KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

Tomas Tamulevičius

ANALYSIS OF BIOMASS POWER PLANTS PRODUCTION SECTOR FOR A MEDIUM SIZED CITY IN LITHUANIA

Final project for Master degree

Supervisor
Assoc. Prof. Dr. Saulius Baskutis

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Analysis of biomass power plants production sector for a medium sized city in Lithuania

DECLARATION OF ACADEMIC HONESTY

25 May 2015

Kaunas

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Content

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MECHANIKOS INŽINERIJOS IR DIZAINO FAKULTETAS

Tvirtinu:

Gamybos inžinerijos katedros vedėjas ______________________ *(parašas, data)*

Doc. Dr. Kazimieras Juzėnas *(vardas, pavardė)*

MAGISTRANTŪROS STUDIJŲ BAIGIAMOJO DARBO UŽDUOTIS
Studijų programa PRAMONĖS INŽINERIJA IR VADYBA

Magistrantūros studijų, kurias baigus įgyjamas magistro kvalifikacinis laipsnis, baigiamasis darbas yra mokslinio tiriamojo ar taikomojo pobūdžio darbas (projektas), kuriam atlikti ir apginti skiriama 30 kreditų. Šiuo darbu studentas turi parodyti, kad yra pagilinęs ir papildęs pagrindinėse studijose įgytas žinias, yra įgijęs pakankamai gebėjimų formuluoti ir spręsti aktualią problemą, turėdamas ribotą ir (arba) prieštaringą informaciją, savarankiškai atlikti mokslinius ar taikomuosius tyrimus ir tinkamai interpretuoti duomenis. Baigiamuoju darbu bei jo gynimu studentas turi parodyti savo kūrybingumą, gebėjimą taikyti fundamentines mokslo žinias, socialinės bei komercinės aplinkos, teisės aktų ir finansinių galimybių išmanymą, informacijos šaltinių paieškos ir kvalifikuotos jų analizės įgūdžius, skaičiuojamųjų metodų ir specializuotos programinės įrangos bei bendrosios paskirties informacinių technologijų naudojimo įgūdžius, taisyklingos kalbos vartosenos įgūdžius, gebėjimą tinkamai formuluoti išvadas.

1. Darbo tema *Biokuro katilinių sektoriaus analizė vidutinio dydžio Lietuvos miestui*

Patvirtinta 2015 m. gegužės mėn. 11 d. dekano potvarkiu Nr. ST17-F-11-2

2. Darbo tikslas *Išanalizuoti biokuro katilinių sektorių, sukurti teorinį modelį, kuris leistų numatyti galimos miesto biokuro katilinės charakteristikas ir ekonominimį atsiperkamumą žinant gyventojų skaičių. Išanalizuoti vidutinio dydžio Lietuvos miesto biokuro katilinės poreikį.*

3. Darbo struktūra *Darbas sudarytas iš įvado, literatūros analizės apie biokurą ir biokuro katilinių struktūras, analitinės dalies, kurioje pateikiami statistiniai ir kiti būtinieji skaičiavimai, ekonomininio atsiperkumo analizės*, darbo pabaigoje pateikiamų išvadų ir *literatūros sąrašo.*

4. Reikalavimai ir sąlygos ______________________

5. Darbo pateikimo terminas 20__m. ______________ mėn. ______ d.

6. Ši užduotis yra neatskiriama baigiamojo darbo dalis

Išduota studentui Tomui Tamulevičiui

Užduotį gavau Tomas Tamulevičius ______________________
(studento vardas, pavardė) (parašas, data)

Vadovas Doc. dr. Saulius Baskutis ______________________
(Pareigos vardas, pavardė) (parašas, data)

Tamulevičius, T. **“**Analysis of biomass power plants production sector for a medium sized city in Lithuania”. *Masters degree* final project / supervisor Assoc. Prof. Dr. Saulius Baskutis; Kaunas University of Technology, Mechanical engineering and design faculty, Manufacturing engineering department.

Kaunas, 2015. 60 p.

Summary in English

In this thesis the analysis of biomass power plant production sector for medium sized Lithuanian city is presented with the aim to create a model, which can help to determine the equipment requirements looking at the city scale. Work consist of introduction, five chapters, conclusions and reference list.

The first and second chapters present theoretical analysis of biomass, possible biofuels and presentation of biomass burning technologies. Economizer is presented.

Third chapter presents calculations of a created model. Yearly thermal power is calculated for medium sized Lithuania city, biofuel are chosen and technical equipment is presented. Then the calculations for biomass power plant is presented. Economizer requirements are presented. Finally the possible technical equipment of two main Lithuanian manufacturers JSC “Enerstena” and JSC “Axis industries” are presented.

Fourth chapter presents the economical evaluation. Final price of a project is presented, depending of different biofuel driven technologies. Then the payback time of all the project is calculated and all the calculations are finished with possible present net value of the project in the end of its lifetime.

Final chapters presents the conclusions of this work and the reference list.

Tamulevičius, T. “Biokuru kūrenamų katilinių sektoriaus analizė vidutinio dydžio Lietuvos miestui”. *Magistro laipsnio* galutinis projektas / atsakingas Doc. Dr. Saulius Baskutis; Kauno Technologijos universitetas, Mechanikos ir dizaino fakultetas, Gamybos inžinerijos katedra.

Kaunas, 2015. 60 lap.

Santrauka Lietuvių kalba

Darbe atlikta biokuru kūrenamų katilių sektoriaus analizė vidutinio dydžio Lietuvos miestui. Darbo tikslas buvo sukurti modelį, kurio pagalba galima būtų nustatyti galimos biokuro katilinės poreikius priklausomai nuo miesto dydžio ir šilumos poreikio. Darbą sudaro įvadas, penki skyriai, išvados ir literatūros sąrašas.

Pirmame ir antrame skyriuose išanalizuotas įvarios biokuro rūšys, kurios yra populiariausios Lietuvoje, pristatytos skirtingos biokuro deginimo technologijos. Taip pat pristatytas ekonomaizeris – vienas iš naujausių įrenginių biokuro katilinių sektoriuje.

Trečiame skyriuje yra pristatyti skaičiavimai, kurie padeda sudaryti modelį. Pirmiausiai pateikiami metiniai šilumos poreikiai vidutinio dydžio Lietuvos mieste, apskaičiuojami biokuro sunauodjimo kiekiai ir trumpai apibendrinamos biokuro deginimo technologijos. Toliau pateikiami skaičiavimai, kurie naudojami išsiaiškinti katilų poreikius ir paskaičiuojamas ekonomaizerio galingumas biokuro katilinei pagal sukurtą modelį. Galiausiai pateikiami dviejų Lietuvos gamintojų UAB „Enerstena“ ir UAB „Axis Industries“ galimi techniniai pasiūlymai.

Ketvirtame skyriuje pateikiami ekonominiai skaičiavimai apie galutinę projekto kainą, po viso projekto įgyvendinimo. Toliau pateikiami skaičiavimai, kuriais metais projektas atsipirks ir vėliau pradės nešti pelną projekto vystytojui ir galiausiai paskaičiuojama grynoji projekto vertė po projekto gyvavimo laikotarpio.

Paskutiniuose skyriuose pateikiamos išvados ir literatūros sąrašas.

Introduction

In our times growing national economy raises demand of constant, stable energy supply that can support the requirements which are existing now. At this moment and for the last centuries the main source of energy are fossil fuel, which are rapidly diminishing. Without any relevant actions, humanity can face disappearance of their mane fuel source really fast. For this reason in our today technology driven world huge investments are made into renewable, environmentally safe and constant energy sources. One of the examples of this kind of technology, which can produce not only electric energy but heat too, is biofuel.

In Lithuania, as the demand of heating is high, constant supply of energy and fuel is a must. But as Lithuania doesn't have their own fossil fuel deposits and the main fuel resources are imported, renewable energy is the best way to solve our problems. For this reason by 2020 in Lithuanian energy strategy there is goal that all of produced energy one-fifth would be from renewable energy sources [1]. As Lithuania has one of the biggest percentage of fertile land and huge wood resources, biofuel and biomass power plants is an answer to the risen demand.

But as number of the biomass power plants has risen in current years, the main development still stays in bigger and more economically powerful cities. For this reason the main task of this work is to analyse a possible biomass power plant in medium sized Lithuania city, by this creating a model, which can show data of possible biomass power plant just looking at scale of the city and demand of thermal power.

The work consist of literature analysis presenting what is biomass and what kind biofuels are used in Lithuania. Then the possible biomass combustion technologies are presented, which are the most popular in Lithuania. In the next chapters a theoretical analysis is presented with calculations of the annual heat demand in a medium sized city of Lithuania. Possible biofuel are selected and the main equipment calculations are presented. The work is finalized with economical evaluation, possible payback time and present net value of a project.

Aim of the work: Analyse biomass power plant production sector for a medium sized city in Lithuania and with this analysis create a model, which can help to determine requirements of a biomass power plant looking at the scale of the city and energy demand.

Objectives of this work:

- Analysis of biomass energy sector and biofuels;
- Presentation of biomass burning technologies;
- Calculations of thermal heat demand for medium sized Lithuanian city;

- Technological analysis of biomass power plant equipment for a designed city;
- Presentation of equipment selection from Lithuanian based companies;
- Economical calculation of a project, overview of payback time and present net value of the project.

1. Analysis of biofuel types and properties

In the boiler plants a wide range of various wood-based fuels are burned. To some extent also straw and other biomass based fuels are used. All these fuels are considered as renewable combustion, which do not produce greenhouse gases.

Sometimes power plants that burn solid fuels, consider using peat, which can be provisionally considered a slowly renewable fuel of biological origin. Peat is often burned together with woodchips in the same boiler, either alternately or simultaneously, and therefore the differences in the properties of these fuels must be known and taken into account.

1.1. Wood fuel types

The wood fuels can be classified by the origin of raw material (Fig.1):

- From forest
- Fuels from short rotation forests
- Recovered wood fuels

Fig. 1 Examples of most popular wood biofuel

Fuels from the forest and energy forest usually can be considered environmentally friendly, but not the recovered wood fuels. This kind of fuels are the ones that is usually impregnated and painted. For this reason processing is therefore complicated and because of these impurities, crushers must be used instead of wood chippers. When using this kind of fuel the requirements for the combustion technology and emissions are much stricter [2].

Another possible classification of wood fuels based on the upgrading level: non-upgraded and refined fuels. The non-upgraded fuels are considered the fuels, which have only been shred or packed during processing, but the mechanical properties have remained unchanged. The non-upgraded fuels are traditional fuel wood, woodchips, compressed waste wood and wood processing residues (sawdust and shavings). The typical representatives of refined wood fuels are wood briquettes, pellets and wood powder.

1.2. Properties of wood fuel

Wood usually consists mainly from cellulose, lignin and hemicellulose. Due to the high carbon and hydrogen content, the lignin has higher calorific value than cellulose and hemicellulose, so for this reason it can produce more intensive flame. In smaller quantities the wood contains also tar, resins and phenols that can cause fouling of heat transfer surfaces and stack interior with the deposits that are difficult to remove.

All solid fuels, including wood fuels and other biofuels consist of combustible and non-combustible parts. Ash and moisture belong to the non-combustible part of these fuels. At the same time ash and the rest combustible matter together (without moisture) form the dry matter of fuel.

Using any kind of wood fuel, moisture plays an important part in the burning process. Calculating the moisture content relationship is valid between the ash content in the dry matter and that in the as-received fuel. In addition the moisture content of fuel is clarified by drying the fuel specimen in the drying stove at to the constant weight. Determining the moisture content of fuel is a significant procedure at receiving fuel in the power plant, especially when the amount of fuel is established by weighing. The moisture content in a tree remains usually around 40 – 60 % and it depends on many circumstances, like the site, tree species and season. In addition, the moisture content in different parts of a tree varies.

When wood dries, first of all the so-called free water is released and later also the bound water or cell water. With the evaporation of cell water the physical properties of wood start to change. The volume of wood shrinks with drying. Depending on the drying conditions, the moisture content of the wood will reach the saturation point. In the outdoor conditions the billets dry to the moisture content of about 20 – 25% and in indoor conditions the wood could be dried to the 8 – 15% moisture content [3].

1.3. Wood biofuel ash products

Burning any wood fuel and other solid biofuels ash content is low, but still the fusibility characteristics of ash have direct impact on the power plant performance. The ash melting may cause slagging of the furnace and formation of hard deposits on the convective heat transfer surfaces.

The fusibility characteristics of wood ash may vary extensively depending on tree species, site of growth, impurities in the wood fuel and also the differences in the ash from different parts of tree are essential. According to different references, the fusibility characteristics of wood ashes vary within the following limits. While for bark the softening temperatures of ash are usually rather high and as a rule, do not cause slagging of the grate, for sawdust and woodchips the softening temperatures are considerably lower (Fig.2). Therefore, the combustion regime must be carefully monitored in order to avoid the slagging problems.

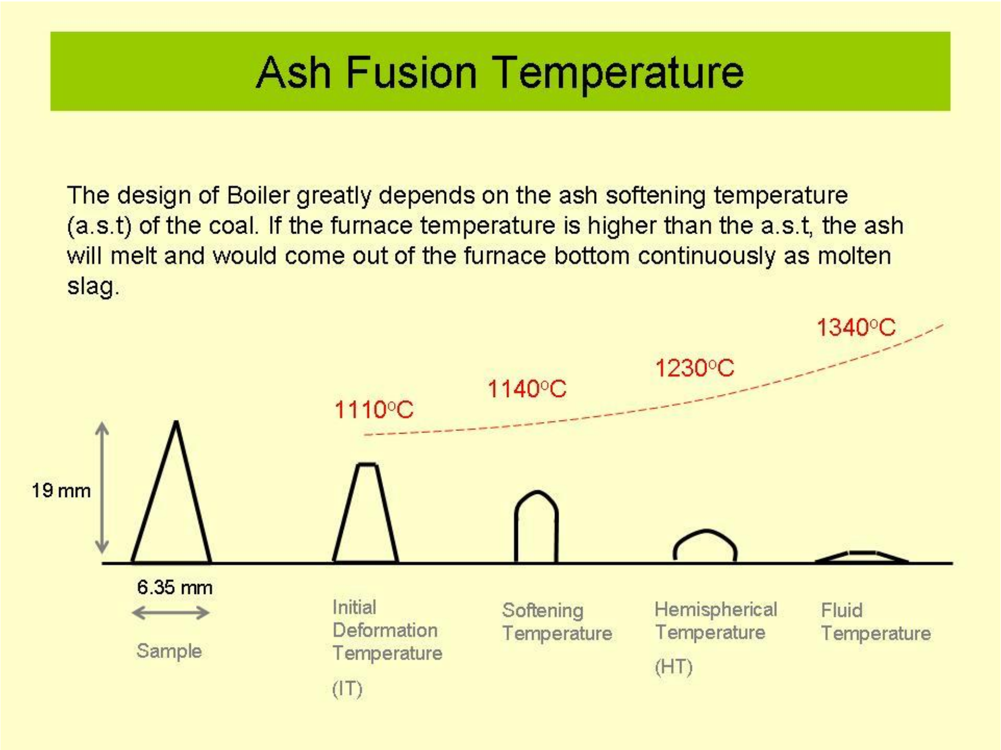

Fig. 2 Graphical presentation of ash fusion compared to the temperature inside the furnace [4]

Fusibility of ash depends on its mineral composition and even minor differences in the composition may change the fusibility characteristics significantly. According to the fuel and ash composition, the fusibility characteristics cannot be reliably predicted in practice. If a boiler plant must use the fuels with unknown fusibility characteristics of ash, application of express analysis methods may be expedient. The method is test burning of a small amount of fuel on a clean grate. After the test slagging is checked either visually or by a simple empirical method. Since in practice, due to the low ash melting temperature, slagging on the grate is a serious problem, introduction of the simple express method in the lab of the boiler plant may allow using of problematic fuels after testing. Earlier these fuels were rejected due to the fear of possible slagging.

1.4. Volume and density of wood fuel

Usually the main characteristics of solid fuels are determined per mass unit, but the amount of many solid biofuels and peat are measured in volume units and therefore it is expedient to present certain properties of these fuels in particular the energy content per volume units.

As many medium and small scale boiler plants measure the received fuel amounts by volume, but knowing the bulk density of woodchips is really important. It is worth knowing that the accuracy of determination of heat content per volume unit depends less on the accuracy of fuel moisture content than determination of heat content per total mass of the fuel. The dry matter content of fuel as received per unit of mass does not depend much on the moisture content. At the same time, the heat content per dry mass is less dependent on the moisture content than the heat content per total mass of fuel (Fig. 3).

Fig. 3 Graphical illustration of wood fuel density [5]

1.5. Straw as fuel and its characteristics

Sometimes biofuel plants along with wood fuels use another solid biofuel group like straw and energy grass harvested from the agricultural land. Several other types of biomass can be grown by farming, which are mostly used for converting into liquid biofuels or gas. As the production and practical implementation of other solid fuels of agricultural origin are still in the phase of testing, nowadays only straw as a fuel is used (Fig. 4).

In some countries the grain of crops has been used. The latter is related to the state subsidies available to farmers whose unsold excess crop can be used this way. Since usually, the grain is not grown for later burning the crop, it’s considered as additive to burning straw.

The composition of straw does not differ much from the respective indices of wood and considering the typical moisture content of straw which should reach below 20% the calorific value of straw is rather higher than that of woodchips. The properties of straw depend highly both on the site, time of growing and weather conditions at the time of growing as well as on the soil quality and fertilizing. The volatile content in straw varies in the range of 60 – 70%, which is to some extent lower than that of wood-based fuels. The ash content in straw is high compared to wood fuels. At the same time the fusion temperature of straw ash may be significantly lower than that of wood-based fuels and softening of the straw of rye, barley and oats begins at very low temperatures. For this reason considerations must be done when selecting the combustion technology and combustion regime of the furnace [6].

Fig. 4 Examples of straw as a feasible biofuel

The most significant problem related to the practical use of straw is small bulk density, which for the uncompressed straw is only around 40 kg per loose cubic meter and that makes the storage and transport of straw expensive. Straw is mainly supplied as compressed big bales. At harvesting the moisture content of straw is usually up to 60%, but for the combustion the moisture content must be less than 20% and reach dry stage of the straw. The straw with higher moisture content must be dried before storage or in the storage space. Drying avoids self-heating and decomposing of straw in the storage.

1.6. Peat as fuel and its properties

Peat is an organic deposit formed from the accumulation of decomposed remains of plants in the oxygen-poor environment. Peat consists mainly of partially decomposed remains of plants and humus. The most essential indices of peat are decomposition degree, moisture content, density and calorific value. Although peat is of biological origin, it is not considered a popular choose as a renewable biofuel, but a slowly it is getting more and more popular.

The peat used as fuel is usually older peat with a higher decomposition degree where the vegetation structure cannot be discerned at all or only to some extent. The main types of peat fuel are the milled peat, sod peat, peat briquettes and peat pellets. The peat structure in general and properties depend highly on the decomposition degree. Some properties of poorly decomposed peat make its use as a fuel complicated. The poorly decomposed peat is hygroscopic and may be damped by air humidity, its low bulk density and compressibility cause difficulties to conveyer transport and combustion, so for this reason only dry peat is used in boilers.

The ash fusion characteristics of peat (Fig. 5) are a bit lower than the respective characteristics of wood. The ash content and properties of ash depend on conditions of peat formation and amount and properties of impurities (sand) in it.

Fig. 5 Example of dried peat

2. Biofuel combustion technologies

Usually power plants using biofuel is combined from various parts like fuel terminal, which may consist of several spaces, fuel handling equipment, boiler and furnace, flue gas cleaning equipment (multi-cyclone, bag filter, etc.), ash handling equipment, combustion air exhauster and safety and control devices.

The lower is the quality and the more diversified fuel is used, the more complicated are both the flow sheer and technical solution of the combustions equipment and the boiler plant as whole. For optimizing the expenses and cost of produced hear, in small scale plant is expected to use fuel of better quality. More complicated technological solutions are required for burning moist woodchips, bark and waste. As a rule, it is economically feasible in large plants.

The central technological part of a power plant is in the boiler with a furnace. Combustion processes and furnace constructions depend highly on the properties of fuel. In order to select the most appropriate equipment for burning biofuels and peat, combustions peculiarities must be understood.

2.1. Combustion technologies

Considering the wide scale of properties of biofuels and peat, many different techniques and combustion of these fuels can be applied like pulverized combustion when co-combustion of wood grinding powder together with liquid fuel is needed, another grate combustion technologies with a wide range of grate construction, next combustion in fluidized bed and fuel gasification and combustion in oil or gas firing boiler.

A certain combustion technology is either technically or economically most expedient in the certain range of boiler capacities. In the conditions of Finland the boilers with the capacity up to 5 MW are usually grate boilers, fluidized bed technologies are mainly used in case of large scale boilers. Differently from Finland and other Scandinavian countries, the fluidized bed technologies for burning wood fuels and peat have not gained much popularity neither in the Baltic countries nor in Poland and Russia, although some examples on the implementation of fluidized bed technology can be given and in the future the situation may change.

The boilers can be classified also according to field of their implementation. In each field there is expedient to use boilers with certain capacity, most appropriate technological solution and preferred automation level.

2.2. Grate construction furnaces

The grate furnace technologies are the most popular in the low to medium capacity range power plants. Usually, the grate furnaces are divided by furnaces with manual or automated fuel feeding, but the most used are automated ones. Due to low ash content in wood fuels, manual removal is acceptable even for quite big boilers.

Different grate types can be classified into categories: solid or fixed grate module, inclined moving grate, travelling grate and special grates for fuels of specific properties, like for burning municipal waste. The most popular constructions are the solid, automated and chain grates.

2.2.1. Furnaces with solid grate construction

Usually solid inclined grates are mounted in the furnace in angle. By using this construction fuel falls under gravity from drying zone to the carbon combustion zone. The inclination angle of solid grate is approximately equal to the angle of fuel falling down. Depending on the fuel type and construction of grate elements, the slopes have to be fixed and installed using knowing the angle.

Typically solid grate with inclination is made by using grate components or bars that are installed in the same direction as the fuel flows. Solid grates, but using steps consists of steps that are installed in the same direction as the fuel flow. The step grate is well suitable for burning sawdust and moist fuel.

In some cases, not only plane inclined grates are being used, but also conical or retort grates can be used. This construction is suitable where the fuel fed with a screw feeder or feed from the top.

2.2.2. Furnaces with automated grates

Speaking about furnaces with automated grates, fire bars in it enables better control over the fuel bed and smoother distribution of fuel on the grate. For this reason more efficient combustion can be achieved and the content of hazardous components can be reduced.

A typical example of the furnace with an automated grate is where the fixed grate bars are located consecutively with the moving bars. The transitional moving of grate fire bars provides even thickness and smooth advancing of the fuel.

Some furnaces are constructed with pre-furnace with a separate boiler. The walls of the pre-furnace have no heating surfaces and this type of furnace suits well for burning moist fuel. The ceramic walls of the furnace are cooled with combustion air that provides air preheating and by doing this, improves the combustion conditions.

For burning very wet fuels, the furnace walls must have a ceramic lining and no cooling system. In this system the temperature of lining is sufficiently high enough to provide heat, which is radiating from the walls, for fuel drying. If a dry fuel is burned in an uncooled furnace, the temperature can rise too fast both in fuel bed and in flame. The result can be melting, slagging of the grate and its air ports, also damaging or even melting of the furnace lining. The cooling conditions of furnace lining set the fuel type to be burned and its moisture content. For burning dry fuel, pellets or furniture industry residues, first of all the cooling furnace walls keep the temperature in the combustion chamber within the acceptable range.

When burning moist fuel in a cooled furnace, the temperatures on the grate will remain low, as the drying conditions of fuel are insufficient. The result is involvement of fuel particles in the ash and incomplete combustion of volatiles, which reduce the combustion efficiency rapidly. Also, unburnt gases and soot may occur in the stack and on heating surfaces and flue gas ducts may be covered with tar. In the furnace wall the combustion air pre-heated and it improves the burning conditions of wet fuel. This type of furnaces widely used and they are well applicable for moderately moist fuels, for example woodchips with the typical moisture content

Another possibility is to use combustion chamber with the rotating conical grate that allows combustion of fuels with rather wide range of moisture, incl. fuels of extremely low and very high, which is up to 65 %, moisture content. In this kind of furnace, the fuel is fed by a screw feeder onto the centre of the conical shape grate where it is distributed over the whole cone surface. Practically any biofuel can be used that can be fed with feeder.

The conic grate consists of concentric rings where the fixed and rotating rings are mounted alternatively to each other and second rotating ring moves in the opposite direction. In the furnaces rotating grates distributes fuel into a very smooth fuel layer over the circumference and entire grate surface. The key to the high combustion efficiency and minimum emission level is an expedient air distribution and control, which contains speed controlled air fans. When the furnace for biofuels and peat is designed as a pre-furnace, it must be connected to a matching boiler in the power plant.

2.2.3. Travelling chain grate type

In large scale boilers the chain grate suits well for burning several fuels in the same furnace, usually main fuel is the woodchips, but peat and coal can be used. Using this type of grate you can change its speed. When changing the travelling speed of the chain grate, the speed of fuel flow can be flexibly controlled, completion of combustion can be achieved and ash from the grate, which is falling down should not contain combustible matter. With this type of grates power plant operators can switch from one fuel to another, like changing woodchips to coal. Another possibility is that travelling speed of the grate can be changed.

2.3. Fluidized bed furnaces

With gradual increasing of the velocity of combustion air forced into the fuel bed, a state can be reached where the fuel bed is carried up by the air, the fuel particles tart to suspend in the air flow. It seems like the bed begins to boil and this is where the term fluidized bed comes. The moisture, released volatiles, ash and also fine fuel particles are carried out of the fuel bed. Fine fuel particles and volatiles are burning in the combustion chamber above the fluidized bed.

When the air velocity is increased to the level higher than needed for the bubbling fluidized bed, the burning fluid particles are carried away with the airflow. In the cyclone-separator solid particles are separated from the air and gas flow and circulated back to the furnace. Since the burning fuel circulates between the furnace and separator, the term used for this combustion technology is the circulating fluidized bed.

Both the bubbling and circulating fluidized beds are good for burning biofuels, peat and waste. For oil shale and coal the circulating fluidized bed suits better. One of the advantages of fluidized bed technology is the possibility to burn different low quality fuels reducing at the same time emission of hazardous air pollutants. In fluidized bed the temperature is relatively low (about 850 °C) and therefore no ash melting and furnace slagging is likely to happen. Also, nitrogen emissions decrease at this temperature and in a Sulphur-rich fuel, the Sulphur can be bound with adding a sorbent (lime) in the ash.

A granulometrically uniform fuel is generally required for fluidized bed combustors. For burning biofuels and peat, the bubbling fluidized bed is formed from an inert material: usually quartz-sand. When activating a fluidized bed, the bed material is heated up to the temperature of 600 °C using gas or liquid fuel start-up burners. After that the main fuel fed into the bed will ignite, the temperature in the bed will rise and the start-up burners used for fluidized bed activating will be switched off. There are some options for feeding the fuel into the bubbling fluidized bed:

- feeding fuel via a vertical duct onto the fluidized bed;
- the fuel is thrown over the cross-section of combustion chamber by spreader-stoker;
- feeding fuel into the fluidized bed through a horizontal channel either by pneumatic or screw conveyer.

Unlike grate furnaces which have difficulties at low capacities, a bubbling fluidized bed furnace with a sand bed can operate efficiently in a wide range of capacities. Due to accumulated heat of the sand bed the boiler can stay even with no load for a short time. Example can be taken the Finnish Putkimaa OY fluidized bed boiler [7]. This boiler is a vertical fire tube boiler with fluidized bed at the bottom of the fire tube. Such a compact design allows building even an exceptionally small fluidized bed boiler from 1 MW. Medium and large scale fluidized bed boilers have typically a parallel to furnace chamber vertical flue gas duct with water-tube heating surfaces.

2.4. Straw combustion

For burning straw boilers of special construction are required where the peculiarities of this fuel type have been taken into account. Herewith the Danish experience on the use of straw as a biofuel is referred.

Since straw is a residue of grain growing, it suits for heating farms. One of the simplest options is burning whole straw bales in the batch-fired boilers. It is a cyclic process: first a straw bale is fed into the furnace through the open furnace door by a tractor; then the door is closed and fuel ignited. The combustion air is blown into the combustion zone from the top. Due to the cyclic burning, combined air control is rather complicated and high combustion efficiency cannot be achieved. When the straw bales are shredded before feeding into the furnace, the fuel can be fed combustion regime easier.

In addition to the technological features, the efficiency of straw fired boilers depends also on the load and capacity of the unit. For example, the efficiency of the above boiler for the cyclic combustion of straw is about 10 % lower than that of the boiler with the automatic feeding of shredded straw while the efficiency increases with the load for both boilers. The straw bales can also be fed into the furnace in series without shredding.

2.5. Combustion of pellets and solid fuel burners

The pellets are a high quality homogeneous fuel the shipping, storage, conveyance and even combustion of which can be automatically controlled as easily as the respective operations of light fuel oil burning.

The pellet combustion system consists of the following main parts:

- fuel storage or tank;
- conveyor for delivering the fuel from the storage to the pellet burner
- pellet burner;
- boiler.

The delivery of pellets from the storage to the boiler can be arranged easily by a screw feeder of the burner. Usually volatiles released at the burner inlet burn in the boiler combustion chamber. A special pellet boiler integrated with a burner and feeding system can be used. Another alternative is replacing an oil or gas burner with pellet burner. The pellet burner can be connected to the boiler via maintenance manhole

Wood pellets are dry volatile-rich fuel, the ignition is not difficult and the combustion process can be easily automated. This proves that the replacement of light fuel oil by pellets causes practically no loss of handling comfort. However, when burning the pellets, the ash must be removed from time to time, but once or twice a week is a sufficient frequency for that.

In general there are two modifications of burners that have been developed and prepared for manufacturing [8].One of the burners is designed for burning dry fuel and the other for wet fuel. Sod peat and woodchips are the most appropriate fuels for the burners. The maximum recommended moisture content is 35%. When burning the fuels with higher moisture content, the capacity lowers significantly (in particular for the sod peat), combustion becomes unstable and losses increase rapidly.

Besides pellets, some other fuels, for example woodchips and even sod peat, might be combusted in the burners similar to pellet ones. As a rule, the fuel burned in such burners must be homogeneous and relatively dry.

2.6. Boiler conversion for burning other fuels

In the descriptions of the above combustion technologies mainly the processes in furnaces have been treated but only little attention has been paid to boilers, i.e., the heat exchange surfaces via which the combustion heat is transferred to the water. In new biofuel fired plants the furnace and heating surfaces make an inseparable integrity. From the point of view of combustion technology and emission level such a complex solution is usually preferred compared to the partial or complete reconstruction of the existing plants.

There are several options for boiler conversion to biofuels or peat in fossil fuel boiler plants:

- adjusting of coal fired boilers for burning biofuels or peat;
- building a pre-furnace to the existing fossil fuel boiler;
- building a grate or fluidized bed system into the existing boiler;
- replacement of the oil or gas burner with solid fuel burner;
- installing a fully new biofuel boiler in place of some dismounted boiler or using free space in the boiler house.

Readjustment of coal fired boilers to burn biofuels and peat of much higher volatile content and lower calorific value usually cannot give a satisfactory result and this alteration of coal fired boilers can be only an emergency solution for a short period.

Replacement of an old boiler with a new biofuel one gives practically as good result as building a new boiler plant, but may be less expensive, because the premises, pipelines and electrical installations of the existing boiler plant can be used. However, adjustment of the new storages and fuel conveyors with the complex of earlier boiler plant is somewhat more complicated than building a new boiler plant. As the capacity of solid fuel burners usually does not exceed some hundreds of kilowatts, this solution can be used only for the readjustment of lower capacity local heating boilers and smaller DH boilers [9].This solution is also suitable for boilers in small family houses.

A pre-furnace can be built to a boiler of almost any type, but it should be considered that the boiler heating surfaces could be easily cleaned from fly ash. This should be taken into account especially when equipping the fire tube boilers with a pre-furnace, because it may obstruct the access to horizontal fire tubes and make regular cleaning complicated.

The flue gases from the combustion of biofuels and peat inevitably contain fly ash and for reducing its deposition on the heating surfaces and making their cleaning easier, the heating surfaces with vertical gas-tubes would be a good solution.

3. Equipment used in Lithuania biomass power plants

Given the wide range of properties of presented biofuels they can be used in various burning technologies:

1. Dust (pulverized) combustion – used vary rarely and only when for example wood sanding dust is mixed with liquid fuel;
2. Grate combustion technology – various types of grates are used. They can be divided into two sub groups, like stationary and moving grates;
3. Combustion in fluidized bed – power plans can be use stationary or circulating fluidized bed.

When burning solid biomass biofuels, choosing the right boilers can be calculated by the needed power output and best suitable technology. Example of the classification according to their use, are indicated in Table 1 [2].

Table 1 Boiler classification by their use

Area of usage	**Output power**
Individual home boilers	15–40 kW
Boilers in apartment houses	40–400 kW
Central heating boilers	0,4–20 MW
Industrial boilers	1–80 MW

Different combustion technology can be used only in specific places according to the boiler capacity. This is calculated including technical and economic viability.

3.1. Grate combustion furnaces

Grate combustion technologies are one the most commonly used in low or medium and low capacity power plants. Usually they are divided into furnaces with manual or automated biofuel feeding system, but nowadays number of manually fed furnaces. In the private house and central heating sectors more widely are used boilers with automatic fuel feeding systems and the ash removal usually can be carried out manually due to low wood biofuel ash level.

Grate combustion technology is a key element of the furnace design. There are many different types of the grate that are used and they can be classified into [2]:

1. Sloped fixed grates;
2. Sloped moving grates;
3. Chain grates;
4. Special grates, with characteristics design for non-traditional fuels like waste.

Different types of grate furnace have their own unique burning technology.

3.1.1. Furnaces with sloped fixed grates

Mostly in this type of furnaces grates are mounted at a certain angle, which lets the biofuel fall only by gravity from the drying zone to the combustion zone (Fig.6) [2].

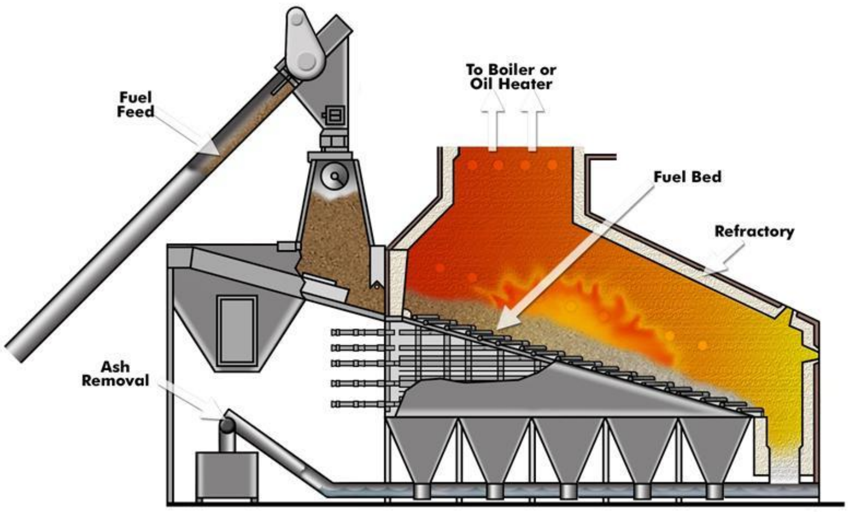

Fig. 6 Furnace with sloped fixed grate

Choosing the right angle of fixing the grates usually depends on the chosen fuel in the power plant, because the angle should be equal to the fuel dipping angle.

3.1.2. Cone shaped furnaces with fixed grates

Some biomass power plans tend to used not only furnaces with sloped grates, but they chose cone shaped furnaces (Fig. 7). In those kind of furnaces biofuel is fed by screw feeder from bottom to the top or vice versa from the top to bottom [2]. This kind of furnaces use up less more space, but price is much higher.

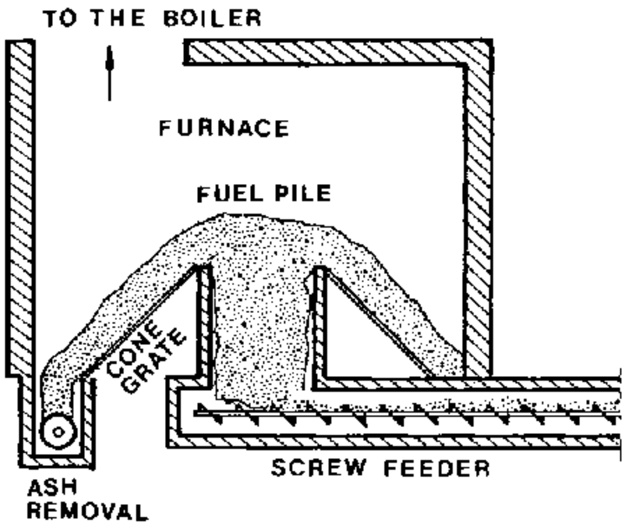

Fig. 7 Cone shaped furnace

3.1.3. Furnaces with sloped moving grates

In the furnaces, which use moving grates movement of the fuel can be controlled much better because of the bed movement (Fig. 8). With this kind of system distribution of the fuel is more uniform, thus leading to more efficient combustion and reducing harmful burning products of the burning process [2]. One of the sub types of this kind of furnace that some biomass power plants use is double grate design furnaces with a fixed upper part for the fuel drying and less sloped moving grate in the combustion zone.

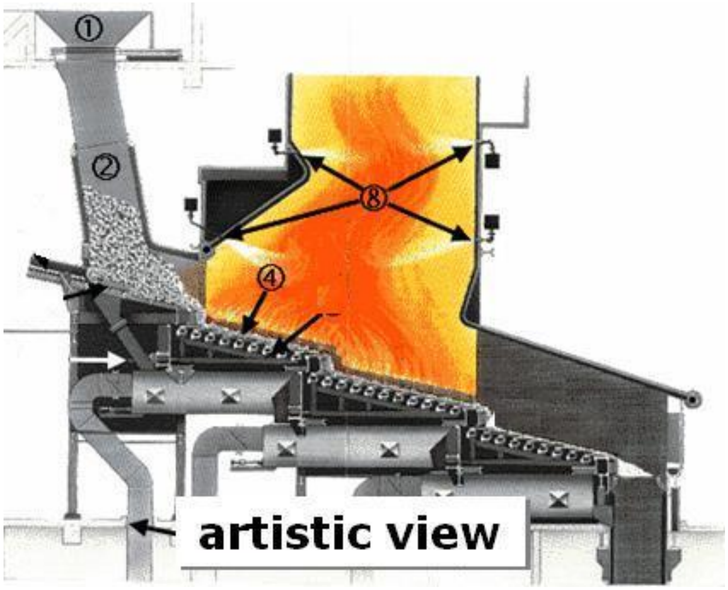

Fig. 8 Sloped moving grates furnace

In this kind of furnaces grate elements move in chessboard kind movement. This movement ensures uniform biofuel layer thickness and smooth movement into combustion zone. Furnace walls don't have any heating elements, for this reason this type of furnace is ideal for wet (35-55% humidity) biofuel.

Inside the furnace the ceramic walls are cooled by the air, which is used in the combustion process. Thus air inside is heated and therefore the combustion conditions are improved. When using very wet fuel, walls in the combustion area shouldn't be cooled and those are usually covered with special ceramic coating. Coatings operating temperature is very high and is enough to radiant heat from the walls to dry the biofuel, contain suitable combustion conditions in the combustion zone [10].

If the dry biofuel would be burned in the non-cooled furnace, the fuel bed and the flame temperature would rise dramatically, thus creating slagging of the grates and damage to the interior of the furnace or even movement mechanism.

3.1.4. Furnaces with moving cone shaped grates

In this kind of furnaces biofuel is fed from the bottom to the combustion area by the rotating conical grate (Fig. 9). Using this furnaces content of moisture in biofuel can vary from particularly low or to very high humidity (65%).

Biofuel is fed to the combustion area from the bottom to the centre of the cone by moving grates, then it's distributed throughout the tapered surface. Using a screw feeder, you can burn virtually any biofuels.

The diameter of the conical grate depends on the furnace capacity and it can vary from least 3,5 MW furnaces that has the diameter of 4,15 m and a maximum of 20 MW with diameter of 9,5 m [10].

Fig. 9 Conical grate furnace

3.1.5. Furnaces with chain grates

It’s the most commonly used technology in high power biomass power plants. Chain grate furnaces are ideal for usage, because power plants can burn several types of biofuels in the same furnace (Fig. 10).

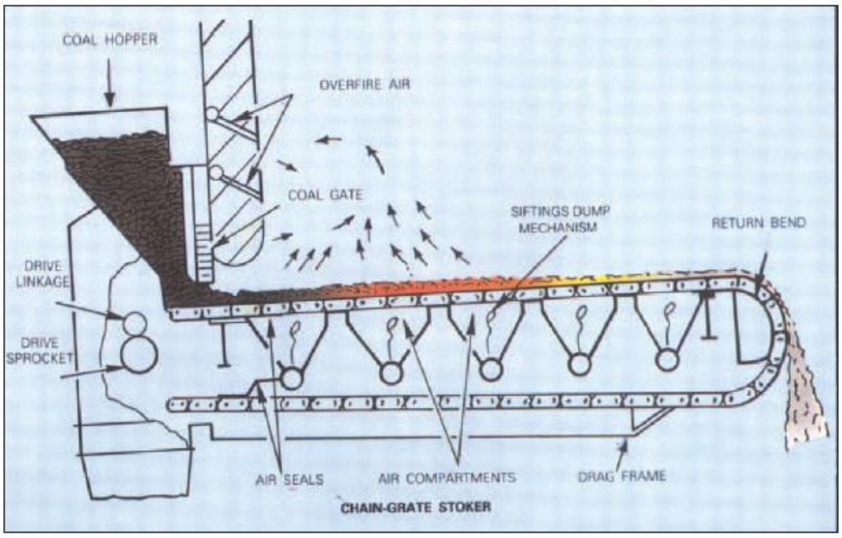

Fig. 10 Example of Chain grate furnace [11]

Mainly for this kind of furnaces biofuel is wood chips, but companies can use peat at the same time. Changing the movement speed of the chain grate, movement of the fuel can be easily adjusted. Thus, having the possibility to keep the fuel burn completely without any other sub products [10].

During combustion, if the power plant decide to the change one fuel to the other it is necessary to change the speed of the grate movement, as well adjusting air supply amounts and proportions.

3.2. Fluidized bed furnaces

Burning solid biofuels, the increasing flow rate of fresh air can cause an affect when air lifts the layer of biofuel and the biofuel particles float in air. It can appear that the fuel bed begins to boil, for this phenomena it’s called fluidized furnace.

Moisture, all the released volatile substances, ash and fine particles of the biofuel can be removed. Fine fuel particles and volatile substances burn in the combustion chamber above the fluidized bed [12].

Fluidized furnaces can be classified:

1. By the temperature of the boiling bed;
   a. High temperature fluidized bed can reach temperature from 1100 °C up to 1200 °C and the low temperature fluidized bed reach temperatures of 750 °C to 950 °C.

2. Accordance to the degree of oxidation of the biofuel in fluidized bed;

3. Accordance to the output of heat from the fluidized bed;

   a. It can be bubbling or circulating fluidized bed.

4. According to the pressure which of the burning process;

   a. Furnaces working at atmospheric or under pressure.

3.2.1. Furnaces with stationary fluidized bed

Using stationary fluidized bed furnace biofuel is fed into the special burning fluid sand layer that is lifted off the distribution plate by blowing air through the plate. Fluidized bed combustion takes place in the layer that is consisted of an inert bed material and burned ashes. Combustion as process takes place both in the dense bottom layer and in less dense upper layer (Fig. 11).

This kind of the combustion technologies are one of the most used and best suited for biofuels, peat and waste incineration [12].

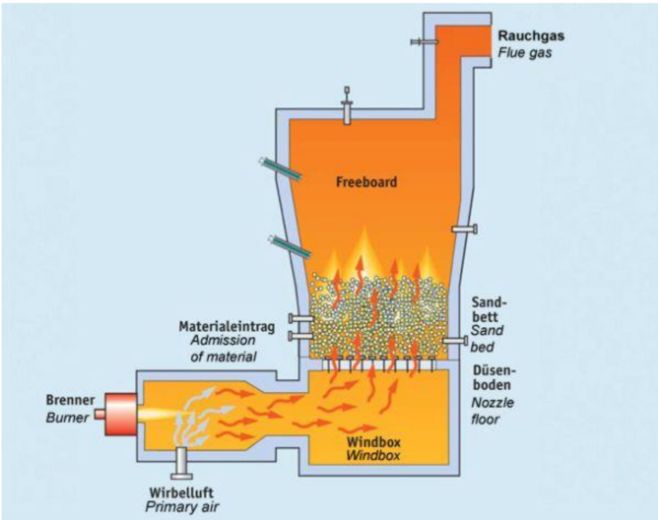

Fig. 11 Example of stationary fluidized bed [13]

3.2.2. Furnaces with circulating fluidized bed.

When the air flow of fresh air in the furnace is increased more than it's necessary, burning particles are taken lift up along with the air flow. In the cyclone solid particles are separated from the air and gas flow and are directed back to the combustion chamber [11]. Since the burning fuel circulates between the furnace and the cyclone, this combustion technology is called circulating fluidized bed (Fig. 12).

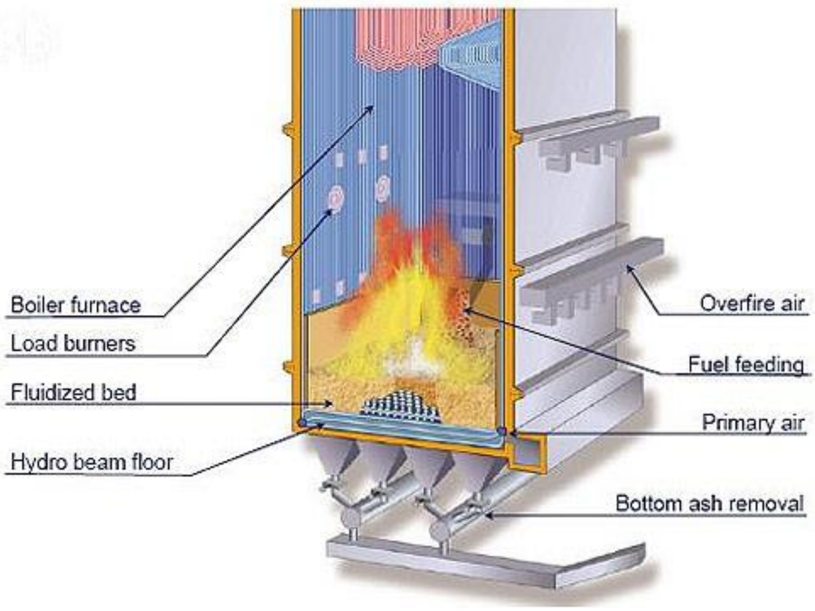

Fig. 12 Example of fluidized bed [14]

Circulating fluidized bed boilers are used in power plants where the required output is greater than 50 MW. Boiler wall structure is fully water cooled and its gas sealed. Burning biofuel bed temperature is usually ranging around 800 °C and because of the mass temperature is almost uniform in all boiler. This kind of temperatures and technology is perfect for burning various biofuels and mixing them with coal or waste [15].

Biofuel boilers with a stationary fluid bed need constant fuel feeding speed and fresh air quantity. This lest keep constant fuel particle size in all of the furnace

This type of biomass power plants with stationary fluid bed furnaces today is one of the most advanced biomass burning types that have more operational stability as comparing to other techniques. But for these biofuel boilers with circulating fluid bed would require much bigger investment [16].

3.3. Economizers

District heating plants is usually use high humidity timber when producing heat in biomass power plants. When this kind of biofuel there is high concentration of evaporated water and for this reason there is a huge loss of disposable heat, which is produced in the power plant. In order to reduce these losses and gain additional heat from the same biomass, usually Lithuanian biomass power plants use economizers (Fig. 13). There are two types of economizers, but mainly in Lithuania power plants are using condensing economizer of the high humidity percentage. Because of the economizers, power plants can gain additionally from 20% to 30% of thermal energy. This is one of the most promising measures for increasing the burned biofuel efficiency [17].

Condensing economizer is a tubular heat exchanger usually made from stainless steel. Such economizers can extract heat is much higher and for this reason we can get more water vapour condensation in the flue gases, thus lowering the cooling water temperature before economizer. In the flue gases water vapour concentration is much higher than the ambient air. When the excess air in the flue gases is much greater then typically, then the relative humidity is lower and therefore conditions for condensation to take place are much worse.

Fig. 13 Example of condensing economizer inner construction

Condensation economizer heat extraction depends on:

- Condensation of water vapour in the smoke, if there is more than better;
- From the cooling water temperature - lower the better;
- From the excess air ratio - lower the better.

The construction of the condensing economizer allows emitted smoke flow into the upper part of the economizer, then flowing down the vertical pipe inside and lastly coming out the bottom of the economizer (Fig. 14). When passed through the economizer tubes, smoke is cooled down to a temperature just few degrees higher than the inflowing hot water temperature. Economizer upper collector is constantly sprayed with a condensate. This kind of spraying is required so that the upper collector is maintained clear, thus avoiding blockaded. Another goal for this is that the heat exchange between the flue pipes and economizer wall is improved. The condensate for spraying inside the economizer is taken from the lower conical part in the middle and is pumped into the upper part of the economizer nozzles. The collected condensate is taken from the middle, because it’s the cleanest and can be used for spraying. Usually in the lower part the deposition of the smoke particulate can collect and created a sludge, which can block the nozzles. Returning hot water in economizer is used to cool the smoke and transfer the heat into required spot. Returning hot water is fed into the economizer by the help of a pump. Returning hot water flows into the economizer lower part by transferring true a space across in economizer tubes and flows out of the economizer at the top. Economizer and all the pipeline is protected against excessive heating water pressure by the safety valves.

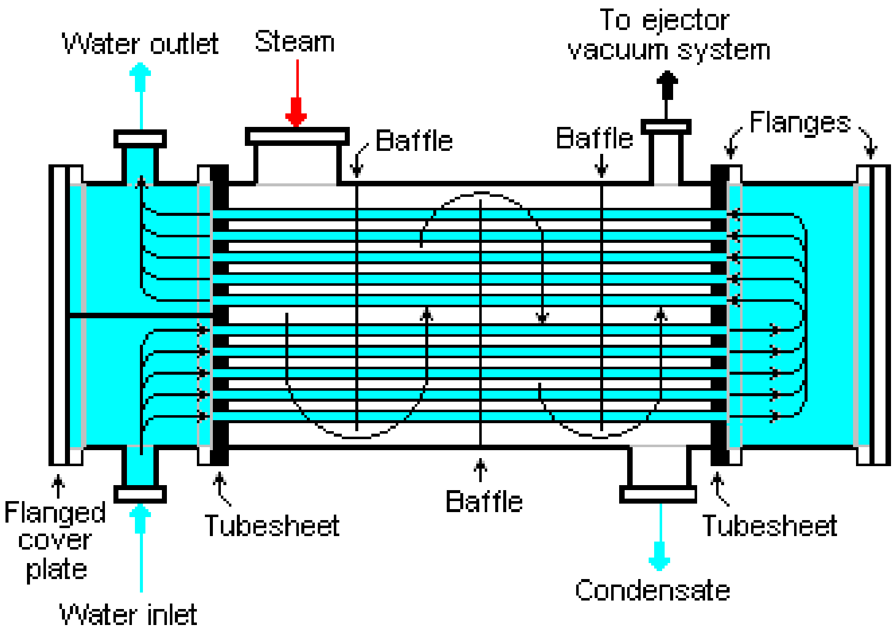

Fig. 14 Workings of condensing economizer [18]

When looking the operating principles of the condensing economizer, everything begins with dry cleaning in lower part of the economizer by removing the dirty water. With this the condensate is supplied to the coagulant mixing tank. All the coagulant dirt molecules start to bind to larger particles. After all the mixing from the previous containers, condensate enters into the flocculants mixing tank, there everything is bonded to a larger dirt particles. When everything is combined into larger particles, the mix then falls into the plate precipitator in which impurities are deposited at the bottom and at the top is transparent water rises. Water is later returned back to the economizer nozzles or poured down the drain before it reaches normal pH balance.

Looking at the use of condensing economizers the advantages are [19]:

- Efficiency of the power plant is improved by 20-30%;
- Lower costs of operation;
- Installation is possible both in new buildings and for existing boilers;
- You can install one economizer for several boilers;
- Longevity - economizer can work for an average of 20 years;
- Economizer is made of stainless steel; Economizer cleaning efficiency can reach up to 90%;
- Reducing the environmental thermal pollution, when smoke temperature for the economizer is only 40-60^0;

- Low temperature difference between the incoming water and the emitted flue gas.

4. Analysis of biomass power plant model for designed city

4.1. Statistical calculations

Theoretical analysis will be provided, what type of biomass power plant a typical, medium size city in Lithuania could use. All the statistical data is taken from Lithuanian Department of Statistics [20], which shows that a medium size city in Lithuania has around 15000 inhabitants. Data of heat demand of a medium city is taken from 2013.

4.1.1. Annual heat demand and heat power calculation

Analysing possibilities for future biomass power plants, first of all the data of average of heat that is being used true all year has to be collected. For this analysis the date was taken from 2013. In the table the average amount of heat was taken form Lithuanian Department of Statistics and the thermal power was calculated using formulas [21]:

- Calculate thermal power for every month:

$$Q_{s,men} = \frac{Q_{vid,men}}{h} \tag{1}$$

where $Q_{vid,men}$ - amount of heat for a month;

h – hours.

- Calculating the average annual power, we have to sum up all the months data:

$$Q_{s,M} = \sum_{i=n}^{n} Q_{s,men,n} \tag{2}$$

where $Q_{s,men}$ - thermal power per month.

Table 2 Thermal heat and power data

Month	Average amount of heat (MWh)	Thermal power (MW)
	2013	***2013***
January	463	0,64
February	331	0,46
March	370	0,51
April	208	0,29
May	92	0,13

June	71	0,1
July	84	0,12
August	88	0,12
September	90	0,13
October	165	0,23
November	253	0,35
December	329	0,46
Total:	**2544**	**3,5**

Heat power calculations are needed to determent what amount of power system has to have that it could meet the needs of the necessary heating requirements. The results of the calculations are presented in the graph (Fig. 15).

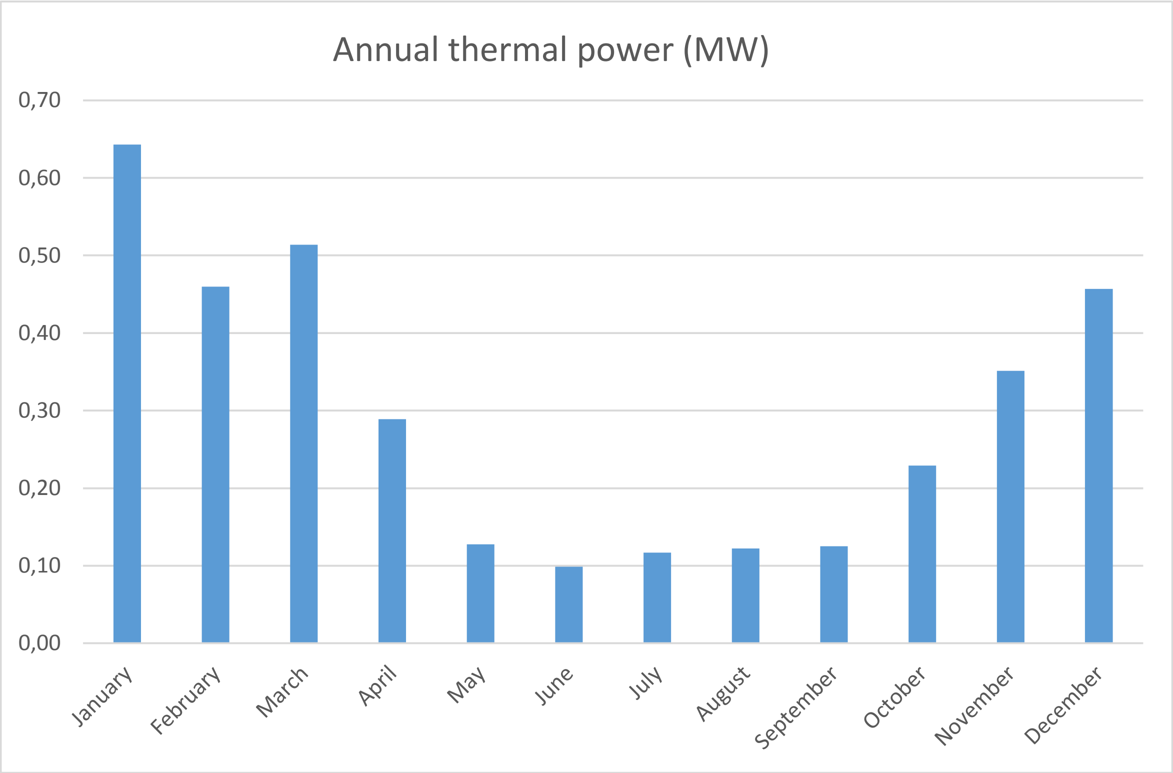

Fig. 15 Annual division of thermal power per months.

From the graph it is seen that the biggest consumption of thermal power was during December – March months and during the rest of the year consumption dropped drastically, so the monthly power consumption ranged from 0,1 MW up to 0,64 MW. This means that industrial power plants, which the boiler capacity usually starts from 1 MW can't work effectively during all the year. For this reason the engineers of the power plants have to calculate the minimum reserve at which the boiler can still work effectively and produce energy at normal cost [22]. Additionally it is seen that the total consumption during the year reached 3,5 MW, so the power plant has to be built for this specific amount of energy.

4.1.2. Selecting energy source and calculating consumption quantity

When selecting the biofuels, wood chips, wood pellets and straw were taken as being the most popular biofuel types in Lithuania [23].

To select the best biofuel an important part goes to the fuel humidity percentage, because it can affect the choice of the technology of the power plant. Humidity can affect total volume of the fuel that is being used. In the table 3, the data of biofuel humidity and calorific value are presented [24]. This data will be used to calculate the total volume that could be used with the annual heat power that uses medium sized city in Lithuania.

Table 3 Data of wood fuel types

Biofuel type	Humidity	Calorific value, Q_z (MJ/t)
Wood chips	55%	2
Wood chips	40%	2,89
Wood pellets	8%	4,44
Straw	15%	4

The amount of biofuel needed in tones, which could meet the heat energy that is demanded, will be calculated using the data of average amount of heat power from table 2 and the humidity will be taken from table 3. Calculations will be made for different biofuel types, with different humidity level, using formula:

$$m = \frac{Q_{vid,men}}{Q_z} \tag{3}$$

Where m - mass (kg), 1000kg =1 t;

$Q_{vid, men}$ - amount of heat for a month (MWh);

Q_z - calorific value (MW/t).

- Wood chips volume in tones, when the humidity is 55% and calorific value 2 MW/t:

Table 4 Biofuel volume in tones when wood chips humidity is 55%

Month	Volume, t
January	231,5
February	165,5
March	185
April	104
May	46
June	35,5

July	42
August	44
September	45
October	85,5
November	126,5
December	164,5
Total:	**1272**

Total amount per year of wood chips that has humidity of 55% reaches 1272 tones, when the power plant energy is 3,5 MW.

- Wood chips volume in tones, when the humidity is 40% and calorific value 2,89 MW/t:

Table 5 Biofuel volume in tones when wood chips humidity is 40%

Month	**Volume, t**
January	160,2
February	114,5
March	128
April	72
May	31,8
June	24,6
July	29,1
August	30,4
September	31,1
October	57,1
November	87,5
December	113,8
Total:	**880,3**

Total amount per year of wood chips that has humidity of 40% reaches 880,3 tones, when the power plant energy is 3,5 MW.

- Wood pellets volume in tones, when the humidity is 8% and calorific value 4,44 MW/t:

Table 6 Biofuel volume in tones when wood pellets humidity is 8%

Month	**Volume, t**
January	104,3
February	74,5
March	83,3
April	46,8
May	20,7
June	16
July	18,9

August	19,8
September	20,3
October	37,2
November	57
December	74,1
Total:	**573**

Total amount per year of wood pellets that has humidity of 8% reaches 573 tones, when the power plant energy is 3,5 MW.

- Straw biofuel volume in tones, when the humidity is 15% and calorific value 4 MW/t:

Table 7 Biofuel volume in tones when straw humidity is 15%

Month	Volume, t
January	115,8
February	82,8
March	92,5
April	52
May	23
June	17,8
July	21
August	22
September	22,5
October	41,3
November	63,3
December	82,3
Total:	**636**

Total amount per year of straw that has humidity of 15% reaches 636 tones, when the power plant energy is 3,5 MW.

Making all the calculations, the volumes of every biofuel type were found out. For better analysis all the result are plotted in the graph, which presents annual fuel consumption (Fig. 16).

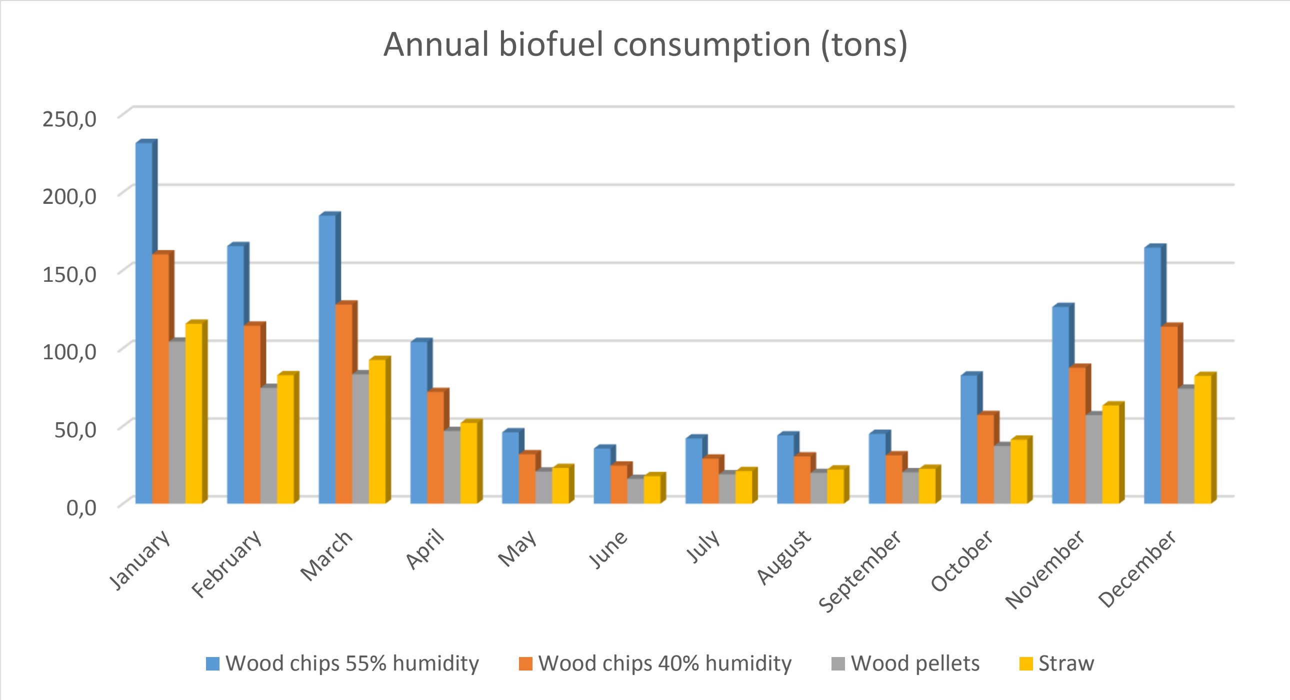

Fig. 16 Biofuel consumption division per months

In the plotted graph we can see how the volume of fuel changes because of the humidity. We can see that burning wood chips, which have 55% humidity the total usage can reach 1272 tons per year and when we are using wood pellets, which has the least humidity percentage, the fuel consumption is only 573 tones. The main thing that influences the amount of the fuel is the differences in the thermal energy that we are getting from one tone of fuel [24].

4.2. Calculating biomass power plant

After calculating statistical yearly demand of medium sized Lithuanian city, we got that the biomass power plant should generate 3,5 MW thermal energy and consumption of biomass fuel should not exceed 1272 tones if the power plant is using wood chips of 55% humidity, 880 tones if the power plant is using wood chips of 40% humidity, 573 tones if the power plant is using wood pellets of 8% humidity or 636 tones if the power plant is using straw of 15% humidity.

4.2.1. Technical data for equipment selection

Analysing possible biomass power plant for a medium sized Lithuanian city, combustion technology is selection by the biofuel type. All the combustion technology data is taken from analysis of the common template for a possible biomass power plant [25]. This evaluation helps to determinate the most technical and economical feasible choice.

- Biofuel boiler technical data, when the fuel is wood chips:

Table 8 Wood chips boiler technical and economical data

Technology	The boiler fired with wood chips
Energy/technical data	
Generating capacity for one unit, MW	~12
Efficiency, %	92
Technical lifetime, years	25
Financial data	
Specific investment (Mil. €/MW device power)	0,5 – 1,1
Fixed and variable annual operating costs (th. €/year 1 MW device power)	4,6

From this table it is seen that boiler, which burn wood chips usually can generate maximum up to 12MW and efficiency of this kind of boiler reaches around 92 percent. It is typical that this kind of boilers specific investment can vary from 0,5 up to 1,1 mil. Euros per 1 MW of produced energy and operational cost can reach up to 5,4 thousands Euros per 1 MW of the boilers capability.

- Biofuel boiler technical data, when the fuel is wood pellets:

Table 9 Wood pellets boiler technical and economical data

Technology	The boiler fired with wood pellets
Energy/technical data	
Generating capacity for one unit, MW	< 2
Efficiency, %	92
Technical lifetime, years	25
Financial data	
Specific investment (Mil. €/MW device power)	0,25 – 0,55
Fixed and variable annual operating costs (th. €/year 1 MW device power)	2,7

From this table it is seen that boiler, which burn wood pellets usually can generate no more than 2 MW of energy and efficiency of this kind of boiler reaches around 92 percent. It is typical that this kind of boilers specific investment can vary from 0,25 up to 0,55 mil. Euros per 1 MW of produced energy and operational cost can reach up to 2,7 thousands Euros per 1 MW of the boilers capability.

- Biofuel boiler technical data, when the fuel is straw:

Table 10 Straw boiler technical and economical data

Technology	The boiler fired with straw
Energy/technical data	
Generating capacity for one unit, MW	~12
Efficiency, %	87
Technical lifetime, years	25
Financial data	
Specific investment (Mil. €/MW device power)	0,5 – 1,1
Fixed and variable annual operating costs (th. €/year 1 MW device power)	4,0

From this table it is seen that boiler, which burns straw usually can generate up to 12 MW of energy and efficiency of this kind of boiler reaches around 87 percent. It is typical that this kind of boilers specific investment can vary from 0,5 up to 1,1 mil. Euros per 1 MW of produced energy and operational cost can reach up to 4 thousands Euros per 1 MW of the boilers capability.

4.2.2. Furnace and boiler calculations

Looking at the possible choice of a biomass power plant for a medium sized Lithuanian city, protection of the atmosphere is a must for an industrial heat production. When cities or companies choose a specific boiler or a furnace, pollution is taken into account for various technical and the most, for economic reasons. Less pollution is produced from a power plant, less the city has to pay pollution taxes. Typically with the combustion products into the atmosphere the emissions of carbon monoxide, nitrogen oxides and hard particles will be release.

In this evaluation, the required heat power is 3,5 MW, the diameter of the chimney is taken 1 meter, temperature of gas coming from the boiler is 170 ^{O}C and all 3 different types of biofuel are looked up. Calorific value of every type of fuel is used from table 3.

In this step, we will calculate the amount a produced smoke. For this we will use [26]:

- Formula calculating theoretical volume of the flue gas (m^3/h):

$$\boldsymbol{V_T = ((\propto -1) * V + V_{theo}) * B} \quad (4)$$

where α – excess air ratio (α = 1,17),

V – theoretical quantity of air. From the references [26], V = 2,82 m^3/kg;

V_{theo} – theoretical amount of smoke, when 1 m^3 of fuel is burned. From the references [25], V_{theo} = 3,75 m^3/kg.

B – maximum hourly fuel consumption (kg/h). It is calculated by using formula [25]:

$$B = {Q * 0.86} / \left({Q_z}/{0.042} \right) * \eta \qquad (5)$$

where, Q – thermal heat power (W);

Q_z – calorific value of the fuel (MJ/t);

η – performance ratio of the boiler (%).

In this part the calculations were made and the results are presented in the table below:

Table 11 Theoretical volume of the flue gas and maximum hourly fuel consumption

Fuel type	**B (kg/h)**	**V_T (m^3/h)**
Wood chips (55% humidity)	3894,9	16473,2
Wood chips (40% humidity)	2695,5	11400,1
Wood pellets	1754,5	7420,4
Straw	2059,4	8710

To analyse the results, a graphical presentation was created, which shows theoretical volume of flue gases and maximum hourly fuel consumption (Fig. 17).

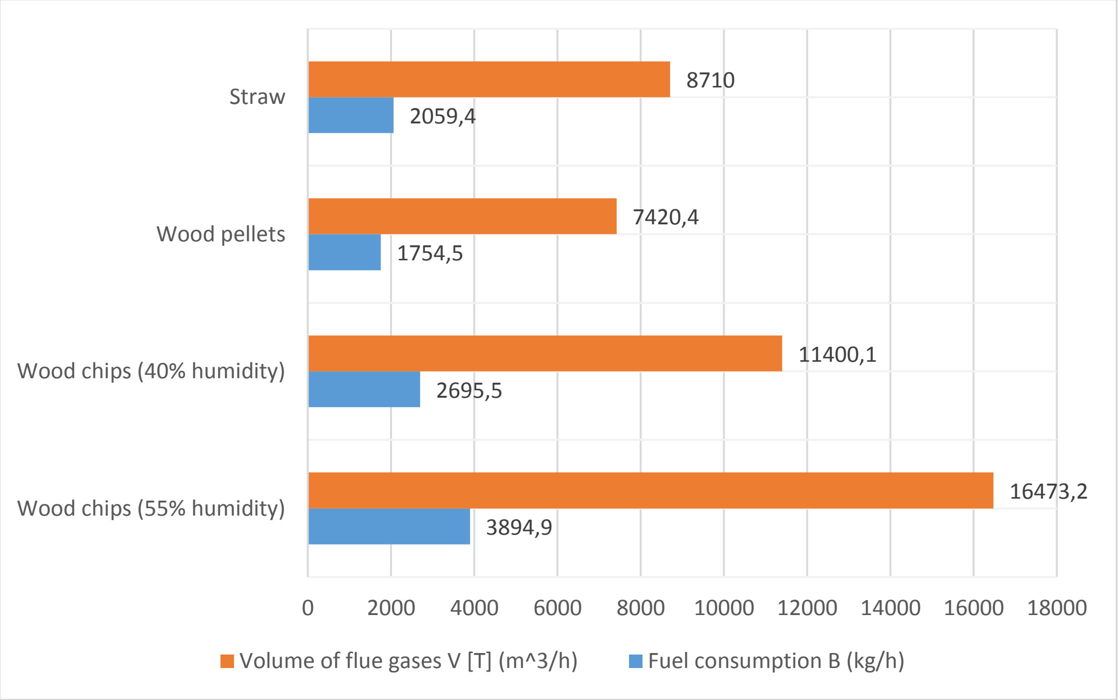

Fig. 17 Volume of flue gases and fuel consumption

From the table 11 and figure 17 it can be seen that biggest consumption, when the power plant is working in its maximum capacity, the wood chips of 55% humidity are burned as the main biofuel source. For this reason this kind of fuel produces the biggest amount of flue gases that is being emitted to the atmosphere.

- Formula calculating actual volume of the flue gas [27]:

(6)

$$V_A = {V_T * (t_D + 273)}/{273}$$

Where, V_T - theoretical volume of the flue gas (m^3/h);

t_D – temperature of the gas coming from the boiler (^OC).

- Formula calculating velocity of flue gas coming from the chimney [27]:

$$Vel = {4 * V_A}/{\pi * d^2} \quad (7)$$

Where, V_A - actual volume of the flue gas (m^3/h);

d – diameter of the chimney (m).

After all calculations (calculations are presented in the appendixes), the result is:

Table 12 Actual volume of the flue gas and velocity of the gases coming from the chimney

Fuel type	V_A (m^3/h)	Vel (m/s)
Wood chips (55% humidity)	26731,2	9,5
Wood chips (40% humidity)	18499,1	6,5
Wood pellets	12041,1	4,3
Straw	14133,8	5,0

For analysis of results, a graph was plotted, which shows actual volume of flue gases and velocity of the gases coming from the chimney (Fig. 18).

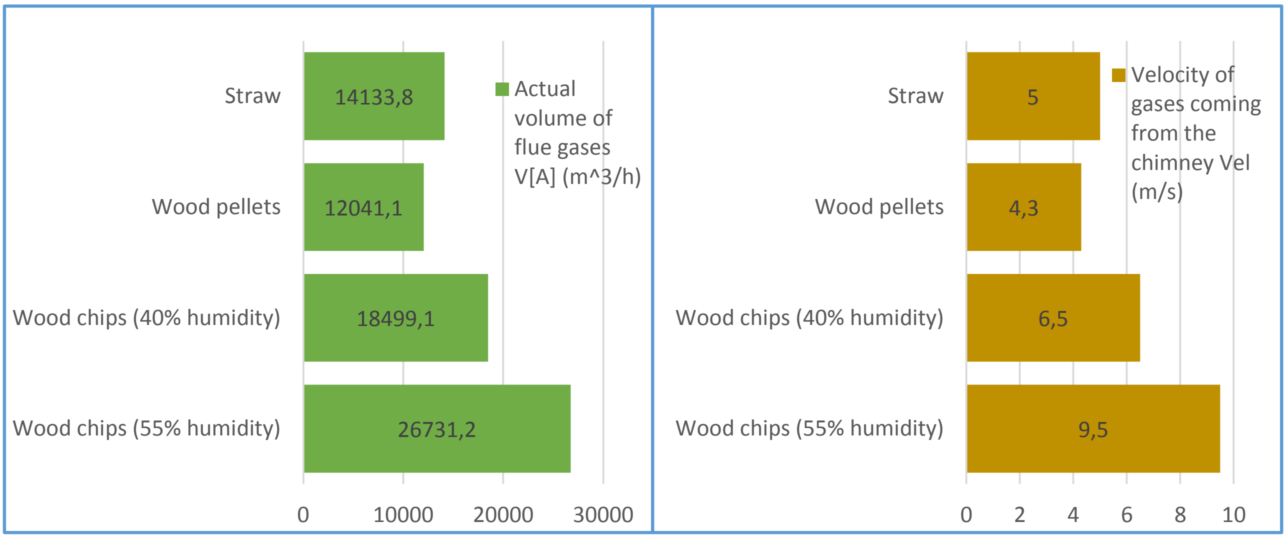

Fig. 18 Actual volume of flue gases and velocity of the gases coming from the chimney

From the table 12 and figure 18, it is seen that the biggest volume of gases is produced by the wood chips of 55% humidity biofuel. At the same time the velocity is greatest when the same wood chips of 55% humidity are burned in the biomass power plant. Those two components influence the total emissions of the biofuel, so for this this kind of biofuel is the most polluting and taxes wises the most expensive biofuel.

After calculating actual volume and the velocity of the gases coming from the chimney, next we have to calculate the yearly CO, NOx emissions and the amount of hard particles released to the atmosphere. When we have estimated how big the emissions are, we can determine which fuel are the worst to use from the ecological point of view. For this reason, we will use this formulas:

- Calculating the yearly carbon monoxide quantity in flue gas (g/s) [27]:

$$\boldsymbol{M_{CO} = 0.001 * C_{CO} * B * (1 - q_4/_{100})} \quad (8)$$

where: C_{co} – carbon monoxide quantity accumulated, when the fuel is burned (kg/t). It's calculated by using formula [27]:

$$\boldsymbol{C_{co} = q_3 * R * Q_z} \quad (9)$$

where: q_3 - heat losses due to incomplete chemical combustion. For biomass q_3 = 1%;

R – coefficient that evaluates heat loss in the smoke, because of CO. For biomass R =1 [27];

Q_z - calorific value of the fuel (MJ/t).

B – maximum hourly fuel consumption (kg/h);

q_4 - heat losses due to incomplete mechanical combustion. For biomass q_4 = 2% [27].

- Calculating the yearly N_{OX} quantity in flue gas (g/s):

$$\boldsymbol{M_{NOx} = 0.001 * C_{CO} * Q_z * K_{NOx} * (1 - \beta)} \quad (10)$$

where K_{NOx} - parameter that describes the amount of NOx per 1 GJ of heat. K_{NOx} = 0,13.

- Calculating the yearly quantity of hard particles in flue gas (g/s):

$$\boldsymbol{M_{HP} = B * A^n * \chi * (1 - \eta)} \quad (11)$$

where A^n - mass of the fuel as the ash content in percents. For biomass A^n = 0,6;

X - coefficient that describes the amount of combustible materials in the remaining slag. For biomass X = 0,005 [27];

η - fly ash catcher capture degree. For biomass η = 0,85 [27].

After all calculations (calculations are presented in the appendixes), the results of emission gases are calculated to tones per year (1 g/s = 31,56 t/y):

Table 13 Calculations of *CO, NOx* and hard particles emissions burning different kinds of biofuel

Fuel type	CO (t/y)	NOx (t/y)	Hard particles (t/y)
Wood chips (55% humidity)	240,80	16	55,23
Wood chips (40% humidity)	240,80	35	38,19
Wood pellets	240,80	82	24,93
Straw	254,69	66	29,35

We got that emissions according to the different fuel types differs. According to the Lithuanian regulations [28], when the power plant total power is equal or more then 1MW, but less than 20MW, the maximum yearly emission are:

- Carbon monoxide *(CO)* = 4000 mg/Nm^3
- Nitrogen oxide *(NOx)* = 750 mg/Nm^3
- Hard particles *(HP)* = 400 mg/Nm^3

So after calculating the yearly emissions, it's know that all the most popular biofuel types in Lithuania doesn't exceeds the maximum limits. But it noticed that some of the fuel types produce more emissions then other types. For this reason the best choice, form the emission stand point, it would be to use the wood chips fuel although the emission of hard particles are the biggest. But this usually comes with this kind of fuel and looking at the emissions, CO and NOx are the most important. The economic impact of the emission to possible biomass power plant will be showed in the economic evaluation part.

4.2.3. Economizer for a power plant

To reach best result of installing a biomass power plant in a medium sized city, installation of economizer is the best practice. As it was presented in paragraph 3.3 there are various types of economizers, but the most popular in Lithuania is the condense economizer. It is selected because of the great efficient when power plant is using biofuel with a high concentration of humidity. Typically this kind of economizer can bust the output of the power plant by 15-20%.

But to choose the best solution for a possible condenser economizer, the heat load must be calculated. For these calculations in our model for medium sized Lithuania city, the formula of economizer heat load will be used [29]:

$$Q_{ECO} = \dot{m}_{ECO} * (h_{ECO2} - h_{ECO1}) \quad (12)$$

where: Q_{ECO} – heat power (kW)

m_{ECO} – mass flow rate of feed water in the economizer (kg/s). Mass flow rate can be calculated using thermodynamics formula:

$$\dot{m} = \rho \frac{dV}{dt} \quad (13)$$

where: ρ – density (kg/m^3). Feed water temperature that is being used in the economizer reaches 170^0. So from the saturated steam table [30], at this temperature ρ = 0,970 kg/m^3:

dV – volume of the economizer (m^3). For this model volume is taken V = 1000m3;

dt – time of the economizer (s). For this model time is taken t = 3600s

h_{ECO2} – specific enthalpy of feed water before the economizer (kJ/kg). From the table of the properties of saturated steam, enthalpy at 170^0 reaches h_{ECO2} = 483,2 kJ/kg;

h_{ECO1} – specific enthalpy of feed water after the economizer (kJ/kg). From theoretical presentation, when using economizers the efficiency improves by 15-20%, so the feed water temperature increases by same percentage. From the properties of saturated steam enthalpy at 190^0 reaches h_{ECO1} = 497,8 kJ/kg.

After collecting all the date and calculations the generated heat load of economizer can be presented:

Table 14 Calculations of condensing economizers heat load

Units	**Data**
Volume (dV)	1000
Time (dt)	3600
Density (ρ)	0,970
Mass flow rate (m_{ECO})	*0,27*
specific enthalpy “before”(h_{ECO2})	483,2
specific enthalpy “after” (h_{ECO1})	497,8
Heat power (Q_{ECO}) (kW)	3,9

After the calculations we get that with this conditions, the heat load of condensing economizer can reach up to 3,9 kW.

4.3. Biomass technical equipment for a medium sized Lithuanian city

After all the calculations, the total consumption of biofuel, total possible volume of emissions and heat power of the boiler and economizer are evaluated, possible technical equipment for a medium sized Lithuanian city can be offered.

For this part as a possible equipment for this kind of power plant, the equipment as comparison will be offered that is made by two Lithuanian companies JSC "Enerstena" and JSC "Axis industries".

4.3.1. Technical equipment burning wood kind biofuel

With all the technical parameters that were collected in previous parts, first equipment form JSC "Enerstena" can overviewed.

When burning wood kind biofuel and mainly wood chips, from JSC "Enerstena", medium sized Lithuanian city, could receive boilers "TERMONERG" [31]. The boilers are of a smoke-tube type with three courses, with an automated cleaning system for the heated surfaces using pressurized air (Fig. 19). Boilers are equipped with maintenance hatches and inspection openings allowing for more efficient operation. The inspection opening is a unique feature only found in boilers manufactured by "Enerstena". Boilers are design and manufacture regarding standard EN 12953. Advantages of these boilers are: high boiler efficiency that can reach up to 90 percent, long boiler service life, automatic cleaning of the surfaces of the boilers and low hydraulic and aerodynamic resistance with low electricity consumption.

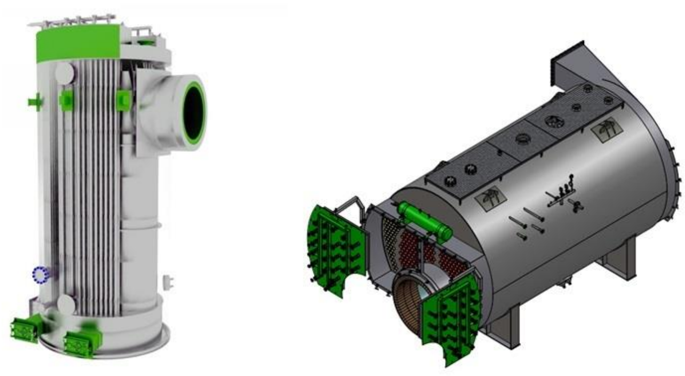

Fig. 19 JSC "Enerstena" boilers "TERMONERG"

Then medium sized Lithuanian city would need furnaces that are made too by JSC "Enerstena". From there products, the best suitable would be "CALIDUM EMBER" [32]. This kind of biofuel combustion furnace (Fig. 20) has an oblique and moving grate, and is operated in accordance with gas generation principles. The combustion process in the furnace is controlled according to the level of oxygen in the flue gas. The fire-resistant structure of the furnace is made of materials resistant to wear and heat. Advantages of this furnace are: furnaces are designed for the combustion of biomass with humidity levels of up to 55% when burning wood chips, furnace frame is cooled by water, emissions NOx and CO, combustion monitoring according to measurements of the CO and O2 in the emitted fumes and available for the combustion of various biomass.

Fig. 20 JSC “Enerstena” furnace “CALIDUM EMBER”

Finally from JSC “Enerstena” with all the equipment that is mentioned, medium sized Lithuanian city would need an economizer that is produced by the same company. For this project the best solution would be economizer “ECONERG” [33]. JSC “Enerstena” can offer not only economizers manufactured (Fig. 21) as heat generating equipment, but also a fully complementary and automated system at a very low cost, which can doesn’t produce any harmful waste. The available condensing economizers can be employed in biofuel boilers with a capacity of up to 50 MW. Advantages of this kind system is that additional capacity of up to 30% may be reached from the nominal boiler capacity, district heating water is heated without an transitional heat exchanger and Effective condensate cleaning system.

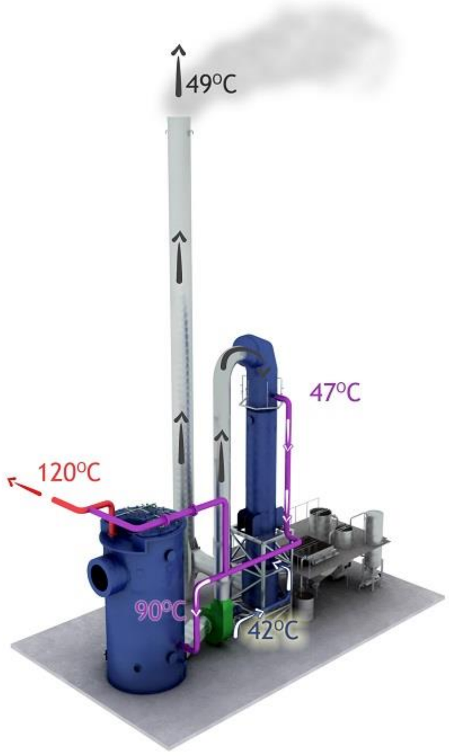

Fig. 21 JSC “Enerstena” condensing economizer “ECONERG”

With all the offered equipment JSC “Enerstena” produces and all the rest of needed additional equipment for biomass power plant. Everything depends on the demand of the customer.

To compare the production of JSC “Enerstena”, another Lithuanian company is taken. JSC “Axis industries” manufactures and install various thermal power equipment. Looking at the demand of the medium sized Lithuanian city firstly this company can offer a suitable boiler.

For the required thermal power JSC “Axis industries” could offer it production boiler “XILO WOOD EV” [34]. EV series is a combination of grate furnaces and water-heating flue-gas-tube boiler, both forming a single compact module (Fig. 21). This kind of combination can offer 2 MW or 4 MW thermal power systems. Biofuel-fired boiler is installed directly on the furnace, therefore, the furnace walls are cooled by boiler water. On the grate, which is cooled by the recirculation flue gas, it is possible to combust wood chips of 30-55% humidity, wood bark, etc. Combustion air supply system allows to tune optimally the burning process and to reduce the emissions by introducing recirculation flue gas. The facility may be additionally provided with boiler soot blowing system. Advantages of this kind of systems is that furnace and boiler combination of the most reputed manufacturers in Lithuania and simple construction allows achieving the lowest manufacturing costs.

Fig. 21 JSC “Axis industries” boiler “XILO WOOD EV”

Then JSC “Axis industries” for a medium sized Lithuanian city with requirements that were specified in previous chapters, can offer condensing economizer. JSC “Axis industries” manufactures “XILO ECO” condensing economizers [35]. This company manufactures direct-contact flue gas condensing economizer witch operation is based on spraying of water (condensed from the flue gas) through the specially designed nozzles into the stainless steel chambers, which ensures very large heat exchange surface (Fig. 22) The flue gas intensively contacts with the sprayed water droplets, which absorb the heat from the flue gas. While the wet flue gas is cooled down, the dew point is reached and the water vapour in the flue gas condenses. This liquid (condensate that is formed from the flue gas) is used in a closed cycle, flows through the plate heat exchanger and transfers the heat to the process, e.g., district heating system. The excessive condensate is removed from the system. Depending on the applied flue gas cleaning system (multi-cyclone, electrostatic precipitator filters, etc.) and flue gas contamination by solid particles, the equipment for condensed water treatment from solid (suspended) particles and sludge sedimentation (consisting of lamella separator, open sand filters, clean water tank, and sludge removal system) may be provided along with this system.

Fig. 22 JSC “Axis Industries” condensing economizer “XILO ECO”

Same as its main competitor, JSC “Axis Industries” can offer all the additional equipment that is needed to start a biomass power plant.

4.3.2. Technical equipment burning straw biofuel

Comparing two biggest bioenergy productions companies that are working in Lithuania at this moment only JSC “Axis industries” can offer solutions for burning straw as biofuel (Fig. 23).

For burning this kind of JSC “Axis industries” can offer straw fired boiler plants “XILO STRAW” [36]. In this kind plant straw bales are lifted onto the worktable of a crusher using a forklift. Four straw bales may be placed on the fuel transfer table. This quantity is sufficient for eight hours of boiler operation when operating with rated capacity under an average calorific value of the fuel. Straw bales are moved from the fuel transfer table to the crusher, from which the crushed straw is transported by means of a scraper conveyor to the screw conveyor, which transfers fuel into the feeder of the furnace. In order to reduce the boiler plant impact on the environment, flue gas cleaning system – a multi-cyclone that cleans the flue gas down to the permitted solid particle concentrations – is used.

Advantages of “XILO STRAW” are that operation of boiler plant is fully automatic, fuel system is suited for operation with rectangle bales, possibility to combust straw as well as straw or wood pellets without performing any modification of the grate, cooled grate that allows burning various types of biofuel of various moisture content (straw up to 20%, pellets up to 8-12%).

Some of the technical specifications:

- Rated power of the system according to the generated thermal energy (hot water): up to 1MW (100%)
- Hot water operating pressure: ≤ 6 bar.
- Hot water operating temperature: ≤ 110°C
- CO: 500 – 1000 mg/Nm³
- NOx: 300 – 500 mg/Nm³
- Solid particles: ≤ 250 mg/Nm³

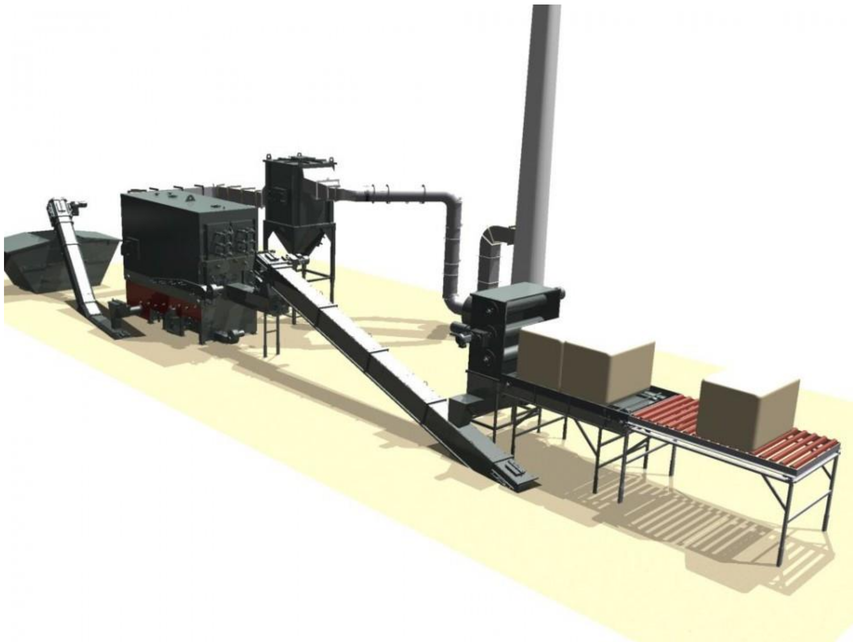

Fig. 23 JSC „Axis Industries" produced straw fired boiler plant „XILO STRAW"

5. Economic evaluation

Looking at all the possible solutions for a biomass power plant important thing is not only look at technical and engineering solutions, but a valuable economic calculation has to be done. Having all the calculations, only then the most economic and beneficial solution can be chosen.

Compering all the possibilities, of the key factors is time. Because building a biomass power plant that would supply thermal power to city, it's a project that lasts more than couple of years. For this reason the considered time of the economic evaluation is 25 years, the operational time of the provided equipment.

During the economic evaluation, the assessment of possible project impact will be done, in which the impact of fuel prices, pollution taxes and the first investment will be evaluated. After that the payback time will be evaluated, which will show how long it will take to make a project economically gainful for the investors. Finally the present net value will be presented looking at the influence of inflation in the country for a presented project and what is project present net value.

5.1. Assessment of possible project impact

Assessing the biomass economic impact, first thing that data of various biofuels must be gathered. This data is taken from Lithuanian Department of Statistics and is presented in the table 15 showing the biofuel prices in the resent years [37]:

Table 15 Various biofuels prices in 2015

Fuel Type	**Wood chips**	**Wood pellets**	**Straw**
Price, €/t_{ne}	172,49	321,45	82,66

Secondly we have to look the pollution taxes that will generated per one year. For this we take the current taxes data from the Lithuanian ministry of Environment and it's presented in table 16 [38]:

Table 16 Rate of taxes for different pollutants in 2015

Pollutant	**Rate of the taxes (EUR/t)**
SO_2	104
NOx	196
Vanadium pentoxide	3855
Hard particles	61

As we know the produced pollution quantity of different biofuel that can be burned in biomass power plant and which is show in table 16, the tax rate can be calculated. The main tax will be calculated only for NOx pollutant, because hard particles tax is set to all the particles except when the burned hard, liquid or gas fuels are burned [37]. Other pollutants aren't produced during the combustion of biofuel.

The calculated tax rate for different biofuels is presented in table below:

Table 17 Tax rate for various biofuel when using it in the analysed model

Biofuel	Tax rate for NOx (EUR/year)
Wood chips (55% humidity)	3136
Wood chips (40% humidity)	6860
Wood pellets	16072
Straw	12936

As it can be seen the biggest price would be for wood pellets and straw biofuel that produces biggest quantity of NOx gases to the atmosphere. The lowest tax rate would be wood chips of 55% humidity. The difference in the prices can be seen in the figure 24.

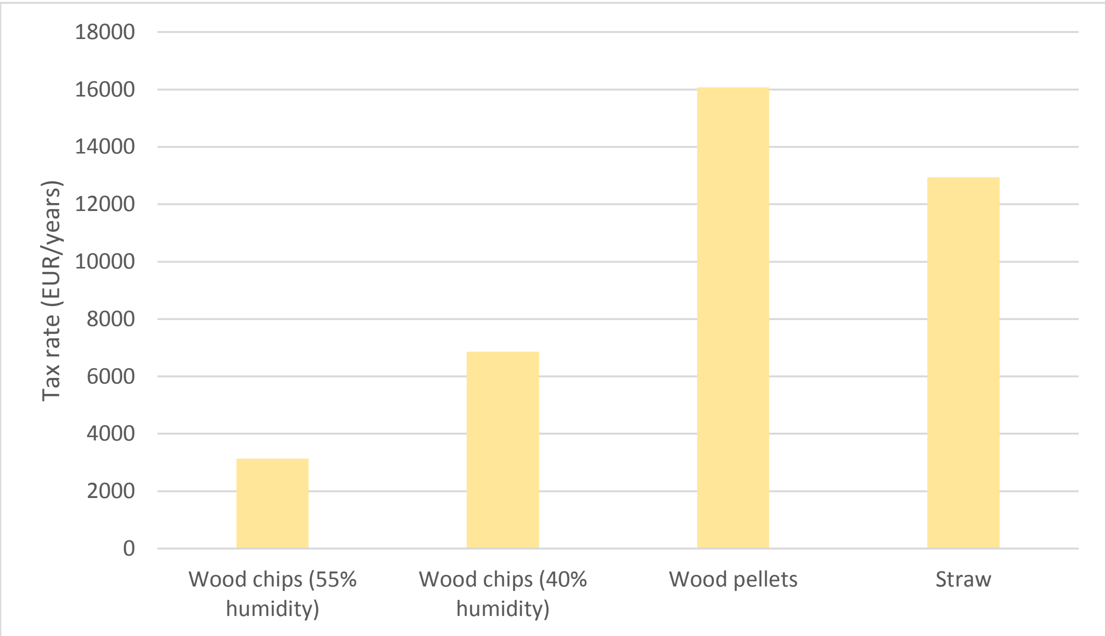

Fig. 24 Tax rate of NOx gases for different kind of biofuel

Plotted graph present graphical illustration of tax rate for various biofuel kinds.

Having all the data, including heat power consumption, biofuel prices and the tax rate, the assessment of this kind of project can be done. For the calculations the necessary investment price and operating costs were taken from tables 8-10. Calculations are made for every kind of biofuel.

Table 18 Different fuel types investment prices, operating costs and cost of the thermal energy

	Biomass boiler burning 55% humidity wood chips	Biomass boiler burning 40% humidity wood chips	Biomass boiler burning wood pellets	Biomass boiler burning straw
Necessary investment only equipment, mln. €	2,8	2,8	1,4	2,8
Used biofuel volume, tons per year	1272	880,3	573	636
Biofuel price, €/t	172,49	172,49	321,45	82,66
Energy cost price for one year, mln. €	0,22	0,15	0,18	0,05
Tax rate, €/year	3136	6860	16072	12936
Operating costs, th. €/year	4,6	4,6	2,7	4,0
Equipment lifecycle, years	25	25	25	25
Total cost of biomass power plant per 25 years, mln. €	3,213	3,238	2,053	3,276

From the table it can be seen that the lowest price are for wood pellets powered biomass power plant. But as technical data suggest, the wood pellets biomass power plants can be produced only up to 2 MW power and this model was for 3,5 MW power plant. For this reason this result can't be taken into account. Then analysing the feasible data, it can be noticed that the final cost are almost similar true 3 different fuel types. But as in Lithuania at this moment the most popular biofuel are wood chips, the best case would be to install up to 55% humidity powered biomass power plant.

5.2. Payback time

Analysing all the possibilities of every project, estimated payback times is an optional calculation. For this reason the simple payback time equation can be used, that can show when the project will become profitable.

To calculate payback time, the formula is used [39]:

$$\boldsymbol{Payback\ time = \frac{Investment}{Yearly\ gain}} \qquad (14)$$

Where *Payback time* – time until the project will become profitable (years);

Investment – primary investment in the project (€);

Yearly gain – gain from the project (€).

For the calculations the primary investment in the project will be used from table 18. To get yearly gain, first we will use the data of yearly thermal power from table 2, where it's 2544 MWh and the average heat price in Lithuania for 2015, which taken form the National Commission for Energy Control and Prices [39] and is 0,12 € ct/kWh. For the yearly gain calculations MWh are changed to kWh and result is that average yearly gain from sold thermal power is *305280 €.*

When all date is put into payback time formula (14), the result is presented in the table 19 bellow:

Table 19 Payback time for different kinds of biofuel powered power plant

Biofuel type	55% humidity wood chips	40% humidity wood chips	Wood pellets	Straw
Payback time (years)	9,2	9,2	4,6	9,2

As it can be seen from the result, the payback times is shortest if the power plant would burn wood pellets. But as mentioned in 5.1 paragraph wood pellets for this model can't be taken into account as the model is designed for 3,5 MW power plant and wood pellet power plant limits are at 2 MW. So in general all for other fuel types the payback time 9,2 years and it means if the price of thermal energy won't change, the power plant will generate profit to its owners.

5.3. Present net value of project

Deciding if the project is a good investment, the implementers of have to calculate the value of all project. This kind of calculations can show what will be the value of their total investment after the projects lifecycle.

The investors of a project use net present value (NPV) calculations to determine the true value of invested money after the life time of a project taking into account deprecation. This kind of deprecation is called discounted rate. The discounted rate is taken form the National bank of Lithuania [41] and it's 7,37 %.

To calculate net present value (NPV) formula is used [42]:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t} - Investement \qquad (15)$$

Where CF_t – cash flow (yearly gain), for this model CF_t=*305280 €*;

k – discounted rate;

t – time of the project (year);

Investment – primary investment in the project.

When all the calculations are made (presented in appendixes), the result of net present value is presented in table 20 bellow:

Table 20 Net present value for different kinds of biofuel powered power plant

Biofuel type	55% humidity wood chips	40% humidity wood chips	Wood pellets	Straw
NPV (mil. €)	0,64	0,64	2,04	0,64

The result show that in the end of the project, that is 25 years, the project will be profitable. For this reason the investment in this kind of project is valuable and financially good decision.

When the result, which shows that the project is financially valuable, is gained, next the investor wants to know at what time the project will start generate a profit. For this reason NPV year by year is analysed and a graph can be presented.

Figure 25 shows the division of NPV and when the project will generate profit.

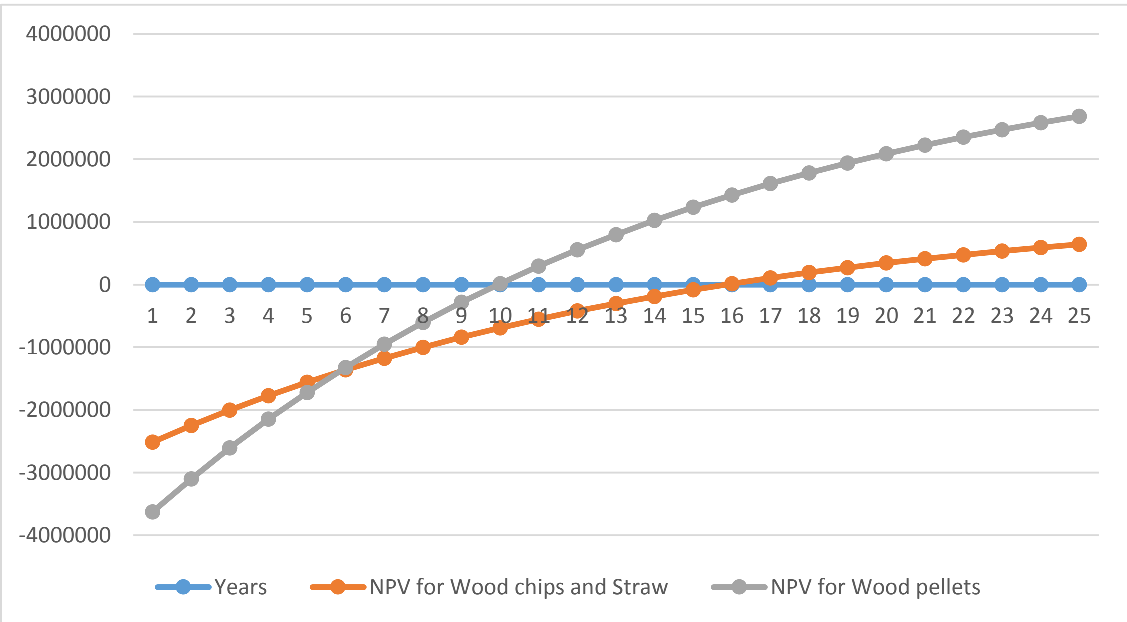

Fig. 25 NPV division per project lifetime

From the figure we can see that the wood pellet powered biomass power plant will start to generate profit much earlier that the wood chips or straw. But for medium sized Lithuanian city power plant model it’s not feasible at it was mentioned in 5.1 paragraph. We can see that the payback time differs from that which was calculated in 5.2 paragraph. It is so, because in this calculations the deprecation of money and equipment is taken into account. For that reason the time period is longer until when the project will start to generate a profit.

6. Conclusions

1. Calculations of thermal power gave a result that medium sized Lithuanian city yearly demand reach up to maximum 3,5 MW of power. This presented a result that this kind of model power plant can equipped only with wood chips or straw biofuel powered boilers. As wood pellet powered boilers reach only up to 2 MW. This means if the demand would be smaller, then the wood pellets powered boilers could be a valuable choice.
2. Analysis of biofuel consumption showed that for a medium sized Lithuanian city, there is a big different when using a fuel with less humidity in it. The difference in fuel consumption can reach almost 70%. For this reason the end price of biofuel is effected, because the total consumption of fuel is one of the major factors effecting the selling heat prices of a power plant.
3. When analysing characteristics of possible furnace and boiler for a medium sized Lithuanian city, pollution is a key factor. The analysis showed that biofuel with less humidity produces less flue gases as hourly fuel consumption is much smaller. This presents that drier fuel is much safer and produces less pollution.
4. Compering various biofuel types, it showed that CO pollutants are the same when wood products are burned and are less than produced by straw biofuel. Looking at the produced hard particles, those are much less when the fuel with the least humidity percentage is burned in a biomass power plant.
5. The least amount of NOx gases can be produced when burning 55% humidity wood chips as compared with other biofuel types. As this pollutant is the only one, which is taxed by the government, it means that the pollution taxes, when burning this kind of fuel is the least one. This show that from pollution taxes point of view, 55% humidity wood chips are the most economical biofuel.
6. The produced pollutants by a biomass power for a medium sized Lithuanian city is less than the regulated quantity and it means that the power plant is safe to use.
7. Condensing economizer is a vital part in a biomass power plant. The calculations showed, that for this kind of modelled biomass power plant for a medium sized Lithuanian city, condensing economizer must be at least 3,9 kW to work.
8. Collecting all the data, it can be seen that the cheapest biofuel is straw, the second one it would be wood chips. As for pollution taxes, when burning straw, power plant owners will have to pay the biggest price as for wood chips pollution taxes are the least ones. As the prices for wood chips vary a lot and when adding everything up, the result shows that economically the wood chip biofuel is the most optimal solution for a biomass power plant.

9. Analysing the total investment for a biomass power plant during 25 years life period, it can be seen that wood pellet and straw powered power plant investment is similar, varies only around 2-5%, the best choice it would be choose wood pellets. As being the most popular biofuel type in Lithuania, prices can vary a lot and the biggest amount of money can be saved on it. Wood pellets weren't considered as they technically can be calculated for this kind modelled power plant.
10. Looking at the economical side of a project, the payback time is one of the key factors. It can be seen that simple payback of this kind of project is around 10 years. This means that for the duration of the project, power plant will generate a profit for the owners of a power plant. But when taking into account the deprecation of money, at the rate of 7.37% which set in 2015, the payback time increases up to 16 years. And the final Net Present value at the end of the project will be around 0,64 mil. €. This show that deprecation is a key factor when analyzing possible investment, but at the end this modelled biomass power plant for a medium sized Lithuanian city would still be profitable for its owners.

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Appendixes

No. 1 Calculations of Actual volume of the flue gas and velocity of the gases coming from the chimney

INPUT

Information bout the furnace	
Q (W)	3500
d	1
Td (oC)	170

colofic value	
Qz cipsai 55proc.	2
Qz cipsai 40proc.	2,89
Qz pellets	4,44
Qz šiaudai	4

Coefficients	
alfa	1,17
V	2,82
V theo	3,75

OUTPUT

B cipsai 55proc.	3894,9
B cipsai 40proc.	2695,5
B pellets	1754,5
B šiaudai	2059,4

V [T]	
cipsai 55proc.	16473,2
cipsai 40proc.	11400,1
pellets	7420,4
šiaudai	8710,0

V [A]	**m3/h**	**m3/s**
cipsai 55proc.	26731,2	7,43
cipsai 40proc.	18499,1	5,14
pellets	12041,1	3,34
šiaudai	14133,8	3,93

Vel	m/s
cipsai 55proc.	9,5
cipsai 40proc.	6,5
pellets	4,3
šiaudai	5,0

No. 2 Calculations of *CO*, *NOx* and hard particles emissions burning different kinds of biofuel

INPUT

Coefficients	
q3	1
R	1
q4	2
K nox	0,13
A n	0,6
X	0,005
ni	0,85

OUTPUT

C [co]	
cipsai 55proc.	2
cipsai 40proc.	2,89
pellets	4,44
šiaudai	4

M [co]	g/s
cipsai 55proc.	7,63
cipsai 40proc.	7,63
pellets	7,63
šiaudai	8,07

M [nox]	g/s
cipsai 55proc.	0,0005
cipsai 40proc.	0,0011
pellets	0,0026
šiaudai	0,0021

M [HP]	g/s
cipsai 55proc.	1,75
cipsai 40proc.	1,21
pellets	0,79
šiaudai	0,93