 150 mm length. Chips from this type of chopper are usually wider as well (Olsson, 1993). However, such long and wide chips are not suitable for automatically feeding into the boiler. These choppers are generally used for chopping thick branches, and are best suited for chopping overgrown (5-6 years) willow stems. It is therefore appropriate to evaluate all three types of chopping mechanisms, to determine their operating parameters while chopping willows, and to assess the quality of chaff.

Recently, interest in willows grown for fuel in Lithuania has been increasing. Big boiler owners claim that willow chaff is suitable for wide use for bio-fuel and they can buy this bio-fuel in unlimited quantities. So, it is appropriate for Lithuanian farmers to expand the cultivation of willows.

In a review of the advantages of willows grown and used for fuel it is appropriate to analyze in-depth and estimate the plant cultivation, the plant harvesting and fuel preparation technologies and viable techniques, which could be used in Lithuanian climate.

The aim of this study was to determinate the biometric characteristics of different maturity willow and topinambour stems and their physical-mechanical properties that have an impact on their preparation and use for energy purposes, as well as the characteristics of willow and topinambour stem chaff prepared by different chopping mechanisms.

MATERIAL AND METHODS

Biometric indicators of energy plant stems

Biometric indicators of plant stems, such as size, mass dimensions, weight, moisture content, density, and yield were determined during the experiments carried out by Lithuanian researchers. The existing procedures were adopted (Jasinskas, 2002; DD CEN/TS 15149-1:2006). Each test was conducted in five replications.

Stem dimensions. Stem length and diameter of 20 field-grown willows (*Salix Wiminalis)* and topinambours (*Helianthus tuberosus* L.) were measured separately in the test. Stem length was measured with measuring tape (accuracy of reading 1 mm) and stem diameter with the Vernier callipers (accuracy of reading 0.1 mm). Measurements were made at:

- 100 mm from the ground level;
- 1,100 mm from the ground level.

Stem weight was determined with balance (accuracy of reading 0.1 g). The average weight of 20 stems and their diffusion confidence interval were calculated.

Stem moisture content was determined in the laboratory. Five stems of willow (*Salix Wiminalis)* and topinambou**r** (*Helianthus tuberosus* L.) were separately chopped into pieces of 10 mm length. Mixing the chaff of each plant, five samples (200 g of mass each) were taken are weighed. Samples were dried for 24 hours at the temperature of 105°C. The dried samples were weighed and then the empty cups were weighed. The moisture content and average moisture content of each sample were calculated. The amount of the water mass M_v, the dry mass M_s, and the relative humidity w_s of the sample were calculated, too.

Evaluation of plant stem chaff physical-mechanical properties

Stem chopping and sample taking were carried out according to the methodology used in Denmark, Germany and Lithuania (Olsson, 1993; Scholz et al., 2006; Jasinskas, 2002). Freshly cut (53-54% moisture) willow and topinambour stems of 2nd and 3rd year growth were chopped. The chopped mass was supplied in bags, from which the chaff samples were taken for the determination of physical-mechanical properties.

Used choppers

Three types of choppers were used (Fig. 1) to chop the already cut energy plant stems:

- drum chopper;
- disc chopper;
- screw chopper.

Three year old stems of willow and topinambour grown in the Institute test plots were chopped with drum and disc choppers. Only three year old willow stems were chopped with screw chopper.

The chopped mass was supplied in bags, from which chaff samples were taken for determination of physical-mechanical properties. The average length of the chaff, the quality of stem chopping was defined (by two different methodologies), as well as the angle of fall and natural crumble. Comparing the physical-mechanical properties of stem chaff chopped with different choppers, the chopping machine operating parameters and their chopping quality can be described.

The average length of the chaff

The traditional chaff (no chips) fineness evaluation methodology was applied to assess the quality of large chaff (Scholz et al., 2006). Five different stem chaff samples were chosen. From each sample 20 pieces were taken and their length was measured with callipers. Then the mean of each sample was measured for the length of chopping fineness, and then the mean of all samples.

Methodology of chaff fineness evaluation

The plant stem chaff fineness used for fuel must be determined by refinement on the basis of boilers used in the combustion chamber, chaff transport equipment and storage requirements. Furnaces with the required fineness of chaff obtained high combustion efficiency. There was no problem with chaff transport to the furnaces and their supply from storages.

Three year old willow and topinambour stem chaff, chopped by two types of choppers – drum and disc chopper – were used in the experiment. The quality of stem chaff and chaff fineness was defined by two different methodologies:

- the Danish methodology was used to define the quality of stem chaff (Olsson, 1993);
- the EU countries use the stem chaff fractional composition determination methodology (Scholz et al., 2006; DD CEN/TS 15149-1:2006).

To apply the first methodology, four sieves with different hole diameters: round, diameter 45 mm, 7 mm, 5 mm, and oblong, width 8 mm, were used. The samples of the chopped mass (2-3 kg) were sifted through the sieves by driving the sieves in a circle horizontally, 10 times to the left and 10 times to the right. The mass left on the different sieves was weighed and percentages calculated.

The permissible values of separate fractions of chaff (chips) are given in Table 1 (according to the methodology used in Denmark, defining the fineness of chips used for fuel) (Olsson, 1993).

Table 1. Estimation of chaff chopping quality

Chaff	Quality of stem chopping (portion of the chopped stems on the sieve, %)				
	ø 45 mm	oblong, 8 mm	ø 7 mm	ø 5 mm	Dust
Fine	< 5%	< 25%	> 40%	< 20%	< 10%
Large	< 15%	< 40%	> 23%	< 15%	< 7%

A second methodology used for determining the fractional composition is based on European Standard (DD CEN/TS 15149-1:2006). About 5 kg of chaff sample was passed via 40 mm diameter sieves with round holes with diameters 63 mm, 45 mm, 16 mm, 8 mm and 3.15 mm. While screening each sample the sieve set was rotated 30 times within a semicircle in a horizontal plane. The mass remaining on sieves was weighed separately. The mass left on the different sieves was weighed and percentages were calculated. Each test was repeated 3 times.

The density of chaff mass

The density of chopped plant stems was determined in a special cylinder (with 5.7 dm^3 capacity) in three replications. The container was filled with the chaff by free filling without any pressure. After filling the container to its upper edge, the chaff was weighed and after estimating its moisture content, dry material density (d.m.) was calculated.

Chaff angles of crumble

Chaff fineness of plant stems used for fuel must be determined by refinement on the basis of boilers used in the combustion chamber, chaff transport equipment and storage requirements. Furnaces with the required fineness of chaff obtained high combustion efficiency. There was no problem with chaff transportation to the furnaces and their supply from storages.

In designing chaff transportation equipment to the furnaces and chaff dispensers and storage bunkers, it was important to determine the crumble angles: the angle of fall α_f and the angle of natural crumble α_n (Jasinskas, 2002). To determine the crumble angles the stand was used (Fig. 2).

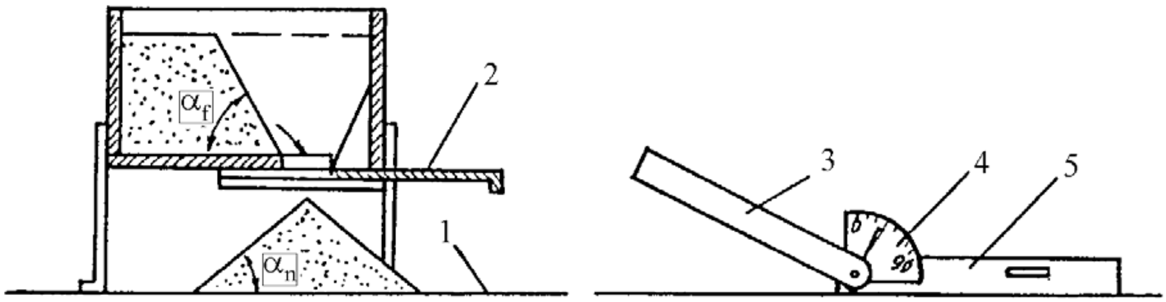


Fig. 2. Scheme of equipment for establishing the angle of fall α_f and the angle of natural crumble α_n: 1 – horizontal surface; 2 – valve; 3 – revolving ruler; 4 – protractor; 5 – ruler underneath with spirit-level.

A portion of chaff (5 kg mass) was poured into a rectangular container. After opening the valve, part of the chaff mass crumbled off. With the help of turned ruler and protractor the angles of crumble were measured:

- the angle of natural crumble α_n (on the horizontal plane);
- the angle of fall α_f (at the bottom of container).

Each test was replicated three times, and mean values of angles and their error values were calculated.

RESULTS AND DISCUSSION

Common biometric indicators of osier plant stems

Test results of biometric indicators of willow (*Salix Wiminalis*) (2nd and 3rd year growth) and topinambour (*Helianthus tuberosus* L.) stems grown in the test plot of AE Institute of Lithuanian Agricultural University are presented in Table 2. The table shows individual stem biometric characteristics, e.g., dimensions (length, thickness of stem in the lower part), weight, moisture content, density and yield.

Table 2. Biometric indicators of willow (*Salix Wiminalis)* (2nd and 3rd year growth) and topinambour (*Helianthus tuberosus* L.) stems

Indicator	Energy plants		
	Willow (Salix Wiminalis)		Topinambour (Helianthus tuberosus L.)
	2nd year growth	3rd year growth	
Stem height, cm	294.8±17.2	355.0±26.5	244.6±15.4
Stem thickness, mm	19.4±1.7	27.7±2.4	17.1±1.5
Stem mass, g	314.6±53.8	635.6±50.1	248.2±63.1
Stem moisture content , %	44.3±6.9	47.1±2.9	72.1±4.6
Stem density, kg·m^{-3} d.m.	149.4±17.3	152.2±15.3	87.2±10.9
Plant stem yield, t·ha^{-1}	6.9±0.6	14.7±0.5	27.7±0.5
Plant stem yield, t·ha^{-1} d.m.	3.8±0.5	7.8±0.6	7.7±1.4

Research results of energy plant stem biometric indicators show that 2nd year willow plant stems grew up to 2.9 m height, 3rd year willow stems grew up to 3.5 m height and the average length of topinambour stems was 2.4 m, and 3rd year willow stem mass average was 2 times higher than that of the 2nd year and 2.6 times higher than the mass of topinambour stem.

Willow stem moisture content ranged within the limits of 44-47% and topinambour stems in the same phase of growth were much wetter with moisture content being about 72%. Topinambour stem density was significantly lower – only 87 kg m^{-3} d.m, while willow stem density was almost twice as much, being 149-152 kg m^{-3} d.m. This shows that the use of willow for fuel is much more efficient because they will burn longer, measured by calorific intake. However, the 3rd year growth of willow yield compared to topinambour stem yield (7.7 t ha^{-1} d.m.) was similar and reached 7.8 t ha^{-1} d.m. This can be explained by adverse weather conditions – a drastic lack of moisture, and no fertilizer supply for the plants. In the same area topinambour was cultivated for 3 years, it was well-rooted and a lot of additional vegetative shoots contributed to greater plant yield.

Evaluation of physical-mechanical properties of willow plant stem chaff

After measuring and calculating the average chaff length of willow and topinambour stems chopped with various coppers, it was determined that the finest chaff obtained while chopping with the smallest disc chopper was l_{vid}=8.6±2.1 mm (for willows), l_{vid}=7.9±1.8 mm (for topinambour). Much larger chaff obtained was chopped by drum chopper – lvid l_{vid}=17.5±3.4 mm (for willows), l_{vid}=14.6±3.5 mm (for topinambour). The largest willow chaff was received by chopping with screw chopper (l_{vid}=22.2±5.6 mm).

Quality assessment of willow and topinambour stem chaff in accordance with the methodology used in Denmark when a set of sieves with different size holes (specified in Table 1) was used, revealed that significantly larger chaff lengths were produced by chopping with drum chopper and screw chopper and more detailed and uniform willow chaff was produced by disc chopper (Table 3). However, the stem of the plant chopped by disc chopper produced a large quantity of dust – in topinambour chaff there was 22.1% of dust and in willow chaff there was 8.1% of dust (according to Table 1 the dust amount in large chips must comprise < 7%).

Larger chaff is obtained when chopped by drum chopper – the identification with 8 mm oblong holes accumulate 88.2% of willow chaff weight, and even 91.9% of topinambour chaff weight. As a result, these choppers are not recommended for the copping of willow and topinambour stems particularly. The chaff chopped with screw choppers was very large, the amount of dust in it being low, only 0.5% of weight, and the identification on sieves with 8 mm oblong holes accumulated even 74.1% of chaff weight (according to Table 1, the chaff may be < 40%).

Table 3. Plant chaff fractional composition (according to the Danish methodology)

Plant	Chopper type	Chopped stem mass left on sieve, %				
		Ø 45 mm	Oblong 8 mm	Ø 7 mm	Ø 3 mm	dust
Willow (3^{rd} year growth)	Disc	0.06 ±0.19	26.42 ±22.24	28.47 ±10.90	36.91 ±8.83	8.14 ±2.91
	Drum	5.92 ±2.56	88.23 ±8.36	4.95 ±4.73	0.78 ±1.15	0.11 ±0.14
	Screw	20.00 ±6.48	74.15 ±5.87	4.31 ±0.32	1.00 ±0.43	0.52 ±0.28
Topinambour	Disc	0.29 ±0.47	36.65 ±30.65	15.54 ±11.36	25.43 ±11.97	22.06 ±8.45
	Drum	1.86 ±1.69	91.88 ±3.77	5.55 ±4.28	0.58 ±1.00	0.11 ±0.18

The assessment of the quality of willow and topinambour stem chaff in accordance with methodology of the EU countries, using a set of sieves with round holes of different diameter, disclosed that similar values were received if compared with the results obtained using the Danish methodology, because larger parts of the chaff were received by chopping with drum chopper and disc chipper chopped more uniformly and finest willow chaff was obtained (Table 4).

Table 4. Plant chaff fractional composition (according to the EU methodology)

Plant	Chopper type	Chopped stem mass left on sieve, %					
		Ø 63 mm	Ø 45 mm	Ø 16 mm	Ø 8 mm	Ø 3.15 mm	dust
Willow (3^{rd} year growth)	Disc	0.98 ±0.40	0.74 ±0.11	69.24 ±5.67	22.76 ±5.66	5.90 ±0.99	0.39 ±0.129
	Drum	1.58 ±1.53	2.19 ±2.02	89.54 ±2.98	6.19 ±1.14	0.81 ±0.37	0.20 ±0.06
	Screw	10.17 ±6.25	7.57 ±2.31	76.06 ±6.67	4.88 ±0.78	1.08 ±0.37	0.25 ±0.16
Topinambour	Disc	2.45 ±2.70	7.84 ±13.07	69.28 ±9.91	14.81 ±7.25	5.12 ±0.93	0.41 ±0.08
	Drum	0.52 ±0.61	4.35 ±7.99	90.39 ±7.37	3,99 ±1.71	0.63 ±0.59	0.11 ±0.11

Chaff fineness was shown by accumulated chaff fraction on Ø 16 mm sieve: willow and topinambour stems were chopped by a drum chopper, 89.5% of willow chaff mass and 90.4% of topinambour chaff mass was left on this sieve; however, when these plants were chopped by disc chopper, much less chaff was left on this sieve – the total of 69.2% of willow mass and topinambour chaff mass.

Willow chaff chopped by screw chopper was also quite large – the chaff fraction part equals to 76.1% of chaff mass accumulated on Ø 16 mm sieve. In the chopped willow chaff, more than 10% particles were larger than 63 mm in length, which is not desirable for bio-fuel from high-quality chaff.

Table 5 presents results of chaff density and crumble angles in case of willow and topinambour stems chopped by drum, disc and screw choppers.

The density of willow stem chaff chopped by different types of choppers was evaluated. The angle of natural crumble varied from 44 to 50 degrees and angle of fall varied from 78 to 83 degrees. The angle of natural crumble of topinambour stem chaff chopped with different choppers varied from 45 to 52 degrees and the fall angle varied from 67 to 85 degrees.

The results in Table 5 show that the density of willow chaff chopped with drum and disc choppers varied from 116 to 157 kg m^{-3} d.m., and it was nearly two times greater than the density of topinambour stem chaff, i.e. from 58 to 67 kg m^{-3} d.m. The density of the chaff chopped by screw chopper was 98 kg m^{-3} d.m. This shows that the density of willow chaff prepared with screw chopper was the lowest and large storages will be needed to keep such chaff.

Table 5. Plant stem chaff density and crumble angles (chopped by drum, disc and screw choppers)

Plant	Chopper type	Chaff moisture content, %	Density, kg ·m^{-3}	Angle of fall, degrees	Angle of natural crumble, degrees
Willow (3rd year growth)	Disc	45.73	214.32±12.04 (116.31 d.m)	51±10.22	81±7.42
	Drum	45.73	289.31±10.68 (157.01 d.m)	44±6.62	78±6.44
	Screw	48.67	190.88±6.67 (97.98 d.m)	50±3.67	83±9.06
Topinambour	Disc	72.14	207.63±11.37 (57.84 d.m.)	45±9.18	85±9.18
	Drum	72.14	241.36±10.26 (67.24 d.m.)	52±13.78	67±5.3

In virtue of the results of the investigations, the storages and park sizes required for willow and topinambour stem chaff can be identified and calculated.

CONCLUSIONS

1. Biometric indicators of energy plant stems were investigated and the results showed that 2nd year growth willow (Salix Wiminalis) plant stems grew up to 2.9 m height, 3rd year growth willow stems grew up to 3.5 m height, and topinambour (Helianthus tuberosus L.) stem average length was 2.4 m, and 3rd year growth willow stem average mass was 2 times greater than that of the 2nd year growth and 2.6 times greater than that of the topinambour stem.

2. Willow stem moisture content ranged within the limits of 44-47% and topinambour stems in the same growth phase were much wetter, the moisture content being about 72%. Topinambour stem density was significantly lower – only

87 kg m^{-3} d.m., while willow stem density was almost twice as much, being 149-152 kg m^{-3} d.m. This shows that the use of willow for fuel is much more efficient and it will burn longer, measured by calorific intake.

3. The 3rd year growth willow yield compared to topinambour stem yield (7.7 t ha^{-1} d.m.) was similar and reached 7.8 t ha^{-1} d.m. This can be explained by adverse weather conditions – a significant lack of moisture and by the fact that the plants were not fertilized. In the same area, topinambour was cultivated for 3 years, it well-rooted and gave additional vegetative shoots, which contributed to greater plant yield.

4. The assessment of the quality of willow and topinambour stem chaff in accordance with the Danish methodology revealed that significantly larger chaff was produced when chopping stems with drum chopper and screw chopper, and more detailed and uniform willow chaff was produced when chopping with disc chopper (Table 3). However, the stem of the plant chopped by disk chopper produced a large amount of dust – topinambour chaff had 22.1% of dust and willow chaff had 8.1% (according to Table 1, the amount of dust in large chips may be < 7%).

5. Assessment of the fractional composition of willow and topinambour stem chaff in accordance with the EU countries' methodology disclosed the fineness of the chaff fraction accumulated on a Ø 16 mm sieve: 89.5% of willow and 90.4% of topinambour chaff was left on the sieve of stems chopped by drum chopper, and of plants chopped by disc chopper, much less chaff was left on the sieve: 69.2% willow and topinambour chaff mass of weight.

6. It was determined that willow chaff chopped by screw chopper was quite large – the chaff part accumulated on a Ø 16 mm sieve was 76.1% of chaff weight. This chopped mass had more than 10% of larger than 63 mm length particles, which is not desirable in case of high-quality chaff used as bio-fuel.

7. The chaff density of willow stem chopped by different types of choppers was evaluated. Angle of natural crumble varied from 44 to 50 degrees and the fall angle varied from 78 to 83 degrees. The angle of natural crumble of topinambour stem chaff chopped with different choppers varied from 45 to 52 degrees and the fall angle varied from 67 to 85 degrees.

8. It was determined that the density of willow chaff chopped with drum and disc choppers varied from 116 to 157 kg m^{-3} d.m. which was nearly two times greater than topinambour stem chaff density that varied from 58 to 67 kg m^{-3} d.m. The density of chaff chopped by screw chopper was 98 kg m^{-3} d.m. That shows that the chaff prepared with screw chopper had the lowest density and large storages will be needed to keep such chaff.

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Energy-saving Lighting Installations and Equipment for Multi-tier Narrow-bench Greenhouse Technologies

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Abstract. Enterprises of the protected ground or greenhouse horticulture centres must have facilities for the necessary supply of heat, water, electric power, natural and artificial optical radiation. The long-term practice of plant cultivation has shown that in autumn, winter and spring, the basic limiting factor in transparent greenhouses is light.

The radiating mode of the greenhouses is one of the major and power-intensive factors of a microclimate. Therefore, in case of artificial irradiation, it is necessary to pay special attention to the minimization of power consumption, which is associated with the selection of a source, type of irradiation device, reflector configuration and location of the lighting fixtures.

The specific consumption (Sharupich et al., 2005) of power resources in the most common greenhouses in the world, which have one fructifying plant layer in the greenhouse volume, constitutes 40-55 mega-calories per 1kg of the product, which is by 40-45% higher than in the case of the technology of intensive cultivation of the culture, using the method of drop watering. The more productive and more power saving technology, i.e. the so-called Dutch technology is not advantageous in the environmental conditions of Estonia.

The latest research works of scientists have revealed that for the protected ground in the second heat-affected zone, including Estonia, multi-tier narrow-bench hydroponics is a more preferable technology. It allows to make more effective use of the greenhouse volume to ensure a simultaneous fructification of 5 layers, to increase the production yield per area unit by 3.0-4.0 times in comparison with the traditional technology, and to reduce the specific power expenses by approximately 70%.

However, the lighting maintenance of the cutting-edge technology which has a specific arrangement of the plant layers on inclined planes has not been sufficiently elaborated as yet. In particular, there are no technical decisions on the special lighting fixtures ensuring the increase of power efficiency of additional artificial irradiation. Therefore, it is essential to enhance the efficiency of one of the high energy consumption processes of artificial irradiation of the plants considering the spatial specificity of the promising multi-tier narrow-bench hydroponics technology.

Key words: multi-tier narrow-bench greenhouse technologies, irradiator, power efficiency

JUSTIFICATION OF THE MAIN PARAMETERS OF SYSTEM FOR ADDITIONAL ARTIFICIAL IRRADIATION IN GREENHOUSE WITH MULTI -TIER NARROW-BENCH HYDROPONICS

The main objective is to increase the energy efficiency of the additional artificial irradiation in greenhouses with multi-tier narrow-bench hydroponics through the use of lighting which is adapted to multi-tier narrow bench hydroponics (MNH) technology.

In 2009, a new Energy Efficiency Target Program was adopted, which takes into account the results of the previous Energy Efficiency Target Program in Estonia for 8 years, the requirements of EU directives 93/76 (SAVE) and many other international acts relating to energy efficiency (Energy Charter Treaty, the Kyoto Protocol, Agenda Baltic 21 for the Baltic Sea Region, etc.). The main requirement of the Program is to grant the application of energy-saving technologies.

The basis of all popular technologies widely used both in Estonian and international practice of frame area agriculture follows one and the same technological principle – only one fructifying plant tier in the volume of one greenhouse. Realization of a new structure-forming principle resulted in principal changes in the technology of growing plants in greenhouses. The principle is (Sharupich et al., 2005) the following: to increase the amount of fructifying layers in the limits of the same greenhouse, i.e. transition to multi-tier narrow-bench hydroponics (developed by Giproniselprom institute) (scheme in Fig. 1).

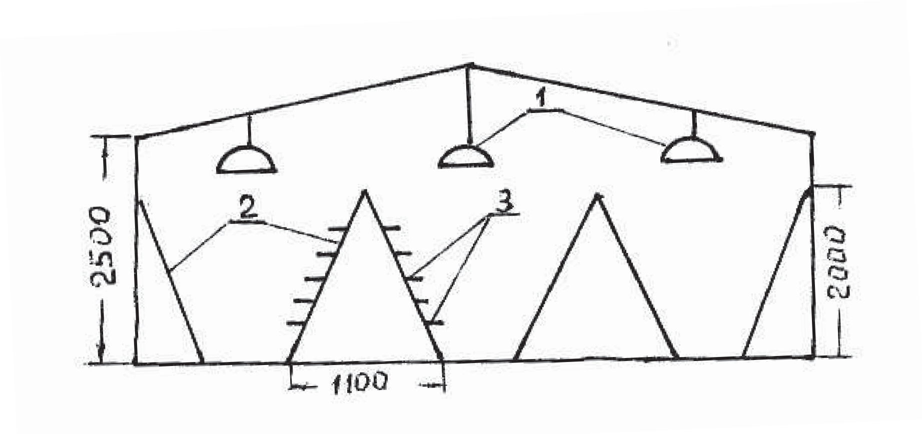

Fig. 1. Layout of equipment according to MNH-technology: 1 – Illuminators; 2 - Dispositions of MNH; 3 – Layers.

A vertical shift of the MNH layers resulted in a significant reduction of costs in the overall energy consumption (Karpov et al., 2005). The power costs when using technology of agronomical physics with horizontal photo culture constitute 70-90 Mcal per 1 kg of product, with the traditional soil technology – 50-55 Mcal kg^{-1}. The value of the same marker in Holland is 25-30 Mcal kg^{-1}. The power costs when using multi-tier narrow-bench technology in translucent greenhouses constitute 8-12 Mcal kg^{-1}.

The multi-tier narrow-bench hydroponics technology is a vegetative cenosis having five simultaneously fructifying layers. An analysis of the used irradiation systems shows that there are no special irradiation sets that will meet the requirements of this technology applicably to the spatial distribution of the flow.

The certain bulk of works presented by several organizations (VNIIS, Giproniselprom, SZNIIMESH, etc.) as well as by many independent authors has been devoted to finding solutions that will help improve the efficiency of irradiation of plants in greenhouses.

The main attention of this research is focused on one of the problems connected with the peculiarities of greenhouse production, such as: promoting energy efficiency by improving the spatial distribution of flow in multi-tier narrow-bench technologies.

It should be noted that the wide scale of power of sufficiently effective discharge lamps can solve the abovementioned problem using a spatial distribution of electric energy (before it is transformed into a stream). However, both SPbGAU and Giproniselprom institute have a negative experience with the development and durable demonstration of multi-tier narrow-bench greenhouses with tubular fluorescent lamps in each tier. This solution obviously seems simple and effective. However, this set attracted the attention of neither scientists nor manufacturers. The main reasons are: a huge number of low-power lamps (hence - increasing complexity of operation and the number of servicers), shading of growing plants from natural light, and additional inconveniences while handling plants. Taking into account the fact that high-pressure gas discharge lamps can have a light output 2-3 times longer than that of fluorescent lamps and that these are preferred in a large-scale greenhouse production, the given study takes them as sources of light.

When selecting the types of radiation sources, preference should be given to those with a higher $\acute{\eta}_{ФАР}$ (not less than 20%). Modern high-intensity gas-discharge lamps for greenhouses (metal halide lamps, high pressure sodium lamps) are produced in a wide range of power ranges all over the world (from 125 W to 6.0 kW) and have $\acute{\eta}_{ФАР}$=0.25-0.30. As a rule, lamps with a high power range have a higher $\acute{\eta}_{ФАР}$ than those with a low power range.

Inclined plane, where the tiers are fixed, has set new lighting tasks concerning the distribution of flow fixtures. The peculiarities of the process are in special requirements for the spatial distribution of the flow source, that do not allow choosing a lamp according to its power like it is traditionally done, and to guarantee the uniformity by calculating the distance to the neighbouring lamp. We analyzed 7 variants of optical schemes (Kabanen 2008), corresponding to the traditional placement of the lamp above the passage between pyramids (Fig. 2, a - g).

The analysis was conducted in accordance with 4 criteria: the scheme of the rays from the reflector, the need for special irradiation devices for the extreme (in front), inclined surfaces, the efficiency of the flow source, the presence or absence of shading cenosis.

The results of calculations and graphical analysis are given in Table 1.

It turned out that none of the variants meets all the four quality criteria. A preliminary analysis of light optical schemes gave reason to assume that the illumination of the lower trays will be substantially lower than that of the upper ones. To make the final decision on the possibility of using the traditional method of irradiation in the MHN-technologies, the needed spatial distribution of the flow of the lamp (light intensity curve) was calculated when horizontal surface turns to a sloping one, and assuming the irradiance level in the characteristic points of the respective tiers.

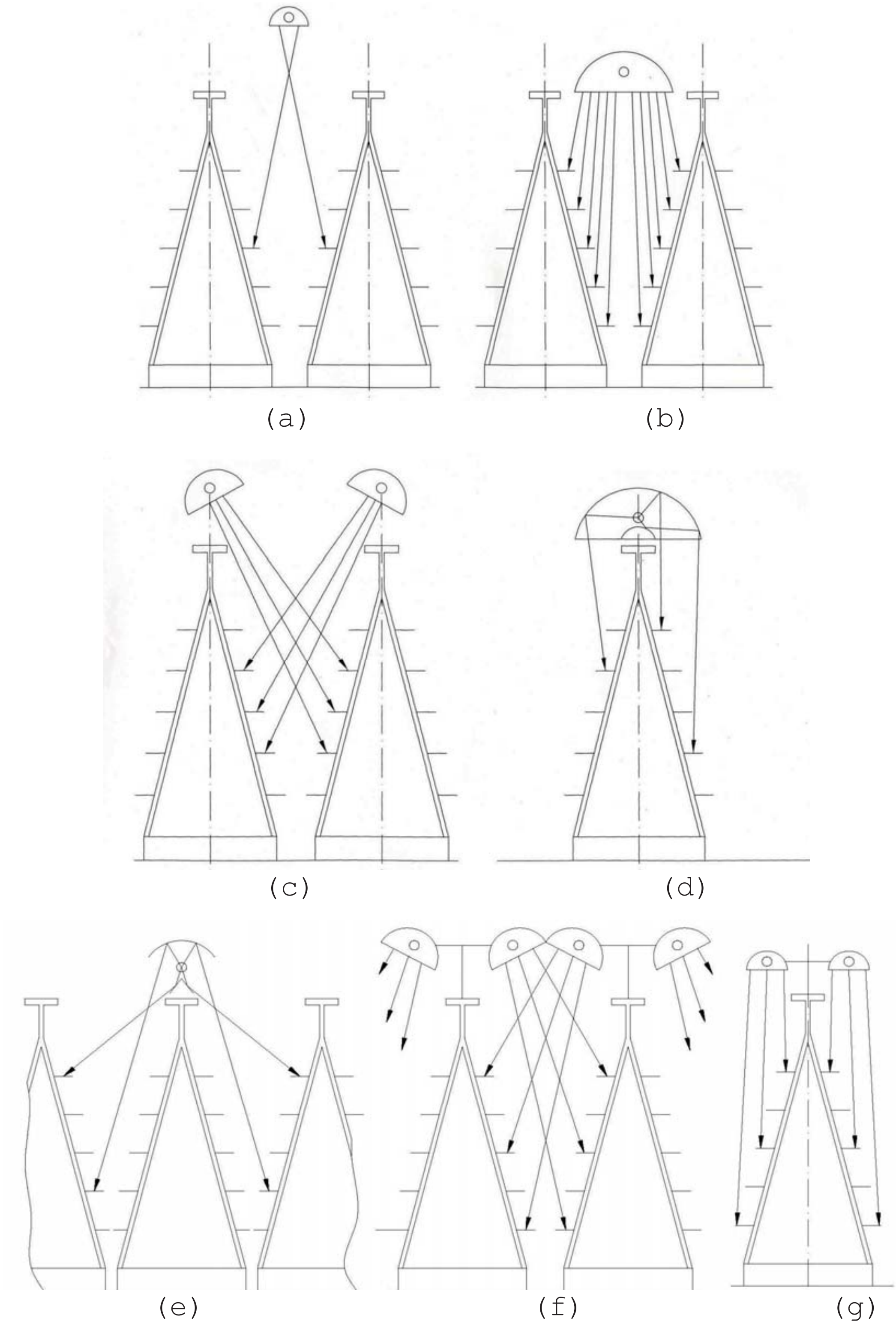

Fig. 2. Layout of irradiating sets (a) between the tiers, variant 1, (b) between the tiers, variant 2, (c) above the tiers, variant 3, (d) above the tiers, variant 4, (e) above tiers, variant 5, (f) removing the axis between the tiers, variant 6, (g) axis between the tiers, variant 7.

Table 1. The results of the analysis of options for optical schemes of upper artificial irradiation for MNH

Criterion	Variant						
	B1	B2	B3	B4	B5	B6	B7
1 – pattern of the reflected rays	+	–	+	–	–	+	+
2 – need for special irradiation sets for additional artificial irradiation of outer MNHs	–	–	–	+	–	+	+
3 – rationality of use of the flow produced by the irradiation sources	+	+	–	+	–	–	+
4 – absence of trays shading each other	–	–	+	–	+	+	–

+ – efficient variant, according to given criterion
– – inefficient variant, according to given criterion

Fig. 3 gives the results of calculations for the lighting of one side of the pyramid with five numbered points, which correspond to the five tiers. It also shows the cross-section of the horizontal surface with preservation of five points' relative positions. The location of the source is determined by the height index H_1 as to the first tier defining the distance index ℓ_1. Since it is important to determine the difference of spatial distribution of the flow for the horizontal and inclined surfaces, the calculations were made for conditional distances of the pyramid and for the illumination index E=100 standard units. The dependence of radiant intensity on angle α was calculated by the formula $I=\ell^{2}\cdot 100\,(\cos\alpha)^{-1}$. Luminous intensity distribution curves (LIDC) for the inclined (upper one) and horizontal (lower one) surfaces shown in Fig. 3 indicate to fundamentally different requirements for the lamps. In particular, the greatest flow by the horizontal surface corresponds to the direction to point 5, the one by the inclined surface – to point 1. This is due to varying regularity of the distance ℓ change while moving from point 5 to point 1 (decreases in the case of an inclined surface, increases in the case of a horizontal surface). It is important not only because the distance index ℓ squared is included in the rating formula but also due to the fact that in the case of inclined surface, index ℓ_1 (first tier) is not high enough. This means that the determining factor is the direct flow from the source of light but not the not yet formed reflected one, which in turn means that the given illumination index E for the first tier actually determines the main fraction power of the source for the first tier. The estimated LIDS also indicate that the luminous intensity that corresponds to the subsequent tiers should grow. This growth requires an increase in the source's intensity, i.e. excess of energy at upper tiers.

The analysis confirmed the assumption that any biological object (plant) contributes significantly to the specificity of the power supply of the production in APK (compared to abiotic production). Modelling of the inclined plane (Fig. 3) was done by turning the horizontal one. The creation of normalized lighting in a minor area does not cause any new problems. However, it is impossible to place the same number of plants in this area and get equal crops. One of the reasons is growing cenosis. Therefore, the specific (per m^2) source intensity in the MNH-technologies should be higher than the one in the projective area. In addition, there appear new relations of the spatial distribution of the flow. Fig. 3 shows l_{min} (the shortest distance) and ℓ_1 (distance to a definite point in the first tier). Angle β_1 is introduced together with the height index of the first tier H_1. In general, we can conclude the following:

$$l_i = \frac{H_i}{\cos\alpha}, \tag{1}$$

Since $\ell_i = l_{min} (\cos\beta_i)^{-1}$, the expression for the irradiance of the horizontal surface of any tier (instead of $E_i = I_\alpha \cdot \cos^3\alpha_I H_i^{-2}$) through ℓ_{min} and β is the form of:

$$E_i \frac{I_\alpha \cdot \cos\alpha_i \cdot \cos^2\beta_i}{l_{min}^2}. \tag{2}$$

Hence, the expression for I_α at distinguished value E_i=const:

$$I_\alpha = \frac{E_i \cdot l_{min}^2}{\cos\alpha \cdot \cos^2\beta}. \tag{3}$$

We got a mathematical model that relates luminous intensity with parameters characterizing the position of a tier on an inclined surface (angle β with a known value of l_{min}). The results of calculations of luminous intensity necessary for the angle $(\alpha+\beta) = 60°$ (which corresponds to the construction of MNH) are given in Table 2 ($E_i \cdot l_{min}$ is accepted as 1.0).

Table 2. The luminous intensity needed for the construction of MNH with the angle $(\alpha+\beta) = 60°$, with $E_i \cdot \ell_{min} = 1.0$

β	50°	40°	30°	20°	10°
I_α	2.55	1.8	1.53	1.47	1.62

The calculation results confirm the requirement for an increase in luminous intensity directed towards the lower tiers. They also show the advisability of ensuring equal irradiance to the tiers by one lamp because the illumination of the upper tiers at small angles β and at relatively short distance ℓ is sufficiently large, specifying the power of the lamp. The illumination of the lower tiers should be brought to norm with the help of a special 'bottom' light source which is placed inside the pyramid.

Calculations of the four set variants for the reflectors of metalized films of different thickness were performed under the programme that has been worked out by Giproniselprom institute.

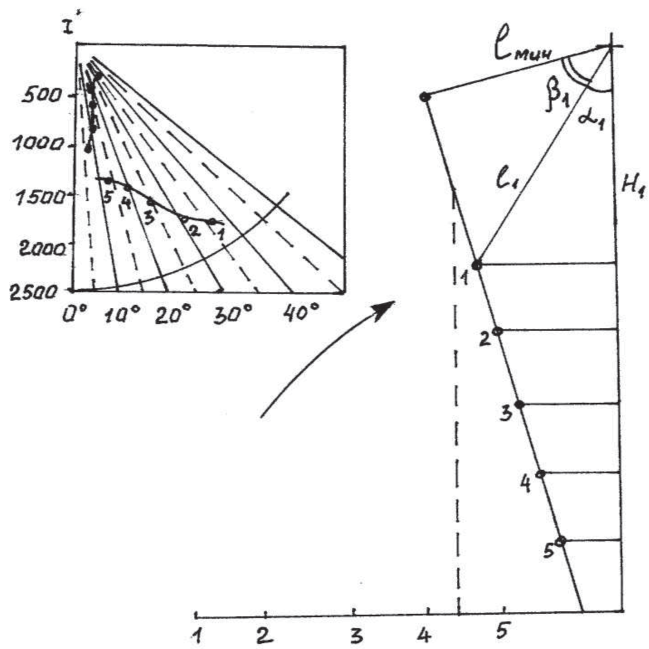

Fig. 3. Analytic model and luminous intensity distribution curves.

As a result of studies, a rational design of irradiator with an HPS-lamp was chosen and a control sample was produced (Fig. 4). A distinctive feature of this sample is the use of polyethylene terephthalate (polyester) films such as PET with an aluminium deposition thickness of 200 microns for the reflective surfaces of the irradiator. The efficiency factor of the irradiator is up to 95%.

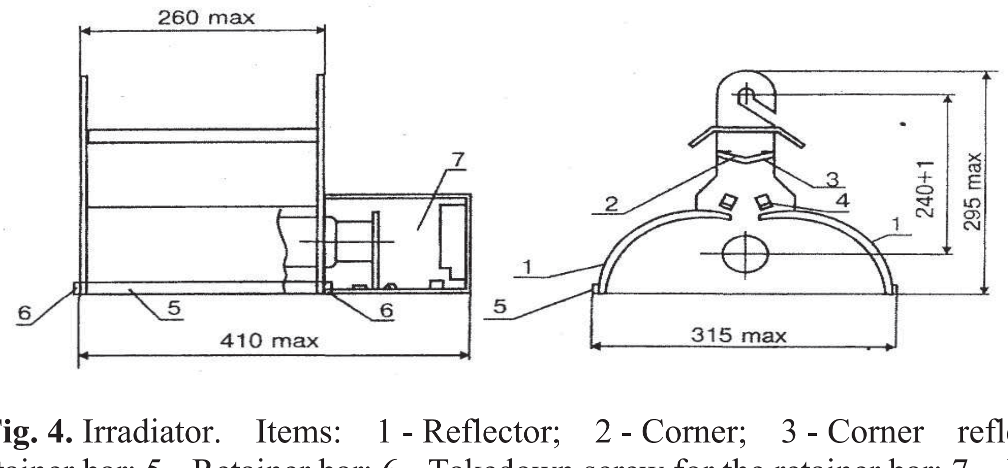

Fig. 4. Irradiator. Items: 1 - Reflector; 2 - Corner; 3 - Corner reflector; 4 - Retainer bar; 5 - Retainer bar; 6 - Takedown screw for the retainer bar; 7 - Box.

CONCLUSIONS

1. A laboratory test of an industrial sample of the designed irradiator with an efficient HPS-lamp confirmed its working capacity under conditions of high temperatures produced by the lamp. It also proved the conformity of lighting parameters to the calculated ones as well as confirmed the possibility of providing the racks of MNH with the specified value of power – 0.8–1.0 kW m^{-2}.

2. Performance tests in a real greenhouse revealed that the lighting parameters correspond to normal requirements, reliability indices of the lighting set are contained within the existing rules, and analysis of the plants during the long growing season revealed no significant differences by levels with a two-tiered system of irradiation.

3. The estimates obtained in economical testing confirmed that due to a more efficient use of light flow, the technological scheme of artificial irradiation of plants ´upper + lower´ compared to ´upper´ option allows to increase the productivity of plants by 52.7%, to reduce the costs of electricity by 1.53-fold per unit of output and to increase the outcome by 1.5-fold in the conditions of the same installed capacity of light sources.

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Preliminary Investigation into Tensile Characteristics of Long Flax Fibre Reinforced Composite Material

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Abstract. Natural fibre composites are materials formed by polymer resin matrix and reinforced with natural fibres mainly formed by cellulose, originating thus from plants, such as hemp, jute, flax, sisal, banana, etc. The advantage of natural fibre materials is their biodegradability and the fact that they are a renewable resource.

In Estonia, the most common plant for natural fibre manufacturing has been flax due to its long tradition of cultivation. Flax is currently no longer grown for textile production because of the economic situation, although the weather conditions are very suitable. Nevertheless, flax is still cultivated in small quantities for linseed oil production in Estonia. Experimental methods for manufacturing non-woven industrial textiles like felt and mats from short flax fibres are depicted. Long flax fibres were used as reinforcement in matrix of epoxy resin for experimental manufacturing of natural fibre reinforced composite material. The most important characteristic of all non-woven materials is tensile strength. The results of the tested natural fibre composite materials are presented. The potential fields of application for long flax fibre reinforced composite material are car, marine and windmill industry.

Key words: Natural fibres, flax, non-woven textile, natural fibre composites

INTRODUCTION

Market demand for environmentally friendly products is growing. The usage of plant fibres is often associated with an eco-design initiative for introducing environmentally friendly materials (Dweib et al., 2004). The advantages of natural fibres over synthetic or man-made fibres, such as carbon and glass, are the low density, low cost, acceptable specific strength properties, biodegradability, ease of separation, and carbon dioxide sequestration (Mohanty et al., 2005). The relative sustainability of biocomposites should be observed at all stages of development. The environmental, economic and social impacts should be evaluated for better understanding of the advantages of natural fibre based bio composites. Bio composites should be compostable at the end of life. All possible solutions for end-of-life products, such as mechanical recycling, incineration and composting should be considered. Composting presumes biodegradable resin matrix, which is appropriate for natural fibre reinforcement (Wallenberg et al., 2004). The relationships between natural fibre properties and resin matrix properties are more complex than those in glass fibre reinforced composites (Hagstrand et al., 2004). Injectable short-fibre thermoplastic compounds are commercially available on the market, but high-performance thermosetting composites with long natural fibre reinforcement are still in a development phase in research laboratories (Bos et al., 2006).

Mechanical properties of bio composites achieved by natural fibre reinforcement are equally important. Natural fibre properties of are influenced by many factors, including plant type and variety, growth conditions and method for extracting fibre bundles (Mohanty et al., 2005).

Traditional production and primary processing techniques have been developed over a long period of time. The main application is production of high value long fibre material for the textile industry (Zhang et al., 2000).

The application of flax fibres in the production of nonwovens is connected with the adaptation of non-linen spinning systems, i.e. with the need for the following operations: cleaning, dividing and shortening of fibres. The application of appropriate blends of fibres would enable their processing as nonwovens with the use of traditional nonwoven machinery lines (Muir et al., 2003).

Flax (*Linum usitatissimum*) can be grown for linseed or fibre production at very high densities to produce high, unbranched stems. Flax fibre is a cellulose polymer, but its structure is more crystalline, making it stronger, crisper and stiffer to handle, and more easily wrinkled (Soiela, et al., 2003). Flax fibres range in length up to 90cm, and average 10 to 20 microns in diameter (See Fig. 1).

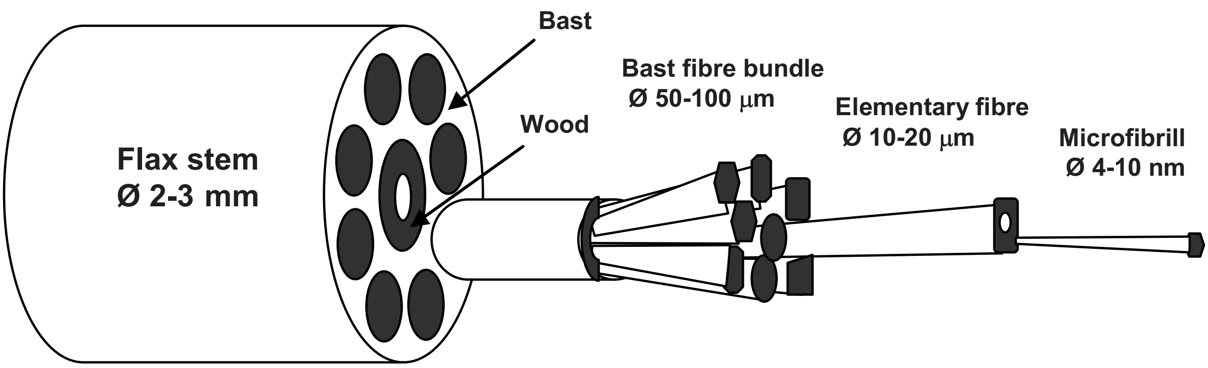


Fig. 1. Internal structure of a flax stem.

High quality fibres are obtained from the upper third of the stem to the base. As the fibre is bast-type, it must be retted to release fibres which are then bleached before use.

Removal of straw from flax fibres is called dressing, which consists of three steps: breaking, scutching and heckling. Breaking breaks up the straw, after which some of the straw is scraped from the fibres in the scutching process; then the fibre is pulled through various different sized hackles to remove the last bits of straw. Enzymes have the potential to provide an improved method of flax retting for textile fibres (Faulk et al., 2008).

Flax fibre is hollow and absorbs up to 12 wt% in water, but it dries quickly. In comparison with synthetic fibres, such as fibreglass, flax fibre is anti-static by nature and does not perspire. The fibres are twice as strong as those of cotton and five times stronger than those of wool. When flax fibre gets wet, the strength of fibre increases by 20%. The mechanical properties of synthetic and natural fibres are compared in Table 1.

Table 1. Physical and mechanical properties of natural and man-made fibres (Mohanty, 2005)

Fibre	Density, G cm^{-3}	Tensile strength, GPa	Elongation At break, %	Specific tensile strength, GPa*m^3 kg^{-1}	Diameter of elementary fibre, µm
Flax	1.5	1.5	3.0	1.0	20
Hemp	1.5	0.7	3.0	0.5	30
E-glass	2.6	2.4	2.5	0.9	3-30
Aramide High modulus	1.5	3.1	1.0	2.1	12
Carbon High modulus	1.8	2.2	0.5	1.2	8

The acquired long fibres are used in textile industry for spinning into yarn, weaving, knitting and geo-textile production. However, as the long flax fibre is used for manufacturing woven textile materials, the shorter ones are used in nonwoven and technical textile production. In addition, short fibres are used in non-textile markets including packaging of materials, reinforcements for plastics and concrete as alternative for glassfibre, insulation or decorative panels, and lining materials for car industry. The main goal of the current study is to develop new long flax fibre reinforced composite materials for marine and windmill industry applications.

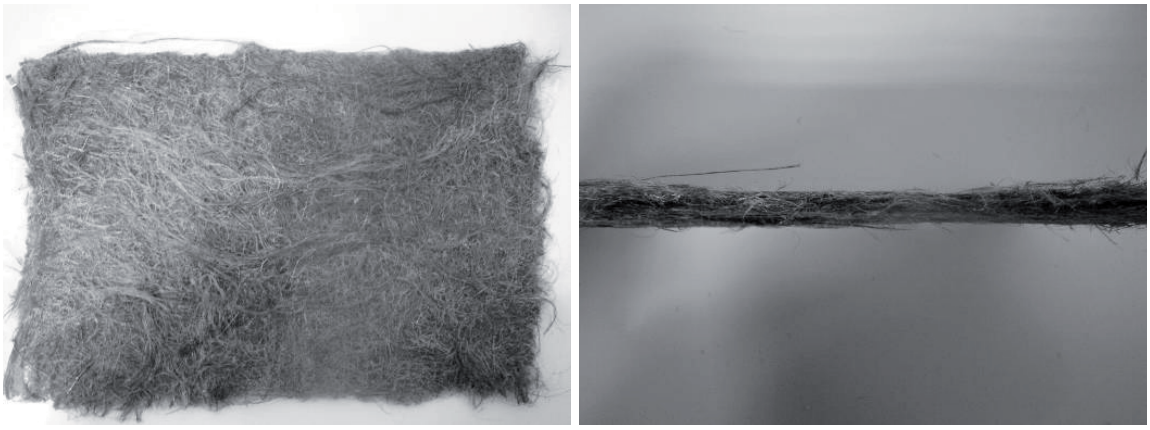
MATERIALS AND METHODS

The aim of the technological tests with flax fibre was the experimental manufacturing of natural fibre composite plate material for cutting tensile test specimens (dog bone shape). In traditional composite products made by hand, using lamination technology with glass fibre, the fibre content in laminate mats is 25 30 wt.%. Hence, our target was to achieve a 20-25 wt% flax fibre content in laminate with thickness 3 mm. The low viscosity (0.5-0.8 PaS) FD epoxy resin was chosen to ensure good wettability properties of flax fibres.

Technological tests with flax fibres (250-300 mm) were conducted according to three different technologies. Firstly, flax fibres were rolled with a radial toothed roller and then combed to divide fibres smoothly and orientate them in one direction. The first lamination tests were carried out by hand lamination with low viscosity FD epoxy resin. The fibres were rolled in a 300x300 mm area, 10 g of fibres per layer. Eight layers were oriented in turn 0° and 90° direction. As flax fibre was sturdy and tough the result of hand lamination was a loose, aerial, soft and flexible material.

For tightening the fibre layers and compression of material, the laminate was consolidated with vacuum bagging technology by using draught pressure -0.8 bar.

After consolidation the laminate resembled felt and was very dry, aerial, loose and flexible, with thickness about 8 mm. The resin content in material was 60 wt.%. It was obvious that vacuum suction had exhausted the resin between the flax fibres. This felt material (see Fig. 2) was not appropriate for tensile tests.



a) b)

Fig. 2. Flax felt plate after vacuum bagging: a) Top view of the material, b) Cross section of the material.

Thirdly, compression moulding technology was used. Two plates 180x180 mm were cut out from the felt and impregnated with FD epoxy resin, after which they were packed in peel-ply fabric and placed between three metal sheets. Between the metal sheets were placed the 3 mm thick edges to assure laminate thickness after compression. Then the metal mould with impregnated flax laminate was placed under press for compression moulding. The press plates were heated up to 30°C to ensure better wettability by reducing epoxy resin viscosity. Metal mould plates were pressed against the edges to achieve the desired 3 mm thickness of the laminates. After one hour the temperature of the press plates was raised to 40°C, and finally, after some period to 50°C. After six hours post curing of the laminate it was cooled down with press plates. The laminate was easily taken out from mould. Flax fibre content in the laminate was 20-25 wt.%. Ten tensile specimens (type 1B) according to standard ISO 527-4 were milled from the laminates.

RESULTS AND DISCUSSION

Tensile test of composite plastic materials was performed according to standard ISO 527-1:2000. The mechanical properties, such as tensile strength, elongation, and modulus of elasticity were determined. Specimens for tensile test were prepared according to ISO 527-2:2000 type 1B. The cross-sections of the specimens were measured with calibrated calliper gauge with measurement accuracy 0.01 mm. The axial extensometer with the gauge length of 50 mm (travel +50% to –10%), was used to measure axial strain in a specimen. The applied testing system was the servo-hydraulic testing machine *Instron* 8800. The tensile tests were performed with loading velocity 2 mm min^{-1}, tolerance ± 20%.

As it follows from Fig. 3, the deformation of the specimens was elastic. As the mechanism of fracture was brittle, from the stress-strain curves, only slight plastic deformation occurred in some tested specimens after elastic deformation before breakage. Flax fibre was broken before pulling it out of the thermosetting resin matrix which means that the strength of the matrix resin was higher than that of fiber. The adhesion between resin matrix and flax fibre was good.

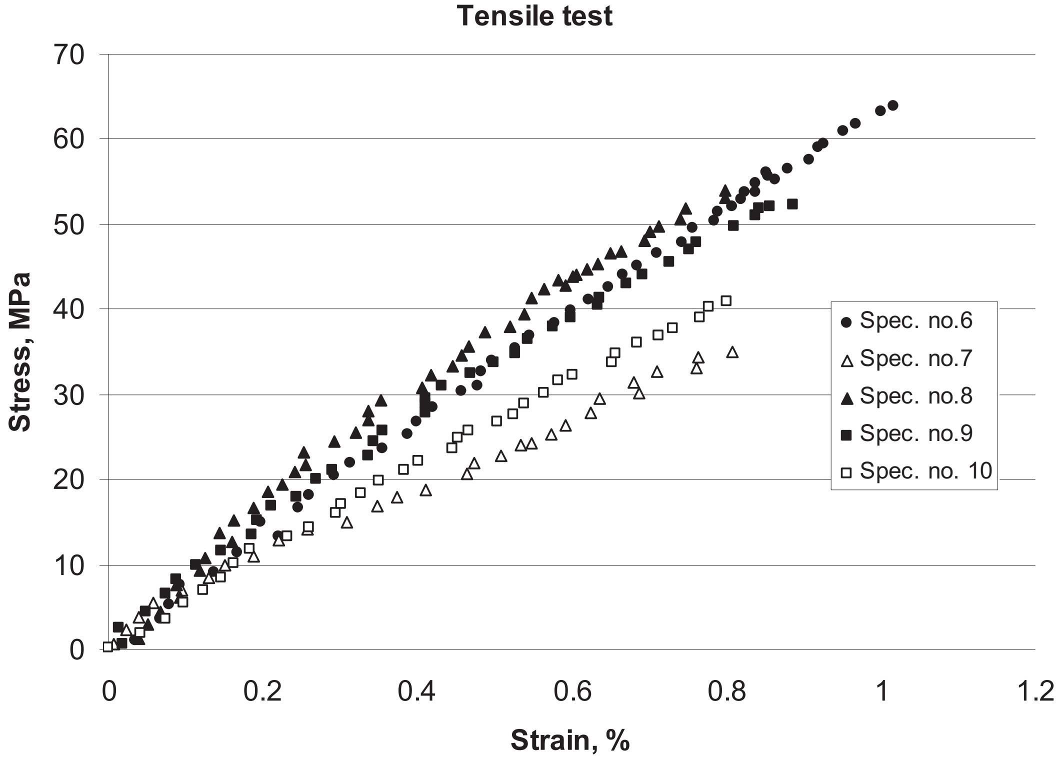


Fig. 3. Stress-strain behaviour of natural fibre composites in tensile test.

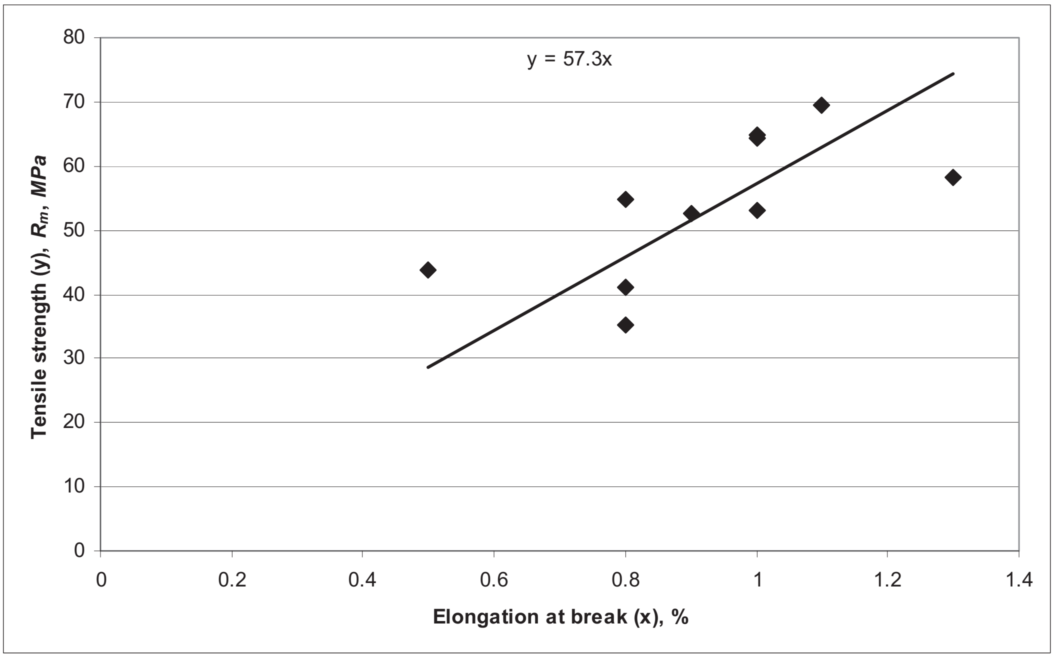


Fig. 4. Tensile strength versus elongation at break.

The dependence of tensile strength on elongation at break is presented in Fig. 4. Mainly elastic deformation occurred and therefore stress-strain behaviour can be prognosticated by linear trend.

According to technical datasheet, the tensile strength of neat resin was 60 MPa. 30% of tested flax fibre composite specimens had better tensile properties than those of neat epoxy resin and 40% of the specimens had 5–10% lower results (see Fig. 4). The tested natural fibre composite specimens are presented in Fig. 5.

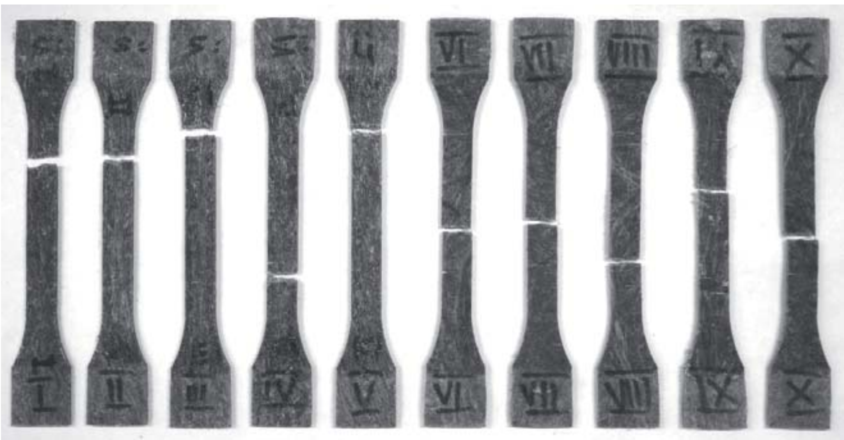


Fig. 5. Breakage of tested tensile specimens

The average elongation at break was 0.9%. According to technical datasheet, the elongation at break for neat FD epoxy resin is 6%. As for flax fibre, elongation at break is 3% (Andersons et al., 2005). This means that elongation at break decreases when epoxy matrix is filled with flax fibres. One of the reasons could be the porosity of the composite material. To study the morphology of flax fibre and epoxy resin matrix with optical microscope, micro polishes of natural fibre composite were made (see Figs. 6-7). As a result of the study it can be concluded that pores at the top surface of the composite affected the tensile test results by forming stress concentrators at the edges of the tensile specimens.

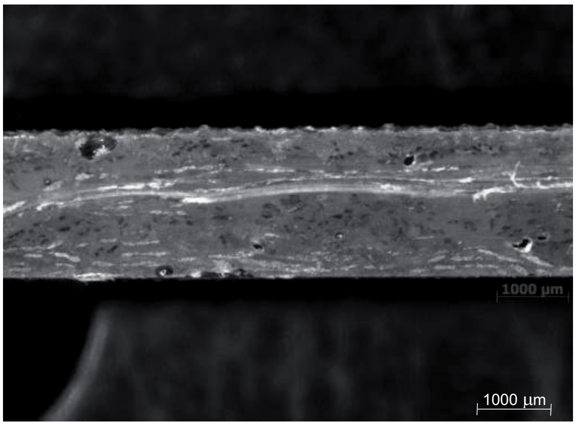


Fig. 6. Cross-section of specimen.

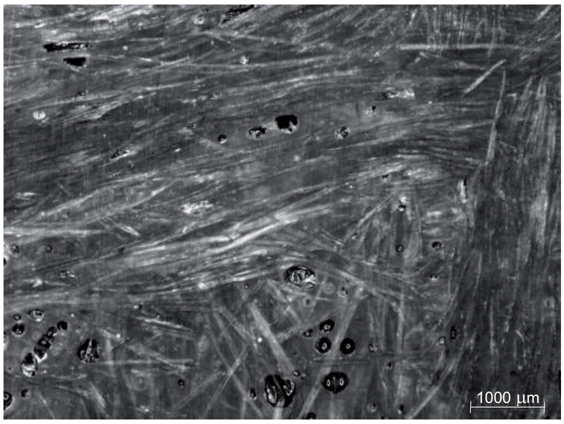


Fig. 7. Top surface of specimen.

These pores could be avoided by using vacuum infusion technique for further experimental manufacturing tests. The suction of the vacuum pump removes air from the composite material. Wettability and surface activation of flax fibre needs further investigation and tests with different matrix resins.

CONCLUSIONS

Short natural fibres are mainly used by automotive industry as reinforcement in injection moulded composites with thermoplastic matrix or sheet moulding compounds with thermosetting matrix.

This work focused on the development of composites with long flax fibre and thermosetting matrix, which are commercially not available on the market. The technological tests with long flax fibre composite manufacturing were successful. The tensile strength of flax fibre reinforced composite was quite similar to neat resin properties. It provides a good basis for the development of new environmentally friendly high performance composite materials.

For further testing, the new flax fibre with better mechanical properties should be used to improve tensile strength and elongation properties. For the manufacturing of bio composites, the availability of suitable bioresins should be considered. The wettability properties and surface activation of flax fibre needs further studying. As flax fibre has lower density than that of glass fibre, it has a good strength density ratio, which makes it a desirable material from the technical, economical and ecological point of view. Long flax fibre reinforced composite material will have application in marine and windmill industry, where a good strength and weight ratio is required.

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Variation in Response of Five Polish Winter Wheat Cultivars to Foliar Copper Application

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Abstract. The aim of the study was to verify whether new, intensive and commonly grown winter wheat cultivars in Poland differ significantly in Cu efficiency. Winter wheat is considered as one of the most sensitive agronomic species to Cu deficiency. Copper fertilization of wheat seems to be a necessity in our country due to common Cu deficiency in Polish soils.

In 2004-2006, three field experiments were conducted in the Experimental Station Osiny in Eastern Poland, where the response of five winter wheat cultivars to foliar copper application was tested. Copper was applied in the form of $CuSO_4 \cdot 5H_2O$ at a rate of 305 g ha^{-1} Cu. Fertilization was performed in spring during the full tillering stage of growth. Analysis of variance was used for statistical calculations. The means were compared using Tukey's test.

It was demonstrated that the five cultivars responded differently to the Cu fertilization, with a medium content of this element in soil. A single Cu spray caused 5-9% increase in grain yield in three out of the five tested cultivars. The other two cultivars did not show any significant yield increase in response to copper application. Besides, all the cultivars accumulated different quantities of copper in plant tissues, such as shoots and grain.

The field trials have proven that winter wheat cultivars are diverse in their nutritional demand for copper. The necessity of winter wheat fertilization with Cu depends not only on the concentration of this nutrient in soil, but also on the tolerance of a given wheat cultivar to copper deficiency.

Key words: winter wheat, cultivars, copper, fertilization requirements

INTRODUCTION

Winter wheat is considered to be one of the most Cu deficit sensitive species (Fageria, 2000; Katyal & Randhawa, 1983). It is also the crop that covers the largest sowing area in Poland. At present, it seems necessary in Poland to fertilize wheat with copper due to the considerable deficiency of this element in soils and crops, as observed in the recent years (Gembarzewski, 2000). An inventory study completed in our country, based on 100,000 samples, has demonstrated that up to 36% of soils in Poland are deficient in Cu (Kucharzewski & Debowski, 2000). In some reports from Australia and Canada, it is claimed that the wheat cultivars grown in these countries are significantly different in their tolerance to copper deficit in soil (Nambiar, 1976; Owuoche et al., 1994; Owuoche et al., 1995; Piening et al., 1989). The purpose of this study has been to find out whether winter wheat cultivars commonly grown in Poland differ in their nutritional demand with respect to copper. It is possible that the decision about copper fertilization of winter wheat should be made depending on what cultivar is to be grown.

MATERIALS AND METHODS

In years 2004-2006, three field experiments were conducted with foliar application of copper to various winter wheat cultivars. The trials were performed at the Experimental Station Osiny near Pulawy (South-East Poland). The soils used for the trials were Haplic Luvisols, acidic or slightly acidic, containing 0.9-1.2% organic matter, well supplied in phosphorus, potassium and magnesium (Table 1).

Table 1. Characteristic of experimental soils

Year	pH KCl	OM	SF I	SF II	P_2O_5	K_2O	Mg	Cu_{HCl}
		%			mg kg^{-1}			
2004	5.2	1.2	18	19	94	143	64	4.7
2005	5.2	1.2	15	24	127	153	40	2.6
2006	6.3	0.9	17	23	128	140	81	2.4

OM-organic matter, SF I-soil fraction<0.02 mm, SF II-soil fraction 0.1-0.02 mm.

The copper concentration in soil extracted with 1 M HCl ranged from 2.4 to 4.7 mg kg^{-1} and was higher in the first year than in the other two years of the experiment. According to the criteria applied in Poland (Gembarzewski & Korzeniowska, 1996), all the three soils were classified as being moderately abundant in copper. Soils moderately rich in copper were purposefully selected for the trials as this factor was expected to cause both positive and, possibly, negative response of some wheat cultivars to copper application. The experiment was set up as a two-factor one with 4 replications, in a split-plot design. Five winter wheat cultivars produced in Polish breeding stations were tested (Table 2).

Table 2. Characteristic of wheat cultivars

Cultivar	Group of wheat	Plant Breeder Company
Kobra	B	Seeds of Kobierzyce Ltd
Zyta	A	Plant Breeding Strzelce Ltd
Sakwa	B	Plant Breeding Strzelce Ltd
Jawa	C	Plant Breeding Strzelce Ltd
Korweta	A	Danko Plant Breeders Ltd

A – quality wheat (very good baking quality), B – bread wheat (good baking quality), C – fodder wheat (weak baking quality).

Copper was applied as $CuSO_4 \cdot 5H_2O$ at the tillering stage of growth at the rate of 305 Cu $g \cdot ha^{-1}$. All the experimental treatments received identical basic fertilization N – 130, P_2O_5 – 60, K_2O –70 $kg \cdot ha^{-1}$. In all the years, chemical control against weeds (Maraton 375 SC) and fungi (Amistar 250 SC+Bavistin 500 WG and

Artea 330 EC) was carried out. The surface of each plot was 30 m^2, with 25 m^2 to be harvested.

All the years when the experiments were conducted were characterized by a lower average rainfall compared to the long-term one (Table 3).

Table 3. Monthly sums of precipitation in Osiny (mm)

Year	Month										Total
	X	XI	XII	I	II	III	IV	V	VI	VII	
2003-2004	49.3	20.1	30.1	20.7	43.6	34.1	38.9	19.0	52.1	93.0	400.9
2004-2005	30.8	54.5	12.7	37.8	17.7	27.8	16.3	66.9	31.6	106.5	402.6
2005-2006	3.6	27.4	64.7	12.1	19.3	40.3	27.1	58.0	19.2	20.7	292.4
1956-2000	42.0	39.0	36.0	25.0	25.0	27.0	41.0	54.0	75.0	82.0	446.0

The 2005-2006 growing season proved to be particularly dry, when, after a dry autumn and winter, April had very little rain while June and July were almost rainless. The average annual temperatures in 2003-2004 and 2005-2006 were close to the long-term average and the differences did not exceed 3% (Table 4). The 2004-2005 season was demonstrably warmer than the long-term temperature and the other two experimental seasons.

Table 4. Mean monthly air temperatures in Osiny (^{o} C)

Year	Month										Mean
	X	XI	XII	I	II	III	IV	V	VI	VII	
2003-2004	5.4	5.0	0.7	-5.0	-0.3	3.3	8.6	12.5	16.5	18.5	6.5
2004-2005	10.1	3.6	1.9	0.5	-3.7	0.2	9.0	13.9	16.4	20.2	7.2
2005-2006	8.6	3.1	0.6	-8.0	-3.8	-0.7	9.2	13.9	17.7	22.5	6.3
1956-2000	8.4	3.1	-0.8	-3.0	-2.2	1.7	7.8	13.4	16.7	18.2	6.3

Soil samples were taken for chemical analyses before the establishment of trials. In addition, aerial parts of wheat plants at the early elongation stage and grain samples were collected from each trial.

Organic carbon in soil was determined by Tiurin method (acc. to Polish standard No. PN-91/Z-15005), pH was established potentiometrically in 1 mol $KCl \cdot dm^{-3}$, P and K were determined using Enger-Riehm method (Polish standards No. PN-R-04023:1996 and PN-R-04022:1996 adequately), and Mg by Schachtschabel method (Polish standard No. PN-R-04020:1994). Copper was first extracted in 1 mol $HCl\,dm^{-3}$ (Gembarzewski & Korzeniowska, 1990) and then determined using AAS method.

Having wet digested (H_2SO_4+H_2O_2) the plant samples, N and P were determined using flow analysis (CFA) and spectrometric detection, K was assayed by flame emission spectrophotometry and Mg by AAS method. Copper in shoots and grain was determined by the AAS method following dry digestion.

Program AWAR (Filipiak & Wilkos, 1995), made by Department of Applied Informatics, Institute of Soil Science and Plant Cultivation in Pulawy, was used to perform the analysis of variance. First, the two-way ANOVA for split-plot was conducted for each year separately. Next, an across-years ANOVA was used. Means were compared using the Tukey test.

RESULTS AND DISCUSSION

The wheat yields in 2004 and 2005 were similar (Table 5). The lower yields in 2006 were caused by the shortage of rainfall, mainly in June and July (cf. Table 3). The weather conditions in the three years significantly affected the general level of wheat yields, although they did not alter the direction of the crop's response to copper application. This enabled us to perform an across 3 years ANOVA (Table 6).

In each year, cultivar Kobra responded to Cu application with a statistically significant increase in grain yield ranged 8.5-10.8% (Table 5). Cultivar Sakwa responded only in 2004 (5.8%) and cv. Zyta in 2006 (9.0%). In none of the years, copper fertilization evoked a significant response of cv. Jawa or cv. Korweta.

The highest increase in yield was obtained in 2006 and the smallest one – in 2004, which is attributable to the content and availability of Cu in soil. The soil in which the trials were established in 2006 had the smallest concentration of this element and the highest pH. It has long been known that Cu is less available when the soil pH is high (Harry & Graham, 1981; Kabata-Pendias & Pendias, 2001).

Table 5. Grain yield (t ha^{-1})

Cultivar – *factor II*	Cu application – *factor I*								
	0	Cu	increase[1] %	0	Cu	increase[1] %	0	Cu	increase[1] %
	2004			2005			2006		
Kobra	9.70	10.53	8.5*	8.24	8.88	7.8*	4.93	5.46	10.8*
Zyta	9.89	10.16	2.7	8.73	9.52	9.0*	4.32	4.44	2.8
Sakwa	10.78	11.41	5.8*	9.87	10.03	1.5	5.32	5.77	8.6
Jawa	10.27	10.35	0.7	9.53	9.79	2.8	4.21	4.13	-1.9
Korweta	9.91	9.81	-1.0	8.68	8.41	-3.1	4.28	4.37	2.2
Tukey LSD (α <0.05):	*II/I factor - 0.412 I/II factor - 0.611*			*II/I factor - 0.473 I/II factor - 0.710*			*II/I factor - 0.516 I/II factor - 0.558*		

[1]) Increase as a result of Cu application, *) Statistically significant

The three-year grain yield means (Table 6) demonstrated that the highest significant yield increase following an application of Cu was obtained for cv. Kobra (8.7%) followed by cv. Zyta (5.1%) and cv. Sakwa (4.7%). The cultivars Jawa and Korweta did not respond with a higher yield to Cu fertilization. In a study based on 115 field trials, Karamanos et al. (2003) obtained average yield increases of 9.9% on soils with low and 46.7% on soils with very low Cu concentration (<0,4 mg·kg^{-1} Cu in DTPA).

Table 6. Average grain yield over 3 tested years (t ha^{-1})

Cultivar – *factor II*	Cu application – *factor I*						Increase %
	0			+Cu			
Kobra	7.62	*A*	*a*	8.29	*B*	*b*	8.7*
Zyta	7.65	*A*	*a*	8.04	*B*	*b*	5.1*
Sakwa	8.66	*A*	*c*	9.06	*B*	*c*	4.7*
Korweta	7.62	*A*	*a*	7.53	*A*	*a*	-1.2
Jawa	8.00	*A*	*b*	8.09	*A*	*b*	1.1
Tukey LSD (α <0.05): II/I factor - 0.255, I/II factor – 0.342							

Yields marked with the same capital letters within the same line and with the same small letters within columns did not differ according to Tukey's test. *) Significant increase as a result of Cu application.

The tested wheat cultivars differed significantly from one another in weight of 1,000 seeds. Copper application did not influence grain size of any tested cultivars (Table 7). The weight of 1,000 seeds from the control and Cu treatments was similar, including that of the cultivars responding positively to copper fertilization. This means that copper nutrition led to a higher number of grains in an ear rather than bigger grain size. The finding supports a well-known, positive influence of copper on the process of grain formation in wheat (Dell, 1981; Owuoche et al., 1994).

Table 7. Weight of 1000 seeds – average over 3 tested years (g)

Cultivar – *factor II*	Cu application – *factor I*		Mean
	0	+Cu	
Kobra	44.0	44.3	44.2 *b*
Zyta	43.4	43.8	43.6 *ab*
Sakwa	46.5	46.5	46.5 *c*
Jawa	39.0	38.8	38.9 *a*
Korweta	43.0	42.4	42.7 *a*
Mean	43.2 *A*	43.2 *A*	
Tukey LSD (α <0.05): Factor I – n.s., factor II – 0.989., IxII – n.s.			

Yields marked with the same capital letters within the same line and with the same small letters within columns did not differ according to Tukey's test.

The five wheat cultivars showed a tendency toward differentiated accumulation of copper in shoots and accumulated significantly different amounts of this element in grain (Table 8). Average over all cultivars showed that an application of Cu led to a considerable increase in the content of this element in shoots but did not cause a change in the content of Cu in grain. The cultivar-related differences in copper accumulation in plant tissues have also been demonstrated by Owuoche et al. (1995).

The aggregate analysis of yields and Cu content in plant tissues showed that cv. Kobra was characterized by the highest Cu demand. In each year of the experiment, it responded with a significant yield increase to Cu application, and the three-year yield increase mean was the highest among the five tested wheat cultivars. At the same time, this cultivar had a lower Cu content in grain and shoots than the other cultivars.

The cultivars Zyta and Sakwa also responded positively to Cu, although the yield increases were neither as high nor as regular as the ones observed for cv. Kobra. The cultivar Zyta contained similar amounts of Cu in tissues to those found in cv. Kobra, whereas the level of this element in tissues of cv. Sakwa was comparable to the ones determined in the cultivars not responding to Cu, i.e. cv. Jawa and Korweta.

Table 8. Copper concentration in wheat shoots and grain–average over 3 years (mg kg^{-1})

Cultivar – *factor II*	Cu application – *factor I*					
	shoots			grain		
	0	+Cu	Mean	0	+Cu	Mean
Kobra	3.2	3.8	3.5 a	2.5	2.5	2.5 ab
Zyta	3.3	4.0	3.7 a	2.4	2.3	2.4 a
Sakwa	3.1	4.4	3.8 a	2.8	3.0	2.9 c
Jawa	3.3	4.8	4.1 a	2.8	2.7	2.8 bc
Korweta	3.4	4.4	3.9 a	2.9	2.9	2.9 c
Mean	3.3 A	4.3 B		2.7 A	2.7 A	
Tukey LSD (α <0.05)	*Factor I – 0.612, factor II – n.s., IxII – n.s.*			*Factor I – n.s., factor II – 0.362, IxII – n.s.*		

Yields marked with the same capital letters within the same line and with the same small letters within columns did not differ according to Tukey's test.

The cultivars Jawa and Korweta had the lowest Cu demand. These cultivars accumulated more Cu in tissues than the other cultivars. Although copper application led to a significantly higher accumulation of Cu in shoots, this was not accompanied by a significant increase in grain yield. This finding confirms that cv. Jawa and Korweta could utilize the copper found in soil much more efficiently than the other tested wheat cultivars.

The differences in copper demand between the tested wheat cultivars, resulting from different efficiency in copper utilization, have also been demonstrated by Owuoche et al. (1994, 1995) and Piening et al. (1989).

CONCLUSIONS

1. The five tested winter wheat cultivars differed significantly in their nutritional demand for copper. At the same concentration of Cu in soil, three out of the five wheat cultivars responded to foliar copper application with 5-9% grain yield increase while the other two cultivars did not respond to the treatments.

2. Copper application caused an increase of this element in shoots but not in grain of all five wheat cultivars.

3. The tested wheat cultivars differed significantly in the content of copper in grain.

4. Copper fertilization did not influence the size of wheat grains in any of the tested cultivars. It is most probable that copper nutrition led to a higher number of grains in an ear rather than their larger size.

5. Due to existing differences in the demand for copper between individual winter wheat cultivars, a decision whether wheat fields should be fertilized with this element needs to be made based not only on the abundance of Cu in soil, but also on the wheat cultivar to be grown.

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The Dependence of Reed Canary Grass (*Phalaris arundinacea* L.) Energy Efficiency and Profitability on Nitrogen Fertilization and Transportation Distance

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Abstract. The increased interest in bio-energy production forces us to consider production sustainability which in turn requires energy crop multi-criteria evaluations. The current study analyzes the dependence of reed canary grass (*Phalaris arundinacea* L.) energy use efficiency and production profitability on nitrogen fertilization and biomass transportation distance. The study used yield data from reed canary grass field experiments conducted in Estonia in 1968-1976. In reed canary grass production, nitrogen fertilization influences the biomass yield significantly and therefore has an impact on production energy efficiency. Although reed canary grass net energy yield increases continuously (0.15 GJ kg^{-1}) with increasing nitrogen application, the optimum energy use efficiency is reached with 117 kg N ha^{-1}. Increased reed canary grass transportation distance results in an average energy efficiency decrease of 7 MJ GJ^{-1} km^{-1}. Reed canary grass cultivation for bio-energy production could be considered at a break-even price of 1.5 EEK kg^{-1}, whereas production profit-loss in this instance depends on nitrogen application. Supplementing profitability analysis with transportation costs results in production net cost and therefore also an increase in break-even price. In the current economic situation the actual buying-up prices do not exceed the production net costs, which is why the negative profitability in reed canary grass bio-energy production must be considered. As the current study evaluated reed canary grass production efficiency on soils with low soil humus content, there is a necessity of extending the study to soils with different fertilizer requirements. The methodology of the current study could be used for evaluating bio-energy production optimization in general despite the results being based on one field experiment.

Key words: Reed canary grass, energy use efficiency, production profitability, biomass transportation

INTRODUCTION

The increased interest in bio-energy production during the last decades has forced scientific research to estimate biomass energy potential. Reed canary grass (*Phalaris arundinacea* L.) has been estimated to be a potential bio-energy crop in northern Europe (Hadders & Olsson, 1997; Lewandowski et al., 2003). It is generally agreed that sustainable bio-energy production requires multi-criteria evaluations. Therefore, economical analysis of production as well as further evaluation emphasizing an optimum resource usage should be performed. Studies have evaluated reed canary grass yields, duration period, winter losses (Landström & Wik, 1997; Pahkala & Pihala, 2000; Saijonkari-Pahkala, 2001; Lindh et al.,

2009) in the Northern conditions, but some comparisons have been made of economy, practical production value and energy efficiency characterizing environmental effects. Research has evaluated energy balances (Venturi & Venturi, 2003), also energy and nitrogen use efficiency (Lewandowski & Schmidt, 2006; Wrobel et al., 2009) in biomass production. Energy gain per hectare and consumption per output unit (e.g. energy use efficiency) are substantial indicators characterizing the environmental effect of production.

In biomass analysis the entire production chain (including transportation) should be considered. Perpiňá et al. (2009) performed a methodology based approach for biomass transport optimization. Studies have indicated dependence of optimum transportation distance on the truck's load capacity and the density of transported matter (Junginger et al., 2001; Lindh et al., 2009). Lindh et al. (2009) conclude that in the case of reed canary grass it is impossible to obtain the full load-bearing capacity of a lorry even with bales, therefore, not the maximum mass but the maximum volume may be the limiting factor in biomass transportation. In Finland the maximum cost-effective transportation distance of reed canary grass is estimated at 60km (Pahkala, 2007), but a detailed profitability analysis in Estonian conditions is lacking.

The aim of the current study was to analyze energy use efficiency (EUE) and the production profitability of growing reed canary grass as a bio-energy crop and its relation to nitrogen fertilization and distance of biomass transportation from the plantation.

MATERIALS AND METHODS

Net energy yield and energy use efficiency

Net energy yield (NEY) is calculated by subtracting the total energy input (EI) from total energy yields. Energy use efficiency (EUE) is the ratio of NEY to EI. The reed canary grass total biomass energy was calculated using a lower heating value of 16.6 MJ kg^{-1} (Burvall, 1997). As a delayed harvest is suggested in biomass energy production in Nordic conditions (Saijonkari-Pahkala, 2001), autumn harvested reed canary grass yields were estimated considering 40% yield losses for spring harvest (Lindh et al., 2009). A total energy input in the plantation was calculated annualizing the total consumed energy input of 12 production years (Landström & Wik, 1997), taking into account direct (fuel) and indirect (seed, fertilizers and field machinery) energy input. Machinery energy consumption included energy for manufacturing (86.7 MJ kg^{-1}) and for repair and maintenance (R&M) as suggested by Bowers (1992). In addition, consumed energy of 8.8 MJ kg^{-1} (Loewer et al., 1977) for transporting machines from plantation to farm was included. Energy input for diesel fuel considers a low heating value of 35.7 MJ l^{-1} (European Commission, 2004), whereas fuel consumption in different machinery operations originates from Rinaldi et al. (2005), Dalgaard et al. (2001) and Mikkola & Ahokas (2009). Field machinery operations included tillage, fertilization, harvesting, and biomass field transport. The total energy consumption in production of agricultural machinery and diesel fuel was evaluated for tillage (ploughing, cultivating and rolling), fertilization (twice a year), and harvesting (mowing and baling). Complete energy-related input for fertilization also included varying N and fixed PK application norms with energy input for the production of fertilizer N 35.3 MJ kg^{-1} (Appl, 1997), P 36.2 MJ kg^{-1} and K 11.2 MJ kg^{-1} (Kaltschmitt & Reinhardt, 1997). Additionally, 10 MJ ha^{-1} y^{-1} (Bullard & Metcalfe, 2001) of seed energy and biomass field transport energy was included in the analysis. As the current study assumed the production of cylindrical bales with a 1.2 m diameter, field transport considers the consumed energy to deliver small cylindrical bales to the field side for further hauling with a truck. For evaluating field transport energy consumption, relationship between the total energy input and harvested area was implemented. The total energy input for field transport included machinery and fuel energy as well as 59 MJ DM t^{-1} (Bullard & Metcalfe, 2001) of energy for biomass loading and unloading.

The transport distance calculation considered a semi-trailer with a useful size of 2.5×2.5×14 m. The capacity of the trailer is 88m^3, containing 44 small cylindrical bales as a full-load. The total energy input (diesel fuel, vehicle and maintenance) for truck transport was considered to be 2.3 MJ t^{-1} km^{-1} (Brindley & Mortimer, 2006), the consumption of full-load truck hauling reed canary grass biomass. Additionally, the energy input for loading and unloading small cylindrical bales to and from the truck was included.

Production costs and profitability

A profitability analysis was performed considering the same field machinery operations and general assumptions (including 40% yield losses) as in the energy analysis taking into account the available data of the current economic situation. The current study considered the average NPK fertilizer costs at 18, 50 and 15 EEK kg^{-1} and a seed cost at 100 EEK kg^{-1}. Price analyses for field machinery and operation service costs by the Agricultural Research Centre and output by the Estonian Research Institute of Agriculture were used. In profit evaluation, the authors included 1,108 EEK ha^{-1} of single area payments to the income and performed an analysis with varying buying-up prices of 0.4, 0.8, 1.2, 1.6 and 2 EEK kg^{-1}. In transport distance profitability analysis, the cost of 15 EEK km^{-1} and a loading/unloading cost was considered.

Description of field trial

The current analysis was performed using yield data from 1968-1976 (Rand & Krall, 1978) on reed canary grass field experiment established on an Albeluvisol soil with a sandy loam texture (soil Corg 12 g kg^{-1}, Ntot 1.2 g kg^{-1}) in Estonia (Olustvere, N 58°33′, E 25°33′). Fertilizers with an annual application of 0, 120, 240 and 360 kg N ha^{-1} were used, whereas 35 kg P ha^{-1} and 133 kg K ha^{-1} for N_0, N_{120}, N_{240} and N_{360} was applied additionally. Reed canary grass aboveground biomass was harvested and measured in autumn.

RESULTS AND DISCUSSION

The average reed canary grass DM yields increased continuously from 2.7 to 9.5 t ha^{-1} y^{-1} with an increase in N input (Fig. 1). Applying 80 kg N ha^{-1} results in a doubled average yield compared to biomass from unfertilized areas. Increasing N application to 240 kg ha^{-1} or 360 kg ha^{-1} resulted in a decline in yield increase. Previously reported high reed canary grass yields (7-8 t ha^{-1} on clay soils) (Saijonkari-Pahkala, 2001) could be achieved on soils with low nitrogen content using more than 200 kg ha^{-1} of fertilizers in which case environmental restrictions should also be taken into account.

On the other hand, the variation coefficient (CV, %) of reed canary grass biomass yield decreases rapidly when increasing N fertilization application to 120 kg ha^{-1}. A further increase in N supply resulted in a CV decrease of 0.02% kg^{-1} which verifies the fact that stable reed canary grass yields could be achieved on soils with low humus content by increasing the N supply. In Estonian conditions, reed canary grass variation coefficient could reach up to 44% depending on pedo-climatic conditions and fertilization (Rand, 1981; Eilart & Reidolf, 1987). The Pahkala & Pihala (2000) six-year-old field trial indicated higher biomass yield variability with autumn sowing compared to sowing in spring.

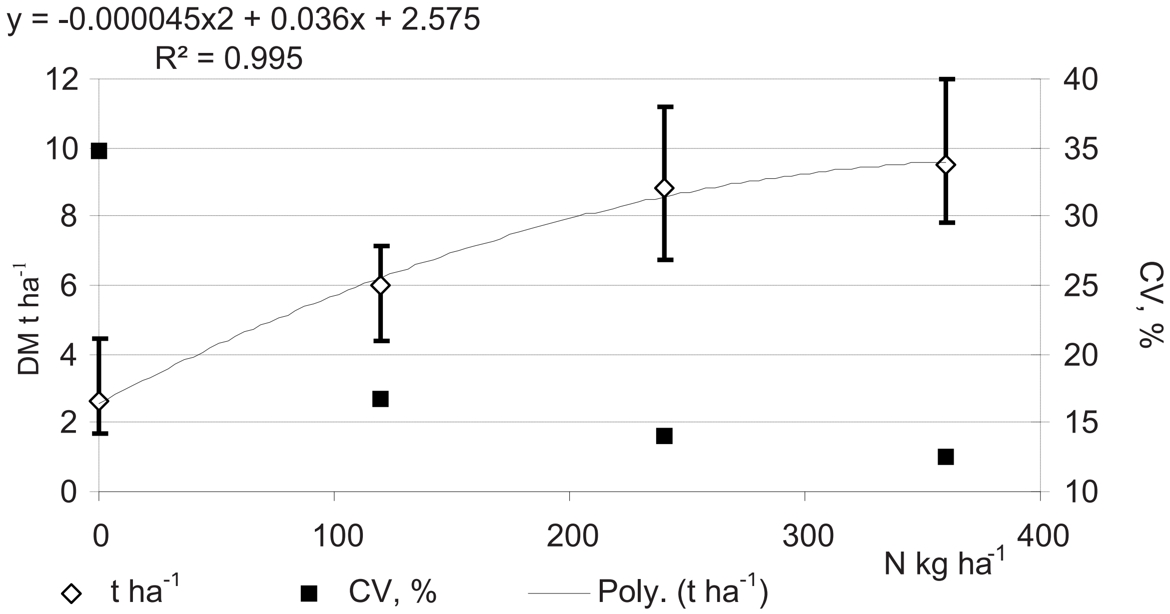

Fig. 1. Dependence of reed canary grass DM yield (t ha^{-1}) and variation coefficient on applied mineral nitrogen rates. Error bars indicate maximum and minimum values.

Energy consumption and production profitability

The average annual energy consumption per tonne of biomass varies with fertilization applications (Fig. 2). A nitrogen input of 140 kg N ha^{-1} results in minimum energy input for production (2.5 GJ t^{-1}). The share of fertilization in energy input increases with an increasing N supply, forming 75% to 89% of total consumption when applying 0-360 kg N ha^{-1}. Energy input for harvesting is the second largest input component in reed canary grass biomass production; as the yield increases, the energy input (GJ t^{-1}) of harvested biomass decreases. Sokhansanj et al. (2009) indicated switchgrass harvesting energy input (GJ t^{-1}) decreasing exponentially with the increasing yield. Biomass transport to the field side and tillage per tonne of production form altogether less than 10% of the total energy input.

The average annual net cost of reed canary grass production decreases from 3.3 to 1.9 EEK kg^{-1} with increasing N application to 238 kg ha^{-1} and increases with increasing N input afterwards. Fertilization costs per tonne of biomass form more than 80% of the total annual costs within all variants in the field experiment. Tillage, biomass transport to the field side and harvesting costs per unit mass altogether decrease with increasing fertilization application.

Production net cost and energy input per tonne of biomass indicate a positive linear relationship, whereas the increase in costs with additional energy consumption varies according to different fertilization norms. An additional energy input of 1 GJ results in a net cost increase of 1,200 EEK in unfertilized areas and 660 EEK with N application of 360 kg ha^{-1}, which indicates that production costs decrease 1.4 EEK kg^{-1} per energy input with increasing N application.

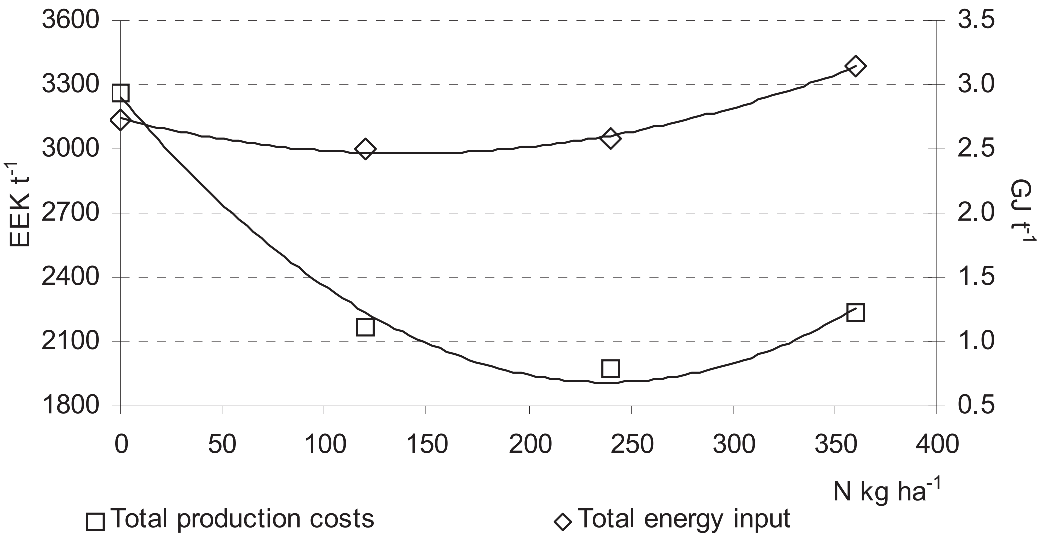

Fig. 2. Dependence of reed canary grass DM production net cost (EEK t^{-1}) and energy input (GJ t^{-1}) on applied mineral nitrogen rates.

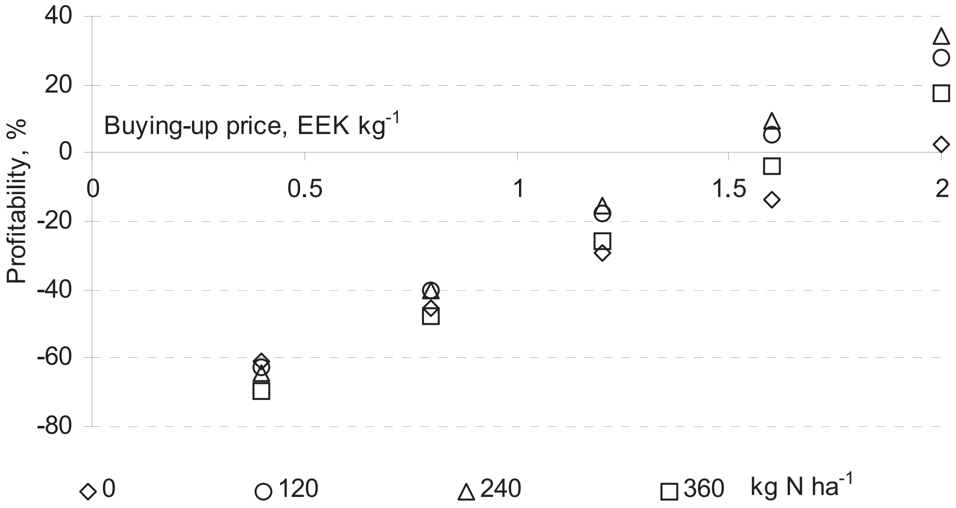

Fig. 3. Dependence of reed canary grass production profitability on applied mineral nitrogen rates and buying-up price (EEK kg^{-1}).

The profitability of reed canary grass production is highly dependent on the buying-up price of biomass and available subsidies. From an economic point of view, cultivation of reed canary grass for bio-energy production could be considered at a break-even price of 1.5 EEK kg^{-1}, although profitability differs within fertilization application norms (Fig. 3). The lowest profitability on Albeluvisols occurs when using high fertilization application rates (e.g. 360 kg N ha^{-1}) and biomass production without N fertilization. In the case of a buying-up price of 2 EEK kg^{-1}, a profit of 34% could be reached, using 210 kg N ha^{-1}. As the current evaluation was based on available data on recent production prices, it must be taken into account that biomass production costs and profitability varies according to different economic situations. Moreover, as the average buying-up price paid to biomass (straw) producers, according to the Estonian Institute of Economic Research, was 0.54 EEK kg^{-1} in January 2010 and the highest price, 1 EEK kg^{-1}, was paid in 2009, negative profitability in biomass production must be considered.

Dependence of energy efficiency and profitability on transportation distance

The average NEY production from fields increases 0.15 GJ kg^{-1} with increasing N applications from 0 to 360 kg ha^{-1}. Energy use efficiency (EUE), as a ratio of energy output to input, indicates the energy produced per unit of energy consumed. Boehmel et al. (2008) declared that EUE is an important criterion for evaluating the suitability of energy crop for bio-energy production. In the current study, average EUE decreased linearly with increasing transportation distance (Fig. 4). The influence of increasing N fertilizer application resulted in an average EUE increase reaching maximum efficiency and decreasing with increased energy input afterwards. An optimum reed canary grass efficiency (5.5 GJ GJ^{-1}), considering, for example, a hauling distance of 10km from the plantation, is achieved using

117 kg N ha^{-1}. The norm of fertilization for reaching optimum efficiency does not change significantly with increasing transportation distance. With an optimum N application, average EUE decreases 7 MJ GJ^{-1} km^{-1} as transportation distance increases. Applying a fertilization norm of 360 kg N ha^{-1} results in the lowest EUE, which indicates that yield decreases to 1 kg of applied fertilizer.

Transportation costs are linearly dependent on distance (Fig. 5). The average hauling costs increase by 1.64 EEK t^{-1} km^{-1} with increasing distance from the plantation. The results of the current study support previous evaluations of a linear relationship between driving distance and transportation costs (Tatsiopoulos & Tolis, 2003; Sokhansanj et al., 2009). Sokhansanj et al. (2009) indicated that in switchgrass production, truck transport is the least expensive option for biomass transportation for distances less than 160 km, but above this mileage the cheapest is rail when comparing four modes of transport. Although the current study considered a truck for biomass transportation with a load of 44 small cylindrical bales, biomass transportation costs could vary when using loads other than this. Lindh et al. (2009) presented an analysis indicating that load size and transport distance effect the formation of transportation costs. The costs of transporting bulk matter exceeded the costs of transporting bales, whereas cylindrical bales with a 1.2 m diameter had the highest costs compared to cylindrical bales with a 1.5 m diameter or large cubical bales.

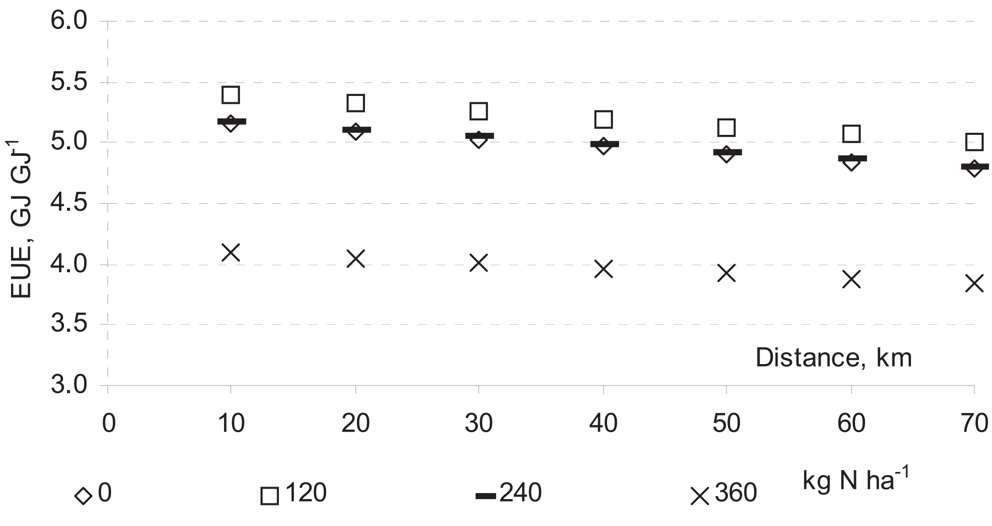

Fig. 4. Dependence of reed canary grass energy use efficiency (EUE) on applied mineral nitrogen rates and transportation distance.

In the current study transportation net costs, applying an optimum N norm of 238 kg ha^{-1}, increased with an increasing hauling distance approximately 2.1 to 2.2 EEK kg^{-1} (Fig. 5). Hauling net costs increased when applying 360 kg N ha^{-1} or 120 kg N ha^{-1} but were highest in plantations without N fertilization. The production of reed canary grass without applying N fertilizer results in an average net cost of 3.4 EEK t^{-1} with a transportation distance of 10 km. Reed canary grass hauling costs could be reduced when using large cubical bales instead of cylindrical bales, or when mixing reed canary grass with wood chips or peat before long-distance transport (Lindh et al., 2009). The advantage of this would be that trucks obtain a near full load-bearing capacity. When transporting reed canary grass, the truck's load is limited by load capacity and not weight. In the current study it was calculated that a trailer with an 88 m^3 capacity could carry 11 t^{-1} reed canary grass loads despite the fact that the truck's potential load capacity exceeds this amount.

Cost effective transportation distance is highly dependent on the buying-up price and applied subsidies. Considering a CAP payment of 1,108 EEK ha^{-1} and buying-up price 1.5 EEK kg^{-1}, negative profitability occurs within all fertilization application norms as the hauling distance increases. A buying-up price of 2.0 EEK kg^{-1} indicates negative profitability on the same terms in reed canary grass production without N fertilization. Pahkala (2007) has referred that an optimal distance for transporting reed canary grass biomass to power plants is less than 60 km. In the current study, if an optimum fertilization norm is applied for reed canary grass production, it will result in a cost effective driving distance of 50 km with buying-up price of 1.6 EEK kg^{-1} and CAP area payments of 1,108 EEK ha^{-1}. Although the profitability of biomass production occurs in aforementioned break-even price, the actual buying-up price in the current economic situation is less than 1.6 EEK kg^{-1} and therefore a negative profitability in reed canary grass production must be considered. The results of the current hauling distance evaluation confirm the statement by Junginger et al. (2001) that maximum transportation distances should not be adopted from literature, though they may provide a general idea on what is viable.

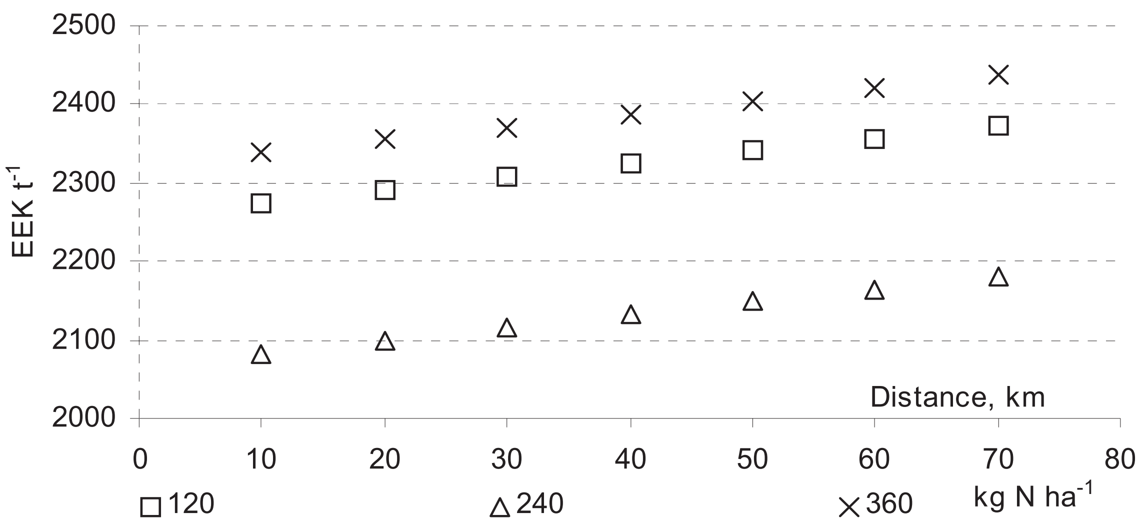

Fig. 5. Dependence of reed canary grass DM net cost (EEK t^{-1}) on applied mineral nitrogen rates and transportation distance.

Although the results of the current study indicate high fertilization application norms to obtain a minimum net cost, environmental restrictions in fertilization should be taken into account. Moreover, it must be considered that production costs and buying-up prices influencing the profitability of biomass production are dependent on the economic situation.

In the current study the output of the energy efficiency analysis indicated reverse results as compared to the output of the economic evaluation of reed canary grass. An optimum EUE could be achieved by reducing the N application norm by more than twice of the norm for reaching a production minimum net cost. Therefore, research must face the challenges of developing a methodology for taking into account several variables in evaluating the biomass production optimum input level. As the current reed canary grass energy efficiency and profitability analysis is performed on soils with low soil fertility, there is a necessity of extending the study to soils with different fertilizer requirements. In spite of the fact that the results presented are based on one field experiment, the methodology of the current original study could be used for evaluating the optimization of bio-energy production in general.

CONCLUSIONS

As the results of the current study indicate an inconsistency in the production of reed canary grass bio-energy, regarding the economical and environmental conditions, biomass multi-criteria evaluations should be emphasized. Although reed canary grass biomass production indicates positive energy efficiency within the applied mineral fertilizer norms, the output of the economic analysis confirms the importance of knowledge-based fertilization. The lowest profitability occurs when using excessive fertilization or when producing biomass without applying N fertilizers. Increasing the transportation distance results in a decrease in both the EUE and production profitability, whereas cost effective transportation distance is highly dependent on the buying-up price and applied subsidies. The current study verifies the importance of analyzing reed canary grass profitability and energy efficiency in local pedo-climatic conditions, whereas the results of the profitability analysis should be considered dependent on the economic situation. Although the results of this study describe production efficiency on a soil with low humus content, the developed methodology could be used for the evaluation of biomass production in general.

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Studies of Operating Parameters in Milking Robots With Selectively Guided Cow Traffic

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Abstract. Milking robots have been launched on Latvian dairy farms only recently. As the technology differs essentially from that of traditional milking, with the introduction of new technology a range of questions has arisen that have not been topical before. For instance, there has been uncertainty about determining the optimal size of the group of milk cows for robots as well as about planning the robot location and the waiting box.

On installing robots in reconstructed barns, it came out that it was not possible to stick to the designs offered by the companies, and after milking the cows were not sent to the barns but back to the waiting box. As a result, the milked cows had a chance to visit the robots repeatedly. Therefore, a question arose – how much does the repeated visiting of robots influence the effective load.

Moreover, there has been uncertainty about the correct location for the robot in relation to the waiting box using several robots. It was observed that usually in such a case one robot is visited more than the other.

The present research tries to answer these recurring questions. The research results showed that the optimal size of the group of cows served by one robot depends on the average milking time and the time necessary for washing the milk line. If the cows return to the waiting box after milking, the effective load of the robot decreases. The location of the robot in the waiting box in relation to the entrance gate essentially influences the number of visiting one or the other robot per day.

Key words: Milking robots, automatic milking systems, size of the group of cows, waiting box design

INTRODUCTION

Cow milking with automated milking equipment or milking robots has been recently introduced on Latvian dairy farms. Milking robots are completely automated devices which the cows can enter at free choice and can get milked at any time of the day without participation of people. Considering that the new technology cardinally differs from cow milking with traditional equipment, during the introduction of robots many unclear questions are faced that are related to changes in barn design and application of new equipment.

In Latvia, milking robots VMS of the company 'DeLaval' with selectively guided cow traffic feed first system are used on all farms. On the application of this system, cows from the lying area can get into the feeding area only through a one-way gate. In order to get back to the lying area, the cows from the feeding area must go through the pre-selection gate where they are directed either to the waiting box if the programmed milking time is due or back to the lying area. After milking, the milked cows are directed back to the feeding area from where they go once more through the pre-selection gate to get back to the lying area (Fig. 1).

Considering the fact that in Latvia milking robots have been installed also in barns which have been built earlier and in which other milking methods have been used, it is not always possible to implement the above described cow traffic system precisely. On some farms the robots are located in this manner that after milking, cows are not directed to the feeding area as envisaged by the recommendations of the robot production companies, but back to the waiting box. This way the cows have a chance to visit the robot repeatedly at short intervals without the set inter-milking interval. Therefore, a question arises – what influence does it have on the technological process as a whole.

There is also uncertainty about the design of the waiting box. It is important to know whether the configuration of the waiting box as well as the location of the robots and the entrance gate in the area influence cow traffic to milking.

Our former research shows that also the size of the cow group milked by robots has great importance. If the selected group is too small, robot idle time occurs that, considering the high price of the equipment is not permissible. If, on the other hand, the group is too large, the robots fail to milk all the planned cows. Therefore, it is important to state the factors determining the optimal size of the group of cows.

In order to find answers to the given questions, publications by researchers from countries with a long experience in milking robot use were studied, for instance, Wendl et al. (2000), Benninger et al. (2000), Purucker et al. (2001), and Artmann (2005); however, satisfactory answers were not found.

Therefore, the following research tasks were set:

- To clarify if the use of selectively guided cow traffic feed first system returning of cows right after milking to the waiting box does not decrease the efficiency of robot application,
- To clarify if the configuration of the waiting box as well as the location of the robots and the entrance gate influence cow traffic to milking,
- To clarify what factors determine the size of the cow group milked by robots.

MATERIALS AND METHODS

The research was performed on three farms (A, B and C). On every farm the cows were milked by two milking robots VMS by the company 'DeLaval'. The farms had different design of waiting box and cow traffic after milking.

On farm A (Fig. 1) the cows separated in the pre-selection gate get into the waiting box and after that they enter any of the robots at free choice. After leaving the robots they get into the feeding area at once.

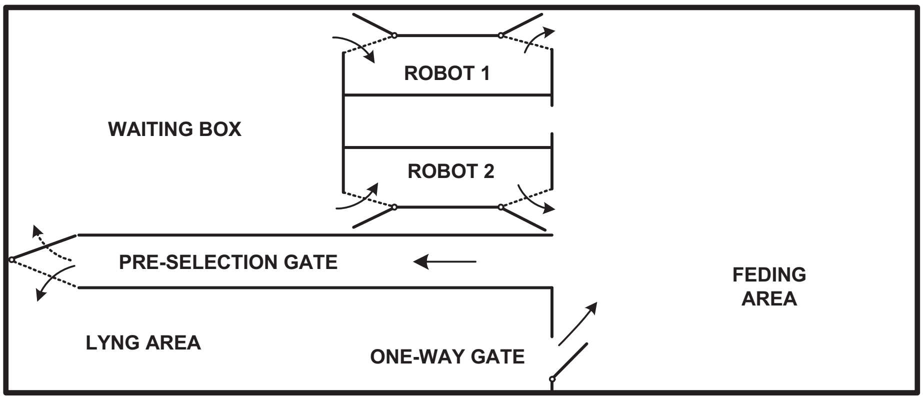

Fig. 1. Design of farm A.

On farm B (Fig. 2) the cows from the robot No. 2 get into the feeding area, from the robot No. 1 - back to the waiting box. These cows get into the feeding area through the post-selection gate of the waiting box that opens only for the milked cows.

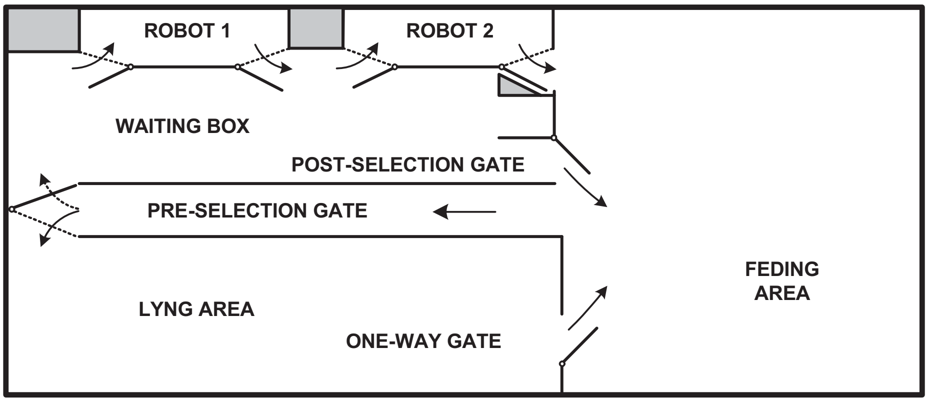

Fig. 2. Design of farm B.

On farm C (Fig. 3) all cows get back to the waiting box after milking. The milked cows from the waiting box get into the feeding area through the post-selection gate of the waiting box.

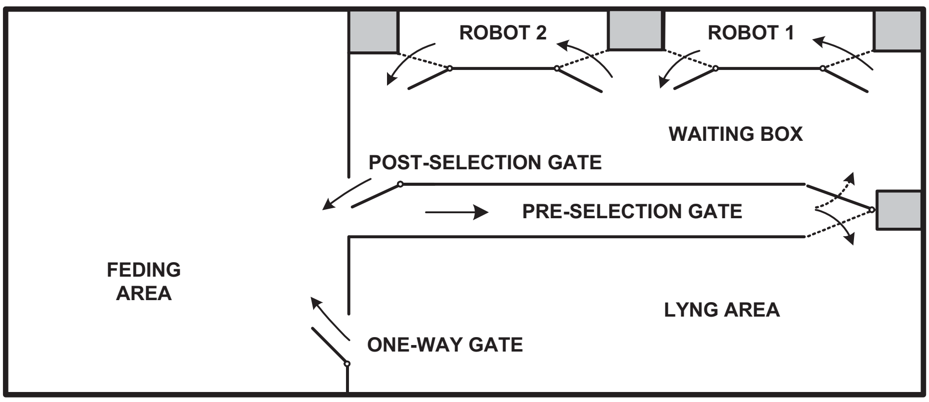

Fig. 3. Design of farm C.

As it can be seen in Figs. 1-3, waiting boxes on different farms differ according to their configuration, as well as according to the location of the milking robots, and pre and post-selection gates in the waiting box are different.

Table 1 shows the indicators characterizing the groups of cows milked by robots.

Table 1. Description of cow groups

Indicator	A	B	C
Number of cows in the group	108	97	94
Average milk yield per day, kg	19.47	24.27	20.60
Average number of milking per day	2.8	2.5	2.5
Average milking length, min	7.48	8.,67	8.87

The experiment lasted for 15 days. The data necessary for the research were obtained from the robot management system and after that processed.

RESULTS AND DISCUSSION

On farm B, after having been milked by robot No. 1 (Fig. 2), but on farm C – by both robots, the cows get back into the waiting box. There they have an alternative: either to go to the feeding area at once after the post-selection gate, or stay in the waiting box, or repeatedly enter the robot. If staying in the waiting box does not essentially influence the total technological milking process, repeated entrance to the robots without milking can reduce their efficient throughput capacity.

In Fig. 4 we can see that on farm B, where two robots are milking a group of cows consisting of 97 animals, an average 20 cows per day have entered the robots without milking, but on farm C (94 cows in the group) – 24 cows. The research results show that on farm B in such a way one robot is uselessly engaged for 20 min. per day, but on farm C – for 30 min. As on both farms the idle time of the robots is approximately 10% (Fig. 6), it is questionable whether in this case repeated entrance to the robots essentially reduces their operation efficiency. An obstructive factor may occur when the size of the cow group is close to the optimal.

The research results show that on farm C where the milked cows return to the waiting box from both robots there is also a larger number of repeated robot visits.

Figure 5 shows that on none of the farms both robots are equally loaded. More often the cows are visiting the robot which is in their sight right after they have entered the waiting box and which is located in the direction of their traffic. For instance, on farm A (Fig. 1) and B (Fig. 2), it is robot No. 2, but on farm C (Fig. 3) – robot No. 1. Thus it is possible to conclude that the location of the waiting box entrance and exit gates as well as the location of the robots has to be planned very carefully. If several robots are used, their location should be considered as a uniform system.

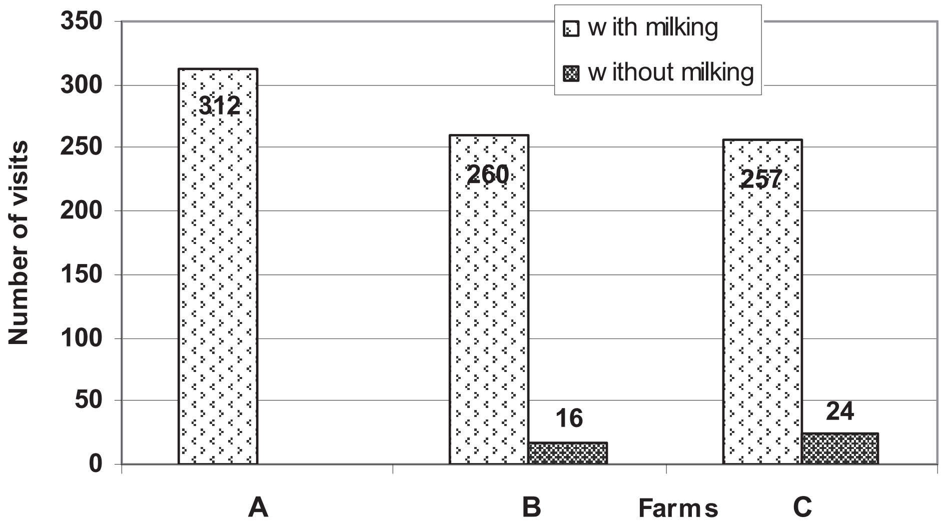

Fig. 4. Total average number of visits to both robots per day.

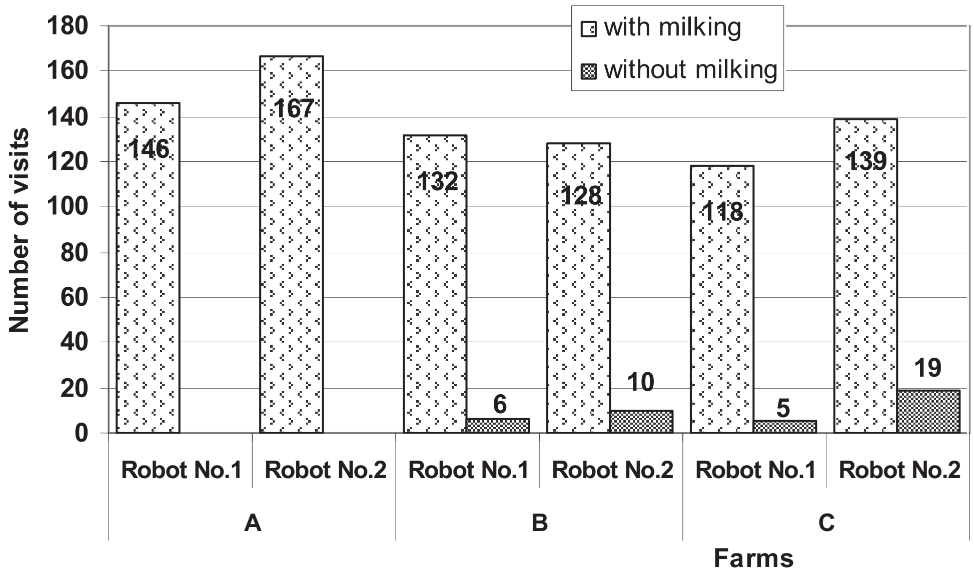

Fig. 5. Average robot visits per day.

Figure 6 shows the average robotic load per day. It is comprised of cow milking, robot visits without milking (on farms B and C), technological time and idle time. Technological time is necessary for draining the milk reservoir and washing the milk line, but idle time occurs when the robot is ready for milking but the cow has not entered it.

In Figure 6 we can see that on all farms there is a considerable robotic idle time regardless of the fact that the cows are milked in accordance with the set milking times per day (Table 1 – the average number of milking per day 2.8; 2.5; and 2.5 times). It means that the number of cows in groups can be increased.

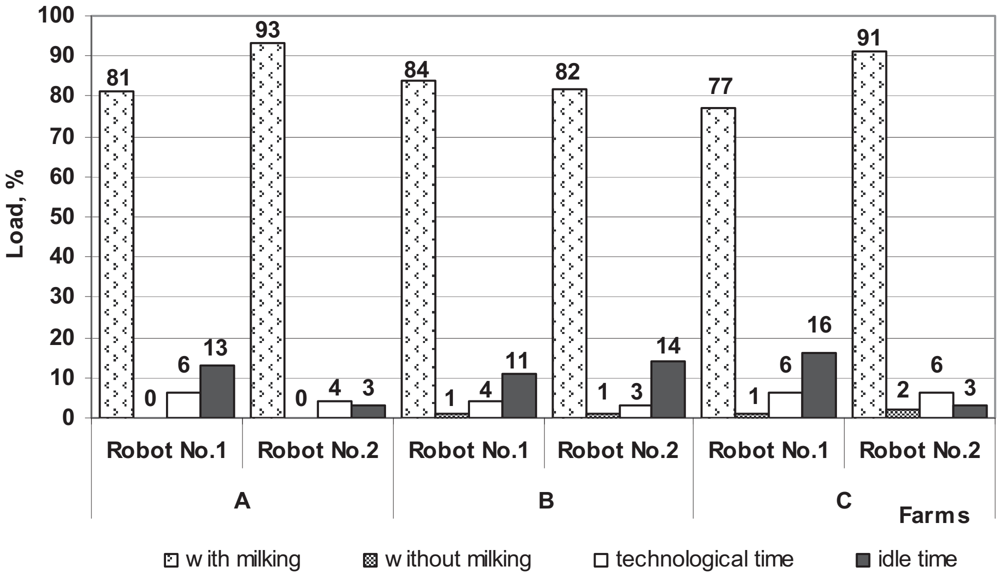

Fig. 6. Average robotic load per day

The optimal number of cows that can be served by one robot is not an unambiguous value. It is influenced by factors that are different on different farms. The most influencing factors are the length of milking, the time necessary for automated udder preparation and attachment to the milking device, and the technological time. Besides, the system determining cow traffic to the milking robots has a great influence, too. In practice three cow traffic systems are used: free cow traffic, guided cow traffic and selectively guided cow traffic. Today there is no unequivocal answer which of them is best. Every one has its disadvantages and advantages.

Involvement of people in the cow traffic is a very important factor. Not always and not all cows enter the robots at free will, the laziest have to be driven. Here arises an essential question: how often should it be done? On our farms where the experiments were performed the cow traffic technology was different. On farm A the person on duty in the barn did it regularly, directing the cows that had exceeded the set inter-milking interval, to the waiting box (the interval was only from 2:00 to 6:00). In turn, on farm B the driving of cows was done irregularly as the auxiliary worker for 5 hours in the morning and 5 hours in the evening was busy working in another barn. At last, on farm C the cows were driven in the morning, i.e., at the beginning of the working day and in the evening before going home. During the day the driving is irregular when the worker in the barn is free.

The influence of such versions of work organization on visiting robots can be seen in Figure 4. At approximately equal milking length on farm A the number of robot visits per day is the biggest. Besides, also the group of the cows served is larger and also the labour consumption of the workers increases.

From these observations it is possible to conclude that the optimal size of the group of cows milked with robots is individual and it can be determined only experimentally considering the definite situation. Besides, in our case the number of cows in groups on all farms can be increased at least by 10 cows.

CONCLUSIONS

1. One of the main factors of robot application efficiency is the size of the group of cows to be milked. The robots should serve a possibly larger group of cows in order to be loaded without special idle time as otherwise the finances used for their purchasing and operation will not be cost-effective.
2. The optimal size of a group of cows is individual for every definite farm. It is influenced by the average milking length for one cow, including the time necessary for automated preparation of the udder and its attachment to the milking cluster. Also the system of cow traffic and work organization on the farm considering the involvement of people in the milking process is of great importance.
3. If several robots are used for milking a group of cows, the load of every separate robot is influenced by the interrelated location of the waiting box gate and the robots. The cows visit more often the robots which are easily accessible and located in the direction of their traffic.
4. If the design of the milking area envisages the return of the milked cows into the waiting box, repeated robot visits are decreasing their efficient load.

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Wind Power in Heat Energy Systems

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Abstract. The article discusses opportunities for the use of wind power plants in order to supply heat to coastal settlements. The possibilities of meeting the needs of heat consumption in the city of Paldiski in Estonia using general data from wind power output serves as an example in the present paper. Monthly electricity and heat consumption graphs and schedules of the Republic of Estonia together with production charts of wind power plants were used as initial data for the research. The investigation of wind energy production charts shows that, due to stochastic peculiarities of the wind, it is especially complicated to match the latter and the electricity consumption charts. There have even been cases, where the dispatcher has been forced to limit wind energy production maxima so that it would not interfere with the work of generators at large power plants. However, satisfactory correlation was revealed between the monthly graphs of both electricity and heat energy overall annual consumption, and wind power production charts. Nevertheless, there are still high deviations, and therefore, in order to use wind energy for heating purposes, powerful storage devices or additional feeding units are necessary to level the fluctuations of electric power produced by wind plants.

The problems related to the production usage of wind power plants in heat and power engineering are to a certain extent less complicated due to the fact that heating systems can be supplemented with additional heat energy storages. Considering the above mentioned issues, the authors suggest a more extensive usage of wind power plants for heating towns and settlements, particularly in cases when production peaks interfere with the work of power systems.

Due to new capacity installations, the overall production of the wind power plants is constantly increasing. Thus, the authors recommend that the maximum power usage coefficient of an operating wind power plant, not their overall production data should be used for analyzing the efficiency of the present power plants and for designing new ones. This will be more correlated with power and heat consumer load curves.

Key words: Energy, heat energy system, boiler, wind power, production and consumption charts

INTRODUCTION

Energy system is a system meant for the production, transmission and distribution of power and heat energy to consumers, which consists of energy producers (power plants and CHP-s, district heating boiler houses), electrical- and heating networks, and consumers.This kind of system is responsible for a smooth supply of high quality electrical and heat energy to consumers.

Since a vast majority of wind power plants produces electrical energy, one of the main wind power engineering problems is matching the wind parks production schedules and energy production and consumption charts. Due to wind stochastic characteristics, the abovementioned charts do not particularly match and, thus, the actual fuel economy and air pollution reduction percentages are considerably smaller compared to those expected (Liik et al., 2005). This problem has been thoroughly discussed by Ivo Palu in his research (Palu et al., 2008; Palu et al., 2009; Palu, 2009).

Wind energy share in the world's power engineering is constantly increasing. The development of wind power engineering in the European Union has been much more rapid than in the rest of the world which is mainly a tribute of praise to Germany and Spain.

In recent years, wind power engineering has developed considerably in the United States of America; in addition, focus on the problems in the field has grown both in China and India. By the end of 2008, 28.8% of all wind parks of 120,798 megawatts installed worldwide is located in the United States, 19.8% - in Germany, 13.9% - in Spain, 10.1% - in China, and 8% - in India. During 2009, 30.9% of additional capacity of 27,061 megawatts were in the USA, 23.3% - in China, 6.7% - in India, 6.2% - in Germany and 27% - in the rest of the world (US and..., 2009).

Estonia's opportunities of wind energy usage are relatively limited, primarily due to the modest size of its territory and population; thus, wind power engineering development data are not in absolute terms comparable to those of the countries considerably larger than Estonia. Nevertheless, significant progress has been made in the field of wind power engineering, which is mainly due to local enthusiasts. Estonian data related to the capacity of wind power plants (at the end of 2008) and their output for the years 2006...2008 is given in Table 1.

Table 1. Wind power plants in Estonia and their power output in 2006-2008

Year	Installed capacity of power plants, MW	Electricity production, $GW \cdot h^{-1}$
2006	31	76
2007	58	91
2008	77	133

The table shows that throughout the observed period, the capacity of wind power plants in the Republic of Estonia has increased by approximately 2.5 and wind energy output by 1.75 times. Furthermore, in 2008, capacity installation increase constituted 32.8% and wind power output growth over 46%.

It is interesting to note that the total capacity of wind parks in Estonia at the end of 2008 accounted for a little over 0.06% of the world's total wind power capacity.

Estonia's power and wind power engineering data in 2008

Figs 1 and 2 represent Estonia's overall power and heat production (consumption) charts in 2008 (Power and..., 2009). Fig. 3 shows data from the same period on the output of wind power plants in Estonia. Figs. 1 and 2 show that the monthly need for both electrical and heat energy to a certain extent correlates to wind power output.

Subsequently, we are to check the compatibility of both electricity and heat consumption charts with the wind power output in Estonia in 2008. Therefore, we analyse the above mentioned charts in proportional units. Fig. 4 shows charts about electricity and heat consumption as well as wind power output.

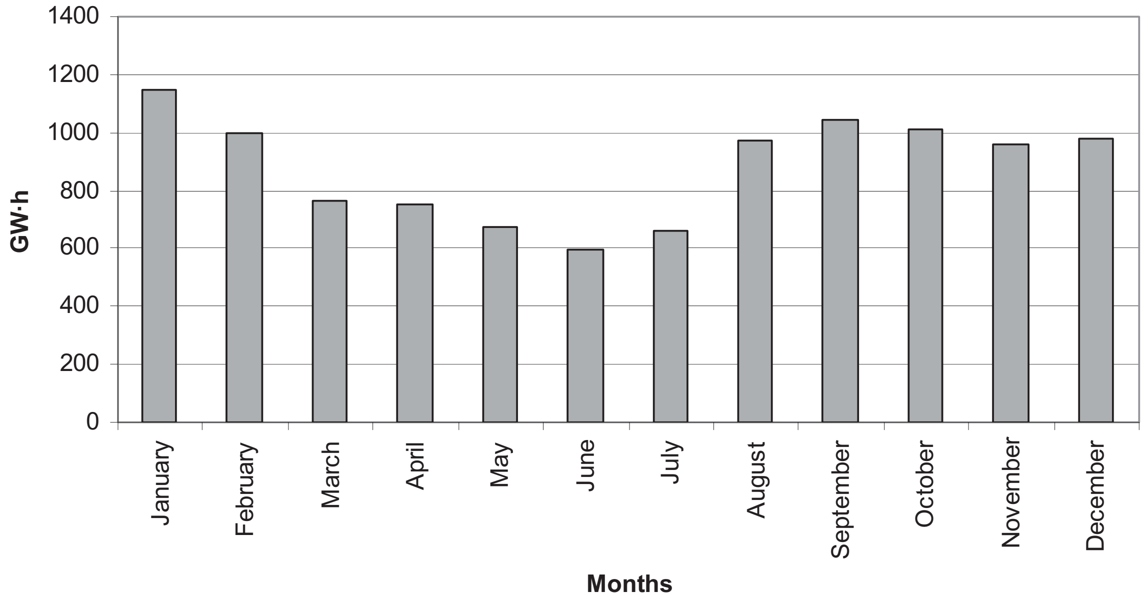

Fig. 1. Electricity production in Estonia in 2008.

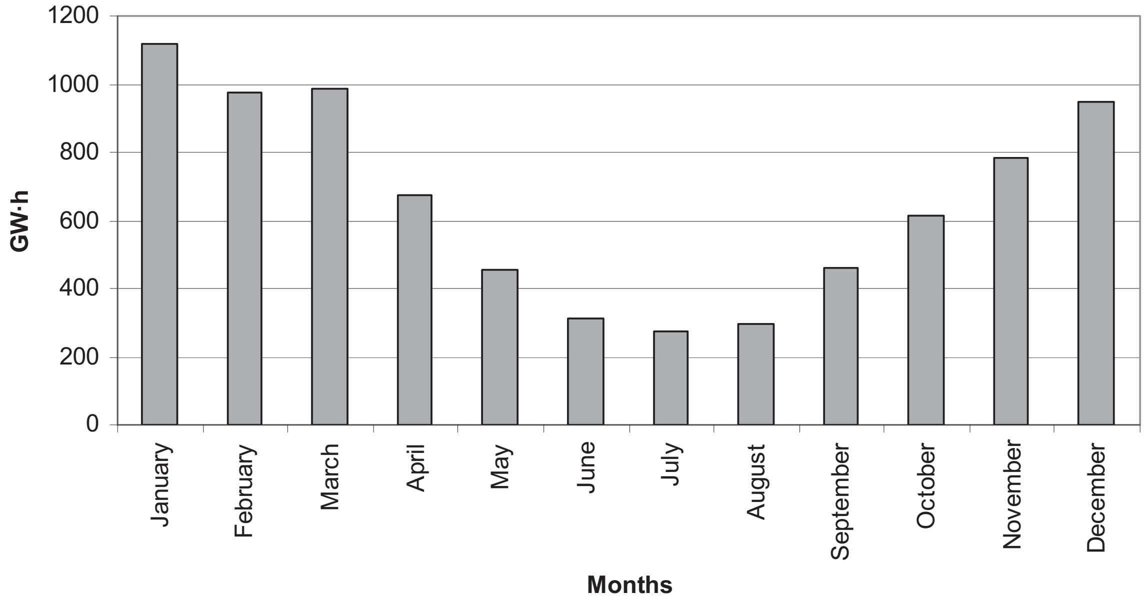

Fig. 2. Heat production in Estonia in 2008.

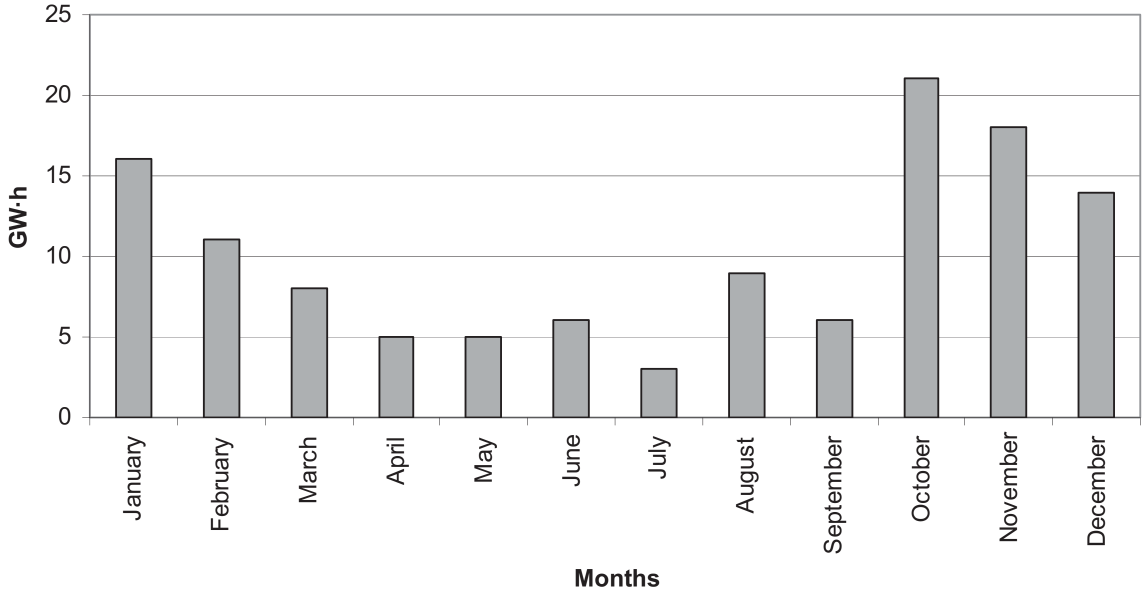

Fig. 3. Wind power production in Estonia in 2008.

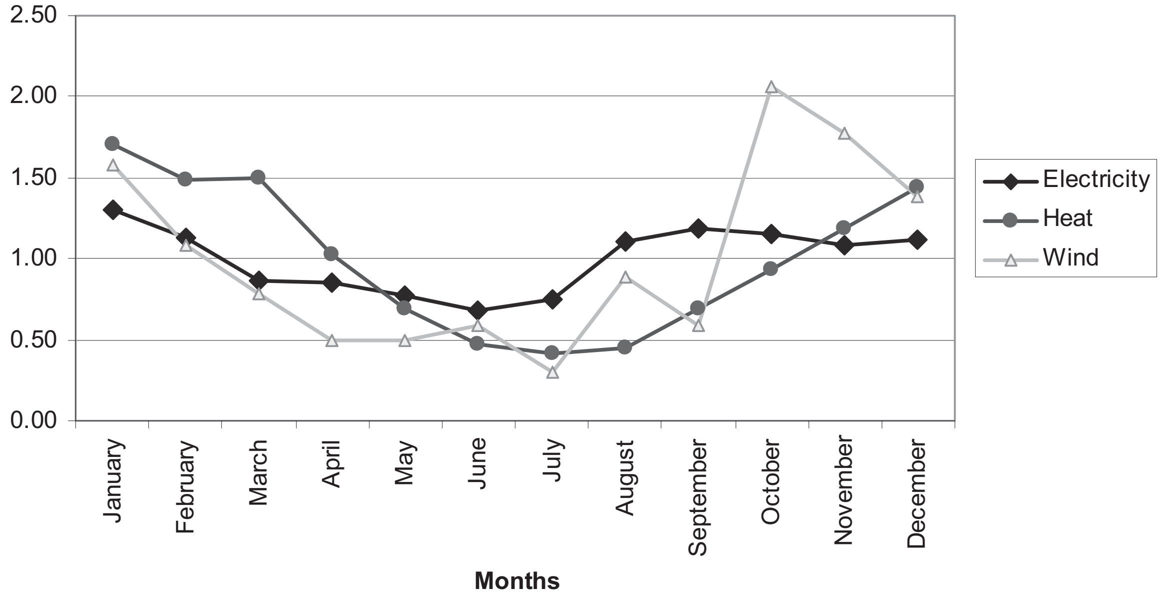

Fig. 4. Estonia's electricity and heat consumption and the wind (electrical) power output in proportional units in 2008.

On the basis of the above mentioned charts, correlation coefficients of wind power output and electricity and heat consumption were marked in Fig. 4. Correlation coefficient values between the wind and electrical power was 0.699, and the wind and heat power was 0.532.

It should be noted that the wind power output characterizes the actual situation, but its potential is of greater interest and is better characterized by the maximum power usage coefficient. For example, the installed capacity of wind power plants in Estonia increased three times in 2008; in February – 0.8 MW (Virtsu additional windmill), in April – 6.9 MW (2-nd Virtsu wind park), and in October – 12 MW (Esivere Wind Farm Stage 1).

In Fig. 5, the overall monthly wind power output in Estonia and the maximum capacity usage coefficient of wind power plants in 2008 are compared.

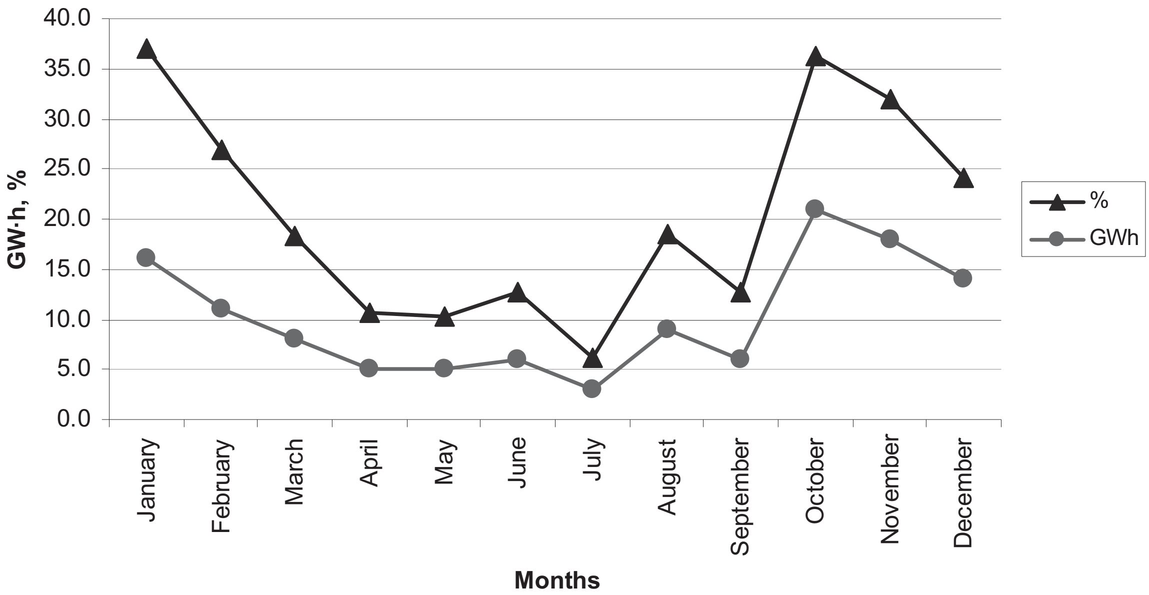

Fig. 5. The output of Estonian wind power plants and their maximal power usage coefficient in 2008.

Correlations between maximum wind power usage coefficient with monthly electrical power consumption and monthly heat power consumption are 0.765 and 0.657, respectively; these are significantly better than correlations with total wind power output data.

Opportunities for wind power usage for heating a small town

Considering the substantial wind resources of Estonian coastal areas, the authors explored the idea of the prospects of wind power usage for heating coastal towns. As the result of the cooperativeness of the employees of Paldiski Heat AS, the authors managed to acquire information on heat production and consumption in the town of Paldiski in 2007 and 2008. Thus, the abovementioned town with a population of approximately 4,350 inhabitants was chosen for analysis.

Fig. 6 shows the monthly heat production in the town of Paldiski in 2008.

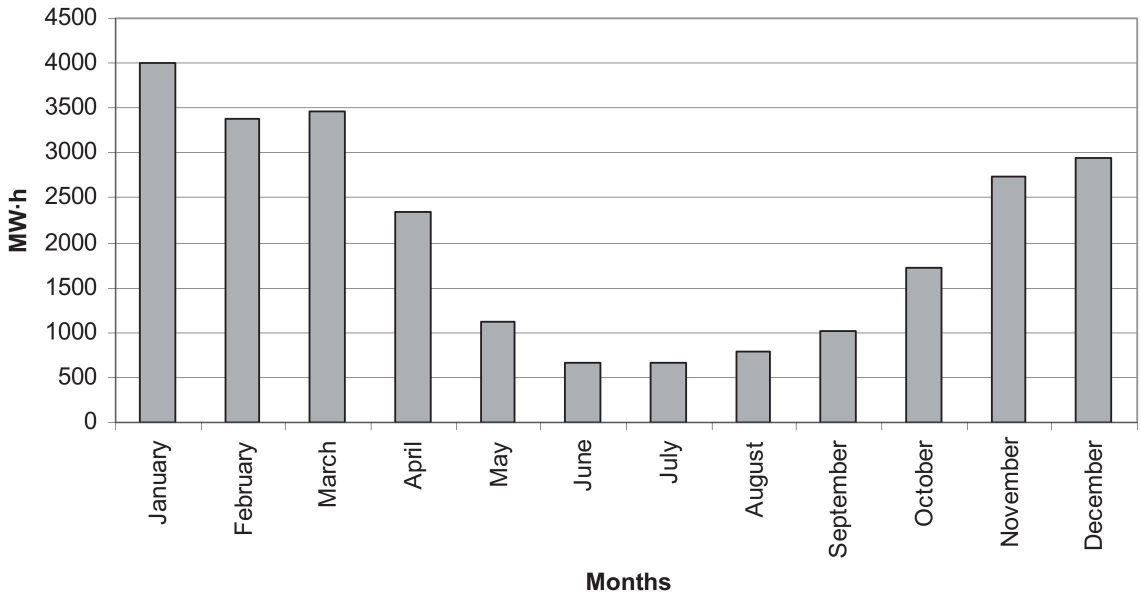

Fig. 6. Heat production in Paldiski in 2008.

Heat power output for the town of Paldiski in 2008 was 24,811 MW h^{-1} (compared to 2007 data: 25,601 MW h^{-1}). The above data show that no significant changes occurred in the town's heat system throughout the year.

Supposing that in order to meet the town's heat consumption needs we intend to build a wind park, the annual power output of which corresponds to the demand (i.e. ~ 25,000 MW h^{-1}). Assuming that the maximum power usage coefficient of a wind park generator corresponds to Estonia's average annual data of a currently operating wind farm (20.4% in 2008), we get the necessary wind park power formula:

$$P = W/(k_{mv} \cdot T), \quad (1)$$

where P is the rated (maximum) power of the wind generator, MW, W - energy produced by the device during the observed time interval, MW h^{-1}, T - observed time period in hours, k_{mv} - maximum power usage coefficient.

In this case, the predetermined amount of energy is 25,000 MW h^{-1} and the period is 1 year (given – 8,760 hours, although in 2008 there were 8,784 hours). Operating with this year's data, we conclude that the capacity of approximately 14 MW is needed to produce the necessary amount of energy.

Since the maximum power usage coefficient of a wind mill differs from month to month, we get the formula (2) to calculate the possible monthly power output in W_k.

$$W_k = P \cdot k_{mv} \cdot T_k \, , \quad (2)$$

where P is power of a wind generator (in this case, 14 MW) and T_k - the calculated number of hours per month.

The results of the calculation are shown in Table 2.

Table 2. Potential monthly power output

Month	Number of hours	K_{mv}	W_{exp}, MW·h^{-1}	W_{Ps}, MW·h^{-1}	Wind parks possible overproduction (+) and underproduction (-), MW·h^{-1}
January	744	37.1	3,864	3,995	-131
February	672	26.9	2,531	3,388	-857
March	744	18.3	1,906	3,459	-1,553
April	720	10.6	1,068	2,333	-1,265
May	744	10.2	1,062	1,113	-51
June	720	12.7	1,280	668	612
July	744	6.1	635	670	-35
August	744	18.4	1,917	788	1,129
September	720	12.7	1,280	1,008	272
October	744	36.2	3,771	1,723	2,048
November	720	32.1	3,236	2,730	506
December	744	24.1	2,510	2,936	-426
Total			25,061	24,811	

This table shows that the expected wind farm power output of 14 MW exceeds W_{exp} heat consumption of the town of Paldiski W_{Ps} during five months of the year, whereas, during the remaining seven months, the indicator is lower. The deficit occurs predominantly during the first months of the year as those are the months of a considerably lower temperature and predominantly lower probability of the occurrence of strong winds. This situation is made more complicated by the fact that underproduction occurs in succession for several months. This requires a unit of a significantly higher power capacity. Similar wind power storage problems are dealt with in the following articles (Põder et al., 2009). In case of minor consumers, chemical storages (batteries) may be used, whereas, in case of major consumers, mainly water based heat capacity storages are necessary.

CONCLUSIONS

All the facts considered, it appears that although the use of wind power systems compared to heat systems is to a certain extent less complicated, in case of year-round usage, several essential problems may occur related mainly to the difference between wind power output charts and consumer needs. As Estonia has no conditions for establishing energy-efficient power storage devices of acceptable energy capacity (hydro-pumped storage, compressed air storages), fuel and gas boiler houses are irreplaceable in local heating systems. In the near future, wind power usage may become economically rational in these heating systems, mainly due to increase in fuel and, particularly, gas price in the international market. The possibilities of wind power usage in gardening enterprises require more detailed investigation. In winter, power is necessary there for heating and lighting greenhouses, and in summer for irrigation (inside and outside the greenhouse), production storage, etc.

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Design Project of Row-independent Harvesting Machine for Energetic Plants

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Abstract. This is a description of an all-purpose, row-independent machine prototype for harvesting energetic plants in the form of chips or chaff. Patent claim P 385 536 was submitted to the patent office, regarding two versions of cutting adapters: the feeding unit equipped with elastic fingers, or equipped with worm rolls. The machine has modular structure allowing its easy modification, while a hydraulic drive with electro-hydraulic control enables to select the optimal operation parameters of working elements and units under various field conditions. The machine can cut plants with shoot diameter up to 70 mm at the height up to 100 mm, and break them up into particles of 20–60 mm.

Key words: Energetic plants, harvesting, row-independent machine

INTRODUCTION

Energetic plants can be harvested as whole shoots or in a broken up form. These different harvesting methods especially refer to willow (Salix viminalis). The one-year plants can be cut in bulk and left in the field or can be loaded into a hopper and unloaded periodically into piles. The cut plants can be tied into bundles or formed into bales wrapped in a net after breaking them up by the flail-type chopping unit of a rolling baler (Lavoie et al., 2007); they can also be chopped in a forage harvester equipped with an adapter for harvesting maize for silage. Harvesting of two- or three-year old or older plants calls for the application of a special cutting adapter, since shoot diameter at base can reach 70–100 mm.

Since there was no local product in the Polish market at the moment of starting the project, the work was undertaken in order to design our own all-purpose machine for harvesting energetic plants in a broken up form; this is the main purpose of this elaboration.

MATERIAL AND METHODS

Specially designed machines for harvesting energetic plants as well as modified machines originally designed for harvesting high-stem plants were analyzed in great detail. Conclusions of the analysis and assumptions taken by the authors (Nowakowski et al., 2008) were the grounds for designing our own machine (patent claim P 385 536) (Lisowski et al., 2008). The task was executed with the aid of computer by application of software SolidEdge. It allowed kinematic spatial analysis of the working elements and units at design stage.

RESULTS AND DISCUSSION

The harvester was designed as a semi-mounted machine (Fig. 1). On the frame part mounted to the tractor the following units were situated: hydraulic oil tank, bevel gear which transfers the tractor PTO drive to the knife drum, and hydraulic pump feeding the hydraulic motors and cylinders via the electro-hydraulic distributor. On the other part of the frame supported by wheels there is the cutting unit, consisting of a knife drum with a counter knife. The cut stems are directed to the hopper of transport mean through the discharge spout. Direction of discharge can be adjusted by rotation of discharge spout with the use of a hydraulic motor, and that of the discharge range by inclination of the spout end.

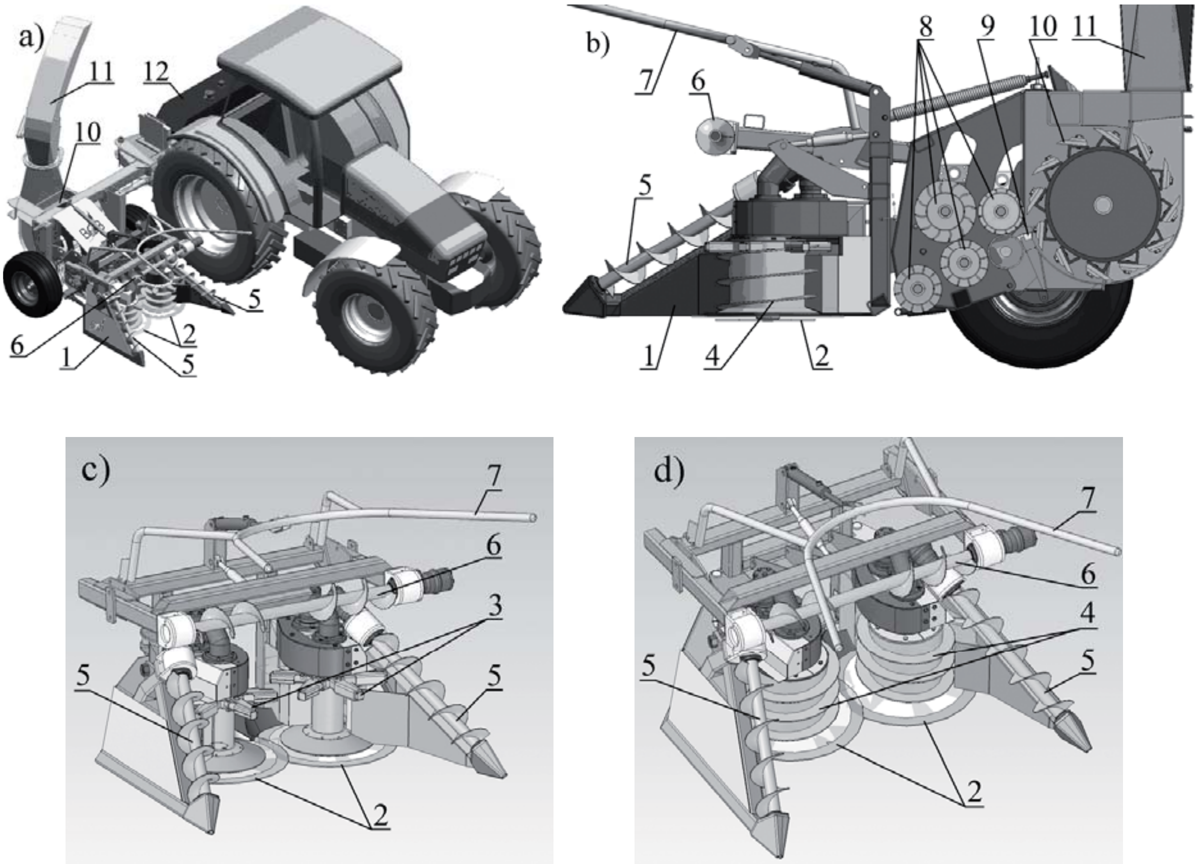

Fig. 1 Cutting machine for harvesting energetic plants: a) working position, b) axial cross section, c) adapter with elastic fingers, d) adapter with worm rolls: 1 – adapter; 2 – circular saws; 3 – elastic finger; 4 – worm rolls, 5 – active dividers; 6 – sloping reel; 7 – sloping element; 8 – toothed pulling-compacting rolls; 9 – counter knife; 10 – drum-type cutting (chopping) unit with knife drum; 11 – discharge spout; 12 – hydraulic oil tank.

Source: Authors' elaboration

The fed material is compacted and held during cutting by the toothed pulling-compacting rolls. The material compaction is obtained due to a pressure of self-aligning top pair of toothed rolls and spiral springs on the lower rolls: Two toothed rolls and one plain roll. The pressing force can be adjusted by changing the initial tension of springs.

The exchangeable cutting adapters are jointed to the body of the roll set. The adapters are unloaded with spiral springs of adjustable initial tension. The cutting height of plants can be adjusted steplessly with the two symmetrical ram-type cylinders.

The key constructional solution of the machine is cutting adapter with driver and lifting-feeding units, designed in two versions. In the first version, the feeding unit is equipped with rotational finger drivers (Fig. 1c), in the second version with vertical worm rolls (Fig. 1d). In both cases, the hydraulic motors are used to drive the circular saws and also the rolls with finger drivers or worms (Fig. 2). The circular saw shafts are driven by the high-speed hydraulic motors of maximal rotational speed about 3800 rev·m^{-1}, enabling to obtain the cutting peripheral speed 100 m s^{-1} with disk diameter 0.5 m. Such high speed is essential to achieve so-called clean cutting of willow stems (Lechasseur & Savoie, 2005). According to these authors, the diameters of circular saws used in machines of that type amount to 450–600 mm.

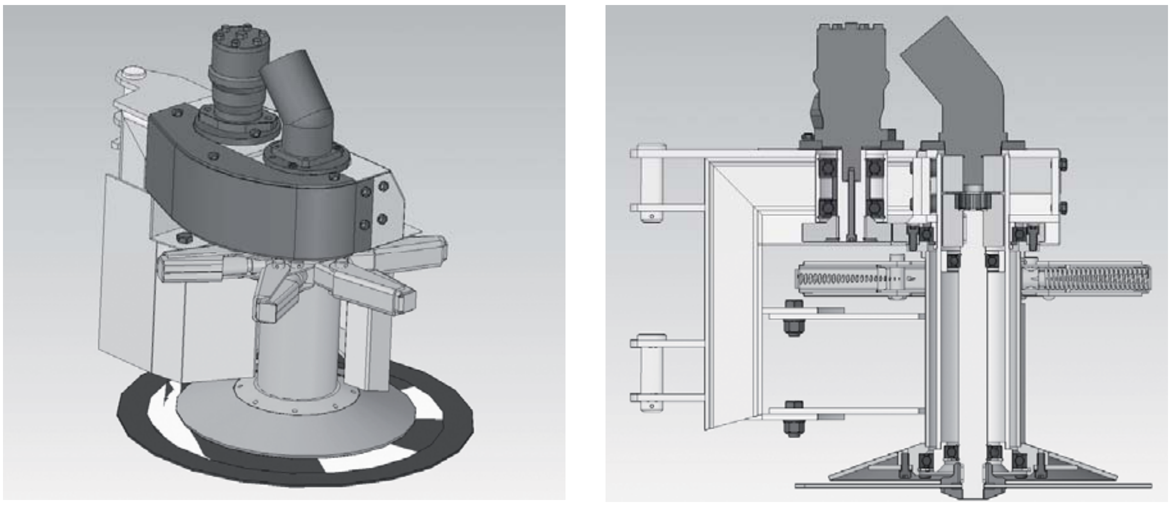

Fig. 2 A cutting-feeding unit with elastic driving fingers.

Source: Authors' elaboration

At cutting speed 100 m s^{-1} the risk of tearing up the fibrous tissue and bark of snag left in the ground is minimal. As a result, the hazard of decay process deteriorating the rate of subsequent growth is decreased. The rolls with driver elements are driven by low-speed hydraulic motor via gear transmission reducing rotational speed to 38 rev m^{-1}. The finger tips reach peripheral speed 1 m s^{-1} at external diameter of drivers equal to 0.5 m. The ratio between peripheral speed of driving material and cutting plants is very high and amounts to 1:100. Such peripheral speed parameters can be obtained at nominal rotational speed of hydraulic motors. Since the ground speed of tractor-machine outfit can be changed depending on field conditions, the application of hydraulic motor controlled with electro-hydraulic distributor would enable to select the optimal rotational speed, making the peripheral speed higher than tractor ground speed. Excess of this speed in the range of 10–30%, determined by kinematic coefficient, should ensure proper driving of the cut plant shoots.

Application of hydraulically controlled inclining element will allow the cutting of plants by circular saws when plants are bent. The energy accumulated in inclined stem will be used after its cutting to direct the base part of shoot to the subsequent unit of pulling-compacting rolls.

The remaining working units of the machine are similar to units applied in forage harvesters for low-stem and high-stem plants for silage.

At design stage, kinematic and dynamic analysis of working elements and machine units were carried out; this enabled to optimize the machine's constructional structure. Exemplary loading of cutting adapter frame is presented in Fig. 3.

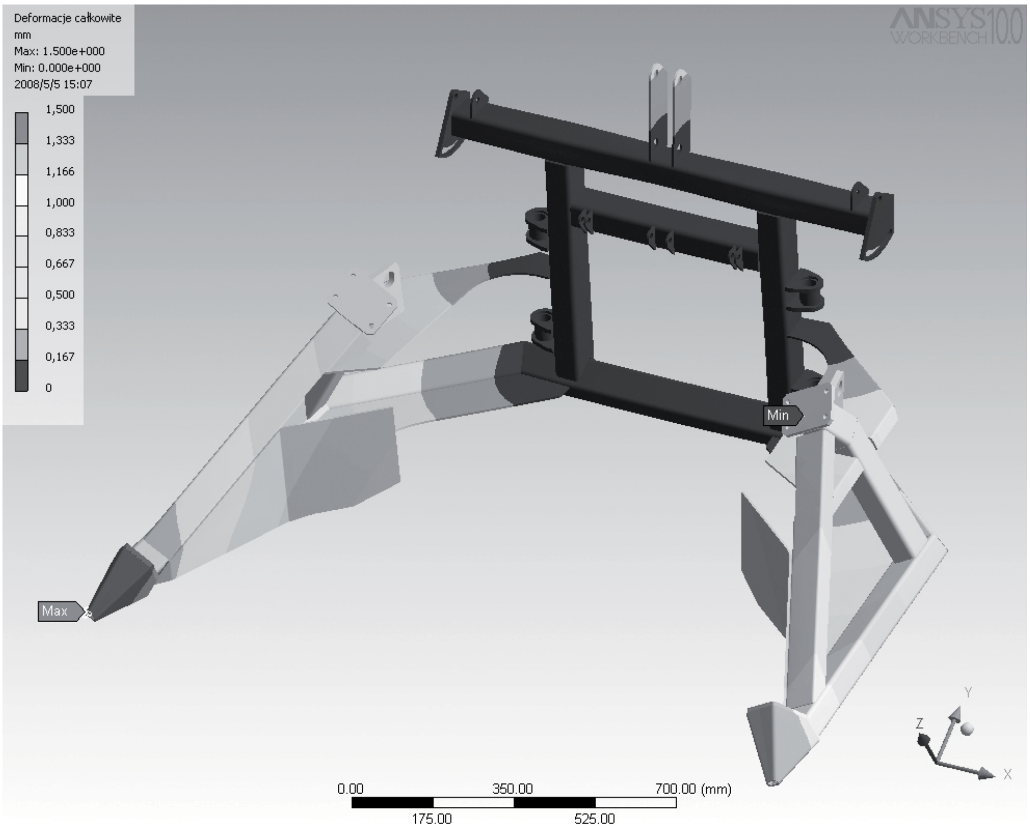

Fig. 3 Total deformation of cutting adapter frame.

Source: Authors' elaboration

Basic technical parameters of the cutting machine prototype are listed in Table 1. It was assumed that the machine will be equipped with row-independent attachment and adjustable dividers, to enable the cutting of separate rows with inter-row distance 0.7-0.8 m (common in Poland, Nowakowski et al., 2008) or twin rows spaced 0.75 m apart.

Table 1. Technical specification of machine for harvesting energetic plants

Item	Parameters
Basic machine:	
Source of power	agricultural tractor 120 kW, class 2 (20 kN)
Number of rows/working width	1-0.75 m
Working speed	up to 8 km·h^{-1}
Coupling with tractor	trailed/semi-mounted
Throughput	30 t·h^{-1}
Ground clearance	300 mm
Chopping unit	drum-type, diameter 600 mm, width 450 mm, rotational speed 700 rev·m^{-1}, number of knives 12
Cutting length	20–60 mm
Cutting adapter:	
Number of cutting disks	2
Cutting height	100 mm
Peripheral speed of disks	75–100 m·s^{-1}
Lifting-feeding unit	finger driver with lifting-feeding roll or worm conveyor
Diameter of harvested shoots	up to 70 mm
Height of cut shoots	up to 9 m
Drives:	
Cutting disks	hydrostatic
Lifting-feeding unit	hydrostatic with reverser
Cutting-discharging unit	mechanical

Source: Authors' elaboration

The ground speed of tractor-machine outfit will depend on field conditions, but the maximal speed will not exceed the recommended 8 km·h^{-1} (Lechasseur & Savoie, 2005). The cutting height of plants 100 mm above the ground corresponds to the range observed in solutions hitherto put forward (50–100 mm, Szczukowski et al., 2006).

The basic machine is equipped with a drum breaking up unit, enabling to cut stems of diameter up to 70 mm into chips of dimensions 20–60 mm (according to PN-91/D-95009 Standard). While harvesting larger diameter stems, especially those exceeding 100 mm, it is recommended to use techniques applied in forestry.

In elaborating the machine design concept it was assumed that it would be of modular structure; its assembly and modifications should result from investigations. Hydraulic drives would facilitate the control of the machine's working units and the selection of the best operational parameters under various field conditions.

CONCLUSIONS

1. Design documentation of the machine prototype equipped with two cutting adapters for harvesting energetic plants was elaborated; the machine meets the assumptions.

2. The design allows the evaluation and measurements of the units' operational parameters at various spatial settings of working elements and machine parameters.

3. The design of the adapter allows the mounting of alternative working elements in order to evaluate their usability under various operational conditions of the device.

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Study on Grinding Biomass as Pre-treatment for Biogasification

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Abstract. Six different samples were collected from local farms in Tartu County in Estonia. Based on preliminary results of fibre tests, four samples with different lignin content were chosen for grinding and biogasification experiments. Next, knife mill and laboratory scissors were used for particle size reduction. The knife mill was used with bottom screen sizes 0.5 mm, 4 mm and 10 mm. With scissors the hay was cut into 2…3 cm pieces. Sieve shaker and Easy Sieve software were used for particle distribution analysis. Biogas potential was determined for different hay samples. Cumulative biogas production was calculated by pressure increase in gas phase of bottles according to ideal gas law. We are going to show in what way the cutting impacts biogas yield. Negative correlation between biogas yield, particle size and lignin content is significant for most hay samples analysed.

Key words: Biogas, milling, particle size, lignin, sieving, hay

INTRODUCTION

With Renewable Energy Act, Estonia has a strategic plan to increase the share of renewable energy up to 25% of final consumption; in 2005 this figure was 18% (2009/28/EC). According to statistics, the final energy consumption in Estonia has been about 113 PJ in 2005 and has increased up to 120 PJ in 2008 (Statistical…, 2009). One possible source of additional renewable energy supply is hay, the traditional animal fodder in Estonia, but today the production and use of hay in agriculture is decreased and therefore it could be used in local energy systems.

There is ca 200 thousand hectares permanent grassland (grassland occupation over 5 years) in agricultural production. The actively sown area was changed 11% in 2006-2008 and the production of green fodder in tons was from 1.5 to 1.9 Mt in a year (Agriculture…, 2009).

There is no statistical figure for the unused biomass potential of permanent grasslands, but researchers at Estonian University of Life Sciences have assessed changes in arable land usage. Growing area of forage crops has decreased by 485,000 ha compared to year 1990 (Astover et al., 2006). About 283,000 ha of agricultural land have been abandoned and 123,000 ha are not included in agricultural registers any more. Compared to activities of animal husbandry in regions we may assume that 40-50% of grasslands are not used for fodder production, but are cut for land maintenance once a year (Roostalu et al., 2008-1).

Kukk and Sammul investigated meadows which are under environmental protection and estimated that semi-natural meadows cover 130,000 ha in Estonia

(Kukk and Sammul, 2006). Biomass production in meadows ranges from 1.7 to 5.7 t $(ha\ yr)^{-1}$. Total production from semi-natural meadows is approximately 182,000 t yr^{-1} of dry matter (Melts et al., 2008).

It is difficult to say what is the energy potential of unused land in Estonia. There is not enough information about the current state of abandoned fields, moreover, future cultivation plans of Estonian farmers are not well known. By rough estimation, the potential for bioenergy from natural grasslands, unused fodder from grasslands and abandoned agricultural land is 6.66, 2.3 and 6.93 PJ, respectively, which makes the total potential ca 16 PJ annually (Roostalu et al., 2008-2). Kask has estimated renewable energy potential of biogas production based on biomass from abandoned agricultural land and found it to be 5 PJ in a year (Kask, 2008).

As mentioned before, the consumption of renewable energy covers about 18% of total energy consumption. This is ca 20 PJ annually and has to increase up to 28 PJ (25%) in a year if total consumption stays at same level. Part of this may come from hay produced on abandoned agricultural land and collected from semi-natural meadows; the calculated energy potential of biomass from these areas is 16 PJ, which theoretically covers the additional need for renewable energy.

One of the technologies for energy conversion of hay is anaerobic digestion with manure in agro energetic chain. The interest of plant operators is not very great as hay is not recognised as one of the main substrates for biogas plant. It can be used in feedstock, but as lignocellulosic material it needs pre-treatment. Many researchers report that pre-treatment of feedstock can increase biogas production, volatile solids reduction (Tiehm et al., 2001) and solubilisation (Tanaka et al., 1997). Particle size may affect the rate of anaerobic digestion as it affects the availability of a substrate (i.e. the surface area) to hydrolyzing enzymes, and this is particularly true with plant fibres (Mshandete et al., 2006). Pre-treatment of biomass feedstock such as milling, pulping and steaming increases pore size and reduces cellulose crystallinity, which is required for bioconversion of lignocellulosic feedstock (Mandels et al., 1993).

In this work we study mechanical pre-treatment of hay. The goal of pre-treatment is to make cellulose accessible to hydrolysis for conversion to biogas. Four types of local hay, different in nutritive value and fibre content were used in this study. Each kind of hay was ground to different fractions with knife mill using a set of four different bottom screens. Different cutting fractions are analysed by particle distribution and, in addition, correlations between particle size, lignin content of hay and biogas yield are described.

MATERIALS AND METHODS

Collection of samples

Six different samples were collected from local farms in Tartu County in Estonia. Samples were picked from storage in small portions and mixed. After the first examination in laboratory, four samples from six, each with different quality and nutritive value, were included in this study.

One of the most interesting hay samples (Fig. 1. #6) was from Alam-Pedja, grown in a nature reserve with requirements to make one late harvest once a year in

July. Consequently, it was growing in a nature reserve without chemical fertilizers, contains a high number of species and has relatively thin stalks. Polder (#5) originates from last late autumn harvest and was growing in Aardla polder. #1 and #4 were harvested in Tartu Agro as cattle feed. Hays # 2 and #3 were growing in semi-natural grasslands.

Fig. 1. Hay samples: 1 - Agro #1; 2 - Leilovi #2; 3 - Märja 3#; 4 - Timothy #4; 5 - Polder #5; 6 - Puurmani #6.

Based on preliminary fibre test results, four samples (#1, #4, #5, #6) with different lignin content were chosen for grinding and biomethanization experiments.

Pre-treatment of samples

All samples were dried at 65° **C** for three hours before milling to avoid particles sticking to the mill chamber. Four different hay samples, each ca 10 litres, were randomly divided into four portions with about the same volume. Then the knife mill Retsch SM 100 (Retsch GmbH, Germany) and laboratory scissors were used for particle size reduction. The knife mill was used with bottom screen sizes 0.5 mm, 4 mm and 10 mm. With scissors the hay was cut into 2…3 cm pieces. During sampling for chemical analyses and biogas test, the pre-treated portions were homogenised by gentle mixing.

Chemical composition analysis

All collected hay samples were analysed at Laboratory of Plant Biochemistry of Estonian University of Life Sciences to determine Cellulose, Lignin, Crude Protein, Hemicelluloses, Natural Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) content. Laboratory uses standard methods of Association of Official Analytical Chemists (AOAC) and methods for NDF and ADF by the company Tecator.

Particle size analysis, sieving

The sieve shaker AS 200 (Retsch GmbH, Germany) and Easy Sieve software were used for sieve analysis. The sieve shaker AS 200 was assembled with collecting pan and sieves 0.020 mm, 0.050 mm, 0.20 mm, 1 mm, 2 mm, 4 mm, 6.3 mm, 8 mm. After sieving, the mass retained on each sieve was weighed. The same kit was used for every sieving test. After each operation, the sieves were cleaned from dust. For all four fractions the hay density by volume was determined and the parameters were fed into Easy Sieve programme. Operating time was set on five minutes and amplitude on 1.5 mm during all tests made with the sieve shaker. As all millings were carried out using the same methods during sample preparation, the results are comparable. The mean results of each fraction calculated by Easy Sieve programme were used for researching the alterations in biogas potential in order to identify divergence and relations induced by particle size.

Biogasification test

Biogas potential was determined by protocol of Laboratory of Environmental Chemistry at Estonian University of Life Sciences. It follows the ideas of Biochemical Methane Potential (BMP) test protocol, invented by Owen to assess cumulative methane production of organic matter (Owen et al., 1979). Preparation of inoculum is performed as described by specialist group of the International Water Association. Fresh inoculum was used in working reactor and was not washed as described in different papers (Angelidaki et al., 2009).

Four different hay samples were previously pre-treated with knife mill and scissors to prepare four different fractions (0.5, 4, 10 and 20-30 mm) for BMP test. Thus, the total number of samples for biogas test was 16. All samples were prepared in triplicate in 575 ml bottles.

The fresh inoculum was taken two weeks before test from anaerobic pilot digester working with agricultural residues; the main substrate was grass silage. It was incubated for 5 days before usage at 35° C for degassing and biodegradation of plant residues left in inoculum. Together with samples the blank bottle with inoculum in triplicate was placed into test assay to measure the background biogas production from the inoculum.

The number of replicates was three and therefore the test assay included 51 bottles, from which 48 bottles were with samples and 3 more bottles with blank inoculum.

Each bottle was loaded with 0.35 g of substrate, 150 ml of inoculum and then distilled water was added to reach 200 ml as total liquid level in bottle. The substrate to inoculum ($S I^{-1}$) ratio was $1\ 5^{-1}$ by g VS. Nutrient medium was not used.

In order to get rid of air oxygen, a flush with gas mix in composition N_2:CO_2 (80:20%) was implemented for 10 minutes before closing the bottles. Then full assay of bottles was incubated at 35° C in Memert isothermal thermo chamber. Basal pressure of experiments was measured after pressure stabilization at incubation level. The experiment lasted for 40 days. The biogas production was measured by manometric method, gas pressure was measured daily by using pressure transmitter 0...4 bar (abs.), Siemens. The chemical composition of the gas was analysed by Varian micro-GC model CP-1900 to indicate methane content in biogas.

Cumulative biogas production was calculated by pressure increase in gas phase of bottles according to ideal gas law. Methane production was calculated by biogas yield and gas composition data. The result of biogasification test is gas production of substrate calculated in standard temperature and pressure conditions (STP). As the study is done by manometric method, the biogas yield is used in regression analyses; methane content is presented as indicator in discussion. Biogas yield dependence on particle size and lignin content is analysed using least square method.

RESULTS AND DISCUSSION

Chemical composition and fibre content of collected samples are presented in Table 1. Samples #1, #2, #5 and #6 with different lignin content were taken for sieving and BMP analyses.

Table 1. Chemical composition of samples (content in dry matter)

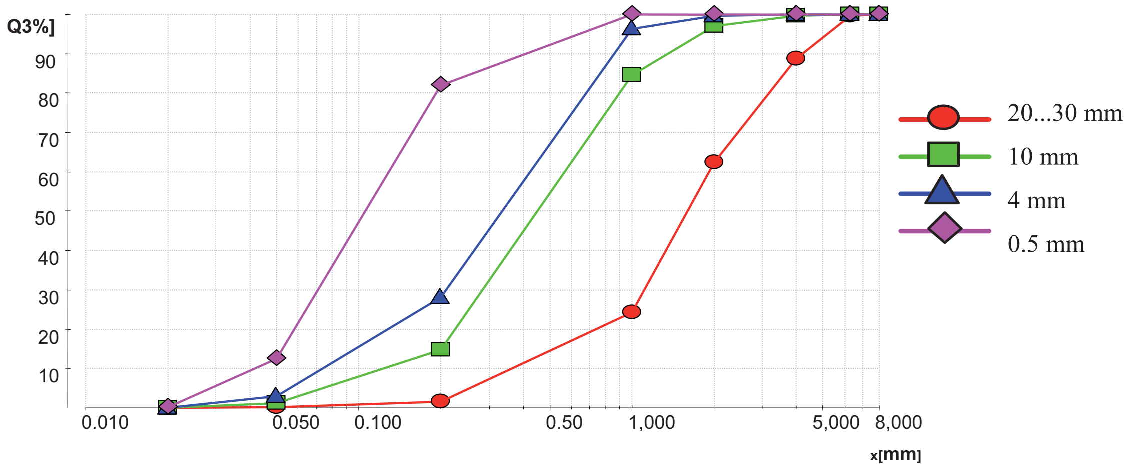
Sample	TP %	Cellulose %	Lignin %	Hemi-celluloses %	NDF, %	ADF, %	DDM %
#1	11.18	30.10	4.08	23.37	57.55	34.18	62.27
#2	10.04	33.37	7.14	34.90	75.41	40.51	57.34
#3	9.10	36.12	7.35	25.82	69.29	43.47	55.04
#4	9.63	38.06	4.90	29.59	72.55	42.96	55.43
#5	11.10	38.57	5.10	33.67	77.65	43.98	54.64
#6	7.76	35.10	8.78	22.35	66.22	43.88	54.72

TP – Crude protein
NDF – Neutral Detergent Fibre
ADF – Acid Detergent Fibre
DDM – Digestible Dry Matter

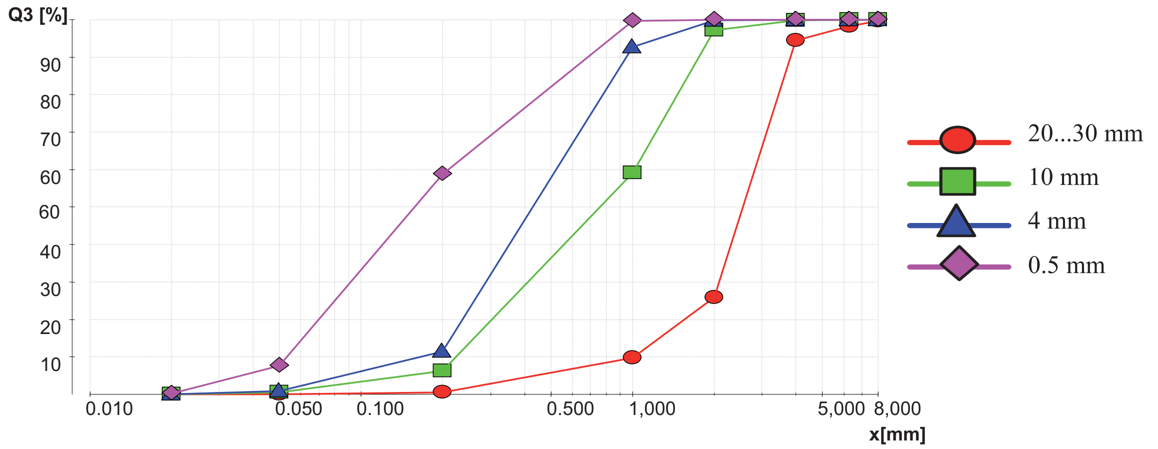
Sieving results of milled materials #1; #4; #5; #6 are shown in Fig. 2. In every fraction it is evident that different hay acts differently in milling process, although it is carried out in the same conditions. All four hay samples were dried conformably and had similar humidity (5%) during the milling process. In all four cutting fractions, materials #4 and #5 appeared to have particles with larger dimensions than those of materials #1 and #6.

Particle size distribution in different hay samples correlates with the origin of the sample. In Figure 2 we can see cutting efficiency in means of small particle quantity in fraction. There are differences between samples and these differences appear in all cutting ranges. For example, in the smallest cutting range (0.5 mm bottom sieve), big differences are detected in mass percentages of particles smaller than 0.2 mm. For samples #1, #4, #5 and #6 it is 80%, 60%, 55% and 70%, respectively. This correlation appears in all cutting ranges of samples.

Agro #1



Timothy #4



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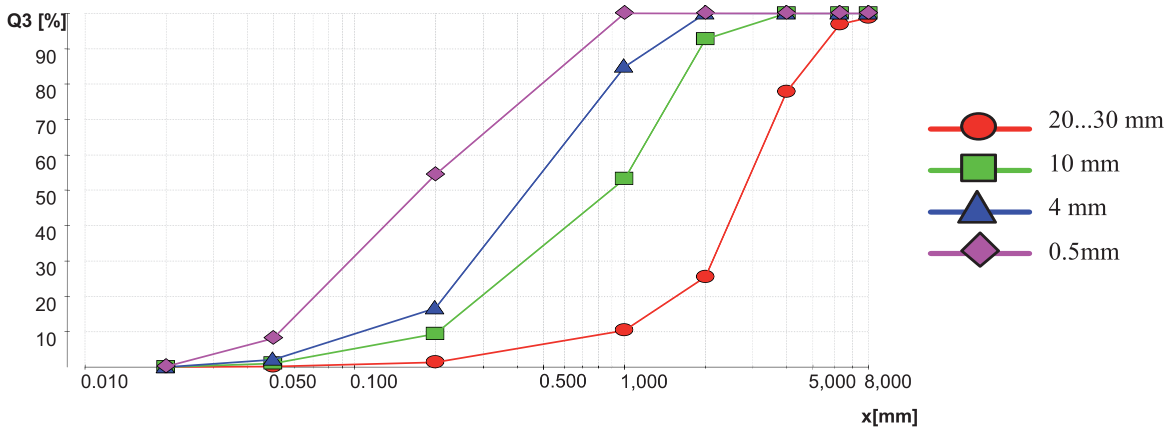

Puurmani #6

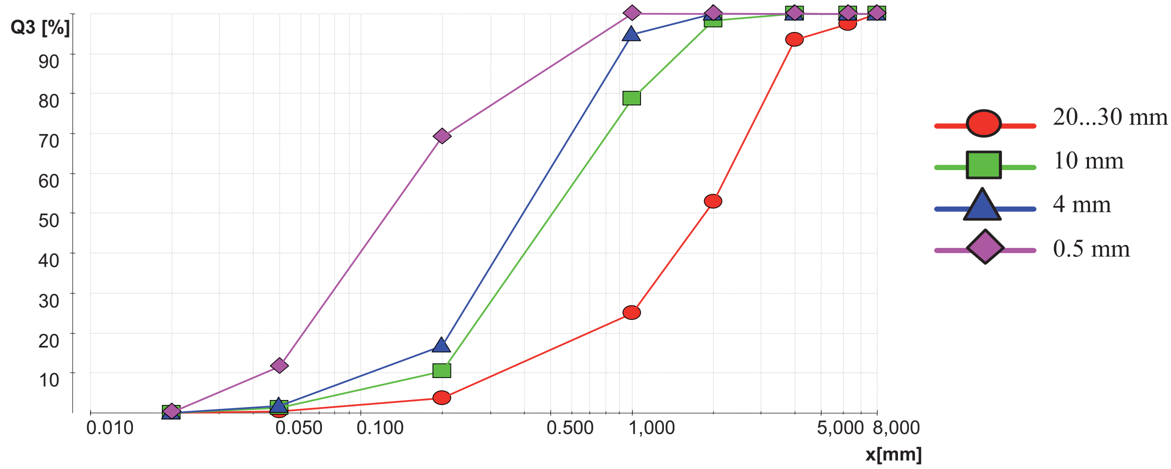

Fig. 2. Distribution of particle size #1; #4; #5; #6 in each cutting fraction.

Results of biogasification have variations in different hay samples and they depend on cutting fraction and fibre composition as well. During the biogasification test methane content was checked to be corresponding to correct anaerobic process. The value of methane content ranged from 59 to 65%. Average values of biogas yield and particle sizes are presented in Fig. 3. It illustrates the cutting treatment effects on mean particle size and biogas yield. In Fig. 4 the average value of biogas yield, standard deviation and quartiles are presented. We can see that the smaller the mean value of particle size, the higher the biogas yield. Correlations between cutting results of hay samples and biogas yield will be analysed next.

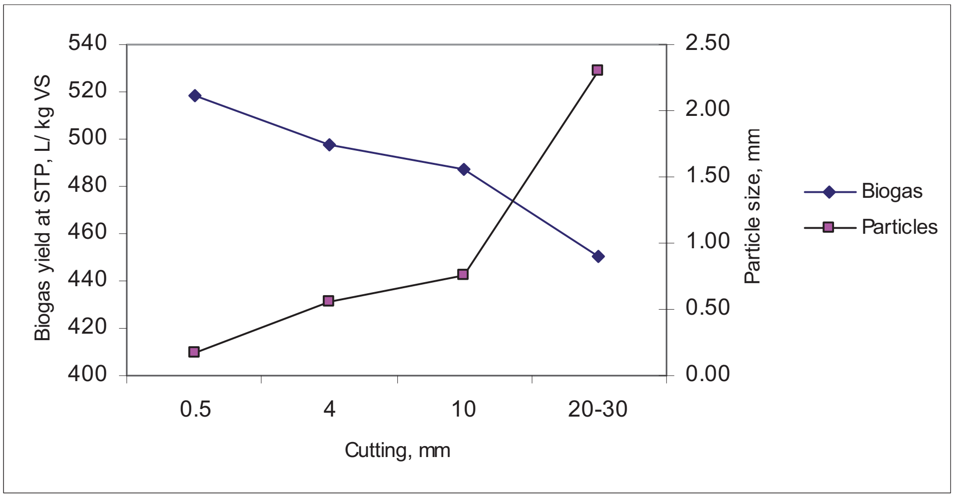

Fig. 3. Biogas yield and mean value of particle size related to cutting fraction.

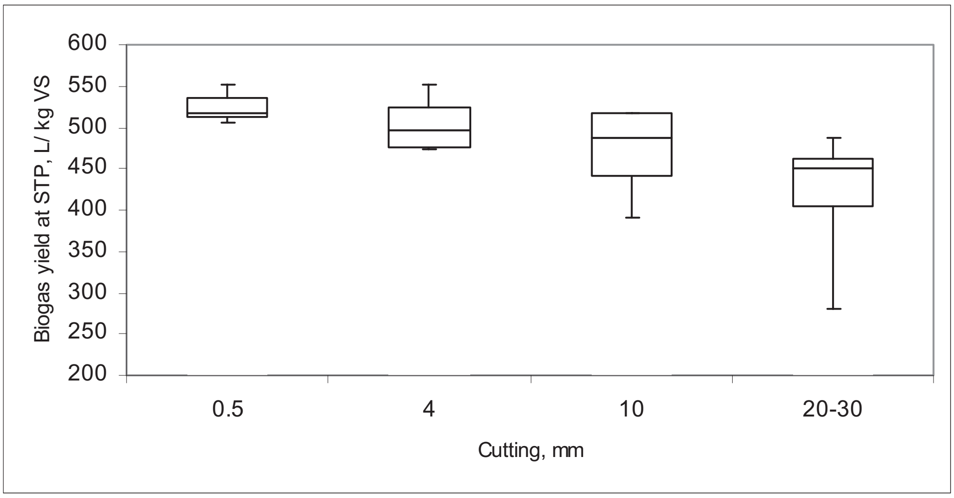

Fig. 4. Biogas yield dependence on cutting fraction.

If different hay samples are analysed separately, correlations between biogas yield and mean value of particle size are high (R^2 value from 0.52 to 0.97). Results are shown in Fig. 5. But the results are not significant for all analysed hay samples; two results have significance level α=0.05. Good results are gained with hay #1 and #2, having good correlation with high significance between biogas yield and mean value of particle size; R^2 values are 0.93 (r = -22,412, p = 0.036) and 0.97 (r = -39,476, p = 0.016), respectively. Regression curves for hay #5 and #6 are not significant. The reason for that can be the smaller number of experiments conducted. After a greater number of experiments we expect to find high correlation between particle size reduction and biogas yield for every type of hay in Estonia.

According to other authors, reduction in fibre size has been found to increase biogas potential, by 16% with fibre size 2 mm, and by 20% with fibre size 0.35 mm (Angelidaki and Ahring, 2000). But they did not find any significant difference in case of fibre sizes 5–20 mm.

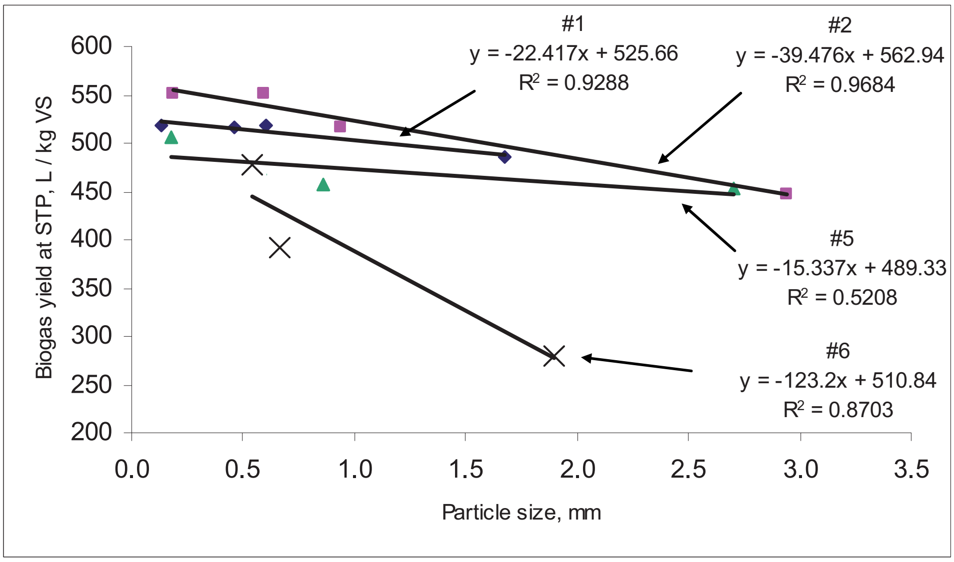

Fig. 5. Biogas yield dependence on content of mean particle size.

In addition, we found high correlation between biogas yield and lignin content. The cutting fraction was made with knife mill with a 10 mm bottom sieve (R^2 = 0.52, r = -28,774, p = 0.002). The results of biogas yield and lignin content analyses are presented in Fig. 6.

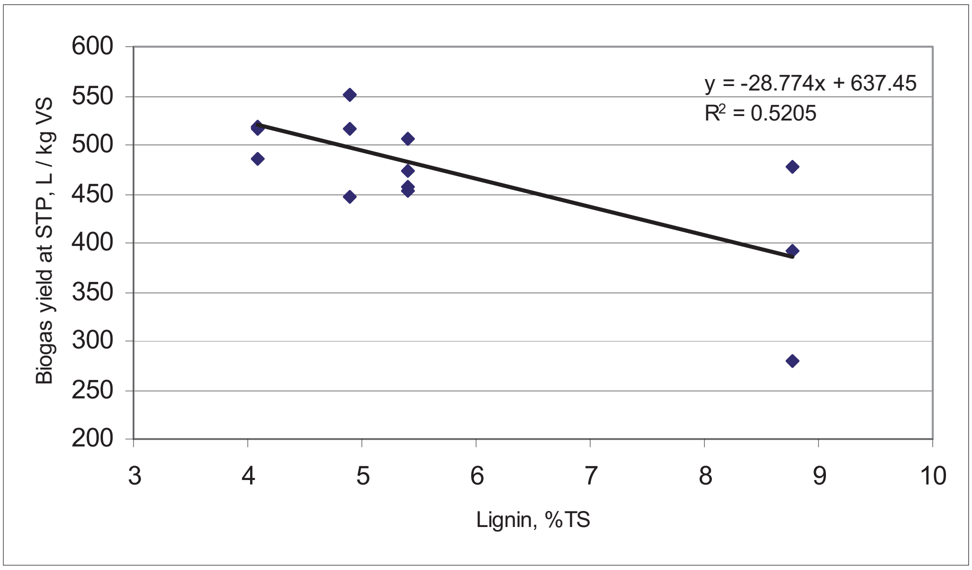

Fig. 6. Biogas yield dependence on lignin content in case of bottom screen sizes 0.5 mm, 4 mm and 10 mm and cut with scissors into 2…3 cm pieces.

CONCLUSION

Both lignin content and particle size have effect on biogas yield. If different hay samples are analysed separately, correlation between biogas yield and mean particle size is significant with R^2 value ranging from 0.52 to 0.97. But results are not significant for all hay samples analysed, as two results needed level $\alpha = 0.05$. Hay #1 and #2 have high correlation between biogas yield and particle size; R^2 values are 0.93 (r = -22,412, p = 0.036) and 0.97 (r = -39.476, p = 0.016), respectively. The correlation between biogas yield and lignin content has R^2 value 0.52 (r = -28,774, p = 0.002). The results show that there is negative correlation between biogas yield and particle size. The same result is achieved as regards biogas yield and lignin content. There are also some doubts concerning the influence of lignocellulosic fibres of hay on the bioconversion of hay into biogas which needs further investigation, e.g. particle size distribution, electricity consumption of cutting mill, and biogas yield depending on lignin content of low quality hay. The biomass of low quality hay which is basically unused could be converted into energy in a biogas plant.

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Energy Management of Future Farms

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Abstract. Energy management in agriculture will be of current interest in the near future. Modern agriculture is run by fossil energy and it is unclear how this energy input will be replaced with renewable energy. The year 2008 gave some foretaste how rapidly and how much energy price can rise. Energy saving and exploiting farm's own energy resources are ways to reduce dependency on oil. Nitrogen fertilizer is the most significant energy input in plant production because ammonia manufacturing is very energy intensive. Crop rotations including legumes, green fertilization, and better manure management are measures to replace synthetic nitrogen. Traditional work chains can be replaced with more energy efficient operations. Direct drilling and grain preservation methods other than drying are good examples. Animal housing requirements for inside temperature and air quality define the demand for heating and ventilation. Along with milking and milk cooling, they are the most significant energy inputs in animal production. Animal welfare has to be respected always; however, by means of heat recovery and biogas production it is possible to save energy and exploit energy from manure. Energy should not be considered as a separate question; on the contrary, a farm has to be considered as a whole and as a part of the rest of the society. Better energy management and plant nutrient recycling are combined issues and require more comprehensive approach than it has been the case.

Key words: Energy, management, bio energy, agriculture

INTRODUCTION

World energy consumption is increasing and the increase is based on fossil energy availability. At the same time fossil energy recourses are diminishing and the wide use of fossil energy has already caused global warming. This has led to discussions and usage of bio energy and renewable energy. At the moment the share of renewable energy is about 13% of the whole energy supply (IEAE Key world energy statistics, 2008). Renewable and bio energy usage and research has been favoured in many countries, for instance the EU has decided to stop global warming to two degrees and the share of renewable energy in 2020 should be 20%.

Fossil energy resources are decreasing, which means that their prices will be increasing and in the future there will be shortage of fossil energy. This means changes also in agricultural production. Although agriculture uses a lot of fossil energy, it is at the moment in plant production energy positive, we get more energy out of production in the form of food and feed than we use in the production. In the future the farms must be more and more self-sufficient in energy usage. This means energy savings, better nutrient recycling and at the end the farm could be energy positive in the sense that besides food, feed and non-food it would also produce energy. In energy savings new methods which consume less energy than old methods must be introduced. For instance direct drilling consumes less energy than conventional drilling and unheated cattle houses consume less energy than the heated houses.

Fig. 1 presents the usage of fields, crop yield and the usage of fertilizers during the years 1961–2008 (Faostat, 2010). During this period the world population has more than doubled, crop field area has remained almost the same, fertilizer use has become six-fold, and crop yield has doubled. From the picture the conclusion can be drawn, that world population has been nourished with an increasing usage of fertilizers. Some 94% of the energy consumed by the fertilizer industry is used for ammonia synthesis and fertilizer production consumes 1.2% of the world's total energy on an annual basis. Natural gas is the primary hydrocarbon feedstock used in ammonia synthesis from which almost all nitrogen fertilizers are derived. (Energy efficiency and CO_2 emissions in ammonia production.)

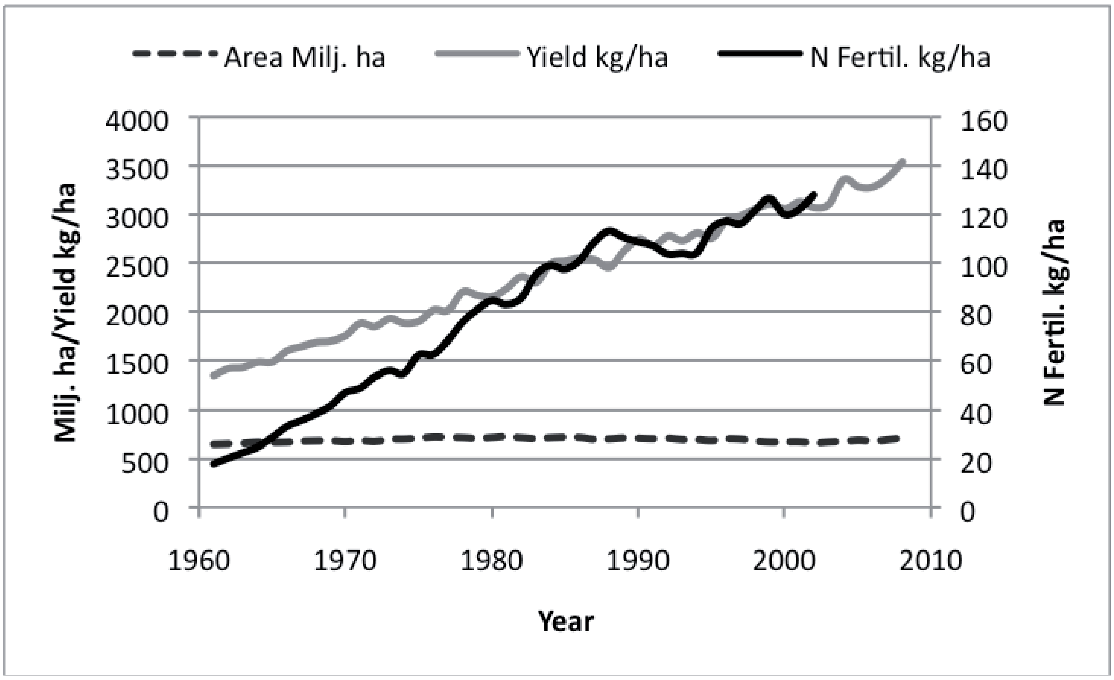

Fig. 1. World crop production and fertilizer use.

The increased food production hinges thus heavily on fossil fuels. World population is at the moment 6.8 billion and it is increasing so that in 2040 the estimation for world population is 9 billion (UN, 2004). This means that food production must increase in the future. This means increased crop field area and increased fertilizer production and possibilities for bio energy production decrease.

Bio energy has also negative environmental effects. During the bio fuel production fossil energy is used. For instance nitrogen fertilizer is mainly produced from fossil energy and its share in the inputs of field bio energy is in many cases dominating. Usage of fossil energy and fertilizers cause also emissions and when this is taken into account the effect of bio energy usage can be environmentally negative. Bio fuels are analyzed according to their energy efficiency, energy ratio and their GHG (Green House Gas) effect. GHG-analysis is normally calculated using the IPCC methods (IPCC, 1996). When biomass is used for energy production, the energy used in the fuel production must be taken into account. This is often expressed as a net energy ratio (NER) (Farrel et al., 2006), which shows the ratio of output energy to input energy. A ratio of one means that the produced fuel includes as much energy as has been used in the production. The ratio should be over one in order to get some energy profit.

The energy used for bio fuel production can be divided into two parts, direct and indirect energy (Ortiz-Canavate & Hernanz, 1999). Direct energy includes the fuel and electricity used during the production. Indirect energy includes manufacturing energies, fertilizers, machines and buildings. For instance, in barley production in Finland the indirect energy forms the larger part of the energy consumption. One of the problems with indirect energy is that machine manufacturing energy figures are hard to get (Ahokas & Mikkola, 2007).

Fig. 2 shows an example of energy distribution between different categories. Fertilizer manufacturing (fertilizer + lime) consumes the most of the energy. In Finnish conditions the crop yield has to be dried to preserve the harvest and drying consumes large amount of energy. Because weather conditions, crop moisture content and soil conditions vary between years, the figures are not constant but change over years. The NER value is in Finland for rapeseed and barley production between 3 and 5 (Mikkola & Ahokas 2009). When emissions to atmosphere are considered N_2O emissions from the soil dominate. Nitrous oxide originates from nitrogen nutrients of soil and is rated to be 298 times more harmful than CO_2 (Forster et al., 2007). Emissions from fertilizer manufacturing take second place.

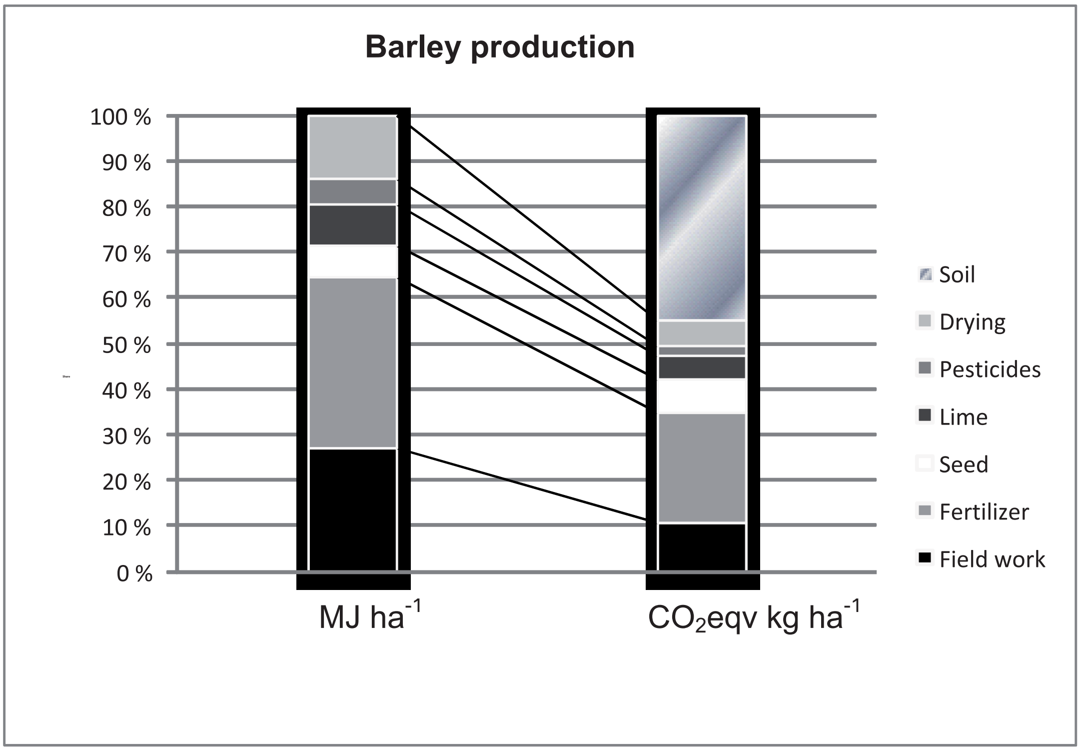

Fig. 2. Energy use in Barley production (11.8 MJ kg^{-1}) and CO_2 emissions (2,122 kg ha^{-1}).

So far energy has been a less important economic factor in agricultural production. Energy has been inexpensive and it has been well available. In the future energy questions will be more important and the farmers must first think about energy saving methods. Later on they could also produce energy for themselves and in the best case for the market.

POTENTIAL OF BIO ENERGY

Wolf et al. (2002) made a study of the potential land area for bio energy production. The study showed that 55% of the agricultural land area at the global level is needed for food production in the future (i.e. year 2050), if a high external input system of agriculture is applied and the remaining 45% can be used for biomass production. If a low external input system is used for food production, then no land area would be available for biomass production. Holm-Nielsen et al. (2006) concluded that by the year 2050 it will be possible to meet the world energy demand with 75-90 percent of all energy by renewable energy (bio energy, wind, hydro power, and solar energy) and bio energy alone can fulfil between 30-40 percent of the entire world energy need. Bio energy potential depends much on world population increase and fertilizer production. At the moment in many countries there is overproduction of agricultural products meaning that the possibilities for field bio energy production are good.

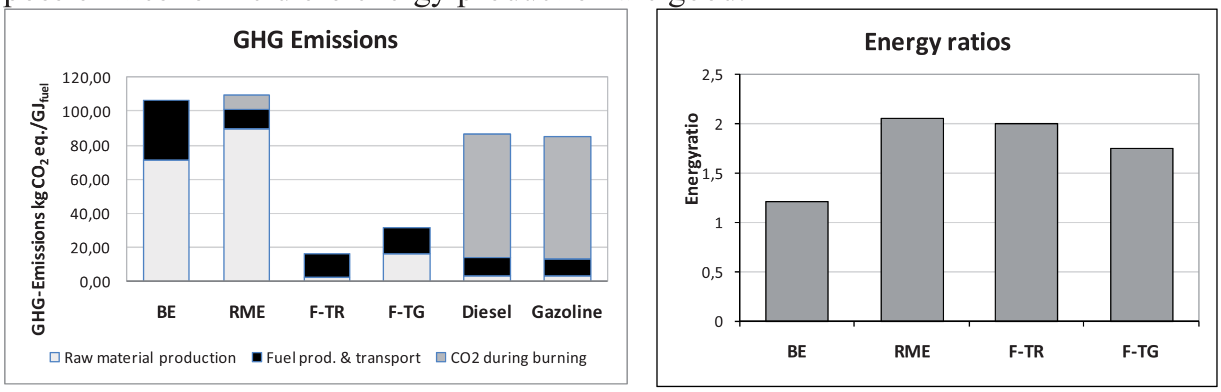

Fig. 3. Green House Gas emissions of fuels (BE = bioethanol, RME = rape methyl esther, F-TR = Fischer-Tropsch fuel made from wood residues, F-TG =Fischer-Tropsch fuel made from green canary grass, Diesel = fossil diesel fuel, Gazoline = fossil gazoline).

Liquid bio fuels

Bio fuels can be divided into two categories, the 1st generation and the 2nd generation bio fuels (BIOFRAC report). The 1st generation bio fuels are mainly conventional bio fuels produced in the traditional way and the 2nd generation fuels can better utilize the lignin and cellulose of biomaterials thus improving the bio fuel yield from the raw material. Fig. 3 shows that the 1st generation bio fuels have significantly higher emissions than the 2nd generation fuels in Finnish conditions (Mäkinen et al., 2006).

Ethanol production has the lowest energy ratio, near one, meaning that in ethanol production almost as much energy is used for production as the product has energy. Biodiesel (RME) and Fischer-Tropsch diesel have better energy ratios, the ratio is near two. The energy ratio depends on the raw material, on the manufacturing system and also on how the residues from the production are utilized. For instance in ethanol production distiller's dried grain with soluble (DDGS) is produced and this can be utilized as feed for pigs.

Fig. 3 shows also GHG emissions for the same fuels and for two reference fuels, fossil diesel and gasoline (Mäkinen et al., 2006). Ethanol and biodiesel (RME) have higher GHG emissions than direct use of diesel or gasoline and in this sense the usage of these fuels is not so friendly from the environmental point of view. The usages of fossil fuels have lower GHG emissions than ethanol and RME. Fischer-Tropsch diesel, using forest residues or reed canary grass as raw material, has much lower GHG effect than ethanol or RME. The field bio energy has a problem with fertilizers. Because of fertilizing nitrogen oxide (N_2O) is generated in the soil and this has a global warming coefficient of 298 resulting in large emissions expressed in CO_2 equivalents. The analyses are in many cases done by allocating all the soil emissions to the produced plant. The soil causes emissions also without any agricultural production. When this so-called natural emission is subtracted from the total N_2O emissions, the situation of biofuels is much more favourable.

The USA and Brazil are dominating in fuel ethanol production. In 2007 their combined share of world production (50,000 mill. litres) was 88%. The USA was producing 50% and Brazil 38% (Annual World Ethanol Production, year 2007). The energy ratios vary from under 1 to about 8 (Macedo et al., 2008, Pimentel & Patzek, 2008) depending on raw material, production efficiency, and analysis boundaries. Macedo et al. (2008) report an energy ratio of 8.3–9.3 for ethanol production from sugar cane in Brazil and in 2020 they expect it to be 11.6 when surpluses are better utilized. Also the GHG effect of sugarcane ethanol was positive.

The EU sets for biofuels and bioliquids 35% GHG saving criteria and starting in 2017 the saving must be 50%. The directive gives detailed instructions for the GHG saving calculations. (EU Directive, 2009/28/EC)

Solid bio fuels

Solid bio fuels such as wood and straw are mainly used for direct burning but they also form the raw material basis for the 2nd generation fuels, when their lignin and cellulose can be dispersed and the hydrocarbon chains are broken and fermented. Efficiency in direct burning is good. Efficiency demands for heating boilers less than 300 kW are given in EN 303-5 standard (EN 303-5) and the classification starts from about 50% efficiency in the lowest class and boilers with the lowest power and ends at 82% efficiency in the highest class for 300 kW boilers. In district heating systems with large boilers the efficiency of energy production is high, but if only electric power is produced in power plants, the efficiency is poor due to the process. In combined heat and power production (CHP) the efficiency can be increased considerably and these types are favoured nowadays.

Good efficiencies with solid bio fuels can also be seen in their energy ratios. For solid biofuels the ratio is normally 14-30 and it is much higher than for liquid bio fuels, which have energy ratios of 1-6 (Venendaal et al., 1997).

In direct burning of biomass bio fuel characteristics vary considerably. Wood material is easy to use because of high density and low ash content. Straw materials are often hard to burn because their density is low and ash content is high. The straw ash has also corrosive substances and ash smelts easily in the furnace complicating burning. The furnaces have to be designed according to the fuel demands and it is hard to use several types of bio fuel in the same furnace.

Biogas

Waste biomaterial and biomass can be utilized for biogas production. When biogas is produced, the energy ratio, when calculated from the energy in the gas, is 2.5-5.0 (Tuomisto, 2006; Berglund & Börjesson, 2006). The energy ratio is high if the biogas can be used directly for heating. If electricity is produced with combustion engines and generators, energy ratio decreases considerably, because the efficiency of the electricity production is low. About 70% of the biogas energy is wasted if engine heat is not utilized. This means that in electricity production without heat utilization the energy ratio of biogas system is about one.

When green biomass is used for biogas production, the mass must be conserved after harvest for later use during winter, when energy demand is high. Besides this proper building, a reactor and gas storage must be built as well as investment in engine and generator is required in electricity production. This is a big investment and if not subsidized, the economy of biogas production will be poor.

Problems with bio fuels

Bio fuel usage is not as easy and trouble free as fossil fuel usage. Biogas plants as well as bio fuel furnaces need service. In electricity production from biogas with combustion engines, regular oil change, filter replacement and other necessary maintenance means must be used. In heat production with direct burning fuel acquisition, fuel charging and ash removal must be done. Compared to fossil fuels this means more maintenance work and also higher costs.

Modern combustion engines are made for sophisticated and homogenous fuels. Also emission values are measured with these fuels. Biofuels have often poorer quality and they are heterogeneous. This can introduce damages to the fuel system or to the engine and it can also increase emissions. The ability to use biofuels varies between engines and before usage the allowed biofuel concentration should be checked. Biofuels have special problems in cold climate. Biodiesel pouring point must be low enough in order to be able to use it. Ethanol has problems with cold starting and also with water in the fuel.

Nowadays fields are mostly used for food or feed production. Energy production differs from these requirements and for fuel production different types of plants should be used, so that the goal would be good energy productivity. Also the collection of biomass may differ from the normal agricultural production needing new harvesting technologies.

ENERGY SAVING IN AGRICULTURAL PRODUCTION

Energy saving is understood in most cases as a measure to save money and to improve economy. People have a low motivation to save energy if it does not improve their possibilities to consume money for other purposes in a relatively short period. Energy has been cheap and only peak oil prices in the 1970s and 2000s have really shaken people to save energy and to look for alternative energy sources.

Energy has a much wider role as a production factor in agriculture than pure energy costs show. Crude oil price reflects immediately to diesel and gasoline prices but also with a short delay to prices of coal, natural gas, nuclear power, and also the price of bio energy. This, for one, reflects the prices of fertilizers, fodder, transport, machines, etc. Modern agriculture is strongly dependent on the fossil energy input. Productivity in agriculture has been increased by replacing human and animal power with machines and technology powered with fossil fuels and electricity.

Energy saving measures usually focus on processes, actions or materials which require a major energy input to the system. This is understandable because significant savings can be gained only from targets which cover the main part of the total energy input. Energy analysis is a measure to identify major energy consumers. Energy use in plant and animal production and possibilities to save energy is considered in the following chapters.

CONCLUSIONS

In plant production, agrochemicals are responsible for half or three quarters of the total energy consumption. Agrochemicals mean in this case fertilizers, lime and pesticides. When the agrochemical group is split further into smaller parts, nitrogen manufacturing is the biggest energy consumer followed by lime and pesticides. Fig. 2 shows how agrochemicals dominate the energy input in plant production. In the case of Fig. 2, application rates for N, P and K were 80, 12 and 36 kg ha^{-1}.

Organic farming is a cultivation system which has to be managed without synthetic nitrogen and there are many measures which could also be utilized in traditional farming. Crop rotations including nitrogen fixing plants, green fertilization, catch crops and under sown crops, good manure management are examples which could be implemented in a wide scale to replace synthetic nitrogen. Känkänen (2001) has discussed versatile issues about these questions and concludes that there are many possible ways to apply biological nitrogen fixing in cereal production. However, it is difficult to express in figures how much these measures, alone or jointly, could cut the energy use.

In grassland cultivation, nitrogen is even more in focus than in cereal production because the share of nitrogen varies between 55-60% from the total energy input. Possibilities to save energy in milk and beef production are excellent, however, because traditional grassland species timothy, meadow fescue and tall fescue produce good yields in terms of mass and quality as mixtures with legumes (Nykänen et al., 2010; Kurki & Sormunen-Christian, 2010). Growing these mixtures requires sometimes more liming and contouring field surface because plants do not stand low pH and standing water, but otherwise there should not be any special obstacle to use the mixtures.

Varied crop rotations and increased cultivation of legumes have also other advantages than energy saving. Perennial plants have a strong root system which increases porosity and humus content in soil. Soil structure improves. Plant diseases and insects are easier to control. Ecological diversity increases when monocultures are interrupted with varied crop rotations.

Agricultural machines also consume a lot of energy (Fig. 2). Direct drilling is a good example about how the traditional cultivation method with heavy primary and secondary tillage operations can be successfully replaced with one less energy consuming operation. Fuel requirement of the traditional work chain from ploughing to drilling is some 35 litres diesel per hectare while only seven litres is needed for direct drilling (Danfors, 1988). Energy demand for field operations is cut to 1-5 of the original energy demand. Besides energy saving, direct drilling reduces labour demand, decreases erosion problems and helps to control nutrient leaching. A similar new thinking is needed in other farm operations, too.

Energy consumption for grain drying is also high, depending on the harvest crop moisture content. Energy use could be decreased with other preservation methods and with improved grain dryer technology.

Animal production

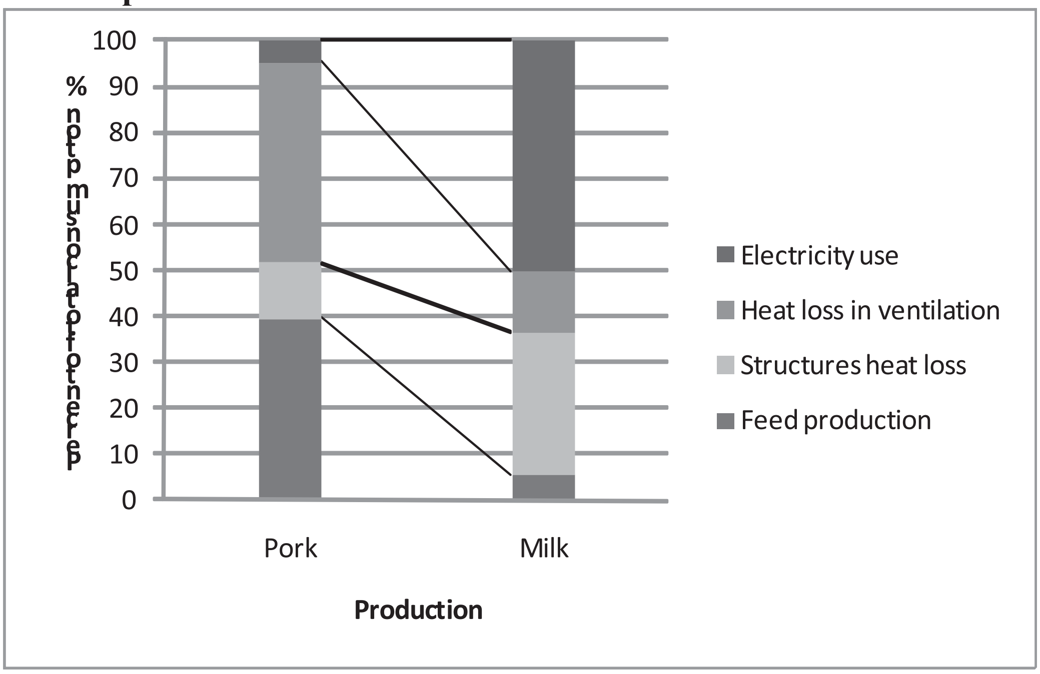

Fig. 4. Share of energy use in pork and milk production.

In animal production, plants produced in the fields are fed to animals. Main part of the products come from own farm, but, in addition, concentrates are bought to give the animals all the necessary nutrients. In animal production, the efficiency is lowered and the energy ratio is in most cases less than one, which means that production consumes more energy than what is used in the production (Mikkola & Ahokas, 2009). In borealis conditions, good shelters are needed for the animals, which means extra energy needed for construction and running of the buildings. Fig. 4 shows the portions of energy consumption in pork and milk production (Mikkola & Ahokas, 2009). In pork production, the indoor temperature of the building must be rather high due to high heat losses. With heat recovery systems this could be decreased. In milk production the cows can be kept in cold cow houses without difficulties and this would remove the energy needed for heating the houses. Milk production consumes much electricity by milking and milk cooling. The efficiency can be improved for instance with milk cooling energy utilization.

DISCUSSION

Energy price and energy availability will probably have a fundamental impact on agriculture during the next decades. If there is not any good substitute for diesel oil having nearly the same properties and a reasonable price, agriculture will face big changes along with other production sectors. Increasing energy costs inflate also prices of other productive goods and especially the price of fertilizers. Year 2008 was a good lesson. Table 1 presents what happened to costs in Finnish agriculture from year 2006 to 2008. During that period fuel prices approximately doubled (Oil Prices, Statistical Review, BP).

Table 1. Costs of Finnish agriculture in 2006 and 2008 and the change of costs (Niemi & Ahlstedt, 2007; Niemi & Ahlstedt, 2009)

Cost	2006, mill. €	2008, mill. €	Change, %
Fertilizers and lime	212	333	+57
Animal fodder	340	437	+29
Energy	353	442	+25
Salaries and employer’s obligations	245	468	+91
Machinery and equipment	661	728	+10
Buildings	335	378	+13
Intrest and rents	268	336	+25
Other costs	707	607	-14

Year 2008 showed that the market can be volatile and unpredictable. Together with rising input prices, prices of agricultural products rose fast as well. No economist had predicted such a rapid change. On the other hand, after that peak prices have recovered approximately to the same level where they were before.

Due to depleting oil resources it is high time to start adapting scanting of fuel supply. Farms which succeeded in cutting their dependence on external energy supply and have energy efficient processes are in a better position facing the increasing energy prices than farms which continue as if nothing has happened. Finnish farms consume a lot of energy but they have also such resources as wood, straw, and manure which can be used to generate energy. There is technology available to exploit these resources but the energy price has been so low up to now that it has not motivated the use of these resources. There is a strong possibility that energy efficient cultivation methods and development of energy production systems on farm level will be in focus in agricultural engineering research.

Energy question should be assessed together with plant nutrient supply, crop rotations, and animal production because good energy efficiency can be achieved only by fitting these sectors optimally together. The idea is not to return to self-sufficiency and the agrarian society, but there are certainly lessons to be learned from the past centuries and also from the practice of organic agriculture.

CONCLUSIONS

At the moment part of the field area can be used for bio energy production and part of fossil energy usage can be substituted with bio fuels. In the future the fields are needed more and more for food and feed production because world population is increasing and the availability of fertilizers can be reduced. Both in animal and plant production by-products (manure, straw, waste) are produced, which could be better utilized in the future for energy and nutrient production.

More effort would be needed to demonstrate energy efficient crop rotations, nutrient recycling, technologies for the use of renewable energy, as well as energy saving technologies in plant and animal production. Tests should be made more in farm conditions because promising tests in laboratories do not always work in practical conditions. Farm-scale tests would also give information about the economy of the new technology.

Energy and emission analyses can be conducted in different ways and the basic data for the calculations vary. This is especially so with indirect energy calculations. For these analyses it is necessary to have a standardized method and common source data.

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Estimation of Residual Flexural Capacity of Existing Precast Concrete Panels by Visual Inspection

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Abstract. The influence of visual assessment grade on the residual flexural capacity of 46 existing precast concrete ribbed panels was studied. Before the tests, the panels were assessed on a 6-point rating scale according to visually distinguishable corrosion deterioration. All panels, the ultimate load of which was lower than the control load, received grade 0 on visual rating scale. Consequently, attention should be paid to panels where the concrete cover of longitudinal reinforcement has spalled (grade 0), which could be a sign of decreasing load capacity. The majority of panels with grade 0 exhibited larger deflections under load than panels with higher grades. Of the 46 panels tested flexural ductile failure was noticed in 36 panels.

Key words: Visual grade, residual flexural capacity, corrosion, precast ribbed panels.

INTRODUCTION

In Estonia, the bearing structures of many existing agricultural and industrial buildings constitute a precast concrete skeletal frame. Particularly intensive construction based on industrially produced (precast) elements started in the 1960s when standardized design solutions and reinforced concrete structure designs were employed. However, the initial signs of corrosion of steel reinforcement became evident in agricultural buildings already in the 1970s. Corrosion was initiated by carbonation, because of high content of carbon dioxide and moisture in the air of an agricultural building. Aggressive indoor microclimate together with relatively porous concrete was the main reason for the high rate of carbonation. Department of Rural Building of Estonian University of Life Sciences (EMU) has gathered data describing the state of concrete load-bearing structures (columns, beams and ribbed panels) in 258 agricultural buildings from 1974 to 1997 assigning grades to 23,336 ribbed ceiling panels (i.e. about 3.5% of the total number of panels in agricultural buildings of Estonia) (Miljan R, 2005). The structures have been visually assessed, using a 6-point scale to reflect the externally distinguishable corrosion damage (Miljan J, 1977). According to this scale grade, 5 corresponds to no visual reinforcement corrosion deterioration detected, and grade 0 to concrete cover that has spalled.

There are about 4,000 agricultural buildings with an average floor space of 1,800m^2 in Estonia today. Many of their precast concrete load-bearing members (columns, beams and ribbed panels) are in service with a cracked or spalled concrete cover. The owners of buildings are most likely concerned about the condition and residual strength of their concrete structures. There is an increasing demand for informed decisions about the capability of structure to serve its intended function or, otherwise, the need for repair or demolition.

This paper reports an experimental study of 14 precast non-prestressed concrete ribbed panels of mark PKZH-2 and 32 prestressed concrete panels of mark PNS-3, PNS-12, and PNS-14. Intentionally, panels in poor condition, i.e. with cracked (grade 1) or spalled concrete cover in longitudinal rib (grade 0) were chosen for structural tests to specify their residual ultimate strength and flexural behaviour. The marks of panels reflect the former Soviet standard GOST. Precast ribbed panels with aforementioned marks are common in the industrial and agricultural buildings of Estonia (but also in other former Soviet countries), built from 1950s to 1990s. All tested ribbed ceiling and roof-ceiling panels had a length of 5970mm and width of 1490mm (Fig. 1).

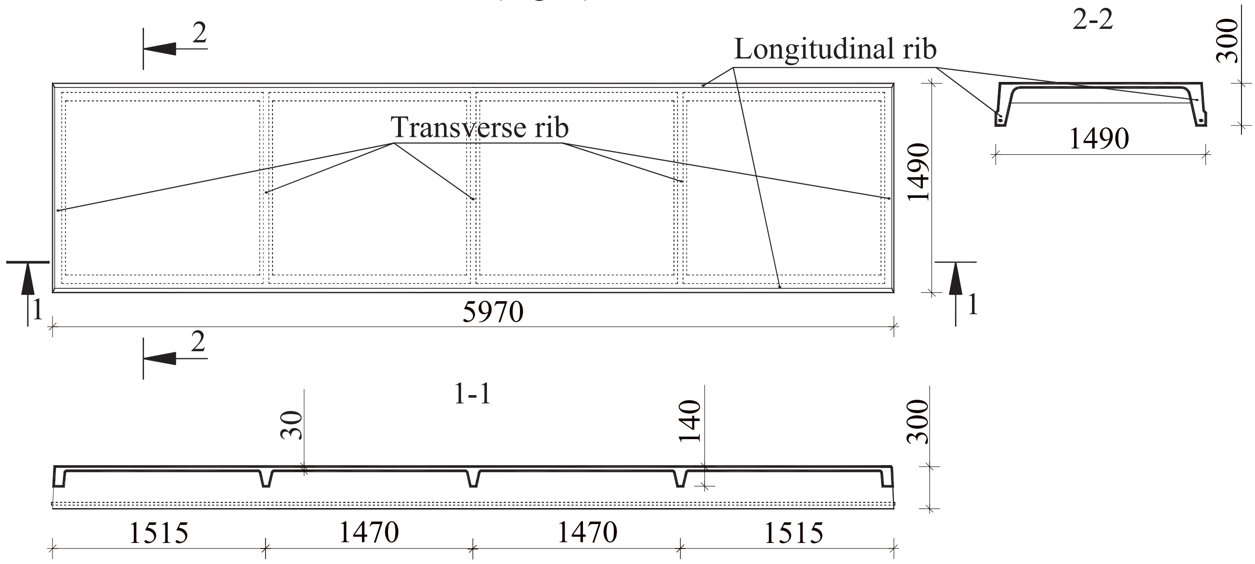

Fig. 1. Top view, longitudinal and transversal section of a precast ribbed panel

Non-prestressed concrete panels of mark PKZH were manufactured (in accordance with GOST 7740-55) from the 1950s until 1964…1965. Prestressed concrete panels of mark PNS were produced from 1964…1965 until at least 1990. Panels PNS-3 was produced in the relatively short period of transition from panel mark PKZH to PNS. Since the mid-1960-ies, production of panels PNS-12 (a further development of PNS-3) and PNS-14 started (Series PK-01-111, 1961).

Over the past few decades, research has been conducted to study the effect of corrosion on the mechanical behaviour of concrete beams or slabs by using accelerated corrosion tests in laboratory. However, laboratory studies cannot fully represent all the aspects of the on-site behaviour of concrete structures. Unfortunately, structural tests concerning the existing corroded reinforced concrete members (Durham et al., 2007; Heymsfield et al., 2007) are rare. Research objects are difficult to find since the owners wish to exploit the concrete structures of a building as long as possible and not to give them away for testing.

Consequently, the first objective of the research is to find the residual flexural strength and behaviour of the existing precast concrete ribbed panels. The second objective is to clarify whether it is possible to estimate the load capacity of a ribbed panel according to visually discernible corrosion damage. Methods that can correlate visual damage with rating categories that are indicative of structural performance are lacking (Higgins & Farrow, 2006).

Research significance. Numerous studies have been conducted regarding chloride or CO_2 penetration and prediction of corrosion initiation. However, few investigators have dealt with corrosion propagation and even fewer with residual load capacity of corroded concrete structures. Unfortunately, tests with real, existing structures are scarce in literature, but those are valuable to substantiate the findings from laboratory study with accelerated corrosion. This study presents the results of visual assessment and flexural tests of 46 existing precast concrete ribbed panels. The reported data are relevant as an experimental reference to models employed in a long service life, structural capacity predictions, and repair optimization.

MATERIALS AND METHODS

Visual scale for assessing the degree of deterioration. Before structural tests, the panels were assessed on a scale developed at the Chair of Structural Mechanics of the former Estonian Agricultural Academy (now EMU) in 1974. Grades were applied to assess visually the changes in the functional state of the panels based on the condition of steel reinforcement and concrete cover. The visual assessment scale distinguishes between six different states as shown in Table 1. If even one feature of a lower grade can be determined during the inspection process, this lower grade is assigned to the reinforced concrete ribbed panel.

Table 1. Classification of deterioration states of the ribbed ceiling panels

Grade	Description of state
5	No corrosion detected
4	1) Less than 20% of the concrete cover of a slab has spalled; 2) Noticeable longitudinal cracks (0.3-1.0mm) in transverse ribs.
3	1) More than 20% of the concrete cover of slab reinforcement has spalled; 2) Less than 20% of the concrete cover of stirrups in the longitudinal ribs has spalled; 3) In transverse ribs wide (>1.0mm) cracks have occurred; 4) Less than 20% of the concrete cover in transverse ribs has spalled.
2	1) More than 20% of the concrete cover of stirrups in longitudinal ribs has spalled; 2) More than 20% of the concrete cover of reinforcement in transverse ribs has spalled; 3) Longitudinal micro cracks (0-0.3mm) due to corrosion in longitudinal ribs.
1	Longitudinal cracks (> 0.3mm) in longitudinal ribs;
0	Concrete cover of the reinforcement in longitudinal ribs has spalled.

Changes in the condition of structures estimated by visual inspection are best described by the assessment of the different deterioration states of ribbed ceiling panels. Ribbed panels have different thickness of concrete cover and diameter of reinforcing bars in slabs, transversal and longitudinal ribs. For example, the ribbed panel of mark PNS-12 has a 10mm concrete cover in the slab, 15mm in transversal and 25mm in longitudinal rib (Series PK-01-111, 1961). This means that in the case of carbonation induced corrosion, generally, the first visual deterioration will first occur in slabs, then in transversal ribs and, finally, in longitudinal ribs.

Structural test series. In this research, structural tests with 46 existing reinforced and pre-stressed concrete ribbed panels were carried out to find their residual flexural capacity. Current study is based on the series of tests of ribbed panels at EMU since 1973. 14 reinforced concrete (RC) panels of mark PKZH-2 and 32 pre-stressed concrete (PC) panels of mark PNS-3, PNS-12 and PNS-14 were tested. Generally, the mark was painted on the panel after curing in the factory already. In the absence of the painted mark, the diameter of the longitudinal working rebar was measured to determine the mark of a panel. The length and width of all panels were 5970mm and 1490mm, respectively. The summary of test series is presented in Table 2. Letter(s) in the first column is associated with the location of panels. RC panels are marked with a hyphen between the letter and the number, while PC panels are marked without a hyphen.

Table 2. Test series of reinforced and prestressed concrete ribbed panels

Panels (amount)	Mark	Object and purpose	Test location	Loading, location	Test year	Age of panels	Test performer
K-1 ... K-7 (7)	PKZH-2	Kärstna pigsty	Kärstna field tests	Sand uniformly, soil	1973	12	J. Miljan
K-8 ... K-10 (3)	PKZH-2	Kärstna pigsty	Tallinn, test hall	Cast iron loads uniformly, RC floor	1974	13	J. Miljan
P11 ... P13 (3)	PNS-3	Pandivere pigsty	Tallinn, test hall	Cast iron loads uniformly, RC floor	1974	10	J. Miljan
VA14 … VA19 (6)	PNS-3	Vao pigsty	Vao field tests	RC foundation blocks uniformly, soil	1975	11	J. Miljan
T-20 … T-23 (4)	PKZH-2	Torma cowshed	Torma field tests	RC curbstones uniformly, soil	1978	15	J. Miljan
L1 … L10 (10)	PNS-12. PNS-14	Luha cowshed	Tartu, EMU lab	Hydrocylinder, 4-point bending, RC force floor	2000 - 2001	26	E. Laiakask
R1 … R8 (8)	PNS-12	Raadi garage	Tartu, EMU lab	Hydrocylinder, 4-point	2002	Un-know	M. Kiviste,

				bending, RC force floor		n	H. Tomann, M. Tarto
V8 … V12 (5)	PNS-12, PNS-14	Corridor of Vara pigsty	Tartu, EMÜ lab	Hydrocylinder, 4-point bending, RC force floor	2005	32	R. Halgma, L. Linnus, T. Salu

As shown in Table 2, all tested panels had been in service for at least 10 years. The panels were demounted and singly loaded. The panels were tested in laboratory (K-8 - K-10, P11 - P13, L1 - L10, R1 - R8, V8 - V12) as well as on site (K-1 - K-7, VA14 - VA19, T-20 … T-23). Structural tests with pre-stressed ribbed panels of mark PNS-12 and PNS-14 are discussed in more detail in another paper.

The panels were lifted to RC blocks, which acted as sub supports. Singly tested panels were simply supported on a steel pin and roller support. All tested panels were loaded in increments of 10% of the control load (q_c) which was kept constant for at least ten minutes on each stage (GOST 8829-85).

The control load was set to test new panels issued from the factory. A few randomly chosen new panels were tested in the factory to check their crack resistance, rigidity and load capacity up to one increment higher than the control load. Repetition tests were due if the ultimate load of a panel issued from the factory was less than the control load but not less than 85% of the control load. The panels did not meet the strength requirements, if a single ultimate load in primary or repetition tests would be less then 85% of the control load (Series PK-01-111, 1961). The design load (q_d) was implemented by the structural engineering design of a building.

In all test series, uniformly distributed loads were imitated to compare the results with the control and design load. The panels were tested to failure or limit state, where deflections of a panel increased without additional load (GOST 8829-85). The maximum load a panel could carry was recorded as the ultimate load (q_u). The existing cracks and cracks developing during the test were carefully recorded with a marker on the panel surface.

Vertical displacements were measured at four corners (on supports) and on both longitudinal ribs at the mid-span of a panel. Generally, precision dial gauges of 0.01mm were applied at the corners and compliant measuring gauges (type Maksimov) of precision 0.1mm and 0.01mm at mid-span of a rib. The mid-span deflection of a panel was calculated as a difference of the mean mid-span deflection of both longitudinal ribs and of the mean displacement at panel supports (GOST 8829-85).

RESULTS AND DISCUSSION

Ultimate residual strength of existing ribbed panels. To compare the residual strength of panels of 4 different marks, the ratio (q_u/q_c) of ultimate load and control load was calculated. The one-way analysis of variance (ANOVA) did not reveal significant difference in the average ratio of ultimate load and control load by the panel marks (PKZH-2, PNS-3, PNS-12, PNS-14) at the confidence level

$\alpha=0.05$. Also, for purpose of comparison, the ultimate load (q_u) of test panels was divided by the design load (q_d).

The control loads of panels PKZH-2, PNS-3 (later PNS-12) and PNS-14 are 387 (GOST 7740-55), 750 (Series PK-01-111, 1961) and 1440 kgf/m^2 (Series PK-01-111, 1961), transformed to kN/m^2 in Fig. 4-7, respectively. The design loads of panels PKZH-2, PNS-3 (later PNS-12) and PNS-14 are 270 (GOST 7740-55), 460 (Series PK-01-111, 1961) and 950 kgf/m^2 (Series PK-01-111, 1961), transformed to kN/m^2 in Fig. 4-7, respectively. The results of visual assessment and flexural test of ribbed panels are presented in Table 3.

Table 3. Results of visual assessment and flexural test of ribbed panels

Panel	Mark	Grade	q_u, kN/m^2	q_u/q_c	q_u/q_d	Failure mode
K-1	PKZH-2	0	4.52	1.19	1.71	TR
K-2	PKZH-2	1	5.18	1.36	1.96	FD
K-3	PKZH-2	0	3.97	1.05	1.50	FD
K-4	PKZH-2	1	4.79	1.26	1.81	FD
K-5	PKZH-2	1	5.16	1.36	1.95	FD
K-6	PKZH-2	0	4.31	1.14	1.63	LR
K-7	PKZH-2	1	4.54	1.20	1.71	TR
K-8	PKZH-2	0	4.10	1.08	1.55	FD
K-9	PKZH-2	0	2.67	0.70	1.01	FD
K-10	PKZH-2	0	2.67	0.70	1.01	SU
P11	PNS-3	2	11.01	1.50	2.44	FD
P12	PNS-3	1	8.07	1.10	1.79	FD
P13	PNS-3	2	9.56	1.30	2.12	FD
VA14	PNS-3	1	8.79	1.19	1.95	FD
VA15	PNS-3	1	8.79	1.19	1.95	FD
VA16	PNS-3	2	9.90	1.35	2.20	FD
VA17	PNS-3	2	9.90	1.35	2.20	FD
VA18	PNS-3	2	9.90	1.35	2.20	FD
VA19	PNS-3	2	9.90	1.35	2.20	FD
T-20	PKZ-2	1	5.64	1.49	2.13	FD
T-21	PKZ-2	2	5.94	1.57	2.24	FD
T-22	PKZ-2	1	5.64	1.49	2.13	FD
T-23	PKZ-2	1	5.43	1.43	2.05	FD
L1	PNS-12	0	9.00	1.23	2.00	FD
L2	PNS-12	4	9.20	1.25	2.04	FD
L3	PNS-12	1	9.25	1.26	2.05	FD
L4	PNS-12	3	9.70	1.30	2.15	FD
L5	PNS-12	1	9.75	1.33	2.16	FD
L9	PNS-12	3	9.04	1.23	2.00	FD
L6	PNS-14	5	16.95	1.20	1.82	FD
L7	PNS-14	0	13.56	0.96	1.46	WR
L8	PNS-14	0	10.17	0.72	1.09	WR
L10	PNS-14	0	15.82	1.12	1.70	SH
R1	PNS-12	0	8.35	1.14	1.85	FD
R2	PNS-12	0	7.26	0.99	1.61	FD

R3	PNS-12	1	9.12	1.24	2.02	FD
R4	PNS-12	1	9.64	1.31	2.14	FD
R5	PNS-12	1	9.86	1.34	2.19	FD
R6	PNS-12	0	8.59	1.17	1.90	FD
R7	PNS-12	1	7.91	1.08	1.75	WR
R8	PNS-12	0	8.28	1.13	1.84	FD
V8	PNS-12	0	9.00	1.22	2.00	SH
V9	PNS-12	0	10.53	1.43	2.33	FD
V10	PNS-12	1	8.80	1.20	1.95	FD
V11	PNS-12	2	9.30	1.26	2.06	FD
V12	PNS-14	1	15.28	1.08	1.64	SH

Failure: FD – flexural ductile, TR – rebar rupture in transversal rib, LR – rebar rupture in longitudinal rib, SU – failure of longitudinal rib near support, WR – weld rupture at support, SH – shear.

The influence of visual appearance (grade) on load capacity (q_u/q_c) of 46 singly tested panels is presented in Fig. 2. Box plot in Fig. 2 was generated with statistical software R. The box plot shows the distribution of the data points around the median (thick horizontal line in Fig. 2), indicating upper and lower quartiles (horizontal edges of the box) and minimum and maximum values (ends of vertical bar).

Fig. 2 shows non-linear decreasing trend of q_u/q_c ratio with decreasing grade of panel. Only a few samples of high grades exist in the current data set. Neither statistical nor substantial reasons exist to assume a trend in q_u/q_c ratio at grade 2 or higher. However, box plots from grade 2 to 0 demonstrate evident decrease of q_u/q_c ratio. The one-way ANOVA revealed a significant effect for grades, $F(5,40) = 5.35; p = 0.0007$. The magnitude of the grade to q_u/q_c ratio was computed as $R^2 = 0.40$. The Tukey HSD test for multiple comparison of means proved a significant difference in q_u/q_c ratio between grade 0 and higher grades.

The ultimate load of only five of the 46 singly tested panels was less than the control load. All of these five panels received grade 0 on a visual rating scale. Consequently, attention should be paid to panels where the concrete cover of longitudinal reinforcement has spalled (grade 0), which could be a sign of decreased load capacity. The visual scale proposed in the paper has the potential to serve as a rational tool for practitioners, operators and asset managers to make decisions about the optimal timing for repairs, strengthening, and/or rehabilitation of corrosion-affected concrete infrastructure. Scale-acquainted engineers can rate reinforced concrete structures relatively quickly and simply to fetch out ribbed ceiling panels (if any) of the spalled concrete cover. Later on the residual flexural capacity of panels with grade 0 needs a structural expert's judgment.

It is also worth mentioning that no panels with a corrosion-induced crack in longitudinal rib (grade 1) were dangerous from the aspect of ultimate residual load capacity.

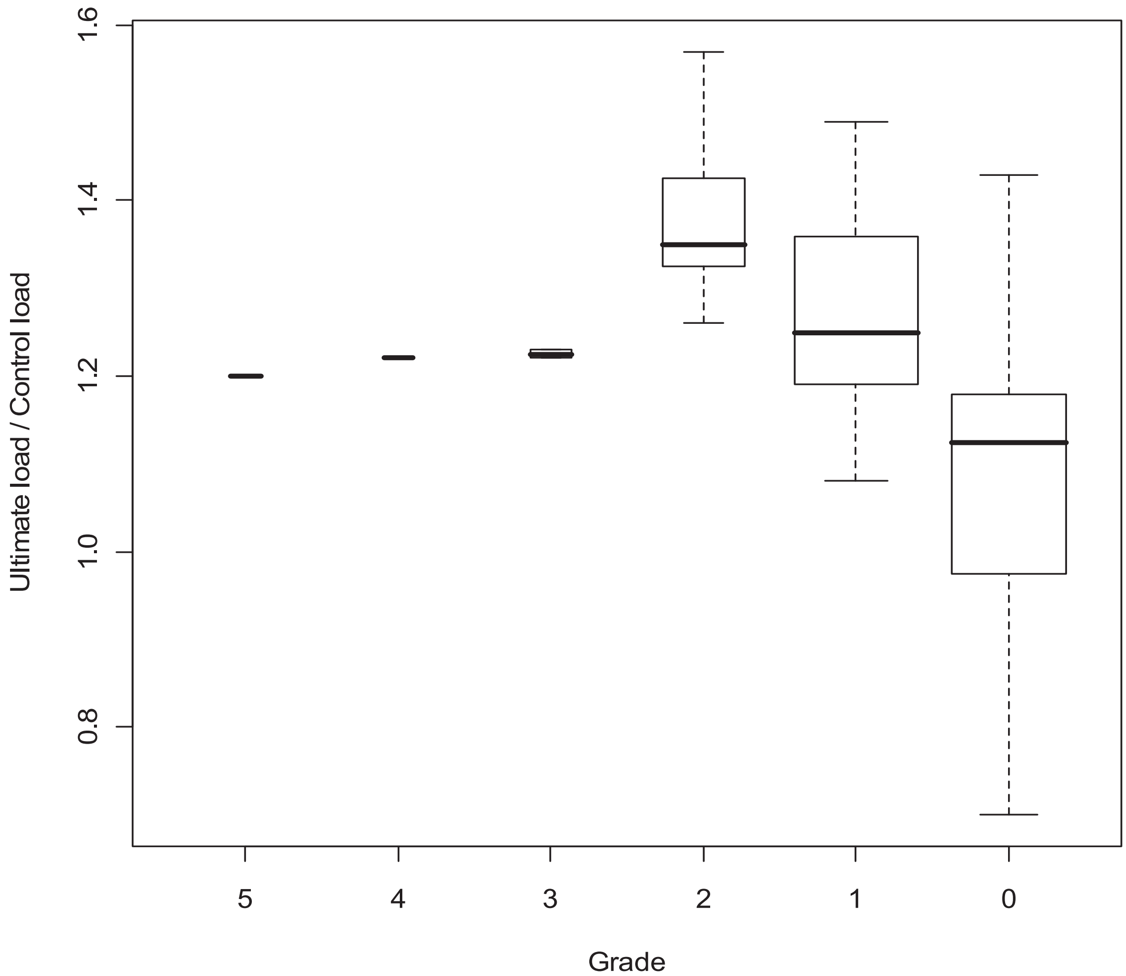

Fig. 2. Box plot of q_u/q_c ratio for singly tested panels of different visual grades. The box plots show distribution characteristics: the median (thick horizontal line), upper and lower quartiles (horizontal edges of the box) and minimum and maximum values (ends of vertical bar) of the q_u/q_c ratio by different grades

Fig. 2 demonstrates that q_u/q_c ratio varies the most in panels with a spalled concrete cover (grade 0). This means that panels, which may have just reached grade 0 as well as panels in critical state in terms of their load capacity are both rated as grade 0. Consequently, panels with a spalled concrete cover should be differentiated to specify their different residual load capacity. Deterioration states employed for panel classification in the current study (in Table 1) were developed already in 1974 and could be updated. Durham et al. (2007); Heymsfield et al. (2007) have tested 33 existing precast non-prestressed channel beams, which were used in short multi-span bridges in Arkansas in the 1950s through the early 1970s. The beams, constructed without shear reinforcement, were categorized as 'good', 'average' or 'poor' as a function of percentage and location of exposed longitudinal reinforcing steel. All these three classifications correspond to grade 0 on the visual rating scale of the current study.

The original objective of the study by Heymsfield et al. (2007) was to establish a correlation for inspection purposes between the beam's visual deteriorated state and its corresponding approximate structural capacity. 5.79m channel beams with similar cross section (ribbed slab) were tested also on a four-point loading frame. It was found that the strength of beams was more a function of a concrete compressive strength rather than deterioration state.

Torres-Acosta et al. (2007) have proposed a durability model based on experimental load capacity values from various investigations (Tachibana et al., 1990; Almusallam et al., 1996; Almusallam et al., 1997; Huang & Yang, 1997; Rodriguez et al., 1997; Mangat & Elgarf, 1999), where results of different structural members (beams, slabs) under accelerated corrosion were presented. Unfortunately, the results of the current study are directly incomparable to the previously mentioned ones due to the absence of control data (new and not corroded) panels and rebar radius loss. Fig. 3 represents an illustrative load-capacity model for a reinforced (or pre-stressed) concrete flexural member (RCM) referred to in Torres-Acosta et al. (2007) and the current study with the addition of research results by Heymsfield et al. (2007) and Li et al. (2008). The model presents the structural load capacity of a RCM as a function of its lifetime. The lifetime T of the flexural member is defined as:

$$T = T_I + T_P + T_{RL} \tag{1}$$

where T_I is the corrosion initiation stage from the time of construction to the time of corrosion initiation; T_P is the corrosion propagation stage during which the steel corrodes until an unacceptable level of corrosion is reached; and T_{RL} is residual life stage from serviceability to ultimate limit state.

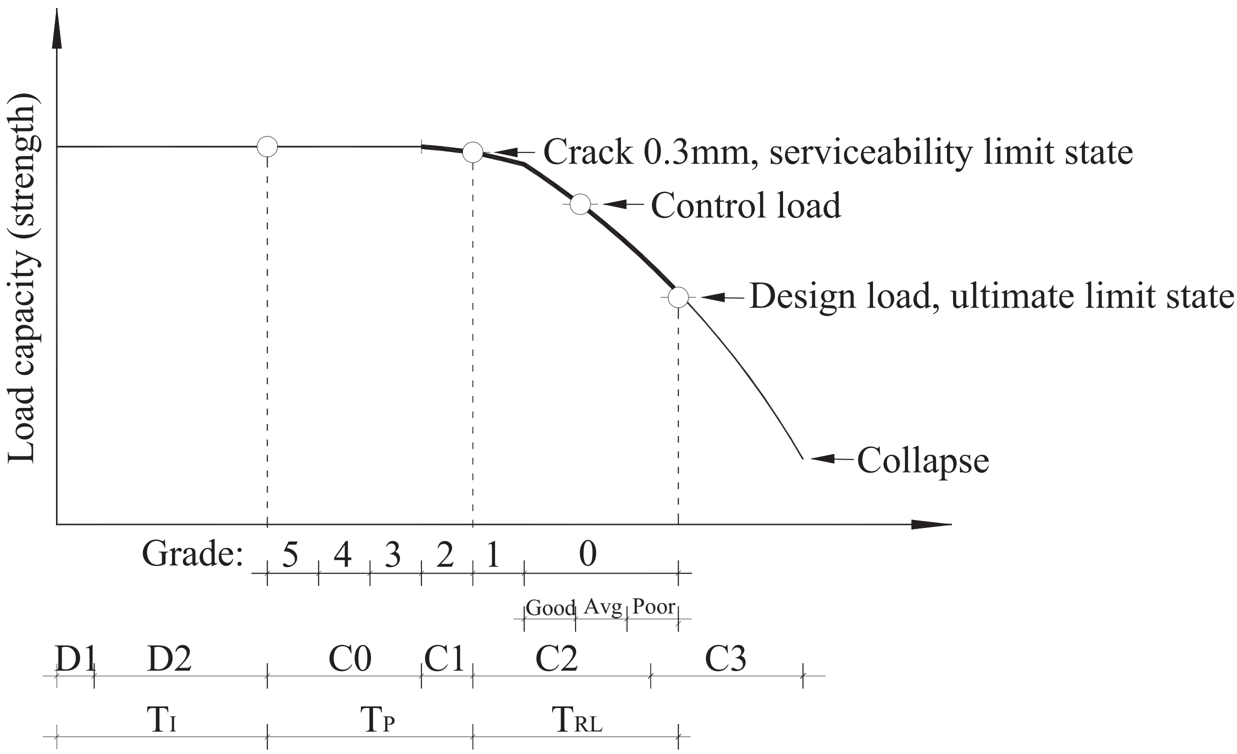

Fig. 3. Load-bearing capacity model for a RCM. Based on Torres-Acosta et al. (2007) and current study with the addition of research results by Heymsfield et al. (2007); Li et al. (2008)

As corrosion progresses, there will be an increasing build-up of corrosion products and associated increased radial stresses, causing longitudinal cracking and, eventually, concrete spalling. In this study, the unacceptable level is defined as corrosion-induced crack in longitudinal rib of a panel if it is more than 0.3mm wide (grade 1). This might also be implied as serviceability limit state of a ribbed panel. Li et al. (2008) stated that once the structure is considered to be unserviceable due to corrosion-induced cracking, there is considerable lifetime left before the structure can be considered to be unsafe. Residual life stage T_{RL} starts from the time the structure becomes unserviceable until the ultimate limit state is reached, before structural collapse.

The categorization of 'good', 'average' and 'poor' by Heymsfield et al. (2007) is also included in Fig. 3. An attempt has to be made to add the six detailed phases of the phenomenological model (Li et al., 2008) for steel corrosion in concrete. However, the model by Li et al. (2008) has a different approach. The latter differentiates six phases (D1, D2, C0, C1, C2, C3) from the mechanics of corrosion applied to the steel bar at a generic cross section of a reinforced concrete member. In addition, the initiation period of the model was based on corrosion induced by chloride attack. It was found that, for practical flexural members subject to chloride attacks, corrosion initiation may start quite early in their service life (Li et al., 2008).

As mentioned before, all panels with visual grade 1 or higher overreached the control load, which explains the location of control load on time axis. Since the structural engineering designers based their calculations on design load, the latter is employed as an equivalent of ultimate limit state in Fig. 3. Thick load capacity line in Fig. 3 represents the period for RCM covered by current structural tests. As observed in Fig. 2 and Fig. 3, the structural load capacity remains almost the same during initiation and propagation period until reaching grade 0 (in residual life period), where the capacity decrease rate is accelerated.

Investigations have been conducted during the past three decades regarding chloride or CO_2 penetration and prediction of corrosion initiation (T_I length). However, few investigators have dealt with corrosion propagation T_P and even less with residual life T_{RL} predictions, which are also needed for durability forecasting (Torres-Acosta et al., 2007). Unfortunately, structural tests with real existing structures are scarce in literature.

Since research data on the residual flexural capacity of the existing structures are rare, the results of the current study are compared to those of accelerated corrosion. However, accelerated corrosion processes simulating real structure corrosion degradation are quite complicated and do not always give comparable results (Torres-Acosta et al., 2007). Commonly, the galvanostatic method is used for accelerating steel bar corrosion in concrete. The surface characteristics of the corroded steel bar, however, are found to be different when corrosion is induced by the galvanostatic method or by the natural environment (Yuan et al., 2007).

Flexural behaviour and failure mode of existing ribbed panels. The flexural behaviour of all test panels is presented in Fig. 4-7 in terms of their load-deflection curves. The curves of panel with grade 2 or higher (no visual deterioration or micro-cracks in longitudinal ribs) are shown with a solid line. A dashed line with long dashes or short dashes describes the load-deflection curve of panels, which received grade 1 or 0, respectively. Panels from the same test series have identical curve markers (if any). Generally, curve markers denote different load increments, except for Fig. 5, where no data has been left to describe different load increments (of panels PNS-3).

Fig. 4 shows the load-deflection curves of 14 reinforced concrete panels of mark PKZH-2. Fig. 4 presents that panels with a lower visual grade tend to have larger deflections at the same load. For example, at control load panel with grade 2 has deflected 6mm, while panels with grade 1 (except for K-5) and 0 have deflected 8…10mm and at least 17mm, respectively. Panels K-3, K-6 and K-8 (with grade 0) deflected at least 40mm at the control load. This trend conforms to Azad et al. (2007), who found that corroded beams had higher deflection than the corresponding control beams at the same load due to degrading stiffness. However, Azad et al. (2007) applied sodium chloride and direct current to initiate and accelerate corrosion, respectively, which complicates the comparison with the current study. It should be noted that only a limited amount of panels of different grades is presented in Fig. 4-7.

The statement that lower grade panels have larger deflections is not clear with panels PNS-3, PNS-12 and PNS-14 in Fig. 5-7. Yet, the majority of panels with grade 0 exhibited larger deflections under load than panels with higher grades.

Although not measured in all test panels, significant initial deflection might appear in existing panels after long-term service. The authors have found that some panels PNS-12 with visual assessment grade 0 differed from others by their relatively large initial deflections of 18mm or more and herewith failed to meet the limit state of deflection. Apart from the loss of flexural capacity, reinforcement corrosion is the primary cause of higher deflections that may lead to serviceability problems.

Of the 46 panels tested, flexural ductile mode of failure was noticed in 36 panels in Table 3. These panels reached a yield plateau, where deflections increased rapidly without considerable load addition. The unconventional failure mode of other 10 panels is marked in superscript on the panel's label in Fig. 4-7. All those 10 panels had serious visual corrosion deterioration and received either grade 0 (7 panels) or grade 1 (3 panels). However, 16 panels with visual grade 0 and 18 panels with grade 1 were tested. The one-way ANOVA did not reveal significant effect of failure mode on average grade of panel, $F(5,44) = 1.59$; $p = 0.18$.

Fig. 4 shows that panels K-1, K-7 and K-10 exhibited no yield plateau. Panels K-1, K-7 failed due to rebar fracture in transversal rib. Accumulation of sand in the middle of transversal rib might have caused that mode of failure. Longitudinal rib of panel K-10 failed near support. Concrete in failure place was crumbled prior to loading tests probably because of poor construction quality. Longitudinal rib of panel K-6 failed in mid-span region due to rebar fracture although panel demonstrated yielding (in Fig. 4) before fracture. Of the 50 panels, only panel K-6 demonstrated longitudinal rebar fracture. Corrosion caused severe reduction of cross-section in longitudinal rebar of panel K-6 was detected on visual inspection. Unfortunately no rebar tensile test was performed in test series K-1…K-7 to verify the ultimate strength or ductility of longitudinal rebar in panel K-6.

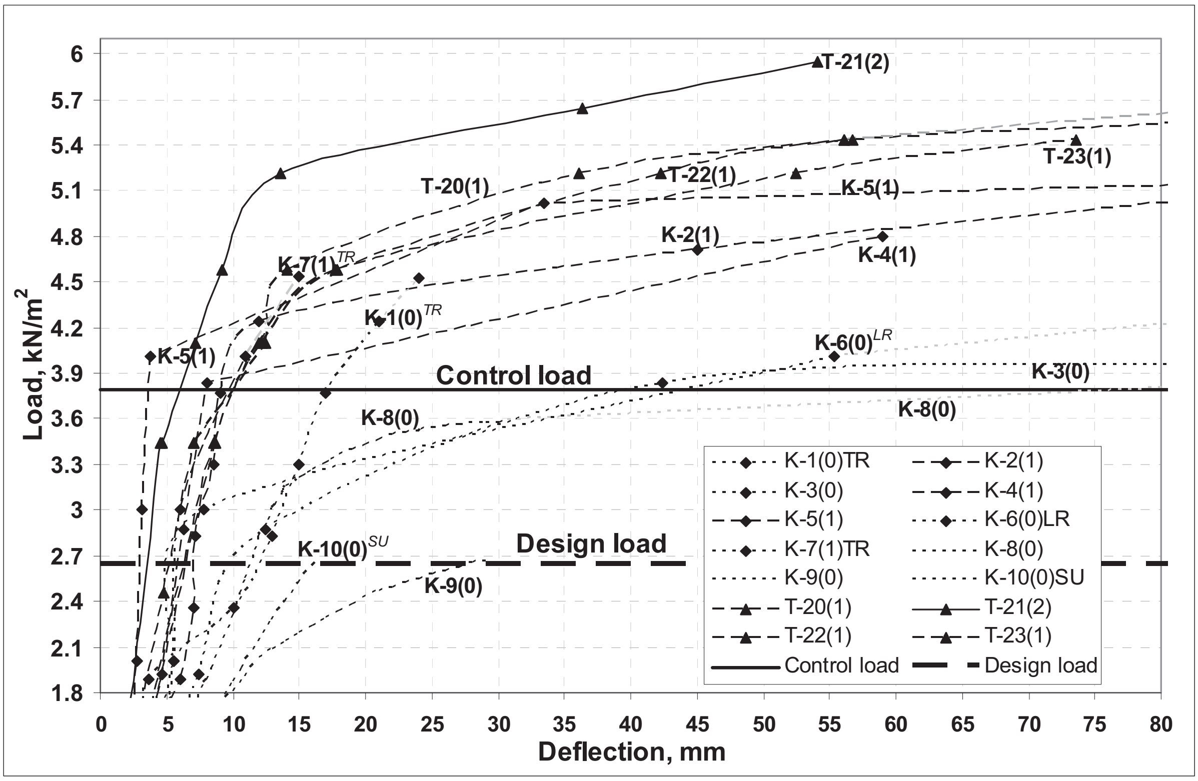

Fig. 4. Load-deflection curves of 14 reinforced concrete panels PKZH-2

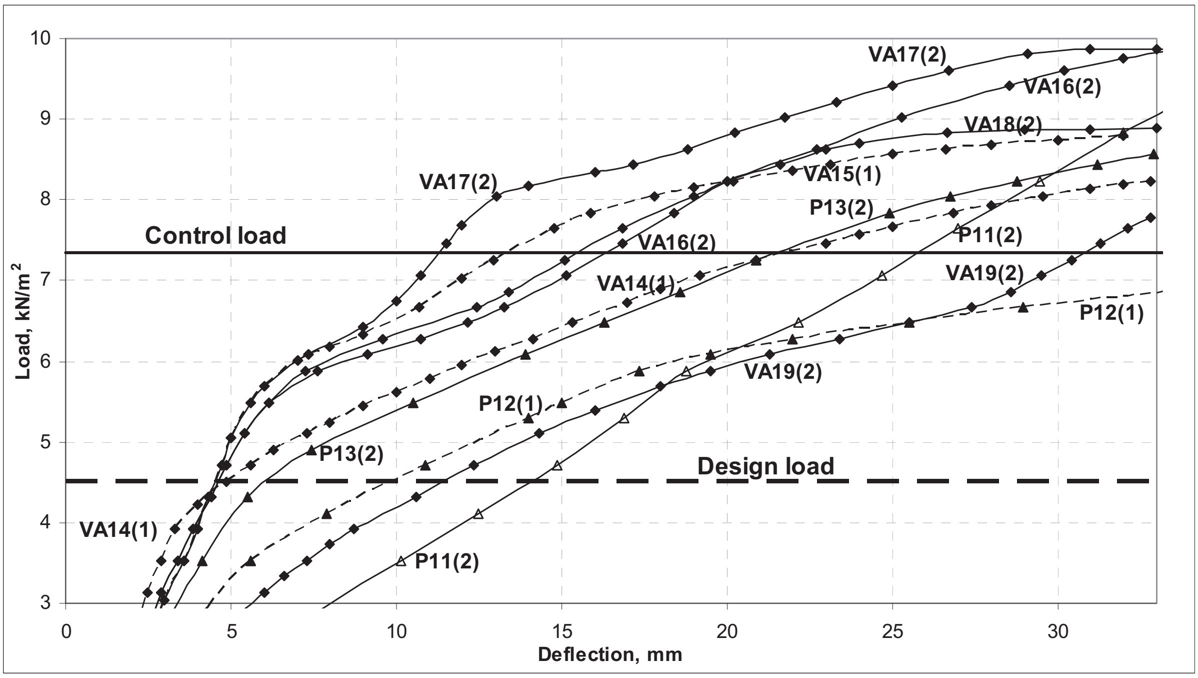

Fig. 5. Load-deflection curves of 9 prestressed concrete panels PNS-3

Fig. 4 shows that panels K-1, K-7 and K-10 exhibited no yield plateau. Panels K-1, K-7 failed due to rebar fracture in transversal rib. Accumulation of sand in the middle of transversal rib might have caused that mode of failure. Longitudinal rib of panel K-10 failed near support. Concrete in failure place was crumbled prior to loading tests probably because of poor construction quality.

Longitudinal rib of panel K-6 failed in mid-span region due to rebar fracture although panel demonstrated yielding (in Fig. 4) before fracture. Of the 50 panels, only panel K-6 demonstrated longitudinal rebar fracture. Corrosion caused severe reduction of cross-section in longitudinal rebar of panel K-6 was detected on visual inspection. Unfortunately no rebar tensile test was performed in test series K-1…K-7 to verify the ultimate strength or ductility of longitudinal rebar in panel K-6.

The failure mode of all nine panels PNS-3 was flexural ductile, which could also be deduced from the load-deflection plots in Fig. 5. The almost linear curve of panel P11 should be pointed out. The other panels PNS-3 demonstrated yielding.

Pre-stressing bars are welded to the details at the support ends of panels PNS-12 and PNS-14 (series PK-01-111, 1961). Weld rupture at support occurred with panels R7 (Fig. 6), L7 and L8 (Fig. 7). These panels showed also a relatively low (but not significant) q_u/q_c ratio when compared to other panels.

Panels V8 (in Fig. 6), L10 and V12 (in Fig. 7) failed in shear with a large inclined crack appearing at the point of concentrated load application. This type of failure can be accounted for by the four-point bending loading arrangement involved.

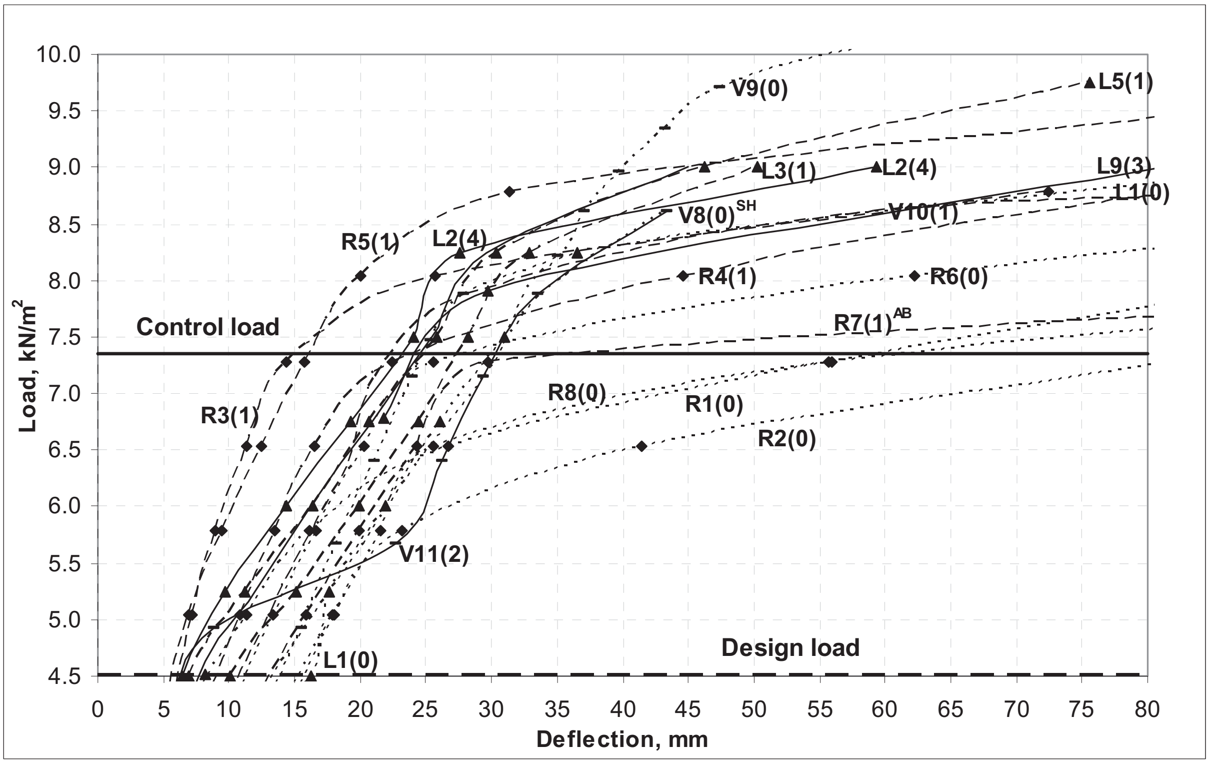

Fig. 6. Load-deflection curves of 18 prestressed concrete panels PNS-12

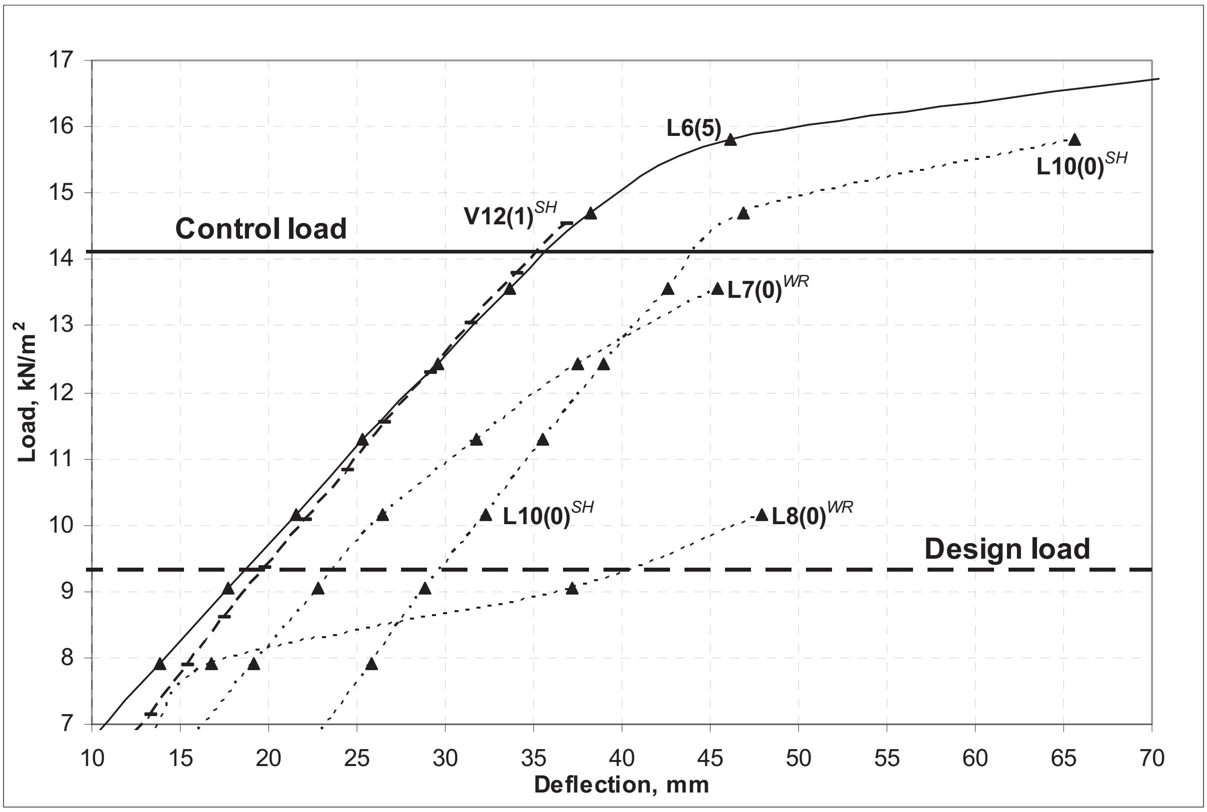

Fig. 7. Load-deflection curves of 5 prestressed concrete panels PNS-14

CONCLUSIONS

Based on the results of the current experimental investigation of the existing precast concrete ribbed panels, the following conclusions can be drawn:

1. All panels, the ultimate load of which was lower than that of the control load, received grade 0 on visual rating scale. Consequently, attention should be paid to panels where the concrete cover of longitudinal reinforcement has spalled (grade 0), which could be a sign of decreasing load capacity.
2. The majority of panels with grade 0 exhibited larger deflections under load than panels with higher grades. Apart from the loss of flexural capacity, reinforcement corrosion also produces higher deflection that may lead to serviceability problems.
3. Of the 46 panels tested, flexural ductile mode of failure was noticed in 36 panels. Other 10 panels had serious visual corrosion deterioration and received either grade 0 (7 panels) or grade 1 (3 panels).

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Prevalence of Musculoskeletal Disorders, Assessment of Parameters of Muscle Tone and Health Status among Office Workers

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Abstract. Our way of life has changed considerably because of increased computer usage. Usually people do not think about links between computer work, fatigue and musculoskeletal disorders.

The aim of the study was to examine the prevalence of musculoskeletal pains, assess the musculoskeletal status and general health condition and to analyze associations between these indices. The methods of the study were based on a questionnaire, myometry and dynamometry. The most common musculoskeletal pains among office workers were neck pain (51.5%) and lower back pain (41.7%). Pains in the hands/wrists (34.5%), knees (29.9%) and elbows (14.6%) were less reported. The measurements of m. *trapezius* showed that the values of the tone were higher in the afternoon. Also, the most values of *m. erector spinae* were higher in the afternoon. The measurements of the grip strength showed a decrease in strength during the day.

The study confirmed the results of many earlier studies that the most common pains among office workers are neck and lower back pains. Office work is a burden especially for the *m. trapezius* and also for the *m. erector spinae*.

Key words: Office workers, musculoskeletal pains, health status, myometry, dynamometry

INTRODUCTION

The rapid development of information technology during the last decades has resulted in a number of changes in the work-life of people (Eltayeb et al., 2007). Regarding the development of technology, the share of physical labour has decreased and the share of mental work has increased. Due to this fact, the number of computer users has noticeably increased as well. In most of the European countries more than half of the working population are computer workers, millions of people are using computer several hours each day (Europan Agency for Safety and Health at Work, 2008). In relation to the use of computers, frequent occurrence of musculoskeletal disorders can be noticed. Several publications have shown that computer work increases the risk of musculoskeletal disorders and according to studies, musculoskeletal pain occurs usually in the neck and in the lower back (Klussmann et al., 2008; Hush et al., 2005; Woods, 2005; Janwantanakul et al., 2008). The assessment of the musculoskeletal status by myometry has not been used much so far but this method has become more popular.

The aim of the study was to examine prevalence of musculoskeletal disorders, parameters of muscle tone and burnout among office workers.

METHODS

The research has been carried out within the framework of the international work and health survey 'Cultural and Psychosocial Influences on Disability' in the participation of 19 countries. The target group was formed by office workers from the University of Tartu and Estonian University of Life Sciences (n=415), whose work involves monotony, forced positions and repetitive movements. The selection criteria for the research participants were following: 1) the length of computer use per working day was to be at least 4 hours; 2) the age of research participants was to be 20...59 years; 3) the length of employment in the present position was to be at least 12 months. The employees who met those criteria formed a sample group.

For the analysis of the results, a questionnaire ('International survey of work and health') has been developed by the University of Southampton based on an international validated questionnaire which has been translated and supplemented by the research authors (Tuomi et al., 1994). The questionnaire consisted of seven parts (76 questions), which involved information about the employee (7), information about his/her current work (9), aches and pains (25), other people`s pain (4), views of the causes and prevention of pain (3), about the general health of the employee (6) and feelings concerning work and colleagues (22). This article does not include the results of the last part of the questionnaire. The questionnaire provided a survey on the employee and the work, on the occurrence of pain in lower back, neck, shoulders, elbows, hands/wrists and knees, on the general health and work ability and on signs of burnout. The questionnaire allowed yes/no answers to the questions about the distribution of pains, and moreover, specification of the exact part of the body and assessment of the duration of pains. An estimation of how much other health problems have distressed or bothered the respondent was possible to make on a 5-point scale (0 – not at all; 1 – a little bit; 2 – moderately; 3 – quite a bit; 4 – extremely).

Myometer 'MYOTON-3' was used to diagnose the functional state of the skeletal muscles of office workers. Myometer is a hand held device developed at the University of Tartu. Myoton exerts a local impact on the biological tissue by means of a brief mechanical impulse. The impact force is small enough so that it does not cause changes in the biological tissue or neurological reactions. The tissue responds to the mechanical impact with damping oscillation which is registered by an acceleration sensor located on the measuring tip of the device. Microprocessor saves and analyzes the signal and outputs the parameters of tone (frequency of the oscillation Hz), elasticity (logaritmic decrement of damping of the oscillation), and stiffness ($N\ m^{-1}$) of the tissue. The results are transfered to a computer; the data is stored and can be visualized as reports, normative measures and graphical evaluations. Muscle performing the movement (agonist) stretches out the antagonist muscle, the speed and ease of the movement is directly related to the stiffness of the antagonist muscle – muscles with higher stiffness require more force for stretching, leading to less economical movement. Muscle elasticity describes the conditions for increasing the frequency of movements and blood supply during the effort. A more elastic muscle releases itself more quickly from the tension of the previous contraction – providing better conditions for the blood supply during the effort. The condition for recovery during the period between training (or work effort) is described by muscle tone, increased tone (associated with muscle pain and decreased performance) – worsened conditions for blood flow (Müomeetria Ltd., 2007; Vain, 2006).

Two of the most heavily loaded muscles of the office workers were measured (*musculus trapezius* and *musculus erector spinae)*. The measurements were conducted twice a day – at the beginning and at the end of working day. Ten repetitive measurements were carried out in every point of measurement.

In addition to muscular strain, hand grip strength was measured with hand dynamometer. Hand grip strength was also measured on both hands at the beginning and at the end of the working day.

The basis for the precondition was that half of the surveyed workers experience musculoskeletal disorders in the neck and lower back area and half of them experience no disorders. Altogether 18 office workers consented to participate in the measuring – 9 employees from the University of Tartu and 9 employees from Estonian University of Life Sciences.

For statistical data processing the computing programme SPSS.13 for Windows was applied. The arithmetic mean and standard deviation (*SD*) were calculated. For ascertaining connections between characteristics, Spearman rank correlation analysis (r – correlation coefficient) was applied, differences between groups were tested with χ^2 -statistic and Student's t-test. Difference $p<0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

As a result of a survey conducted in October and November 2008, 243 question forms were returned (response rate 58%), among which 204 office workers who met the selection criteria formed the sample group. 137 of them were from the University of Tartu and 67 from Estonian University of Life Sciences, 31 of them were male and 173 of them were female. The average age was 40.3 (*SD* 10.0) years. The length of employment of approximately two thirds of the respondents (61.4%) was more than five years, of one third (31.4%) up to five years and of a minority (7.2%) less than a year. The mean number of working hours per week was 40.3 (*SD* 5.0) hours. 14% of office workers worked up to 70 hours per week. According to the new labour contract the working time should not be more than 48 hours per week to 7 days period relating to four months period (Töölepinguseadus, 2009). The mean length of computer work per day was 6.6 (*SD* 1.5) hours.

Among all respondents, 80.4% had had musculoskeletal pain in different parts of the body during the last 12 months. Half of all workers (51.5%) reported pain in neck and a little less than half (41.7%) of workers reported pain in lower back. About one-third reported pain in hand/wrist (34.5%), in shoulders (30%), in knees (29.9%) and a small portion of workers reported pain in elbows (14.6%). Shoulder, elbow, hand/wrist and knee pain was studied both in the right and the left limb as well as in both sides of the body, although this presented no statistical differences.

As most employees (91.2%) were right-handed, pains showed a tendency to occur more frequently in the right shoulder and hand area. As for knee pain, both sides of the body were equal. The duration of pain, characterized in Fig. 1, lasted in the case of more than one third of the employees for 1...6 days and in the case of as many employees for 1...4 weeks. Pain lasting for 1...12 months occurred less. More than a quarter of the employees have experienced pain in the neck and knees for longer period of time, slightly less in shoulder, elbow and lower back.

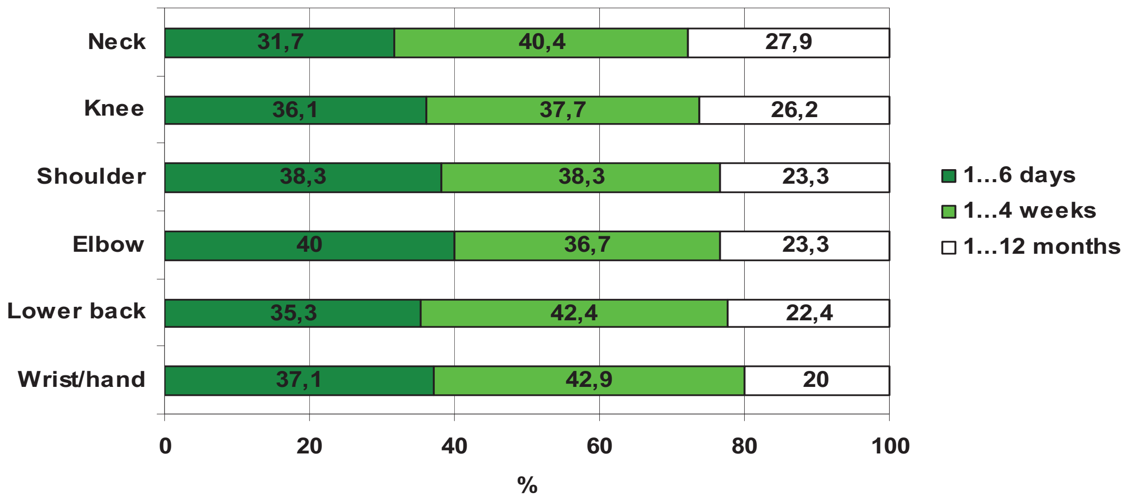

Fig. 1. Musculoskeletal pain duration in different body parts within the last 12 months.

In earlier studies, most of the attention was on the upper limb disorders (Klussmann et al., 2008). Many studies include both upper limb disorders and also upper and lower back pain and headaches (Janwantanakul et al., 2008; Woods, 2005). Pain in knees and other lower limbs (Janwantanakul et al., 2008; Woods, 2005) are examined less because these pains are not directly connected with computer work. The comparison of different studies (Table 1) shows a resemblance between the results. Pains in the neck and lower back were most frequent in all countries, followed by pain in hand/wrist or in shoulders, then pain in knees and pain in elbows. The results of studying Estonian office workers are similar to results from Germany, a bit lower than results from England and higher than results from Thailand.

Table 1. The prevalence of musculoskeletal disorders among office workers during the last 12 months in different countries (% of repondents) (Klussmann et al., 2008; Woods, 2005; Janwantanakul et al., 2008)

Part of the body	Estonia	Germany	England	Thailand
Lower back	42%	-	54%	34%
Neck	52%	55%	58%	42%
Shoulder	30%	38%	37%	16%
Elbow	15%	15%	8%	5%
Hand/wrist	35%	21%	51%	20%
Knee	30%	-	14%	12%

During the last month, the tendency of musculoskeletal pain occurrence has been the same as during the last 12 months. During the last month, the majority of pains occurred in neck (32.4%) and lower back (23.5%). Fewer pains occurred in wrist/hand (20.6%), shoulder area (19.6%), knee (17.6%) and elbow (8.8%). In shoulder and arm area, pain occurred more often on the right-hand side of the body; however, regarding to knee pain, both sides were equal. In approximately two thirds of the employees who had had pains during the last month, the duration of pains had been 1...6 days (Fig. 2). Longer lasting pain was rarer among office workers (pain which lasted more than 2 weeks occurred in about a quarter of the cases in the shoulder area, lower back and neck).

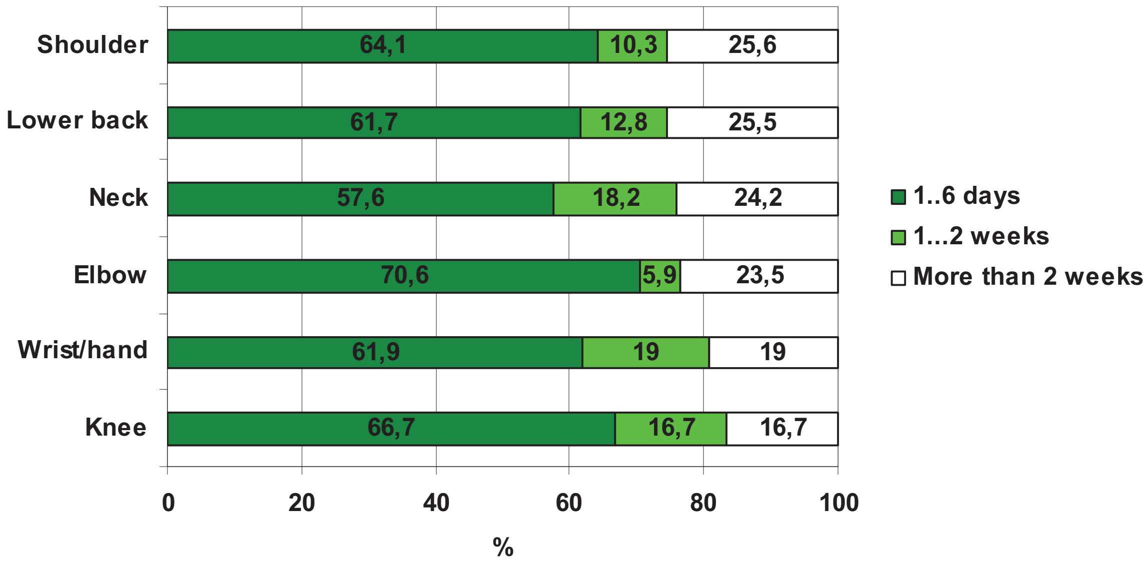

Fig. 2. Musculoskeletal pain duration in different body parts within the last month.

Musculoskeletal pains did not stop the employees from going to work (89.5%) (Fig. 3) and if they did, most sick leaves were taken due to lower back (10.6%) and neck (8.6%) pain. Although more than half of the office workers were convinced that musculoskeletal pain was caused by their work, their sick leave, however, resulted from other ailments (54%) (Fig. 3). This allows us to conclude that people continue going to work with musculoskeletal pains and do not pay much attention to them. This conclusion is further confirmed by the fact that although the vast majority was of the opinion that neglecting musculoskeletal pains may cause chronic disorders, nevertheless more than half of the office workers did not consult a doctor, a medic or an alternative doctor.

Considering other general health related complaints, office workers (% respondents) mostly suffered from overall faintness and dizziness (52%) and numbness or twinges in parts of the body (42.1%). Hot and cold spells (38%), muscle weakness (33.5%), pains in heart and chest (33%), nausea or upset stomach (32.9%) and shortness of breath (28.9%) occurred to a lesser extent.

The overall health assessment of half of the workers (50.5%) was rather high, of 36.8% average, of 6.4% very high, of 5.9% rather low and of 0.5% low.

Musculoskeletal pains, except for shoulder pains, were related to other health complaints (p=0.0001...0.001; r=0.3). Lower back pains affected health ($p\leq$0.0001; r=–0.4), however, pains in other parts of the body did not. Employees experiencing lower back and neck pains, were more aware of other people's lower back ($p\leq$0.0001; r=0.3) and neck pains (p=0.001; r=0.2).

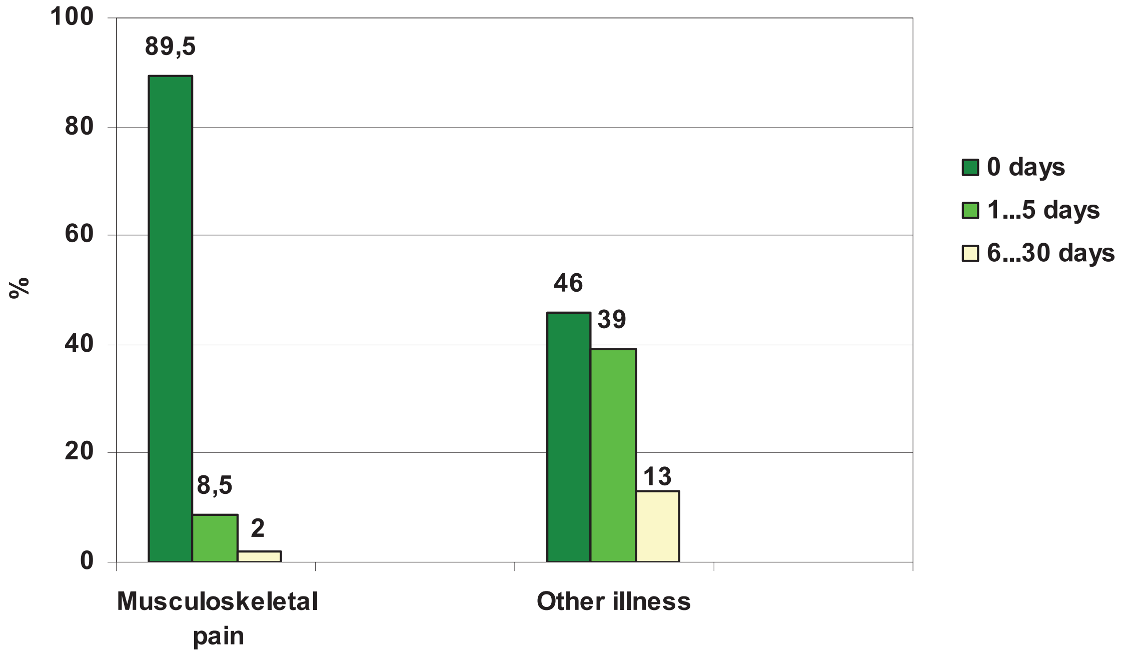

Fig. 3. Sick leave duration in case of musculoskeletal pains and other illnesses.

Measurement result values of muscle tone parameters varied from individual to individual when measured both at the beginning and end of the working day (Table 2). Statistically significant difference could be noticed between the morning and evening measurement values only in case of *musculus erector spinae* elasticity (95% *CI*: 0.1496...0.0007; p=0.052). In most cases the measured parameter value showed the tendency to be higher in the evening than in the morning. So we can conclude that computer work burdens neck and lower back area.

According to the sex, age and body mass index of the individual concerned, the software of the appliance enabled us to establish individual norms for muscles both in the right and left side of the body of the examined persons. Meeting the norms in case of *musculus trapezius* tone parameter values was insignificant (0...33%). *Musculus trapezius* tone, for instance, failed to meet the norms in any of the measurings. *Musculus erector spinae* tone parameter values met the norms in more cases (27...50%).

In office workers with no musculoskeletal disorders *musculus trapezius* tone parameter values were lower and *musculus erector spinae* tone parameter values were higher than in those employees who had musculoskeletal disorders. This was contrary to the expected results, thus concluding that lower back disorders should not be underestimated by office workers who have no muscoloskeletal disorders.

Table 2. Mean measuring results of skeletal muscle tone parameters at the beginning and end of working day and their difference

Muscle	Parameter	Morning	Evening	Difference %
M. trapezius right	Tone Hz	15.78 (*SD* 1.98)	15.98 (*SD* 2.09)	1.25
	Elasticity	1.17 (*SD* 0.24)	1.18 (*SD* 0.22)	0.85
	Stiffness N m^{-1}	272.21 (*SD* 41.74)	275.06 (*SD* 38.81)	1.04
M. trapezius left	Tone Hz	16.41 (*SD* 2.44)	16.78 (*SD* 2.62)	2.21
	Elasticity	1.19 (*SD* 0.21)	1.24 (*SD* 0.17)	4.03
	Stiffness N m^{-1}	283.04 (*SD* 44.57)	284.44 (*SD* 46.18)	0.49
Erector s. right	Tone Hz	15.33 (*SD* 2.38)	16.37 (*SD* 2.77)	6.35
	Elasticity	1.29 (*SD* 0.28)	1.32 (*SD* 0.28)	2.27
	Stiffness N m^{-1}	325.15 (*SD* 60.14)	332.09 (*SD* 85.26)	2.09
Erector s. left	Tone Hz	16.73 (*SD* 3.07)	16.96 (*SD* 3.22)	1.36
	Elasticity	1.37 (*SD* 0.19)	1.44 (*SD* 0.20)	4.86*
	Stiffness N m^{-1}	330.61 (*SD* 60.27)	320.48 (*SD* 76.74)	– 3.06

* statistically significant difference ($p<0.05$)

The value of measuring results of hand muscle strength was higher at the beginning of the working day than at the end (Table 3). Hand grip strength decreased after the working day both in the right and in the left hand. The arithmetic means of parameters measured in the morning and in the evening were statistically significantly different (95% *CI*: –37.5044...–12.6356, p=0.001 right hand, 95% *CI*: –22.0608... –0.8293, p=0.036 left hand). The hand of office workers, who were displaying musculoskeletal disorders in wrist/hand, grew more tired than the hand of office workers who did not display such kind of disorders.

Table 3. Mean muscle strength at beginning and end of working day and differences in measuring results

Hand	Morning N	Evening N	Difference %	p
Right	196.75 (*SD* 50.19)	189.66 (*SD* 49.91)	–11.30	0.001
Left	221.82 (*SD* 51.71)	201.11 (*SD* 48.91)	–5.69	0.036

CONCLUSIONS

The majority of all respondents reported musculoskeletal pains in different parts of the body during the last 12 months. In different parts of the body, most pains during the last 12 months and during the last month occurred in the neck and in the lower back. These were followed by pain in wrist/hand, shoulder, knee and elbow. As for other general health complaints, office workers displayed mostly overall faintness, dizziness, and numbness or twinges in different parts of the body. Hot and cold spells, muscle weakness, pains in heart and chest, nausea or stomach disorders and shortness of breath occurred less. Despite of occurrence of musculoskeletal disorders and other health complaints, general health assessment of half of the employees was rather high. Most musculoskeletal pains were associated with other health related complaints. Lower back pain affected the overall estimation of health. Other people's pains were more noticed.

Other health related complaints affected work attendance significantly more than musculoskeletal pain. Among most of the office workers musculoskeletal pain did not cause to miss a single working day, while other diseases caused more than half of office workers to be absent from work. Office workers did not go to see the doctor because of musculoskletal pains, thus concluding that the severity of musculoskeletal disorders are underestimated and the disorders are not associated with the specificity of computer work.

The possibility of lower back pains should not be underestimated by office workers who had not had muscoloskeletal disorders, because especially their *musculus erector spinae* tone parameter values were higher than those of the employees who had had musculoskeletal disorders. The hands of office workers, who were displaying musculoskeletal disorders in wrist/hand, grew more tired than the hands of office workers who did not display such kind of disorders.

According to the results of the study, the workstations of office workers should be designed ergonomically – the position of chair and table must be proper and shoulder/upper limbs must be in neutral position. More knowledge about the reasons of musculoskeletal disorders in computer work must be passed on to office workers.

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Preliminary Investigation into Mechanical Properties of Clay Reinforced with Natural Fibres

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Abstract. Nowadays natural materials are popular and favoured in civil engineering. At the same time it is important to use renewable and local materials which have low CO_2 production. One of these materials is clay reinforced with natural fibres. For production purpose it is necessary to find the natural fibres which have suitable properties and can be grown in large amounts. This kind of fibre is flax, which produces a strong fibre. The article focuses on flax as a reinforcing natural fibre in clay which can be used for walls and undercoat plasters. Flax is milled to fractions with different length and mixed with clay, sand and water. Dried clay mix cube's compressive strength is measured. Finally the best fraction as for flax length and amount is suggested for future experiments to find out the best fraction of fibres for clay with good compressive strength.

Key words: Undercoat plaster, natural fibres, flax, clay fibre fraction size distribution, compressive strength

INTRODUCTION

Earth building is an ancient construction method, rarely in use in contemporary architecture. There are many methods for building with earth. The simplicity of construction and possibility of achieving good construction quality with minimal costs gives hope that this method can provide answers to the big questions of our time (Sargentis et al., 2009).

Clay can be used as binder component in walls built of adobe, cob, rammed earth (Minke, 2006), and/or plaster. Reinforcement interacts with the soil to produce a composite material in which the roots are fibers of relatively high tensile strength and adhesion inherent in a matrix of lower shear strength soil (Huat et al., 2005).

Clay has a good reputation of being an indoor relative humidity regulator due to its good and fast moisture absorptivity (Mauring et al., 2009).

The notion non-industrial materials in building is linked to local materials which makes it worthy of interest again (Morel et al., 2001), owing to the need to reduce the energy consumption of the building industry. The concept of non-industrial building materials means materials being manufactured using a simple, quick process with low embodied energy and raw materials from the site or the vicinity.

The mechanical properties of construction materials depend on several factors, including the characteristics of the raw material and the manufacturing process. This manufacturing process is generally evaluated by measuring dry density (Morel et al., 2007).

The dry density of non-industrial products varies more when moulding water content is under 22% (Kouakou et al., 2009). This happens due to the fact that manually moulded samples are not homogeneous. At the same time the most important parameter for earth materials – compressive strength – is bigger in samples with higher dry density.

MATERIALS AND METHODS

Sand and clay

Dried screened sand is used in this study. The manufacturer of the sand is AS ´Silikaat´ in Estonia. The sand is extracted from the Männiku quarry. The fraction of the sand is 0.63-2 mm (fineness module is 2.7-3.7 and fine particle 0.063 mm content is less than 5%). A photo of the sand is shown in Fig. 1. Ground clay is used as a plastering agent. The manufacturer of the clay is SIA ‘Ceplis’ in Latvia. The colour of the clay is deep orange-red. A photo of the clay is shown in Fig. 2.

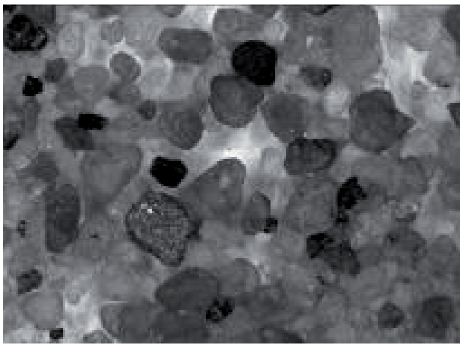

Fig. 1. Photo of the sand used in this study.

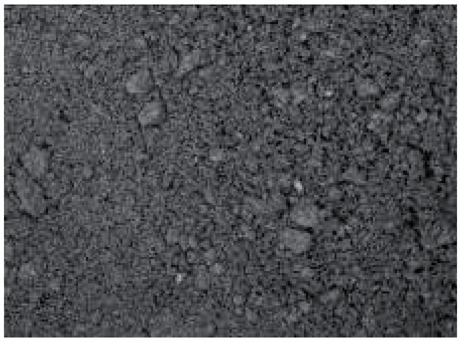

Fig. 2. Photo of the clay used in this study.

Particle size distribution of clay is shown in Fig. 3. Laser light scattering method (particle size measurement instrument: Fritsch Analysette 22) shows that the average particle in the clay content is 6 μm.

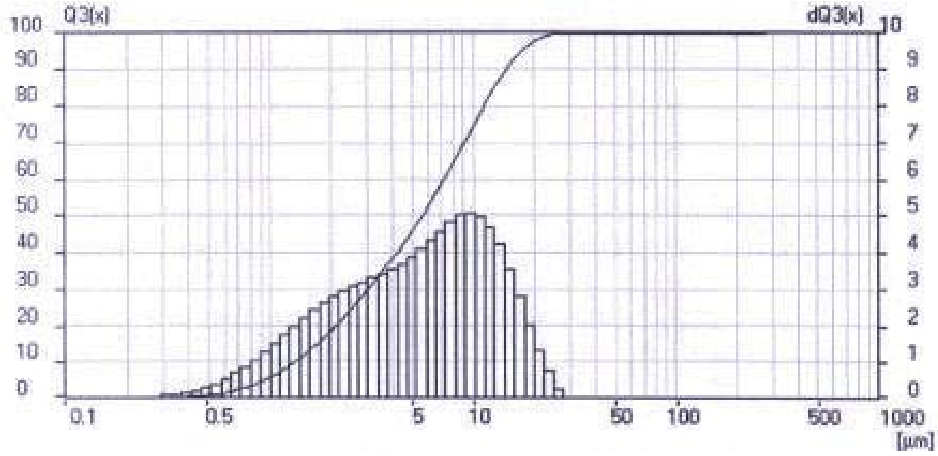

Fig 3. Particle size distribution in clay.

Fibres

Natural fibres used in this study were flax fibres (*Linum usitatissimum*). In this study the fibres were cut in 5, 30 and 50 mm long pieces as shown in Fig. 4 and added to the clay and sand mixture. Flax fibres are hollow tubes consisting primarily of cellulose. Fig. 5 shows the fibres through stereo microscope.

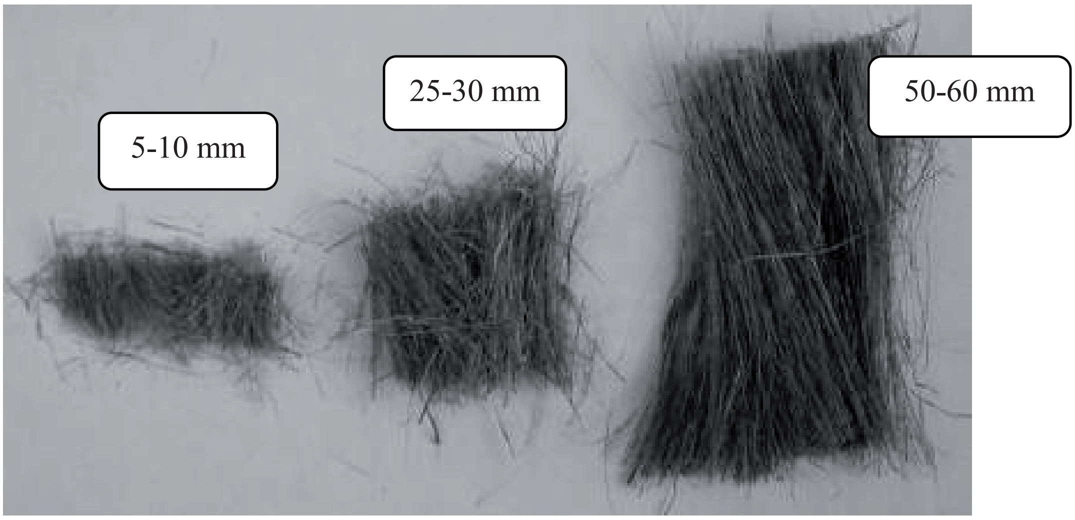

Fig 4. Different lengths of fibres.

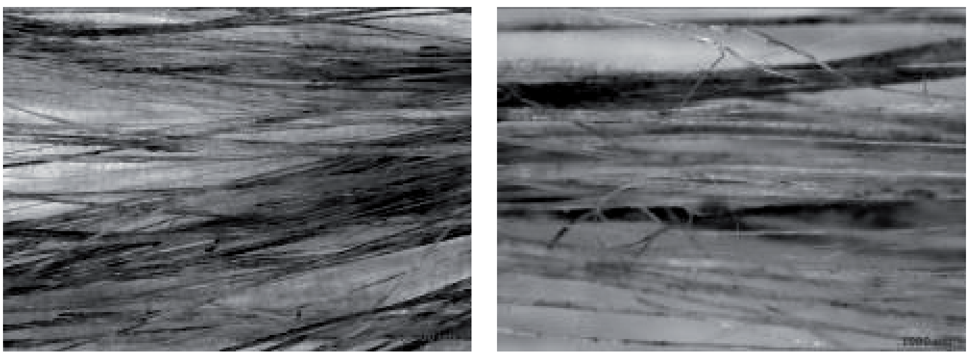

Fig 5. Flax fibre observed through stereo microscope.

Preparation of samples

Clay and sand were mixed with a whisk. The volume ratio was 1:3. The optimum volume of water (20%) was added and stirred until the mixture was homogeneous. The mixture of clay and fibre was then divided into four portions, into three of which were added flax fibres, mixed by hand (there was 14 g fibre in each cube).

Cubes with dimensions 10x10x10 cm were produced. Three cube specimens were prepared for each test. A total of 12 cubes were prepared (three of them were non-fibrous samples). After a three day long drying period the reinforced clay was removed from the moulds and turned upside down to evaporate water from every part at the same rate. The total drying period lasted for7 days. The specimens were dried in lab at room temperature (25°-28°C).

RESULTS AND DISCUSSION

Testing system INSTRON 8516 was used to determine the compressive strength (Fig. 6). Specimens were compressively loaded at a rate of 5 mm min^{-1}. The specimens were in a plastic bag to collect specimen particles for next investigations.

Fig 6. The compressive test.

The results of the experiments show that the compressive strength depends on the length of flax fibres. The results of the compressive test are shown in Table 1. The non-fibrous specimens had the lowest compressive test results (0.55 MPa). Adding fibres increased the compressive strength. Fibre length 30 mm gave the best compressive test results (0.83 MPa). Compared to non-fibrous specimens, compressive strength increased 50%. The strength results of fibre with the length of 50 mm were lower than those of fibre with the length of 30 mm.

Table 1. Compressive test results

	Specimen label	Maximum Load (N)	Compressive Strength (MPa)
2	II non fibrous	5,205	0.50
3	III non fibrous	5,759	0.60
Mean		5,482	0.55
4	I fibre length 5 mm	6,735	0.70
5	II fibre length 5 mm	6,633	0.70
6	III fibre length 5 mm	5,941	0.60
Mean		6,436	0.67
7	I fibre length 30 mm	8,180	0.80
8	II fibre length 30 mm	10,421	1.00
9	III fibre length 30 mm	7,464	0.70
Mean		8,688	0.83
10	I fibre length 50 mm	7,888	0.80
11	II fibre length 50 mm	7,586	0.80
12	III fibre length 50 mm	7,048	0.70
Mean		7,507	0.77

The compressive diagram is shown in Fig. 7. The test was stopped when maximum load decreased 40%. Testing of the non-fibrous specimen after the maximum load had been achieved showed that the load decreased rapidly and compressive extension after cracks formation was 3-4 mm. Adding fibres with 5, 30 and 50 mm length helped to prevent the spread of cracks significantly. The load decreased after cracking more slowly and the compression extension was bigger.

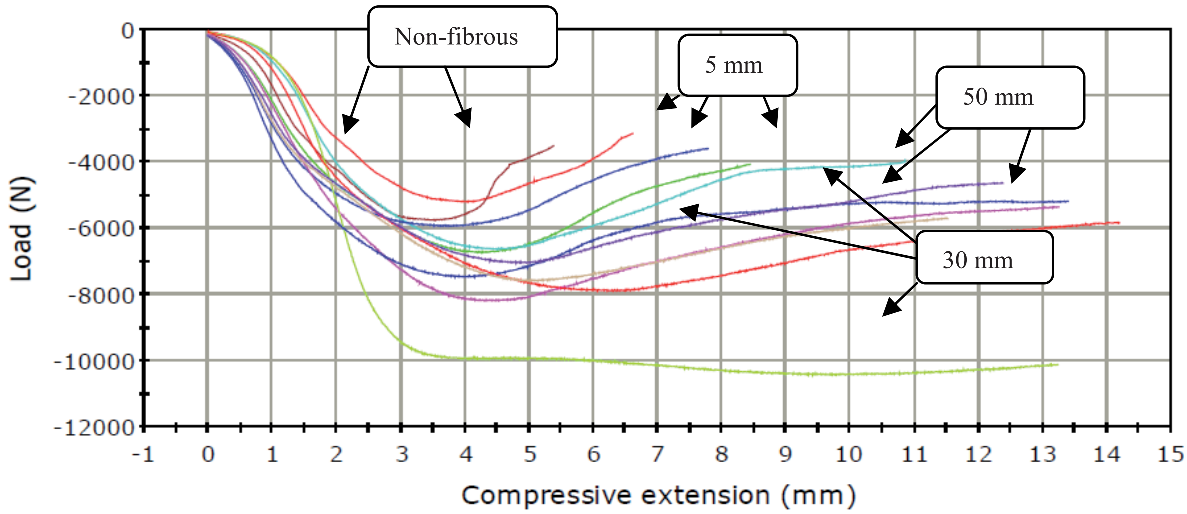

Fig. 7. Compression diagram.

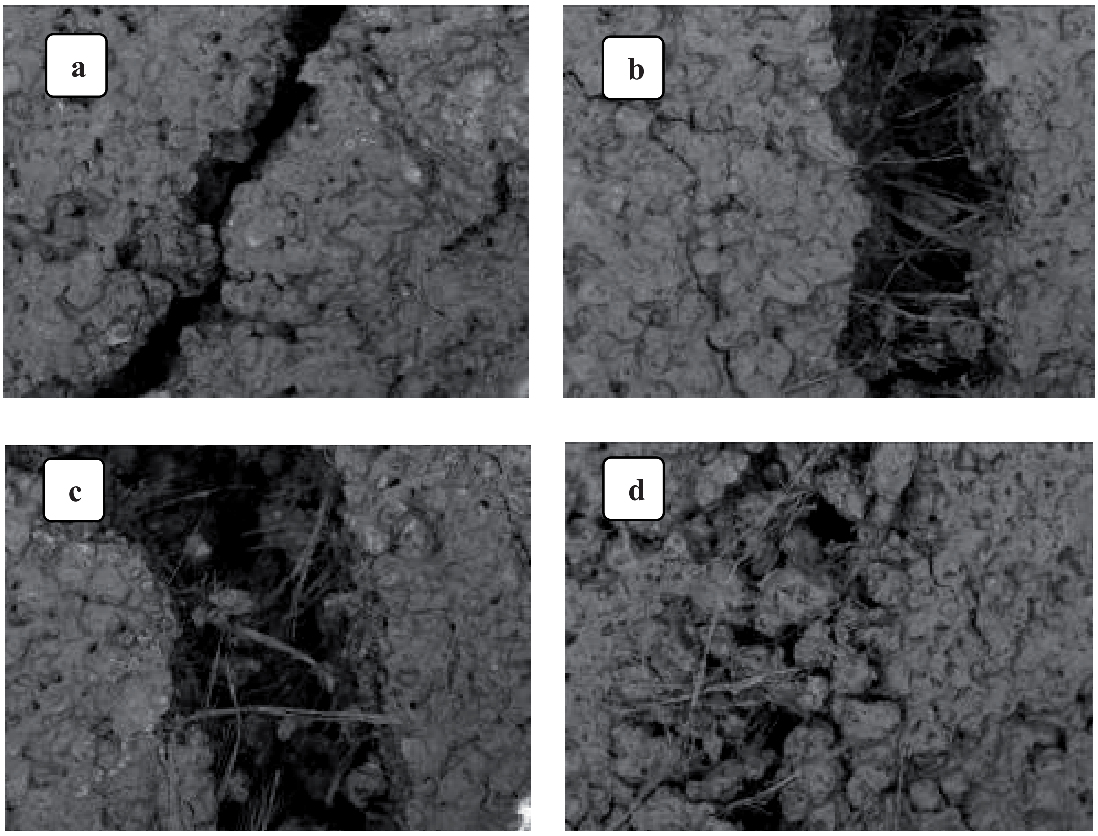

Fig. 8. Photos of cracks generated during the compressive test: a) non-fibrous, b) fibre length 5 mm, c) fibre length 30 mm, d) fibre length 50 mm.

Crack size is related to compressive extension, the presence of fibres and exerted load. Fig. 8 shows the cracks, generated during the compressive test. The reason why the crack of a non-fibrous specimen is the smallest is that after cracking the loads were low. Fibres of 5 mm in length were pulled out of the matrix (Fig. 8 b) while fibres of 30 mm in length cracked during the test. Fibres of 50 mm in length were not distributed homogenously in the matrix and caused lower compressive strength than fibres of 30 mm in length. As it can be seen in the compression diagram, the strength of specimens was retained at extension up to 13 mm. Behaviour and properties of clay mix with longer fibres in the cracks is useful when cracks in the wall need repairing as the fibres act like reinforcement for the new mix.

Based on compressive strength results and ability to obtain uniform mixture of clay and fibre, the 5-30 mm fraction is good for a new plaster for walls and undercoat. For future experiments it is necessary to test fibres between 5 and 30 mm with different length distributions.

CONCLUSIONS

1. Flax fibres used in this study increase compressive strength and prevent the spread of cracks.
2. Compressive tests give the best results with using specimens with 30 mm fibre length which ensure the highest compressive strength.

3. Compressive strength is similar when using 5 mm or 50 mm long fibres.

4. Fibres with the length of 30 mm were broken after the compressive test and 5 mm fibres were pulled out of the matrix, which is visible in the photographs. That kind of behaviour is of great help when clay plaster or a wall needs repairing, as the fibres in the cracks act like reinforcement for the new repairing mix.

5. Fibre of 50 mm in length is difficult to mix uniformly and the uneven distribution of matrix does not allow a homogenous distribution of the load to the fibres, which causes lower compressive strength, visible in Fig. 8, photograph d).

6. Having regarded the compressive strength and the mixing, the optimal fibre fraction is between 5 and 30 mm. This fraction will be most suitable for future experiments, enabling the number of tests needed and having good perspective for investigation.

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Fuel Consumption Studies of Spark Ignition Engine Using Blends of Gasoline with Bioethanol

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Abstract. The increased oxygen content in blends of gasoline with bioethanol causes the necessity for increasing fuel supply to the engine. Car oxygen sensor, reacting to the presence of oxygen in the exhaust gases, increases the amount of injected fuel. Consequently, the higher concentration of bioethanol in fuel blends usually also increases fuel consumption. This study explores how an increase in bioethanol concentration in fuel blends affects the standard car's fuel consumption and determines which elements of the system limit the maximum possible concentration of bioethanol in the blend with gasoline.

Key words: bioethanol, fuel consumption, air-fuel ratio, spark-ignition engine

INTRODUCTION

The decrease of fossil fuel stocks and the increase in their prices, as well as climate change, requires scientists to devote more attention to renewable energy sources and their application researches. Bioethanol (C_2H_5OH) is one of the renewable forms of energy that is produced from biomass. Cereals, corn, sugar beet and sugar cane, potatoes, wood, etc. could be used as raw material for ethanol production. One of the main applications of bioethanol in vehicles is its use as a fuel for Otto engines. There is a number of ways in which bioethanol or its blend with gasoline can be used:

- use of pure bioethanol or with special additives without fossil fuel presence (an example of Brazil, where most vehicles use unhydrated bioethanol with 4% water content);
- use of ethanol-gasoline fuel mixtures with high ethanol content (up to E85) in Flexible Fuel Vehicles (FFV) or adapted gasoline engine cars designed specifically for this purpose;
- use of ethanol-gasoline fuel mixtures with low ethanol content (up to E20) in non-adapted cars. As mentioned in F. Yüksel & B. Yüksel investigations (2004), gasoline-ethanol mixtures, which contain up to 20% ethanol by volume, can be safely used without causing any damage to the engine.

The physical and chemical properties of bioethanol are different from the fossil fuel properties; therefore its use in Otto engines also differs. Ethanol will corrode mechanical components, especially those made of copper, brass and aluminium due to the water solubility in bioethanol (Wu et al., 2004). The lowest calorific value of bioethanol is about one third less than the calorific value of gasoline, so for the engine to develop the same power as when using gasoline, it is necessary to supply about one third more fuel. But on the other hand, bioethanol has better anti-knock properties. In different studies an octane number of ethanol is mentioned in the range of 106 to 111, but the gasoline octane number, depending on the brand is from 88 to 100 (RON). The better anti-knock properties of ethanol allow increasing engine compression ratio, thereby increasing engine efficiency and reducing fuel consumption. From the view point of the combustion nature, the self-ignition temperature and flash point of bioethanol are higher than those of gasoline, which make it safer for transportation and storage (Yüksel & Yüksel, 2004). These and many other properties of biofuel alter Otto engine operating characteristics. The higher the ethanol content in used ethanol-gasoline blend, the more engine construction changes and regulations are needed.

One of the most important automotive exploitation characteristics, which is of interest for every driver is fuel consumption. A lot of different studies on ethanol-gasoline fuel mixture use and their impact on the environment worldwide are being carried out. Most of them are related to fuel consumption either at constant engine speed modes, or modes, which do not reflect the use of the car in real road conditions.

This investigation was conducted to determine fuel consumption and other parameters of the car, simulating real motion modes on a chassis dynamometer, using a standard non-customized car and fuels A95 (E0), E10, E20, E30, E40, E50 and E85. For comparison the studies performed by M. Koç et al. (2009) can be mentioned. The effect of ethanol-unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine was determined. Specific fuel consumption of a single-cylinder four-stroke spark ignition engine at different compression ratios (10:1 and 11:1) at the engine speed range from 1,500 to 5,000 rpm was analyzed. The used fuels in this study were E0, E50 and E85. The results show that the average specific fuel consumption at 10:1 compression ratio for E50 and E85 fuels, in comparison with the E0 fuel, was increased by 20.3% and 45.6% respectively. At the compression ratio of 11:1 the increase was 16.1% and 36.4% respectively. It means that specific fuel consumption mainly depends on the percentage of ethanol in ethanol-gasoline fuel mixture. To reduce fuel consumption using high ethanol content blends, it is necessary to increase the engine compression ratio.

MATERIALS AND METHODS

Experiments were carried out using the standard 1.8 litre spark ignition engine car VW Passat. The main car and engine technical data are given in Table 1.

Table 1. The technical characteristic of the experiment object

Model	VW Passat
Production year	1997
Engine	4-cylinder 20-valve SI 1781 cc engine
Compression ratio	10.3
Fuel & ignition system	Bosch Motronic M3.8.2

Engine power, kW (Hp)	92 (125)
Engine control	Closed-loop control
Gearbox	5-gear manual

Fuel consumption measurements were carried out by running the car on the chassis dynamometer Mustang MD-1750 in the following modes: idle running, at a constant speed of 50 km h^{-1} in 4th gear, at constant speeds of 90 km h^{-1} and 110 km h^{-1} and in 5th gear, as well as in the IM-240 cycle mode and a specially developed urban traffic cycle, which corresponds to the real driving conditions of the Latvian city Jelgava (Dukulis & Pirs, 2009). The high-precision system AVL KMA Mobile was used as the fuel consumption measurement device. Its main technical data are given in Table 2 (AVL KMA Mobile Fuel Consumption Measuring System, 2008).

Table 2. AVL KMA Mobile technical characteristic

Parameter	Unit	Value
Measuring range	l h^{-1}	0.35–150
Fuel density range	g cm^{3}	0.5–2
Measuring error	%	0.1

Statoil A95 gasoline and bioethanol produced at Jaunpagasts Plus Ltd. Company were used as fuels for these experiments. By mixing the corresponding proportions the following experimental fuel blends were obtained: A95 or E0 (pure gasoline), E10, E20, E30, E40, E50 and E85.

In addition to fuel consumption, air fuel ratio (AFR) according to the oxygen sensor data as well as exhaust gas temperature (EGT) (approximately 200 mm from the exhaust valves) was measured. The measuring devices for these data are included as optional units in dynamometer, and the data values are recorded into the bench control platform software. The block diagram of measuring system is shown in Fig. 1.

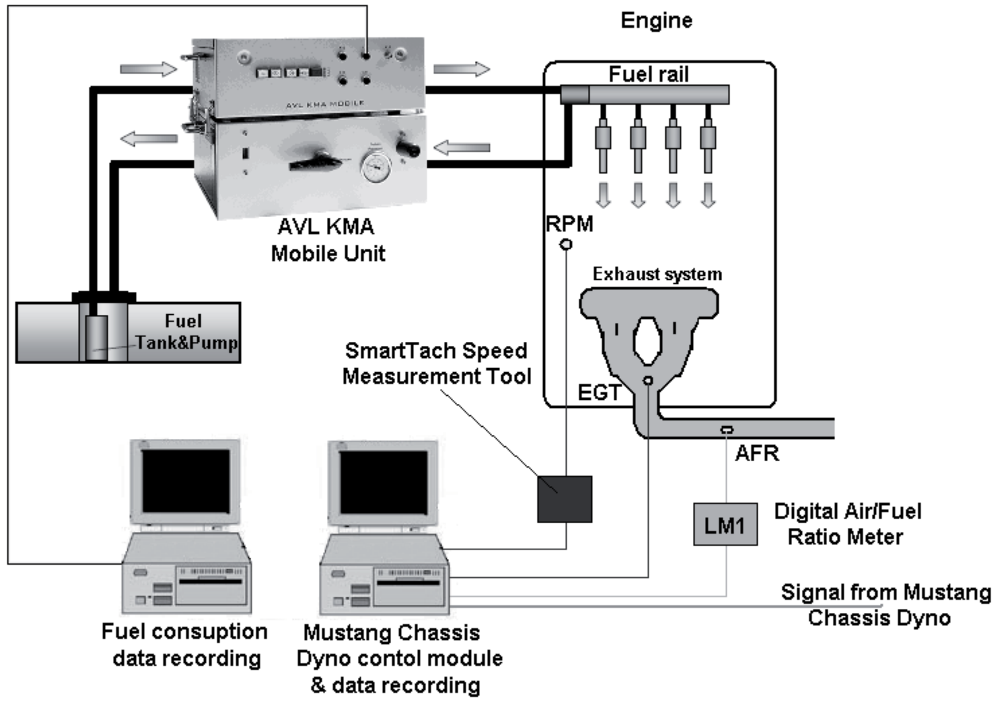

Fig. 1. Block diagram of measuring system.

The sequence of experiments, the number of repetitions and other issues related to measurements are taken from the methodology developed and approbated in previous tests (Dukulis at al., 2009).

RESULTS AND DISCUSSION

The engine fuel supply system was managed using the closed loop control principle, which means that the fuel injection quantity was adjusted according to the oxygen sensor signal. Sensor was inserted into the exhaust manifold. Engine management system helps to prepare air-fuel mixture so that it would close to stoichiometric ratio, i.e., air-fuel ratio 14.7:1, or $\lambda = 1$. Since the ethanol molecule also has an oxygen atom, then by supplying such ethanol-gasoline blend into the fuel supply system fuel becomes leaner. The engine control unit responds to the oxygen sensor signal and adjusts the duration of the injection, increasing the fuel supply. Regardless of bioethanol content in the fuel mixture, engine control system will try to keep the air-fuel ratio to be stoichiometric.

The fuel consumption changes depending on the concentration of ethanol in the fuel blend and driving mode are shown in Fig. 2.

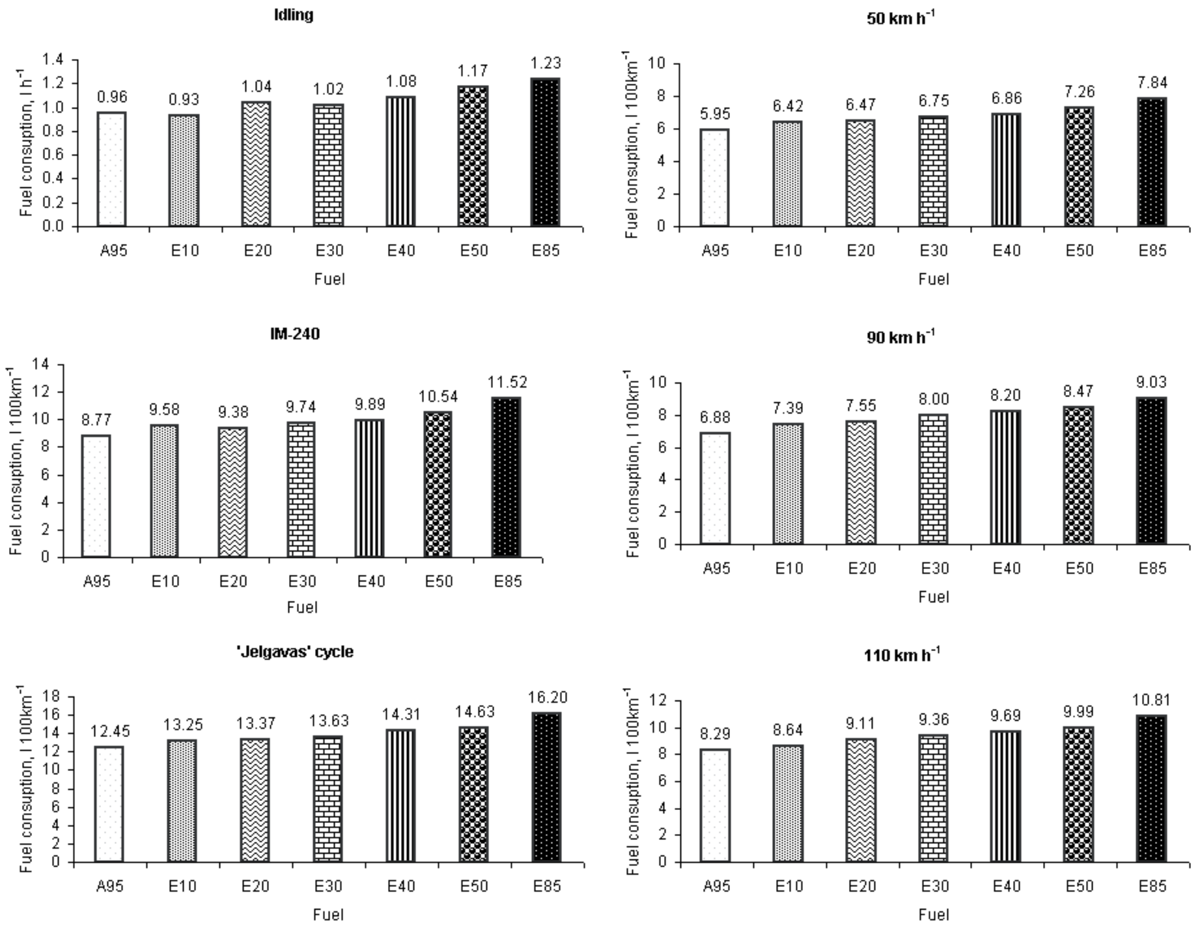

Fig. 2. Results of fuel consumption measurements.

Looking at the constant driving modes, an increase in driving speed, consequently also the engine speed and load, also increases fuel consumption. Dealing with fuel consumption during driving cycles (IM-240 and 'Jelgavas' cycle), higher fuel consumption with all fuels is using the 'Jelgavas' cycle, because the nature of this cycle is more aggressive – frequent driving up and stopping according to the city's traffic conditions. The trends of the fuel consumption change depending on the bioethanol content in fuel blend in all testing modes are similar, i.e., increasing the ethanol content of the fuel mix, fuel consumption will increase. Summarizing all experimental modes, the average fuel consumption change was calculated as a percentage compared to pure gasoline A95 (Fig. 3).

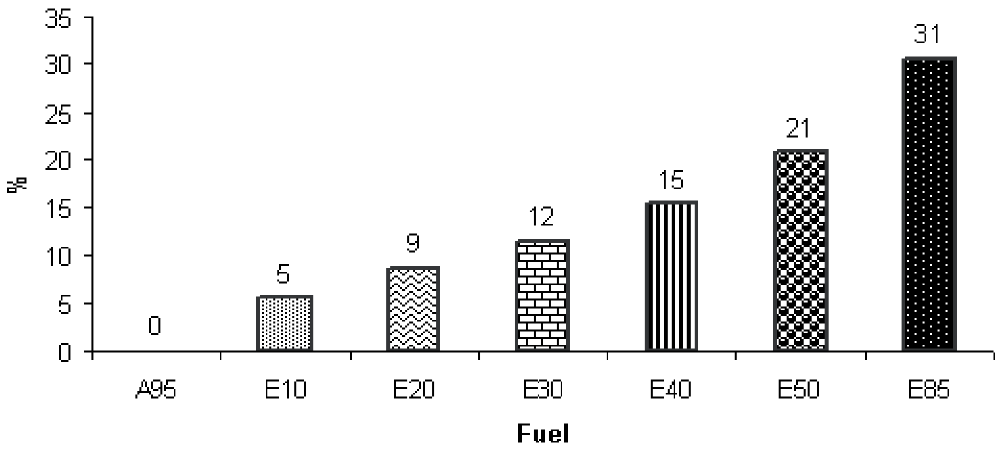

Fig. 3. Average fuel consumption changes depending on bioethanol content.

To ascertain that the ethanol-gasoline fuel mixtures used in non-modified cars with this type of fuel supply and management system do not cause major engine operation mode changes, two more important parameters were analyzed: the air-fuel ratio (AFR) determined by oxygen sensor signal, and the exhaust gas temperature (EGT). Fig. 4 shows the AFR and EGT value changes while driving at a constant speed (50 km h^{-1}, 90 km h^{-1}, 110 km h^{-1}), depending on the used fuel.

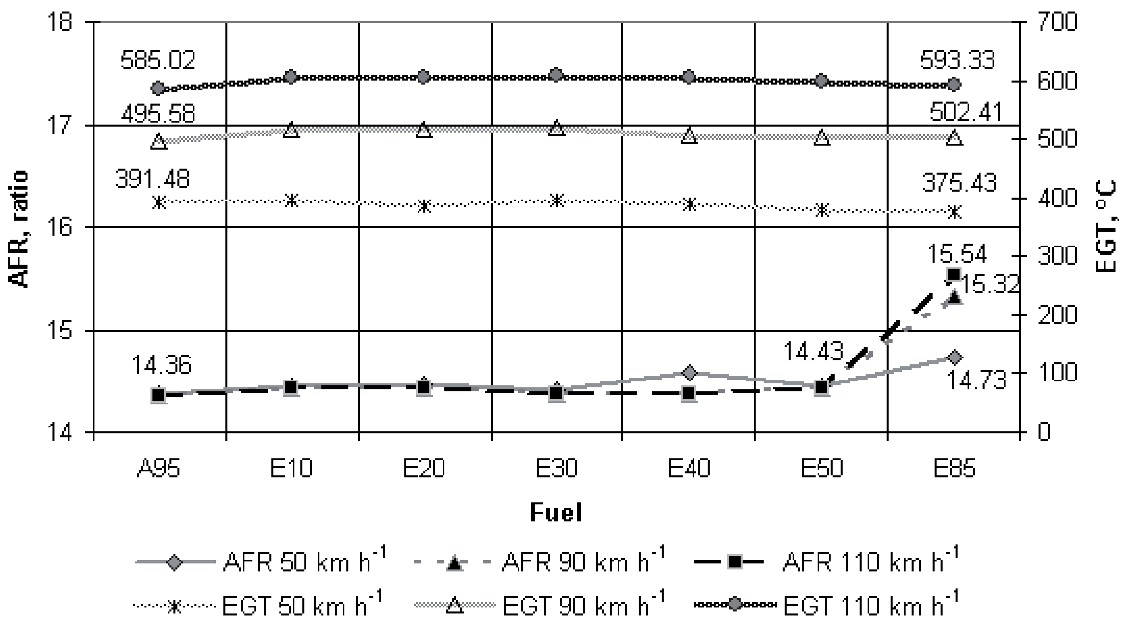

Fig. 4. AFR and EGT changes using different fuels.

As can be seen from Fig. 4, the exhaust gas temperature change is insignificant, regardless of used fuel content and driving speed. Temperature variation does not exceed 5% compared to the gasoline A95 exhaust gas temperature.

Air-fuel ratio change in the ethanol-gasoline fuel mixtures from E10 to E50 is very small (not more than 1.5% compared to the gasoline A95), while the E85 fuel in AFR variation in all experimental regimes is essential. At a constant speed of

50 km h^{-1} AFR value increases by 2.4%, at 90 km h^{-1} – by 6.7%, but at 110 km h^{-1} – by 8.2%. This means that when using E85 fuel in a non-modified car, the engine fuel system with closed loop control system cannot more provide an air-fuel ratio of 14.7:1, due to the fact that the productivity of nozzles or fuel pump is not sufficient for the used biofuel.

Despite the fact that the stoichiometric ratio of pure bioethanol is 9:1, as a result the stoichiometric ratio of ethanol-gasoline blend will be different from the optimal gasoline AFR (14.7:1), the car can use a fuel mixture with ethanol content up to 50% (E50). During the tests no factors affecting engine performance, including power loss, were observed.

CONCLUSIONS

1. The maximum ethanol content of the fuel mixture, which can be used in the non-modified car, differs from that of the car's model. Mostly it depends on the type of fuel system and its control peculiarities, as well on the fuel pump and nozzle productivity.
2. The fuel consumption test results show that until 100% of the nozzle load is not reached, by increasing the ethanol content of the fuel mixture by 10%, fuel consumption increases by 3–6%.
3. Analyzing AFR and EGT values using bioethanol fuel, it was proved that the standard car used in experiments without any conversion is able to run on bioethanol-gasoline fuel blends of up to 50% of ethanol content. If the E85 fuel is used in this car, then by increasing the engine load the fuel becomes too lean.
4. Using blends from E0 to E85, the required AFR value theoretically has to be within the limits of 14.7:1 to 9.0:1, but the experiments proved that the engine is able to operate without problems also with the leaner bioethanol-gasoline fuel blends.

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Elaboration of Basic Methods for Automatic Analysis of Cows' Gait

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Abstract. Two different methods for automatic registration and analysis were used to produce data for comparison and analysis of lame and healthy animals' gait in Estonia.
A walk over mat with two quazi-piezoelectric sensors was elaborated and tested in co-operation with University of Helsinki. Preliminary analysis indicates that lameness can be seen as asymmetric gait and thus the quazi-piezoelectric walk-over mat is a promising tool for automatic leg problem detection.
A video-system was introduced to record walking pattern of cows in co-operation with Catholic University of Leuven. For video recordings three cameras were used to obtain top, side and leg views with StreamPix software video-signal capture. Possibilities of image based separation of dairy cows with real time vision system and preliminary settlement of this was developed. A model-based motion scoring system is proposed for derivation of image parameters needed for lameness detection.
About 600 cows once a week were investigated in a large dairy farm during four months' period. Dairy cows' gait pattern was recorded with the aid of quazi-piezoelectric walk-over mat and video-system. Preliminary lameness scoring was performed in the cowshed visually by two experts. These scoring results were later specified by expert commission on the basis of video-recordings. Lameness scores (according to Sprecher et al) were assigned as follows: 1–6,012 cases, 2–1,181 cases, 3–522 cases, 4–105 cases and 5–37 cases from total 10,653 cases. The database of cows' identification numbers, lameness scores and disordered legs description was created, that allows synchronization of walk-over mat signals data and video files.

Key words: dairy cattle, lameness, PLF, leg health, monitoring, welfare

INTRODUCTION

Lameness has been classified as the most important welfare problem in dairy cows (Anonymous, 2001). Farm Animal Welfare Council states (2009): 'Lameness is a major reason for premature culling of dairy cows, typically accounting for about 10% of culls. It causes considerable pain and distress to the cow, increases veterinary costs, takes much staff time, reduces milk yield and can also impair fertility. A recent UK study of mobility in 29,760 cows during 200 farm visits showed that the average prevalence of lameness was 17% though this varied greatly between seasons and farms, ranging from 1.4 to 49%'.

When lameness is detected in an early stage, the chances of a successful treatment and recovery are higher. Usually farmers and veterinarians detect lame cows by visual observation, scoring cows from 1 (sound) to 5 (severely lame) according to Sprecher et al (Sprecher et al., 1997). However, studies have shown that there are difficulties detecting animals in the early stages of lameness and mild cases of lameness are undiagnosed until they have progressed in severity. A cross-sectional study was conducted to estimate the prevalence of clinical lameness in high-producing Holstein cows housed in 50 free-stall barns in Minnesota during summer. The mean prevalence of clinical lameness was 24.6%, which was 3.1 times greater, on average, than the prevalence estimated by the herd managers on each farm. The prevalence of lameness in first-lactation cows was 12.8% and prevalence increased on average at a rate of 8 percentage units per lactation (Espejo et al., 2006).

Nowadays loose housing cowsheds with application of precision livestock farming (PLF) are becoming favoured in the whole world. However, as automation lessens contacts between human and animal to minimum, possibilities to discover individual animal's welfare and health problems in proper time decreases. With increasing number of cows the need for an objective, automated scoring which may enable earlier, more accurate detection of lameness grows (Berckmans, 2004, Poikalainen et al., 2004, Kokin et al., 2007).

Automatic detection of clinical symptoms of leg disorders in self-service units (milking robot, automatic concentrate feeder, etc.) – a four-balance system, where each of the legs is weighed – has been elaborated in cooperation of Finnish and Estonian researchers (Poikalainen et al., 2004; Pastell et al., 2005, 2006a, 2006b). Self-service technology, where such units are used, is effective primarily in middle size cowsheds (50-100 cows).

In large loose housing cowsheds the milking parlour and total mixed ratio are mostly used. The theoretical investigations of cows' gait patterns have been carried out in several countries, for example in Belgium (Maertens et al., 2007), USA (Carvalho et al., 2007) and others. There are three basic approaches for elaboration of automatic cows' gait registration and analyses – using of walk-through scales, systems with pressure sensitive walk-over mats and automatic video-imaging analyses.

Walk-through scales, based on vertical ground reaction force measurements of individual limbs were elaborated by Rajkondawar et al (Rajkondawar et al., 2001, 2006). The system consists of two parallel force plates with levelling platforms before and after the plates. Vertical forces measured over time for each plate can be used to calculate a number of limb movement variables. To separate the results of a group of animals walking through the system into multiple records of individual animals SoftSeparatorTM algorithm was developed. The system is now available commercially.

The preliminary investigations of using mats with sensors responding to the foot pressure have been carried out by different research groups (e.g. Maertens et al., 2007). At the University of Helsinki and Estonian University of Life Sciences a walk-over mat with two quazi-piezoelectric sensors was elaborated and tested for automatic cows' gait registration in free stall cowshed (Pastell et al, 2008).

Automatic use of video records for the assessment of cows' gait is studied in Belgium at Leuven Catholic University (Maertens et al., 2007, Poursaberi et al., 2009). Research has proved that vision techniques have great potential to be used for continuous quantification of lameness in cows. The results suggest that the automatic method by vision analysis is feasible to present the cows' real locomotion situations. The first results showed a positive linear relationship between cows' track ways overlap and locomotion scores by human visualization (Song et al., 2008).

There are no detailed comparative studies of different systems for automatic registration of cows' gait patterns yet. Also the problems of automatic cows' gait analysis combining different methods – particularly from the application possibilities point of view – have not been studied sufficiently.

MATERIALS AND METHODS

It is reasonable to build up the system for registration of gait as autonomous module. Such module must sustain to the hard environmental conditions in cowsheds and has to be suitable for future integration into general technological network. The system for inspection, identification and gait registration of dairy cows was installed in Estonia at loose housing cowshed according to this concept. Temporary monitoring station with two computers (one for video- and another for walk-over mat signals) was established close to the identification gate. Dairy cows' gait pattern was recorded simultaneously with the aid of quazi-piezoelectric walk-over mat and video-system (Fig. 1).

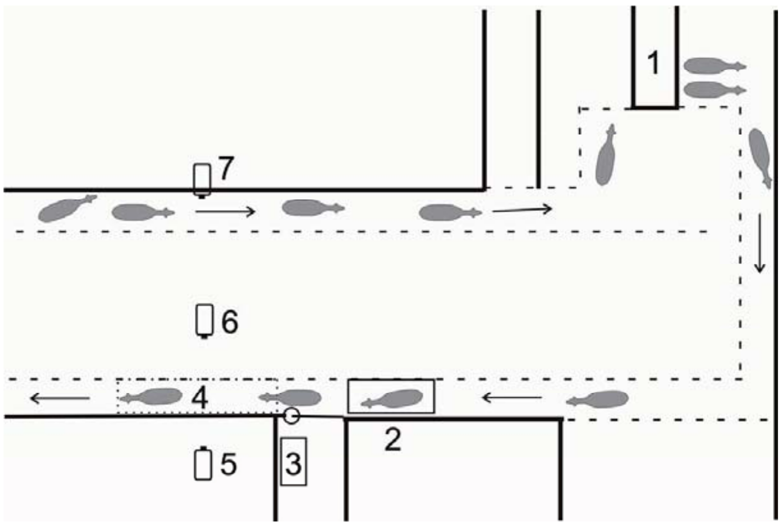

Fig. 1. The scheme of the experiment: 1 – milking parlour; 2 – identification gate; 3 – monitoring station; 4 – pressure-sensitive walk-over mat; 5-7 – video-cameras.

Quazi-piezoelectric walk-over mat

An electromechanical film Emfit (Emfit Ltd., Finland) was used as pressure sensitive element for the walk-over mat (Pastell et al., 2008). It is a thin, flexible, low-price electret element, which consists of cellular, biaxially oriented polypropylene film coated with metal electrodes, which can detect only dynamic forces (Paajanen et al., 2000). A force affecting the sensor causes a change in the film thickness resulting in change of the charge of the sensor that can be measured as voltage signal.

The sensors were placed sequentially and protected by sealing them between two 15 mm thick rubber carpets. The data was recorded at 200 Hz using USB-data acquisition unit (NI USB-6008, National Instruments, USA). The step force of each leg was identified from the measurement data (Pastell et al., 2008). The scheme of the automatic cows' gait registration system using walk-over mat with quazi-piezoelectric sensors and the placement of this in the cowshed are given on the Fig. 2 and 3.

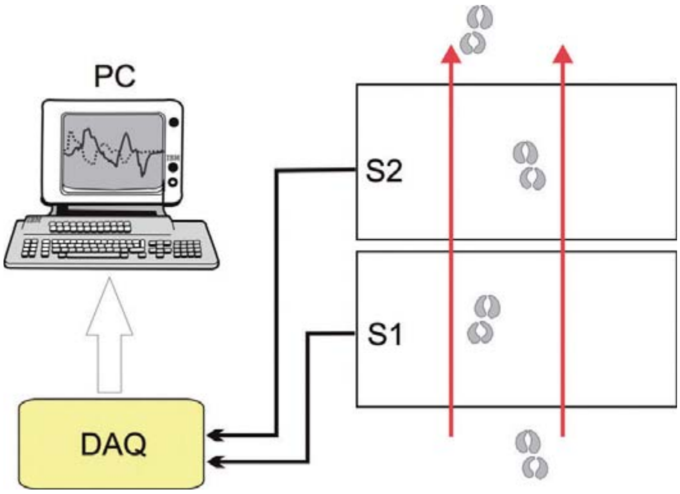

Fig. 2. The scheme of the automatic cows' gait registration system: PC – computer; DAQ – data acquisition unit; S1 – first sensor; S2 – second sensor; ↑- direction of cows' moving.

Fig. 3. Quazi-piezoelectric walk-over mat position in the alley.

Data was transferred into EXCEL format, cows' identification numbers were added and preliminary analysis was carried out. As a result the steps of cow's different legs were identified from video recordings and synchronized with signals of the walk-over mat. Of dynamic data acquired by measurements general and some specific numerical characteristics were calculated, including minimum and maximum peak values, number of peaks, time intervals between the peaks, steepness of slopes and integrated area of graphs.

Video-system

A video-system for cows' walking patterns recording was introduced in co-operation with Catholic University of Leuven. Three cameras were used to obtain top, side and leg views with StreamPix (NorPix Inc., Montreal, Canada) software video-signal capture (Figs. 4 and 5). All three cameras were GUPPY from ALLIED Vision Technologies with 1.4/3.5 mm lens, Pentax TV 1/1.8 4.8 mm lens and Theia C 1.3 mm NITTOH KOGAKO lens for hoof, side and top view cameras respectively. Examples of acquired images are given on Fig. 6.

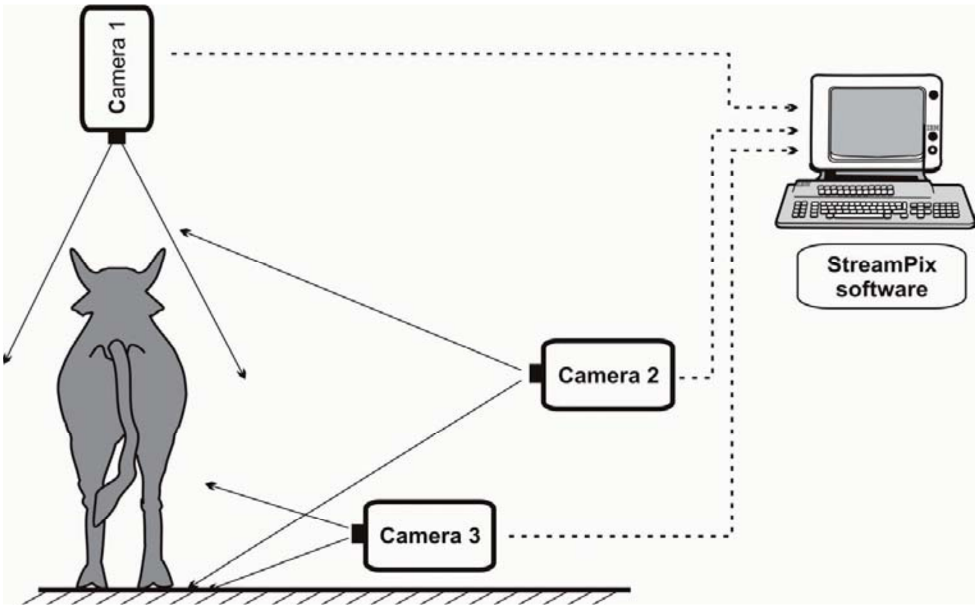

Fig. 4. The scheme of the video-cameras' position in the cowshed.

Fig. 5. Installation of video-system in the cowshed: 1 – top camera; 2 – side camera; 3 – hoof camera; 4 – calibration mat.

Fig. 6. Hoof, side and top camera images.

Videos of identified cows from different cameras are analyzed with specific software in Leuven. A model based motion scoring system is used for derivation of image parameters needed for lameness detection (Pluk et al, 2009).

Lameness scoring and the formation of database

About 600 cows once a week were investigated during four months' period. The cow' gait was registered with walk-over mat and video-system described above. Visual evaluation of the lameness score and lame leg was carried out at the same time. Lameness score was detected by visual observation, scoring cows from 1 (sound) to 5 (severely lame) according to Sprecher et al (Sprecher et al., 1997). Preliminary scoring was performed in the cowshed by two experts, later scoring results were specified by expert commission on the basis of video-recordings. Video and Excel files were encoded as follows: cow's number_lamenesss score and disordered leg_date_time (Fig. 7).

Fig. 7. Encoded video-recording.

The EXCEL database consisting of cows' identification numbers, lameness scores, disordered legs description and some other cows' data was created that allows synchronization of walk-over mat signals data and video files.

RESULTS AND DISCUSSION

During the experiment 10,970 cows' gait patterns were recorded, from which 10,653 cows were identified. Lameness scores were assigned as follows: 1–6,012 (76.5%) cases, 2–1,181 (15.0%) cases, 3–522 (6.6%) cases, 4–105 (1.4%) cases and 5–37 (0.5%) cases from total 7,857 scores assigned. Lameness score was not assigned when cows moved too quickly or too close to each other (2,796 cases).

As the cows walk in a row one after the other, it is essential that their movement speed should be moderate and with regular pattern. Otherwise it is difficult to get usable information about individual cow's gait (Fig. 8). Standstill, slipping, crush, flowing etc complicates interpretation of sensors' signals from the walk-over mat.

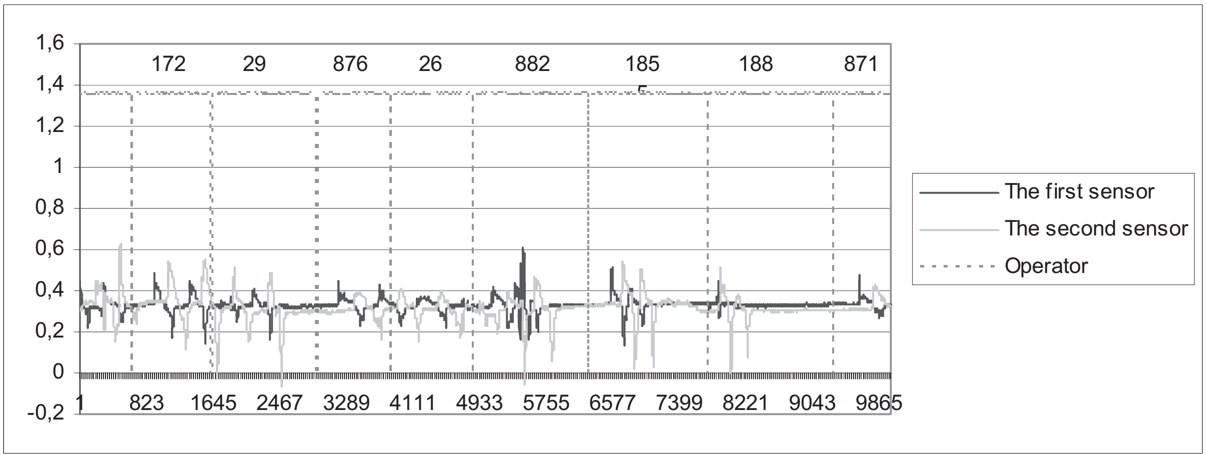

Fig. 8. Walk-over mat data. Individual cows' data (identification number in the top line) are separated by operator's signals.

It is possible to distinguish visually between healthy and lame cows when they pass the walk-over mat in moderate tempo (Fig. 9). More regular pattern indicates healthy cows' gait, certain irregularity and additional slopes indicate lame cows' qait. Analysis of the measurement data showed that healthy cows gait curves had lower number of peaks (5-7 positive and 4 negative peaks versus up to 13 positive and 6-7 negative peaks), the number of turning points was accordingly 12-13 versus 18-23 and the first peak was substantially higher than the second one. The distance between peaks also depends on the cow's lameness. All these informative parameters of the walk-over mat output curve should be used as inputs for lameness detection algorithms, based on stochastic analysis (neural network, fuzzy logic etc). Therefore the elaboration of lameness detection algorithms and their comparison will be the next and most complicated step of the investigation.

However, even though there are clear indications that the signals of healthy and sick cows are different, there are some complications to be solved (Pastell et al, 2008). It has turned out that the variability of signals for both sound and lame cows makes automatic detection unexpectedly difficult. In the same time, measuring the gait daily helps to quantify the amount of natural variation in the gait of different cows and to deal with the data more appropriately. To simplify the use of the models it is reasonable to apply separation of some measurement results before processing.

Output signals of the walk-over mat are also influenced by cows' behaviour. For example these signals do not indicate to which leg (left or right side) belongs the first peak of the curve. A successful measurement requires that both, the fore limb and hind limb, have hit the sensor in a proper manner. A significant portion of the measurements did not fulfil these requirements due to the unpredictable and anxious behaviour of the cows. These problems could be solved by special measures which influence the step behaviour of cows accordingly (the proper leg hits the proper sensor). Specific experiments are needed for that.

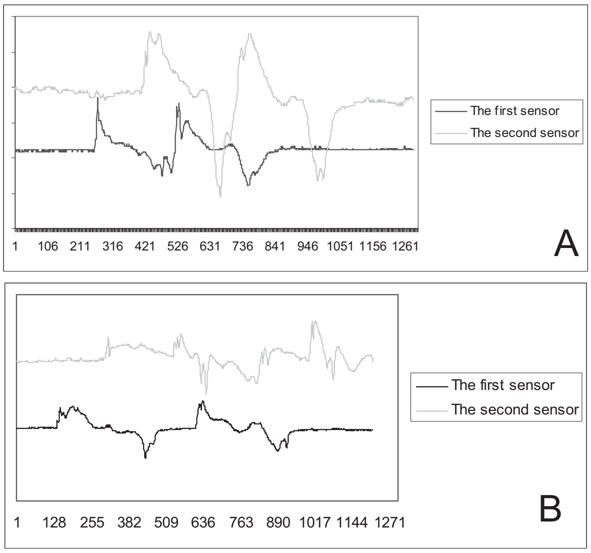

Fig. 9. Healthy (A) and lame (B, lameness score 3) cow's gait patterns.

Gait analyses using video-recordings is also quite complicated, especially when cows pass the recording zone in a row. In this case an automatic separation of cows in a sequence is necessary to get information about gait features from individual cow. Possibilities of image-based separation of dairy cows with real time vision system were analyzed and preliminary technical solutions were developed in the Catholic University of Leuven (Poursaberi et al, 2009). An algorithm for cow separation was proposed based on local image filtering and statistical analysis of binary images frame by frame. The proposed algorithm is under improvement to cope with extra overlap (more than two cows), variant background light conditioning, missing parts of reconstructed binary image from cow (sometimes some parts of body is similar to the background and in reconstruction we miss these parts). Gait analyses of this experiment by video-recordings are described in Pluk et al (Pluk et al, 2009).

These two methods (use of walk-over mat and video-recording) can be compared and if useful, combined for more reliable results.

CONCLUSIONS

The number of lame cows' scoring in the heard under observation was large (23.5%). From these cases significant to severe score was in 8.5% of cases.

From the tests conducted we may conclude that automatic detection of lameness by means of quasi-piezoelectric walk-over mat and by video images analysis is possible.

From the output signal of quasi-piezoelectric walk-over mat some informative parameters (number of peaks in the gate curve, distance between peaks, number of turning points, relative height of the subsequent peaks) can be used in algorithms for automatic detection of lameness.

Disturbing influence of certain behavioral pattern and crowding of cows can be eliminated by automatic separation of cow's data. Some technical means to influence cow's step behavior can be used for leg signal determination.

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The Estimation of Wind Lull and Consumption Factor Influence on Autonomous Wind Energy System

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Abstract. Due to the stochastic output of wind generators, some kind of storage device will be necessary to ensure a constant energy supply by an autonomous energy system. The necessary storage capacity depends on wind data and consumption factor. The latter describes the ratio between average production capacity and average usage capacity. In addition to average wind speed, the frequency and duration of windless periods must be considered as well. The concept of energy lulls has been outlined to describe the influence of duration, frequency and distribution of windless periods on a wind energy system. Location has strong influence on energy lull length; the difference in average duration between a coastal area and inland is more than two fold. Weibull distribution can be used to describe the probability of energy lulls.

Key words: Wind speed, wind energy, consumption factor, wind lull, energy lull, autonomous power system

INTRODUCTION

Although most of Estonia is supplied by the national electric grid, there are some applications for autonomous power systems. There are locations which lack electric network and where building a new connection would be economically unjustifiable. The cost of a fossil fuel generator may be also too expensive. Renewable energy sources, especially wind energy, can often be the primary sources of energy, as they are usually available in geographically remote and demographically sparse areas (Georgilakis et al., 2009). The stochastic output of WTG (wind turbine generator) is one of the biggest problems while using a small autonomous wind energy system. A backup generator or storage device will be necessary to ensure constant energy supply. The selection of the storage device depends on the characteristics of wind generation device and the consumer. Different simulation algorithms and methods for optimal system design are being researched, e. g. Simulated Annealing (Ekren & Ekren, 2010) or design spaces for wind-battery systems (Roy et al., 2009). Wind energy can be described in terms of momentary and average speed during some period. Average wind speed can describe potential wind energy in some location but nevertheless, it does not provide an overview of wind energy parameters. Annual energy production calculation based on wind data and the expected generator capacity found according to consumption might not provide the necessary energy supply reliability. The prediction of annual energy production according to the power curve of generator might be insufficient. There may occur relatively long periods without wind. The concept of energy lull has been introduced to describe periods without wind energy production (Põder et al., 2009). 5-year wind data from two different locations have been analyzed to find out the length of energy lulls and the capacity of storage device.

MATERIALS AND METHODS

WTG output depends on wind speed. For example, Estonia can be divided into two areas with different wind speeds at standard measurement height 10 m: 1) islands, seashores and Lake Peipsi (average wind speed 5-7 m s^{-1}) and 2) inland (average wind speed 2.5-3.5 m s^{-1}) (Kull, 1995). Wind data from years 2004-2008 was obtained from EMHI (Estonian Meteorological and Hydrological Institute) where average wind speed for 1 h period at 10 m height was measured. Small wind generators (impeller's circle area up to 200 m^2 and power up to 50 kW) were considered; therefore, wind speeds were transposed to their typical 30 m height (EVS, 2006). Hellman power law with exponent $k_H = 0.25$ for seashore and $k_H = 0.29$ for inland was used for this purpose (Annuk & Tomson, 2005). Wind data was divided into quarters according to the seasons. In total 19 quarters were analyzed. As average wind speed does not provide a good overview of wind energy parameters, the concept of energy lulls is being introduced. Most small wind turbines have the cut-in speed 2.5 m s^{-1} or higher and the cut-out speed 25 m s^{-1} (Annuk et al., 2008). A wind lull can be described as a period without any wind. An energy lull can be defined as a period without wind or with wind speed less than 2.5 m s^{-1} that is inapplicable for wind turbines (Põder et al., 2009). Wind speeds more than 25 s^{-1} were not considered due to low frequency (Annuk et al., 2008). As wind speed measurement interval is 1 h, the shortest energy lull length is 1 h. Wind data from Pakri (located in coastal area) and Viljandi (located inland) were analyzed (Fig. 1).

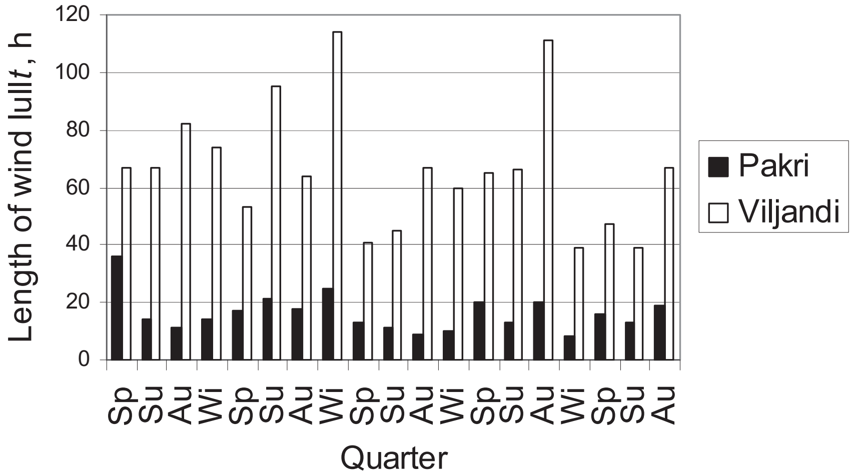

Fig. 1. The extreme values of energy lulls according to seasons (Sp – spring, Su – summer, Au – autumn, Wi – winter) during 2004-2008.

In case of an autonomous system, the storage device should be able to ensure energy supply for the duration of maximum energy lull. Detailed long-time windspeed measurements are needed for such a solution (Celik, 2003; Kaldellis, 2002). On the other hand, the probability of wind parameters can be described with Weibull distribution (Mathew, 2006; Cellura et al., 2008; Garcia et al., 1997). According to our measurement data, the relative length of energy lull l can be described using Weibull distribution, thus the cumulative distribution function is:

$$F(l) = \int_a^b f(l)dl = 1 - e^{-\left(\frac{l}{c}\right)^k}, \tag{1}$$

where *F(l)* – cumulative probability distribution function, *f(l)* – probability density function, l – relative length of energy lull, c – Weibull scale factor, k – Weibull shape factor.

The Weibull distribution function *f(l)* of energy lull can be mathematically expressed as:

$$f(l) = \left(\frac{l}{c}\right)^k \frac{k}{l} e^{-\left(\frac{l}{c}\right)^k}. \tag{2}$$

The probability of a certain energy lull can be found by the cumulative distribution function. The probability between lengths l_1 and l_2, when $1 \le l \le 48$ is given by:

$$P(l_1 < l < l_2) = e^{-\left(\frac{l_1}{c}\right)^k} - e^{-\left(\frac{l_2}{c}\right)^k}. \tag{3}$$

The average length of energy lull is:

$$t_m = \frac{\sum_{i=1}^{n} t_i}{n}, \tag{4}$$

where t_m – average length of energy lull, h; t_i – total duration of energy lulls with same length; n – total sum of energy lulls.

The duration of relative energy lull is equal to minimum length of energy lull based on wind speed measurements 1 h, thus $l_m = t_m$.

The probability of average energy lull is:

$$P(l_m) = e^{-\left(\frac{l_m}{c}\right)^k}, \quad (5)$$

where $P(l_m)$ – probability of average energy lull, l_m – duration of average energy lull.

There are different methods to determine parameters c and k. In this study the graphical method is used (Mathew, 2006). With a double logarithmic transformation of cumulative distribution function $F(l)$ can be written as:

$$\ln\{-\ln[1 - F(l)]\} = k\ln(l_i) - k\ln C. \quad (6)$$

Graphically the relationship gives an almost straight line (Fig. 2).

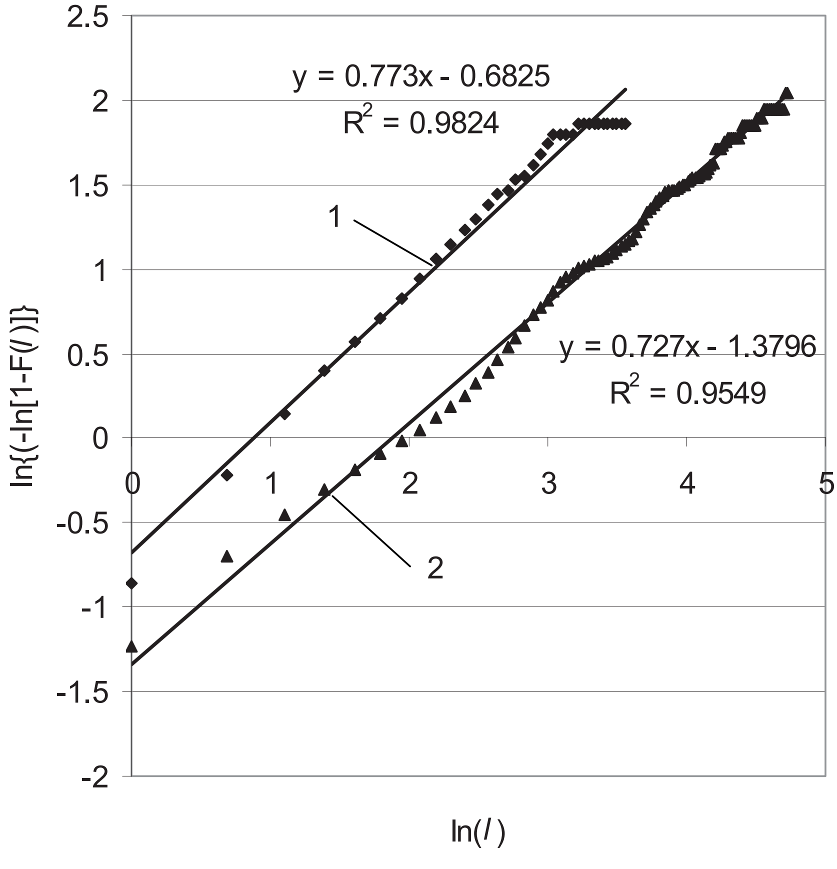

Fig. 2. Determination of *k* and *c* values (1 – Pakri, 2 – Viljandi).

According to equation 6, *k* gives the slope of the line and *–k ln c* represents the intercept. Obtained relationships have high correlation coefficients ($R^2 > 0.95$).

RESULTS AND DISCUSSION

Histograms were found for energy lulls in Pakri and Viljandi (Figs. 3-4). The frequency of shortest energy lulls is highest.

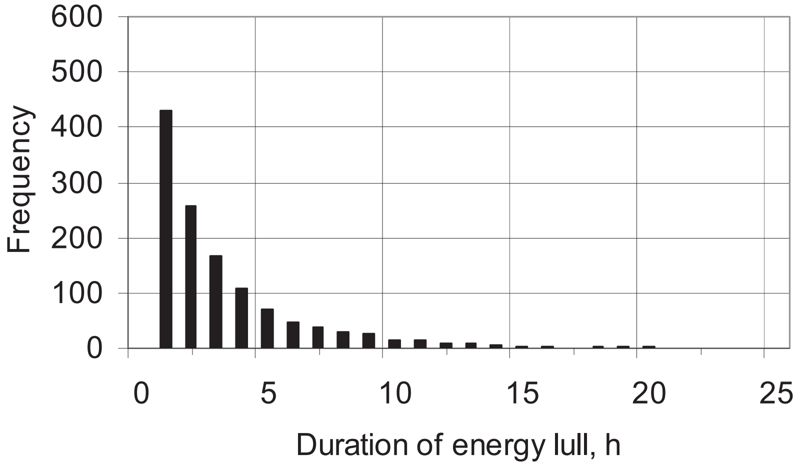

Fig. 3. Histogram of energy lulls during 2004-2008 in Pakri.

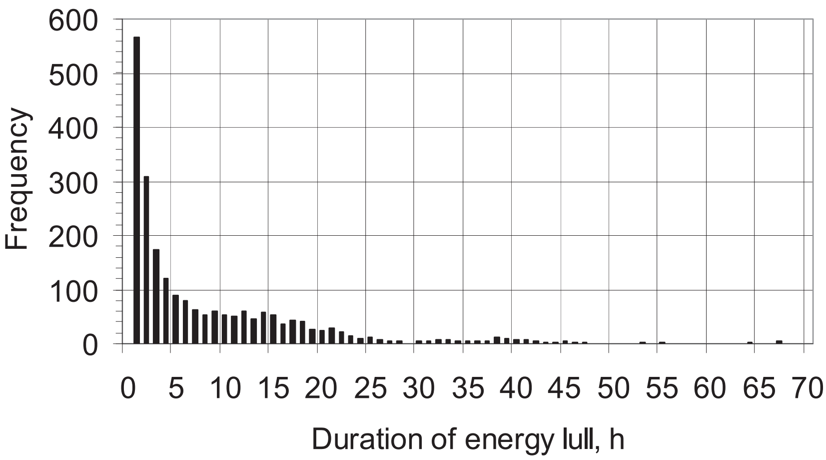

Fig. 4. Histogram of energy lulls during 2004-2008 in Viljandi.

The results of wind speed and energy lull analyses at 30 m height are given in Table 1.

Table 1. Wind data results

Location	Average wind speed v, m s^{-1}	Max. lull, t_{max}, h	Average energy lull t_m, h	Weibull shape factor k	Weibull scale factor c
Pakri	6.1	36	3.4	0.773	2.418
Viljandi	3.0	114	8.8	0.727	2.557

According to Table 1, average wind velocity has influence on average and maximum energy lull length. Weibull shape and scale factors are similar for both locations.

The cumulative Weibull distribution function of Pakri and Viljandi energy lulls
was calculated (Fig. 5). This shows the probability of energy lull length being lower than *l*.

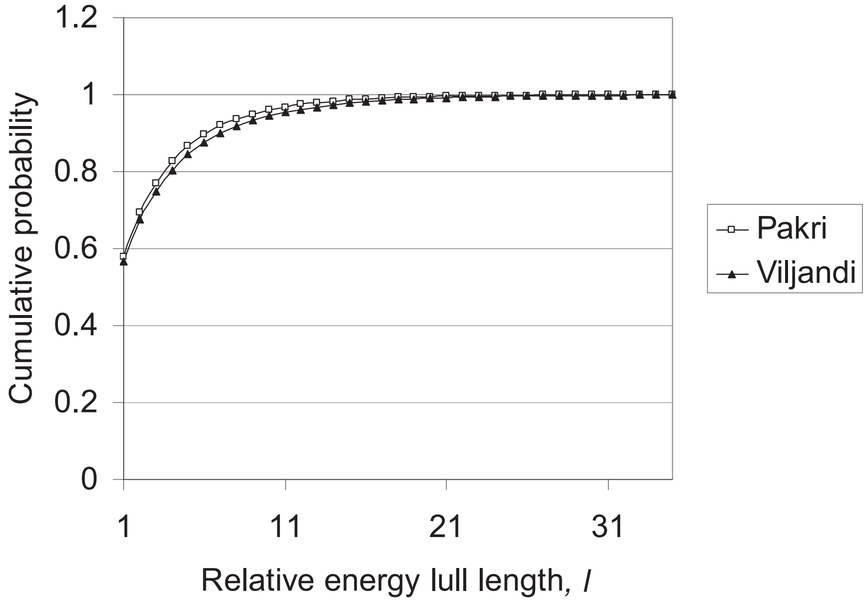

Fig. 5. Cumulative Weibull distribution function of energy lulls in Pakri and Viljandi.

Pakri and Viljandi wind data can be analyzed as a sample case of energy balance in an autonomous energy system. Energy shortage is a situation where the balance of energy production and usage is negative. The load is expected to be constant throughout the whole year, because in an autonomous system all the energy produced must be consumed.

In a real world energy system the occurrence of equal generation and usage capacities cannot appear due to losses in generation and storage process. For compensation, the average generation capacity must be higher than average consumption capacity. During a given period, the amount of energy used must be less than the amount of energy produced whereas the ratio is called consumption factor β (Põder et al., 2009). The storage device must be able to store a sufficient amount of energy to cover the maximum possible shortage of energy. Therefore, it follows that prior to applying the consumption load, the storage device is expected to contain a sufficient amount of energy to cover the shortage. Variations in generated and stored energy together with different consumption factors in Pakri and Viljandi are calculated (Figs. 6-9). The average annual consumption capacity has been equalized with the average annual load. Data from quarters 1-15 is included because of the longest location of energy lulls.

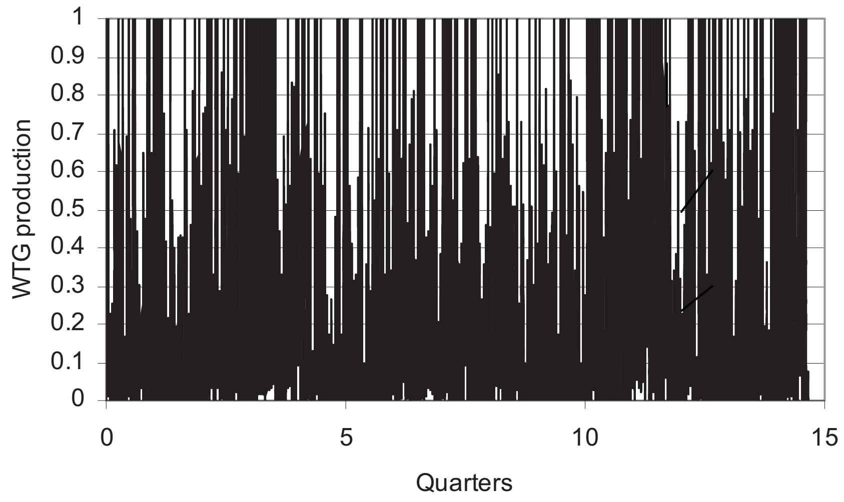

Fig. 6. Variation in WTG energy production in Pakri during 2004-2008 at 30 m height.

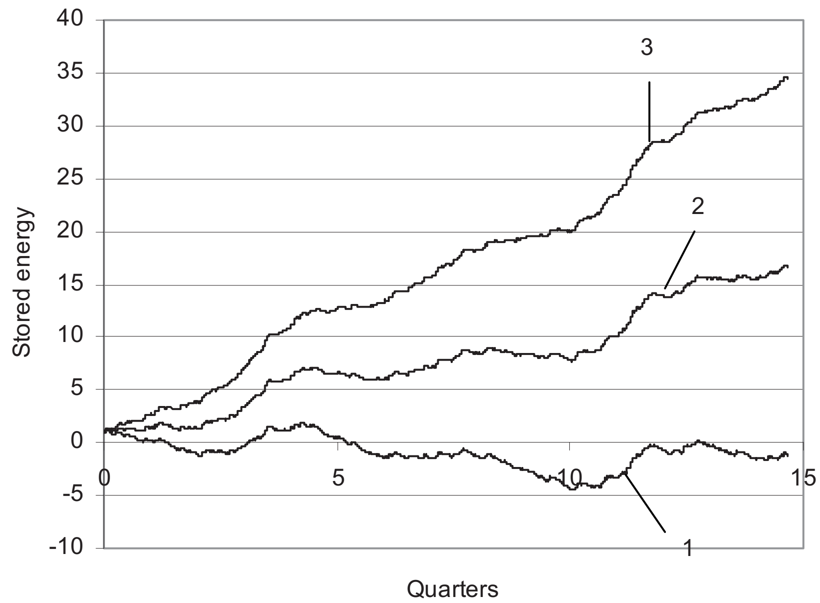

Fig. 7. Variation in stored energy in case of different consumption factors (1-β = 1.0; 2-β = 0.75; 3-β = 0.5) in Pakri during 2004-2008 at 30 m height.

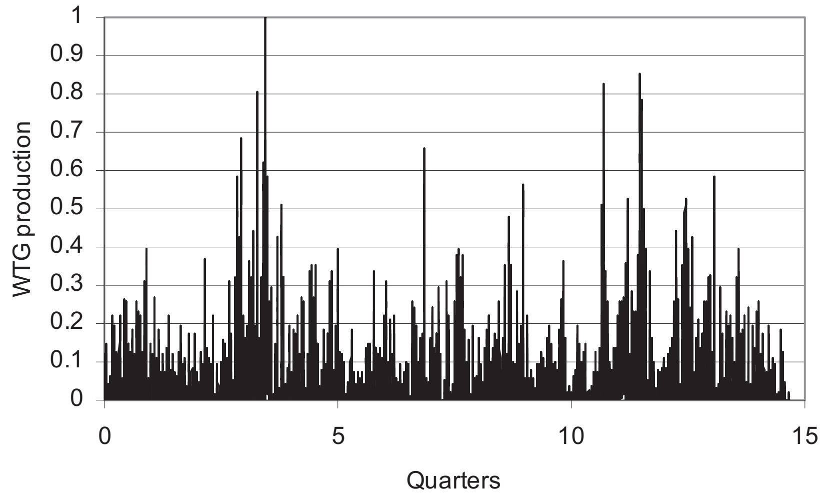

Fig. 8. Variation in WTG energy production in Viljandi during 2004-2008 at 30 m height.

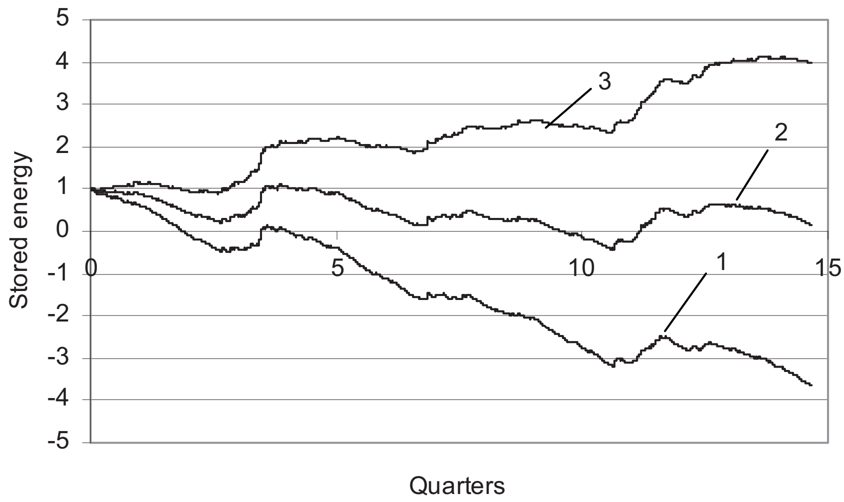

Fig. 9. Variation in stored energy in case of different consumption factors (1-$\beta = 1.0$; 2-$\beta = 0.75$; 3-$\beta = 0.5$) in Viljandi during 2004-2008 at 30 m height.

According to Figs. 6 and 8, the amount of generated energy depends on site wind data (Pakri has higher average wind speed than Viljandi). Wind velocity has also strong influence on energy production and consumption balance (Figs. 7 and 9). In case of Pakri consumption factor $\beta = 0.75$ ensures constant energy supply (balance is positive), in Viljandi it not enough (storage is empty during certain time periods). $\beta = 0.5$ ensures continuous energy supply in Viljandi. The consumption factor β must be evaluated to ensure continuous energy supply in case of an autonomous wind energy system.

CONCLUSIONS

1. According to measurement data, the frequency of shortest energy lulls is highest.

2. According to 5-year wind data, the average duration of energy lulls is highest inland (Pakri – 3.4 h, Viljandi – 8.8 h).

3. The probability of energy lulls can be described by Weibull distribution function with factors $k = 0.727$, $c = 2.557$ for inland and $k = 0.773$, $c = 2.418$ for coastal area in Estonia.

4. During the sizing of storage devices for autonomous wind energy systems, it will be useful to consider the probability of energy lulls in addition to wind speed probability.

5. Time of the year does not influence the length of energy lulls.

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State of the Art in Bioethanol Production

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Abstract. The objective of the present study is to provide an overview of available literature on problems and potential solutions in bioethanol production. The preparation of an overview of bioethanol as motor fuel requires knowledge of its chemical-physical properties and different production methods. The study points out the most popular opinions and test results to characterise the production of bioethanol. This overview considers potential methods for producing ethanol and production technologies suitable for ethanol as motor fuel, especially most recent achievements in converting carbohydrates into ethanol.

Key words: Biofuel, bioethanol, production methods, lignocellulosic biomass, bacteria

INTRODUCTION

There are two global biorenewable transportation fuels that might replace oil-derived gasoline and diesel fuel. These are bioethanol and biodiesel. Owing to its widespread availability, biorenewable fuel technology will potentially result in the employment of more people than fossil-fuel-based technology (Demirbas, 2006).

Biofuels obtained from renewable sources can be classified on the basis of their production technologies, biofuels of first and second generation and biofuels of third and fourth generation. The first-generation fuels refer to biofuels made from plants rich in oil or sugar. The feedstock for such biofuels consists in oil plants (plant seeds) which are pressed to yield oil that can be processed into diesel fuels by esterification; sugar-containing feedstock is processed to yield ethyl alcohol, which is then used as gasoline additive or individual fuel. However, the production of first-generation biofuel is economically unreasonable, because of discarding cellulose and hemicellulose – which constitute the majority of the carbon resource of the plants – in the course of the process. Furthermore, the biofuels of this generation also compete with food products intended for human consumption.

The second-generation biofuels (*Biomass to Liquid*) are made from organic materials, such as straw, wood residues, agricultural residues, reclaimed wood, sawdust, and low-value timber. Feedstock also includes short rotation plants and trees (perennial grasses, short-rotation coppice) and quickly growing algae. Although the second-generation biofuels allow improving CO_2 balance, they do not yield major benefit in comparison with the first-generation fuels, considering the high amount of fossil fuels used for their production.

Biofuels of the third and fourth generation are produced from algae by using modern gene and nanotechnologies.

Bioethanol as motor fuel for internal combustion engines

Ethanol or ethyl alcohol (CH_3CH_2OH) with molecular weight M = 46.7 is also known as alcoholic spirit, grain spirit, absolute alcohol and ethyl hydrate. Depending on its water content, production method and final use, there are several ethanol products available on the market. 99% alcohol (mostly referred to as absolute alcohol) is used for preparing tinctures and pharmaceutical preparations, solvents and preservatives, antiseptics and perfumes. Ethanol represents a crucial functional component in the composition of alcoholic drinks produced by carbohydrate fermentation. If alcohol is used for purposes other than drink, it is denatured with such additives as methanol, pyridine, formaldehyde, etc. Tables 1 and 2 provide an overview of biofuels by generations, including respective feedstock and production processes.

Table 1. First and second generation biofuels, their feedstock and technological processes (Sims et al, 2008)

First-generation (conventional) biofuel			
Type of biofuel	Name	Biomass feedstock	Production process
Bioethanol	Conventional bioethanol	Sugar beet, sugar cane, sugar sorghum	Hydrolysis & fermentation
Pure plant oil	Pure plant oil (PPO)	Oil plants (e.g. rape seed)	Cold-pressing/extraction.
Biodiesel fuel (plant energy)	Rape methyl-/ethyl ester) RME/REE Fatty acids methyl/ethyl ester (FAME/FAEE)	Oil plants (e.g. rape/ turnip rape seeds, sunflower seeds, soy beans, etc.)	Cold-pressing/extraction/ transesterification.
Biodiesel fuel (waste grease)	Fatty acids methyl/ ethyl ester (FAME/FAEE)	Biodiesel cooking and deep-fry grease	Transesterification
Biogas	Upgraded biogas	(Wet) biomass	Anaerobic digestion
Bio-ETBE		Bioethanol	Chemical syntheses
Second-generation biofuel			
Type of biofuel	Name	Biomass feedstock	Production process
Bioethanol	Cellulose ethanol	Lignocelluloses	Upgraded hydrolysis & fermentation
Synthetic biofuels	Mixed higher alcohols Bio-dimethyl ether	Lignocelluloses	Gasification + syntheses
Biodiesel (hybrid biodiesel from the first and second generation)	NExBTL	Plant oils and animal fats	Hydrogenation (Refining/ enrichment)
Biogas	SNG (Synthetic Natural Gas)	Lignocelluloses	Gasification & syntheses
Bio-hydrogen		Lignocelluloses	Gasification & syntheses or biological process

Table 2. Third and fourth generation biofuels, their feedstock and technological processes (Demirbas, 2009)

Third-generation biofuel			
Type of biofuel	Name	Biomass feedstock	Production process
Biodiesel	*Oilgae* Algae diesel	*Algae*	Gene and nanotechnology & esterification
Fourth-generation biofuel			
Type of biofuel	Name	Biomass feedstock	Production process
Bio gasoline Bio jet fuel Biodiesel	Synthetic oil	Vegetable oil (CENTIA ™ oil from algae)	Hydrolytic conversion/deoxygenating

ANALYSIS OF PRODUCTION TECHNOLOGIES OF ETHANOL

Ethanol production is commonly classified into chemical and microbiological. Chemically synthesized ethanol is produced by hydration of ethylene, a by-product of oil-manufacturing. This is industrial alcohol with wide range of applications. Fig. 1 lists the sources for industrial ethanol.

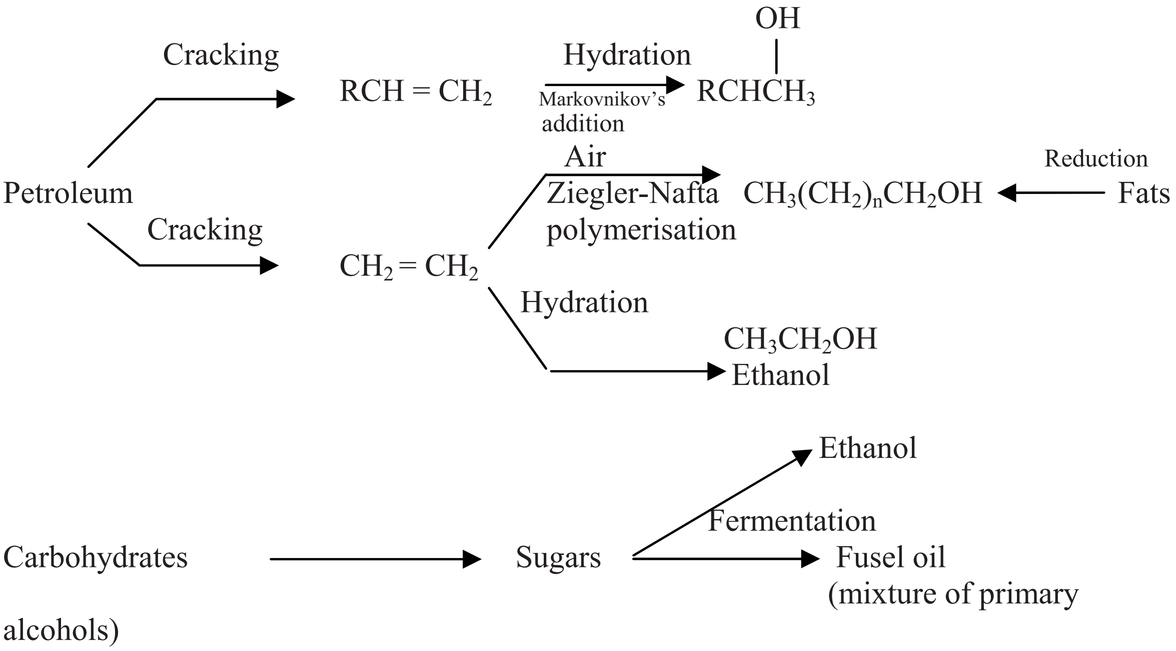

Fig. 1. Sources of industrial production of ethanol (Ullmann, 1990a).

Physical properties

In its plain form, ethanol is a colourless liquid. It is soluble in water as well as in ether, acetone, benzene, and other organic solvents. Anhydrous alcohol is hygroscopic; it achieves certain stability after absorption of water to the extent of 0.3-0.4%. The main parameters of anhydrous ethanol are the following (Ullmann, 1990a),

Boiling point	78.39°C
Liquefaction temperature	-114.15°C
Refractive index n at 20°C	1.36048
Densities, d^{20}_{4}; d^{15}_{4};	0.79356; 0.78942
Flash point (in closed cup)	13° C
Dynamic viscosity η	1.19 mPa·s^{-1}
Calorific value,	
• lower	29,895 kJ kg^{-1}
• upper	29,964 kJ kg^{-1}

Azeotropic mixture consists of 95.57% ethanol and 4.43% water by volume. Therefore, normal distillation allows yield of 95.57% ethanol by volume. Further removal of water from azeotropic mixture can be done either by using tertiary solvent, molecular sieves, membrane method or some other method.

Chemical properties

Chemical properties of ethanol are dominant due to the presence of a functional group – OH in the compound, which enables industrially important chemical reactions, such as dehydration, halogenization, recovery of esters, and oxidation (Ullmann, 1990b).

Synthetic ethanol

There are two main methods for industrial production of synthetic ethanol (Ullmann, 1990a),

1) Direct catalytic ethylene hydration reaction,

$$C_2H_4\,(g) + H_2O\,(g) \leftrightarrow C_2H_5OH\,(g) \qquad \Delta H = -43.4 \text{ kJ.} \qquad (1)$$

Reaction kinetics in the presence of phosphoric acid and multiple catalysts has been studied by several authors (Ullmann, 1990a). For example H_3PO_4 – in the presence of silica gel, and blue lead oxide – in the presence of silica gel catalyst. A nomogram has been prepared depending on the variation of process parameters, pressure, temperature, molar water-ethylene ratio. Under normal reaction conditions, the molar ethylene water ratio is 1.1; at temperatures between 250-300°C, at the pressure of 5-8 MPa, ethanol conversion reaches 7-22%.

Conversion is more efficient at lower temperatures (reaction 1), but this also involves formation of diethyl ether by secondary reaction,

$$C_2H_5OH + C_2H_4 \leftrightarrow C_2H_5OC_2H_5. \qquad (2)$$

At higher pressure ethylene is polymerized, yielding butylenes and higher olefins.

Technical and patented literature describes several catalysts for ethylene hydration (Ullmann, 1990a). Diatomic loams (diatomite, zeolite) are used.

2) Indirect ethylene hydration, esterification-hydrolysis or H_2SO_4 process, based on absorption of high volume ethylene in concentrated sulphuric acid (Ullmann, 1990d). Using diluted H_2SO_4 produces diethyl ether in addition to ethanol.

$$C_2H_4 + H_2SO_4 \leftrightarrow C_2H_5OSO_3H \qquad \Delta H = -60\ kJ \qquad (3)$$

$$C_2H_4 + C_2H_5OSO_3H \leftrightarrow C_2H_5OSO_2OC_2H_5 \qquad (4)$$

Hydrolysis is performed in three steps,

$$C_2H_5OSO_3H + H_2O \leftrightarrow C_2H_5OH + H_2SO_4$$

$$C_2H_5OSO_3C_2H_5 + H_2O \leftrightarrow C_2H_5OH + C_2H_5OSO_3H$$

$$C_2H_5OSO_3C_2H_5 + C_2H_5OH \leftrightarrow C_2H_5OC_2H5 + C_2H_5OSO_3H.$$

Products include ethanol and 5-10% diethyl ether. Ether yield is verified by varying reaction conditions, especially by changing ethylene and sulphuric acid ratio. Industrial production makes use of additional methods as well (methanol homologization, methanol and methyl acetate carbonylation, syngas heterogeneous and homogenous catalysis). Chemically synthesized methods will not be further considered by the authors of the present article, because we focus on the use of feedstock of biological origin for producing motor fuel.

Ethanol recovery from fermentation of carbohydrates

Biochemically, ethanol (first-generation) is produced from plant feedstock containing high quantity of carbohydrates. Fermentation involves yeasts. The commonest yeast species include highly productive species, such as *Saccharomyces cerevisiae, S. uvarum* (formerly *S. carlsbergensis*), and *Candida utilis.* The species *Saccharomyces anamnesis and Schizosaccharomyces pombe* have also been used. The species *Kluyveromyces* together with the ferment lactose are good for producing ethanol from whey (Ullmann, 1990d).

Ethanol production by yeast is characterized by high selectivity, low accumulation of by-products, high ethanol yield, high fermentation rate, good tolerance toward both increased ethanol and substrate concentrations, and lower pH value. Viability and genetic stability of yeast cells under process condition and at high temperature are also desirable.

At present, bioethanol as a fuel is mostly produced by fermenting plant carbohydrates with yeast. Carbohydrates are grouped as soluble carbohydrates – sugars (e.g. sucrose from sugar cane, sugar sorghum or sugar beet), storage carbohydrates – such as starch from grains and tubers, structural carbohydrates – such as cellulose, hemicellulose and pectin. The principal carbohydrate is starch contained in grain crops – corn, wheat, barley and oats, but also in potato, Jerusalem artichoke, etc. Two major forms of starch exist – amylose and amylopectine (BeMiller, 1996). Amylose is a straight chain polymer of glucose molecules joined by α (1-4) glycosidic bonds (Fig. 2). This primary structure results in long polymers coiling into a helical conformation (BeMiller, 1996).

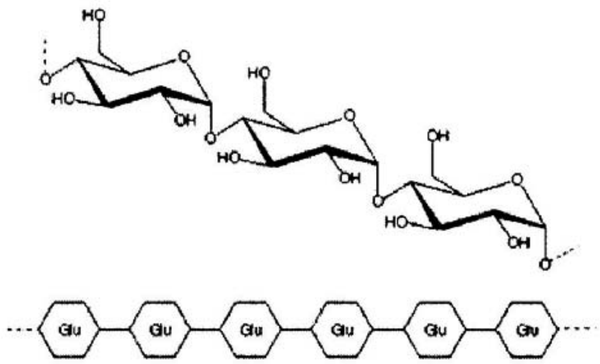

Fig. 2. Structure of amylose (BeMiller, 1996).

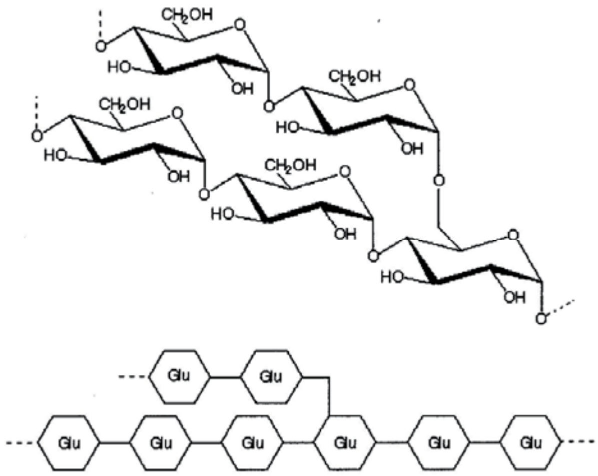

Fig. 3. Structure of amylopectin (BeMiller, 1996).

Amylopectin (Fig. 3) is also primarily a straight chain of glucose molecules joined by α (1-4) glycosidic bonds, but it also includes branches occurring at every 24 to 30 glucose units consisting of α (1-6) bonds. Starch is semi-crystalline and transitions to an amorphous state (a gel) at 60-70^{o}C, through a gelatinization process where water molecules disrupt the hydrogen bonds within and between starch molecules. Starch, especially gelatinized starch, can be easily hydrolyzed to yield individual glucose molecules.

Hydrolysis of starch (polysaccharides) into sugars by enzymatic activity and fermentation into ethanol by yeast enzymes takes place according to the following scheme,

$(C_6H_{10}O_5)_n$ → hydrolysis of starch → $C_6H_{12}O_6$ → sugar fermentation → $CH_3CH_2OH+CO_2$.

Summary reaction,

exponent 10 exponent 2

$C_{12}H_{22}O_{11}$ → $2C_6H_{12}O_6$ → $4\ C_3H_3O_3^-$ → $4\ C_2H_6O + 4\ CO_2$.

disaccharides monosaccharides pyruvate ethanol carbon dioxide

Production of ethanol as motor fuel

There are two types of industrially manufactured ethanol fuels for engines, anhydrous and hydrous ethanol fuel (Ullmann, 1990). Anhydrous ethanol is used in the production of Ed75-Ed 85 Automotive Spark-Ignition Engines. These fuels are specified by Standard ASTM D 5798 and E85 in Europe by Swedish SVENSK STANDARD SS 155480,2006 and European Standard CWA 15293,2005.

Anhydrous bioethanol as motor fuel

For producing fuel ethanol from grains, modern industry uses dry-grind process which involves 4 major steps, preparation of the grain (grinding, liquefaction, and saccharifaction), fermentation of the sugars, recovery of the ethanol, and drying of the ethanol (Fig. 4).

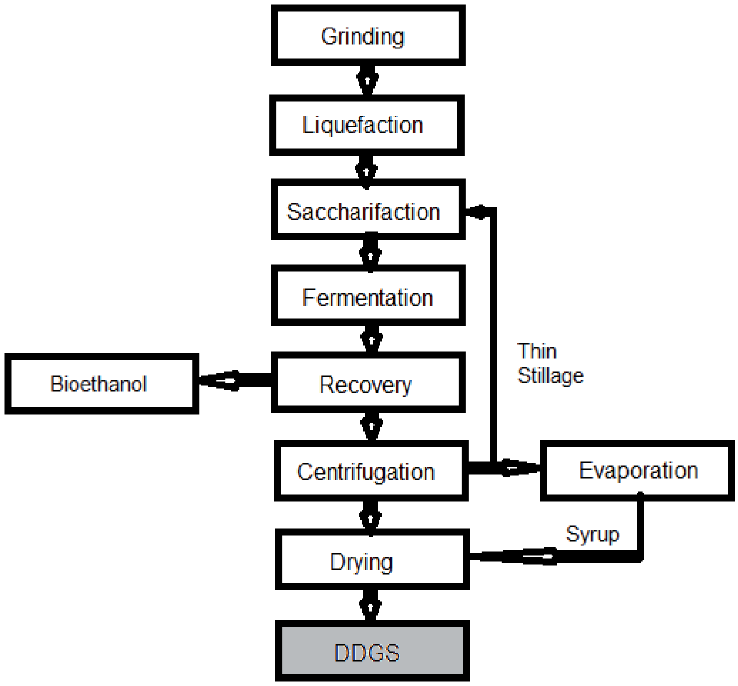

Fig. 4. Technological overview of dry grind bioethanol process (McAloon, 2000).

Preparation of the grain takes 8-12 days (Kwiatkowski, 2006). Broken kernels and foreign materials such as metal, dirt, cobs, etc. are removed. The cleaned grain is then ground in hammer mills fitted with screens, which provide grain particles of a more uniform size so that more than 90% of the ground grain has a diameter of 0.5 to 2mm (Rausch, 2005).

Liquefaction involves combining the ground grain with process water to form slurry which is approximately 30% solids by weight (Kwiatkowski, 2006). Ammonia and lime are added at this step to adjust the pH of the slurry to 6.5. The ammonia, which contains nitrogen, also serves as a nutrient for the yeast. The slurry is heated to 88^{o}C by direct steam injection. Then a thermostable enzyme (α-amylase) is added to cleave the starch molecules at random points along the middle of the polymer chain and to break the starch into smaller water soluble fragments called dextrins. After approximately one hour, the output from the first step of liquefaction is combined with recycled water from the end of the ethanol distillation process, so that water accounts for approximately 15% of the final volume of the mash (McAloon, 2000). As the liquefied slurry is cooled to 60°C, it is channelled to the jet-cooker (Kwiatkowski, 2006). Using a new enzyme technology developed by *Genencor* allows for the rapid hydrolysis of granular starch and eliminates the need for gelatination of the starch slurry by jet-cooking, thus significantly lowering the energy consumption (Shetty, 2005). After that, during the second stage of liquefaction, H_2SO_4 is added to the slurry to lower the pH to 4.5. An additional enzyme, glucoamylase (also called β-amylase) is added to break the starch and dextrins into glucose via a stepwise hydrolysis of glucose. The slurry is held at 60°C for 5-6 hours as the glucoamylase hydrolyzes the dextrins to fermentable glucose (Schenk, 2002). After saccharification, the slurry (which is now called mash) is cooled to 32°C. The cooled mash then enters the fermentation tanks.

A popular alternative to mash-presaccharification is to add glucoamylase during the filling of the fermentor. In that case the saccharification and fermentation of the starch takes place simultaneously (Power, 2003).

Sugar fermentation

Fermentation under anaerobic conditions uses microorganisms *Saccharomyces cerevisiae* to convert sugars to ethanol. Ethanol production process results in the production of ethanol and CO_2 and heat. One molecule of glucose yields 2 molecules of ethanol and 2 molecules of CO_2. One kilogram of glucose will theoretically produce 0.51 kilogram of ethanol and 0.49 kilogram of CO_2.

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Ethanol}}{2\,C_2H_5OH} \qquad G^o = -85 \text{ kJ mol}^{-1}$$

In the fermentation step, yeast grown in seed tanks is added to the mash to ferment the simple sugars to ethanol. The other components of the grain kernel (protein, oil, etc.) remain largely unchanged during the fermentation process. E.g. corn oil helps to prevent foaming during the fermentation. Fermentation is a downstream process that occurs continuously.

Fermentation is a continuous process also in case of dry-grind facilities. While continuous fermentation has greater reactor productivity (one fermenting for approximately 46-48 hours) because it is continuously operating with high yeast loads, much more care needs to be exercised to prevent contamination with bacteria, especially species of *Lactobacillus*. These bacteria allow production of organic acids that lower ethanol yields (Graves, 2006), (Bayrock, 2001), (NL514253).

Ethanol production by yeast has high selectivity, low accumulation of by-products, high ethanol yield, and high fermentation rate. Yeasts have to be viable and genetically stable, but also tolerant to high temperatures during the process.

In addition to ethanol, carbon dioxide (CO_2) is also produced during fermentation. Usually, the carbon dioxide is not recovered as a sellable product. If recovered, this carbon dioxide can be cleaned, compressed and sold for carbonation of soft drinks or frozen into dry-ice for cold product storage, for sandblasting in car service and metal industry, etc. If the carbon dioxide is not recovered, it is cleaned and vented to the atmosphere.

Production of hydrated bioethanol as motor fuel

A system has been developed for the production of 85-95% bioethanol by volume with low energetic value as motor fuel. Such a fuel is used in engines that require pure alcohol and not gasoline or gasoline blended fuels. This distillation process is mostly used in Brazil. Hydrated ethanol to be used as motor fuel is called AEHC ´hydrated Ethanol Fuel´ (E100) (Orlando Volpato Filho, 2009), relevant specification has been filed (Fuel Ethanol Specifications Brazil, 2008-2010).

Ethanol pre-distillation and post-distillation (fusel oil) fractions are removed similar to traditional technology used in production of dehydrated ethanol. Process is complete when fractional distillation does not reduce water content any more (azeotropic mixture, ca 95.6% by volume). Maximum final water content is 4.9% by volume.

Ethanol dehydration

Industrial dehydration of ethanol is performed by distillation or non-distillation methods. Dehydrating ethanol-H_2O mixture (94.75% by vol.) by using distillation methods is possible when using azeotropic distillation, i.e. by using triple azeotropes. The third component in ethanol water mixture is benzene or toluene (Ullmann, 1990a).

Non-distillation methods allow significant reduction in the need for energy required for removal of water. Most commonly used non-distillation methods in ethanol industry include solvent extraction, carbon dioxide extraction, adsorption method using molecular sieves, and membrane technology (Ullmann, 1990a).

In case of solvent extraction ethanol is dissolved in certain liquids that are practically non-soluble in water. This difference in solubility can be used for recovery of ethanol from water solution by solvent extraction. For instance, solvent extraction is used by Energol Corporation (USA), which has low total energy consumption (3,500-3,700) per kJ kg^{-1} ethanol.

The University of Pennsylvania and General Electric has developed a process that uses di-butyl phthalate as a water-immiscible solvent for purifying ethanol. This solvent has much higher boiling point than ethanol, and ethanol can therefore be separated in a single distillation step with low losses of solvent.

Extraction with carbon dioxide uses so-called critical liquids, i.e. gases that are compressed to a point where they acquire equilibrium between gas and liquid. Extraction is performed selectively from grain mesh with CO_2 at its critical point, 7.3 MPa and 31°C. Ethanol jet is brought to the pressure of ca 4.8 MPa to remove CO_2. CO_2 is removed and ethanol remains in a liquid state. This method requires only 1/3 to 1/2 of the energy of normal distillation, but the expenses of entire process are 20% higher. When using low-cost CO_2 as a by-product of fermentation process, the price drops significantly. This is important because some of the solvents will inevitably leak during ethanol distillation and have to be replaced.

Dehydration by adsorption method uses molecular sieves with pores that allow water to pass through, but retain ethanol. Molecular sieves may be synthetically produced or naturally occurring zeolites (e.g. clinoptilolites) or proprietary resins. The 95 vol. ethanol is dehydrated in molecular sieve columns; 75% of adsorbed material is water, 25% is ethanol. When the column is saturated, the stream is directed to a fresh column and the saturated column is regenerated. The regeneration stream containing 25 vol. ethanol is fed back to the ethanol distillation system.

Dehydration by membrane technology is based on vaporization of water through membrane module. This is a new method where evaporator consists of several semi-permeable membrane modules made of poly(vinyl alcohol) resins. The 94 vol. ethanol is preheated to 60^{o}C and pumped to the semi-permeable membrane modules of the pervaporator. Water permeates the membrane down its concentration gradient; a phase change occurs from the liquid phase at the membrane inlet to the vapour phase in the permeate. Water is thus separated without azeatrope formation. The driving force for permeate flow is provided by a vacuum of less than 1 kPa at the permeate inlet. The total energy consumption is the sum of the evaporation and the condensation enthalpies.

The condensed permeate contains a small amount of ethanol and can be recycled to a rectifying or distillation tower for recovery of ethanol. A pressure of (4-7) MPa is usually applied to remove the water by forcing it across the membrane. The ethanol retention of new noncellulosic membranes is much higher than that of the cellulose acetate membranes used earlier (80% compared to 50%). Reverse osmosis may prove useful for savings in energy costs by concentrating ethanol to about 10% prior to distillation.

The researchers of Latvian universities (Bremers et al, 2009; LV13691) have experimented with removing water from ethanol by using new methods, as this process is the most energy-intensive stage in ethanol recovery. They have suggested dehydration of bioethanol already during the rectification process as well as performing simultaneous adsorption by supplementing the rectification column with a substance adsorbing water molecules (either laboratory zeolite or Zeolite Sylobead MS564). Combination of rectification and water adsorption allows reducing the number of rectification column beds and the energy spent on removing water by ca 70%.

Production of bioethanol from cellulose biomass

Lignocellulose biomass, including wood waste, agricultural waste, household waste, etc. represents a renewable resource which has stored solar energy in its chemical bonds (McKendry, 2002). It has great potential for bioethanol production, when compared to ethanol produced from grain, tubers and sugar plants, because it is a widely available cheap feedstock which does not compete with human food products. General scheme of producing ethanol from biomass is shown in Fig. 5.

It is known that the main difficulty in converting lignocellulose biomass into second-generation ethanol consists in breaking down structural and chemical biomass complex (Fig. 6). In the course of breakdown process cellulose feedstock is affected by enzymes which allow further recovery of ethanol. Biomass consists of polysaccharides – cellulose and hemicellulose, which are hydrolysed into single sugar components, followed by further recovery of ethanol by well-known and elaborated fermentation technologies. Enzymatic activity in lignocellulose hydrolysis gives a good yield and minimum amount of by-products; it has lower energy consumption, milder operating conditions and represents an environmentally friendly processing method (Saha, 2000; Wingren et al., 2005).

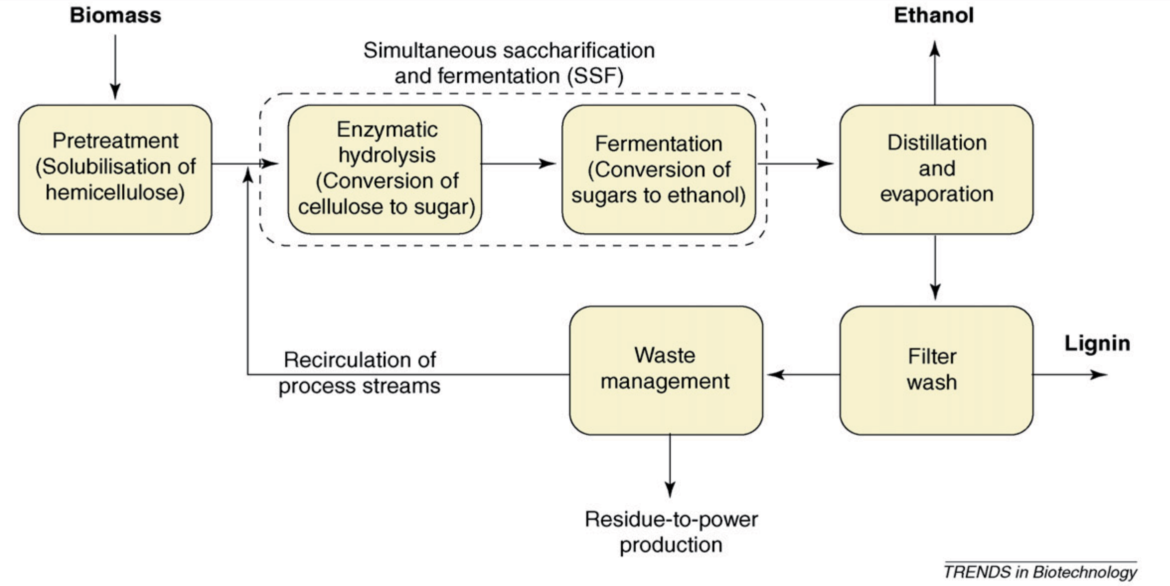

Fig. 5. Scheme for production of ethanol from biomass (Hahn-Hägerdal & Pamment, 2004).

Considering that the sugars required for fermentation are bound to the lignocellulose structure, pre-treatment of biomass is required in order to remove and/or modify lignin and hemicellulose matrix before enzymatic hydrolysis of polysaccharides. Unlike starch which is a crucial source of energy in plants, cellulose has mostly structural role as it provides plant cells with mechanical durability with hemicellulose and lignin. Natural cellulose materials do not have high reactivity; therefore, fermentable saccharification requires large cellulose surface and broken cellulose microfilm structure. Reactivity of natural substrates is also reduced by lignin.

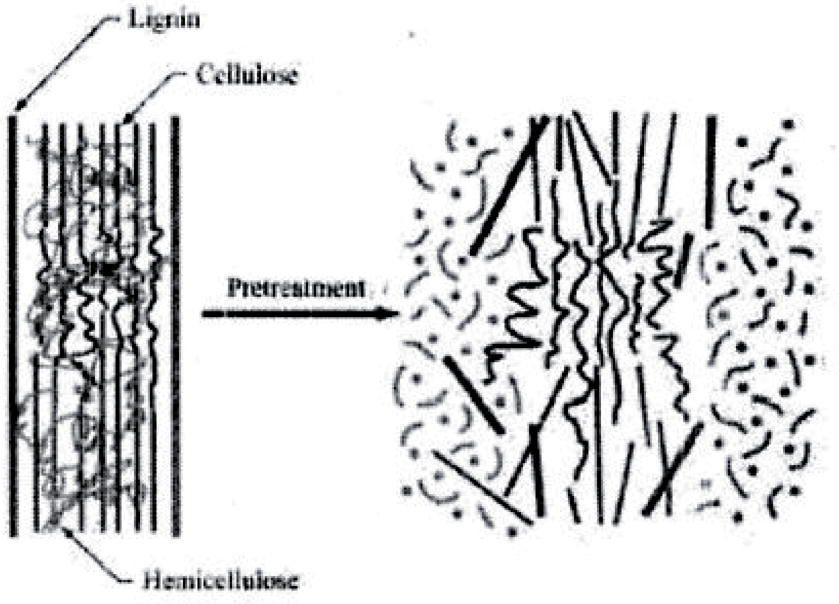

Fig. 6. The structure of lignocellulose material and changes induced by pre-processing (Yi Zheng et al., 2009).

The goals of pre-treatment of lignocellulose feedstock are to preserve hemicellulose, reduce generation of inhibitors and energy cost (National Research Council, 1999). Pre-treatment techniques have generally been divided into three distinct categories, including physical, chemical and biological pre-treatment (Yi Zheng et al., 2009). Physical method consists in steam explosion without catalysts, hot water liquid pre-treatment, mechanical grinding and high energy radiation.

Steam explosion is the most widely used method due to its low cost (McMillian, 1994; Hsu, 1996; Chandra, 2007). Here hemicellulose hydrolysis is performed by using steam and organic acids (Weil et al, 1997). Crucial factors with regard to steam explosion include time, temperature, particle size and humidity (Ballesteros et al., 2008; Negro et al. 2003). Usually the temperature is between 160 and 270^{o}C, processing time ranges from seconds to a couple of minutes. About 90% of the pre-treated mass is subject to further enzymatic activity, whereas relevant percentage in case of non-treated mass is only 15% (Grous et al., 1986). This method provides low hemicellulose yield (Wright, 1988; Excoffien et al., 1991; Heitz et al., 1991).

Hot water pre-treatment is performed with water in liquid state at elevated temperatures (Brandon et al., 2008; Dien et al., 2006; Negro et al., 2003; Rogalinski et al., 2008). This method increases cellulose processing output, extraction of sugars and recovery of pentose, but resulting pre-hydrolysate may contain sugar fermentation inhibitor (Van Walsum et al., 2008). Conversion of lignocellulose material depends on its origin. Pre-hydrolysates rich in sugar can be fermented into ethanol directly. Ca 80% of hemicellulose produced from corn fibre (Allen et al., 2001) and sugar cane bagasse (Laser et al., 2002) can be subject to enzymatic process. Wheat straw sugar yields 53% and enzymatic hydrolysis yields 96% (Perez et al., 2007).

The most efficient but also the most expensive and energy-intensive method is mechanical comminution of lignocellulose feedstock. Biomass material can be comminuted by various chipping, grinding and milling. The milling can be further detailed into hammer and ball-milling (wet, dry, and vibratory rod/ball milling) (Rivers et al., 1987; Yoshida et al., 2008), compression milling (Ryu et al., 1982), (Tassinari et al., 1977), pan milling (Zhang et al, 2007), etc. Mechanical processing disrupts cellulose structure, reduces polymerization level, increases special surface of cellulose biomass when biomass is broken down to smaller particles.

Chemical alkali-based methods are used in order to reduce the price of pre-treatment (Abdi, et al., 2000, Carrillo et al., 2005, Pinto et al., 1996; Silverstein et al., 2007); physical methods include γ-radiation (Yang et al., 2008) and (Youssef & Aziz, 1999) dilution with sulphuric acid (Ballesteros et al., 2008; Martin et al., 2007; Marzialetty et al., 2008; Sun et al., 2005; Zheng et al., 2007; Zheng et al., 2008), and other diluted acids such as diluted HNO_3 (US5221357, US5366558), HCl (Mehlberg, 1979, Herrera et al., 2003), H_3PO_4 (Israilides et al., 1978), (Um et al., 2003; Vazquez et al., 2007). But basic chemical pre-treatments include concentrated HCl and H_2SO_4 (Goldstein et al., 1983; Vedernikov et al., 1991), in order to produce fermentable sugars.

Biological pre-treatment uses microorganisms for decomposing wood, the effect of white and brown soft-rot fungi and bacteria in order to modify the chemical composition and/or structure of lignocellulose biomass so that it could be subjected to processing with enzymes (Kurakake, 2007; Lee, 2007, (Singh, 2007). Brown soft-rot fungi have greater impact on cellulose and less on lignin, whereas white soft-rot fungi have greater impact on the lignin component (Schurz, 1978). Zheng et al. have studied (Zheng, 2009) organisms that are more efficient in decomposing lignin.

Research on biomass pre-treatment for the purpose of breaking down lignocellulose feedstock has continued for years, but none of the results have been introduced in industrial application of ethanol production due to low economical profitability. Only a few pre-treatment methods such as diluted acid and steam explosion have been tested with success. Until this day the best-known practice in the world is sample production of ethanol from cellulose in relevant Iogen Corporation facilities in Canada. Iogen Corporation uses modified steam explosion pre-treatment of the feedstock in order to enhance enzymatic cellulose ethanol production at the yield of 340 l/t per fibre (Iogen Corporation, 2010).

These days the factory cost of ethanol production from cellulose still exceeds the production cost of grain ethanol by 2.5-4 times. In June 2006 the price of bioethanol made of lignocellulose was 0.59 USD/l in the United States of America. The United States have set a goal of producing bioethanol from lignocellulose at the price of 0.28 USD/l by 2012 (Solomon, 2007).

Already in 2008 Japanese researchers reported on the successful completion of the programme for producing ethanol from cellulose by using only microorganisms. Until then chemicals, such as H_2SO_4, etc. had been used for cellulose decomposition to glucose. They have prepared large quantities of bacteria for that purpose. In that case there is no need for expensive special lignocellulose biomass pre-treatment. This is the most prospective modern tendency in industrial production of ethanol, as it would be the cheapest production method in the future (as it does not require chemicals or large amounts of water, it is less polluting and provides maximum yield when producing ethanol from carbohydrates. Bacteria prevent a problematic situation that might occur when using fungi. Several authors have analysed the problems arising from soft-rot fungi, because the use of fungi leads to generation of inhibitors that hinder decomposition of carbohydrates during the pre-treatment process. Generation of inhibitors is impossible when using bacteria.

The bacterium *Escherichia coli* KO11 has been used in hydrolysis of sugar cane bagasse (Hahn-Hägerdal, 2004), hemicellulose corn fibres (O'Brien, 2004) and *E. coli* FBR5 corn cobs (Hahn-Hägerdal, 2004), and rice kernels (Saha, 2005). Patent No. WO2009008206 registered by Japanese researchers Nanba Hiromi and Tanaka Hidehiko allows conversion of cellulose material by using *koji mold* bacteria from rice malt.

Bioethanol from algae

Production of motor fuel from algae has been subject to research for decades. Now there is an opportunity to produce bioethanol simultaneous to the third-generation biofuel – algae diesel (*Oilgae*) (WO2010006228, WO2009154437, US2009298159, CN191580857, etc). The production scheme is shown in Fig. 7. Carbohydrates in algae oil can still be converted to starch.

For years Japanese researchers have studied the saccharification of sea algae by marine bacteria (Mitsufumi Matsumoto, 2003), (Tadashi Matsunaga, 2009). There are several new patents on recovery of starch from algae, US2009075353, US2010041926, JP55011317, JP1023001, WO2009125037, etc.

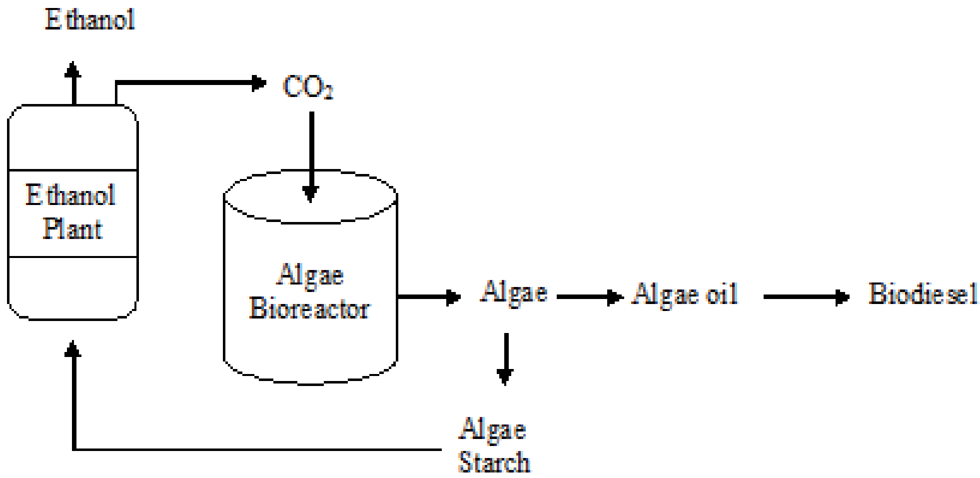

Fig. 7. Technological scheme for producing biodiesel and ethanol from algae http,//www.oilgae.com/algae/pro/eth/eth.html.

CONCLUSIONS

This present study provides an overview of potential methods for industrial ethanol production. The main attention is paid to carbohydrates as technologies for producing bioethanol are based on renewable resources. It comprises both the potential recovery of dehydrated bioethanol and hydrated bioethanol for the purpose of using them as motor fuels. In addition to sugar and starch based and lignocellulose feedstock used for producing ethanol, the authors have also pointed out the most recent tendencies of the last decade.

These include,

1) Production of ethanol from cellulose by using bacteria; this method allows exclusion of energy-intensive pre-treatment of feedstock and combine hydrolysis and sugar fermentation process,

2) Algae oil and ethanol recovery by using gene modification and nanotechnology.

Institute of Technology of Estonian University of Life Sciences continues activities for gaining knowhow for producing bioethanol in farm environment at optimum price as well as for its use in internal combustion engine.

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Indoor Air Temperature and Ventilation in Uninsulated Loose Housing Cowsheds with Different Types of Non-transparent Roofing in Hot Summer

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Abstract. As the indoor temperature of uninsulated cowsheds is in correlation with outdoor temperature, it may happen that indoor temperatures in cowsheds soar in hot summer. Roof temperature and spatial distribution of indoor air temperature at 1m (cow level) was studied in 8 uninsulated cowsheds with three different types of roof – non-asbestos cement sheets (4 cowsheds), metal (2 cowsheds) and insulated with 25 mm mineral wool plate (2 cowsheds) at outdoor air temperatures 26.8...32.0°C in at least 25 points of the cowshed. All openings were open in the cowsheds.

Roof (indoor surface) temperature values of 47.1°C were recorded as highest at non-asbestos cement roof in outdoor air temperature of 30°C. The average indoor surface temperature of the insulated roof (28°C) was about as high as outdoor air temperature (29°C).

Average indoor temperature in cowsheds varied 27.6-29.7°C. Smallest indoor-outdoor air temperature difference (Δt) was 0.8°C and occurred at lowest outdoor temperature (26.8°C). The biggest Δt of -2.3°C occurred at highest outdoor temperature (32°C).

If the roof was insulated, Δt varied -0.5-1.1°C. In four cowsheds with non-asbestos cement sheet roof, Δt of 0.8…-1.9°C was recorded. In cowsheds with metal sheet roof, Δt of -1.2… -2.3°C was recorded.

Standard deviation of indoor temperatures at the measurement points s (describes the ventilation efficiency) was s=0.59…0.84 in the cowsheds with insulated roof and s=0.46…0.66 in the uninsulated ones. The ventilation in cowsheds was good and air moving schemes uniform.

As a result of the investigation, the following conclusion can be made: indoor air temperature and ventilation efficiency in hot summer days are not influenced by roof material (non-transparent) or the presence of insulation..

Key words: Air temperature, uninsulated cowshed, ventilation, summer

INTRODUCTION

Today a lot of cows are kept in loose housing and uninsulated cowsheds. Borders having U-values of 6-7 W m^{-2} K^{-1} are comparable with single glass windows. Investigations carried out in cowsheds show that closing vent openings up to very small ventilation rate in cold weather will lead to significant indoor-outdoor temperature difference (Pajumägi et al., 2003, 2007).

It is well known that cows tolerate cold more than heat. Upper Critical Temperature for cows is given as 25-26 ºC (Berman et al., 1985; Hamada, 1971). Feed intake in lactating cows begins to decline at the ambient temperatures of 25-26ºC and drops more rapidly above 30ºC. At 40ºC, dietary intake may decline by as much as 40% (National Research Council, 1989). Heat will cause stress that may lead to dropping the milk yield and a heart condition. Sczütz et al. (2008) found out that cows preferred standing in a shaded area instead of lying.

There are two main problems in the cowsheds in summer in hot weather: indoor air temperature caused by high outdoor temperature and radiant heat load from the sun-heated roof. Jeppsson and Gustafsson (2001) recorded that absorptance factor for transparent polycarbonate roofing was 0.36 and for non-transparent fibre cement roof 0.20 and ventilation rate was 0.070 and 0.035 $m^3m^{-2}s^{-1}$, respectively.

The roof of uninsulated cowshed offers good shading for cows in hot weather (West, 2003) Shading, which provides protection from direct solar radiation, is one way to minimise the effects of heat stress (Kadzare et al., 2002)

MATERIALS AND METHODS

Tests were carried out at 8 Estonian cowsheds in 5 farms (Table 1) with commonly used design solutions and three different types of roof – non-asbestos cement sheets (4), metal (2) and insulated with 25 mm mineral wool (2). End walls were mostly from metal and walls were covered with plastic material.

Measurements were performed in hot summer with non-cloudy weather. Air temperature was measured outdoors before and after indoor test.

In cowsheds the measurements were carried out at 1m above floor level in at least 25 points (A1–E5 in Fig. 1) in the course of one hour. The following portable measuring devices were used: thermo-hygrometer Testo 615 (range -20…+70ºC and 5…95%, accuracy ±0.7ºC, 3%) and infra-red thermometer Raytek (Raytek Raynger ST™ RAYST2XHCG, resolution 0.1ºC). Infra-red thermometer was also used for measuring the cows' surface temperatures to evaluate the effect of the building as a shade.

Air movement in the cowshed was visualized with smoke using bellows.

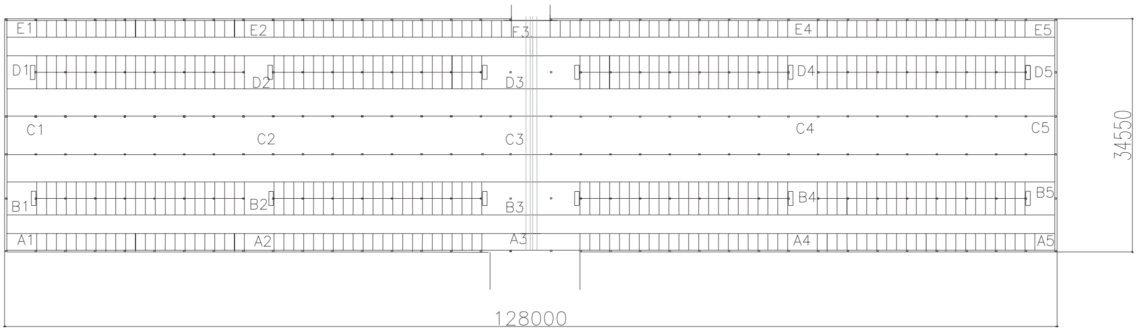

Fig. 1. Typical plan of a cowshed A1…E5 measurement points.

Values of air velocity and relative humidity were recorded as well, but excluded from this analysis, because the use of the spatial temperature distribution is proposed as a measure to assess ventilation efficiency (Pajumägi et al., 2008).

RESULTS AND DISCUSSION

Measurements were carried out at outdoor air temperatures of 26.8...32.0°C in at least 25 points of the cowshed (Table 1). In the cowsheds, all openings were open.

Table 1. Roof surface, outdoor and indoor air temperature (°C)

Cowshed, Roof type	Item	Outdoor	Indoor temperature					Δt*
			Min	Max	Average	Stdev	Range	
No 1	Air	28.6	27.2	29.6	28.1	0.75	2.4	-0.5
insulated	Roof		25.2	33.1	28.5	2.54	7.9	0.4
No 2	Air	28.9	26.7	29.9	27. 8	0.84	3.2	-1.1
insulated	Roof		24.9	31.4	27.9	1.78	6.5	0.1
No 3	Air	26.8	26.5	29.1	27.6	0.59	2.6	0.8
cementos	Roof		25.7	42.5	33.9	4.75	16.8	6.3
No 4	Air	29.2	27.9	30.5	28.7	0.64	2.6	-0.5
cement	Roof		26.7	45.1	38.3	5.56	18.4	9.6
No 5	Air	28.5	27.5	29.5	28.2	0.46	2.0	-0.3
cementos	Roof		29.7	46	38.7	4.4	16.3	10.5
No 6	Air	30	26.7	30	28.1	0.66	3.3	-1.9
cement	Roof		26.3	47.1	36.8	5.61	21.2	8.7
No 7	Air	30.9	28.8	30.8	29.7	0.59	2.0	-1.2
Metal	Roof		21.2	44.4	36.7	5.4	23.2	7.0
No 8	Air	32	28.5	30.9	29.7	0.59	2.4	-2.3
Metal	Roof		30.4	43	36.9	3.45	12.6	7.2

* - Δt for air is calculated by indoor-outdoor air and for roof as roof surface – indoor air temperature

Air temperature

Outdoor temperature varied 26.8…32.0°C, whereas average indoor temperature varied 27.6…29.7°C (Table 1). The smallest indoor-outdoor air temperature difference (Δt) was 0.79°C and occurred at the lowest outdoor temperature (26.8°C). The biggest Δt of -2.33°C occurred at highest outdoor temperature (32°C).

If the roof was insulated (25 mm glass wool plate), Δt varied -0.53…-1.12°C. In four cowsheds with non-asbestos cement sheet roof, Δt of 0.79…-1.91°C was recorded. In cowsheds with metal sheet roof, Δt of -1.22…-2.33°C was recorded.

Indoor-outdoor temperature difference depending on outdoor temperature is given in Fig. 2. At higher outdoor temperatures the Δt was bigger and indoor air temperature was lower than outdoors, which indicates good effect of shade.

There was no correlation between outdoor air temperature and standard deviation of indoor temperature (Fig. 3). Standard deviation of indoor temperature s was 0.59…0.84 in a cowshed with insulated roof (Fig. 4a) and 0.46…0.66 in an uninsulated one (Fig. 4b).

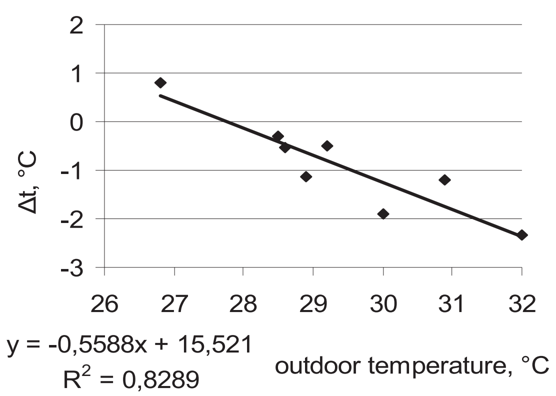

Fig. 2. Indoor-outdoor temperature difference depending on outdoor temperature.

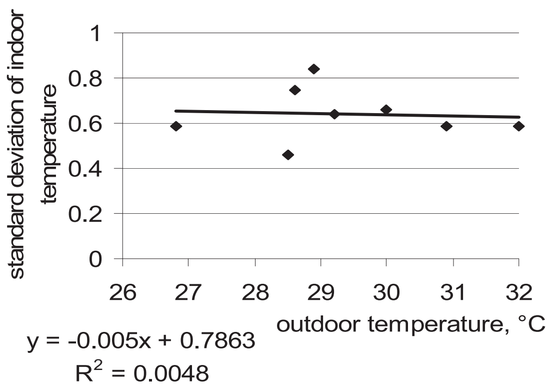

Fig. 3. Dependence of standard deviation of indoor temperature on outdoor air temperature.

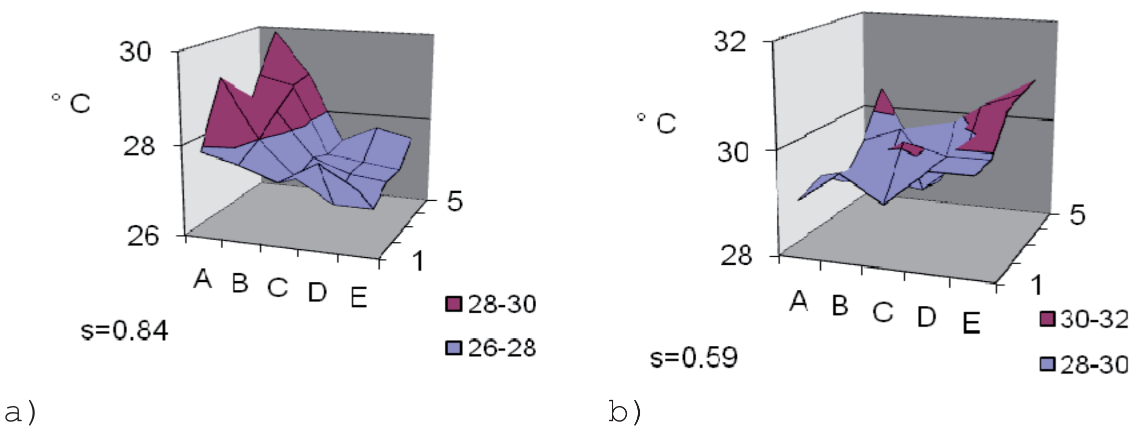

Fig. 4. Air temperature distribution in the cowsheds: a) insulated; b) metal sheet roof.

The use of spatial temperature distribution is proposed as a measure to assess ventilation efficiency (Pajumägi et al., 2008). Standard deviation of indoor air temperature characterizes ventilation efficiency in the cowshed:

- $s<0.8$ — ventilation is good — mark 1;
- $s = 0.9…1.3$ — ventilation is satisfactory (lack of animals in number or ventilation openings are too widely open; effect of chimney does not work) —mark 2;
- $s>1.4$ — ventilation is unsatisfactory (important ventilation openings are closed) — mark 3.

In all cases the standard deviation of indoor temperature was under 0.9, which indicates good ventilation. In a cowshed with metal sheet roof the air moving scheme was more uniform (Fig. 5), because heated roof activates airflow under the roof and intensifies ventilation.

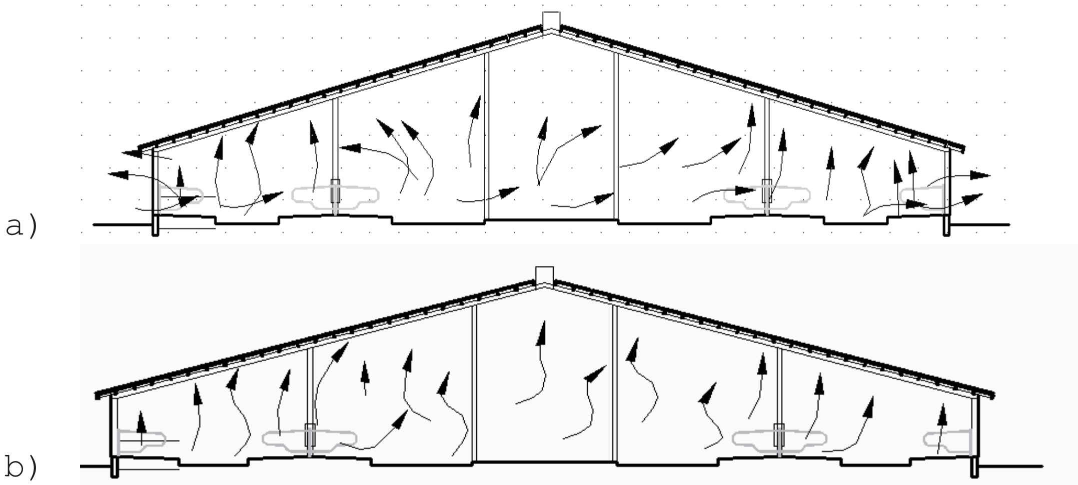

Fig. 5. Air moving schemes: a) insulated roof; b) metal sheet roof.

Roof temperature

Roof (indoor surface) temperature value of 47.1°C was recorded as the highest in case of non-asbestos cement roof at outdoor air temperature of 30°C and average indoor air temperature of 28.1°C. The average roof temperature of cowsheds with non-asbestos cement sheets was 33.9…38.3°C. Difference between average roof surface and indoor air temperature varied 6.3…10.5 in these cowsheds. The average indoor surface temperature of the insulated roof (~28°C) was about the same as outdoor (29°C) and indoor (~28°C) air temperature. Maximum value of 33.5°C was recorded**.** In a cowshed with metal sheet, maximum roof temperature was 44.4°C and difference between average roof surface and indoor air temperatures was about 7°C.

Spatial distribution of roof temperature in cowsheds with insulated and metal sheets is presented in Fig. 6.

There is problem of long wave radiant heat load in cowsheds with high indoor surface temperatures, but that can be regulated by materials or surface paints.

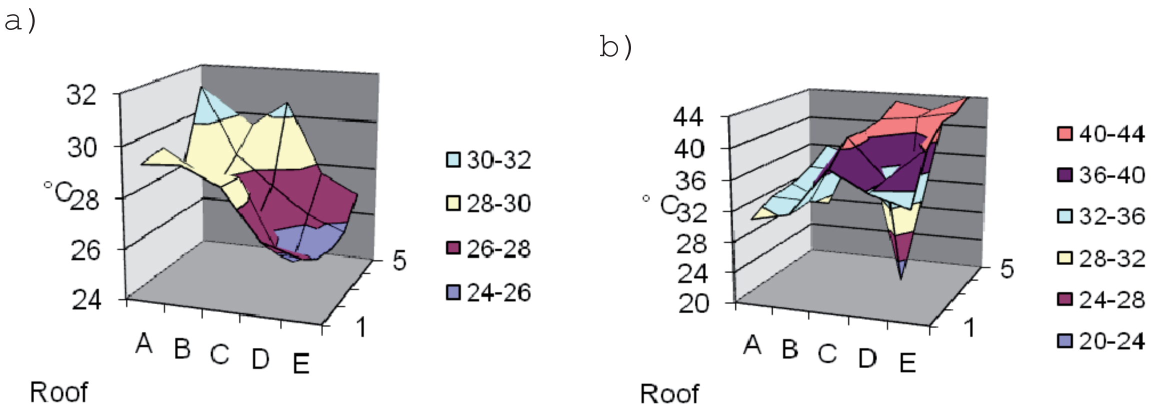

Fig. 6. Roof surface temperatures: a) insulated; b) metal sheet.

One of the possibilities for evaluating the effect of the building as a shade is to measure the cows' surface temperatures. In Fig. 7, cow's hair coat temperatures in a hot summer day are given. The cow is lying by the side wall; the plastic wall curtain is removed. The temperature of dark (52) and bright (40) hair coat exposed to direct sun is 19 and 7°C higher than in the shaded area (33°C).

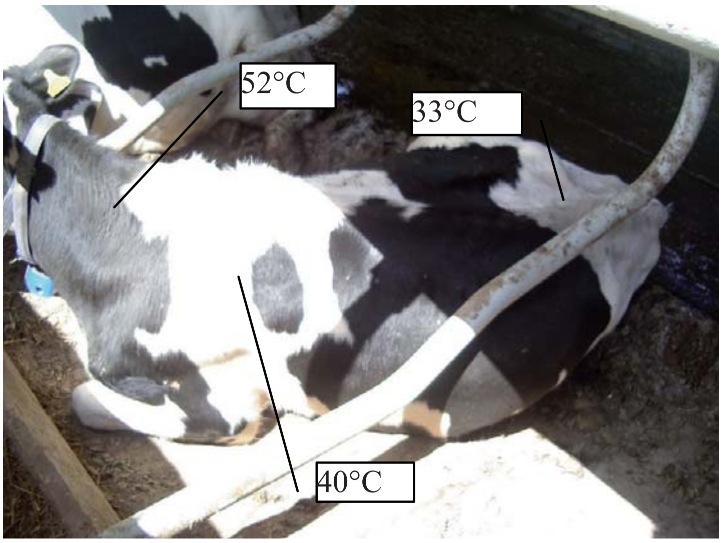

Fig. 7. Cow's hair coat surface temperatures exposed to sun and in the shade.

Relative humidity was recorded 28.7...48.7% outdoors, 30.0...48.7% indoors and 34.9...47.4% as average indoors. Dependence of indoor relative humidity on indoor air temperature is given in Fig. 8.

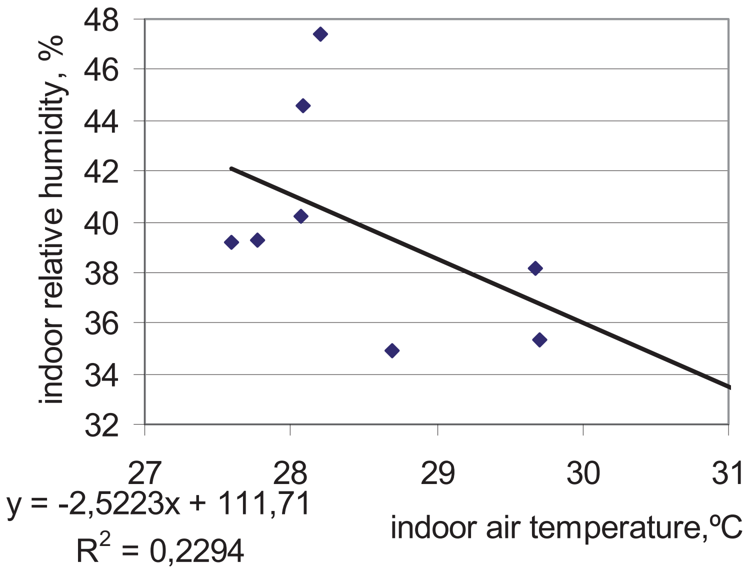

Fig. 8. Dependence of indoor relative humidity on indoor air temperature.

CONCLUSIONS

This study focused on hot summer weather. In spite of high roof temperatures the indoor air temperature was mostly the same or lower than outdoors.

Ventilation was more uniform in a cowshed with higher roof temperatures (metal sheet and non-asbestos cement sheets), but overall ventilation was good in all cowsheds.

Heated roof activates airflow under the roof and intensifies ventilation.

A cowshed (mostly the roof) offers good shade in hot weather in spite of the roof material.

From that point of view uninsulated non-transparent materials like non-asbestos cement and metal sheets are both suitable for roof-covering materials in summer conditions.

Roof insulation will not give better protection in hot weather.

Radiant heat load can be reduced by choosing inner and/or outer surface covering.

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Yield of Winter Wheat Grown under Zero and Conventional Tillage on Different Soil Types[5]

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Abstract. In three-year field trials, conducted in West Poland, the growth and development of winter wheat grown under zero tillage (ZT) and conventional tillage (CT) methods on four soils were investigated. The soils were different mainly in grain fraction distribution and content of organic matter. The tested soils were sandy loam (SL), loamy sand (LS-1, LS-2) and sand (S). In GPS-fixed sites, in ZT and CT fields, yield of aerial part biomass in four growth stages: stem elongation, second node, and heading and inflorescence phases, was compared. In addition, yields of grain and straw were tested. On medium and coarse textured soils (SL, LS-1, LS-2), more biomass was produced by wheat under CT than ZT, but on very coarse textured soil (S), the biomass yields obtained from wheat growing under both soil tillage methods were identical. On medium textured soils and on coarse textured (LS-1) soil, wheat under CT contained more N and P as well as much more Ca and Mg in tissues than under ZT. In contrast, on the other coarse textured (LS-2) soil and on very coarse textured soil, wheat plants under ZT were generally characterized by identical or slightly higher nutrient content than plants under CT. Despite periodic fluctuations in biomass yields between ZT and CT for particular growth stages of wheat, the yields of grain and straw were the same for both soil tillage methods, irrespective of the soil type.

Key words: Wheat, zero tillage, yield, growth stages, types of soil

INTRODUCTION

Reduced soil tillage has certain advantages, as it prevents soil erosion, reduces water loss and decreases crop cultivation costs in comparison with conventional soil tillage with a plough. An extreme example of simplified soil tillage is the zero method, also known as the direct drilling method, which involves sowing seeds into unploughed soil using a specialist seed drill. The references suggest that zero tillage (ZT) leads to differentiated results. Yields from zero tillage fields are often higher than those from conventional tillage ones, but there are also cases when no differences appear between zero and conventional tillage fields or when yields under zero tillage are lower (Ernstein & Laxmi, 2008). There are many factors influencing the results of direct sowing, including soil, climate and the duration of ZT implementation (Martinez et al., 2008). Higher crop yields under ZT than under

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CT are typically obtained in dry climate (Wang et al., 2007). In the moderate climate of West Poland, with mean annual precipitation of 550 mm and mean annual temperature of 8.5^{o} C, zero tillage rarely generates higher yields than conventional soil cultivation methods. The advantages of using ZT depend both on the weather, especially distribution of precipitation, and the type of soil. Besides, nitrogen fertilization, forecrop, as well as weed infestation and disease outbreaks can alter the direct effect of ZT on yield volume (Małecka & Blecharczyk, 2008).

The impact of the type of soil on effects of ZT consists in the fact that ZT changes physical properties of soil, particularly soil density together with air and water relationships, as well as soil chemical and biological characteristics in comparison with CT. The extent and intensity of such changes caused by the 'no-plough' method in soil obviously depends on soil texture. In heavier soil, for example, such changes happen faster and reach deeper than in lighter soils.

Some claim that sandy soils are not suitable for zero tillage. In Poland, over 60% of arable land consists of sandy soils. The purpose of this study has been to compare the growth and development of winter wheat grown under zero and conventional tillage on 4 types of soil of different texture.

MATERIAL AND METHODS

The experiment was conducted in 2007-2009 at the Experimental Station in Baborowko near Poznań (West Poland). It involved winter wheat fields, which had been cultivated for three years before the trials under conventional tillage (CT) or zero tillage (ZT) methods. Conventional tillage involved stubble ploughing and seed ploughing to the depth of 25 cm as well as pre-seeding soil cultivation with a power harrow. Zero tillage was performed without mechanical soil tillage, mulching the soil with comminuted straw. Seeds were sown using a special type of seed drill and weeds were controlled with herbicides only. Fertilization was identical for both soil tillage methods. All fields received basic fertilization: N - 30 (autumn) and 120 (spring 80+40), P - 17 and K - 50 kg ha^{-1}.

In GPS-fixed points in ZT- and CT-fields, the biomass yield of aerial parts of wheat plants in 4 growth stages: early stem elongation (I), second node (II), heading (III) and inflorescence (IV), was assessed. In addition, yields of grain and straw were measured. Plant samples were collected by cutting whole aerial parts of wheat growing in an area of 1 square meter.

The experiment was established on four soil types: Haplic Phaeozems, sandy loam (SL); Haplic Arenosols (Brunic), loamy sand (LS-1); Albic Luvisols, loamy sand (LS-2) and Albic Luvisols (Arenic), sand (S). The soils were different in texture, organic matter content and nutrient abundance (Table 1).

The years during which the experiment was conducted were quite different as for weather conditions. The highest average monthly temperatures, exceeding the multi-year mean, were recorded in 2007 (Table 2). Moreover, the year 2007 had the highest total precipitation from March to July, exceeding the multi-year average (Table 3). Noteworthy is an extremely dry April and a very wet May, when over 2.5-fold more rain fell compared to the multi-year average. The year 2008 was characterized by the average monthly temperatures higher than multi-year average. The total rainfall from March to July was the lowest compared to the other analyzed years, yet at a level of the multi-year average. Nonetheless, the distribution of rainfall was less favourable than in 2007, because after very heavy rains in April came very dry May and June. In 2009, higher temperatures were recorded in April, compared to the other years or to the multi-year average, and the rainfall was relatively low. The temperatures in May and June were lower than in the other years, while the rainfall was quite high.

Table 1. Characteristic of experimental soils

Soil	pH KCl	OM	SF I	SF II	SF III	P	K	Mg
		%				mg kg^{-1}		
SL	6.4	1.38	65.8	27.5	6.7	92	116	97
LS-1	6.3	1.34	79.8	14.9	5.3	72	115	95
LS-2	6.2	1.03	83.8	4.8	11.4	67	96	93
S	6.3	1.07	88.3	7.4	4.3	89	84	66

OM-organic matter, SF I-soil fraction 2.0-0.05 mm, SF II-soil fraction 0.05-0.002 mm, SF III -soil fraction <0.002 mm.

Table 2. Mean monthly air temperatures in Baborowko (^{o}C)

Year	Month					
	III	IV	V	VI	VII	Mean
2007	6.7	11.0	16.5	19.8	20.2	14.8
2008	4.4	9.0	15.0	19.4	20.7	13.7
2009	4.1	12.4	14.1	16.2	20.0	13.4
1971-2006	3.1	7.8	13.5	16.4	18.4	11.8

Table 3. Monthly sums of precipitation in Baborowko (mm)

Year	Month					
	III	IV	V	VI	VII	III-VII
2007	55.9	3.8	119.4	59.0	94.7	332.8
2008	50.1	71.4	14.9	18.0	69.5	223.9
2009	50.6	17.2	76.8	91.4	75.8	311.8
1971-2006	29.6	31.0	49.5	59.4	77.3	246.8

Dry matter yield of aerial wheat parts in the consecutive growth stages was determined alongside grain and straw yields from $1m^2$ of field. The results underwent analysis of variance. For comparison of the differences between the means, the Tukey test ($\alpha < 0.05$) was applied.

Soil samples were taken for chemical analyses before the trials. Organic carbon in soil was determined by Tiurin method, pH was established potentiometrically in 1 mol KCl dm^{-3}, P and K were assessed using Enger-Riehm method and Mg was assayed by Schachtschabel method.

In all plant samples, after wet mineralization (concentrated H_2SO_4+ 30% solution of hydrogen peroxide), N and P content was determined with flow spectrophotometric method, K with emission spectrophotometry and Ca and Mg with AAS.

RESULTS AND DISCUSSION

The wheat biomass yield determined in the plant's subsequent growth stages differed according to soil tillage method (CT or ZT), depending on the year, which was connected with the weather (Fig. 1).

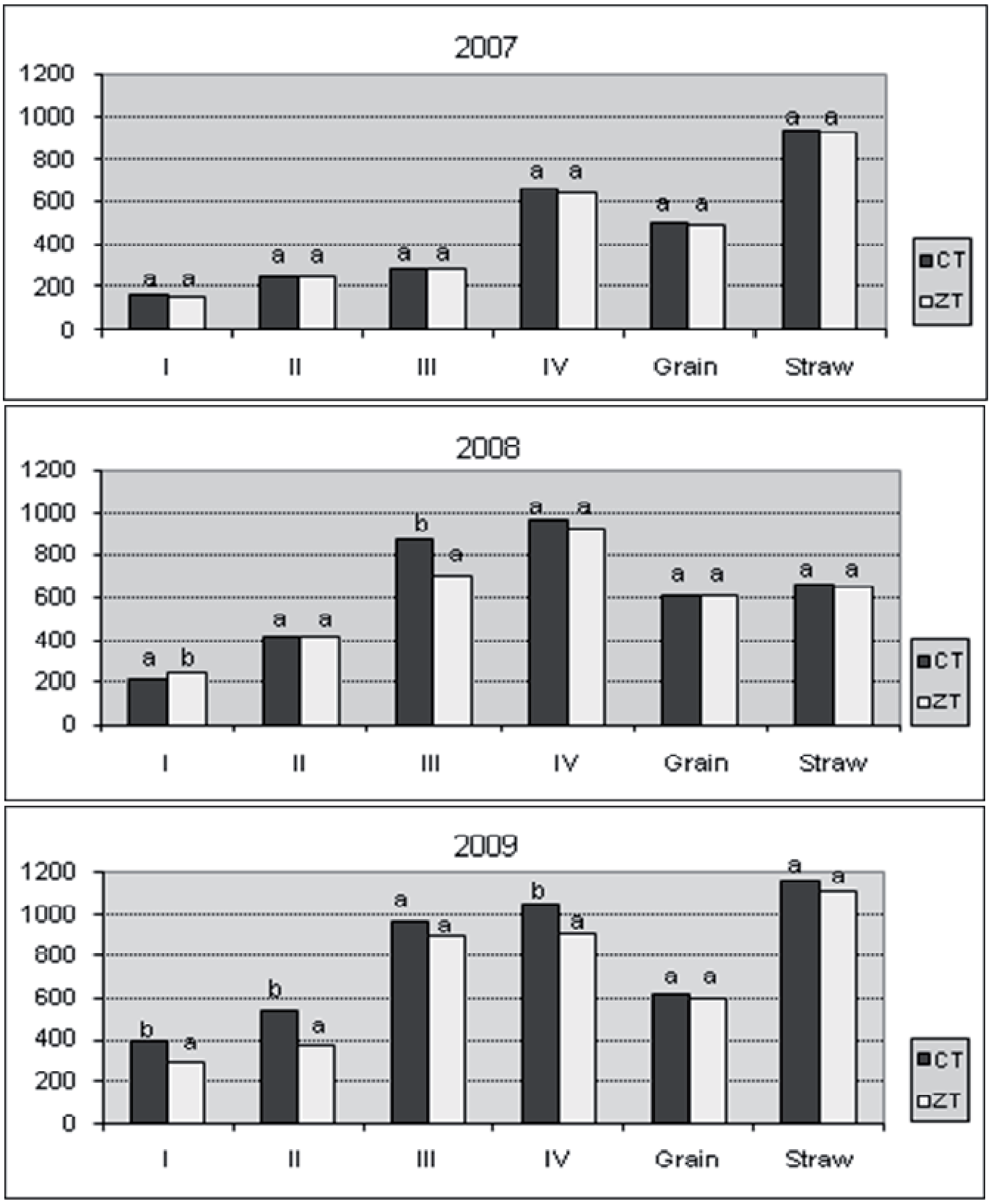

Fig. 1. Yield of wheat dry aerial parts (g m^{-2}) during subsequent growth stages (I – IV) and final yield means of soil types. Identical letters denote lack of differences tested with the Tukey test ($p < 0.05$).

In 2007, which was characterized by higher than average rainfall during the growing season, especially in May, and relatively high average air temperature, the biomass yield in each growing phase was identical to both soil tillage methods. It was noteworthy that in the driest year, 2008, during the drought in May–June, although the biomass yield tended to be higher under CT than under ZT, the biomass increase between phase III and IV was much higher in the ZT (32%) than in the CT field (11%). In 2009 with a little less rainfall and lower average temperature than in 2007, significant differences were observed in biomass yields in favour of CT method. Higher plant yields from ZT than from CT fields are usually obtained in dry climate or in years with less rainfall (Arshad et al., 1999; Bonfil et al., 1999; De Vita et al., 2007) because in a dry year, plants are less vulnerable to yield loss under ZT rather than under CT method. It is so because more water is accumulated in soil tilled according to zero tillage method, which is a consequence of lower evaporation and changes in the soil's water permeability when no mechanical soil tillage is involved (Rasmussen, 1999; Martinez et al., 2008). An extensive study performed by Erenstein et al. (2008) proves that water productivity indicators in wheat cultivation are higher for ZT than for CT. Also Mrabet (2000) found superior wheat water use efficiency under ZT in a semiarid area.

Although there were certain differences between CT and ZT in wheat biomass yield during the early growing phases, the yields of grain and straw from ZT and CT trials were identical, independent of the year of experiment. This finding is attributable to the fact that in the climate prevailing in West Poland, crops growing under ZT tend to enter the vegetative phase later than plants under CT, which is due to lower temperature of the upper soil layer in early spring. The topmost soil layer, down to 5 cm deep, treated with ZT is more compact and moist than soil receiving CT (Martinez et al., 2008), and consequently, it warms up more slowly. In the later growth stages, the growth and biomass accumulation under ZT can accelerate and the grain yields from fields under both types of soil tillage can become even.

Obviously, apart from the thermal and moisture conditions, the rate of biomass increase is affected by soil type and soil abundance in nutrients. When analyzing differences between CT and ZT applied to different soil types, it was determined that, in general, wheat growing on heavier soils (SL and LS-1), containing more organic matter, had more biomass under CT than under ZT (Fig. 2). On lighter soils with less organic matter (SL-2 and S), wheat under ZT produced as much biomass as wheat plants under CT. The yields of grain and straw, irrespective of the soil type, were identical for both soil tillage methods.

The differences in the biomass yields between CT and ZT could have been caused by the differences in the nourishment of wheat plants during the growing season (Fig. 3).

Wheat under CT on SL and LS-1 soils contained more Ca and Mg as well as more N and P than wheat under ZT. In contrast, on LS-2 and S soils, wheat plants growing under ZT tended to contain the same or slightly higher levels of these nutrients compared to wheat growing under CT.

Many authors report on differences in the distribution of macronutrients in soil, depending on the soil tillage method. Most nutrients appear in higher concentrations in a soil receiving zero tillage than in a soil tilled conventionally, but only in the top 0-5 cm soil layer, and start decreasing along with the depth

(Franzluebbers & Hons, 1996; Martin-Rueda et al., 2007; Tarkalson et al., 2006; Wright et al., 2007). Zech et al. (2000) found varied concentrations of nutrients in soil under CT and ZT depending on a rainy or dry season.

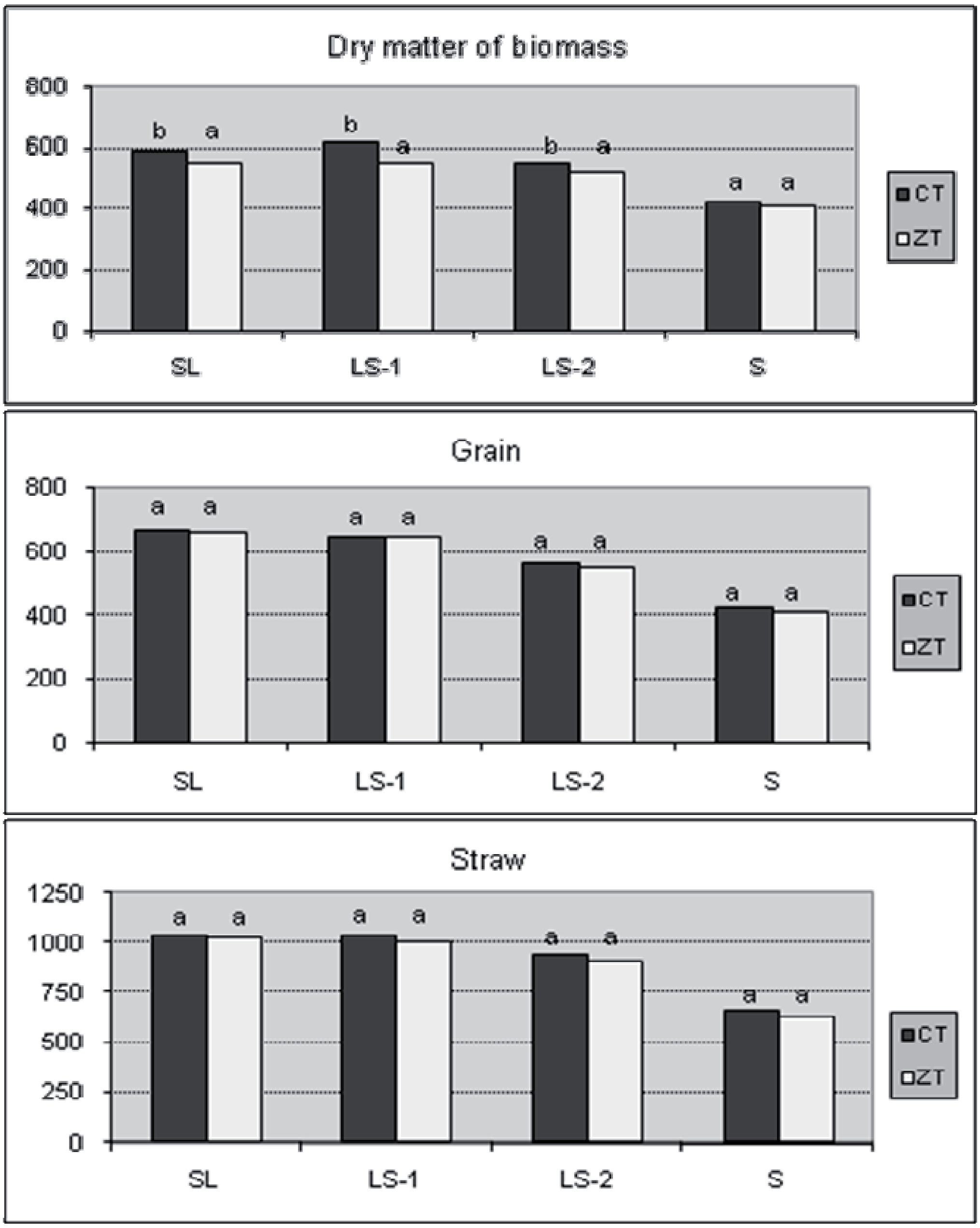

Fig. 2. Wheat yield (g m^{-2}) on different types of soil. Mean biomass for 4 sampling dates and 3 years; for grain and straw – means for three years.

Identical letters denote lack of differences tested with the Tukey test
($p < 0.05$).

In a study conducted by Stanisławska-Glubiak & Korzeniowska (2009), differences appeared in the levels of micronutrients in plants under CT and ZT during the early vegetative season. These concentrations were typically higher under CT, unless there was drought, when more nutrients occurred in plants growing under ZT. Lavado et al. (2001) report that soil tillage methods have a relatively weak influence on the content of micronutrients in plants growing under the soil and climatic conditions prevalent in South America.

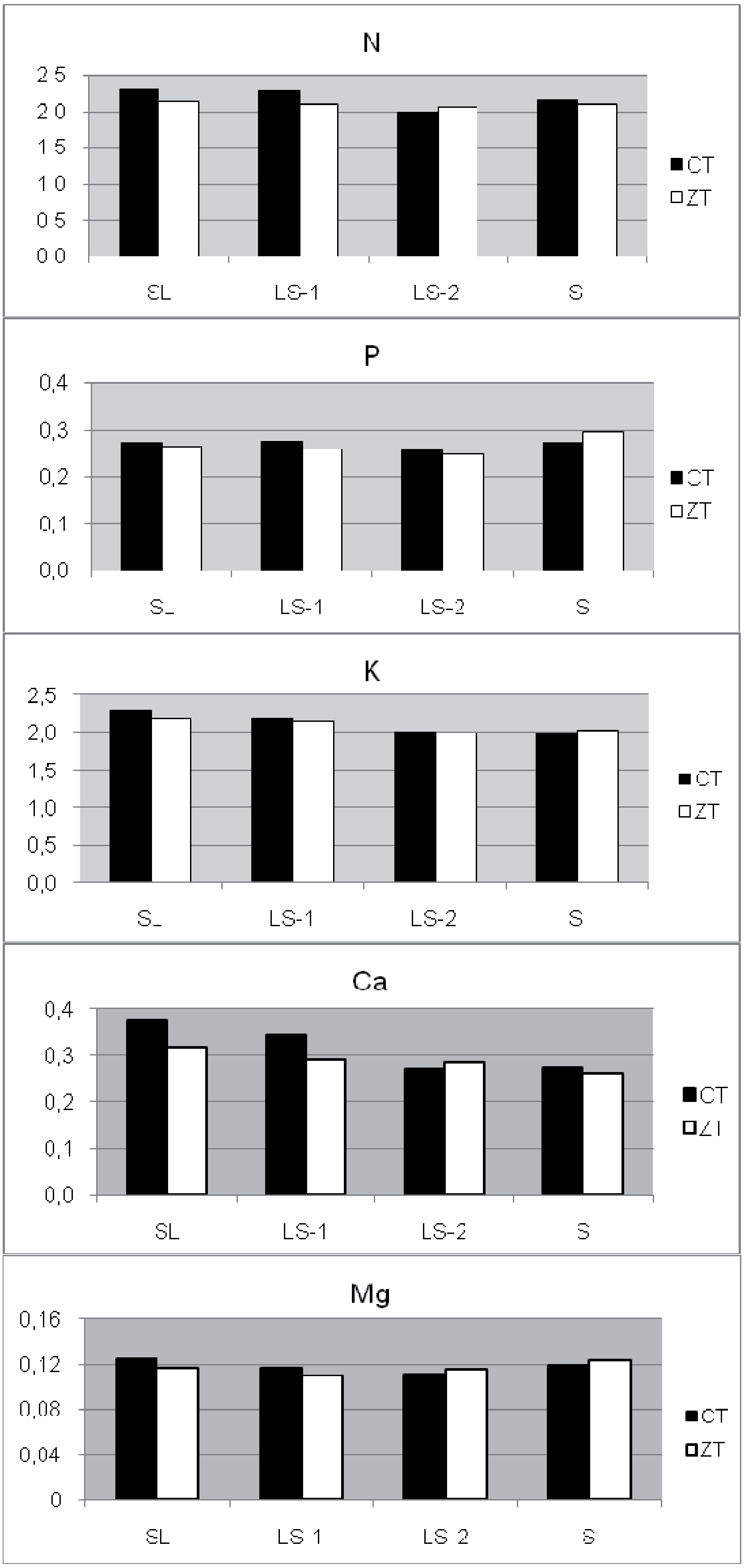

Fig. 3. Content of macronutrients (%) in dry matter of wheat aerial parts on different types of soil – means for 4 sampling dates and 3 years.

It seems, however, that among the many factors which modify the differences between CT and ZT in the content of macronutrients in soil and plants, soil type can also play a role. It can be expected that under inferior moisture conditions, typical of lighter soils, wheat under ZT takes up nutrients from the soil more easily than wheat growing on CT soil, which has manifested itself in terms of biomass formation as well as grain and straw yield.

CONCLUSIONS

1. Under the moderate climatic conditions prevailing in West Poland, small and periodically occurring (from the stem elongation to the inflorescence phase) differences between zero and conventional soil tillage methods were found in terms of winter wheat biomass yields. Such differences, generally in favour of CT, were shaped by the soil and weather conditions.
2. The type of soil produced an effect on the nourishment of plants with basic nutrients, as well as on the volume of biomass yields obtained until the inflorescence phase. On medium and coarse textured soils, wheat growing under CT obtained more biomass, whereas on very coarse textured soil, the wheat biomass yields under ZT and CT were identical.
3. During insufficient rainfall, wheat biomass increase was higher under ZT than under CT. However, when precipitation was moderate, more biomass was produced by wheat growing under CT.
4. Periodically occurring fluctuations in biomass yield produced under CT and ZT did not have any influence on the later grain and straw yield, which was identical for both methods of soil tillage, independently from the soil type. This finding supports the idea of using zero tillage in agricultural practice in West Poland, both for economical and environmental reasons.

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Possibilities of Heat Exchanger Use in Pigsty Ventilation Systems

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Abstract. There is a considerable increase in energy demand during autumn-winter conditions due to the necessity to keep optimal microclimatic conditions in pigsties. When heat exchangers are used in the ventilation systems on the premises of pigsties, clean and cold air (in the autumn-winter period) gets an amount of heat energy from unclean but warm air. Up to now heat exchangers have not been used widely in Latvia and therefore there is no experience about the use of heat exchangers for microclimatic stability in piggeries. The goal of the investigation is to clear out the possibilities of heat exchanger use at farms in Latvian climatic conditions.
The article deals with experimental results obtained from experiments about plate counter-flow heat exchanger models with plastic cellular boards (HE PVC) and plastic plates (WVT 120K) as heat transfer surfaces. Operational parameters which describe the energy efficiency of heat exchangers were calculated – power of recovered heat energy Φ, heat transfer coefficient, and coefficient of performance (COP) by recovered heat. The parameters were analyzed depending on outside air temperature in an interval from +6°C to -16°C.
In the weather conditions of Latvia it is important to achieve heat transfer as completely as possible, widening thus the interval of heat deficit coverage towards lower outside air temperature.

Key words: Heat exchanger, pigsty, ventilation system

INTRODUCTION

Researches into possibilities of recuperation of heat energy from polluted outflow air have been conducted in Germany and other countries of the EU (Air Heaters..., 2009; Abluftsysteme…, 2008; Healthy..., 2009).

Nowadays several companies offer appropriate recuperative outflow air heat exchangers. According to constructional details polluted outflow air heat exchangers are classified as: tubular heat exchangers-double pipe, shell and tube, coiled tube; plate heat exchangers - gasketed, spiral, plate coil, lamella; extended surface heat exchangers-tube-fin, plate-fin; fixed matrix regenerators, rotary (Kuppan, 2000). The basic flow arrangements of the air in a heat exchanger are: parallel-flow, counter-flow, and cross-flow. The choice of a particular flow arrangement is dependent upon the required exchanger effectiveness, air flow paths, packaging envelope, allowable thermal stresses, temperature levels, and other design criteria. When selecting a heat exchanger for a given duty, the following points must be considered: construction materials; operating pressure and temperature, temperature program, and temperature driving force; flow rates; flow arrangements; performance parameters - thermal effectiveness and pressure drops; fouling tendencies; types and phases of matter; maintenance, inspection, cleaning, extension, and repair possibilities; overall economy; fabrication techniques; intended applications.

To raise the level of energy efficiency of the ventilation systems of pigsties, it is practical to introduce heat exchangers. A heat exchanger is a device built for efficient heat transfer from one medium to another. When a heat exchanger is used in the ventilation system on the premises of a pigsty, clean and cold air (in the autumn-winter period) gets an amount of heat energy from unclean but warm air. Respiration of pigs and processes occurring on the surface of manure cause the generation of carbon dioxide and ammonia, which are considered harmful gases not only for people and animals but also for the equipment, as high relative humidity (occurs also during respiration of pigs) influences working conditions as well. Therefore the materials used for the construction of heat exchangers must have high resistance to corrosion and high thermal conductivity.

Heat exchangers have not been widely used in livestock breeding in Latvia, mainly because of the shortage of experience of the use of heat exchangers in our climatic conditions. Experimental plate heat exchanger HE-PVC is made of polyvinylchloride (PVC) cellular boards, which are set at a certain distance by means of wooden lathes. Through the space between the boards blows unclean warm outflow air, but through the cellular board hollows blows fresh warming up air (Ilsters et al., 2007). Plate heat exchanger is a type of heat exchanger that uses plates to transfer heat between two gases or fluids. This has a clear advantage over a conventional heat exchanger as the gases (fluids) are exposed to a much larger surface area because the gases (fluids) spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of temperature change. Plate heat exchangers are usually used for low or medium pressure heat transfer applications; in our case we have low pressure application. The counter-flow arrangement was organized because this is the most efficient of all flow arrangements for single-pass arrangements under the same parameters. The developed experimental heat exchanger is made of polyvinylchloride cell boards as they allow simple construction and easy manufacturability, corrosion strength and high thermal conductivity of material (Ilsters, 2005). The heat exchanger WVT-120K produced in Germany was chosen due to its appropriate operational parameters (Table 1).

The aim of the research is, firstly, is to analyze the exploitation parameters of a recuperative outflow heat exchanger, which are obtained in conditions of production and, secondly, to analyze the effect of using an outflow air heat exchanger on heat balance in pigsty depending on outside air temperature.

OBJECTS AND METHODS

The experimental results obtained in previous years were used for calculation and analysis. The investigation was carried out in a 500 head stable for fattening pigs in Ogre region, Latvia. The size of the stable was 12 x 60 x 2.7 m. The stable has 1.5 brick thick walls, wood plank ceiling covered by straw. The resting places of pigs are littered by sawdust. The manure is removed by scraper conveyer. Up to now there was no equipment in the pigsty for warming up the inflowing fresh outside air. The scheme of heat exchanger location and air distribution pipes is shown in Fig.1.

During the investigation the temperature in the pigsty, the outside air temperature and relative humidity, the velocity of air flows and changes in its temperature before and after the application of heat exchangers was measured. For the acquisition of the abovementioned data in every 2 hours a HOBO type logger H08-007-02 and BoxCar computer program were used. The precision of measuring air temperature was ±0.2°C, for the relative humidity of air ±5%.

The main technical parameters of the experimental heat exchanger HE-PVC and the heat exchanger WVT-120K manufactured in Germany are given in Table 1.

Table 1. Main technical parameters of the industrially produced experimental heat exchanger WVT-120K

Indices	HE-PVC	WVT-120K
Type	Counter-flow, plate	
Location	horizontal	vertical
Distance between plates, m	0.010	0.025
Heat transfer area, m^2	100	52 (calculated)
Productivity of heat flows, $m^3\ h^{-1}$	2,200	2,200 – 4,800
Power of heat energy at ΔT=30°C, kW	under 17	under 27

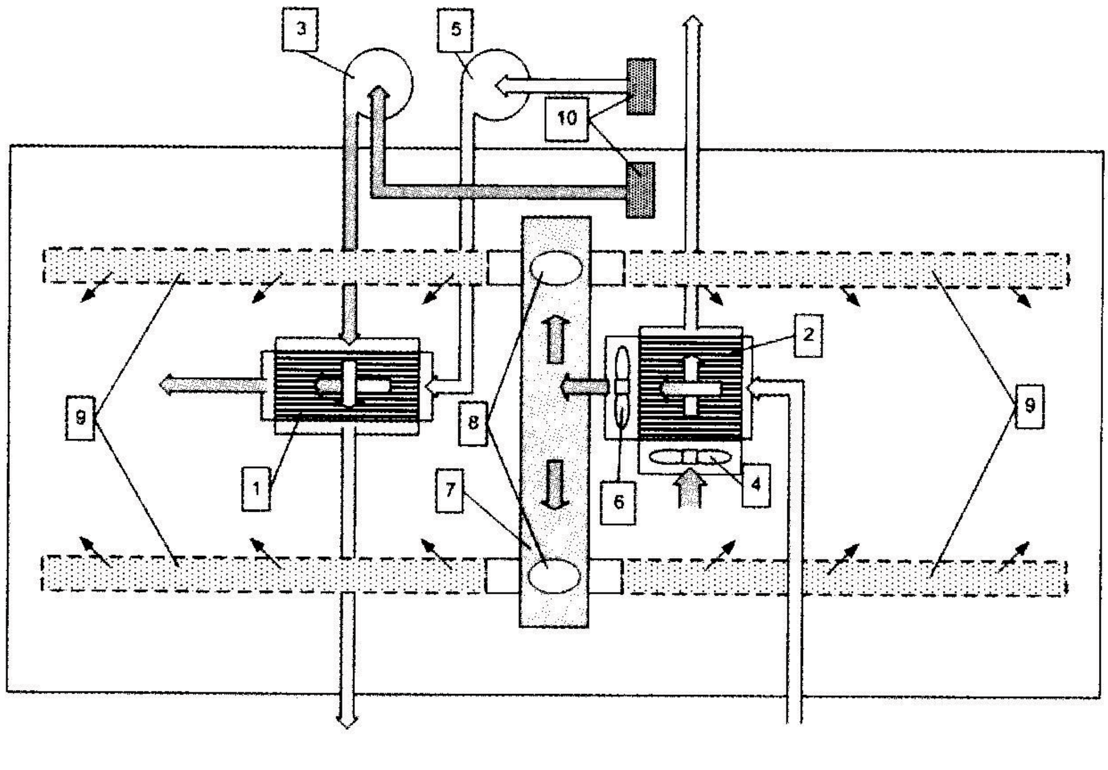

Fig.1. Location scheme of heat exchangers and air distribution canals in sty with 500 fattening pigs**:** 1 – experimental heat exchanger; 2 – heat exchanger WVT-120K; 3, 4 – air outlet ventilators; 5, 6 – air inlet ventilators; 7 – air distribution

pipes; 8 – air distribution collector; 9 – perforated air distribution pipes; 10 – air filter.

While analyzing the heat balance of pigsty it is important to determine the outside air temperature in case of heat deficiency; in addition, it is necessary to determine the value of heat deficiency when the outside temperature goes below par. This T_d temperature was calculated (Ilsters et al., 2008):

$$T_d = -T_c - 2T_c \cdot Q_d \cdot \left(Q_{com} - Q_{vap}\right)^{-1}, \tag{1}$$

where T_c – inside air temperature, °C;

Q_d – heat deficiency at negative outside temperature value, when $2T_c = -2T_{out}$;

Q_{com} – total power of heat losses, W;

Q_{vap} – energy needed for liquid evaporation from the floor, W.

Calculations of heat exchanger performance according to well known heat transfer coherences have been performed (Celmins et al., 1967):

$$Q = D_1\left(i_1' - i_1''\right)\eta = D_2\left(i_2'' - i_2'\right), \tag{2}$$

where D_1, D_2 – consumption of heat transfer medium, (kg s^{-1});

i_1', i_1'' – initial and end heat capacity of inside air, J kg^{-1};

i_2', i_2'' – initial and end heat capacity of outside air, J kg^{-1};

η – coefficient of device efficiency (COP),

and the following heat transfer equation (Ilsters et al., 2007) has been used

$$Q = Fk\Delta T, \tag{3}$$

where F – area of heat transfer surface, m^2;

k – coefficient of heat transfer, W m^{-2}·K^{-1};

ΔT – average temperature between two heat carriers, K.

RESULTS AND DISCUSSION

During the experimental investigation over the winter months the weather conditions were typical of Latvian winter. The temperature dropped below -20° C interspersed with periods of thaw. A detailed analysis of experimental heat exchangers was carried out at negative temperatures, when more fresh air heating is necessary. The efficiency of the heat exchanger WVT-120K varied depending on the outside air temperature: at the outside temperature above -10° C, the productivity of ventilators was on average about 3,500 m^3 h^{-1}, but at the outside temperature below -10° C, the productivity of ventilators was from 2,200 to 2,500 m^3 h^{-1}. Therefore, at lower temperatures, it was possible to achieve the designed power of the heat exchanger WVT-120K, even though the heat transfer coefficient was comparatively high. As the distance between the heat transfer plates of the heat exchanger WVT-120K is 2.5 times greater (compared to the heat exchanger HE-PVC), the outflow air gives less heat energy to the inflow air. However, the greater distance protects the heat transfer plates more from icing, as icing of the experimental heat exchanger HE-PVC (Fig.2 and Fig. 3) started when the outside air temperature was about -15° C. The obtained results show that the structure of the heat exchanger WVT-120K (Fig. 4) with appurtenant technical parameters is more suitable for use in pigsties with superior heat insulation of boundary constructions. Vertical performance of the heat exchanger WVT-120K which contributes to the refinement of the heat transfer plates and equips the heat exchanger with axial ventilators operated with small power monophase engines, is more appreciated (Ilsters et al., 2008).

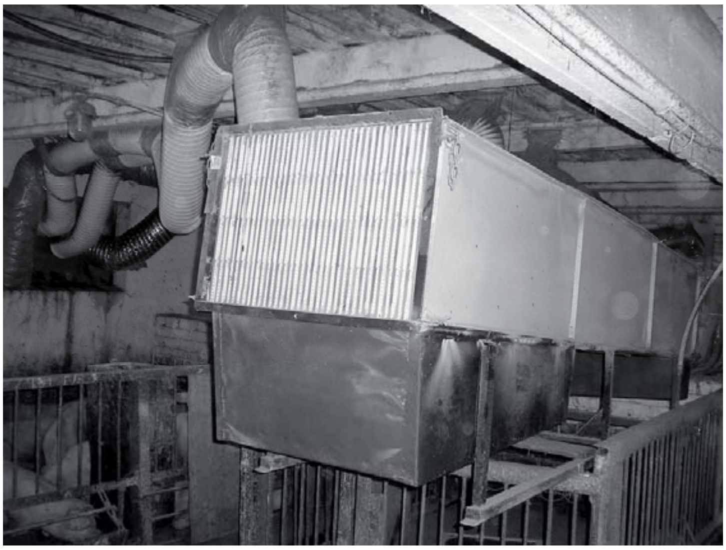

Fig. 2. Experimental heat exchanger HE-PVC testing in fattening pig barn of 500 animal places.

Average values of operational parameters (which depend on outside air temperature) of the experimental heat exchanger HE-PVC and the heat exchanger WVT-120K were obtained during the experiment. Power of the recuperated heat from outside airflow of the experimental heat exchanger during the experimental investigation increased from 9.4 kW to 12.6 kW at temperature drop from 0° C to -

15° C. In the case of heat exchanger WVT-120K, power of recuperated heat from outside airflow increased from 9.7 kW to 13.6 kW. As for the heat transfer coefficient, the situation is similar. During the temperature drop from 0° C to -15° C, the heat transfer coefficient of the experimental heat exchanger increased from 13.3 W m^{-2} $°C^{-1}$ to 10.1 W m^{-2} $°C^{-1}$, but in the case of the heat exchanger WVT-120K, the heat transfer coefficient decreased from 24.0 W m^{-2} $°C^{-1}$ to 20.2 W $m^{-2}$$°C^{-1}$. The value of the coefficient of performance by recovered heat for the experimental heat exchanger fluctuated between 0.54 and 0.88, but the value of COP by recovered heat for the heat exchanger WVT-120K varied between 0.23 and 0.40, respectively, due to decrease in the outside air temperature. Better heat recuperation of the heat exchanger HE-PVC is achieved mainly due to lesser distance between the heat transfer plates (Ilsters et al., 2008).

After the analysis of operational parameters it is possible to draw the conclusion that the use of the heat exchanger HE-PVC is more suitable for Latvian weather conditions than the heat exchanger WVT-120K.

It is necessary to calculate the payback time of the PVC heat exchanger. The calculations were made using operational parameters of the heat exchanger which were determined experimentally at the average outside air temperatures of Latvia. The data is given at heat loss level through the building constructions 1.5 W m^{-2} K^{-1} (referred to the floor area).

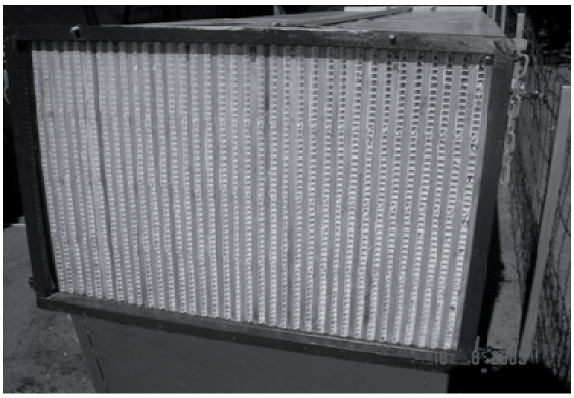

Fig. 3. Front view of the experimental heat exchanger HE-PVC.

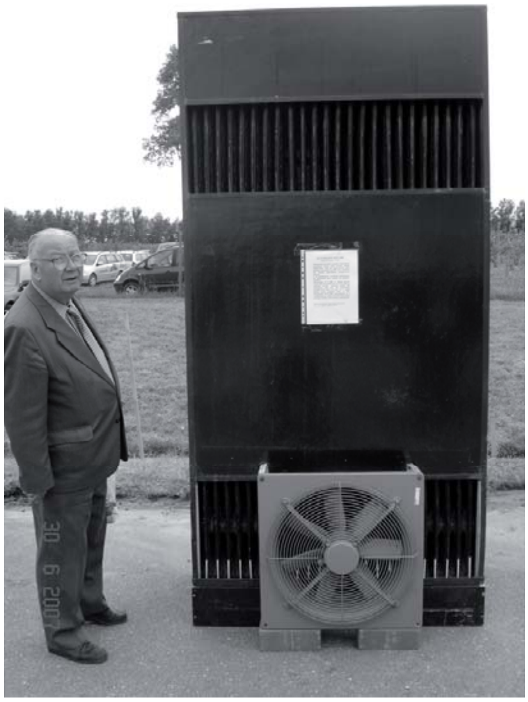

Fig. 4. WVT-120K heat exchanger.

With reference to formula (1), the calculated outside air temperature at which the heat deficiency in the pigsty occurs if the heat exchanger for preheating the inflow of outside air is not used, is -5° C. But when the heat exchanger is used for preheating the cold inflowing outside air, the temperature is -12° C.

For calculating the economy of heating costs, the present liquefied gas price in Latvia 0.7 € kg^{-1} was taken. The price of the experimental heat exchanger is estimated at 600 €. The accounted economy value using the heat exchanger HE-PVC is about 130 € per year.

Considering the average monthly temperatures in Latvia (Borisovskij A., 1983), it is necessary to use the heat exchanger at full rate during the cold weather months from October to March. During the rest of the year, the use of heat exchangers is recommended only at night if the outside air temperature drops below -5° C. According to our calculations, the payback time of the experimental heat exchanger HE-PVC, not considering the interest rate, is about 4.6 years.

CONCLUSIONS

1. In the weather conditions of Latvia it is important to achieve a heat transfer as complete as possible, widening the interval of coverage of heat deficit towards lower outside air temperature.
2. In case of the experimental heat exchanger, more complete heat transfer from warm to cold air is achieved due to relatively small distance between the heat transfer plates.
3. Vertical location of recuperative counter-flow heat exchanger is favourable, facilitating the refinement of heat transfer plates during thickening of the condensate.
4. Calculations show that heat deficiency in a pigsty starts to occur at the outside air temperature -5° C if the heat exchanger is not used. If the heat exchanger is used, the heat deficiency starts to occur at the outside air temperature -12° C.
5. Calculation shows that payback time of the experimental heat exchanger HE-PVC is about 4.6 years, not considering the interest rate.

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Investigation of Solar Collector Irradiated from Both Sides

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Abstract. The ordinary flat plate solar collector receives solar radiation only from one side of its surface. Another side is covered with a heat barrier. The solar collector with reflectors has been developed and examined to track the sun. The absorber of this type of a collector was irradiated from both sides. The experimentally obtained energetic parameters of the collector tracking the sun have been compared to those of the ordinary flat plate solar collector. In order to complete the experiment, a special stand has been developed. The experimental investigation has been carried out at the intensity of radiation 2,000, 1,000 and 500 W m^{-2} in different combinations. The temperature has been measured in certain points of different parts of the collector by several thermocouples. With the aid of a multi-meter, the obtained results were collected to the memory of a computer, and later processed and analyzed. When a collector surface is tracking the sun, the heat energy produced by the collector is 1.4 to 1.5 times higher in comparison with a stationary solar collector of the same size. A solar collector tracking the sun and irradiated from both sides depending on the reflection quality of the reflector's material is able produce about 2.5 times more heat energy then a stationary flat plate solar collector irradiated only from one side.

Key words: Sun, solar collectors, efficiency

INTRODUCTION

The amount of heat energy produced by a solar collector depends on the type of collector, its working surface direction towards the sun, meteorological conditions of the location and many other factors. There are different collectors: The so-called flat plate solar collectors, parabolic collectors or those concentrating sun beams, spherical collectors, stationary and sun tracking collectors, and others.

It has been stated that in order to produce as much heat energy as possible, the surface of the receiver of solar radiation has to be directed perpendicularly towards the sun beams. In this case the efficiency of a solar device will be at its maximum. The ordinary flat plate solar collector receives solar radiation only from one side of its surface. Another side is covered by a heat barrier. The efficiency of these collectors is in practice no higher than 40–60%, depending on the atmosphere's mass, nebulosity and lucidity, the intensity of solar radiation, the time and day of the year, etc. In order to increase the efficiency of solar collectors, several original constructions, such as a spherical collector, a collector with canal absorbers, a flat plate solar collector with polycarbonate cell absorber, a solar collector with two-plate absorber, and a sun tracking solar collector with reflectors (Ziemelis et al., 2007; Iljins et al., 2007; Ziemelis et al., 2008; Putans et al., 2008; Putans et al.,

2008) have been developed and examined both in laboratory and outside conditions on a house roof.

The absorber of a solar collector with reflectors has to be tracking the sun all day round, because the sun beams striking the reflectors are reflected from them on the rear side of the absorber, only if the collector is in a perpendicular position towards the sun beams. Thus the absorber of the collector is irradiated from both sides simultaneously with direct and reflected radiation. The experimentally obtained energetic parameters of a sun tracking collector with those of an ordinary flat plate solar collector have been compared and analyzed. Our experimental investigation has shown that such a system makes the solar collector device more expensive. At the same time the collector receives more solar radiation energy and produces more heat energy (Putans et al., 2005).

The main objective of the research is to determine the thermo-energetic parameters of a solar collector, the absorber of which is irradiated from both sides, and compare these results with the corresponding data of an ordinary flat plate solar collector.

MATERIALS AND METHODS

In order to investigate the properties of a sun tracking solar collector with reflectors, we developed such a collector (Fig. 1). In the experimental examination of the collector it was stated that at irradiation of the rear surface of the absorber with two glass mirrors of collector size (glass thickness 4 mm), the radiation intensity received by the collector rear side is 1-1.2 of the frontal radiation striking the collector.

Fig. 1. A sun tracking solar collector with reflectors.

To clear out the energetic parameters of the collector irradiated from both sides, experimental investigation has been carried out both in laboratory and field conditions. For that a special stand (Fig. 2) has been developed, containing a collector 1; an absorber 2; a heat accumulation basin (0.72 liters) 3; a circulation pump 4; a heat carrier flow meter 5; two glass covers 6; a funnel 7; a heater 8 (infrared lamp); thermocouples for measuring the heat carrier temperature at the out flow from the absorber 9 (T_{out}), inflowing into the absorber 10 (T_{in}), and surrounding air 11, respectively; a thermometer for air temperature T_o measuring; multi-meters (micro-voltmeters) 12 and 13. The collector consists of a box-type absorber placed into a wooden box, and covered from both sides with glass covers. The absorber area is 0.1m^2 (240 x 430 mm), its capacity is 0.3 liters. The system capacity is 1.2 liters. The laboratory equipment has been presented in Fig. 3.

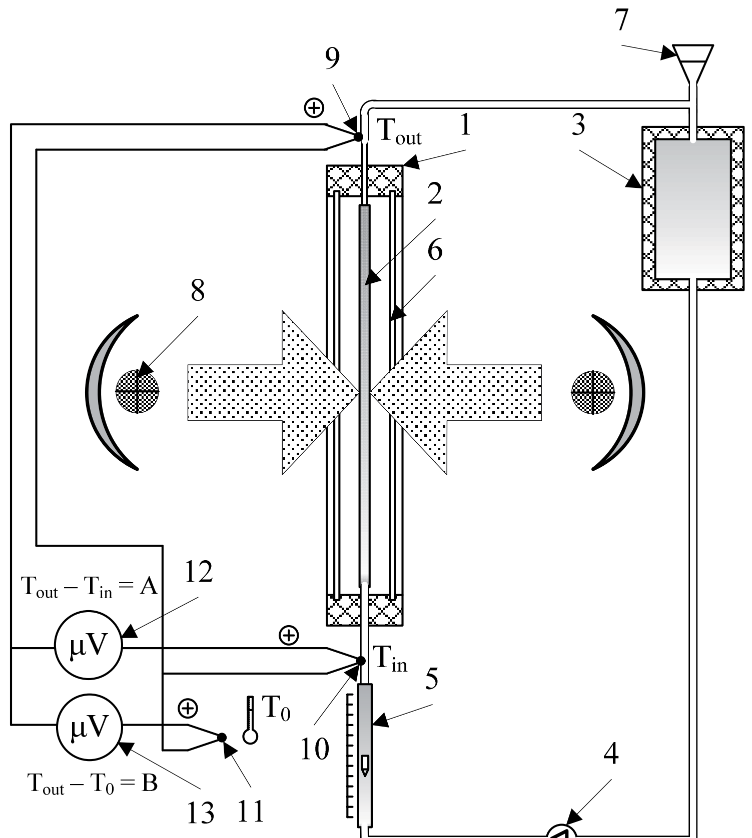

Fig. 2. A stand for the experimental investigation of solar collectors: 1 – collector; 2 – absorber; 3 – heat accumulation basin; 4 – circulation pump; 5 – heat carrier flow meter; 6 – glass cover; 7 – funnel; 8 – heater; 9, 10, 11 – thermocouples for temperature measuring; T_o – thermometer; 12, 13 – multi–meters.

As it has been mentioned above, the absorber received global solar radiation from its front side and reflected solar radiation from its rear side reflectors (mirrors), which were of the same size as the absorber (Fig. 1). The intensity of reflected radiation on the rear side of the absorber was 1–1.2 from the intensity on the front surface. It means that the intensity of solar radiation which the absorber received was about two times higher than the one an ordinary solar collector receives, when irradiated only from the front surface. The irradiation intensity of the collector was measured with a device consisting of a pyranometer thermo battery and a multi-meter (Fig. 4). The device was graduated this way that 1,000 W m^{-2} radiation power corresponded to the voltage of 10 mV. The necessary intensity of the surface irradiation was installed by the use of the device, changing the distance between the lamp and the absorber.

Fig. 3. A stand for investigating the absorber of the solar collector with reflectors.

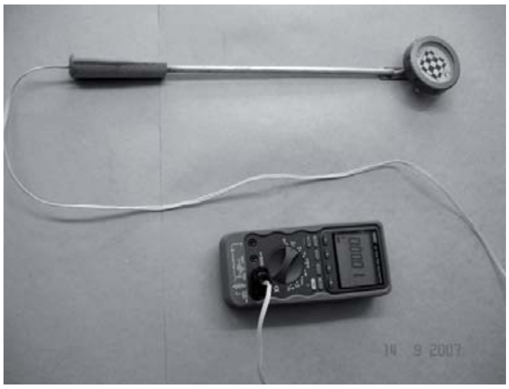

Fig. 4. A device for measuring radiation intensity.

RESULTS AND DISCUSSION

In order to determine what part of solar radiation, received from both surfaces of a flat plate, the solar collector is able to convert into heat energy, an experimental stand (Fig. 2) has been used. The absorber of the collector has been irradiated from both surfaces (Fig. 5) and from one side (Fig. 6).

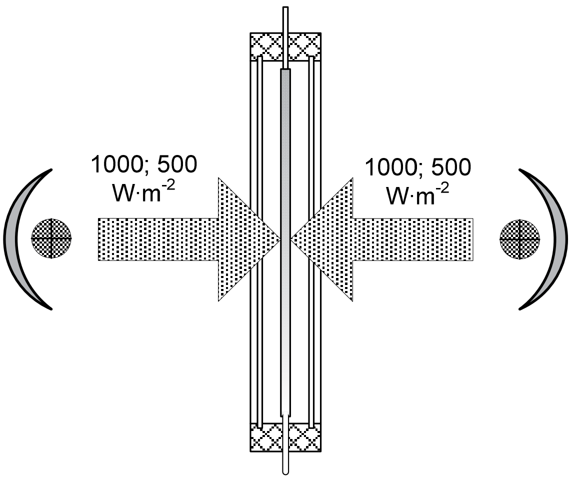

Fig. 5. Cross section of the collector irradiated from both sides.

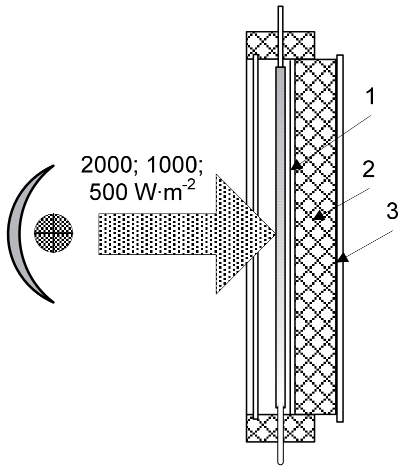

Fig. 6. Cross section of the collector irradiated from one side: 1 - plastic film; 2 - rock wool; 3 - cover.

When both surfaces of the absorber are irradiated with 1,000 W m^{-2} intensity (1,000 + 1,000 = 2,000 W m^{-2}), the double T_{in}-T_o increase is not obtained in comparison with irradiation of one absorber side with 1,000 W m^{-2} intensity. When one side of the absorber surface is irradiated with 2,000 W m^{-2} intensity, the increase in obtained heat power has doubled (Fig. 7). The same regards to the curves in Fig. 8.

In Tables 1 and 2 the numerical values of the examined collectors are given: Maximum temperature of the produced and consumed energy amount, efficiency of different types and power of radiation during 75 and 120 minutes of heating.

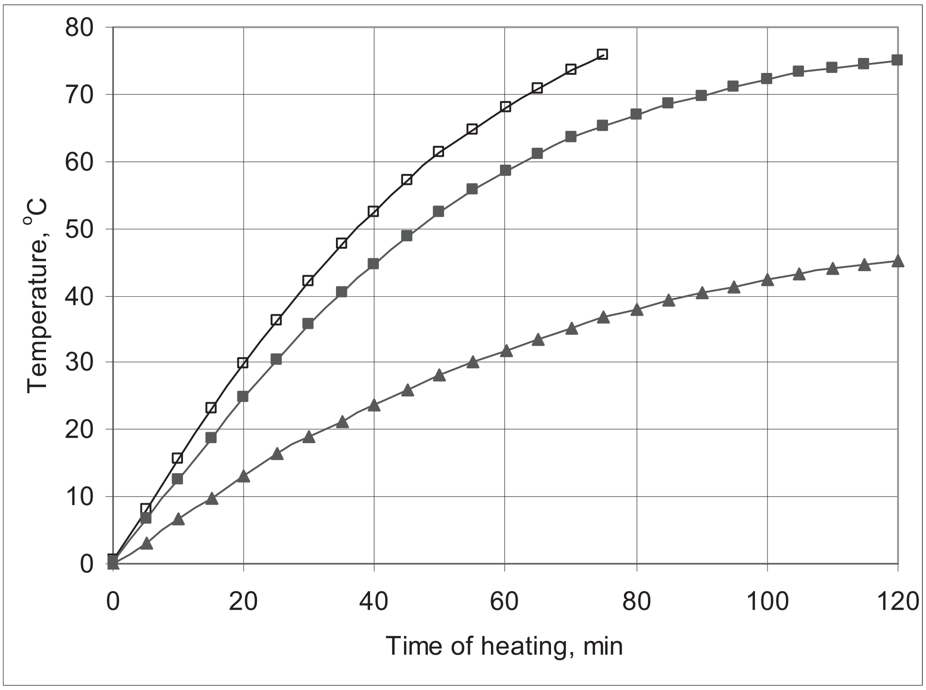

Fig. 7. Temperature $T_{in} - T_o$ increase at different regimes of irradiation: —□— 2,000 W m^{-2}; —■— 1,000 +1,000) W m^{-2}; —▲— 1,000 W m^{-2}.

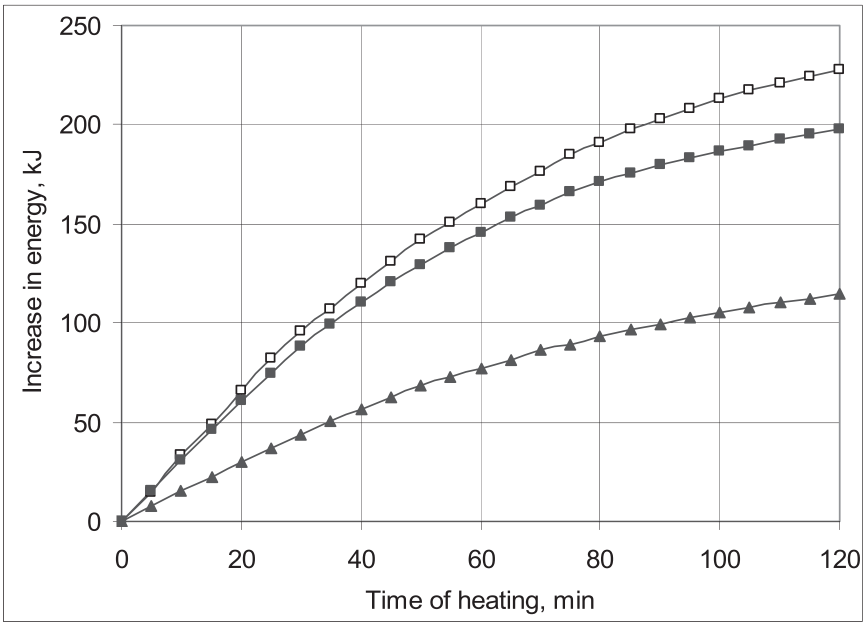

Fig. 8. Heat energy increase at different regimes of irradiation: —□— 1,000 W m^{-2}; —■— (500 +500) W m^{-2}; —▲— 500 W m^{-2}.

In order to evaluate the produced amount of heat energy, Tables 1 and 2 present irradiation of the absorber only from one side with power 500 W and 1,000 W, respectively, as a reference point. In this case the other absorber surface is covered with a heat barrier (Fig. 4). It follows from Tables 1 and 2 that if both surfaces of the absorber with power equal to the reference power are irradiated, 1.73 and 1.77 times more heat energy is produced. If only one surface of the absorber with two times higher power is irradiated, 1.99 and 2 times higher amount of heat energy is produced.

Table 1. Energetic parameters at irradiation of the absorber surface with power 500 and 1,000 W m^{-2}

No.	Parameters	Absorber irradiated by power, W m^{-2}		
		500		1,000
		one surface irradiated, another insulated	both surfaces irradiated	one surface irradiated, another insulated
1.	Time of heating, min.	120	120	120
2.	$T_{in}–T_{o\ max}$, ˚C	22.7	39.2	45.2
3.	Power consumed, kJ	360	720	720
4.	Power produced, kJ	114.4	197.4	227.3
5.	Efficiency average	0.32	0.27	0.31
6.	Gain	1	1.77	2

Table 2. Energetic parameters at irradiation of the absorber surface with power 1,000 and 2,000 W m^{-2}

No.	Parameters	Absorber irradiated by power, W m^{-2}		
		1,000		2,000
		one surface irradiated, another insulated	oth surfaces irradiated	one surface irradiated, another insulated
1.	Time of heating, min.	75	75	75
2.	$T_{in}–T_{o\ max}$, ˚C	22.7	39.2	45.2
3.	Power consumed, kJ	450	900	900
4.	Power produced, kJ	114.4	197.4	227.3
5.	Efficiency average	0.32	0.27	0.31
6.	Gain	1	1.77	2

It follows on the basis of these and abovementioned data that while using selective tracking and a solar collector with two reflectors of collector size, the produced heat energy in comparison with a stationary collector irradiated only from one side is 1.43 x 1.77 = 2.5 times higher. Solar collector area for a family of 4 people is usually about 4.5 m^2. If a selective and sun tracking collector with reflector is used, its working surface area can be decreased up to 1.8 m^2.

CONCLUSIONS

1. A sun tracking solar collector without reflectors produces 1.4–1.5 times more heat energy in comparison with a stationary operating flat plate solar collector of the same size.

2. A sun tracking solar collector with reflectors and a selective absorber produces 2.5 times more heat energy in comparison with a stationary flat plate solar collector of the same size placed under optimal angle and irradiated only from one side.

3. If the absorber of an ordinary flat plate solar collector is irradiated with twice as high radiation intensity, it produces almost twice as much heat energy.

4. When the absorber of a collector is irradiated from both sides with equal radiation intensity, it produces 1.75 times more heat energy than in case it is irradiated only from one side, the other one having a heat barrier.

5. The design of a sun tracking solar collector with reflectors is simpler, if the absorber is irradiated from both sides; therefore, this variant is advisable for practice.

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Specific Features of Establishment and Maintenance of Tractor Fleet in a Typical Estonian Agricultural Holding

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Abstract. In spite of the high reliability of modern tractors, they are no perpetuum mobiles and need at times designated by the manufacturer's technical condition regular diagnostics, the diagnostic results being determined on the basis of work and the amount of content, technical maintenance and repair, if necessary. This study examines the design and maintenance problems of an Estonian representative farm tractor compared to similar indicators in the Republic of Latvia. The outlines of a typical company are based on expert opinions. These indicators have been analyzed and compared to those of the whole Estonia at the level of one particular farm in real terms. The machine/tractor maintenance-related economic and technical indicators have been set to ensure the reliability of machine/tractor use in competitive agricultural production. The investigation examines the company's actual use of machine/tractor, tractor upkeep and methods for determining the composition of the qualitative and quantitative indicators.

Key words: Tractor, tractor maintenance procedures, maintenance costs, machine-tractor park, repair, diagnostics

INTRODUCTION

Today the number of tractors working in the fields of the Republic of Estonia reaches ca 32 thousand tractors (Statistics Estonia, 2008). Despite the high reliability indicators of a modern tractor, it still needs regular diagnostics of its technical condition at intervals specified by the manufacturer, diagnostics-based technical maintenance and repairs, if necessary. All this accounts for a high volume of repair work that has to be arranged and performed by our farmers or relevant service-providers. The republic still lacks an overview of the problems and indicators of reliability and maintenance of machinery. Due to the application of a highly regulated and mandatory system of tractor maintenance during Soviet times, our system was significantly different from the systems ensuring tractor reliability applied elsewhere in the world. We should also consider the fact that in Soviet times tractor manufacturers were actually not interested in servicing tractors during their useful life. Because of national planned economy, collective holdings were constantly short of new tractors and manufacturers realized their entire production already at the gates of the factory without any problems.

As a result of advancement in technology, extended range of applications, enhancement of automatic processes, increase in loads and speed, reliability has become more and more important. Solutions to the aforesaid issues represent one of the main sources for costs saving by increased efficiency, material, labour and energy. More complex technology means more expensive failure management. In order to keep a tractor in good working order, the amount of money spent on its repair and technical maintenance during its lifetime is twice as high as the amount spent on purchasing a new tractor (Olt & Traat, 2009).

The present study views the problems regarding the establishment and maintenance of tractor fleet in a typical Estonian agricultural holding, and compares it with similar indicators applicable in the Republic of Latvia (based on limited source data). The outline of a typical holding is based on expert assessments. These indicators have been analyzed at national level and compared to the actual indicators of one particular agricultural holding. For the purposes of the study the latter is referred to as Agro2. According to our knowledge, a similar study has not been carried out in Estonia before.

Objective of the study: To determine economic and technical indicators related to the maintenance of machinery/tractor fleet in order to ensure reliability of machinery/tractor fleet required for their competitive exploitation in production of agricultural products.

Pursuant to the objective, the **purpose of the study** was to determine the actual expenditure on utilization and maintenance of machinery/tractor fleet of the holding, provide a systemic approach and assess the status of resources.

MATERIAL AND METHODS

The present study is based on a qualitative approach to the reviewed problem. A qualitative approach allows the parallel usage of various evidences – documentation, interviews, etc. In several stages of the study, quantitative methods of research and analysis were also used, but a qualitative approach is still dominant, which means that numerical indicators are not used as major arguments when drawing conclusions from empirical evidence. Instead, the study is more similar to the description of factors affecting the development of machinery maintenance and the potential direction of such development.

The present paper uses materials from two previous studies: firstly, a survey carried out in 2009, in which participated expert technical managers of the holdings. In the course of the survey a questionnaire of 68 questions with more than 200 markers was prepared. All the experts had higher education and long-term employment (10-25 years) in the field of exploitation and maintenance of tractors. The opinions of all the experts carried a lot of weight. The majority of respondents had worked as chief engineers and mechanical engineers in collective and state farms during Soviet times. Thus they were capable of assessing the changes and rearrangements made in the course of time.

Most of the experimental material was collected from accounting databases, made available by the technical manager of the holding. The majority of data was retrieved from first-hand communication with the accounting department of the holding, which grants the accuracy and reliability of these data. The survey was carried out in spring 2009, by performing interviews with technical managers of 20 major agricultural holdings, and, in addition to that, information was collected about the expenditure on tractor maintenance.

As of 1 March 2009, the composition of the tractor fleet in the Republic of Estonia comprised of 82% technically old and 18% modern tractors. The proportion of new tractors in total number of tractors is extremely small. During the past 5 years, new tractors constituted only up to 3.8% of the annual number of tractors in active use, according to ARK (ARK, 2009). In Latvia this number is much higher, 6.3%, i.e. the relevant figure in Estonia differs by 1.6 times. From 2000 to 2007 there have been no significant quantitative changes in the composition of tractors in Latvia and in 2000 it reached 54,820 tractors, which was increased by 8.6% by 2007, i.e. within 6 years. The majority of these tractors consist of purchased new tractors. (Kopiks & Viesturs, 2009) The proportion of tractors that allow adequate operation does not exceed 50% and only 38% of them pass technical inspection. Tractor fleet in agricultural holdings shows signs of aging. In 2007 the number of tractors in agricultural holdings with over 50ha of area under cultivation increased by 3.3 times in comparison with the relevant figure in 2000. Average annual growth rate of tractor fleet in terms of tractors manufactured within the past 6 years during the period 2000-2007 was 6.3%. Absolute increase in tractor fleet in terms of tractors produced within the past 6 years was by 1,678 tractors, compared to 2,000 (Kopiks & Viesturs, 2009).

Holding **Agro2** provides work for 23 employees and utilizes 1506 ha of arable land (as of 2008), which is partially rented and partially owned by the holding. The holding makes regular use of 20 tractors, half of which are technically old and another half are more recent and more powerful modern tractors. The composition of tractor fleet during three years is provided in Fig. 1.

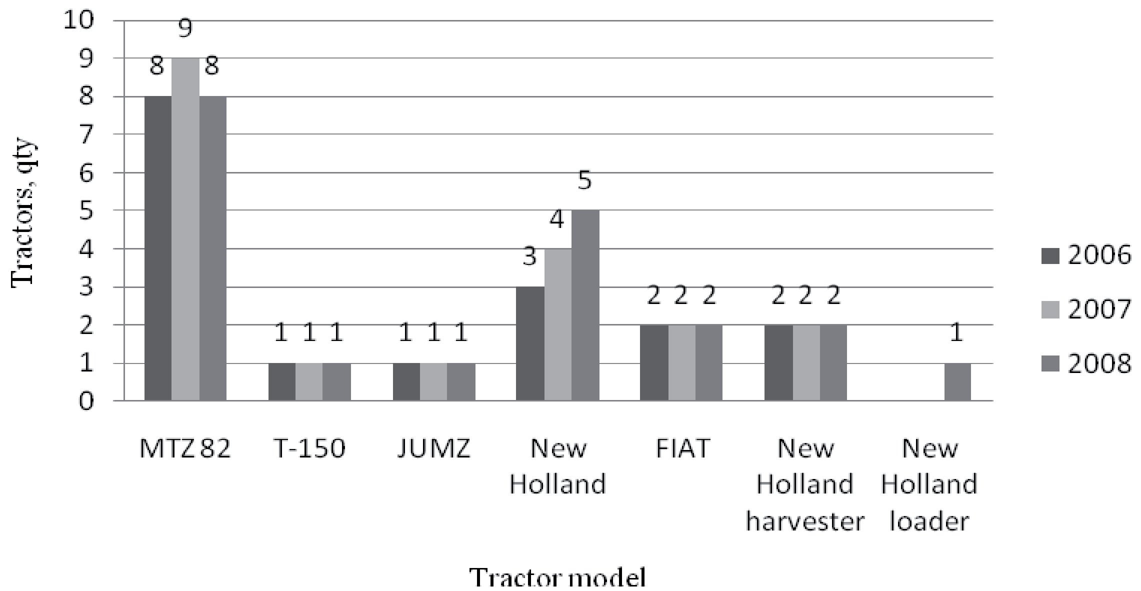


Fig. 1. The composition of tractor fleet of Agro 2 during three years.

The study observed 20 agricultural holdings with high turnover all over Estonia. Primary fields of activity of these companies were animal husbandry and plant production. The total area of land cultivated by these agricultural holdings ranged from 1,000 to 10,000 hectares. The holdings to be studied were divided into four groups according to the area of arable land (Table 1).

The experts divided the holdings according to the area of land under cultivation and based on their sustainability. In 2007 the average area of arable land under cultivation in hectares was 315 ha for legal persons and 21 ha for private persons (Table 2). In our opinion the experts were correct and the agricultural production is kept alive only by medium-sized and large agricultural holdings that represent the main actors with sustainable area of arable land under cultivation starting from 1,000 ha. These assessments are based on actual profit-earning activities; they are not derived or calculated by unreasonable formulas.

Table 1. Distribution of holdings by the area of cultivated land, expert opinion

No.	Designation of agricultural holding	Area of cultivated land, ha
1.	Small agricultural holding	up to 1,000
2.	Medium-sized agricultural holding	1,001...2,000
3.	Large agricultural holding	2,001...4,000
4.	Very large agricultural holding	over 4,000

Table 2. Average area of arable land under cultivation in ha and change in comparison with 2001 in %. (Source: *Statistics Estonia)*

Year	Total number of households by qty and change in comparison with 2001 in %		Average area of arable land under cultivation in ha and change in comparison with 2001 in %		Average area of arable land under cultivation in ha and change in comparison with 2001 in %					
					Total average ha change %		Private person, ha change%		Legal person, ha change %	
2001	55,702	0%	871,213	0%	16	0%	10	0%	400	0%
2003	36,792	-33%	795,640	-8.7%	22	+37.5%	13	+30%	450	+12.5%
2005	27,688	-51%	828,926	-4.9%	30	+87.5%	17	+70%	441	+10.2%
2007	23,257	-59%	906,833	+4%	40	+125%	21	+110%	315	-21.3%

The sample was composed of 20 agricultural holdings with the highest turnover. The motivation behind such selection was the fact that the proportion of modern tractors in these holdings was the highest and their exploitation was the most intensive. Another important factor in choosing the sample was the accuracy and reliability of the holdings under examination.

The analysis of expenditure on technical maintenance and fuel is based on data received from Agro2. Source data were collected by going through source and combined records of the holding with regard to the types of expenditure during 2006-2008. The information is truthful, unambiguous, reliable and traceable.

The experimental material was collected by using interviews performed at the site of the holdings under study. Interview comprised questions about the maintenance of the tractor fleet, i.e. diagnostics, technical maintenance and repairs, as well as agricultural questions, a general opinion of the technical manager and assessment of the current situation. The interview ended by examining the sites for maintenance of the machinery in a given agricultural holding to find out the actual situation and level. The interview was performed in the form of a single prepared questionnaire which was used in all holdings. The experimental material was collected in spring 2009 and most of the agricultural holdings were revisited to specify the information.

RESULTS AND DISCUSSION

A future trend of Estonian agricultural holdings consists in replacement of technically out-of-date equipment with modern machinery. Today we are facing a situation characterized by the shortage of qualified labour – a problem which can actually be solved by help of up-to-date machinery (the work performed by 1 modern tractor equals to the work made by 6 to 8 technically out-of-date machines. Another important reason is that vendors manufacture and distribute agricultural machinery and equipment with increased productivity and in order to use them it is necessary to have modern and powerful tractors. Such a situation is characterized by the fact that the hydraulic system of MTZ type tractor can lift only 800kg, but new agricultural equipment requires much more powerful suspension systems which are available in modern tractors. Another advantage of modern tractors is that the working environment of the operators of these tractors, the driver's compartment in other words, is significantly more work-friendly and has more comfort than the old machinery (Ministry of Agriculture).

According to the Estonian Motor Vehicle Registration Centre (ARK), a total of 607 new modern tractors were registered in 2008. The most popular of them included 143 Valtra, 135 John Deere and 75 New Holland tractors. The tractors of MTZ type are still there, 85 of which were registered in 2008. According to ARK, a total of 22,673 wheel tractors were registered in Estonia as of 31 December 2008. Distribution of these tractors by age is shown in Table 3 (data from *Estonian Road Administration*).

Table 3. Tractors registered in Estonia by age as of 31 December 2008

Age, yrs	Up to 2yrs	3– yrs	6–10yrs	Over 10yrs	Total
Wheel tractors, qty	3,332	2,371	1,627	15,343	22,673
Wheel tractors, %	14.70	10.46	7.18	67.67	100.00

Investments in the renewal of tractor fleet must be based on prior detailed calculations, taking into account the production conditions of a given production unit. The holdings that are more efficient in implementing new machinery show more rapid economic development and greater competitive ability (Möller, 1977). Tractor models preferred by the agricultural holdings participating in the study in comparison with the area of arable land under cultivation are provided in Fig. 2.

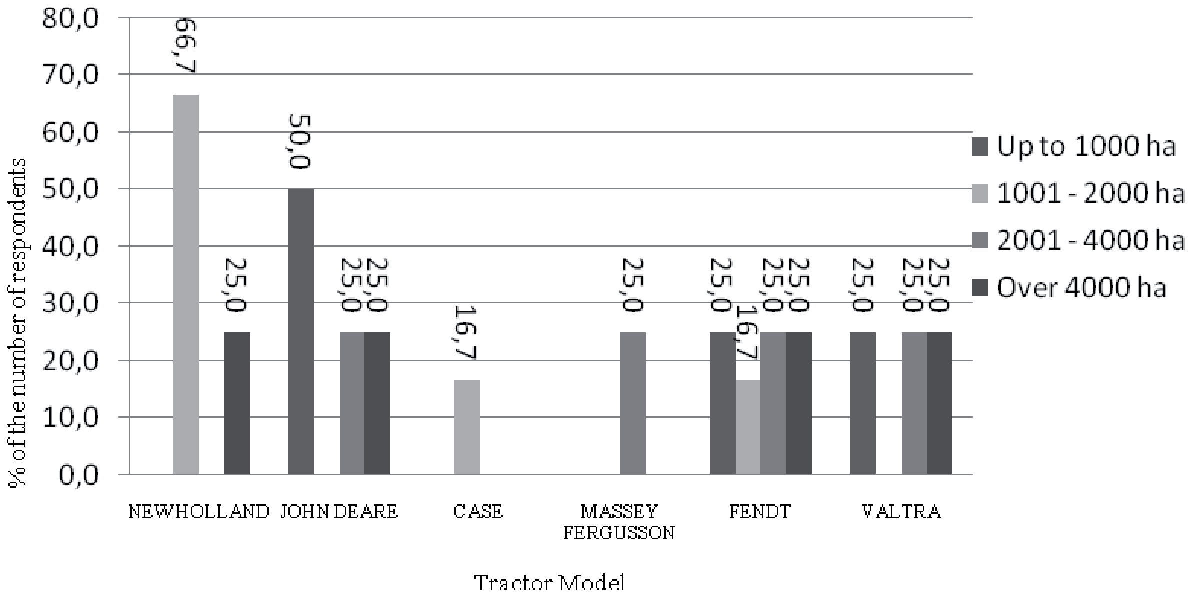


Fig. 2. Preferred tractor models according to experts, based on the area of cultivated land.

According to the results of the study, medium-sized holdings prefer New Holland tractors (66.7%). The most preferred modern tractor for small agricultural holdings is John Deere. Large and very large agricultural holdings have no clear preferences. The analysis of the questionnaires revealed that none of the experts of agricultural holdings preferred tractors of MTZ type, despite the fact that 85 tractors of that type were acquired in 2008. There are several reasons why some agricultural holdings have remained loyal to a certain tractor model, relevant expert opinion is given in Fig. 3.

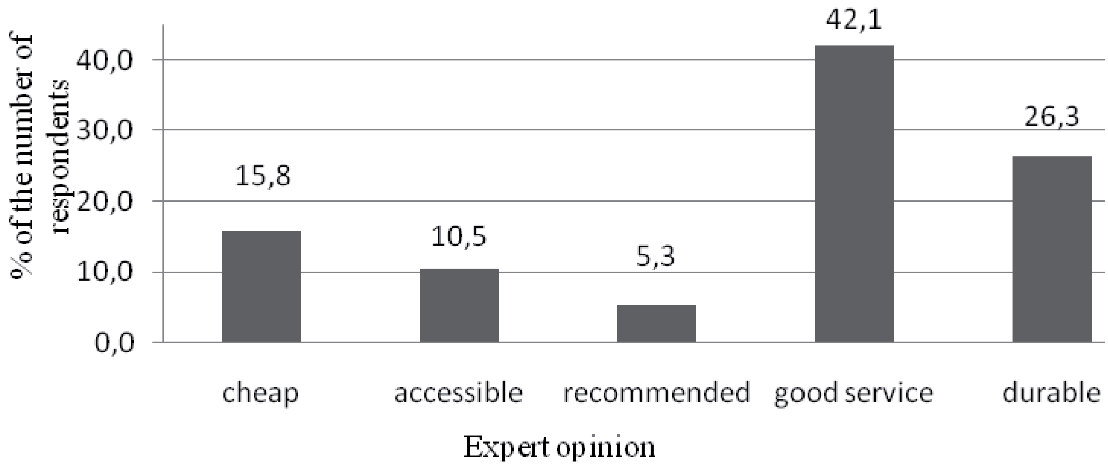
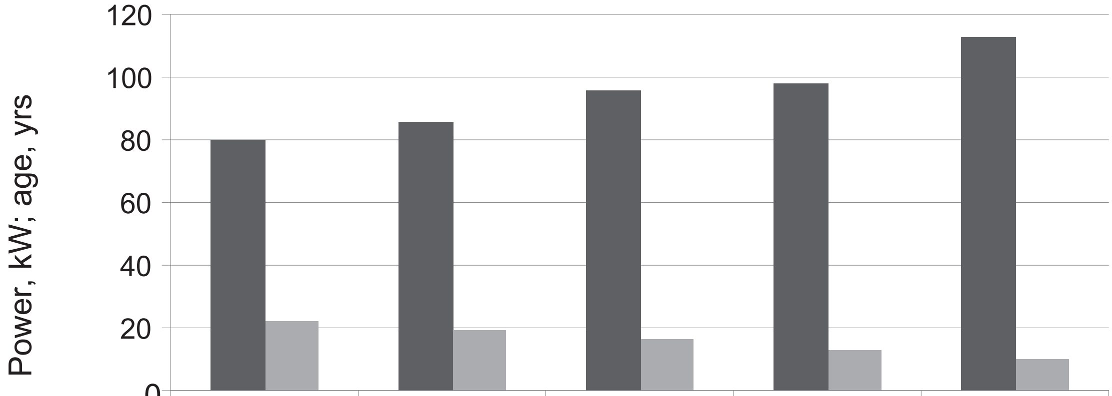


Fig. 3. Expert opinion on motivation of purchasing modern tractors.

According to the study the price is not a decisive factor when purchasing a modern tractor. Only 15.8% of respondents considered the price to be a decisive factor in tractor acquisition. Many experts (68.4%) preferred a tractor with good service and durability. The survey did not support the common understanding that tractors are purchased based on price. The selection is made on the basis of various technical conditions. There have been significant changes in the qualitative composition of tractors in Latvia, where the power rating of machinery increased by 15% in 2007, in comparison with 2000 (Kopiks & Viesturs, 2009). In Estonia the average age of tractors has decreased from 22.3 to 9.7 years over the past 5 years (renewal rate 43%) and the number of old tractors has been reduced, while engine power has increased from 80 kW to 113 kW in just five years (increase of power 30%).

Within the past 5 years, the average age of tractors has decreased and the power rating has increased (Fig. 4).



	2004	2005	2006	2007	2008
■ Power, kW	80	86	96	98	113
■ Age, yrs	22.3	19.4	16.2	13.2	9.7

Fig. 4. The average age and power of tractors over 5 years.

One criterion considered today by the heads of agricultural holdings before acquisition of a new tractor is its engine power. As the power of modern tractors yields up to 600 hp, the purchase must be preceded by a careful consideration of particular aggregates or jobs the tractor is expected to perform. This process involves calculations comprising the average area and shape of the field of the holding as well as its soil structure, when considering soil cultivation equipment, etc. Pursuant to the power supply of the agricultural equipment, a tractor with suitable power rating is selected. The second aspect considered in choosing a new tractor is the amount and nature of work performed by the tractor, i.e. acquisition of a tractor with certain power rating, which is later on supplemented by suitable accessories (Möller, 1977). The most suitable power rating in Estonia according to expert opinion, depending on the area of cultivated land, is shown in Fig. 5.

Estonia is currently in the situation where tractors with power rating of 81–160 hp are mostly preferred by small agricultural holdings. Medium-sized and very large agricultural holdings prefer power rating of 191–240 hp. According to the managers of large agricultural holdings they do not prefer one power rating to another and their holding exploits special tractors with different power rating.

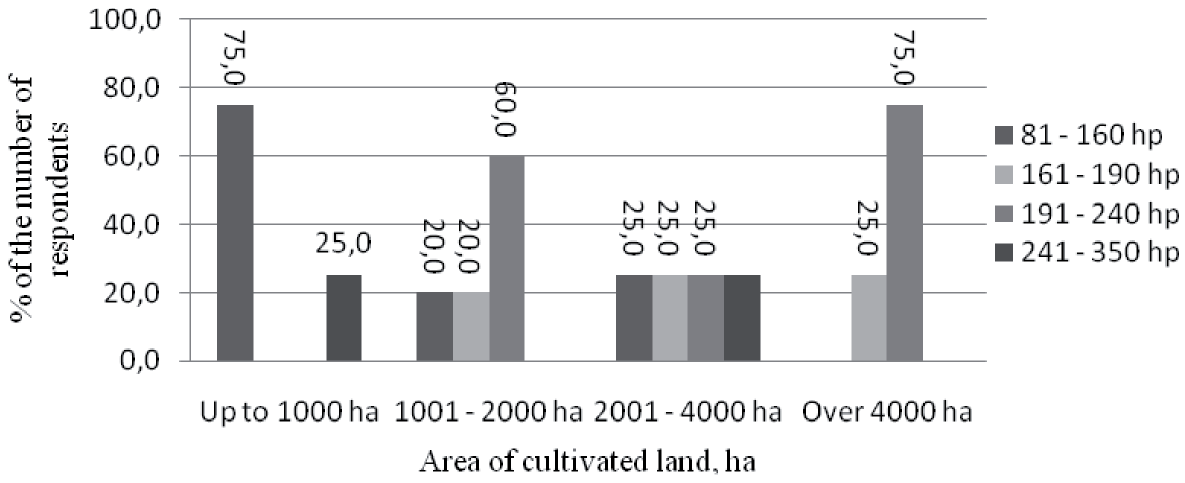


Fig. 5. The preferred power rating depending on cultivated land area.

Just as all other means of production, a tractor requires intensive use, otherwise the work-hours, hectares, tons or other measuring units will be too expensive and operation and production becomes futile. Acquisition of expensive machinery is only reasonable when a tractor is used to the maximum extent all year round and the pay-back period is as short as possible. The cost-effectiveness of modern tractor equals the amount of work it does. The optimum number of work-hours in a year shows the extent of work the tractor should perform in a year to ensure economical profitability. Expert opinion on the optimum annual work-hours per tractor depending on the area of cultivated land is shown in Fig. 6.

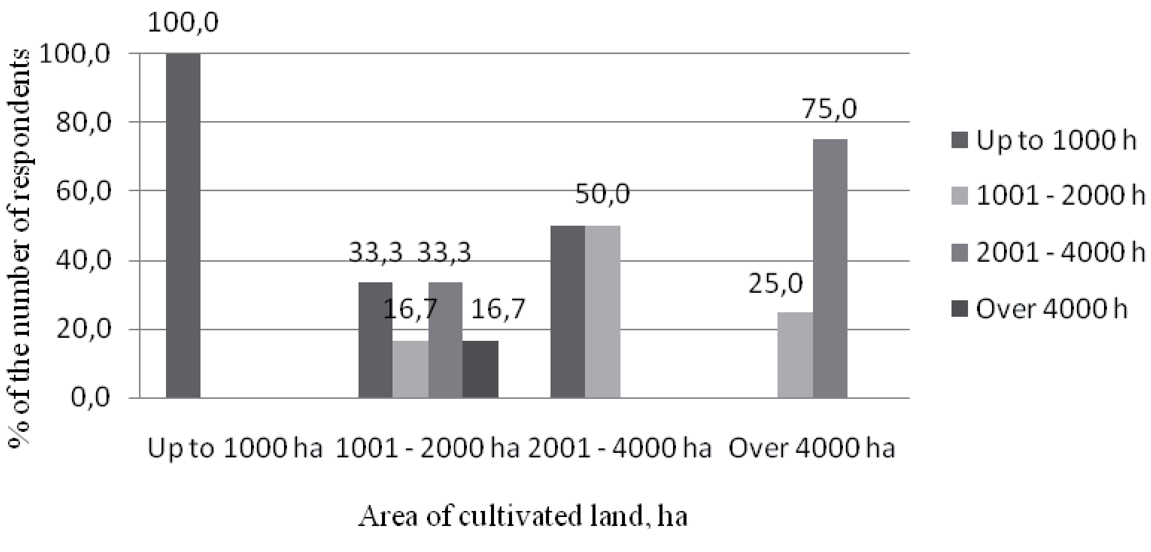


Fig. 6. Expert opinion on tractor's optimal annual number of work hours, depending on cultivated land area.

Pursuant to the expert opinion the optimal annual number of work hours of a tractor is 1,000 h in case of small agricultural holdings (up to 1,000 ha). Considering that our survey scale started from 1,000 work hours, the number of work hours would probably be even lower in case of small agricultural holdings. The managers of large agricultural holdings (over 1,000 ha) have different opinions – half of them believe 100–1,500 work-hours to be optimal and half of them think that the optimum number of annual work hours is 1,501-2,000. Three quarters of the managers of very large agricultural holdings consider 2,001-2,500 to be the optimal number of annual work-hours. The study proves that large and very large agricultural holdings are able to exploit tractors at full load and more evenly.

Diagnostics-based repairs of tractors

The diagnostics of tractors has shifted to the front. Technical maintenance and repairs are only performed after receiving instructions based on the results of diagnostics, i.e. diagnostics determines the technical condition of the machine and the extent of technical maintenance and (where necessary) repair works to be done and registers it in the main computer (Tšernoivanov, 2003; Mihlin, 1976).

In this case one advantage of communication is that the tractor does not need to be disassembled in order to find out the cause of the failure. All devices of the tractor are connected to common data bus and by connecting this bus to special control panel, it is possible to view from the screen, which device needs to be repaired or replaced. The same bus can be used for fixing a certain failure, for example it allows setting correct injection time.

Navigation system is developed in view of finding those failures that may disappear by the time the tractor is brought to the service station. All kinds of failures can be saved in the memory by a certain code, so that they can be demonstrated in the service station. Upkeep of machinery becomes more and more complicated and requires new skills. Despite the seemingly simplified control over the machine (lots of navigation and control tasks are performed by electronic units), modern machines are actually much more complicated than before.

Performance and resources of the machine or its components can be restored by current or basic repairs. Current repairs are performed to ensure the performance of the machine during its operation. It consists in replacement, restoration or regulation of separate aggregates and mechanisms with low resource. During current repairs the equipment is subjected to diagnostics to identify assemblies and aggregates that need to be replaced. After the equipment is assembled and adjusted, it is tested. (Nikolaenko, 1984; Mihlin, 1976)

Basic repairs are performed in order to restore the technical resource of the machine. The machine is completely disassembled, all details are cleaned, old parts are replaced by new or restored parts, after which the equipment is assembled and its mechanisms and units are adjusted. Assembly is followed by adjustment and testing of the equipment. Basic repairs are performed for sophisticated machinery and equipment (tractors, harvesters, cars, as well as their components), simpler machines are subjected to technical maintenance and current repairs (Tšernoivanov, 2001 & 2003; Mihlin, 1976).

The majority of agricultural holdings purchase tractor diagnostics service from tractor vendors and technically out-of-date machinery is repaired by the holding itself. Contrary to technically aged technology, many Estonian agricultural holdings have the repair works of modern machinery done by the specialists of tractor vendor. Significant changes have been made in the qualitative composition of tractors in Latvia, as their power rating is increasing. In 2007 the total tractor power increased by 15% in comparison with the year 2000 (Kopiks & Viesturs, 2008).

Fuel consumption

Increasing fuel prices force us more often to think about savings. Savings can be induced by two ways. The first one is the regular technical maintenance of the tractor. If a tractor is in good technical condition, it ensures optimum fuel consumption. Another method to save the fuel is to use proper techniques for operation and selection of cultivation tools. This means finding suitable tool for each job and for each tractor and making relevant adjustments.

A tractor's diesel fuel consumption can be calculated by the following formula:

$$L = \frac{k_l \cdot q \cdot P_m}{\rho}$$

where L is fuel consumption, l h^{-1};

k_l – engine power efficiency or level of effort: hard work 0.6–0.7, average work 0.4–0.5, light work 0.3;

q – specific fuel consumption for diesel, kg $(kWh)^{-1}$;

P_m – rated engine power of tractor or non-road vehicle, kW;

ρ – fuel density for diesel, kg l^{-1}, $\rho = 0.86$ kg l^{-1}.

The expenditure on fuel per hour u_k can be calculated by formula

$$u_k = r_k \cdot L$$

where r_k – fuel price, EUR l^{-1}.

Due to the high consumption and high price of diesel fuel, many agricultural holdings keep records of the amount of money spent on fuel in a year. The assessment of keeping such records (in comparison with cultivated land area) provided by agricultural holdings participating in the study is provided in Fig. 7. This kind of problem is beyond comprehension for several specialists from abroad, as they cannot understand how it is possible to organize business operations without keeping records of fuel consumption. Considering that Estonian agricultural holdings are allowed to use cheaper marked (blue) diesel fuel, which is not subject to excise tax (it is prohibited to use blue fuel in non-agricultural diesel fuels and police performs relevant checks on the road), it is common to store it in separate filling stations of former collective farms dating back to Soviet times, in metal containers (3-50 m^3). It should be noted that the quality properties of blue fuel are identical to those of the unmarked fuel and it is suitable for use in passenger cars and trucks with diesel engine. A typical refuelling scheme has been described below.

A tractor operator drives to the filling station of an agricultural holding, fills the tank and fixes the amount received by signing the fuel storage documents, based on the pump reading. At the end of the month all fuel amounts received from the tractor operators are added together without identifying the drivers, and registered as production costs under the entry ´total expenditure on tractors´. This is as far as it goes. According to the methods used by us this scheme does not comply with the purpose of the study and relevant note ´no records kept on fuel consumption´ is made in the company database. Such problems are characteristic only in our region and they provide a good example of the goals and purpose of the regional generation.

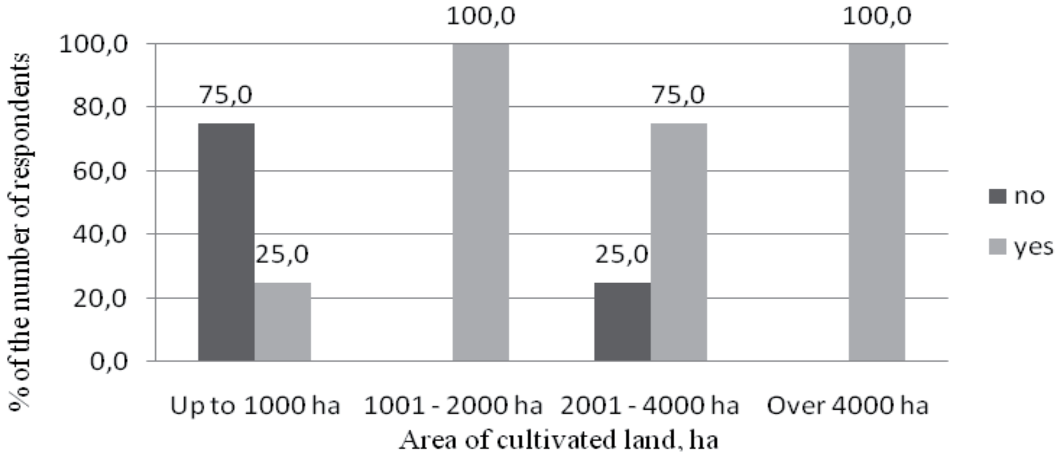


Fig. 7. Proportion of agricultural holdings keeping records of fuel consumption compared to cultivated land area.

The study revealed that medium-sized and very large agricultural holdings keep such records 100%. Three quarters of experts from small agricultural holdings believe that keeping such records gives them no benefits.

The private limited company Agro2 has kept such records for approximately 10 years, because the expenditure on fuel consumption is twice as high as the expenditure on repair and technical maintenance of tractors. Fig. 8 shows expenditure on fuel and repairs of Agro2 during the previous year.

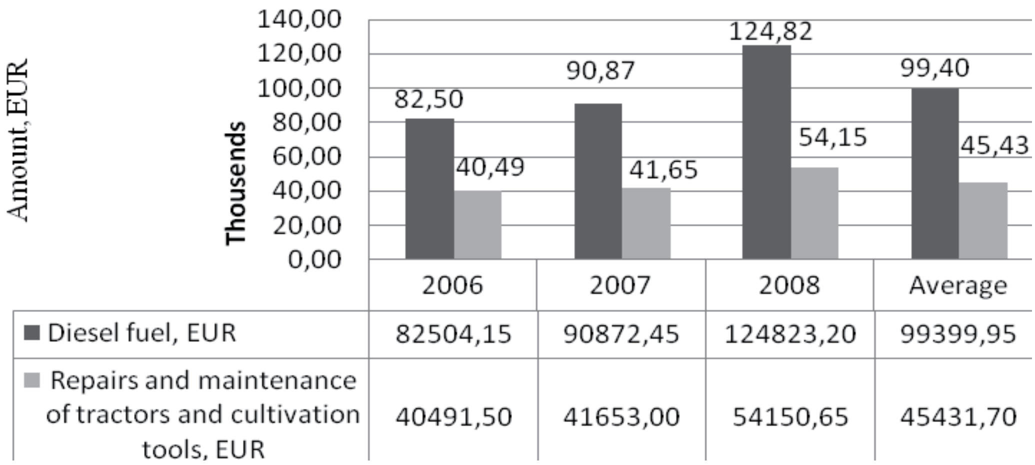


Fig. 8. Agro2 expenditure on diesel fuel in comparison with its expenditure on spare parts for tractors.

The amount spent on diesel fuel needs careful observation. According to the manager of the holding, keeping these records gives an overview of the extent of diesel fuel savings when using modern tractors and agricultural machinery. On the other hand, it provides an opportunity to predict the estimated investment in diesel fuel for seasonal works in spring or autumn.

Organization of repair works

In the private limited company Agro2 repair works are organized as follows – large-scale basic repairs are performed in winter, when tractors are used to a lesser extent. Such organization of work allows better all-year-round staff employment in an undertaking with a seasonal production cycle. In spring, summer and autumn only emergency repairs are performed for tractors and agricultural machinery, as this is the main cultivation time and tractors are working in the field most of the time. Tractors are divided between drivers, so that each driver has his own tractor to take care of. The holding has 7 tractor drivers/mechanics responsible for the machinery, plus three special workers. Each tractor driver has to repair his own tractor, with some assistance if needed, but the tractor driver is held personally responsible for the quality of repairs and good technical condition of the tractor. All major repairs are performed in the service hall which has the necessary equipment and tools.

In terms of purchasing new tractors, Latvian agricultural holdings attributed the highest priority to MTZ tractors in 2000 and 2007. But the number of actual acquisition of MTZ tractors in comparison with all tractors purchased within a year has decreased since 2000. In Latvia these tractors constituted 72% in 2000, but decreased to 26% by 2007. In Estonia the proportion of MTZ was 77.7% in 1998 and dropped to 13.2%. In 2007 the decrease in the proportion of MTZ tractors in comparison with all tractor models was greater in Estonia (13.2%) than in Latvia (26%) (Kopiks & Viesturs, 2009).

Pursuant to collected information, the more preferred trademarks of new tractors in Latvia include Valmet (Valtra), John Deere, Case. In addition to the abovementioned models, Fendt and New Holland are preferred in Estonia. This shows that price is not decisive in the renewal process of tractors, other important factors include reliability, energy intensity, efficient implementation, fuel consumption, comfort and other parameters.

The trends with regard to tractor fleet of the Republic of Latvia:

1. According to data analysis, the structure of tractor fleet in Latvian agricultural holdings is about to change in numbers, increasing the market share of energy-intensive tractors.

2. During the period 2001-2007 the total power rating of tractor fleet has increased by 15% or 390,475 kW.

3. The structure of tractor fleet of agricultural holdings depends on the total area of the farm and plant production volumes.

4. Farms with total area of arable crops 200-300 ha and tractors with power rating 80-100 kW constitute 85%.

5. Agricultural holdings have a tendency to grow, increased numbers of energy-intensive machinery and renewal rates reduce the number of tractors, and

technologically modern tractors enable to predict that in the future the number of tractors in the Republic of Latvia may reach 24-28 thousand.

SUMMARY

The tractor fleet of Estonian agricultural holdings is old. According to ARK the proportion of tractors older than 10 years was 67.8% in 2008, whereas the proportion of tractors not older than 5 years was only 25.1% of all registered tractors. Technically out-of-date tractors are gradually replaced by modern tractors. While only 23 new modern tractors were registered in 1990, the total of 629 tractors was registered in 2008. This process is irrevocable and the pace of modernization of the tractor fleet is determined by the position of tractor in the long and tense list of necessary investments in agriculture.

All in all the following results were achieved:

1. Many experts (68.4%) preferred a durable tractor with good service when planning acquisition of a modern tractor and for them price was not the deciding factor. Price was considered the most decisive factor by only 15.8% of experts.
2. The study proves that large and very large agricultural holdings are able to provide full and even load on tractors. The private limited company Agro2 represents a medium-sized agricultural holding and according to the manager of the holding the optimal annual number of work-hours is 1,500.
3. Own workforce is used for technical maintenance of old tractors 100% both in the private limited company Agro2 and 20 major agricultural holdings in Estonia. Similar to the private limited company Agro2, 47.0% of the agricultural holdings participating in the study perform technical maintenance of modern tractors by using their own workforce. Pursuant to expert opinion this allows to save up to 160 EUR per each technical maintenance session.
4. Medium-sized and very large agricultural holdings keep 100% records on the expenditure on diesel fuel. Three quarters of the experts from small agricultural holdings believe that they gain nothing from keeping such records.
5. During the past three years, the average sum of 100 EUR for fuel consumed by tractors (2006-2008) is supplemented by 46 EUR for repairs and technical maintenance. These expenses should be considered when preparing the cost of tractor works.

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Papers should be strictly followed instructions

Structure

Title, Authors (names), Authors' place of work with full address (each on a separate line), Abstract (up to 250 words), Key words, Introduction, Materials and methods, Results and discussion, Conclusions, Acknowledgements, References.

Example:

A study of synergistic effect of greater wax moth *Galleria mellonella* (Lepidoptera: Pyralidae)

M. Kuusk[1] and K. Lepp[2]

[1]Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Kreutzwaldi 64, EE51014 Tartu, Estonia; e-mail:
[2]Institute of …

Abstract. In laboratory pupal…

Key words: *Galleria mellonella*, respirography, synergistic interaction

Introduction

In many countries rural inhabitants for insect control use various local plants (Smith & Jones, 1996; Brown et al., 1997; Adams, 1998).
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Page size and font

- The file should be prepared using **Microsoft Word** **97** or a later version
- Set page size to **B5 Envelope (17,6 x 25 cm)**, all margins at **2** cm
- Use **single line** spacing and **justify** the text
- Use font **Times New Roman**, size **11**; for Abstract, Key words, References and tables use **10** points
- Use **tabs 0,8**
- Do not use page numbering

- Use *italics* for Latin biological names and for statistical terms (*t*-test, $n = 193$, $P > 0.05$)
- Use single ('……') instead of double quotation marks ("……")

Tables

- All tables and figures must be referred to in the text (Table 1; Tables 1, 2)
- For tables use font Times New Roman, regular, 10 points
- Use **TAB** and not space bar between columns
- Do not use vertical lines as dividers, only **horizontal** lines are allowed
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Figures

- Use only black and white for figures
- Use font **Arial** within the figures
- Legend below the figure must not be in a frame of the figure
- All figures must be referred to in the text (Fig. 1; Fig. 1, a, b; Figs 1, 3; Figs 1–3)

References

- **Within the text**

In case of **two** authors use **&**. In case of more than two authors, reduce to first author "et al."

Smith & Jones (1996); (Smith & Jones, 1996)
Brown et al. (1997); (Brown et al., 1997)
Adams (1998); (Adams, 1998)

When referring to more than one publication, arrange them using the following keys: 1. year of publication (ascending), 2. alphabetical order for the same year of publication:

(Smith & Jones, 1996; Brown et al., 1997; Adams, 1998; Smith, 1998)

- **For whole books**

Name(s) and initials of the author(s), year of publishing, title of the book (*in italic*), publisher, town of publishing, number of pages.

Tritton, D. Y. 1988. *Physical Fluid Dynamics*. Clarendon Press, Oxford, 350 pp.

Shiyatov, S. G. 1986. *Dendrochronology of the Upper Timberline in the Urals*. Nauka, Moskva, 350 pp. (in Russian).

- **For journals articles**

Name(s) and initials of the author(s), year of publishing, title of the article, abbreviated journal title (*in italic*), volume (*in **bold***), page numbers.

Titles of papers published in languages other than English, German, French, Italian, Spanish, and Portuguese should be replaced by an English translation, with an explanatory note at the end, e.g., (in Russian, English abstr.).

Karube, I. & Tamiyra, M. Y. 1987. Biosensors for environmental control. *Pure Appl. Chem.* **59**, 545–554.

Frey, R. 1958. Zur Kenntnis der Diptera brachycera p.p. der Kapverdischen Inseln. *Commentat.Biol.* **18**(4), 1–61.

Danielyan, S.G. & Nabaldiyan, K.M. 1971. The causal agents of meloids in bees. *Veterinariya* **8**, 64–65 (in Russian).

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Ritchie, M.E. & Olff, H. 1999. Herbivore diversity and plant dynamics: compensatory and additive effects. In Olff, H., Brown, V.K. & Drent, R.H. (eds): *Herbivores between plants and predators. The 38th Symposium of the British Ecological Societ*. Blackwell Science, Oxford, UK, pp. 175–204.

....………

Please note

Use ‘**.**’ (not ‘**,**’) : 0.6 ± 0.2

Use a ‘comma’ for thousands - 1,230.4 (one thousand two hundred and thirty and four tenths)

Without space: 5°C, 5% (not 5 °C, 5 %)

Use ‘–’ (not ‘-’) and without space: pp. 27–36, 1998–2000, 4–6 min, 3–5 kg

Spaces: 5 h, 5 kg, 5 m, C : D = 0.6 ± 0.2

Use ‘kg ha^{-1}’ (not ‘kg/ha’)

Use ‘ ° ’ : 5°C (not 5^{o}C)