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Analysis of economical, social and environmental aspects of agroforestry systems of trees and perennial herbaceous plants

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Abstract. The aim of this study was to determine the economic, social and environmental aspects, that promote choosing an agroforestry system and continuing agricultural production instead of simple afforestation of agricultural land. Material for the study was collected in an experimental demo field located in the central part of Latvia (56°41 N and 25°08 E) established in the spring of 2011, nearby Skrīveri. Two legumes – fodder galega (*Galega orientalis* Lam.) 'Gale', poor-alkoloid lupine (*Lupinus polyphyllus* L.) 'Valfrids' and two perennial grass cultivars – reed canary grass (RCG) (*Phalaris arundinacea* L.) 'Bamse' and festulolium (*x Festulolium pabulare*) 'Felina' were sown between the tree rows and in monoculture on drained mineral soil. Four different fertilisation treatments for herbaceous plants – control (without fertiliser), mineral fertilisers, wastewater sludge and wood ash were used. Biomass, seed yield, agricultural management cost have been investigated since the establishment of experiment in 2011. Potential benefits from growing herbaceous plants for seed, biomass production and possible future income from tree wood and non-wood goods were calculated. Management cost of agroforestry system, plantation forest and traditional sowing were analyzed. The growth of herbaceous plants for seed production together with hybrid aspen in agroforestry system during a 5 year period has a positive balance with all types of fertilisers. The growth of herbaceous plants in a monoculture for biomass production in a 3 year period had a positive balance for all types of organic fertilisations at both cutting frequencies. Positive balance by applying mineral fertiliser was achieved only at two-cut cutting regime.

Key words: agroforestry, fertilisers, hybrid aspen, herbaceous plants, DM yield, seed yield, cash flow.

INTRODUCTION

Agroforestry is a perspective way of biomass production that combines simultaneous growing of woody plants with agricultural crops on the same area for different purposes. Agroforestry is the combination of agricultural and forestry technologies to create integrated, diverse and productive land use system in which two or more plant species interact, one of the species being perennial and having a woody consistency (Somarriba, 1992; Garrett et al., 2000; Dupraz et al., 2005). It is a system of land management that integrates tree and shrub plantings with crops or livestock in order to generate economic, environmental and social benefits. In this era of global warming, fast degradation of land productivity and other environmental hazards, agroforestry is indeed a stake for natural resources and socio-economic sustainability (Gangadharappa et al., 2003). Agroforestry, like multifunctional agriculture, has the objective of promoting economically, socially, and environmentally sustainable rural development (Leakey, 2012). Agroforestry provides opportunities to increase the value of total production through marketing of multiple products from a given unit of land (Feldhake et al., 2008).

Agroforestry practices offer many advantages such as crop and livestock protection, soil and stream conservation and protection, diversification of agricultural revenues through the production of timber and non-timber forest products, promotion of biodiversity, landscape enhancement and carbon sequestration (Cole, 2010). Also, these practices are believed to reduce nonpoint source pollution from row-crop areas by improving hydraulic properties of soil and reducing surface runoff (Paudel et al., 2011).

The main productive advantages of agroforestry systems are linked to better use of resources in a spatial and temporal scale and smaller competition of plants for nutrients. In this system, the woody plants are less influenced by lasting periods of drought, and a stable annual increase in biomass is ensured (Bardule et al., 2013).

Agroforestry adds plant and animal biodiversity to landscapes that might otherwise contain only monocultures of agricultural crops (Noble & Dirzo, 1997; Guo, 2000). Mixing tree species, allowing for small clearings and water catchments in planting, and incorporating understory vegetation can greatly improve habitat for many animals and create micro-site conditions for plant species (Spies & Franklin, 1996).

Design and evaluation of agroforestry systems requires thorough knowledge of relationships between agriculture and forestry. Complementary and supplementary relationships mainly resulting from biological factors make agroforestry an efficient system of land use (Filius, 1982). Agroforestry can be an appropriate technology in areas with fragile ecosystems and subsistence farming.

The advantages of agroforestry systems can confer important social benefits at a farm level, in the different biogeographic regions of Europe and at the same time benefit the general public (Rigueiro-Rodriguez et al, 2008). Farmers in Mediterranean areas felt that the principal benefit of silvoarable systems would be increased farm profitability (37%), whereas farmers in Northern Europe placed greatest value on environmental benefits (28%) (Graves et al., 2008).

One of most promising in term of fast growing tree species in nordic conditions is aspen. While in Southern countries eucaliptus are growed under agroforestry system in Baltic states alternative use of abandoned agricultural areas in Latvia is hybrid aspen (*Populus tremula* L. x *P. tremuloides* Michx.) plantation establishment. Hybrid aspen has high growth potential in Baltic region (Tullus et al., 2012). First breeding plantation of hybrid aspen in Latvia were established in 1960th (Smilga, 1968). Hybrid aspen seams very promising, because in first research plantation is acquired data, that volume increment can reach up to 20m^3 ha^{-1} yr^{-1} in plantation lifespan of 25 years (Tullus et al, 2012a). The highest growth of hybrid aspen plantations of 25 years lifespan can reach 300 m^3 ha^{-1}, the wood is white, with low number of branches which makes the plantation establishment attractive to forest owners (Pavlovics et al., 2010). Aspen wood is suitable for producing light, dense, smooth and non-transparent paper (Treimanis, 2008). In short-rotation plantation forestry harvest times usually correspond with time, when the mean annual increment is the highest, because of the economic profitability of the plantation (Tullus et al., 2012b). For reaching of larger dimensions and saving on planting material costs, lover planting density are recomended. According to Latviana regulation, should be planted at least 800 trees per ha, what alows to combine growing of trees with 'tadicioanal agriculture' between rows.

Agroforestry has the ability to provide short-term economic benefits while the farmer waits for traditional longer-term forestry products. An example of an agroforestry system is a riparian buffer planting that can attenuate flooding effects and protect water quality, while providing wildlife habitat, recreational opportunities and harvestable products, for example, biomass and seed yield of herbaceous plants.

The perennial cropping in the agroforestry system is more successfully used in practical terms; not only it reduces costs, but also facilitates the maintenance of the area in the technical sense, because subsequent tillage between the trees can be problematic.

Economics is concerned with the analysis of choice and decisions: which goods are produced with which resources, and how much of these resources may be used in order to achieve certain objectives. Economic studies of agroforestry systems have shown that financial benefits are a consequence of increasing the diversity and productivity of the systems which are influenced by market and price fluctuations of timber, livestock and crops (Benjamin et al., 2000).

There are no economic studies of agroforestry systems in Latvia. Economic evaluation of grassland sward production has shown the necessity of long – persisting plant use. Production costs of a unit of grass dry matter can be decreased by prolongation of a sward use, and it was stated by significant correlation ($R^2 = 0.95$). Significant relationship between the swards – longevity and swards – establishment and management costs ($R^2 = 0.93$) was established.

Fodder galega and other longest-persisting grasses are good for such purpose (Kirila et al., 2002). In case of two perennial ryegrass seed production years, constant costs (expenses used for establishing sward) decreased twice, in general, lowering total costs. Consequently, from the economic point of view, two production years of perennial ryegrass seeds are profitable – irrespective of somewhat lower seed yield, a certain decrease in expenses was achieved, when seed fields were established and generally higher gross income was obtained (Būmane, 2009).

The successful development of herbaceous plants between trees rows depends on identifying species which are well adapted to low – input biomass production with high yield potential. Reed canary grass, festulolium, and galega are well known in Baltic countries as long-persisting, productive grasses and legume suitable for biogas or fuel pellet production (Tilvikiene et al., 2010; Adamovics et al., 2011). The perennial lupine has a highly developed root system, it grows well in sandy soil and is well adapted to low fertilisation input (Dubrovskis et al., 2011). The above-mentioned species of herbaceous plants grow very well in cool temperate climate. They have good winter hardiness and they survive well in conditions present in Latvia. It is also an important factor that a successful seed production for further varieties propagation is possible. Seed production sowings of perennial herbaceous plants together with woody plants can be a successful decision for financial benefits by decreased production costs and multiple products from a given unit of land.

This paper on economic, environmental and social aspects of agroforestry estimates factors influencing the choice of combination of agriculture and forestry compares the financial flows of agro-forestry systems with the prospect to earn an income from afforestation and distribution of production from agroforestry.

MATERIALS AND METHODS

Study site

The data for this research was collected from demonstration field trials located in the central part of Latvia (56°41 N and 25°08 E) nearby Skrīveri. Study site was established in the spring of 2011 on drained mineral soil. Soil type is classified as a *Phaeozems/ Stagnosols* with a dominant loam (at 0–20 cm depth) and sandy loam (at 20–80 cm depth) soil texture. The content of carbon (C) in soil arable layer – 23 g kg^{-1}, pH KCl – 6.1, plant available phosphorus (P_2O_5) – 277.1 mg kg^{-1}, potassium (K_2O) – 136.8 mg kg^{-1}.

Meteorological conditions during the trial years were different. Year 2012 was characterized by rich precipitation, the annual rainfall was 928 mm (it is 139% of its long-term average rate in Latvia). Precipitation during the vegetation period in 2013 was slightly lower in the long-term average and its distribution was not favourable for grass growth – hot and dry periods were interrupted by short, heavy rainfalls. Lack of moisture in July and August had a negative impact on the development of plants. Precipitation distribution for vegetation period in two trial years is shown in Fig. 1.

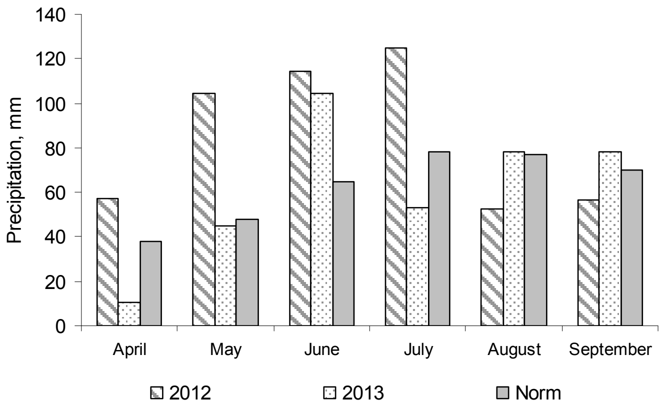

Figure 1. Precipitation during vegetation periods (2012–2013) compared with meteorological norm (Skriveri meteorological station data).

Design and planting material

Two different clones (4 and 28) of hybrid aspen (*Populus tremuloides x Populus tremula*) were planted in the agroforestry system, the planting material originated from JSC 'Latvijas valsts meži', Latvia. The average spacing between trees was 2.5 x 5.0 m and the planting density – 850 trees per ha.

Two perennial legumes – fodder galega (*Galega orientalis* Lam.) 'Gale', poor-alkoloid lupine (*Lupinus polyphyllus* L.) 'Valfrids' and two perennial grass cultivars - reed canary grass (RCG) (*Phalaris arundinacea* L.) 'Bamse' and festulolium (*x Festulolium pabulare*) 'Felina' were sown between the tree rows and in monoculture.

Perennial grasses and legumes for seed production were sown in 2.5 m wide strips between six trees rows, and the size of one plot was 60 m^2. Between the trees and grass lines an empty space of 1.25 m was provided. Thereby swards used for seed production cover half of planted area in this block. Monocultures of herbaceous plants (without woody plants) were sowed in a separate block for biomass production with a 20 m^2 harvest recorded plot size.

Seed production sowings between trees were carried out in mid – June of 2011, biomass production sowings in monoculture were sown in mid – July of 2011 in four replications, using the seeders 'Nordsten NS-1025'. Grasses and legumes were sown without a cover crop using a narrow row spacing for all species in the grass monoculture trials for biomass production and for RCG and festulolium in seed production trials between trees, and broad row spacing (36 cm) for galega and lupine in seed production sowings between the trees.

Seeding rates: galega 12 and 30 kg ha^{-1}; lupine 30 and 60 kg ha^{-1}; reed canary grass 10 and 15 kg ha^{-1} and festulolium 12 and 12 kg ha^{-1} germinating seeds for seeds and biomass production respectively. Legume seeds were treated with nodule bacteria preparations before sowing, wet nitragin grown on agar was used for galega, peat powder mixed with nitragin – for lupine. The plantation was fenced in the autumn of 2012.

Treatments

Four replications of three different fertilisation subplots – control (no fertilisation), wastewater sludge and wood ash, the size of each – 30 x 24 m, were established in the combined woody – herbaceous plantation in the spring of 2011. I class (according to regulations of the Cabinet of Ministers of the Republic of Latvia No. 362) wastewater sludge (dose 10 t_{DM} ha^{-1}) from Ltd. 'Aizkraukles ūdens' (*Aizkraukle Water*) and stabilized wood ash from the boiler house in Sigulda (dose 6 t_{DM} ha^{-1}) were spread mechanically before the planting of hybrid aspen and sowing of legumes and perennial grasses (Table 1). Heavy metals target values and precautionary limits are not exceeded in fertilised soils according to legislative regulation for soil and ground quality (regulations of the Cabinet of Ministers of the Republic of Latvia No. 804). For comparative evaluation of grasses and legume seed yields along with the mentioned fertilisers there was also a mineral fertiliser option included: N25:P50:K125 for the legumes and N60:P50:K125 for the grasses. In the block of herbaceous plants grown in monoculture for biomass production in addition to the above mentioned fertilisation variants the digestate from Training and Research Farm 'Vecauce' was included, treatment dose 30 t ha^{-1}.

Table 1. Chemical composition (content of elements, g kg^{-1}) of fertilisers

Fertiliser	N	P	K	Ca	Mg	Mn	Fe	Na
Wood ash	0.40	10.9	31.6	224.8	30.9	3.1	4.6	1.6
Wastewater sludge	25.9	16.3	2.2	10.9	11.3	0.3	23.4	0.2
Digestate (g L^{-1})	2.1	0.4	3.3	0.10	0.35	0.01	0.05	0.29

In the control fields, no fertilisation was used, the fertilisation with sewage sludge and ash was done once as initial – in the establishment year, the fertilisation with mineral fertiliser was done every year, total 6 times.

Measurements and statistical analysis

Biomass, seed yield, agricultural management cost were investigated since establishment of experiment in 2011. Herbaceous plants seeds were collected by using a small experimental harvesting *Wintersteiger* and seed yield was determined. Herbage biomass dry matter was recorded using two cutting frequencies – 2 cuts per vegetation period and 1 late cut in October.

For the estimation of economical efficiency of perennial grasses and legumes biomass and seed production between the tree rows and in monoculture, the production costs and income calculations have been done. In the economic model all prices, technologies and growing condition were based on Latvia's conditions. Equipment transportation to the plantation and transportation of the end product to the customer is considered to be 20 km. The establishment and management costs of field trial agroforestry plantation in Skriveri were taken into account. Potential benefits from growing of herbaceous plants for seed, biomass production and possible future income from trees wood and non-wood goods were calculated. Economical calculations according to plantation life-cycle starts with the establishment costs, which includes ploughing, trenching and cultivation, also glyphosate type herbicides were used to reduce weed impact. Sowing and cutting costs are the same for all plant species, seeding rates are different for every specie in every type of management. All prices were taken from The Latvian Rural Advisory and Training Centre review 'Technical service prices in Latvia, 2013' (Tehnisko pakalpojumu cenas ...).

Income was calculated for obtained biomass dry matter yield and seed yield based on average hay, bale silage and seed production prices in Latvia in 2013. For herbage monoculture fields calculations were done for a 3 year (2011–2013) period – sowing year, first and second sward production years where biomass is used for biogas production at a frequent cutting regime, and for grass pellets production for heating at an extensive cutting regime. Income from seed production sowings between trees was calculated for 5 production year period, based on two harvest year average seed yields.

The experimental data of perennial grasses and legumes biomass and seed yield were statistically analyzed by applying the analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Sowing (plantation establishment) year

Perennial grasses and legume provide full herbage yield in the first production year or the next year after sward establishment. Dry matter (DM) yield in the year of establishment could reach about 5 t ha^{-1} depending on sowing time and meteorological conditions. Our trial with a late sowing time (middle of July) and unfavourable weather conditions caused lower average DM yields –1.89 to 3.30 t ha^{-1} depending on species. Dry and warm weather in July and August had a negative impact on plant growth and utilization of applied fertiliser. Applying sewage sludge and digestate provided significant increase of mean DM yield in the sowing year. The influence of wood ash and mineral fertiliser was not significant.

The first production year of dry matter

Sowings of perennial lupine did not establish well in the first year, the plants were weak and there were quite few generative sprouts. Very poor vegetation was the cause why lupine was excluded from trials and its DM and seed yield has not been evaluated.

In the first production year the average grasses and legume dry matter yields were estimated as satisfactory (6.76 t ha^{-1}). Grasses and legume dry matter yields were dependent on the applied fertiliser type and grass species and cutting frequency (Fig. 2.). Each of the applied fertiliser provided significant increase of mean DM yield for investigated species in comparison with control (5.68 t ha^{-1}). The highest RCG and festulolium DM yield were achieved by using mineral fertiliser on average for both cutting frequencies (9.11 and 9.74 t ha^{-1} respectively). An essential DM yield increase was provided by 38% applying wastewater sludge. Digestate treatment provided significant RCG and galega DM yield increase (on average 1.45 t ha^{-1}).

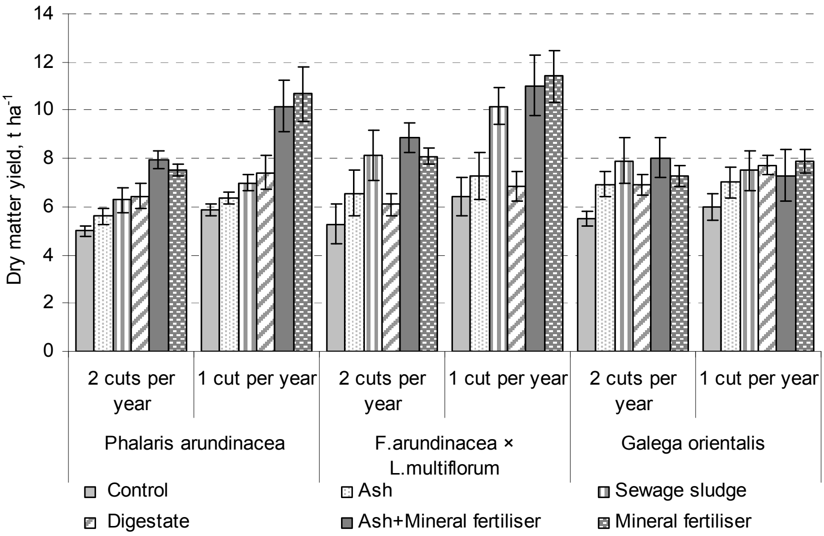

Figure 2. The DM yield of herbaceous plants in the first year of sward use, t ha^{-1}; error bars indicate standard errors.

The highest average DM yield (8.00 t ha^{-1}) was achieved with cutting once in a season – at a crop senescence in comparison with a two – cutting frequency (6.91 t ha^{-1}). The effect of fertilisation was expressed better by applying one cut in a season – the average increase of DM yield was 2.43 t ha^{-1}, in comparison with the average DM yield increase (1.95 t ha^{-1}) at two-cutting regime.

The second production year of dry matter

In the second production year average grasses and legume dry matter yields were estimated as moderate (5.48 t ha^{-1}). The lowest yield in the second year can be explained by meteorological conditions – very late spring and an insufficient amount of precipitation and unfavourable distribution of rainfall in summer.

In the second production year the similar effect of fertilisation was observed on grasses and legume dry matter yields. The highest RCG and festulolium DM yields were achieved by using mineral fertiliser on average for both cutting frequencies (9.50 and 7.09 t ha^{-1} respectively). Sewage sludge and digestate application had positive effect on DM yield production (Fig. 3.). The applying of wood ash did not provide significant DM increase for both intensities of management. It can be explained by meteorological conditions – dry and hot weather during the summer.

The highest average DM yield was given by reed canary grass at the management with one late cut. The average festulolium DM yields did not differ significantly between two cutting regimes. The highest average DM yield at a frequent cutting regime was given by galega, as nitrogen fixing papilionaceous plant with highly developed root system that reaches deep into the soil and good regrowth after cuts. By mowing galega once per season in autumn relatively low DM yield was obtained, which can be explained by partial plant defoliation.

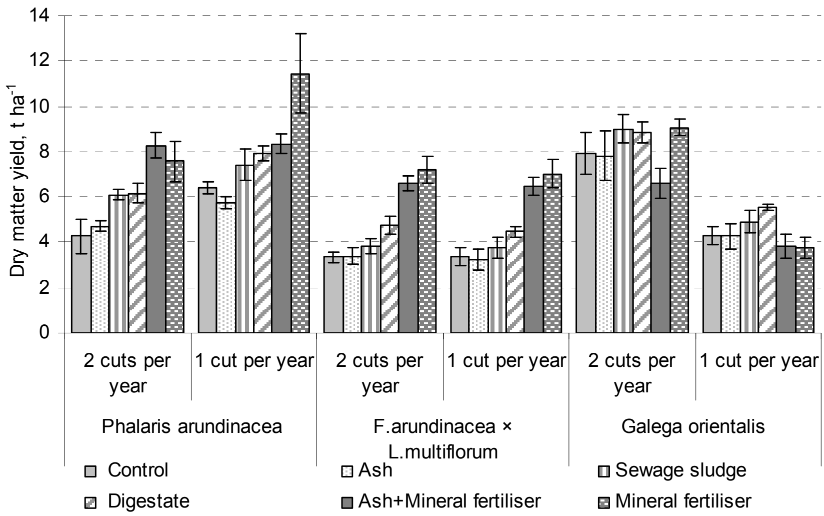

Figure 3. The DM yield of herbaceous plants in the second year of sward use, t ha^{-1}; error bars indicate standard errors.

Seed yields

The average seed yields of the herbaceous plants species obtained in the first year of use are estimated as good for festulolium and moderate for reed canary grass and galega. Seed yield formation was influenced by plant biological traits and meteorological conditions.

Fodder galega has very slow development in the sowing year and in the first year of use (Parol & Viiralt, 2001). The seed production of forage legumes including galega are very unstable. The most important factor for legumes forming seed are the weather conditions, therefore seed yield varies by year, depending on weather conditions at the time of flowering and harvesting (Meripold, 2005). Numerous rainy days during the vegetation period in 1st year of use did not allow the pollination of galega flowers and made a negative effect on the seed yield, therefore the obtained galega seed yields were quite poor.

The results of the first production year indicate that in general the use of fertilisers in the plantation facilitated higher yields of seeds. An essential increase of seed yield for all grass species was provided by applying wastewater sludge (Table 3). The highest increase of seed yield by applying the sludge was observed for RCG (175 kg ha^{-1} or 136% more in comparison with control variant). The increase of festulolium seed yield was 275 kg ha^{-1} or 23%, but for galega it was respectively 134 kg ha^{-1} or 95% more in comparison with the control. The greatest increase of seed yield (363 kg ha^{-1} or 31%) for the quick-growing festulolium was provided by the use of mineral fertilisers. As to galega being a nitrogen fixing papilionaceous plant the greatest increase of seed yield (230 kg ha^{-1} or 163%) was provided by the use of ash.

Table 2. The seed yield of perennial grasses in 1st and 2nd year of use (2012–2013) in agroforestry system, kg ha^{-1}

Fertiliser	Reed canary grass		Festulolium		Galega	
	1st year of use	2nd year of use	1st year of use	2nd year of use	1st year of use	2nd year of use
Control	129	197	1,176	202	142	427
Mineral fertiliser	225	436	1,539	278	185	535
Sewage sludge	304	373	1,451	191	276	444
Ash	241	282	1,296	220	372	568
Mean	225	322	1,365	223	244	493
$LSD_{0.05}$	153.2	220.0	253.5	54.3	123.1	128.3

In the 2nd production year seed yields of RCG and galega were estimated as being good. It is characteristic for both species to give the full seed yield in the second production year. Festulolium seed yield in the second production year was considerably lower. Low seed yield was caused by big aftermath length after seed harvest in previous year. The grate aftermath did not affect RCG and galega development in spring, but festulolium had later spring regrowth and plants were weak.

The results of the second production year indicate that in general the use of fertilisers in the plantation facilitated higher yields of seeds.

Economic evaluation

The combined cultivation of trees and grasses on the same area give possibility to save costs and earn an incomes in first years, which cover starting expenses. The soil preparation, herbicide use, land taxes and administration costs are the same for both systems, so growing these species in agroforestry system gives chance to consolidate them.

First incomes from hybrid aspen plantation, if they are growing for log production, will be in the plantation 20th year from thinning and the second incomes in the final felling at the plantation age of 40 years. Hybrid aspen growing together with perennial herbaceous will give first incomes in the first year of plantation, which gives possibility to cover establishment costs, planting material, planting and tending costs after 3–5 years from plantation foundation. The perennial herbaceous in agroforestry system usually grows 4–5 years. After 5 years, to keep seed yields high, is necessary to parse the plantation. In first 5 years the trees remains higher dimensions, so later it's hard to do trashing, seed collection and fertilisation. That's why perennial herbaceous grows in agroforestry system usually for first 4–6 years.

The growth of herbaceous plants for seed production in agroforestry system during a 5 year cycle has a positive balance with all types of fertilisers. The most beneficial for the reed canary grass under the specific conditions was ash fertiliser, it provided the highest profit – on average 610 EUR ha^{-1} a year, sludge fertiliser had a slightly lower profit – on average 566 EUR ha^{-1} a year. The results for galega were similar to RCG, ash and sludge fertilisers provided almost the same profit – 533 and 537 EUR ha^{-1}.

The best results for festulolium obtained by using of sewage sludge (455 EUR ha^{-1}) and ash (416 EUR ha^{-1}).

Average site preparation costs in establishment year in all plantation models are 101 EUR ha^{-1}. Hybrid aspen establishment costs in all plantation models first year are 899 EUR ha^{-1}, the main costs are for planting stocks, planting and defensive remedies. In the latest years costs for hybrid aspen are insignificant, which mainly consists of agro – technical care and defensive remedies.

For the perennial herbaceous crops establishment costs, seeding, cutting, trashing, seed drying, transport costs, land taxes and grants are the same for all crops. Although seed cleaning, seed prices and seeding rates vary in different species. Also fertilisation costs are different for every fertiliser.

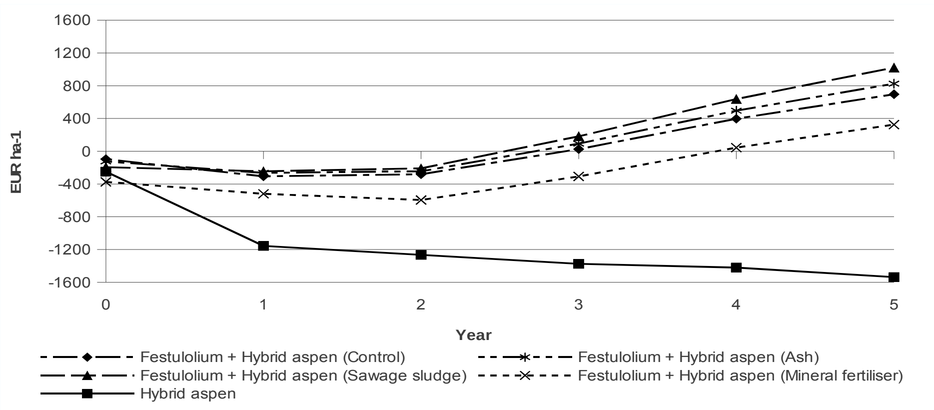

Figure 4. Accumulated cash flow of hybrid aspen and festulolium agroforestry plantation with different fertilisation.

In model, where festulolium and hybrid aspen are grown together, the best results shows fertilisation with sewage sludge, where accumulated cash flow after 5 years is 1,021 EUR ha^{-1}, positive cash flow is achieved after 1st year, mainly because of the high yield in first year. The worst results shows fertilisation with mineral fertiliser 325 EUR ha^{-1}, because of the high mineral prices and fertilisation every year, which gives extra expenses (Fig. 4).

In model, where galega and hybrid aspen are grown together, best results shows fertilisation with sewage sludge, where accumulated cash flow after 5 years is 1, 432 EUR ha^{-1}, positive cash flow is achieved after 3rd year. The worst results shows fertilisation with mineral fertiliser 105 EUR ha^{-1}, (Fig. 5).

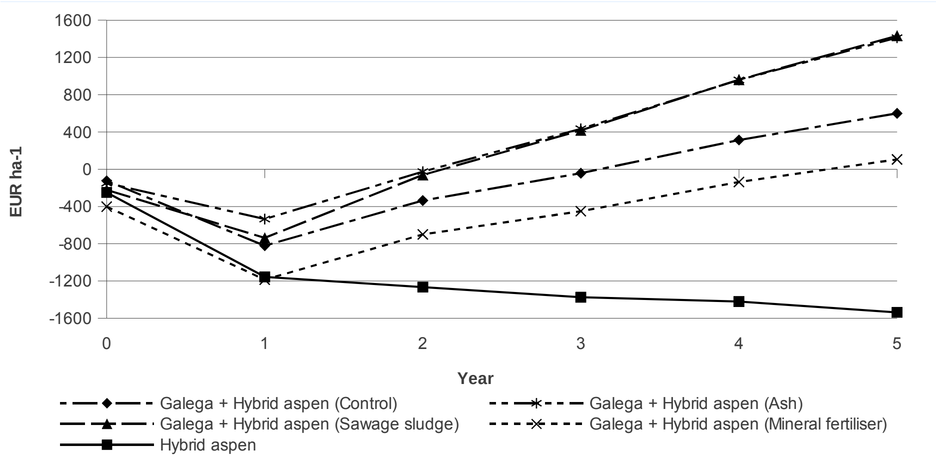

Figure 5. Accumulated cash flow of hybrid aspen and galega agroforestry plantation with different fertilisation.

Galega is one of the longest-persisting plants in swards, notable for a high productivity without mineral fertilisation (Virkajarvi & Varis, 1991), so this time use of fertilisers in galega swards was not economically substantiated.

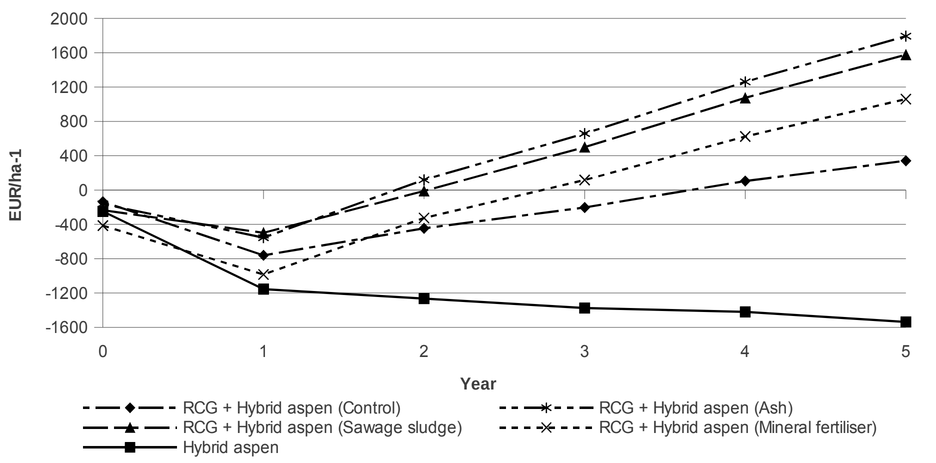

Figure 6. Accumulated cash flow of hybrid aspen and reed canary grass (RCG) agroforestry plantation with different fertilisation.

In model, where reed canary grass and hybrid aspen are grown together, best results shows fertilisation with ash, where accumulated cash flow after 5 years is 1,793 EUR ha^{-1}, positive cash flow is achieved after 2nd year. The worst results shows in control 341 EUR ha^{-1}, (Fig. 6).

In situation where hybrid aspen is grown alone, the accumulates cash flow in year 5th is 1,537 EUR ha^{-1}. The negative cash flow will be till year 20th, when the first incomes from thinning will come.

After comparing the calculated balance for each fertiliser variant we observed that the use of wastewater sludge and digestate as fertilisers for herbaceous plants provided the highest profit (Table 3).

Table 3. The average revenues per year for herbaceous plants sowings in monoculture in 3 year cycle management, by 1 time grass harvest and at frequent cutting regime system per year (2012–2013), EUR ha^{-1}

Fertiliser	Reed canary grass		Festulolium		Galega	
	1 cut per year	2 cuts per year	1 cut per year	2 cuts per year	1 cut per year	2 cuts per year
Control	119	158	67	116	40	211
Ash	85	177	98	136	28	221
Sew.sludge	112	177	126	216	60	300
Digestate	109	199	151	128	30	231
Mineral fert.	-46	23	-97	27	-213	17
Mean	83	147	69	125	-11	196

The growth of herbaceous plants in a monoculture for biomass production in a 3 year period had a positive balance in practically all variants, except for the mineral fertiliser variant – by mowing herbaceous plants once per season for production of burning fuel did not develop a positive balance. Growing galega for biogas production provided the highest profit (on average 196 EUR ha^{-1} per year), it was slightly lower for reed canary grass (on average 147 EUR ha^{-1} per year).

After analysing the results of our study, we can discuss general tendencies providing evidence for the fact that the use of mineral fertilisers, which ensure bigger growth of yields, not always is economically justified. Furthermore, the use of other fertilisers, in our case it was wood-ash, which does not ensure a noticeable growth in dry matter yield, turned out to be economically justified for fertilisation of seed sowings, as the plants need to be provided with different food elements (K, P, Ca, Mg, microelements), unlike it is with biomass production.

CONCLUSIONS

The combined growing of trees and grasses on the same area, give possibility to save costs and earn an incomes in first years, which cover starting expenses.

Reed canary grass, festulolium, and galega could be successfully grown for biomass and seed production between trees rows in the agroforestry system in Latvia. The use of different bio-energy and municipal waste products as fertilisers in general provided higher biomass and seed yields.

The growth of herbaceous plants for seed production together with hybrid aspen in agroforestry system during a 5 year period has a positive balance with all types of fertilisers. Festulolium and galega the best cash flow results shows with sewage sludge fertilisation, reed canary grass with ash fertilisation.

The growth of herbaceous plants in a monoculture for biomass production in a 3 year period had a positive balance for all types of organic fertilisations at both cutting frequencies. Positive balance by applying mineral fertiliser was achieved only at two – cutting regime.

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Analysis of physical and mechanical properties and of gross calorific value of Jatropha curcas seeds and waste from pressing process

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Abstract. The research was performed with an aim to investigate physical and mechanical properties and a gross calorific value of *Jatropha curcas* seeds and particular products (waste) of a pressing process. Sizes of seeds, an energy which is necessary for pressing an oil and a setting of the gross calorific value were tested parameters. Tests were performed at *Jatropha Curcas* seeds of a brown colour (that means gnaw). The pressing process waste amounts up to 80%. The proportion of the kernel mass to the coat mass is 1:0.62. From the research results it follows that the coat mass is 37.60%. The seed coat belongs among interesting material owing to the gross calorific value. For pressing the whole seeds it is necessary of about 30% higher energy than for pressing the kernels of *Jatropha curcas*.

Keywords: coat of seed, energy, kernel, pressing, seed, oil – cakes.

INTRODUCTION

In the long-term run of a sustainable development it is very important to use the energy resources in the most efficient way (Gürdil et al., 2009). Of course also the use of financial ‘resources’ should be optimized in order to reduce the impacts on human health and the environment as much as possible, while the created abundance is becoming more easily available to all parts of the world’s population (Malaťák & Passian, 2011).

In recent years biofuels have obtained a considerable interest, due to the implementation of ruling and gradual replacement of fossil fuels. World research is focused mainly on searching of new and effective sources of biofuels. From the ecological point of view vegetable oil-based biofuels are in many aspects better than fossil fuels, such as in the agricultural machinery area (Pexa et. al., 2013). Potential place to obtain these biofuels is primarily in tropical and subtropical areas where facilities for the harvest a few times per year and yield maximization are.

A sustainability in the energy consumption area is inextricably linked with the search of new alternatives. It is one of the options that is currently preferred by the ‘green energy’, ‘renewable energy sources’ and others. The reason is the limited amount of fossil fuels. Another problem is the use of petroleum derivatives in the production area of polymeric materials. The availability of petroleum is limited due to the dynamical increase of energy consumption (Ružbarský et al., 2013).

One of production steps at gaining the oil is a pressing process (Kabutey et al., 2012). Wastes come into being from this process. These wastes are used as feed, fertilizer prospectively as fuel.

According to the requirements for biofuels and yield production tropical plant berries from the countries in the tropical zone are particularly suitable. In the tropical belt countries there are several dozens of prospective oleiferous plants as oil palm, coconut, cotton, soya, Jatropha curcas and others (Herák, et al., 2013a; Herák, et al., 2013b; Kabutey, et al., 2011).

A contemporary scientific literature pays attention namely to one of prospective produces which is a produce of the tropical and subtropical zones *Jatropa curcas*. In terms of analysis Jatropha curcas is one of the prospective crop in the area of tropical and subtropical belt (Petrů, et al., 2012; Herák, et al., 2013a;). Seeds of the plant Jathropa Curcas contain a high percentage of the oil which is wildly used – it is used e.g. at the production of the biofuels (Kabutey, et al., 2013; Samsuri & Zoveidaviapoor, 2014).

In the industrial production of the oil whole seeds are pressed, however there are processes in which only kernels are pressed. Due to this there is a need to determine the possible utility of the other seed subcomponents. Tests were performed at seeds of a brown colour (that means gnaw). The aim of research is an analysis of *Jatropa curcas* seed from the utilization point of view of the pressing process waste (a cake). Owing to the nature of cake it is not possible to use them as feed. Another source of the waste is a seed peel which comes into being during the pressing process of higher quality oil that means determined for the pharmacy (Herák, et al., 2013c; Ružbarský et al., 2013).

The research was performed with an aim to investigate physical and mechanical properties and a gross calorific value of *Jatropha curcas* seeds and particular products (waste) of a pressing process. Sizes of seeds, an energy which is necessary for pressing an oil and a setting of the gross calorific value were tested parameters.

MATERIALS AND METHODS

Tests were performed at seeds of a brown colour (that means gnaw) made in Indonesia. A humidity of tested seeds was 23%.

At first an analysis of tested seeds (200 pieces) was performed. A size and a mass of particular seeds were set. Further, masses of particular parts of the seed were set. The seeds mass was measured in a following way: seeds were measured before dividing the episperm (the kernel and the episperm together), subsequently the episperm and the kernel were divided and the kernel was weighed (alone).

The mass of the seeds was reviewed on analytic scales with the accuracy of 0.1 mg. The seeds sizes were measured by means of a digital sliding gauge Mitutoyo.

Gross calorific value evaluation of *Jatropha curcas* was performed with the brown coloured seeds that are overripe (Fig. 1). In the measurements there were used the samples of seeds that were crushed.

The gross calorific values were measured for seed coat, seed kernel, whole seed and cake (kernel with seed coat) (Figs 1 and 2). In the Fig. 3 there is a seed cut in which a portion of particular parts is visible.

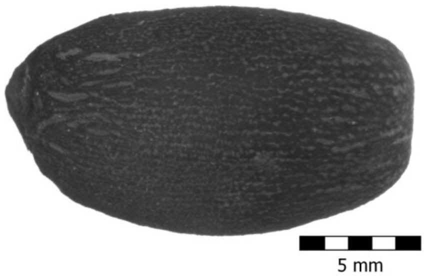


Figure 1. *Jatropha curcas* seed with coat.

Figure 2. *Jatropha curcas* seed kernel.

Individual parts of the seed were separated mechanically by hand and with using a special knife. An emphasis was placed on a minimal contamination of the parts.

A pressing was in progress at whole seeds and at kernels alone (Fig. 4). The pressing was in progress on the machine ZDM5t (500 kN) with a software TIRAtest (Fig. 5). A deformation speed was $10 \text{ mm} \cdot \text{min}^{-1}$. The pressing equipment was of a cylindrical shape (60 mm). A dump was till the height 80 mm.

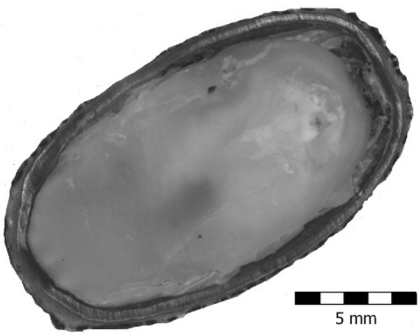


Figure 3. Cut through *Jatropha curcas* seed with coat.

Figure 4. Preparation of pressing.

The basic instrument to evaluate the gross calorific value of each variant of the experiment was calorimeter PARR 6200 Calorimeter (Fig. 6) and digital scales for accurate laboratory weighing. An oxygen bottle was used for tests. Experiments were performed in accordance with the standard CSN EN 14 918 (2010).

Individual prepared tested variants of experiments were mechanically crushed. To evaluate the gross calorific value for each variants of the experiment the material was prepared and weighed at intervals of 1 to 3 g. The seed was inserted into the test container where the wick was placed (the wick is to ignite the seed). Then the container was closed and there was created an air overpressure which is necessary for a combustion process. The second container was filled with two litres of distilled water, which is used for cooling. The container with the spacemen was placed into the container with distilled water and subsequently it was placed into the test area of calorimeter. The container shell (located test seed) is measured by sensors and another sensor measures the water temperature depending on time.

Figure 5. Pressing equipment and evaluation machine.

Figure 6. Testing instrument – PARR 6200 Calorimeter.

RESULTS AND DISCUSSION

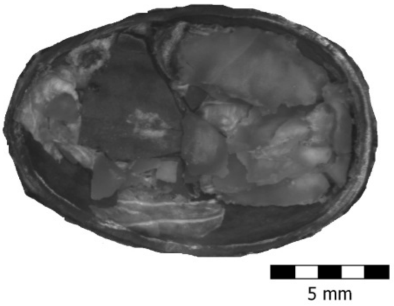
When testing the seeds size following values were determined: the seed thickness 11.25 ± 0.43 mm, the seed length 18.27 ± 0.77 mm and the seed height 8.94 ± 0.50 mm. An average seed mass (calculated from the masses of 200 seeds) amounted 0.6476 ± 0.1117 g at the proportion of the kernel mass to the coat mass 1:0.62. The kernel mass was 0.4041 ± 0.0909 g. From the research results it follows that the coat mass is 37.60%.

Sirisomboon et al. (2007) ascertained different results. They determined the proportion of seeds kernel to 52% and seeds coat to 48%. At analysing 200 pieces of seeds imported from Indonesia 8% of bad seeds was ascertained. Fig. 7 shows the cut through the seed where the damage of the seed kernel is visible.

Graphical exemplification of the seed sizes of *Jatropha curcas* subcomponents was prepared by a program Statistica with method of least squares (MLS) as can be seen in Figs 8, 9 and 10. The Tukey's HSD test was used for the statistical comparison of mean values.

The difference among the tested series is clear in the comparing of the mean data set values. In the light of statistic there is not homogeneity among the tested series.

It is clear from the results that the research results cannot be generalized on one average seed. Huge differences are among the seeds.



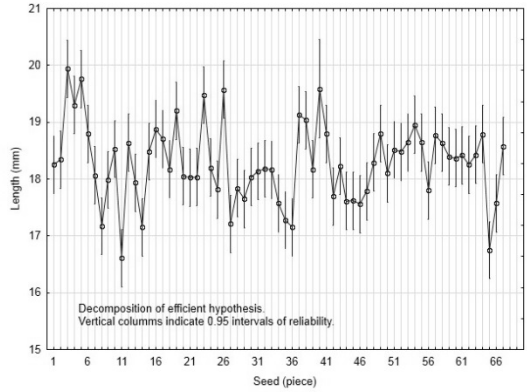
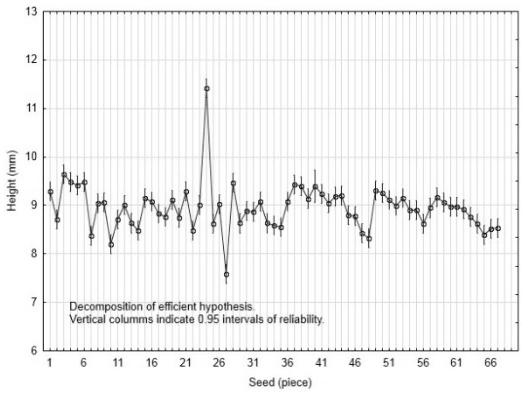


Figure 7. Cut through mouldy *Jatropha curcas* seed.

Figure 8. Length of *Jatropha curcas* seed.



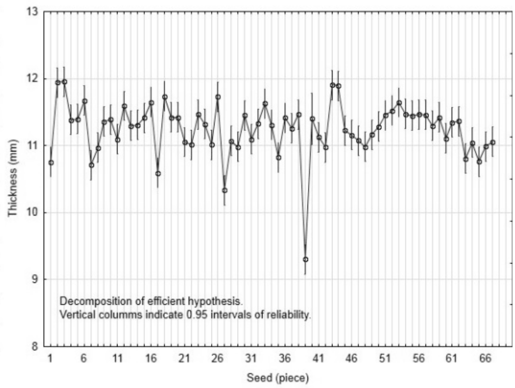


Figure 9. Height of *Jatropha curcas* seed.

Figure 10. Thickness of *Jatropha curcas* seed.

Pressing was performed for getting oil – cakes from the seed and the kernel of *Jatropha curcas*. The measurement results evaluation was in progress according to the methodology of Herák (Herák, et al., 2013a). The course of the pressing process is visible in Fig. 11. The energy for the pressing amounted 439,450 J at the seeds and 307,507 J at kernels alone at the maximum loading force 55,000 N. The pressing process waste (the oil – cakes) are visible in Fig. 12.

Graphical exemplification of the gross calorific value results of *Jatropha curcas* subcomponents was prepared by bar chart with error bars Fig. 13. The difference among the tested series is clear in the comparing of the mean data set of gross calorific value and inconsumable residues.

The gross calorific value of testing variants exceeded the gross calorific value of wood (Ružbarský et al., 2013). Solid fuels made from woody biomass reach following gross calorific values: forest wood chips 18.74 MJ kg^{-1}, polar pellets 18.2 MJ kg^{-1}, energy sorrel spruce pellets 16.54 MJ kg^{-1}, lucerne pellets 16.61 MJ kg^{-1}, knotweed pellets 17.62 MJ kg^{-1} and oats grain 17.17 MJ.kg^{-1} (Malaťák & Passian, 2011).

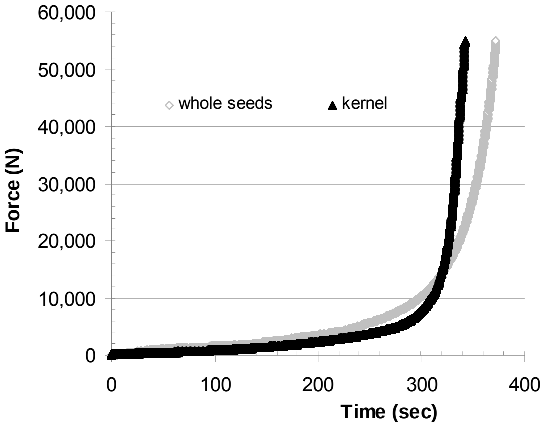


Figure 11. Pressing course.

Figure 12. Oil – cakes from pressing process of whole seeds.

Tested materials from *Jatropha curcas* seeds reach good results. Gross calorific value results of tests of orientation (compressed oxygen was used at the tests) can be used as a starting point for next experiments.

The gross calorific value of the oil – cakes of *Jatropha curcas* is of 31% on average lower than of the seeds. It follows from the results that it is effective using of the waste.

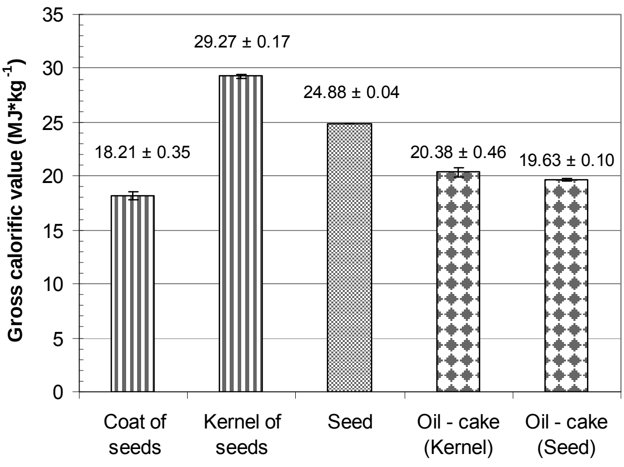


Figure 13. Gross calorific value of particular *Jatropha curcas* products.

CONCLUSIONS

In recent years biofuels have obtained considerable interest, due to the implementation of ruling and gradual replacement of fossil fuels. World research is focused mainly on searching of new and effective sources of biofuels. Potential place to obtain these biofuels is primarily in tropical and subtropical areas where are facilities for the harvest a few times per year and yield maximization. However in these areas there is problematic infrastructure and availability of efficient technologies very often event.

In this paper *Jatropha curcas* seed is analysed from the view of the size and mass of the seed, the influence on the pressing process and the gross calorific value of the subcomponents. These conclusions can be determined:

- The gross calorific value of the oil – cakes of *Jatropha curcas* is of 31% lower than at seeds.
- The pressing process waste (oil – cakes) amounts up to 80%.
- Sizes and a mass of the seed – It is clear from the results that the research results cannot be generalized on one average seed. Huge differences are among the seeds.
- The proportion of the kernel mass to the coat mass is 1:0.62. From the research results it follows that the coat mass is 37.60%. The seed coat belongs among interesting material owing to the gross calorific value comparable with the wood.
- For pressing the whole seeds it is necessary of about 30% higher energy than for pressing the kernels of *Jatropha curcas*.

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Experimental pilot device for thermal analysis of biomass co-firing

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Abstract. The share of biomass in the transformation sector of Latvia accounts for only 15%, at the same time natural gas share in transformation sector is about 80%. Nonetheless, an ongoing natural gas price growth stimulates its full replacement with biomass. The goal of the research was to construct an experimental pilot device, where could be possible to combust biomass with gaseous fossil fuel. The pilot device was equipped with the following measurement instruments: thermocouples for local temperature measurements and gas analyzer for measurements of flue gas composition, temperature, and combustion efficiency.

Key words: wood product, combustion, gaseous fuel, pilot device.

INTRODUCTION

European Commission and Council Directive 2009/28/EC was approved in year 2009 in order to promote use of renewable energy resources (RES). One of the main aims of the Directive is to achieve 20% of the total European member state energy consumption to be produced from renewable energy sources in 2020. In 2010 this figure accounted for only 10% (EUROSTAT, 2012). Comparing the existing situation with the data from year 1990 it can be concluded that the share of RES in total energy consumption has increased by 143.4%, or in average – by 4.5% per year (EEA, 2012). Despite such a rapid growth additional measures are necessary to be taken in order to provide implementation of the Directive.

Increasing the use of biomass can provide growth of renewable energy share, because it is a cheap and easily available fuel, which requires minimum processing and has a relatively simple combustion technology (Williams et al., 2012).

In comparison to fossil fuels biomass has a number of benefits that could stimulate its use. For example, reduction of greenhouse gas (GHG) emissions and reduction of energy dependence (Beloborodko et al., 2013).

Wood is the most common renewable energy resource in Latvia. Households consume more than 50% of wood fuel (Fig. 1). Wood fuel consumption for heat and electricity production (transformation sector) equals to 15% in average ('LR Central statistical bureau,' 2013).

In the transformation sector natural gas is mainly used for heat and electricity production. The share of natural gas in the transformation sector was 80% in 2011, while the share of wood fuel was 15%. Such a low level of wood fuel use for energy production can be explained by the differences in biomass structure, elemental composition, moisture content, and calorific value of various types of biomass, which affect the efficiency (Arena et al., 2010).

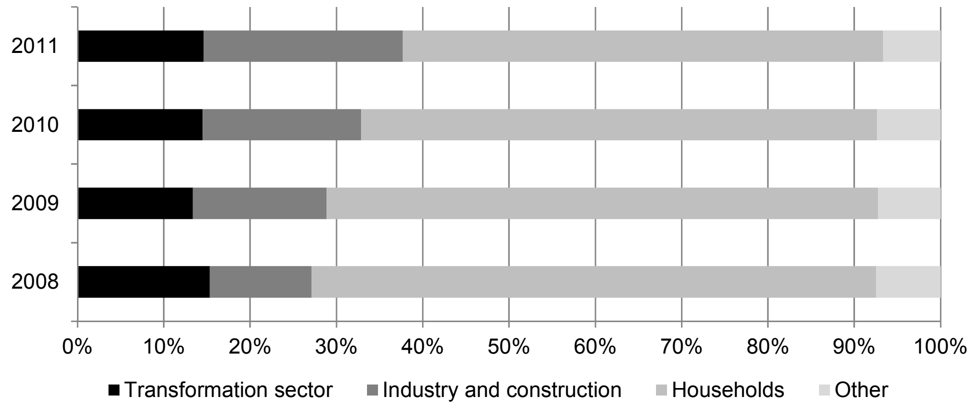

Figure 1. Wood fuel consumption in sectors in Latvia (LR Central statistical bureau).

Determination of biomass composition is an important step to be taken before its combustion, because the composition of the fuel defines combustion characteristics, the quality, potentially used technologies, and emissions that are formed during fuel combustion (Vassilev et al., 2010). The chemical composition and physical properties of biomass depend on several factors, which can be divided into three groups:

1. type of biomass/product;
2. growing conditions, including factors such as day light, geographical location, climate, soil type, and use of fertilizers and pesticides;
3. biomass harvesting and processing (Cuiping et al., 2004; Vassilev et al., 2010; Villeneuve et al., 2012; Williams et al., 2012).

Natural moisture of wood is one of the most important factors that limit use of wood in the transformation sector (Beloborodko et al., 2012). Moisture reduces the combustible substances in the fuel and affects combustion process: hinders fuel ignition, prolongs drying time, reduces fuel combustion heat, and reduces efficiency (Demirbaş, 2001). Wood fuel moisture content affects the wood biomass combustion temperature, increases CO emissions, thus reducing CO_2 emissions (Bhattacharya et al., 2002; Bignal et al., 2008). However, at the same time completely dry wood combustion does not provide maximum efficiency. It has been shown (Yuntenwi et al., 2008) that a small moisture content must be present in biomass in order to reduce emissions and increase combustion efficiency.

Combustion of biomass involves a number of complex physical and chemical processes: heating, moisture evaporation, pyrolysis and gasification with formation of volatile compounds, ignition and combustion of these compounds, and the last stage – formation of charcoal and gas products (Fig. 2) (Nussbaumer, 2003; Obernberger & Thek, 2004; Van Loo & Koppejan, 2007; Shen et al., 2009; Sakalauskas et al., 2011).

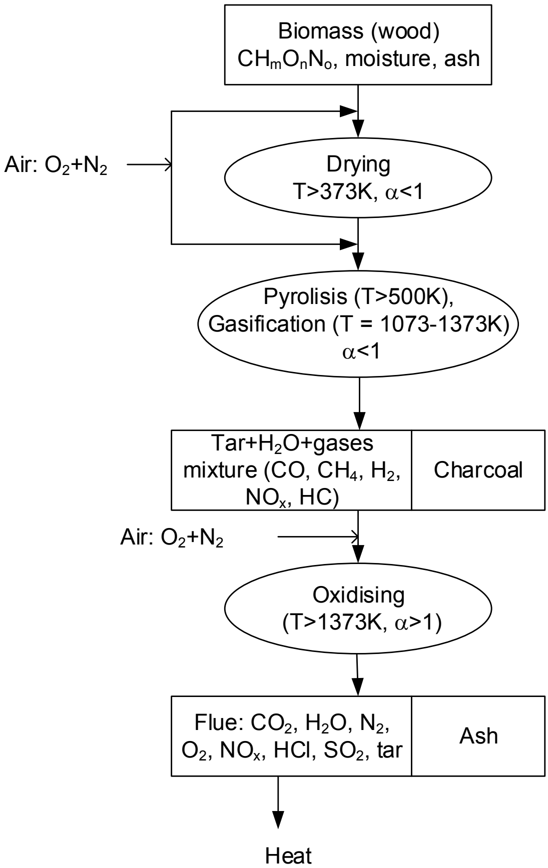

Figure 2. Biomass combustion stages (Obernberger & Thek, 2004).

The main environmental objective of fuel combustion is to ensure efficient fuel combustion with the least greenhouse gas emissions produced. There is a variety of options (Van Loo & Koppejan, 2007) to provide reduction of emissions and more efficient energy production during wood biomass combustion. These options are related to the fuel (wood biomass types, moisture content), combustion equipment (design, fuel and air supply) and combustion conditions (combustion temperature, residence time). Co-firing of biomass with gaseous fossil fuels will be investigated in this research.

Co-firing is a combustion process when two or more fuels are combusted in one technological device. In general, renewable energy sources (biomass) are combusted with fossil fuels (coal or natural gas). There is a great interest in biomass co-firing with fossil fuels worldwide because the share of RES in total energy consumption can be increased and greenhouse gas emissions can be reduced by replacing fossil fuels with RES (Al-Mansour & Zuwala, 2010; Berndes et al., 2010). The amount and type of greenhouse emissions during co-firing depend on co-fired fuel type and percentage of fossil fuel used. Studies in Europe and the United States have established that burning biomass with fossil fuels has a positive impact both on the environment and the economics of power generation. The emissions of SO_2 and NO_x were reduced in most co-firing tests (depending upon the biomass fuel used). The CO_2 net production was also inherently lower, because biomass is considered CO_2 neutral. In addition, total fuel costs can be reduced in some cases if the biomass processing costs (transportation, grinding, etc.) are lower, on energy basis, than the primary fuel processing costs on an energy basis (Sami et al., 2001).

MATERIALS AND METHODS

The general objective of this study was to develop a stable, effective and controllable process of co-firing a fossil fuel (propane, natural gas) with renewable fuel (wood biomass, straw pellets, lignin), providing control of a burnout of the biomass char and volatiles, as well as control of the flame dynamics, processes of the heat/mass transfer and the formation of polluting emissions by co-firing a fossil fuel with renewable one.

In the framework of the research a specially constructed pilot device with a capacity up to 3 kW was created to co-fire wood biomass with gaseous fossil fuel. The layout of the pilot device is shown in Fig. 3.

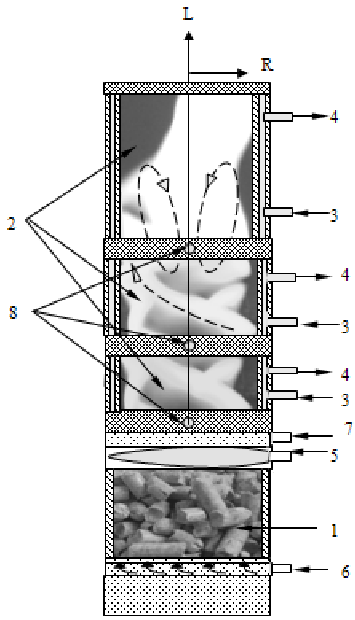

Figure 3. Pilot device: 1 – wood fuel gasifier; 2 – water-cooled combustor; 3 – inlets of cooling water flow; 4 – outlets of cooling water flow; 5 – gas burner; 6 – nozzle of primary air supply; 7 – nozzle of secondary air flow; 8 – diagnostic sections.

The pilot device includes a biomass gasifier (1), water-cooled channel (2) and a premixed propane/air burner (5). Combustion conditions in the system are varied by varying the mass flow rate of the primary air (6) into the bottom part of the combustor and the mass flow rate of secondary tangential air flow (7), introduced from the two tangential air nozzles of inner diameter D = 5 mm. The primary airflow ignites the volatiles and initiates combustion, while the secondary airflow completes the fuel combustion. It is possible to combust only wood biomass without gaseous fuel supply to compare co-firing process with wood fuel self-sustaining combustion. The residual ash is removed from the bottom part of the combustor.

The total length of the experimental pilot device (L) is 1,600 mm. The height of the gasifier is 240 mm and the diameter is 60 mm. The length of the three cooled channel sections is 500 mm (100 mm, 75 mm and 325 mm).

Sections (8) with outlets for diagnostic probes are located between the sections of the water cooling channel. The diagnostic sections were formed to insert measurement instruments. The following measurements should be done in order to study co-firing of wood biomass with gaseous fossil fuel:

- local flame temperature measurements using a Pt/Pt-Rh (10%) thermocouples that are used for temperature measurements up to 1,600−1,700 K.
- temperature and composition of combustion products and combustion efficiency using a gas analyzer TESTO 350−XL. A computer program TESTO 350−M/XL was used for data processing. O_2 %, CO_2 %, CO ppm, NO ppm, NO_2 ppm, NO_x ppm, air excess α % and combustion process efficiency % were measured to control combustion processes;
- velocity measurements (axial and tangential) using Pitot's tube.

Thermocouples, gas analyzer and Pitot's tube placement can be changed depending on the object and purpose of the experiment.

The duration of each experiment should be about 2,400 second or 40 minutes, thus ensuring full combustion of the wood biomass. The data should be registered each second. The on-line calorimetric measurements of the cooling water flow were recorded by using data plate PC-20.

The main characteristics of the pilot device are:

- the mass flow rates of primary and secondary airflows could be varied in a range of 20−90 l min^{-1};
- the rate of stoichiometric propane supply − could be varied in a range from 0.5 to 0.85 l min^{-1};
- the heat rate released from the propane combustion - from 770 to 1,400 J s^{-1};
- the additional energy supply from the propane combustion could be varied from 10% up to 25% of the net amount of the total heat released during the burnout of wood pellets and volatiles;
- the total heat output during the burnout of wood pellets with propane is estimated to be in a range from 4 up to 5 kWh.

Propane/butane/air flame was formed when radial propane and butane flow and tangential air flow are mixed in the channel. The diameter of the channel was 20 mm (Fig. 4). The mixture of propane/butane was supplied to the burner through six radial openings (Ø 0.3 mm) that were placed in the channel wall. Tangential air flow was formed by air supplied through eight tangential openings (Ø 3 mm) at the base of the burner.

The supply of propane/butane and air in the pilot device was controlled by using differential pressure meter calibrated before the beginning of experiments. The differential pressure meters to control air and propane/butane supply in the burner and rotameters to control primary and secondary air supply in the gasifier.

The following formulas were used for the calculation of propane and air consumption using differential pressure meters data in mm (ΔH). The formulas were derived during calibration process of differential pressure meters.

$$\begin{aligned} Q_{prop} &= 0.064\sqrt{\Delta H(mm)} \\ Q_{gaiss\_prop} &= 0.54\sqrt{\Delta H(mm)} \end{aligned}, \text{ l min}^{-1} \tag{1}$$

where: ΔH – water column height (mm) in the corresponding differential pressure meters.

The experiment steps are following. The discrete doses of the wood fuel (up to 320 g) are inserted into the gasificator up to the inlet port of the propane flame flow that is used to initiate the wood fuel gasification and complete the burnout of the volatiles. A height of the wood fuel in the gasificator at the initial stage of the flame formation is about 150 mm. Both the primary and secondary airflows were supplied by a compressor and were injected by tangential inlets. The primary air at a rate 38 l min^{-1} is supplied below the wood fuel layer with the aim to initiate the wood fuel gasification, while the secondary air swirl at a flow rate up to 70 l min^{-1} is supplied above the inlet port of the propane flame flow, providing the gradual mixing of the swirling air flow with the flow of volatiles and gradual burnout of the volatiles. The intensity of swirling flow is described by a dimensionless parameter S. S is a swirling number. It is estimated by using the following formula (Palies et al., 2010):

$$S = \frac{2}{3}\frac{v_{az}}{v_{tg}} \tag{2}$$

where: v_{ax} – axial velocity; v_{tg} – tangential velocity.

To provide the detailed research of the swirl effect on the flow field formation and flame structure, the complex measurements of the flame parameters include the local measurements of the axial and tangential flame velocity compound by using the Pitot tube. The local measurements of the flame temperature at different distances from the outlet of the gasifier were carried out by using the Pt/Pt-Rh (10 %) thermocouples, while the local measurements of the flame composition (O_2, CO, CO_2, NO, NO_x and NO_2) and combustion efficiency were performed using the gas analyzer Testo 350XL.

To control the correctness of O_2, CO_2 and CO measurements the diagram developed by Russian scientist Karjakin was used as the second tool for flue gas analyzing. Karjakin diagram is used to analyze incomplete combustion containing CO. The diagram is a simple right triangle – one leg represents specific for every fuel maximal CO_{max} content, the second leg in the same scale is 21 – maximal O_2 content.

The diagram links O_2 content (line segment AH = MG) with CO_2 content (line segment AM = HG) and CO content in dry flue gases (line segment DE) (Fig. 4).

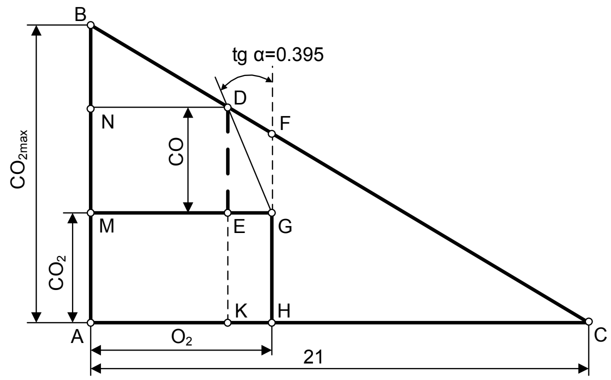

Figure 4. Karjakin diagram.

The diagram allows defining one of three parameters CO_2, O_2 and CO, if two of them are given.

If CO_2 (AM) and O_2 (AH) are given values, then line segment DE is representing CO. The angle DGF must be such to get tg $\alpha = 0.395$.

From triangles NBD and ABC we can obtain:

$$\frac{\mathrm{NB}}{\mathrm{CO}_{2\max}} = \frac{ND}{21} \text{ or } \mathrm{NB} = \frac{\mathrm{ND}\cdot\mathrm{CO}_{2\max}}{21}$$

Line segment ND=AH-EG=O_2-DEtgα=O_2-COtgα. Then

$$\mathrm{NB} = \frac{\mathrm{ND}\cdot\mathrm{CO}_{2\max}}{21} = \frac{(\mathrm{O}_2 - \mathrm{COtg}\alpha)\mathrm{CO}_{2\max}}{21}$$

On the other hand

$$\mathrm{AB} = \mathrm{AM} + \mathrm{MN} + \mathrm{NB} \text{ or } \mathrm{CO}_{2\max} = \mathrm{CO}_2 + \mathrm{CO} + \frac{(\mathrm{O}_2 - \mathrm{COtg}\alpha)\mathrm{CO}_{2\max}}{21}$$

From this equation CO content in dry flue gases

$$\mathrm{CO} = \frac{\mathrm{CO}_{2\max}(21 - \mathrm{O}_2) - 21\mathrm{CO}_2}{21 - \mathrm{CO}_{2\max}\,\mathrm{tg}\alpha}$$

If the given values are O_2 (AH) and CO (DE) then CO_2 (KE) content can be expressed as

$$\mathrm{KE} = \mathrm{CO}_2 = \frac{\mathrm{CO}_{2\max}}{21}(\mathrm{COtg}\alpha + 21 - \mathrm{O}_2) - \mathrm{CO}$$

If the given values are CO_2 (HG) and CO (DE) then O_2 (AH) value can be expressed as

$$\mathrm{AH} = \mathrm{O}_2 = 21\text{-}\left(\frac{21(\mathrm{CO}_2 + \mathrm{CO})}{\mathrm{CO}_{2\max}} - \mathrm{COtg}\alpha\right).$$

RESULTS AND DISCUSSION

The amount of produced heat energy during wood biomass and gaseous fuel co-firing depends on wood fuel amount (grams) and gaseous fuel supply (kJ s^{-1}). For example, when in initial experiments 320 grams of wood pellets where co-fired with propane/butane mixture and supply of propane/butane mixture was in range from 0.7 up to 1.16 kJ s^{-1}, heat energy volume produced from gaseous fuel varied between 22% and 35% of the total heat production.

The flue gas composition was tested using gas analyzer Testo 350XL. The measured CO_2, O_2 and CO were checked with Karjakina diagram (Fig. 5). Such comparison allowed to exclude in further statistical calculations some measurements not corresponding to the mathematical basis of diagram.

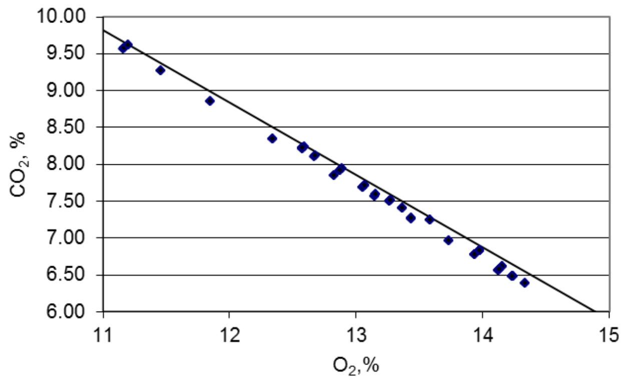

Figure 5. The part of Karjakin diagram. The line is a line segment of the chart hypotenuse.

First experiments of co-firing the wood granules with propane have shown that it can provide more effective burnout of wood granules, increasing a rate of wood pyrolysis, thermal breakdown of volatiles, as well their ignition and burnout, depending on rate of propane/air supply into the swirl burner and air excess ratio inside the gasifier.

The flame dynamic has an important role in gaseous and solid fuel stable combustion process. The correct flame dynamics creation promotes an effective fuel mixing with air flow and complete combustion of volatiles. The air flow in the pilot device was divided into three steams:

- air supply in propane/butane burner;
- primary air supply in the base of the gasifier;
- secondary air supply above the wood biomass layer.

Primary air was supplied below the wood biomass layer to provide initiation of wood biomass gasification. Secondary air was supplied above the wood biomass layer and propane/butane burner to ensure complete combustion of volatiles. The secondary air was supplied tangentially through the two openings with a diameter of 5 mm, thereby ensuring the formation of a swirling flow. Swirling flow is widely used in combustion chambers as a possibility to control the flame size and shape, stability and intensity of combustion.

The secondary air supply was chosen in such a way that the swirling number S is greater than the value of 0.6 to form a recirculation zone. The recirculation zone is described by changes in the velocity distribution and high flow turbulence level, providing an intense flame mixing components at the molecular level with interrelated chemical reaction speed changes in the combustion zone (Tang et al., 2002; Syred, 2006).

The first experiments showed that for given system configuration and the cold air flow conditions at the initial stage of the wood fuel gasification the air swirl can be characterized by relatively high swirl intensity, determining the variations of air swirl number ($S \approx 2/3 v_{tg}/v_{ax}$) in a range of 0.8–1.3. The flow field structure in the primary mixing region indicates the formation of the well pronounced central recirculation zone (Fig. 6). The maximum tangential velocity (v_{tg}) occurs almost at the same radial distance from the axis as the peak of the axial velocity (v_{ax}) – close to the channel walls. The non-zero values of the axial flow velocity recorded near the axis of combustor are determined by the influence of primary air supply at the bottom part of the gasifier and can be increased by increasing the primary air supply, penetrating through the layer of the wood pellets and central recirculation zone. The formation of the flow field structure near the outlet of the secondary air is developing at high level of the turbulence, providing the variations of Reynolds number in a range of 3,000–10,000. The higher turbulence levels, determining mixing of the flame compounds at the initial stage of the flow field formation are fixed in the inner shear layer of the velocity gradients by decreasing the primary air supply into the bottom part of the gasifier below 50 l min^{-1}.

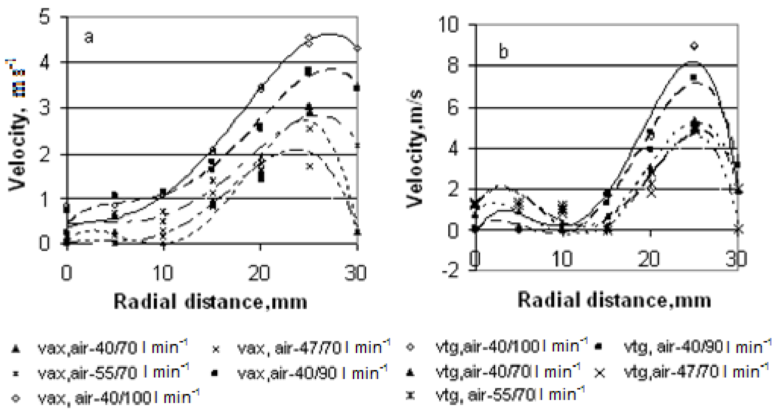

Figure 6. The influence of the rates of primary and secondary air supply on the formation of the flame flow field at the initial stage of the flame formation (L = 30 mm above the secondary air inlet).

The time dependent variations of the flame temperature have shown that during the burnout of the wood fuel the axial flame temperature gradually decreases with correlating decrease of a height of the wood layer inside of the gasifier (Fig. 7, a, b), so gradually increasing a distance between the inlet port of a propane flame flow and upper part of the wood layer and promoting transition to the self-sustaining wood fuel burnout. At this stage of the wood fuel burnout the additional heat supply by the propane flame flow predominately is used to complete the burnout of volatiles, produced during the self-sustaining wood fuel combustion.

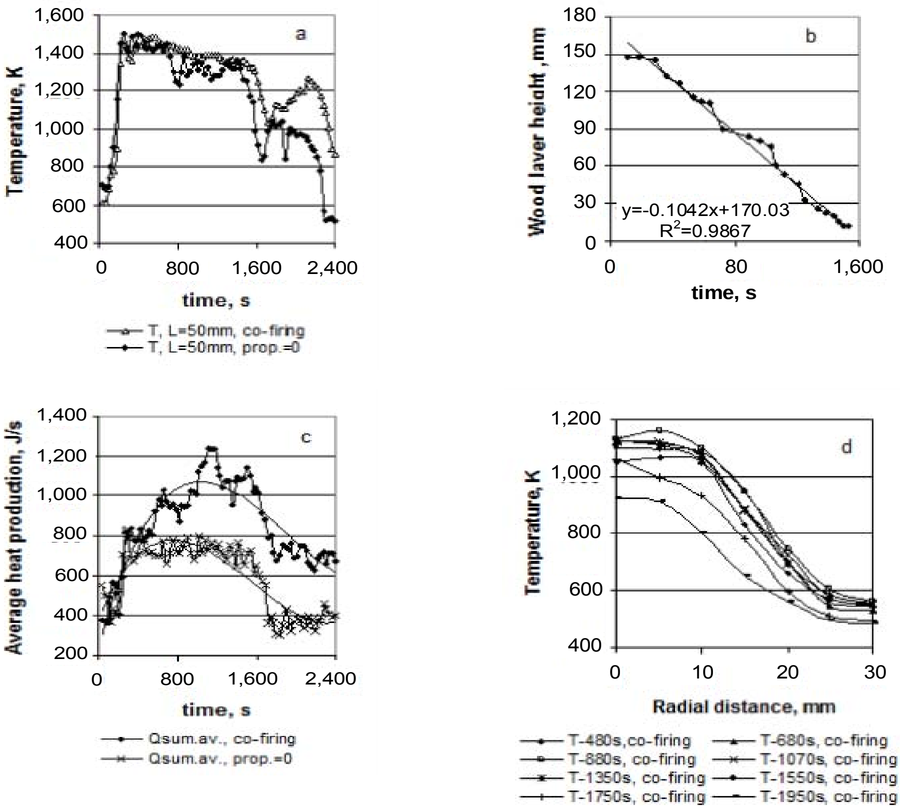

Figure 7. The time dependent variations of the flame temperature (a), height of the wood pellets inside of the gasifier (b), heat production rate (c) and variations of the shape of the flame temperature profiles (d) at different stages of the swirling flame formation and wood fuel burnout, constant rate of propane co-fire (30%) and constant primary and secondary air supply rates (40/70 l min^{-1}) into the combustor.

The swirling flame flow field formation during the burnout of the volatiles with no propane co-fire indicates the formation of the intensive pulsations of the temperature and heat production rate, determined by the turbulent mixing of the flame compounds (Fig. 7, c). As follows from Fig. 7, stabilization of the flame temperature and heat production rates during the burnout of the volatiles can be achieved by co-firing the wood fuel with propane. The time dependent measurements of the heat production rate have shown that the peak value of the heat production rate during the burnout of the volatiles can be achieved at 1,000–1,400 s, when the intensive burnout of the volatiles promotes the radial expansion of the flame reaction zone (Fig. 7, d) with correlating increase of the heat flow to the channel walls. During the end stage of the wood fuel burnout, when the axial flame temperature starts to decrease and flame reaction zone narrows in width (Fig. 7, d) a correlating decrease of the heat production rate downstream of the flame channel flow has been observed (Fig. 7, c).

CONCLUSIONS

There is a relatively high potential for wood fuel use in Latvia. Amount of woodland has doubled during last 100 years and has reached 50.9%. Despite the high potential, the specific weight of wood use in energy transformation sector is not sufficient and makes only 15%. At the same time share of natural gas in the transformation sector is approximately 80%, but its continuously growing price provides conditions for partial natural gas substitution with wood fuel, simultaneously providing conditions for more efficient combustion of wood.

The process of natural gas being replaced by wood fuel in the transformation sector is a complex process that requires a long-term development strategy. One of the possibilities to increase wood fuel share in heat and electricity production is wood co-firing with gaseous fuel. A special pilot device was constructed with an aim to investigate wood fuel and gaseous fossil fuel co-firing process.

A lot of attention has been paid to the air supply during pilot device construction in order to provide sufficient air supply. The secondary air above the wood biomass layer was supplied tangentially providing formation of swirling flow. By changing the swirling number S in the burner outlet and recirculation of combustion products it is possible to provide targeted fluctuation of temperature in the combustion zone, thus varying the speed of chemical reactions in the combustion zone and the composition of combustion product.

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Integrated analysis of biomass co-firing with gaseous fossil fuel. Environmental criteria analysis

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Abstract. The goal of the research described in the paper is to study co-firing of wood pellets and gaseous fossil fuel, evaluating the influence of co-firing on efficiency, produced energy volumes, and emission production. In order to achieve the set aim and objectives a special pilot device for wood pellets and propane/butane co-firing was constructed in an accredited laboratory. The results of the experimental research allow running a complete analysis of co-firing and evaluating the influence of magnetic field on efficiency, produced heat energy volumes, and emission production. The research has a high practical significance and is aimed to increase the level of wood biomass use for energy production as well as to ensure its effective application.

Key words: combined combustion, emissions, propane/butane, wood pellets.

INTRODUCTION

There is a great interest in biomass and fossil fuel co-firing among energy producers (Van Loo & Koppejan, 2007). Co-firing or combined combustion process is a process, where two or more fuels are combusted simultaneously. Usually a renewable energy source, for example biomass, is combusted together with a fossil fuel, for example, coal or natural gas. An essential advantage of wood and fossil fuel co-firing process is reduction of greenhouse gas emissions during combustion process (Al-Mansour & Zuwala, 2010; Berndes et al., 2010). Global warming could be limited by replacing greenhouse fossil fuels (up to 70%) with CO_2–neutral renewable energy sources. Another important factor is a possibility to provide a stable and controllable heat energy production by combusting wood fuel with different composition, structure, and moisture content. Fossil fuel co-firing with wet wood fuel (moisture content – 60%) provides faster heating and thermal decomposition (Arena et al., 2010).

Wood and coal co-firing process is the most common type of co-firing. However, this co-firing process has a number of technical problems: grinding and fuel feeding problems and increased amount of slag production. The share of coal in the transformation sector of Latvia is not as significant as the share of natural gas (higher than 80%), so this study is proposed to investigate co-firing of wood biomass and gaseous fossil fuel with an aim to analyze formation of emissions, combustion efficiency, and heat production.

From previous researches (Barmina et al., 2009; Zaķe et al., 2009; Suzdalenko et al., 2012) it was concluded that gas and wood fuel co-firing promotes enhanced wood fuel gasification at the primary stage of swirling flame formation, while the propane/butane injection into the flame reaction zone results in enhanced burnout of the volatiles.

MATERIALS AND METHODS

Co-firing of wood pellets with various moisture content and propane/butane mixture was performed in the framework of the research experiments. All experiments were carried out at the Heat and Mass Transfer laboratory of Institute of Physics of the University of Latvia, where a special pilot device had been constructed for this purpose. The layout of the pilot device is shown in Fig. 1.

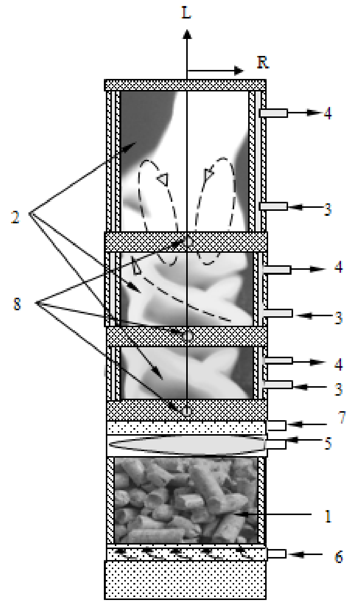


Figure 1. Pilot device: 1 – wood fuel gasifier; 2 – water-cooled combustor; 3 – inlets of cooling water flow; 4 – outlets of cooling water flow; 5 – gas burner; 6 – nozzle of primary air supply; 7 – nozzle of secondary air flow; 8 – diagnostic sections.

The main parts of the device are wood fuel gasifier (1), propane/butane/air burner (5), and cooled channel sections (2), where volatile matters are produced and ignition and combustion occur. In order to ensure gasification and full combustion of volatile matters the air is supplied through two tangential inlets at the bottom of the gasifier (6) and at its upper part (7) above the wood biomass layer. Sections with outlets for diagnostic probes are located between the sections of the water cooling channel. The probes are meant for sampling combustion zone temperature, gas composition, and making axial and tangential velocity measurements. Propane/butane/air flame is formed when radial propane and butane flow and tangential air flow are mixed in the channel.

During the experiments wood pellets were combusted with and without propane/butane mixture. Wood pellets moisture content varied from 8% to 25%. A moderate volume of wood pellets was used for combustion in the experiments: in co-firing experiments it was 500 grams of pellets. Propane/butane mixture was supplied with the air. Calorific value of propane/butane mixture was equal to 108.46 MJ m^{-3}. During the experiment supply propane/butane mixture varied from 0 to 1.55 kJ sec^{-1}.

Primary air supply in the experiments was equal to 47 l min^{-1}. This volume was meant for induction of wood pellet gasification. Secondary air supply was equal to 69 l min^{-1}. The secondary air was supplied in order to provide full combustion of volatiles. Primary air supply provided initiation of wood pellet gasification, while secondary air supply provided formation of swirling flow, which significantly affected the volatile matters mixing with air, as well as shape, size, and stability of the flame and combustion (Palies et al., 2010).

A set of flame parameter measurements was performed during the experiments: local flame temperature ($T = f(t)$) measurements, measurements of the temperature and composition (O_2, CO_2, CO, NO_x), combustion efficiency, and local measurements of radial distribution of axial and tangential flame velocity at different stages of the combustion process. Also, measurements of the produced heat were made to analyze the co-firing process.

Thermocouples, gas analyzer probe, and Pitot's tube were used in order to obtain valid data about the processes occuring in the combustion chamber. The first thermocouple was placed at 157 mm above the propane/butane burner, the second – at 187 mm above the propane/butane burner, and gas analyzer was placed at 386 mm above the burner.

Thermocouples were placed in the center of the channel (R = 0), while the gas analyzer probe was placed according to the objective of each experiment: either in the center of the channel (R = 0) in case of making kinetic measurements of the flame composition, or was being moved radially in the channel when making measurements of the flame composition and radial distribution of velocity in the steady combustion process. Measurements of the flame composition and radial distribution of velocity were made moving the probes with an interval of 30 seconds in the direction from the center of the flame to the channel wall and backwards. Diameter of the channel, where combustion process is developed, was 60 mm.

Length of each of the experiment was 2,400 second or 40 minutes, which provided full combustion of the wood pellets. In all of the experiments propane and butane were combusted first, but wood pellets were added at the 60^{th} second of the experiment.

RESULTS AND DISCUSSION

Wood pellets with different moisture content (W = 8%, 15%, 20%, 25%) were co-fired first with propane/butane and then without any gas supply. Moisture content in the fuel has a negative impact on combustion process: it creates difficulties for fuel ignition, prolongs drying, and reduces fuel heating value and combustion efficiency (Demirbaş, 2001; Vassilev et al., 2010).

Fig. 2 shows the influence of moisture content on wood pellet combustion temperature during self-sustaining combustion of wood pellets.

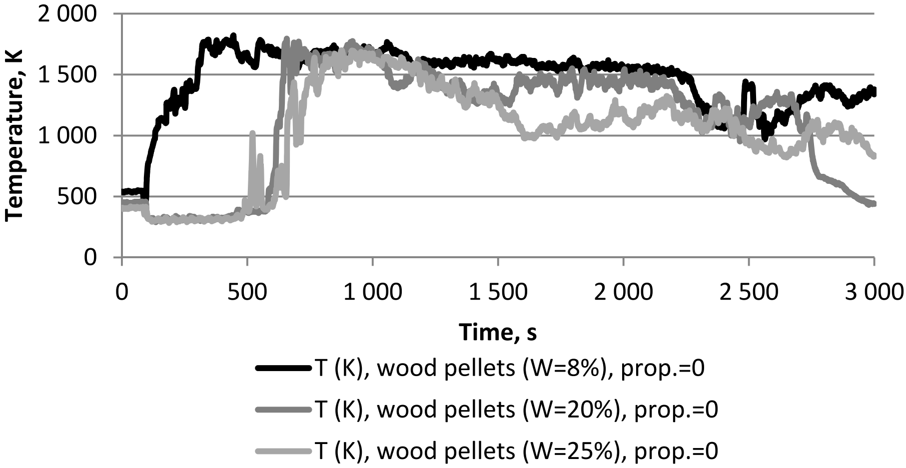


Figure 2. Influence of wood pellets moisture content on the temperature.

The process of wood pellet combustion starts with wood pellet endothermic heating, drying, and thermal decomposition processes. As shown in Fig. 2 wood biomass essentially depends on content of moisture in wood at the beginning of thermal decomposition stage. Faster wood pellets drying and inflammation of volatile compounds was noticed during combustion of wood pellets with moisture content W = 8%, which influenced reaching maximum temperature of combustion zone – 1,821 K. Temperature at the beginning of thermal decomposition process decreases (after the 100th second), when wood pellet moisture content is increased, due to domination of endothermic processes of wood heating and drying, thus limiting development of volatile compounds and inflammation. The influence of moisture content at maximum temperature during combustion process is shown in Table 1.

Table 1. Wood pellet moisture content influence on the average temperature

Moisture content of wood pellets	W = 8%	W = 20%	W = 25%
Average temperature	1,463 K	1,125 K	1,029 K
Maximum temperature	1,821 K	1,794 K	1,700 K
Time	445 s	657 s	875 s

The highest average temperature of 1,463 K (Table 1) was detected combusting wood pellets with the smallest moisture content (W = 8%) and maximum temperature was reached at the 445th second. Average temperature for pellets with 25% moisture content was by 30% smaller comparing with the same of dry pellets, and later start of the volatile ignition was observed.

About 25–30 g of charred pellets were left over in the gasifier at the final stage of combustion during moist wood pellet combustion experiment. These charred pellets continued glowing with slight increase of flame temperature at the end of the experiment. Self-sustainable combustion of wood pellets is characterized with unstable combustion process with pronounced temperature fluctuations (Fig. 2) and average temperature about 1,747 K.

It is possible to improve wet wood pellet combustion process using co-firing with propane/butane mixture.

Propane/butane supply in case of moist wood pellet use provided faster development of volatile compounds (Fig. 3): maximum temperature has been reached already at the 175th second after the beginning of wood pellet gasification process. Faster volatile compound combustion was also observed during co-firing process.

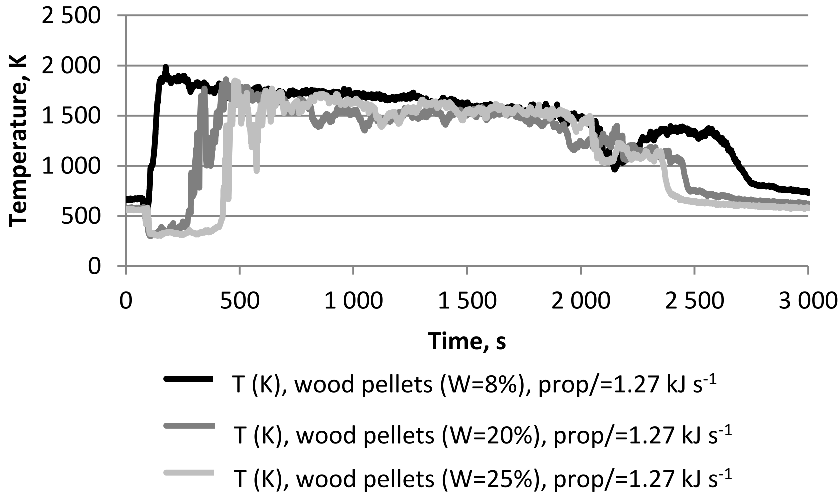


Figure 3. The influence of propane/butane supply on temperature during co-firing process.

After evaluating the results of the experimental measuring the following empirical equation has been obtained. The equation shows influence of wood pellet moisture content and propane/butane supply on average temperature in the combustion zone:

$$T_{avg.} = 1715.23 - 27.15W + 117.83q \qquad (1)$$

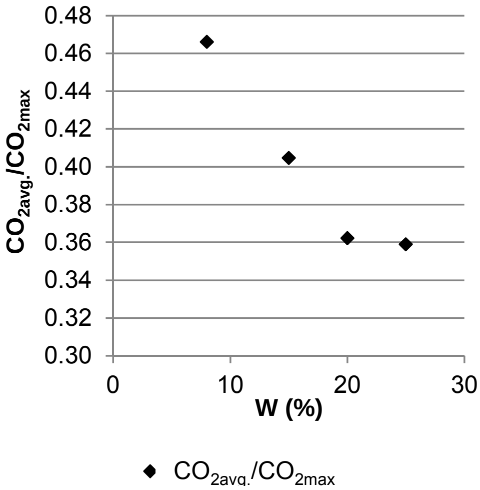
where: W – moisture content of wood pellets, %; q – supply of propane/butane, kJ s^{-1}.

The moisture content of wood pellets influences produced heat energy, which decreases by increasing moisture content of wood pellets. If propane/butane was supplied to the base of combustion zone, the total produced heat increased. The influence of moisture content of wood pellets and propane/butane supply is described with the following equation:

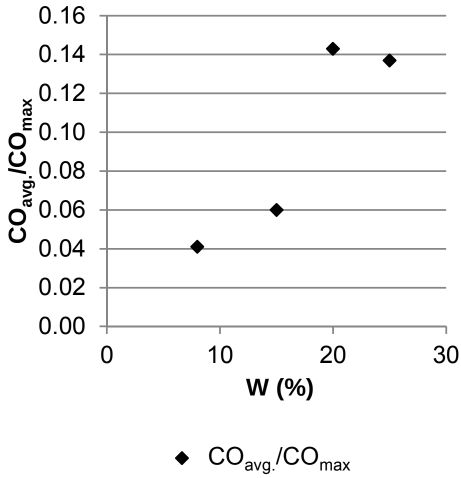
$$Q_{avg.} = 2.42 - 0.08W + 0.35q \qquad (2)$$

where: W – moisture content of wood pellets, %; q – supply of propane/butane, kJ s^{-1}.

The analyses of combustion process products confirm that the main factor, which influences the formation of emissions and their concentration levels during wood fuel combustion, is moisture content in the wood.



a)



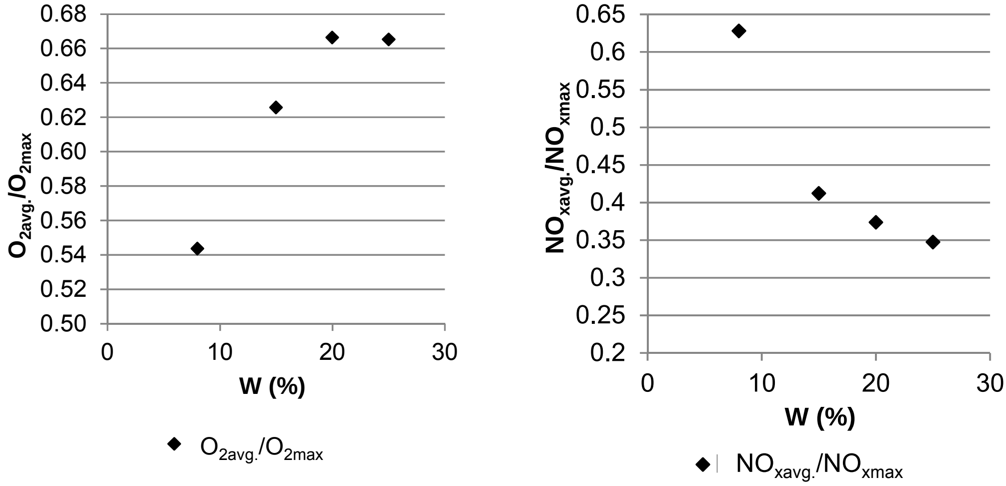
b)

Figure 4. The influence of wood pellets moisture content on relative changes in $CO_{2avg.}/CO_{2max}$ (a) and $CO_{avg.}/CO_{max}$ (b).

Fig. 4 shows the influence of wood pellet moisture content on formation of CO_2 and CO emissions during wood pellet combustion without gaseous fuel supply. The influence of moisture content on CO_2 and CO emissions has been evaluated during the experiment by relating average CO_2 and CO emissions to the maximum value. In case of CO it was the maximum value, which was reached during the experiment, but maximum quantity of CO_2 was calculated depending on the speed of propane/butane supply (kJ sec^{-1}). If the wood pellet moisture content is increased, CO_2 emissions decrease, but CO emission volume increases. These results can be described with the linear correlation.

Fig. 5a shows fluctuations of $O_{2avg.}/O_{2max}$ volume depending on moisture content of wood pellets. In this case the average value of O_2 during the experiment was attributed to 21 (O_{2max}). When the moisture content in wood pellets increases, $O_{2avg.}/O_{2max}$ increases and average O_2 concentration in products increases, too, which confirms that in case of pellet moisture increase, less air should be supplied for total burn-off of the fuel.

NO_x emissions during combustion process develop in accordance to Zeldovich's mechanism, which development is mainly influenced by the temperature at the combustion zone, air supply in the device, and nitrogen content in the biomass (Williams et al., 2012). Increase of moisture content in wood pellets provides changes of wood pellet elementary composition – nitrogen content decreases and oxygen content increases. These factors significantly influenced formation of NO_x emissions in combustion zone: if moisture content of wood biomass was increased, then decrease of NO_x concentration was observed (Fig. 5b).



a) b)

Figure 5. The influence of wood pellet moisture content on relative changes in $O_{2avg.}/O_{2max}$ (a) un $NO_{xavg.}/NO_{xmax}$ (b).

It is important to arrange biomass combustion process not only ensuring limited exhaust of hazardous emissions into the atmosphere, but also providing higher heat production and effectiveness of combustion process. Moisture content of wood pellets influences efficiency of combustion process – during the experiment efficiency decreased when moisture content in wood was increasing (Fig. 6).

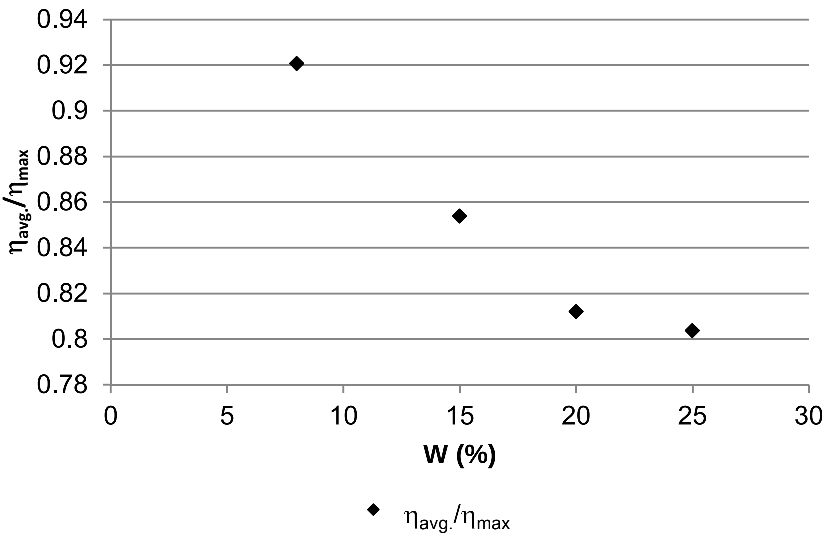


Figure 6. Influence of wood pellet moisture content on relative changes in $\eta_{avg.}/\eta_{max}$.

It is possible to improve combustion process of moist wood pellets by supplying more propane/butane mixture into the wood pellet gasifier. Table 2 compares experimental results for wood pellet self-sustainable combustion and for co-firing process. Propane/butane mixture supply was changed from 0.9 kJ s^{-1} to 1.16 kJ s^{-1}. Wood pellet moisture contents was equal to 20%.

Table 2. The influence of propane/butane supply on combustion products and efficiency

	W = 20%				
	$CO_{2avg.}/CO_{2max}$	$CO_{avg.}/CO_{max}$	$O_{2avg.}/O_{2max}$	$NO_{xvg.}/NO_{xmax}$	$\eta_{avg.}/\eta_{max}$
Prop. = 0 kJ s^{-1}	0.36	0.14	0.67	0.38	0.77
Prop. = 0.9 kJ s^{-1}	0.38	0.10	0.64	0.41	0.80
Prop. = 1.03 kJ s^{-1}	0.39	0.08	0.63	0.42	0.81
Prop. = 1.16 kJ s^{-1}	0.43	0.07	0.60	0.43	0.82

Supply of propane/butane into the combustion camera intensifies wood fuel combustion process, increasing CO_2 concentration, but decreasing CO concentration.

If combusting of wood pellets is performed with supply of propane/butane to the device, the increase of relative $O_{2avg.}/O_{2max}$ volume concentration in products is slightly lower, because supply of propane/butane increases average temperature of combustion zone, providing complete combustion of volatile compounds.

Slight increase of NO_x concentration in products is observed due to supply of propane/butane to the combustion zone. Nevertheless, maximum NO_x concentration in products when propane/butane is supplied to the device does not exceed 70 ppm, which is provided by small nitrogen concentration in wood fuel (0.18%), which, in turn, provides an environmentally cleaner combustion process.

It is possible to increase combustion efficiency for moist wood biomass combustion by supplying propane/butane to the gasifier. During the experiment combustion efficiency was increased with higher supply of propane/butane to the combustion zone.

CONCLUSIONS

The following conclusions were made in the result of co-firing of wood pellets with different moisture content with supply of propane/butane:

- Duration of wood pellet thermal decomposition significantly depends on the moisture content. Moisture in the wood biomass delays formation and ignition of volatiles, as well as their combustion, in the process of which the highest temperature in the combustion zone is reached. Moist wood biomass combustion could be improved by supplying propane/butane, thus intensifying formation and ignition of volatile compounds.
- It was stated as the result of experimental research that supply of propane/butane to the wood pellets layer provides higher amount of produced heat energy. Combustion of wood pellets with 25% moisture content without supply of propane/butane produced 0.87 kWh of heat energy during the experiment. Co-firing this wood with gaseous fuel of 1.27 kJ s^{-1} generated 36% greater amount of heat energy;

- The analysis showed that formation of CO_2 emissions in the process of wood pellet combustion is significantly influenced by the moisture content in the wood pellets: CO_2 emission formation is reduced if moisture content increases, while CO emission volume increases. This proves that using supply of propane/butane to the wood fuel provides intensification of volatile formation, ignition, and combustion, as well as formation of CO_2 emissions, but concentration of CO emission in combustion products is reduced;
- An increase of moisture contents in the wood fuel provides increase of average O_2 concentration in the products, which means that increase of moisture content in the biomass limits combustion of volatiles and air supply has to be reduced in order to provide complete fuel combustion. Combustion of wood pellets with supply of propane/butane to the device provides slightly lower increase of relative $O_{2avg.}/O_{2max}$ volume concentration – by 11% in comparison with wood pellet combustion without supply of propane/butane, since supply of propane/butane increases average temperature in the combustion zone, providing more complete combustion of volatiles;
- An increase of moisture content in wood pellets limited formation of NO_x emissions, which is related to increase of oxygen concentration. At the same time, during wood co-firing with supply of propane/butane a moderate NO_x emission increase which was related to the increase of average temperature;
- Processing the experimental data on combustion efficiency showed that supply of propane/butane and changes of moisture content in the wood pellets influence efficiency of combustion process. It increases when supply of propane/butane in the combustion zone is increased and reduces when wood pellets moisture content is increased.

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Cleaner pellet production – an energy consumption study using statistical analysis

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Abstract. This study investigates and analyses the methodology for introducing cleaner wood pellet production. A statistical model is developed for the energy consumption analysis. Efficiency indicators have been chosen which allow determining the impact on the production process. The developed model can be used in other similar type of industries. This study has processed large empirical data with statistical methods in order to establish the efficiency indicators. The modelled results enable to define the indicators which lead to higher efficiency and hence to the cleaner production.

Key words: Energy efficiency, energy optimization, improvement of the production process, industrial process.

INTRODUCTION

Production of wood pellets in the Baltic countries has been growing (Mola-Yudego et al., 2013) as new large and small scale facilities emerge. Cogeneration plants are added next to the most advanced production sites of wood pellets in order to improve the production efficiency and secure cleaner production (Anderson & Toffolo, 2013; Kohl et al., 2013). The concept of cleaner production comprises the aspects of resources consumption. Reducing the resources consumption is an essential tool for industrial production. Efficiency is the basis for analysing and developing guidelines for continuous improvement in the production process (Song et al., 2011). At pellet production facilities, these resources are biomass, which is the raw material for pellets, and fuel for energy production, electricity, heat, and water. The contribution of this study is to develop a model for efficient use of these resources.

The second section introduces the materials and methods; the 3rd section outlines the modelling study results and includes the discussion. The 4th section concludes the study and makes recommendations for future work.

MATERIALS AND METHODS

Production description

When wood pellets are produced, they have to comply with generally accepted quality standards. Only clean sawdust can be used for production. The sawdust may not contain any impurities, it has to be dry, free of any sand, abrasive particles and chemistry. The produced pellets must be mechanically robust, should not contain any small sawdust particles, and have to be free of any foreign objects.

Damp sawdust is the basic material for the production of wood pellets. After additional processing, cellulose fibre and technological wood chips can also be used for the production. Processing of wood chips takes place at a special cutting device. The system of the cutter consists of a range of electrical machines like chippers, peelers, conveyors, ventilators, hydro devices, etc.

The wood chips that are made of branches and bark can be used as fuel and are combusted for production of flue gases and for energy production in the cogeneration plant. The furnace system in the flue gas production consists of several electrical motors that power the equipment for ensuring operation of the furnace, i.e. heating, cooling, feeding of fuel, ventilators, valves, and hydro machinery. The heat from the cogeneration plant on the other hand is transferred to belt-type dryers. The biggest electricity consumers of belt dryers are ventilators, which suck heated air through sawdust.

Sawdust needs to be dried to obtain the required humidity level for the production of wood pellets. Dried sawdust material is dosed to a hammer mill where the sawdust is crushed. During the milling process, dried sawdust is turned into small particles and dust, a uniform substance is obtained. The milling system consists of several electrical motors that power the equipment to ensure milling of sawdust, i.e. heating, cooling, a dosing device, a ventilator, a worm-type transporter, a mill, and hydro machinery.

In the granulating device, there is a process during which the mix of sawdust is delivered into two pressing rolls and a rotating matrix. The process results in production of hot pellets with a diameter of 8 mm. The following process is cooling and screening, where the pellets become hard and are cleaned of any dust. After this process, the pellets are ready for storage and transportation. The granulating system consists of several electrical motors that power the equipment, i.e. conveyors, suction devices, coolers, worm-type transporters, a vibrant-sieve, dosing devices, a mixer, a central lubricating system, and presses. On Fig. 1 the operational scheme of the pellet production facility with indications to analysed data is shown.

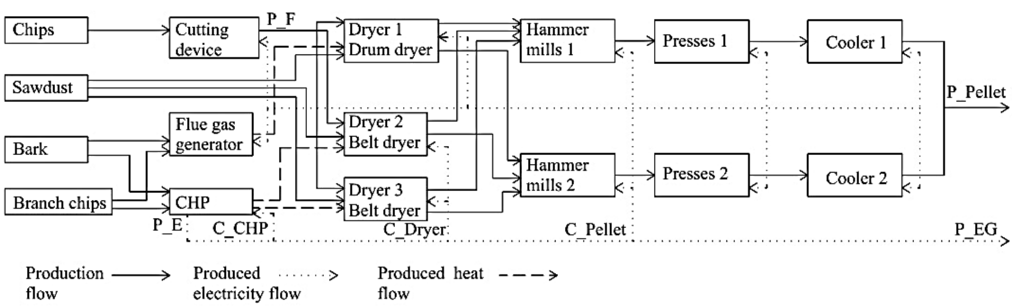

Figure 1. The operational scheme of the pellet production facility with the analysed indicators.

If power consumption at an industrial production facility is reduced, the share of generated electricity available for sale on the electricity market increases. Optimization of the production of the entire facility reduces the electricity bill of the pellet plant and increases the revenues from electricity sales.

This study will provide an analysis of power generation at a cogeneration plant, P_E. The target is to find the factors which have an impact on the power generation and therefore, once these factors have been defined, the next step is to optimize the production accordingly. Table 1 shows the list and explanations of the analysed data.

Table 1. Analysed data

Abbreviations	Explanation	Unit
C_CHP	Cogeneration plant power consumption	kWh
C_Dryer	Power consumption of the belt dryers	kWh
C_Pellet	Power consumption of the pellet production facility, excluding the belt-type dryers	kWh
E1 = C_DP	Power consumption of granulation	kWh
C_Total	Total power consumption	kWh
P_E	Produced electricity	kWh
P_EG	Produced electricity to grid	kWh
P_Pellet	Produced pellets	t
P_F	Sawdust crushed in the cutting device	m^3
C_DP/P_Pellet	Power consumption per produced ton of pellets	kWh t^{-1}
C_CHP/P_E	Power consumption per generated kWh	kWh kWh^{-1}

Analysis and data processing

Authors (Savola et al., 2007; Söderman & Ahtila, 2010) have used the modelling programme MINLP, MILP or simulation software (Mikita et al., 2012; Mobini et al., 2013). In this study, the empiric data was processed by applying statistical methods for data processing, correlation, and regression analysis. By means of a correlation analysis, the mutual link between two values and its strength are determined. The regression analysis is used for identifying the statistical importance of the multi-factor regression model and its coefficients (Blasnik, 1995).

The computer software STATGRAPHICSPlus was used for statistical processing of the data and development of the multi-factor empiric model. A similar model has been developed by other authors (Revina, 2002; Beloborodko et al., 2012).

In order to select the type of the regression equation, the linkage of the parameters by means of performing the correlation analysis is established by a single-factor linear model. The strength of the mutual link between independent and dependent random variables (correlation) can be assessed by means of a correlation coefficient. In case of a single-factor mathematic model, the Pearson's equation (1) is used for its estimation:

$$r = \frac{\sum_{i=1}^{m}(x_1 - x) \cdot (y_1 - y)}{(m-1) \cdot S_x \cdot S_y}, \tag{1}$$

where: x_i and y_i are the independent variables and pairs of their corresponding dependent variables; x and $y$are the arithmetic values of independent and dependent variables; S_x and S_y are the variables of the selection dispersion.

Correlation coefficients were used for evaluating the accuracy of the mathematic models describing the strength of the correlation. It is assumed that a correlation is good if the correlation coefficient is above 0.8. It should be noted that in software for statistic processing of data, the squared correlation coefficient is usually calculated. When the value R^2 is multiplied by 100, the value that characterises the changes of dependent variables is described by the resulting empiric equation. For example, $R^2 = 0.9$ indicates that the relevant regression equation characterises 90% of the changes of the dependent random variables.

Correlation analysis of produced electricity

In this study, the purpose is to analyse the operation of the production facility and find the correlation between produced electricity *P*_E and the following parameters:

- Cogeneration plant power consumption *C*_CHP, kWh;
- Power consumption of the belt dryers *C*_Dryer, kWh;
- Power consumption of the pellet production facility *C*_Pellet, kWh;
- Produced pellets *P*_Pellet, t;
- Crushed sawdust *P*_F, m^3.

RESULTS

Only the graphs where correlation between the values of dependent variables and independent variables can be seen are presented below. The dependence of electricity generation on the auxiliary power consumption of the cogeneration plant *C*_CHP is presented in Fig. 2.

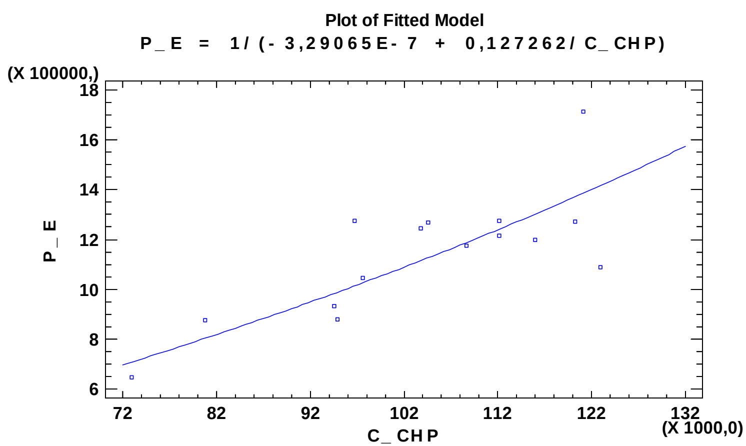

Figure 2. Produced electricity *P*_E depending of the CHP power consumption *C*_CHP.

In Fig. 2, it can be seen that there is a good mutual correlation between both variables. The value of the squared correlation coefficient as determined by the analysis is $R^2 = 0.75$ and the correlation coefficient $R = 0.87$. The relationship between the variables is non-linear and it is defined as follows, (2):

$$P\_E = 1/(-3.29065E\text{-}7 + 0.127262/C\_\mathrm{CHP}), \quad (2)$$

The Eqn (2) explains 75% of the analysed changes in the data and it can be used for approximate calculations. 25% of generated electricity should be explained by the impact of other parameters.

The analysis of the data correlation shows that there is a certain correlation between the produced electricity *P*_E and the power consumption of the pellet production facility *C*_Pellet. The changes of the values are presented in Fig. 3.

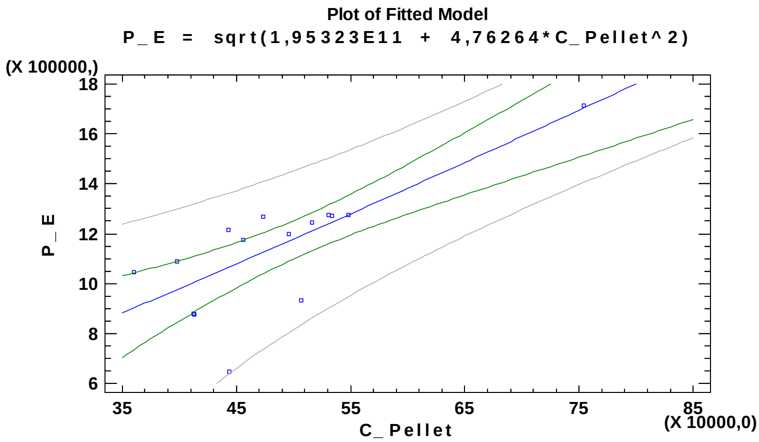

Figure 3. Produced electricity *P*_E depending on the power consumption of the pellet production facility *C*_Pellet.

The mutual correlation of the analysed variables is described by the value of the squared correlation coefficient $R^2 = 0.71$ and the correlation coefficient $R = 0.84$. The relationship between the variables is non-linear and it is defined as follows, (3):

$$P\_E = sqrt(1.95323E11 + 4.76264 \cdot C\_\mathrm{Pellet}^2), \quad (3)$$

The mutual correlation of the variables is slightly lower than the correlation to the CHP electricity consumption. Eqn (3) explains 71% of the changes in the studied data. The impact of other parameters is higher, e.g. 29% of the electricity generation. The review of the correlation of other parameters demonstrates that there is no considerable correlation. Therefore, in further multi-factor regression analysis, the changes in the dependent variable of the produced electricity depend on two factors, i.e. the cogeneration plant power consumption *C*_CHP and the power consumption of the pellet production facility *C*_Pellet, Eqn (4):

$$P\_E = f(C\_\mathrm{CHP};\ C\_\mathrm{Pellet}), \quad (4)$$

The performed correlation analysis of the data makes further regression analysis easier, as the set of factors that needs to be included in the multi-factor regression equation has been established.

Regression analysis of the data of power generation

The regression analysis is aimed at obtaining an empirical equation that would provide a quantitative description of the power generation depending on the indices that characterise the operation of the pellet production facility. These characteristics are statistically important and would serve as the basis for improving and evaluating the energy efficiency of the production facility. The regression analysis defines the accurate quantitative parameters of the change in random variables, i.e. explains the importance of the stochastic link by functional relationships.

The sequence of the regression analysis was as follows:

- the rule of the distribution of the dependent variable, i.e. the produced electricity *P*_E, was verified;
- the regression equation was established by applying the smallest square method;
- statistical analysis of the obtained results was performed.

The results of a regression analysis are correct if the rules for its application are complied with (Beloborodko et al., 2012). The number of rules is high and they cannot always be fully followed in practice. There are several main preconditions behind the application of the regression analysis. The use of the regression analysis of the data is correct if the normal distribution law is applicable to the dependent variable (produced electricity *P*_E). This requirement is not applicable to independent variables. The above means that the analysis starts with establishment of the distribution of dependent variables and the analysis may be continued if this distribution complies with the rule of the normal distribution. The results of verification of the rule of distribution are presented in Fig. 4. Normal distribution within logarithmic coordinates is graphically presented by a line. As can be seen in Fig. 4, the analysed data are placed close to the line in the graph. It means that the distribution is close to the rule of normal distribution and the application of the regression analysis is justified.

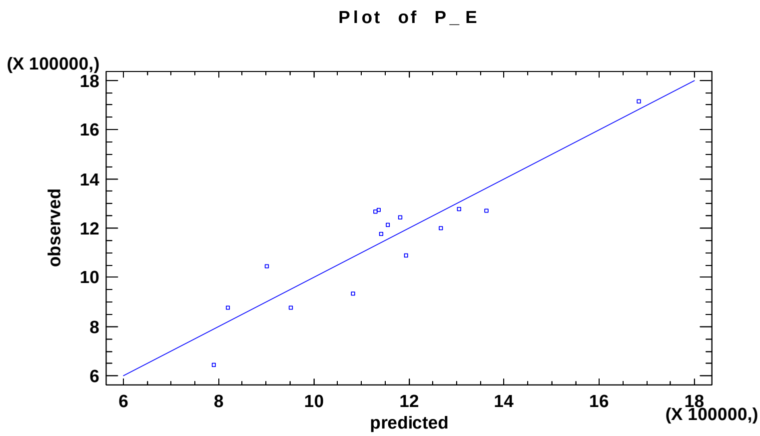

Figure 4. Distribution of the produced electricity *P*_E values.

When empirical models are developed in the form of the regression equation, several issues have to be solved. Whether the model comprises all the independent variables describing the analysed phenomenon and whether the model does not comprise unnecessary and non-essential variables, thus making the model too complicated. The answer to the above questions is provided by evaluation of the statistical importance of the variables contained in the model and the dispersion analysis of the model (Beloborodko et al., 2012).

The regression equation that is used by the author does not contain the effects of double and triple interaction of independent variables and is as follows in Eqn (5) (Beloborodko et al., 2012):

$$y = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + \ldots + b \cdot x = b_0 + \sum_{i-1}^{n} b_1 \cdot x_1, \quad (5)$$

where: y is the dependent variable; b_o is the free member of the regression; $b_i \ldots b_n$ are the regression coefficients and $x_1 \ldots x_n$ are the independent variables.

The regression equation that corresponds to the Eqn (5) and was obtained as the result of statistical processing of the data and contains statistically important independent variables, as in Eqn (6):

$$P\_E = b_0 + b_1 \cdot C\_CHP + b_2 \cdot C\_Pellet \quad (6)$$

The values of the coefficients of the regression equation and their statistical values are presented in Table 2.

Table 2. Coefficients of the regression equation and their values

Coefficients b_i	Values	t statistics	P value
Constant b_0	-5.27157	-2.36019	0.0360
Coefficient b_1	9.39524	4.27046	0.0011
Coefficient b_2	1.42205	4.10665	0.0015

In the data processing, the level of importance P = 0.1 was selected and it corresponds to the probability of credibility 0.90. For the purpose of evaluation of the importance of the coefficients $b_0 \ldots b_n$ of the regression Eqn (6), the t criterion with the Student's distribution with f freedom levels is applied in Eqn (7).

$$f = m - (n + 1), \quad (7)$$

where m is the volume of the data which is the subject of the analysis, n is the number of independent variables in the regression equation.

The level of freedom is defined in Eqn (8):

$$f = m - (n + 1) = 12 - (2 + 1) = 9, \quad (8)$$

The value of the t criterion corresponding to these values as taken from the tables of the Student's distribution is $t_{tab} = 1.9$. As can be seen from Table 2, the relationship (Blasnik, 1995) $> t_{tab}$ is valid in all cases. It means that all the parameters are important and should be maintained in the equation.

The study has resulted in obtaining a regression equation that defines produced electricity depending on the data of the production facility, i.e. the cogeneration plant power consumption C_CHP and the power consumption of the pellet production facility C_Pellet in Eqn (9):

$$P\_E = -5.27157 + 9.39524 \cdot C\_CHP + 1.42205 \cdot C\_Pellet, \qquad (9)$$

The value of R^2 as determined as the result of statistical processing of the data which was established in the empirical model equals 0.83. It means that the established model (8) explains 83% of the change in the analysed data. The remaining 17% refer to independent variables that have not been included in the equation or defined in the study or the effect of their mutual interaction.

Evaluation of adequacy of the regression equation

Evaluation of the adequacy of the equation (9) is performed by means of the dispersion analysis by applying the Fisher's criterion F. For this purpose, the relationship between the dispersion of the dependent variable and the balance dispersion is analysed, Eqn (10):

$$F(f_1 f_2) = \frac{S_y^2(f_1)}{S_{atl}^2(f_2)} \qquad (10)$$

where: $S^2_y(f_1)$ is y dispersion of the dependent variable and $S^2_{atl}(f_2)$ is the balance dispersion.

The balance is defined as the difference between the dependent variable and the value calculated by means of the regression equation $y_i - y_{iapr}$.

The value as determined by means of the dispersion analysis performed by the software is F = 19.16. The obtained value is compared to the table value of the criterion, which is determined by applying the values of the freedom levels, Eqn (11):

$$f_1 = m - 1 = 12 - 1 = 11 \text{ and } f_2 = m - n = 12 - 2 = 10 \qquad (11)$$

The table value of the Fisher's criterion is $F_{tab.} = 2.9$. As can be seen, the relationship $F > F_{tab}$ is valid and it means that the Eqn (9) is adequate and can be used for describing the analysed data within the framework of their change:

- For produced electricity from 0.65 to 1.72 GWh per month;
- For the CHP power consumption C_CHP from 0.07 to 0.12 GWh per month;
- For the power consumption of the pellet production facility C_Pellet from 0.36 to 0.75 GWh per month.

Verification of the rules of correct application of the correlation analysis

When following establishment of the regression equation, it is possible to perform verification of the rules of correct application of the regression analysis based upon a range of other indices. These are autocorrelation, multicollinearity and heteroscedasticity.

By means of application of the Durbin-Watson's (DW) test, in the course of statistical treatment of the data and the data analysis, the DW criterion has been established. Its value equals 2.3 and exceeds the marginal value of 1.4. This means that there is no considerable autocorrelation of the balance and assessments of the values by means of the smallest squared values method in the course of the analysis are not performed.

The verification has been performed by analysing the correlation matrix of the coefficients calculated by means of the regression equation, presented in Table 3.

Table 3. Correlation matrix of the coefficients of the regression equation

Coeff.	Const.	*C*_CHP	*C*_Pellet
Const.	1.0000	-0.7155	-0.3338
*C*_CHP	-0.7155	1.000	-0.4095
*C*_Pellet	-0.3338	-0.4095	1.000

The analysis of the correlation matrix of the coefficients of the regression equation demonstrates that there is no considerable correlation between the coefficients and independent variables. This is attested by the low values of the correlation coefficient in Table 2. The values presented in the Table are below 0.5 or close to this level, and this means that the evaluation of the coefficients of the regression equation is correct.

The verification of the heteroscedasticity has been performed by means of graphic analysis of the distribution of balances depending on the cogeneration plant power consumption *C*_CHP. If an increase of variations can be seen in graphs (the points form a triangle or a wedge), it means that there is heteroscedasticity. The distribution of the balances is presented in Fig. 5.

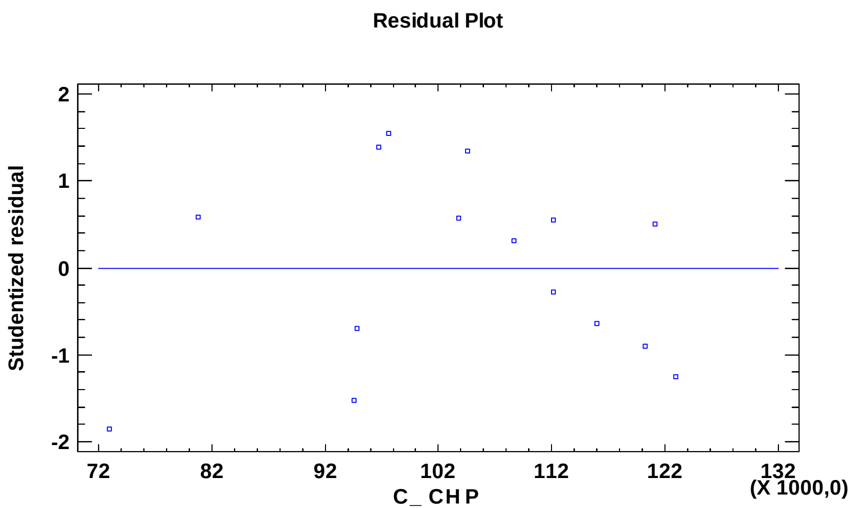

Figure 5. Distribution of balances depending on the cogeneration plant power consumption *C*_CHP.

In Fig. 5, it can be seen that there are no considerable changes in the distribution of balances depending on the cogeneration plant power consumption *C*_CHP. The values of the balances are similar along the whole range of changes in *C*_CHP. The distribution of the balances has been analysed based on other factors. In all cases, the conclusion has been that there is no heteroscedasticity and the standard error has been identified correctly.

One of the types of verification of the regression equation is related to the verification of the signs of its constituents and the fact that there is a logical explanation behind them. The identified changes in the equation from the physical essence perspective are described in the processes. In the regression equation for determining the produced electricity *P*_E (9), the signs of all the parameters are positive and an increase in their values causes an increase in produced electricity *P*_E. When the CHP power consumption *C*_CHP is increased, the produced electricity increases because, for a power plant to be able to generate more electricity, it has to consume more resources. The visible trends comply with the essence of the processes and there is a logical explanation behind them.

The question as to how complete is the correlation between the results calculated by means of the regression equation and the analysed data is among the basic questions regarding the use of empirical equations. It can only be stated in the case of satisfactory correlation that the model adequately describes the situation in practice and its use for simulating the situation is correct. For the purpose of verification of the adequacy of the empirical equation, the empirical and calculated data have been compared. The graphic presentation of the data comparison is in Fig. 6.

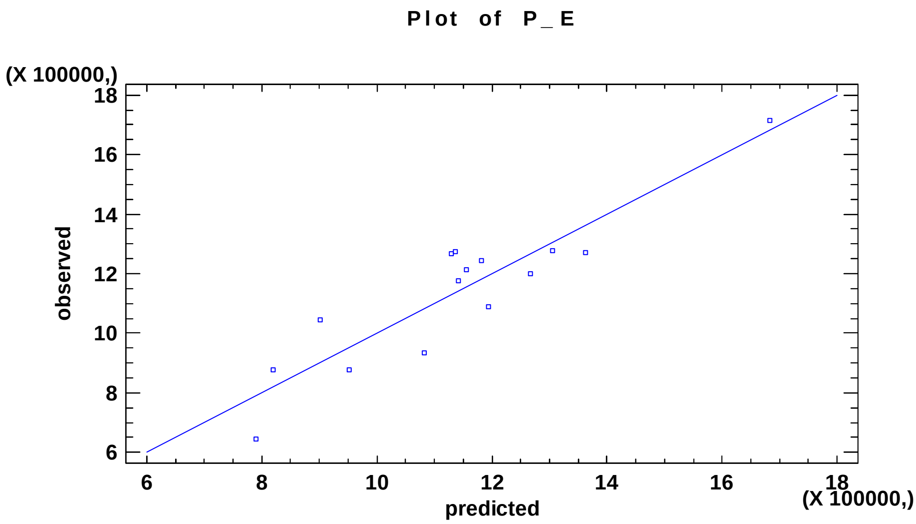

Figure 6. Comparison of the analysed and calculated data of produced electricity.

As can be seen from Fig. 6, there is a good correlation between both data sets. If the calculated value corresponded accurately to the surveyed data, the points would be located on the line in the figure. There is an increased dispersion of points at low values of the reduction of power generation.

CONCLUSION AND FUTURE WORK

Using the statistical processing and applying the methods of regression analysis, the most important factors describing the operation of the production equipment were identified. The relationship between the produced electricity and the parameters impacting this is defined by the regression equation which was obtained during the data processing. During the regression analysis, tests were performed at every stage regarding the correctness of the implemented steps.

According to the performed analysis, the electricity produced is determined by two statistically important parameters, cogeneration plant power consumption and power consumption of the pellet production facility. The adequacy of the equation was verified by applying the Fisher's criterion. The equation describes 83% of the changes in produced electricity.

This study has shown that there is a possibility to find a good equation which describes some independent values using variable values. This study shows that there is a possibility to make a model which describes all factory processes. This additionally enables to use this model for demand side management and hence improve the economic feasibility of the facility.

In future, this task should be studied further. More data must be gathered about another values, analysed and put in a model which can describe factory work.

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Analysis of wood fuel use development in Riga

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Abstract. Use of wood fuel is a sustainable solution of district heating system development for the countries which do not have fossil fuel reserves, but have rich forest resources. The study analyses the options for wood fuel use in Latvia's capital, Riga. The STATGRAPHICS Forecasting and regression analysis modelling tools were used to develop two possible forecasting curves showing the trend of wood fuel use until the year 2020. The results show that the share of the amount of heat produced by wood fuel in Riga could reach 25% of total heat demand if the current trend continues.

Key words: wood fuel, forecasting, renewable energy sources, district heating.

INTRODUCTION

The transition to renewable energy source use is a topic of interest for many involved parties: scientists, enterprises, the society and policy makers. Latvia has a target of 42% renewable energy supply by 2020 (Blumberga et al., 2008). One of the leading renewable energy sources in the energy balance is wood fuel, because the Baltic countries have abundant supplies of wood (Dubrovskis, 2011).

In recent years, more and more installed technologies of district heating (DH) systems in Europe are based on renewable energy sources. Sweden and Denmark in their energy strategies aim at switching to renewable energy sources by 2050 (Joelsson & Gustavsson, 2012; Parajuli, 2012). Latvia is slowly following the experience of the Nordic countries. Two renewable energy sources – hydropower and biomass – hold a significant position in Latvia's total energy production. Hydro resources are used mainly for power generation, but biomass is used for production of heat. Nevertheless, most of the boiler houses and co-generation plants in Latvia are still dependent on natural gas resources (Barisa et al., 2013).

Forests cover around 50% of Latvia's territory and the total growing stock is 631 million m^3 (Latvian Central Statistical Bureau, 2013). The average forest processing rate in Latvia reaches 12 million m^3 per year (Barisa et al., 2013). In his research, Dubrovskis (2011) has assumed that the available biomass potential in Latvia is around 25–30 TWh $year^{-1}$. He concludes that, for the time being, the annual logging rate complies with the basic principles of sustainable development.

Latvia is currently not among the countries with the highest biomass share in total fuel consumption even if the price of biomass is around two times lower than the price of natural gas. Madlener (Madlener, 2007) has analysed the framework conditions for successful biomass DH system development. He concludes that sufficient reserves of wood resources are not enough; policy support and grants are also necessary to decrease the share of fossil fuel use. Perednis (2012) emphasises that the problems of collecting, storage and transportation of cutting residues should also be solved by promotion schemes and government support.

Over the past years, the technologies for biomass combustion have been significantly developed. Heat generation efficiency has increased due to the development of wood fuelled cogeneration stations (CHP) (Mathiesen at al., 2012; Troung & Gustavsson, 2013). One of the lately discussed solutions for efficiency increase in CHP is integration of a heat storage system (HSS). Simulations have shown that integration of a HSS can increase the overall energy generation efficiency by around 8% if storage volume is sufficient (Noussan at al., 2013).

The potential of bioenergy development in Latvia has been analysed in several articles (Romagnoli et al, 2012; Barisa et al., 2013). Barisa et al. have analysed different development scenarios of biomass from forestry, energy crops, and agricultural residues. The authors conclude that the largest biomass potential is associated with the use of forest logging residues and timber processing by-products (Barisa et al., 2013). A sustainable biofuels logistics system in Latvia has been investigated by Blumberga et al. (2012). The authors conclude that the use of biomass storage terminals could increase the delivery costs but minimize the moisture content of the fuel. Nevertheless, the most suitable transportation scenario is to chip wood logs in the forest and deliver the wood chips directly to the boiler house.

The main aim of this paper is to analyse the use of wood fuel for district heating in Latvia's capital, Riga, and to forecast the future development of the wood fuel share in the overall thermal energy balance of the city. The paper also summarises the different combustion technologies that have been installed in boiler houses in Riga.

The main hypothesis of the research is that 25% of the total thermal energy consumption of Riga can be produced by using wood fuel by the year 2020.

METHODOLOGY

Algorithm of methodology

The modelling algorithm of the research is presented in Fig. 1. The algorithm consists of seven different modules: initial data, data processing, assumptions, target setting, forecasting, climate indicator calculation, and obtaining and discussing of results.

The forecasting process began with data collection from a DH company in Riga. The research is based on the data about the heat produced in the period from 2006 to 2013. The collected data was processed and normalised. In order to set a target for the wood fuel use potential, several assumptions were made. Then, the forecasting was done by using two different methods. The forecast results were used to evaluate the wood fuel use development tendencies from which the possible CO_2 emission reduction was calculated.

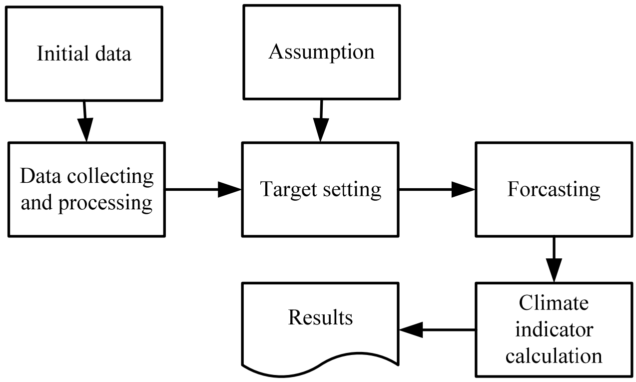

Figure 1. Algorithm of the methodology.

Initial data

A particular DH company of Riga was analysed in this research. The heat for Riga has been produced in 48 boiler houses of the DH company and an additional amount has been bought from other sources (JSC 'Rigas Siltums', 2012). The average amount of heat produced is around 4,000 GWh per year. The proportion of the different heat sources providing heat for the city can be seen in Fig. 2.

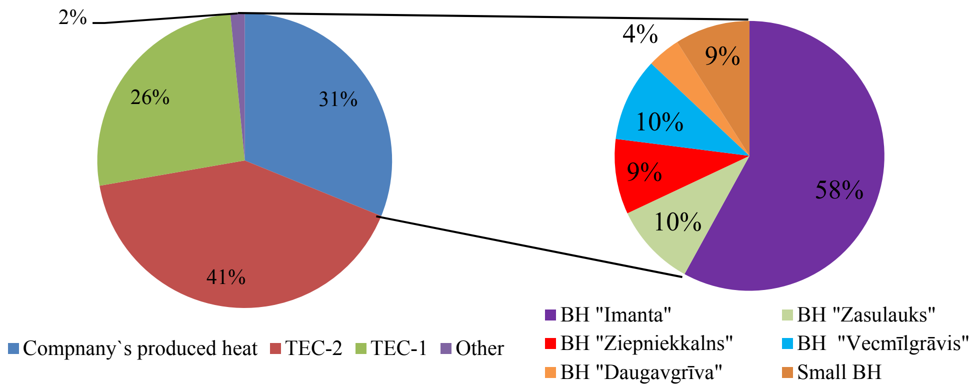

Figure 2. Proportions of heat produced by sources (TEC- thermoelectric power station, BH- boiler house).

Fig. 2 shows that most of the heat has been bought from an electricity producer (see TEC-1 and TEC-2). Around 30% of the total heat demand has been covered by the heat produced in the boiler houses owned by the DH company (its own boiler houses). This research particularly focuses on this part of the heat produced because it can be directly influenced by the DH company. In recent years, the company's largest district heating plants (except the 'Imanta' boiler house) have gradually moved towards the use of wood chips.

In October 2006, the first wood fuelled cogeneration station, 'Daugavgriva', with a steam boiler and turbine generator of 0.6 MW, started operations in Riga.

Another heating plant using wood chips was launched in 2010. The 'Vecmilgravis' heating plant has an installed capacity of 2 x 7 MW, because two AK-7000P1 water boilers with a sloping moving grate in front were constructed. Both heating plants are equipped with a flue gas condenser.

In 2012 two more modern heating plants 'Ziepniekalns' and 'Zasulauks' were starting the heat production from the wood chips. The heating plant 'Ziepniekalns' has installed co-generation technology with power capacity 4 MW. The boiler with a modern combustion area and the capacity of 20 MW is installed in.

The main reason for the use of wood fuel is the ability to reduce the heat production costs. This was caused by two main aspects:

1. The rapid increase of fossil fuel prices (see Fig. 3). The price of natural gas increased around 2.5 times during an eight year period (compared with the year 2000);

2. Latvia has undertaken to fulfil its international commitments on countering climate change (UN FCCC, 1992). In 2005, Latvia joined the GHG emissions trading system.

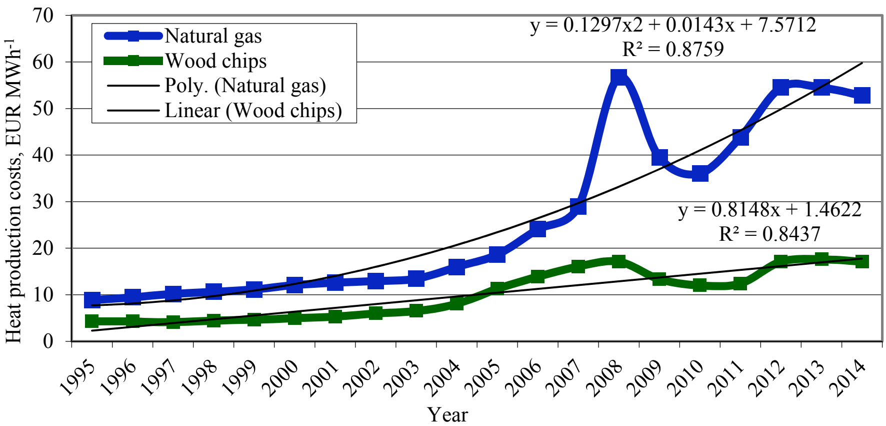

Figure 3. Price dynamics of different fuels.

The use of cheaper fuel reduces the heat tariff by around 1 Euro MWh^{-1} at the end of the year 2013.

Data collection and processing

Historical data about wood fuel consumption and the amount of heat produced in particular heating plants were collected in order to model the existing situation. Additionally, data about the total amount of heat produced by the DH company were obtained.

Processing of the data allowed researchers to evaluate whether all of the collected data could be used for modelling. The technological process of heat production was continuous but with short stops due to repair work. Consequently, all of the collected data can be considered reliable.

The initial data were normalised so the heat consumption corresponds to a standard year with a heating period of 203 days and the average heating season temperature of 0°C.

Assumption

One of the fundamental assumptions within this research is that the climatic conditions in Latvia will remain the same. The second assumption concerns the fuel price dynamics. The authors assume that the price levels will continue to change according to the previous trends (see Fig. 3.) and the price of natural gas in 2020 will be three times higher than the price of wood chips.

One of the most important criteria to model the forecast is the selected forecast period. The authors have chosen to develop the forecast until the year 2020, because the European Union targets for the increase of the renewable energy resources share has been set for 2020 (European Commission, 2012).

Target setting

Three different wood fuel use scenarios have been developed for the particular company:

- Pessimistic (wood chips share of 40% of the heat produced in company-owned boiler houses);
- Ordinary (wood chips share of 60% of the heat produced in company-owned boiler houses);
- Optimistic (wood chips share of 80% of the heat produced in company-owned boiler houses).

In the pessimistic scenario, it was assumed that financial capital will not be freely available for the company and fossil fuel prices will remain at the existing level or will decrease. Thus, significant new capacities of wood fuel will not be installed. In the ordinary scenario, the main assumption was that financial support related to 'green energy' will be available for the company and the use of wood will develop gradually. In the optimistic scenario, investment will be available and the price of fossil fuels will increase. Consequently, the company will almost completely switch to renewable energy sources, leaving a small share of fossil fuels covering the peak loads.

Forecasting

Two different tools were used for forecasting the amount of heat produced of wood fuel: STATGRAPHICS Centurion 16.1.15 software and a regression analysis model developed with Excel.

For the model in STATGRAPHICS, the period of 1 month and a seasonality of 12 months were used. An ARIMA (p,d,q)x(P,D,Q) model was chosen for the forecasting, because it has been widely used for modelling in different scientific fields. The general form of the model can be expressed in terms of the backwards operator B, which operates on the time index of a data value. Using this operator, the model takes the form (Zhu & Wei, 2013):

$$\begin{aligned}(1-B-B^2-\ldots-B^p)(1-B^s-B^{2s}-\ldots-B^{Ps})(1-B)^d(1-B^s)^D\,(Y_t-\mu) = \\ = (1-B-B^2-\ldots-B^q)\,(1-B^s-B^{2s}-\ldots-B^{Qs})a_t\end{aligned} \tag{1}$$

where a_t is a random error or shock to the system at time t, and μ represents the process mean for the stationary series.

A residual autocorrelation function with a confidence level of 95% was used to test the forecast model. The residual autocorrelation at lag k measures the strength of the correlation between residuals *k* time period apart. The residual lag *k* autocorrelation is calculated from:

$$r_k = \frac{\sum_{t=1}^{n-k}(e_t - \bar{e})(e_{t+k} - \bar{e})}{\sum_{i=1}^{n}(e_t - \bar{e})^2} \tag{2}$$

where: t is the time period; e_t is one period ahead of forecasting; n is the sample size (number of observations used to fit the model); $t + k$ is the forecasting time. The developed STATGRAPHICS Centurion forecasting model was compared with the regression model developed from the yearly data.

Climate indicator calculation

Installation of new technologies using renewable energy sources means that no burning of other fossil fuels is necessary. This reduces the amount of emissions emitted in the atmosphere due to the change of fuel and development of advanced combustion technologies with increased boiler efficiency. The avoided GHG emissions E (t CO_2 per year) are calculated in this research.

RESULTS

Data about heat production in Riga were collected in order to evaluate the wood fuel use potential. When comparing the yearly amount of heat produced from wood fuel and the total heat produced in the company-owned boiler houses (see Fig. 4.), high further potential can be seen. The share of wood fuel use has increased from 3% in 2006 to 21% in 2013.

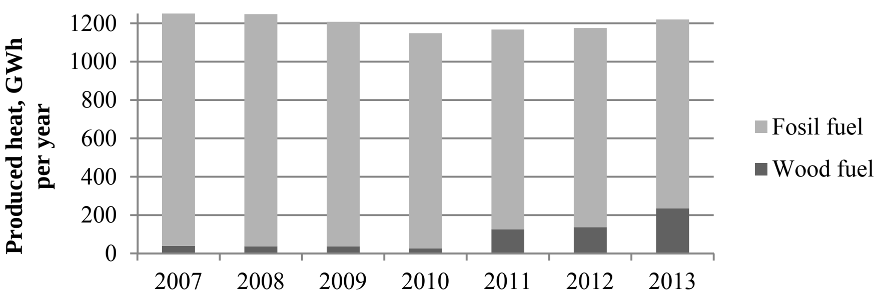

Figure 4. Produced heat by energy source per year.

Fig. 5 shows the heat produced from wood chips per month in four different boiler houses in the period from 2006 to 2013. It can be seen that during the last 3 years there has been a significant increase in wood chips use as three new boiler houses were adjusted for biomass use. Two of them were reconstructed in 2013, so it is not yet possible to evaluate their operation.

Since 2006, the heat produced from wood fuel has increased from around 3 GWh per month to 33 GWh in November 2013. This rapid increase is due to two newly reconstructed boiler houses, 'Ziepniekkalns' and 'Zasulauks'.

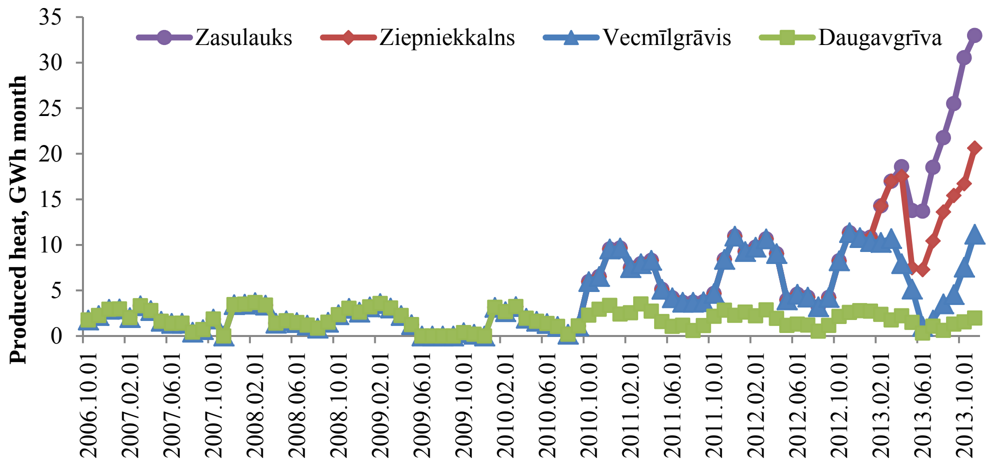

Figure 5. Changes in heat produced from wood chips in different boiler houses.

Historical data about heat production from wood chips was used to develop two different forecasting models. The first model was developed by using the regression analysis method. Fig. 6 shows the trend line for the increase in wood chip use in the period from 2007 to 2013, which was further adjusted for evaluation of wood chip potential.

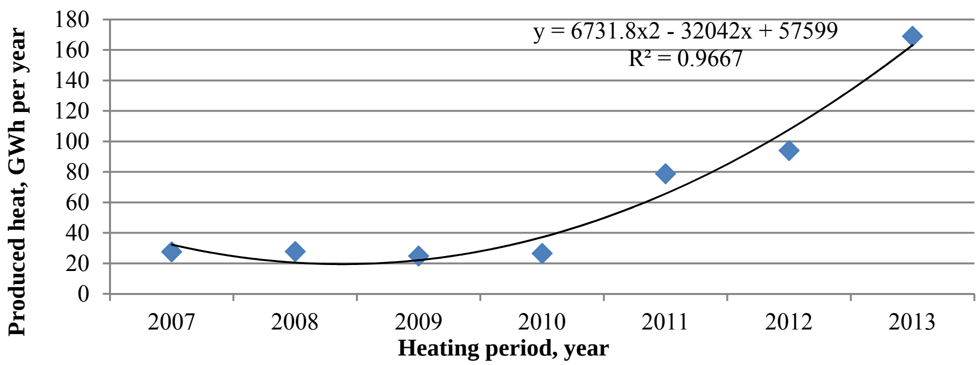

Figure 6. Regression analysis of heat production from wood chips.

The second forecasting model was developed by using monthly data about heat produced from wood fuel. The results of the ARIMA time series model can be seen in Fig. 7. The 'Ziepniekkalns' and 'Zasulauks' boiler houses were not included in this model due to the lack of data about their operations. The ARIMA model requires data from at least 24 months of operations.

The seasonality of heat production can be seen in Fig. 7. Nevertheless, the overall tendency towards heat produced from wood chips is increasing by covering more of the city's heat consumption. The model shows that it would be possible to produce around 600 GWh during the coldest months by 2020. In order to compare both of the models, the monthly data from the ARIMA model were summed to obtain yearly data.

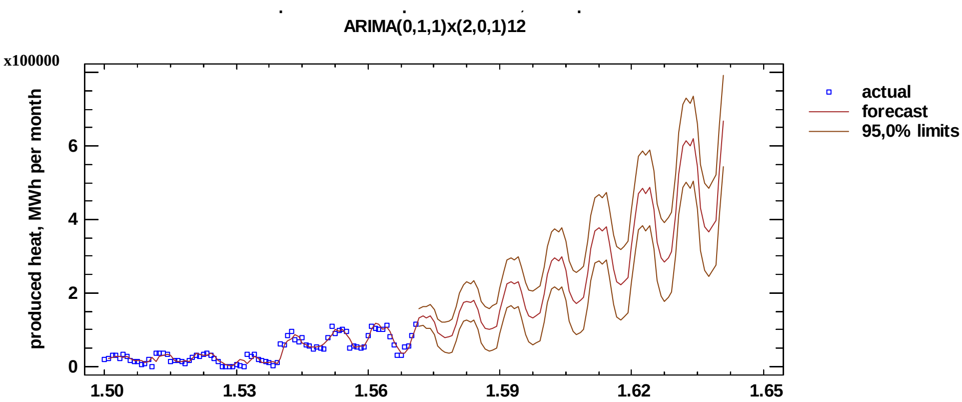

Figure 7. ARIMA forecast model (2006–2020) (1.50–1.53 three-year period).

The results obtained from both forecast models can be seen in Fig. 8. There is a small difference between the forecasting models. According to the regression analysis, it would be possible to produce 40% of the total heat with wood chips by 2016. The STATGRAPHICS model shows that the same amount of heat from wood fuel can be produced by 2015. Both models show that the company could almost completely exclude fossil fuel use by 2020, if it sets even more ambitious targets.

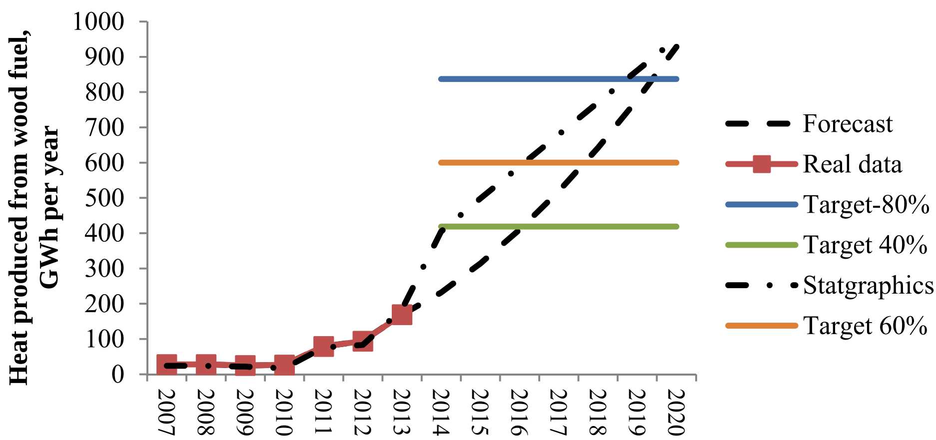

Figure 8. Results of the forecast models by using regression analysis and STATGRAPHICS Forecasting.

To reach such a target, it would be necessary to ensure continuous wood chip supply. As mentioned before, the availability potential of wood chips in Latvia is around 25–30 TWh. In order to reach the optimistic scenario, it would be necessary to use around 3% of the available wood chips in Latvia.

Use of wood fuel results in a significant CO_2 emission reduction. The avoided CO_2 emissions in the 13-year period (from 2007 to 2020) were calculated assuming that the industry will substitute the use of natural gas. The total CO_2 emission reduction for different scenarios can be seen in Table 1.

Table 1. The sum of avoided CO_2 emissions for different scenarios

Scenario	Avoided CO_2 emission, thous. t	Produced heat, GWh
From 2007 to 2013	99	439
Target 40% (2007–2020)	576	2,568
Target 60% (2007–2020)	782	3,484
Target 80% (2007–2020)	959	4,275

Table 1 shows that, until now, around 100 thousand tons of CO_2 emissions were avoided from 2007 to 2013 by introducing wood fuelled boiler houses instead of using natural gas. An almost tenfold reduction in emissions will be achieved if the target of 80% of heat from wood fuel is reached by 2020. The amount of avoided emissions in the analysed period would be around 1 million tons CO_2 if 80% of the heat would be produced from wood chips.

CONCLUSION

The study analyses the options of wood chip use in Latvia's capital, Riga. The STATGRAPHICS Forecasting and regression analysis modelling tools were used to develop two possible forecasting curves showing the trend of wood chip use until the year 2020.

The results show that the lowest target, with a wood fuel share of 40% of the company-produced heat, can be reached by the year 2014–2016. A level of 60% of the heat produced with wood fuel could be reached by 2015–2017. By 2020, the company would produce around 850 GWh by using wood fuel if ambitious targets are set. The availability of wood chips in Latvia is high; the wood fuel increase potential is two times higher than the use in 2013.

Wood fuel use for heat production has a positive impact on the environment due to the decrease of CO_2 emissions. In the case of the optimistic wood usage scenario, it would be possible to reduce CO_2 emissions by around one million tons in a thirteen-year period. In order to accurately determine the impact on the environment, the life cycle of wood fuel harvesting should also be analysed, and the particulate matter from wood combustion needs to be taken into account.

In order to further increase the use of wood fuel for district heating, additional financial support for installation of new technologies is required. Other forecasting trends would be observed if a sharp change in fuel price levels would occur.

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VI ENGINEERING EDUCATION

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Analysis and synthesis of the walking linkage of Theo Jansen with a flywheel

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Abstract. This paper presents the results of cinematic and dynamic calculations of Theo Jansen's walking linkage on the worksheet of Mathcad. To validate the cinematic calculations, a video clip with simulation of the motion of Theo Jansen's mechanism is composed. The synthesis of a flywheel for Theo Jansen's linkage input link to decrease the fluctuation in its rotation is considered in detail.

Key words: theory of mechanisms and machines, Theo Jansen linkage, flywheel, Mathcad.

INTRODUCTION

Humans are mainly using wheeled vehicles for on the ground transportation. But if we look around in the nature, there is no biological creature moving on wheels. To move on the ground, living creatures use legs or crawl. Compared to wheel locomotion, walking has many advantages: lower energy consumption, no need for roads, better to cross over obstacles, the contact with ground is in a determined point, the ground is damaged less (Moldovan et al., 2011). Hence, the scientists are trying to design vehicles which are using legs or other locomotion ways that are inspired from nature.

A Dutch physicist and artist Theo Jansen started to use a twelve-bar mechanism for legs in his kinetic sculptures (Jansen, 2007). This mechanism is now called the 'Theo Jansen linkage' and it can be used for walking vehicles.

There are several studies for the Theo Jansen linkage. Komoda and Wagatsum (2011) proposed an extension mechanism for climbing over bumps. They demonstrated that lifting up of the linkage centre (pivot O_1, Fig. 1) will raise the leg's orbit upward and the combination of a cycle and up-down motion provides a new elliptic orbit for climbing over bumps with about 10 times the height of the original. In their later work, they propose to move the pivot O_1 (look Fig. 1) periodically, this will also ensure movement over bumps (Komoda & Wagatsum, 2012). Moldovan et al. (2011) showed a walking robot as a part of a mechatronic system and the design of the leg structure based upon the CAD design and forward kinematics. Giesbrecht et al. (2012) optimize the design of the Jansen linkage. The optimization is set up to minimize the energy input and maximize the stride length; they based the optimization on the dynamic of the force analysis.

In this paper, the Jansen linkage movement in a resisting environment is analysed. The fluctuating forces in the resisting environment and the reduced moment of inertia on the driving link are causing speed fluctuation. To reduce speed fluctuation, a method for calculating a flywheel to the linkages on a Mathcad worksheet is demonstrated. A virtual model of the Jansen mechanism is composed on a worksheet of Mathcad for validation of kinematic calculations. A video clip is composed from the virtual model.

MATERIAL AND METHODS

Description of the walking mechanism of Theo Jansen

The twelve bars of the linkage with measurements are OA = 250 mm, OO_1 = 690 mm, AB = 910 mm, BO_1 = 650 mm, CO_1 = 970 mm, BC = 790 mm, AE = 1,030 mm, EO_1 = 660 mm, ED = 790 mm, DF = 1,150 mm, EF = 670 mm and CD = 920 mm. There are the same measurements for rear links (Fig. 1). The measurements originate from the thesis of Ingram (2006).

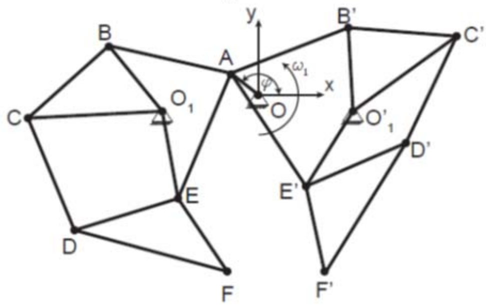

Figure 1. Theo Jansen mechanism.

The link OO_1 is fixed and the constructive angle between the x-axis and the link is $\gamma = 11.16$ degrees. In the calculations, the link OA has constant counter-clockwise angular velocity $\omega_1 = 30$ rad s^{-1}. The movement of the link OA will finally cause movement of the point F and F', these points are like the leg's feet. The loops of the points F and F' are triangular with these links alignments.

In the calculations, the link masses are found by $m = 0.5 \cdot l$, where l is the length of the link. To determine the moment of inertia of the links, the following formula is used: $I = m \cdot l^2/10$. For the triangles BCO_1, DEF and $B'C'O'_1$, the D'E'F' moment of inertia is found by the Huygens-Steiner theorem (Lepik & Roots, 1971).

Determination of coordinates, velocities and accelerations analogues

The kinematic calculations were made on a worksheet of Mathcad; this method has been introduced in previous papers (Aan et al., 2012a; Aan & Heinloo, 2012).

On the basis of kinematic calculations, the simulation of linkage movement with pivot F and F' velocity and acceleration vectors, a video clip was composed on a Mathcad worksheet (Aan, 2014). A frame from the video clip is on Fig. 2.

Analysis of the loops of the pivots F and F'

If we look at Fig. 2, the loops of the pivots F and F' look triangular. On Fig. 3, the lower part of the pivot F loop is zoomed. From there one can see that the lower side of the triangle is not a straight line. By analysis of Fig. 3, the starting point, where the body weight of the pivot F is taken is set to x_1 = -1.1498 m, y_1 = -1.3708 m and the end point x_2 = -0.2055 m, y_2 = -1.3708 m. For the pivot F', the corresponding values are x'_1 = 0.2055 m, y'_1 = -1.3708 m and x'_2 = 1.1498 m, y'_2 = -1.3708 m. According to the value of the rotating angle φ, the pivot F is connected with the ground when $\varphi = \varphi_1 = 252$ degrees and leaves the ground when $\varphi = \varphi_2 = 132$ degrees. Pivot F' is connected with the ground when $\varphi = \varphi'_1 = 48$ degrees and leaves the ground when $\varphi = \varphi'_2 = 288$ degrees.

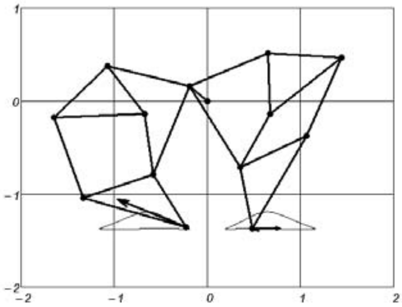

Figure 2. A frame from video clip (Aan, 2014).

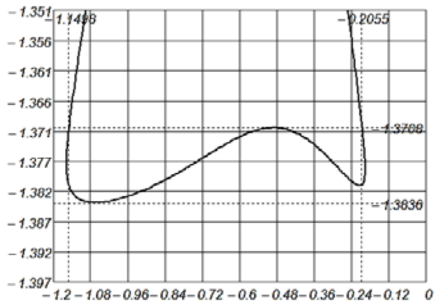

Figure 3. Zoomed lower part of the pivot F loop.

From Fig. 3, one can see that the leg (points F and F') is moving from right to left, it will leave the ground at the point (x_2, y_2) and touch it again at the point (x_1, y_1). In this study, the foot is moving in the environment (snow, water, mud, etc.) between these points, where resisting forces are applied to it. The resisting force projection on the x axis is F_{tx} = 250 N and on the y axis F_{ty} = 150 N, same for the rear leg. According to this analysis, the dependency of the resisting force on the rotation angle φ and from points (x_1, y_1) and (x_2, y_2) is defined by the following program on a worksheet of Mathcad (Fig. 4).

$$F_t(\varphi) = \left| \begin{array}{l} F_t \leftarrow F_t \quad \text{if } \varphi_2 \le \varphi \le \varphi_1 \\ 0 \quad \text{otherwise} \end{array} \right. \qquad F'_t(\alpha) = \left| \begin{array}{l} F_t \leftarrow F_t \quad \text{if } \varphi \le \varphi'_1 \vee \varphi \ge \varphi'_2 \\ 0 \quad \text{otherwise} \end{array} \right.$$

Figure 4. Programs for determination of resisting forces (left point F, right point F'), where F_t – magnitude resisting force.

Reduced resisting torque and moment of inertia

The resisting forces and moment of inertia will be reduced on the link OA. For the resisting forces, the following equation is used:

$$M_r \cdot \omega_1 = \sum_k (F_k \cdot v_k \cdot \cos \alpha_k) + \sum_u (M_u \cdot \omega_u), \tag{1}$$

where: M_r – magnitude of resisting torque on link one (OA in this case); F_k – magnitude of resisting force; v_k – magnitude of velocity; α_k – angle between force and velocity; M_u – pivot's resisting torque and ω_u – pivot angular velocity. In this case, the equation (3) is in the form of

$$M_r(\varphi) = F_t(\varphi) \cdot v_F(\varphi) \cdot \cos 180° + F'_t(\varphi) \cdot v'_F(\varphi) \cdot \cos 180°. \tag{2}$$

The kinetic energy of the linkage was determined by the well-known König theorem (Lepik & Roots, 1971). In order to use the König theorem, the following mechanism links parameters must be determined: moments of inertia, angular velocities, masses and centre of mass velocities; these values are found by the methods which are described above.

The reduced moment of inertia (Artobolevski, 1961) on the link OA can be presented in the form:

$$I_r(\varphi) = I_{OA} + m_{AB} \cdot v_{AB}(\varphi)^2 + I_{AB} \cdot \omega_{AB}(\varphi)^2 + I_{BCO1} \cdot \omega_{BCO1}(\varphi)^2 + m_{CD} \cdot v_{CD}(\varphi)^2 + I_{CD} \cdot \omega_{CD}(\varphi)^2 + I_{EO1} \cdot \omega_{EO1}(\varphi)^2 + m_{AE} \cdot v_{AE}(\varphi)^2 + I_{AE} \cdot \omega_{AE}(\varphi)^2 + m_{EDF} \cdot v_{EDF}(\varphi)^2 + I_{DEF} \cdot \omega_{DEF}(\varphi)^2 + m_{AB} \cdot v'_{AB}(\varphi)^2 + I_{AB} \cdot \omega'_{AB}(\varphi)^2 + I_{BCO1} \cdot \omega'_{BCO1}(\varphi)^2 + m_{CD} \cdot v'_{CD}(\varphi)^2 + I_{CD} \cdot \omega'_{CD}(\varphi)^2 + I_{EO1} \cdot \omega'_{EO1}(\varphi)^2 + m_{AE} \cdot v'_{AE}(\varphi)^2 + I_{AE} \cdot \omega'_{AE}(\varphi)^2 + m_{EDF} \cdot v'_{EDF}(\varphi)^2 + I_{DEF} \cdot \omega'_{DEF}(\varphi)^2, \tag{3}$$

where: I – moment of inertia; m – link mass; ω – link angular velocity; and v – link centre of mass velocity.

Reduction of the fluctuation of the input link's coefficient of speed with a flywheel

Input link OA angular velocity can be determined, in this case with reduced resisting torque (2) and moment of inertia (3), with the following equation (Artobolevski, 1961)

$$\omega(\varphi) = \sqrt{\frac{I_r(0)\cdot\omega_0^2}{I_r(\varphi)} + \frac{2}{I_r(\varphi)} \cdot \Delta T(\varphi)}, \tag{4}$$

where: $I_r(0)$ – value of reduced moment of inertia at $\varphi = 0$; ω_0 – unknown value of $\omega(\varphi)$ at $\varphi = 0$; and $\Delta T(\varphi)$ – change of the linkage kinetic energy. The exact formula for the determination of ω_0 cannot be derived. To find ω_0, one can use an approximate formula (Lepikson, 1998)

$$\omega_0 = \frac{n\cdot\omega_1}{\sum_{i=0}^{n} \sqrt{\frac{I_r(0)}{I_{ri}} + \frac{4\cdot\Delta T_i}{I_{ri}\cdot\omega_1^2}}}, \tag{5}$$

where in this case n = 360, because the calculations are made with a step 1 degree, started at $\varphi = 0$ until $\varphi = 360$ degrees.

In equation (4), change of the linkage kinetic energy is determined with the following equation

$$\Delta T(\varphi) = M_m \cdot \varphi + \int_0^{\varphi} M_r(\varphi) d\varphi, \tag{6}$$

where M_m – constant driving torque of the link OA.

The results of equation (4) are shown on Fig. 5. Because of the reduced moment of inertia in equation (3) and the fluctuating resisting forces, angular velocity is also not constant.

The coefficient of speed fluctuation is defined as

$$\delta = \frac{\max(\omega(\varphi)) - \min(\omega(\varphi))}{\frac{\max(\omega(\varphi)) + \min(\omega(\varphi))}{2}} \tag{7}$$

Accordingly to equations (4) and (7), with these linkage parameters, the speed fluctuation is $\delta = 0.47$. When the fluctuation is ≥ 0.2, large variation must be allowed in the mechanism (Shigley et al., 2004). To decrease fluctuation, a flywheel must be added to the mechanism and equation (4) takes the form

$$\omega(\varphi) = \sqrt{\frac{(I_r(0)+I_f)\cdot\omega_0^2}{I_r(\varphi)+I_f} + \frac{2}{I_r(\varphi)+I_f}\cdot\Delta T(\varphi)}, \tag{8}$$

where I_f is the moment of inertia of the flywheel.

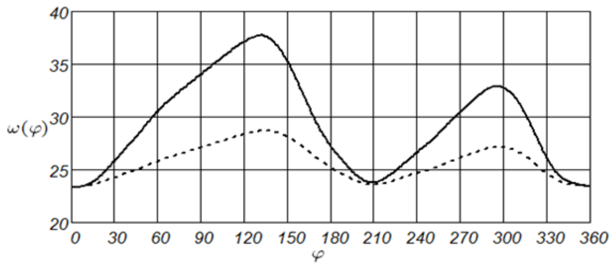

Figure 5. Link OA angular velocity according to formulas (6) and (10) $I_f = 1kg \cdot m^2$ (dotted line).

In consideration of equations (7) and (8), a program can be used on a worksheet of Mathcad to find fluctuation as a function of the flywheel's moment of inertia (Fig. 6).

$$U(I_f) = \left| \begin{array}{l} for\ \ n \in 0..360 \\ \quad \omega(\varphi)_n \leftarrow \sqrt{\dfrac{(I_r(0)+I_f)\cdot\omega_0{}^2}{I_{r_n}+I_h} + \dfrac{2}{I_{r_n}+I_f}\cdot\Delta T_n} \\ \delta \leftarrow \dfrac{max(\omega(\varphi)) - min(\omega(\varphi))}{\dfrac{max(\omega(\varphi))+min(\omega(\varphi))}{2}} \end{array} \right.$$

Figure 6. Program to find fluctuation as a function of the flywheel's moment of inertia.

The results according to the program on Fig. 6 are shown on Fig. 7. For example, if fluctuation must be $\delta \leq 0.1$, then according to Fig. 7, the flywheel's moment of inertia must be $\mathrm{I_f} \geq 3\ \mathrm{kg}\cdot\mathrm{m}^2$.

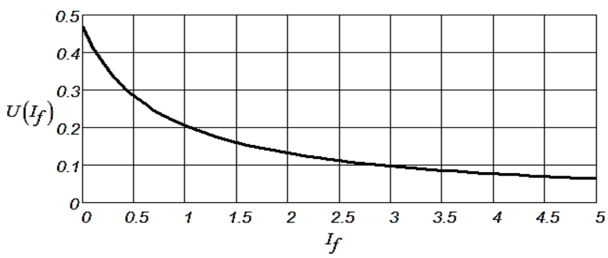

Figure 7. Fluctuation according to the flywheel's moment of inertia.

CONCLUSIONS

1. In this paper, the results of the calculations of Theo Jansen's mechanism are presented on a worksheet of the Computer Package Mathcad. According to the kinematic calculations, a video clip was composed on a Mathcad worksheet, where linkage motion is simulated together with the pivots' F and F' velocity and acceleration vectors.
2. The loops of the pivots F and F' are analysed and their movement under resisting forces determined.
3. The results of synthesis of a flywheel for the Theo Jansen's linkage are presented.

The method presented in this paper can be used in the teaching process of the engineering subject 'Mechanics of Machinery' and also by engineers in their everyday work.

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Cooperative problem-based learning approach in environmental engineering studies

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Abstract. Market requirements and competition in the job market set the necessity for an engineering specialist capable of not only analysing the theory of a situation but also able to transfer theoretical knowledge into practise. In order to lessen the degree to which students are isolated from those real-life situations with which they will be working with daily upon graduating, it is important to integrate a problem-based learning approach based on the study course. The paper describes a Cooperative Problem-Based Learning Approach used in Environmental Engineering Studies and provides progress analysis about 8 years of experience in organizing the course.

Key words: environmental management systems, teaching method, Environmental Science, study course, students.

INTRODUCTION

Improving engineering education is essential to ensure development of a sustainable society which has an appropriate balance among social security, favourable environmental conditions and economic progress. An environmental engineering education should develop professionals who can make changes to their environment with negligible negative impact. As discussed by Maghugj et al. (2006), the role of the university can be evaluated through the production of knowledge and impact on society. Sustainability is an issue which presents more challenges to engineers – the necessity for a holistic view on problems requires a more profound understanding of cross-cutting issues. A more diverse understanding of various problem solving techniques gives the engineering more flexibility to choose application appropriate to any given situation. The integrated approach which will be required in the workplace needs, thus to be mirrored during the study period of the engineering sciences (Eriksson & Mäkitalo, 2013).

According to Ghaffari and Talebbeydokhti (Ghaffari & Talebbeydokhti, 2013), nowadays universities can provide theoretical and special courses, academic programs and laboratory works to maximise the students' involvement with real industry players and real projects. Nguyen & Hens, (2013) suggest that environmental engineering education is better delivered through specialised programmes rather than as part of larger civil engineering programmes. It is argued that within specialised programmes, it is possible to give appropriate attention to the significant issues, relevance and characteristics of environmental engineering. Another source (Kapranos, 2013) adds the importance to consider the ethical behaviour of preparing professional engineers which is perhaps even more complicated in reference to environmental engineers since these have a moral obligation not only to society (social responsibility), but also to the state of the environment (strong ecological responsibility). Development of Environmental Science Programmes in Latvia is described in detail by Kļaviņš, (2008), Kļaviņš & Zaļoksnis, (2009) and Blumberga et al. (2010).

Cooperative Learning (CL) is an interactive learning process designed to establish well-suited and sustainable groups for learning with interdependent members. The groups cooperate together to complete tasks (Adi et al., 2012). CL learning looks to achieve interdependence and accountability in the students on the individual level (Yusof et al., 2012).

Several studies (Leola et al, 2011; Rasmussen, 2012; Mintz & Tal, 2013; Zint et al., 2013;) found that there are gaps between environmental, economic and social knowledge and that students do not consider that their studies have contributed a lot to the views they hold on the environment. This indicates the need to excel practise-based learning models during studies to bridge the gaps students identify among the various disciplines one needs to apply for sustainable approaches and to ensure that studies have a positive impact on shaping their attitudes and knowledge.

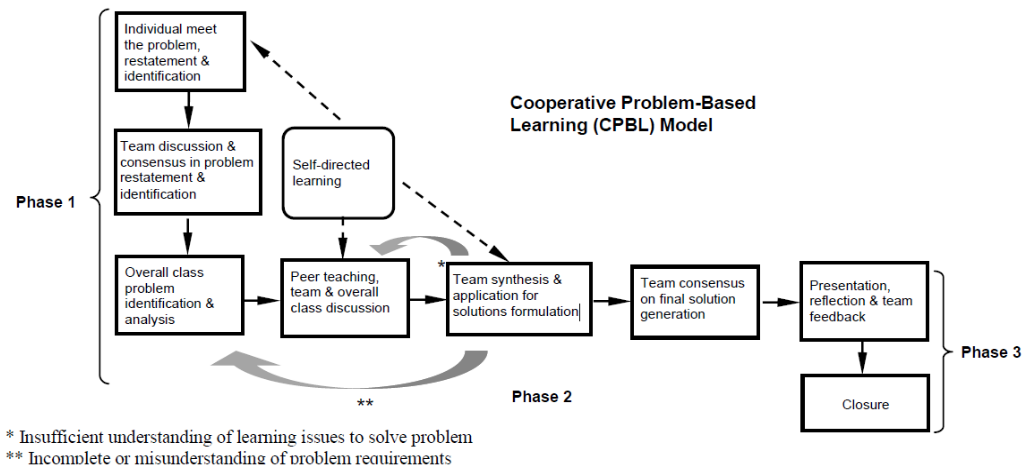

Figure 1. The Cooperative Problem-Based Learning (CPBL) Framework (Mohd-Yusof et al., 2011).

Case Model educational approach is a good way to focus on one issue or problem. It is a positive way to explore complex issues and give time for their deep analysis by the students (Razali & Zainal, 2013). Similarly, the Problem-Based Learning (PBL) approach deals with a real problem and it helps to improve problem-solving and meta-cognitive skills (Yusof et al., 2012; M. Sánchez et al., 2013). According to experience of the University of Sheffield, Department of Materials Science & Engineering, *Use of a Research Role Playing Exercise to Fast Track the Development of Early Stage PhD Researchers* (Kapranos, 2013), role play and simulation exercises help to develop various skills in students such as time management, project planning, literature analysis, personal relationship building, and others. As described by Tan (Tan, 2009) the PBL approach helps in advancing skills in a multi-disciplinary approach and pushing students to expand on their existing skills.

The Cooperative Problem Based Learning CPBL also includes principles of problem-based learning and working in teams. It also applies a multi-disciplinary, over-arching approach to problem-solving to produce professionals who can better grasp complex interrelationships between environmental, economic and social issues (Mohd-Yusof et al., 2011).

This study integrates CPBL based learning method in the *Environmental Management* course of an engineering science programme by integrating knowledge on developing an environmental management system with real practical experience in working with an actual, working industrial company. The objective of the offered teaching model is to improve the quality of learning through a variety of approaches that the students engage in as part of the process: desk review of legal environmental and sector-specific regulations, rapid assessment of environmental risks from a short site visit, analysis of environmental risks through rough calculations, prioritization and discussions. The students in parallel build interpersonal skills on team work, negotiation skills with real business people from the companies with which they cooperate and a larger appreciation for the challenges in putting environmental priorities against those of social, economic and other competing concerns.

METHODS AND MATERIALS

Implementation of the CPBL based learning method is carried within the 'Environmental Management Systems' course (4.5 ECTS). The course on Environmental Management Systems is implemented as part of the two year Master study programme 'Environmental Science' (120 ECTS) of the Riga Technical University and it is defined as a compulsory study course. The main objective of the course is: to acquire theoretical knowledge on the principles of environmental management systems according to international principles (EMAS and ISO 14001) and practical experience on its application in Latvia, Europe and elsewhere; to acquire practical skills on resolving environmental issues on the municipal level and in the private sector. General themes included in the study course on Environmental Management Systems are given in Table 1.

The plan of the course offered includes the development of such skills and competencies as:

- Work groups – distribution of roles and responsibilities within the group, networking skills;
- Critical analysis of information – assessment of the legislative and other regulatory acts and frameworks, analysis of documents provided by the companies, data credibility evaluation;
- Integrated approach in solving problems – application of knowledge and skills acquired from other courses, situational analyses, optimization of the company's facilities (see Fig. 2);
- Development of certification documentation – use of language and forms, balance of company interests (in regard to financial, human resource concerns and

capacities) with environmental, use of language and forms, development of procedures, protocols, etc.;

- Presentation skills – development of training programme, as well as actual training of company representatives; presentation and argumentation skills in presenting results to the company.

Table 1. General themes included in the study course on Environmental Management Systems

Topics	Teaching method	Academic hours spent
Introduction to EMS, main elements of ISO 14001	Lecture	2
Environmental aspects	Lecture and practical class	4
Environmental policy	Lecture	2
Legal acts and other requirements	Lecture and practical class	4
Evaluation of aspects	Lecture	4
Resources, roles and responsibilities	Lecture	4
Introduction with a case industry	Site visit and lecture	4
Cooperative task at the case industry: identification of environmental aspects	Site visit and practical class	4
Group presentations and discussions on results	Practical class	4
Checks and monitoring. Internal audit	Individual work	4
Management review, Comparison of separate and integrated EMS and final evaluation of the situation in the case company	Practical class	4
ISO certification audit. Analysis from the experience of other companies	Lecture and practical class	4
Training on EMS conducted in the case company. Presentation of the EMS manual to the case company.	Practical class	4

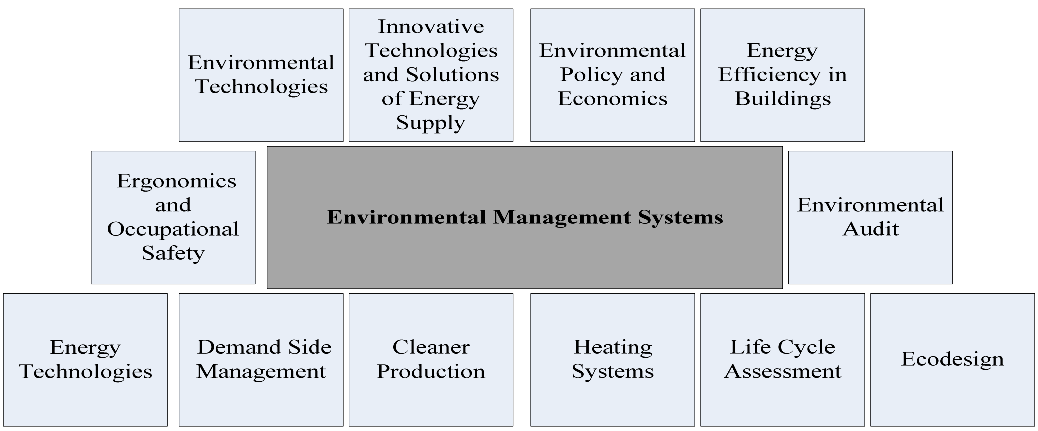

Figure 2. Important courses used in environmental management skills.

Implementation of the presented CPBL based learning method in the Engineering Science programme includes two consequential phases:

- 1st phase: development of the study concept and testing of the method internally within the institution (preparation phase);
- 2nd phase: application of the method in external enterprises (method implementation and improvement phase);
- 3rd phase: application of conceptual understanding of environmental management systems from the company-level to the national, regional and global-levels.

RESULTS AND DISCUSSION

The research results are reflected in three, previously defined development stages of study methods, the experience of which was gained in the period from 2006 to 2013.

1st phase: One of the first environmental management programmes developed in accordance with the ISO 14001 standard was in 2007 with the development of an environmental management system for the Institute of Energy Systems and the Environment (IESE) of the Riga Technical University. At the time this was the first attempt to take such a voluntary step to introduce real environmental protection measures. As opposed to the experience of other national higher educational institutions, the responsible parties for the implementation of the EMS and development of the appropriate manual were students rather than employees of the Institute (see Fig. 3).

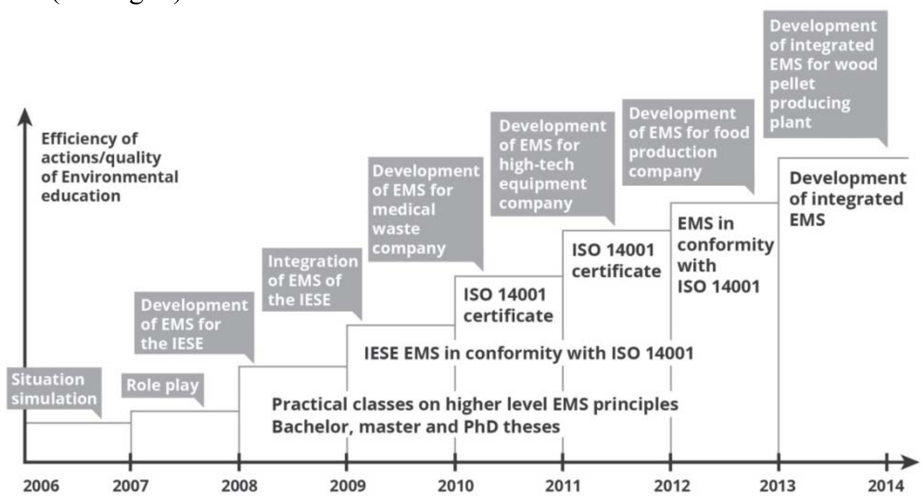

Figure 3. Progress of introduction of the CPBL teaching method in the study course Environmental Management Systems.

The efficiency of actions and the quality of the environmental education provided is assessed through a combination of: (a) anonymous student evaluations on the course completed annually which include questions on the relevance to the course to improvement of their skills and knowledge, the efficiency of the course in achieving its objectives, the quality of the lecturers and their performance; (b) performance of students in exams and practical exercises; (c) peer review of results through internal audit of the main result of the course; (d) degree of changes implemented in the student-developed ISO 14001 programme by the target beneficiary (company) before certification.

As an institution that deals with environmental training of specialists, the main motivation for the introduction of the EMS in IESE was the interest of its staff and students to see how such a system: can impact educational processes and outcomes and create a positive image of the Institute among other environmental education organizations and higher education institutions, thus contributing to the sustainable development of Latvia as a whole. The results of the internal audit and management review conducted by the students showed that the established environmental management system and its implementation was in conformity with ISO 14001 standard requirements.

The introduction of the EMS in the Institute made several improvements in regard to environmental issues at the Institute:

- Sorting and recycling of used paper and cardboard was organised;
- Complete replacement of incandescent light bulbs with energy-saving lightings in two rooms;
- Arrangements made for the collection of used printer/copier cartridges;
- Instructions placed in the office and study rooms of the Institute with information on how to increase efficiency in use of lightening, electrical equipment and heating systems;
- Optimization of the Institute's documentation and procedures;
- Student surveys were introduced to improve the quality of studies.

As a result of the prioritization of environmental aspects, the quality of studies at the Institute proved to be the most important, albeit indirect, environmental aspect among all – both direct and indirect aspects. Since the Institute is not a large organization then, in comparison, its water, energy and material consumption is a lot smaller than it could be in other types of organizations. Thus, it was analysed that the quality of the studies (and thus their ability to develop qualitative environmental professionals), although indirect, is the aspect of the Institute that leaves the largest impact on the environment. The knowledge and skills that the students acquire, the scientific studies and research that are conducted in the Institute are the 'products' that are responsible for positive changes in society in sustainable development.

During the time from the launch of the Environmental Management Programme in the Institute the following has been achieved in terms of environmental performance (i.e. reduced pressure on the environment):

- The Institute has lobbied to achieve changes in the University to allow for student course works to be submitted electronically and for it to be possible to make any paper submissions (documents, theses, course works) on double-sided printed pages (both previously not allowed in the University);
- Since the priority environmental aspect, albeit indirect, was identified as the students themselves, then the increase of number of graduates in policy-level and decision-making positions in the Ministry of Environmental Protection and Regional Development, national agencies dealing with environmental monitoring, and others are considered to be testimony of improved performance;

- An annual open course on environmental issues was developed in 2008 and has steady increase (from 48 in the first year to almost 200 in 2014) of participants from the ministries of environment, agriculture and economy and other state institutions responsible for environment issues in Latvia, as well as environmental consultancy companies and other sector professionals. This shows an increase in the interest of specific knowledge and skills in decision-making on these pertinent issues in Latvia and the role of the Institute.

The main conclusions drawn during the implementation of the Institute's EMS were as follows:

- A good environmental management system in a higher educational establishment facilitates improving the attitudes of students, teachers and other employees towards the environment. Therefore, despite the fact that each individual is responsible for his/her own behaviour and its impact, the shared environmental performance improved significantly.
- It is important to include every person in the organization in the EMS implementation process, not only those who are directly responsible for environmental issues within the organisation. Experience shows that students are very happy to educate their professors in issues on how to maintain the EMS that they've created. Such information exchange between the students and the faculty members is organised in special meetings and within the annual internal audit process.
- The creation of an EMS in a higher education establishment where there is no environmental specialist training would require more time due to additional training that would be needed for the students and employees, since they would not have previous knowledge on environment issues.

2nd phase: The teaching methodology of the environmental management course in the Riga Technical University Institute of Energy System and Environment Institute is continually improved since 2006 (see Fig. 2). The goal of this teaching method is to provide an integrated platform for both theoretical knowledge and developing practical skills set on the establishment and maintenance of environmental management systems on all levels in various spheres. This process begins with a simple organization level – the students' own Institute and individual existing industrial companies. When the theory and practical skills in building an EMS are developed, the students can grasp better the contexts and complexities of environmental management that are present on the country level, on the regional level (among EU countries) and in the international fora (on issues related to international conventions and the management of such globally).

The experience from working with the students and employees from various companies in different sector has led the *Environmental Management Systems* course lecturers to conclude that is not possible to learn how to create, audit and maintain an environmental management systems without practical experience. Students in most cases have little understanding before the course begins about the real situation in companies – the financial difficulties they face, the organizational and technical obstacles prevalent in each company, resistance to change from employees and sometime even a negative attitude against introducing environmental management systems. Student surveys conducted prior to the adaptation of the course indicated that students viewed this course as dull. Even theoretical tests and regular course work did not produce good results. Thus, year after year, the teaching methods have been advanced (see Fig. 2) in response to positive feedback from students in the previous year, and the introduction of each new method produced even better results (both from the viewpoint of the engagement of students and the quality of their work, and from the viewpoint of the students themselves through improved feedback on the course's popularity).

The skills of the students' are built through various steps in the practical work which are related in the points below.

1. The first trial was the **simulation** of an actual situation. Students are divided in small groups, and in parallel with lectures, are asked to develop a specific element of an environmental management system (policy, procedure, plan, etc.). These are prepared in line with a brief description of a fictional company prepared by the lecturer.

2. The more detailed view of the complexities of creating and implementing an EMS were provided through a role play. Each student throughout the semester filled the role of a specific person in a company by organizing meetings, resolving issues, making relevant decisions and preparing the necessary documentation. This allowed students to gain experience on group work and a deeper understanding of environmental aspects, their prioritization and the development of appropriate actions to deter the increase of any negative environmental impacts.

3. Another layer of experience is gained through the development and audit of the Institute's own environmental management system. Although this system has not been certified, each year the students are given the opportunity to audit the system and to check its progress through a documentation audit.

4. The best results are reached from the development of an environmental management system for an existing enterprise. In the past years, under the direction of their lecturers, the Institute's master's students have prepared EMS for four different industrial sector companies. These are a hazardous medical waste management company, a high-tech equipment manufacturer, a food manufacturing company and most recently – a wood pellet producing plant. The first two companies have already received their ISO 14001:2004 certification, which testifies that the systems developed by the students are conformity with all relevant international requirements. The last (wood pellet production company) involved the development of an environmental management system within an integrated system (ISO 14001 + ISO 9001 + OHSAS 18001).

The 3rd phase of the course is the application of the concepts which the students have acquired on environmental management systems and their individual elements (roles and responsibilities, programmes, prioritization, reporting and monitoring, etc.) from the organizational (company) level to higher, much more complex and larger-scaled hierarchical structures in environmental management on the systemic level – the country-level (primarily Latvia), the regional level (the European Union) and the global level. Through this exercise, the students conduct a **comparative analysis** of the elements of environmental management which can be identified at the various levels.

Through this, and a specific **gap assessment**, the students formulate the issues which are problematic and present challenges for countries, the EU and the global environmental conventions for ensuring proper management of environmental issues at each level.

CONCLUSIONS

A CPBL teaching method used in Environmental Science programme within a study course on Environmental Management Systems is presented in the Paper. The described educational programme and teaching methodology achieves its desired goal – increase in the level of specialists entering the workplace with improved skills on environmental management in:

- National environmental institutions,
- Local government institutions,
- Industrial and service sector companies,
- Project and planning offices,
- Educational establishments at all levels,
- International projects on environmental and clean technologies.

Since the students each year are required to become familiar with a specific company, they receive the skills on how to research and identify environmental aspects directly at their possible source and origin – with minimal access to documentation and one short site visit at their disposal for exploratory work. This develops skill in conducting rapid assessments, and the fact that the works is conducted with real company representatives means that the options for improvements in the company's system have to be realistic, implementable and economically sound in the existing market.

Due to the framework of the ISO 14001 standard and its logical approach Plan-Do-Check-Act, regardless of what position students will take in the future, they have a clear understanding of the cycle of planning and the importance of evaluating one's results and feeding lessons learned from the evaluation back into improving further processes.

The challenges and complexities in managing environmental issues on a broader scale (on the country, regional or global level) are hard concepts to grasp. The conflicting and competing interests (socio-economic, environmental, agricultural, health), resource constraints and political issues are difficult for students to grasp and challenging for educators to illustrate. By experiencing first-hand the difficulties in assessing environmental aspects, resolving conflicting interests, prioritizing actions, etc. on a much smaller scale (company-level), the students gain perspective on how these complexities may be magnified. As the number of actors, the geographical area, the scale of environmental issues, resource capacities and other issues increase on the national, regional and global level, the students draw conclusions on the gaps in environmental management at each level which prevent certain improvements and advancements in policy and actions.

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Farm-to-table concept: How the industry and commerce are integrated to the academic education system

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Abstract. The academic education within the complete farm-to-table concept was brought together at the Seinäjoki University of Applied Sciences (Seinäjoki UAS), combining the schools of Agriculture, Food and Biotechnology engineering and Hospitality management as school of Food and Agriculture. By a close cooperation, the schools of primary production, food engineering, and commerce & marketing, establish a way to efficiently facilitate the learning process of the students, and help them to obtain knowledge of all stages in the production of food. Accomplished employees with multiple skills and good understanding of the complete food chain are in greater demand. This is particularly evident in case of SMEs. Large companies may rely more on specialists. The good knowledge of marketing and sales, as well as the product development and the logistics are further areas that possess room for improvement in many companies located in South Ostrobothnia region. Furthermore, companies evaluate sustainability and ethical responsibility as values of greatest significance. From the educational perspective, a comprehensive theoretical knowledge accompanied by well-organized practical training periods is important.
Approaches to tighten up the interactions between the education at Seinäjoki UAS school of Food and Agriculture and the enterprises in southern Ostrobothnia region are further evaluated. Education implementing projects is becoming regularly utilized in the student curricula at UAS. Students learn cooperativity, sharing and taking responsibility, and they learn to take initiatives and to solve problems – important skills in real working environment. Re-grouping students with different acts as an innovative and motivating force for students and gives an option for companies to introduce themselves. Novel technological solutions for data collection and analysis, based on mobile laboratory equipment and other systems, open up new possibilities for education within the farm-to-table concept.

Key words: Farm-to-table concept, learning environment, integration, mobile technologies.

INTRODUCTION

The development of a good education system requires a long-term cooperative strategic planning. Southern Ostrobothnia has selected a strategic plan to implement an attractive, requirement-based and creative education system into Southern Ostrobothnia for the years 2015–2020. This region, with about 200,000 inhabitants, has Seinäjoki University of Applied Sciences (Seinäjoki UAS) as the only higher education unit which gives BA bachelor level degrees. City of Seinäjoki possesses, however, a a consortium of different universities in addition to Seinäjoki UAS, including Tampere, Helsinki and Vaasa universities, as well as the Tampere University of Technology and

Sibelius Academy. The University Consortium of Seinäjoki was established 50 years ago particularly to strengthen the research efforts in the area, and to complement the established education system. This has formed a basis onto which new pedagogic methods, including project-based methods, were easily structured. A major driving force for the establishment of the new strategic plan for Southern Ostrobothnia has been the focus of the European scientific policy, in which the European innovation partnership (EIP) is accentuated (European Union, 2014). EIP strategy offers the small and medium size enterprises new opportunities to take part in innovation projects e.g. in the Horizon 2020 program. Integration of the education system is crucial in this process.

Key focus area of the South Ostrobothnia, as well as of Seinäjoki UAS, is agro-industry, including agriculture and food sectors. As the customer-oriented hospitality management sector is also well represented, the complete farm-to-table concept typifies the area. The role of the higher education units is significant in the integration process of SMEs and education. Novel approaches are needed, which increase the cooperative actions between universities and SMEs and enable closer participation of the study curricula system with the interests of SME development strategies, including proliferate information technologies. In order to further develop the SME operations and the new education, good innovation atmosphere needs to be created. It is possible that study curricula need expansions from strict, narrow-niche curricula to be expanded into multi-skill curricula, with more entrepreneurial intentions. To gain more understanding about the past developments in the integration process in the education sector with the three farm-to-table units, this paper will focus on looking the past education system in agriculture, food processing & biotechnology, as well as hospitality management sectors at Seinäjoki UAS from the alumni perspective. The paper covers the present education system and evaluates the employed pedagogical methods to increase the entrepreneurship attitude and multi-skill identity of the experts at the agriculture, food processing and hospitality management sectors.

MATERIALS AND METHODS

The material considering the data of the evaluation of alumnis is collected from the data published by Elina Varamäki et al as several separate papers (Varamäki et al., 1999, 2002, 2005, 2007, 2011). Analysis of 'food agronomist' survey is based on interviews conducted in year 2011 by Hanna Helander and Margit Närvä. Altogether 19 companies or organizations were interviewed. Potential to employ students from Seinäjoki UAS as well as the size of the company was used as the selection criteria. Micro-companies were omitted. Companies and organizations were interviewed between November 2010 and January 2011.

RESULTS AND DISCUSSION

New advanced studies option for agronomy

Farm-to-table concept, as it is described today and how the current education system in Seinäjoki UAS is formed, is brought together as an integrated unit of agriculture, food processing and biotechnology engineering and hospitality management. To better evaluate the functionality of the current curricula at the School of Food and Agriculture, and to improve the education to better meet the needs of the business and commerce within the food and agriculture sector, we first evaluated the functionality of the new advanced studies module that combines the first two the farm-to-table concept study programmes, Degree Programme in Agriculture and Rural Enterprises and the Degree Programme in Food Processing and Biotechnology. In this module, agronomist students take selected parts of the studies from the degree programme of Food processing and biotechnology (40 ECTS) to strengthen their knowledge in food processing part. Those students are later called ‘food agronomists’. Interviews concerned interviewees’ opinion about planned education, the know-how of food agronomists, and the suitable position in labor market.

The majority of the interviewees appreciated planned food agronomist education. A few interviewees brought out that there will be need for few food agronomists yearly, but if the number of graduating food agronomists increases much, the labor market will be quickly saturated. The versatile know-how brought by the education was considered as a positive matter and the education was considered well suitable to South Ostrobothnia. In the interviewees' opinion, a food agrologist should have the knowledge of raw materials and they should understand food processes from several separate points of view. The studies of the management, which are included in the education, were considered advantageous. On the other hand, the interviewees pointed out that the agriculture know-how is important.

According to the answers, food agronomists have many options in the labor market. According to the interviewees, food agronomists could act as entrepreneurs or in the small and medium-sized companies in where the know-how must be wide. In large companies, the suitable positions for them are between primary production and food processing, for example in duties with raw material acquisition. Suitable tasks for the food agronomist include product development, advisory tasks, and tasks relating to the primary production, the acquisition of the raw material. Furthermore, the different connection tasks, marketing, development projects, quality control, and administration would be potential options. The first food agronomists graduated in the spring of 2013. They had jobs in the food industry. Some of them are planning to run their own company in the future.

Have the studies met the expectations of the working life?

The curricula within the Degree Programme in Agriculture and Rural Enterprises appeared to well meet the expectations from the working life throughout the period of last 20 years. More than 60% of the alumni were employed in positions that matched the curriculum very well (Varamäki et al., 1999, 2002, 2005, 2007). Alumni of the Degree Programme in Food Processing and Biotechnology were employed in positions that matched slightly worse the curricula than the alumni of the school of agriculture. However, as the surveys typically combined all engineering schools, no separate analysis of the alumnis in the Degree of the Food Processing and Biotechnology Programme can be made from the complete time frame of 18 years. However, in the survey conducted in year 2004 (Varamäki et al., 2005), only 1/3 of the Food Processing and Biotechnology alumnis were employed in positions that fully matched their education. Even less of the alumni of hospitality management were employed in positions fully matching their curricula, as only 20% replied that their current position matched fully the curricula. Noteworthy is that 23% were employed in positions other than what they were educated for. In year 2007, this group was even slightly increased to 29% (Varamäki et al., 2007). Several alumnis wanted more supportive education in career planning (Varamäki et al., 2011), and according to the data presented above, improved career planning during the studies might be worth consideration to facilitate the proper positioning of the alumnis later.

Useful skills

When the study subjects were estimated, the alumnis of agriculture and rural enterprises estimated the studies of economics especially useful, in addition to animal and cultivar production courses throughout the 20 years survey period. Foreign language skills were regarded by many, about 30% of alumnis, as too little among the studies of agriculture and hospitality management. This may reflect also the need for the skills for international affairs, which was evident among all the three investigated degree programmes. Needs to further develop such skills was evident, but also other skills important in business and commerce, such as leadership and customer orientation skills, which were only barely achieved during the studies. Especially the alumnis of the degree programme of agriculture and rural enterprises evaluated customer orientation skills poor, as did the food processing and biotechnology alumnis. About 21% of the latter alumnis also noted the education of juridical aspects worth deeper study (Varamäki et al., 2011). According to Jumppanen and Närvä (2013), even more skills in marketing are needed also in agriculture and food industry sectors.

The integration process between working life and studies is biased at the stage of practical training and the final work. Students maintain and gain even more motivation for studies during the practical periods, and obtain important practical skills. According to surveys conducted within industry & commerce, the attitude towards trainees that arrive to work in companies for a short period is not always very good (Zacheus, 2009). Moreover, it is thought that from the educational perspective in Finland too low level of information is given about the expertises required in working life (Zacheus, 2009). Integrated projects with companies and applied universities require different type of skills from the teachers, compared to the traditional education methods, because the interests between teachers, students and company employees need to be handled properly (Stauffacher et al., 2006). Cooperative work between business and commerce and the universities may also become problematic, if heavy theoretical information and formalities are carried out with the project without a realistic approach to the problem (Freeman et al., 2004). In Seinäjoki area, a good networking between universities, businesses, and organizations has been established both at the regional level by bringing different institutions physically close to the same campus, as well as by actively communicating with local companies and authorities. Universities utilize little lecturing expertise from working life (Zacheus, 2009). This resource should be seen as an underutilized source to improve integration opportunities between working life and universities. On the other hand, lecturers at the universities may remain distanced from working life connections. As an approach to fill this gap, specific training, so-called business toolbox package, followed by short-term visits at the companies and SMEs, is implemented at the Seinäjoki UAS in a project ‘PK-Inno’.

Projects and R&D

Multi-skills are required in current society. Applied universities produce employees typically for various expert positions, and it appears that multi-skill expertise is in demand in the competence development of the agricultural and food industry sectors (Jumppanen & Närvä, 2013). Looking from the educational perspective, theoretical background is well covered in all farm-to-table chain educating units according to the surveys (Varamäki et al., 1999, 2002, 2005, 2007, 2011). Skills such as project management, is only recently becoming more and more educated. However, project-type learning was more and more implemented as part of the curricula from the beginning of the millennium. Learning in projects, designed to engage students with investigations with authentic problems, is much about a motivation force for a student (Blumenfeld et al., 1991). In the curriculum of the degree programme of agriculture and rural enterprises, learning in projects was regarded as very useful in their current work by 48% of the alumnis, whereas in the food processing and biotechnology and in hospitality management programmes, 50–60% of the alumnis found project learning very useful. As a learning environment, projects are known to operate with societal and social contexts, and include ideas, such as intentional and action learning, problem-solving skills and ability to share expertise (Ward & Tiessen, 1997). Interestingly, alumnis at the Degree programme of food processing and biotechnology evaluated skills, such as ‘control of change’, ‘organizational skills’ and ‘responsibility and ethics’ only as poorly achieved during the studies (Varamäki et al., 2011). These skills can be difficult to evaluate, as projects typically do not have right answers or one way to be accomplished. Organizational skills are among those that may well develop during the project-based learning. Teachers may also have difficulties to manage and sustain project-based learning (Tobin & Capie, 1988). Project design and implementation must be well balanced so that the students do not get frustrated. Well-structured projects preferably carried out as a group work, support development of organizational skills and leadership development. As one of the novel approaches to implement project-based learning at Seinäjoki UAS, FramiPro® learning environment was developed. The broad field of higher education, including culture, economics, environment, agriculture, health care and technology, the education areas of Seinäjoki UAS – were brought together as a project-type learning platform, where the various expertise and different backgrounds of students were efficiently utilized to create novel innovations.

Research and product development is a specific group of activities within business and commerce, and contribute to the maintenance of a good competitivity. Evaluation of pedagogical methods used in the three different degree programmes of the School of Food and Agriculture at Seinäjoki UAS indicated that within the degree programme of hospitality management, the curricula especially well supported those skills to be improved, according to the survey by Varamäki et al. (Varamäki et al., 2007). The alumnis evaluated by 67% those skills very well achieved, whereas the alumnis of the degree programme of agriculture and rural enterprises only 32% estimated research methodological skills as well achieved (Varamäki et al., 2007). New innovations form an integral part of R&D. The education system at the level of applied universities, which produces experts for multiple sectors along the farm-to-table concept, is taken into account at Seinäjoki UAS Food and Agriculture. Multi-skills expertise, where innovations mostly form at the interface between different platforms and joint groups, will be more implemented to students' curricula even further. We will see important to create learning environments, where students from different study degree programmes can work and study together. Such needs are clearly expressed in the survey of Varamäki et al (2011), in which the alumnis of the Degree programme of food processing and biotechnology was investigated. Innovation policy and the joint ventures between education organizations and institutions and SMEs is currently regarded as one of the leading themes also at the level of European Union, as exemplified by the establishment of stakeholders advisory platforms, European Innovation Partnerships (EIPs) within the EU strategy Innovation Union (European Union, 2014). One of the five partnerships is on agricultural sustainability and productivity.

Another aspect to improve within the university curricula appears to exist in the guidance for practical training and the final thesis. At Seinäjoki UAS in the school of Food and Agriculture this aspect has been addressed by implementing mobile technologies as tool to keep contact and make the documentation process easier in situ at the training place, such as in the farm. The traditional role of teaching is changing at the higher education level. Novel mobile ICT technologies offer new opportunities to integrate business and education. A project Frami Food exemplifies an approach at Seinäjoki UAS to utilize mobile ICT technologies to integrate business R&D, but also to collect and store measurable data to be utilized in cross-disciplinary approaches, thus creating spaces for novel innovations. Several other projects have been running during the last few years that contribute networking and business relations. For example, Agro Living Lab, developed by Seinäjoki UAS, is a project where farmers and students from Agriculture and rural enterprises together develop new technological innovations. Project workshops, used to develop engineering studies and facilitate innovative networking for future trends in agricultural and food processing sectors, is another example. These approaches have gained a very positive feedback from both the students and from the partners involved. Seinäjoki UAS supports the broad field of higher education, including culture, economics, environment, agriculture, health care and technology –expertise that were brought together as FramiPro®, a project-type learning platform, where the different backgrounds of students were efficiently utilized to create novel innovations.

Seinäjoki UAS as producer of skills of entrepreneurship

Training of the entrepreneurship is an important part of studies at the curricula of applied university. In Seinäjoki UAS, a relatively large proportion of young and adult alumni become entrepreneurs (6.5% and 10.5%, respectively), a high degree compared to the situation in other universities in Finland (Varamäki & Heikkilä, 2011). Southern Ostrobothnia region is predominantly a region with a lot of small and medium size enterprises, which is line with this notion. Even 18% of the alumnis after graduating during the years 1997–2000 worked as part-time entrepreneurs in the year 2010 (Varamäki & Heikkilä, 2011). Obviously studies of entrepreneurship need to be encouraged and supported even after graduation, in the form of implemented supplementary courses. The values give are compiled from all fields studied at Seinäjoki UAS. While the curricula of the agriculture unit well supports the high degree of entrepreneurial attitude, there appears to be room for improvement in food and biotech engineering curricula, as about 1/3 of the alumnis estimated that they did not gain any entrepreneurial skills during the studies (Varamäki et al., 2007). Also in the unit of hospitality management, entrepreneurial skills were estimated as rather poorly achieved (Varamäki et al., 2007).

Entrepreneurial actions should be promoted in the current societal context. Various entrepreneurial initiatives have been conducted at different educational levels, although the evaluation of these to measure the impact of these initiatives on the development of the entrepreneurial intention development or the establishment of entrepreneurship as alumni. Entre Intentio –measurement tool has been launched at Seinäjoki UAS to get information and encouragement system for students to reveal their interest for entrepreneurship, even at the very early phase of the studies (Varamäki & Joensuu, 2012). The self-evaluation approach will, on one hand, help to encourage the student´s self-evaluation to support her/his future intention to become entrepreneur, and on the other hand to guide the study curricula to facilitate entrepreneurial skills. It was noted that teaching the entrepreneurship along with the other studies did not affect the potential of alteration of the entrepreneurial intention, whereas the influence of the close social connections (relatives, friends, student colleagues) was important (Varamäki & Joensuu, 2012). Entrepreneurship education is not just education entrepreneurship. At the level of higher education, skills to development include proactivity, leadership, innovativeness, capability to tolerate insecurity and risk taking. How to educate these skills? Current approaches in Finland realized at different applied universities are more commonly taking as part of their curricul, such as project learning and problem-solving approaches. At Seinäjoki UAS, also multiple approaches have been conducted, which are briefly introduced below. At school of Food and agriculture, traditionally a high amount of students become entrepreneurs (to continue as farmers), whereas entrepreneurship in technology-biased level (Degree programme of Food processing and biotechnology), or in the degree of hospitality management is clearly an option only for a small minority of alumnis.

CONCLUSIONS

Farm-to-table concept is a complex chain, the governance of which requires a multiple sources of expertise. Universities of Applied Sciences serve as important units to act as links between higher education, research, product development, and innovations. A close cooperation between the education and enterprises is needed, and the proper networking forms a good basis for sustainable development of the food chain. Similar networking which is required in the business and commerce sector is required at the level of education. Good progress has been achieved in Seinäjoki UAS, as exemplified by the curriculum for a food agronomist. Integration of education and working life still requires both pedagogical and technological developments, where the new managerial role of the teachers especially in the project-based learning process is implemented. Although the different degree programmes within the Farm-to-table concept possess their own clear specialties, the closer cooperation facilitates the positioning of the alumnis to the working markets as multi-skill persons.

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Some practical applications of e-learning in OHS and ergonomics in higher education

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Abstract. The computer based e-learning in Moodle environment and other computer applications in the teaching of occupational health and safety (OHS) are investigated. The social constructivist learning theory is effective method for teaching and learning of OHS and ergonomics issues in the university education. The computer programme for determination of the safety level at enterprise is presented. The simple computer applications are very suitable educational tools for e-learning of OHS and ergonomics. They could be also used by the employers of small and medium-sized enterprises. The scope of practical applications of e-learning in OHS and ergonomics in higher education is analysed on the basis of the scientific literature and analysing the methods used in the EU.

Key words: e-learning, occupational health and safety, ergonomics.

INTRODUCTION

We are living in time of global changes. New competence requirements in information and knowledge management mean new challenges for national educational systems and also for higher education.

Tallinn University of Technology's (TUT) Strategy for Provision of Education has been prepared for the period of 2012–2015, keeping in mind long-term perspectives until the year 2020.

The Vision 2015 contains: TUT is an internationally recognized university which provides competitive education on all levels of higher education. TUT strives for high-quality education based on contemporary study methods and forms, stimulates creative thinking, is student-oriented and flexible. The graduation rates have gone up, including also the proportion of full-time students and students who graduate within nominal study duration. TUT is a recognized provider and developer of lifelong learning options ensuring substantive as well as formal diversity and quality of education. The university systematically introduces the possibilities of science and innovation, popularizes technological knowledge, and motivates constantly and systematically gifted young people to study in TUT.

The Vision 2020 contains: TUT is one of the leading universities of technology in the Baltic Sea region and an active partner in cooperation networks of universities, clusters and state institutions. Provision of education in the international research university combines provision of education, research and innovation. Research and technical achievements are quickly integrated into the study program which ensures the development of young lecturers and research fellows as well as specialists who value innovation and are necessary for the society.

The study materials of all compulsory subjects shall be available for the students via a single e-learning environment or the study information system. Study courses and materials in an e-learning environment should be in conformity with the quality standards developed by the e-Learning Development Centre.

The university shall ensure the sufficient material base in order to carry out the study process effectively. The infrastructure supporting studies, also on a regional basis (a sufficient number of auditoriums in conformity with current requirements, a single e-learning environment etc.) and a support structure (educational technology and multimedia centre with up-to-date technical equipment and specialists) for lecturers upon preparation the study materials have been developed.

TUT has developed the user-friendliness and functionality of the study information system and the cohesion of the study information system and the e-learning environment. There is an in-service training information system which is a part of a single study information system. The development of the study information system takes place systematically and strategically. All information systems support different study options and forms thereby enabling joint development of the provision of education (Tallinn University of Technology, 2012).

According to the strategy of e-learning in Tallinn University of Technology, approved at 2006, for year 2013, 95% of courses have to be provided by support of e-learning environment. Since 2003 – more than 550 courses by support of e-learning environment (BlackBoard or Moodle) have been created.

PBL (problem based learning) is an educational format that uses real-life problems as a starting point for acquiring knowledge and requires students` active involvement in this process. It is a method that encourages independent learning and gives students practice in tackling complex or new situations and discovering their gaps in knowledge with respect to understanding a problem in its relevant context. Deeper understanding of the material rather than a superficial coverage is encouraged by PBL. PBL encourages students to become more involved in, and responsible for their own learning. Each problem or case should encourage the student to develop an understanding for the interrelation of real life problems, as is the case with most problems in ergonomics and safety in enterprises.

Macroergonomics includes OHS, ergonomics at workplace, psychology and physiology; major accident risk etc. The discipline is particularly spread in the US (Glendon et al., 2000; Hendrik et al., 2005).

THE AIM OF THE PAPER

The blended learning with the web-support of the Moodle e-learning environment and web-based practical applications, based on social constructivist learning theory and problem-based learning (PBL) have been investigated. It is an effective tool for teaching and learning the Occupational Health and Safety (OHS) and Ergonomics in higher education.

OHS AND ERGONOMICS EDUCATION IN TALLINN UNIVERSITY OF TECHNOLOGY

Since 2006, in the Department of Work Environment and Safety, the courses in Work Environment & Ergonomics and Risk & Safety Sciences are supported by the Moodle e-learning environment. These disciplines are obligatory to all faculties. Courses have been provided according to the principles of social constructivist learning theory. The main attention is paid to the problem based learning (PBL). Courses have been provided as a blended learning in combination of face-to-face learning and computer-based-learning by support of the Moodle e-learning environment (Siirak, 2000, 2011, 2012; Tint & Siirak, 2000).

There are two main basic courses in the field of OHS and ergonomics for the students in Tallinn University of Technology: 1) 'Risk and safety science' for technical specialities (mechanical, civil engineering, chemical and electrical engineering) and 2) 'Work environment and ergonomics' for the economic and infotechnology specialities (Tint et al., 2012; Kalkis et al., 2013; Koppel et al., 2013).

Case studies for solving the OHS and ergonomic problems and prevent accidents in enterprises are included to the learning process. A study-tool for practicing the determination of safety level at the enterprise (safety audit) by the students of info-communication technology (ICT) as a course assignment for examination was created.

STUDY-TOOL FOR PRACTICING THE DETERMINATION OF SAFETY LEVEL AT THE ENTERPRISE (SAFETY AUDIT)

Safety audits are a vital way of verifying that a company's safety management is working properly. Several methods have been developed for supporting safety auditing: questionnaires, interviews, observations and document reviews. Safety management system in six Estonian enterprises were assessed using Diekemper & Spartz (1970) (D&S) method, which was modified by Kuusisto considering the demands of the OH&S standard OHSAS 18001:2007 (Diekemper, 1970; Kuusisto, 2000). The investigated enterprises were selected from the manufacturing industries. These enterprises' assessments are given as the examples for students.

Table 1A. Modified Diekemper & Spartz method for assessment of safety system. Determination of activities' safety levels (area A)

A. Organization and administration

Activity	LEVEL I (Poor)	LEVEL 2 (Fair)	LEVEL 3 (Good)	LEVEL 4 (Excellent)
1. Statement of policy, responsibilities assigned	No statement of safety policy. Responsibility and accountability not assigned	A general understanding of safety, responsibilities and accountability, but not in written form	Safety policy responsibilities written and distributed to supervisors	In addition to previous items, safety policy is reviewed annually. Responsibility and accountability is emphasized in supervisory performance evaluations

The assessment in this method is carried out on four level systems: level 1(poor); level 2 (fair); level 3 (good); level 4 (excellent) (example Table 1A).

Table 1B. Results of auditing of safety system in Estonian enterprises (Järvis & Tint, 2008)

Industry	**A***	**B***	**C***	**D***	**E***	Total score
Case I (printing industry)	13	15	11	11	10	60
Case II (mechanical industry)	10	10	10	9	8.3	47.3
Case III (plastics industry)	9	12	10	11	11.6	53.6
Case IV (wood processing industry)	8	10	10	11	11.6	50.6
Case V (textile industry)	13	15	10	9	10	57
Case VI (water purification plant), OHSAS 18001 implemented	18	18	19	15	15	85

*Maximum score in each area (A, B, C, D, E) is 20. Maximum total score is 100

The modified D&S method addresses 30 activities. These are categorized into the following activity areas:

A* – organization and administration (statement of policy, responsibilities assigned; direct management involvement; safety instructions to hazardous tasks; workplace design; health care);

B* – industrial hazard control (housekeeping-storage of materials; machine guarding; maintenance of equipment, guards, hand tools; material handling- manual and automated; and personal protective equipment);

C* – fire control and industrial hygiene (chemical hazard control references; storage of flammable and explosive materials; ventilation- fumes, smoke and dust control; skin contamination control; fire control measures);

D* – supervisory participation, motivation and training, line supervisor safety training; training of new employees; job hazard analysis; training for specialized operations (fork trucks, grinding, punch presses, solvent handling, etc.); worker/manager safety contact and communication);

E* – accident investigation, statistics and reporting procedures, accident investigation by line personnel; accident cause analysis and statistics; near-accident investigation).

The results of the implementation of the D&S method for external safety audit are given in Table 1B and a computerized method for determination of safety level is presented in Fig. 1.

Explanation: The safety activities are divided into 5 groups: (characterized earlier). In these five groups in every group there are 3–5 activities (seen in Fig. 1), for example it begins with organization and administration and safety policy has got a mark '1' at the enterprise. The total mark for safety policies in the example enterprise is 55 (Fig. 1). In Table 1B we can see the real numbers of some enterprise, for example printing industry 60 points (Järvis & Tint, 2008).

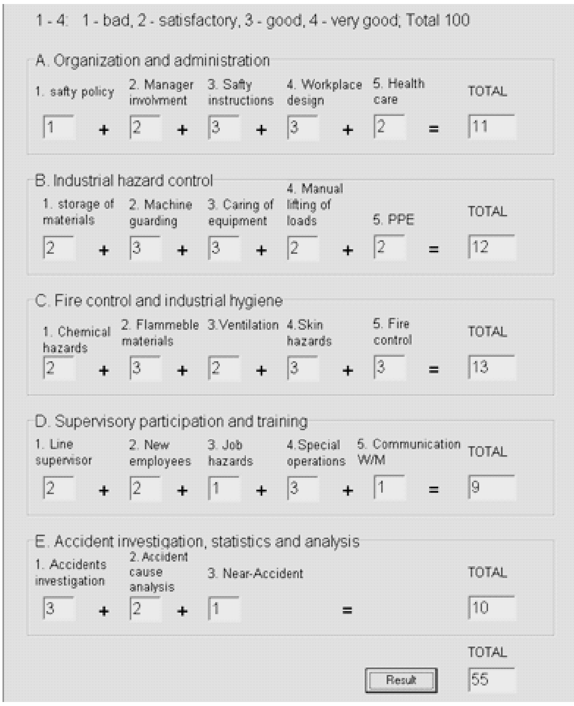

Figure 1. Use of a computerized method in the determination of safety activities at enterprises.

RESULTS AND DISCUSSION

Structural changes in industry and economics have taken place in the 21st century and the globalized world needs responsible qualified engineers and scientists. It also provides new challenges before the OHS and ergonomics in higher education, the new possibilities, dimensions and solutions are opening to OHS specialists. One of the new possibilities and solutions in education of engineers is the problem-based learning (PBL) by blended learning with the support of the Moodle e-learning environment.

The study-tool for practicing the determination of safety level at the enterprise (safety audit) in combination with blended learning by computer based support in the Moodle e- learning environment is very effective learning tool in higher education for solving the problems of OHS and ergonomics at the enterprise. The development of other learning tools is in progress.

CONCLUSIONS

Moodle e-learning environment is a very effective learning tool supporting blended learning encouraging students motivation for learning activities and interests to the course for solving the OHS and ergonomic problems in enterprises.

New learning and teaching solutions will open before the high-school teachers in the future development of the Moodle e-learning environment according to the rapid development of ICT, m-learning and social media.

The advantage of blended learning is the face-to-face contact between the students and teachers personally and it is enriching the learning process. According to our experiences, the activities in the Moodle e-learning environment (assignments, learning forums etc.) and practical applications of e-learning encourage the students interest for working in the classroom face to face with the teacher in a new level.

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