LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

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BIOENERGY TECHNOLOGY

MASTER´S THESIS

UTILIZATION OF MEAT AND BONE MEAL FOR ENERGY PRODUCTION

Examiners: Professor Esa Vakkilainen

Professor Juha Kaikko

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ABSTRACT

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Utilization of Meat and bone meal for energy production

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At the end of the 1990s the stock breeding in the Europe was suffering from the animal disease epidemics such as Bovine spongiform encephalopathy (BSE) and foot –and mouth disease. The European Union (EU) tackled to this problem by tightening the legislation of animal by-products. At this point, rendering and fat producing industries faces new challenges, which they have to cope with in a way of trying to find alternatives to their products (animal fats and meat and bone meal). One of the most promising alternatives to utilize these products was to use them in energy production purposes.

The purpose of the Thesis was to examine the utilization possibilities of Meat and bone meal (MBM) for energy production. The first part of the Thesis consists of theory part. The theory part includes evaluation of basic properties of MBM as a fertilizer and as a fuel, legislative evaluation and evaluation of different burning techniques. The second part of the Thesis consists of burning tests in Energy laboratory of LUT with different mixtures of peat and MBM. The purpose of the burning tests was to identify co-firing possibilities of peat and MBM and emission- and ash properties for peat and MBM.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto

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Lihaluujauhon hyödyntäminen energiantuotannossa

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Tarkastajat: Professori Esa Vakkilainen

Professori Juha Kaikko

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1990-luvun lopulla Euroopan karjatalous kärsi eläintautiepidemioista kuten suu- ja sorkkataudista sekä hullun lehmän taudista (BSE). Euroopan Unioni (EU) tarttui ongelmaan tiukentamalla eläinsivutuotteiden lainsäädäntöä. Tämän johdosta renderöinti- ja rasvateollisuus kohtasi uusi haasteita, joista niiden oli selvittävä löytämällä uusia vaihtoehtoja tuotteillensa (eläinrasvat ja lihaluujauho). Yksi merkittävimmistä vaihtoehdoista näiden tuotteiden osalta oli alkaa hyödyntää niitä energiantuotannossa.

Tämän diplomityön tarkoituksena oli tutkia lihaluujauhon hyödyntämismahdollisuuksia energiantuotantoon. Diplomityön kirjallisuusosio sisälsi mm. lihaluujauhon lannoite- ja polttoaineominaisuuksien, lainsäädännön ja eri polttotekniikoiden selvityksen. Diplomityön tutkimusosiossa tutkittiin lihaluujauhon ja turpeen yhteispolton mahdollisuuksia Lappeenrannan teknillisen yliopiston Energiatekniikan laboratoriossa polttokokein. Polttokokeiden tarkoituksena oli selvittää lihaluujauhon ja turpeen yhteispoltosta syntyvien päästöjen ja tuhkan ominaisuuksia erilaisilla turpeen ja lihaluujauhon seosyhdistelmillä.

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ABBREVIATIONS

BFB	Bubbling fluidized bed
BSE	Bovine spongiform encephalopathy
CFB	Circulating fluidized bed
CO2	Carbon dioxide
CO	Carbon monoxide
CH4	Methane
CHP	Combined heat and power
FTIR	Fourier Transform Infrared spectroscopy
kg	Kilogram
kW	kilowatts
MBM	Meat and bone meal
MJ	Mega Joules
NOx	Nitrogen oxides
N2O	Nitrous oxide

LIST OF SYMBOLS

q_v	Volume flow rate
q_m	Mass flow rate
Δ	Delta
Φ	Fii
Cp	Concentration Product Value

1. INTRODUCTION

In Finland slaughter industry produces over 200 000 tones of animal by-products per year and from this amount rendering industry utilizes 90 000 tons per year. Meat and bone meal (MBM) is produced in a rendering process as a by-product of the process. Honkajoki Oy and Findest Protein Oy are the only accepted rendering plants in Finland, which can produce MBM in their operation. The total production amount of MBM in Finland is about 30 000 tons per year /1/.

The production process of meat and bone meal is a multi-stage process. At the first-stage there is a reception of raw materials like TSE risk materials and dead production animals from farms. When raw materials are received they are first crushed to the particle size of not more than 50 mm. In practice this means, that target is to crush raw materials to the particle size, which is less than 20 mm. When this operation is finished, next stage consists of separation of metals from crushed raw materials. For this purpose, there is metal separation, which sort out metals from raw materials and also manual checking of metal separation is carried out in this phase. After this stage, crushed raw material mass goes to heating drum. In heating drum, crushed raw material mass is heated up (20 minutes time and 3 bar pressure) with saturated water so that the temperature of the mass achieves 133 °C. This heating process guarantees that heated material is now completely sterile. After this, fat is compressed out from heated material and dry protein-rich material is now grinded to very fine powder with hammer mill. Particle size is now less than 2 mm and at this point material looks like dry lime or potato powder. This fine powder is then put into large bags for storage /6/.

Due to the BSE crisis, safe disposal of MBM is required to prevent the expansion of diseases from stock breeding. According to the Waste

Management Hierarchy, the most potential alternative for safe disposal of MBM is thermal disposal, particularly incineration with energy recovery. Another thermal disposal option for MBM is the co-incineration in cement kilns. Before starting to use MBM as a fuel in energy production, lots of research must be done concerning the composition and behavior of MBM as a fuel, because its composition is not similar with that of coal or wood. MBM is characterized as a high volatile and high ash containing fuel (30 %-w/w) with lower heating values from 17 to 20 MJ/kg. It contains alkali and alkaline earth metals due to its bone content, particularly calcium, phosphorus and chlorine. From this point of view, there exist two types of energy generation applications to use MBM as a fuel in energy production. These two types are utilization of MBM as a secondary fuel in combustion process (co-combustion) and utilization of MBM as a primary fuel in stand-alone combustion process. At this point I am going to evaluate the possibilities to utilize MBM as a secondary fuel in co-combustion process with coal, peat and olive bagasse /28, 29, 30/.

There has been performed several pilot scale co-combustion studies for coal and MBM which have shown, that most often used technology for co-combustion process is circulating fluidized bed technology. Nowadays also industrial scale applications for co-firing of coal and MBM are used in central Europe. Performed studies have shown that MBM has good fuel properties compared to other conventional fuels. Combustion temperatures around 780 °C can be used when MBM is co-combusted with coal so that it is possible to avoid bed agglomeration. Usually quartz is used as bed material in combustion process of MBM and coal. Addition of high mineral matter MBM at low temperatures to coal mixtures can increase the reaction rate of combustion. At high temperatures reaction rate of combustion is reduced because of the fact that mineral content of MBM undergoes major transformation reactions such as crystallization of calcium to hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$). Addition of high volatile

MBM fuel to coal increases CO emissions and this means that use of secondary air is essential to meet the regulations. It can be also noticed from pilot scale studies, that SO_2 emissions were higher, when the amount of coal in the mixture was increased. At this point, the high Ca content of MBM can help to reduce SO_2 emissions because calcium can act as SO_2 scavenger. Co-combustion of MBM with coal also creates NO_x and N_2O emissions. NO_x emissions can be reduced by increasing the share of MBM in the coal mixture. The reduction of N_2O emissions can be achieved due to the catalytic effect of the char and CaO rich ashes. Formation of PCDD/F during combustion of MBM alone is high, but the levels of PCDD/F emissions can be reduced by co-combustion process of coal and MBM. The ash content of MBM is higher than compared to coal. Performed studies have shown that total amount of ash can be reduced, when amount of MBM in the mixture is less than 20 %. It must be also said, that increasing the amount of MBM in the mixture has led to production of ashes with higher content of heavy metals. On the other hand, leaching rates of these chemical species has not increased. It seems that, produced ashes can be characterized as ecotoxic. Recent studies have also shown that MBM produces finer fly ashes. This means that, in addition to cyclone installations in industrial applications, the use of bag filters is necessary to bring down ash levels so that it is possible to meet limits of EU regulations /35, 36, 37, 38, 39, 40/.

Pilot-scale combustion studies for MBM have been done with several blends of milled-peat in circulating fluidized bed boiler. These results have shown that the temperature during combustion of MBM and peat is good to keep around 850 °C with minimum residence time of 2 seconds, because of the demand of Waste Incineration Directive. In that way it is possible to meet legislative requirements for all atmospheric emissions. Combustion studies also indicate, that fluidization and bed agglomerations problems can be avoided, when combustion of MBM-peat mixture was steady /44/.

The experimental procedure consists of combustion trials, which purpose is to define fuel- and ash properties for class 2 MBM and also test how milled peat and MBM can be combusted together. MBM, which is used in combustion trials, has the form of granulated fertilizer (80 % MBM and 20 % grain) and also powder form of MBM (100 %) is used. The combustion trials are carried out with 80 kW VETO boiler at Energy laboratory of LUT.

2. BACKGROUND FOR THE THESIS

At the end of the 1990s the stock breeding in the Europe was suffering from the animal disease epidemics such as Bovine spongiform encephalopathy (BSE) and foot –and mouth disease. The European Union (EU) tackled to this problem by tightening the legislation of animal by-products. At this point, rendering and fat producing industries faces new challenges, which they have to cope with in a way of trying to find alternatives to their products (animal fats and meat and bone meal). One of the most promising alternatives to utilize these products was to use them in energy production purposes /1/.

In Finland slaughter industry produces over 200 000 tones of animal by-products per year and from this amount rendering industry utilizes 90 000 tons per year. Meat and bone meal (MBM) is produced in a rendering process as a by-product of the process. Honkajoki Oy and Findest Protein Oy are the only accepted rendering plants in Finland, which can produce

MBM in their operation. The total production amount of MBM in Finland is about 30 000 tons per year /1/.

Picture 1. Meat and bone meal /2/

2.1 Prizztech Oy

Prizztech Oy is a project-management company, which operates in innovation environment. The main office of the company is located in Pori and other offices are located in Rauma, Kankaanpää and Huittinen. The company is divided to four different branches, which are: Research and Development Units, the Satakunta Centre of Expertise programme, the Business Development Centre and Service Business Unit /3/.

2.2 Honkajoki Oy

Honkajoki Oy is a company, which refines by-products from slaughter industry. The company was established in 1967 to Honkajoki. Main products of the company are: animal feeds, fertilizers, animal fats and district heat. Honkajoki Oy also processes TSE risk-materials and organize national collection and treatment of dead production animals from farms. The company is also accepted to operate as a rendering plant to handle high risk animal wastes /4/.

2.3 Vatajankosken Sähkö Oy

Vatajankosken Sähkö Oy is an energy company, which was established in 1926 to Northern part of the Satakunta. It produces heat and electricity from local energy sources, which is then distributed to the customers. Kankaanpään Kaukolämpö is part of the Vatajankosken Sähkö Oy and its main duty is to produce district heat to the customers' /5/.

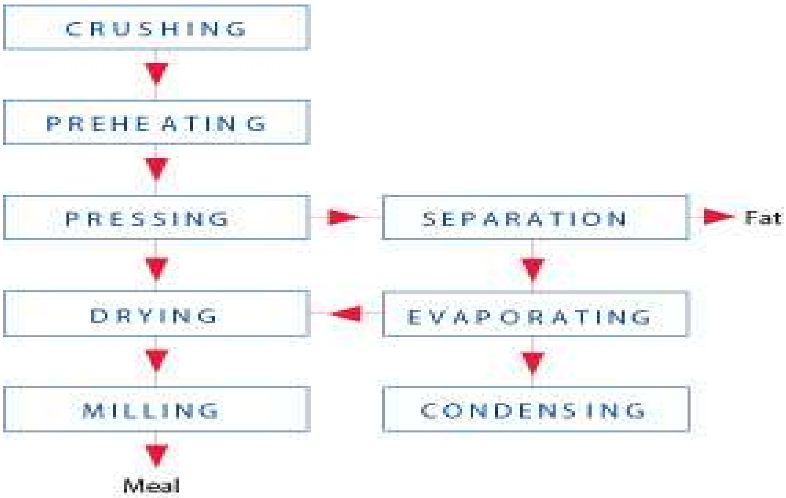
2.4 Purpose of the Thesis

The purpose of the Thesis was to examine the utilization possibilities of Meat and bone meal (MBM) for energy production. Theory part of the Thesis consists of basic theory of MBM and it utilization possibilities in energy production, description of possible boiler techniques and examples of co-firing of MBM with other fuels such as coal and peat. Also characterization of MBM ashes and emissions during combustion are introduced in theory part of the Thesis. Legal issues, such as Waste Incineration Directive and EU animal-by products regulation, are also defined in theory part of the Thesis.

The research part of the Thesis consists of making combustion schedule for the MBM laboratory tests and the actual combustion trials for MBM in laboratory. Purpose of the combustion trials is to define fuel and ash properties of the MBM. The combustion trials are carried out with pellet boiler in Lappeenranta University of Technology. After the combustion trials, the results are analyzed and possible utilization possibilities of MBM as a fuel for energy production will be defined. Also utilization possibilities of MBM ashes and their potential applications for example using as a fertilizer will be defined. The last part of the Thesis consists of technical and economical consideration for less than 20 MW CHP plant.

3. PRODUCTION PROCESS OF MEAT AND BONE MEAL AND ITS UTILIZATION POSSIBILITIES

The production process of meat and bone meal is a multi-stage process. At the first-stage there is a reception of raw materials like TSE risk materials and dead production animals from farms. When raw materials are received they are first crushed to the particle size of not more than 50 mm. In practice this means, that target is to crush raw materials to the particle size, which is less than 20 mm. When this operation is finished, next stage consists of separation of metals from crushed raw materials. For this purpose, there is metal separation, which sort out metals from raw materials and also manual checking of metal separation is carried out in this phase. After this stage, crushed raw material mass goes to heating drum. In heating drum, crushed raw material mass is heated up (20 minutes time and 3 bar pressure) with saturated water so that the temperature of the mass achieves 133 °C. This heating process guarantees that heated material is now completely sterile. After this, fat is compressed out from heated material and dry protein-rich material is now grinded to very fine powder with hammer mill. Particle size is now less than 2 mm and at this point material looks like dry lime or potato powder. This fine powder is then put into large bags for storage /6/.



Picture 3. Rendering process of MBM /7/.

Handled raw material amounts are increased because of Animal by-products regulation. Nowadays it is not possible to bury dead production animals from farms to densely crowded animal areas, which means that collection of dead production animals must be organized by animal treatment plants, which are Honkajoki Oy and Findest Protein Oy. Nowadays bodies of pork and poultry, which belongs to class 2, are handled in Findest Protein Oy and bodies of cattle, sheep and goat, which belongs to class 1, are handled in Honkajoki Oy /6/.

3.1 Utilization of MBM as animal feeds in food processing industry

At this moment, utilization of MBM as animal feeds in food processing industry is restricted with EU regulations due to the possibility of BSE occurrence. Before restrictions, local MBM was used about 25 million kilograms per year in animal feeds industry for pork and poultry feeds as a source of proteins and minerals. In future, utilization of these animal feeds could be allowed with separate EU regulation. Prerequisite is that, MBM is manufactured from class 3 animal by-products like for example lungs, gastric and bloods, which are allowed to use in food processing industry /6/.

3.2 Possibilities to utilize MBM as a fertilizer

In every year 10 000 tons of meat and bone meal is utilized as a fertilizer in Finland. Due to the BSE epidemics, European Union forbids utilization of meat and bone meal as a fertilizer in 2001, but it has been revealed from restrictions again in 1th of May 2006, which means that utilization of meat and bone meal for fertilizer purposes can be started again. In addition to this, EU Organic legislation allows to use meat and bone meal as a fertilizer, which means that it is possible to use it in organic farming /1/.

Picture 4. MBM as a fertilizer /8/.

Meat and bone meal belongs to organic animal fertilizers. It is a suitable fertilizer for grains, potatoes, oil plants and for gardening plants. Meat and bone meal can be utilized in Finland in a way of organic N- or NP-fertilizer in farming. Nitrogen and phosphorous-ratio of meat and bone meal is 8:6. The fertilization effect of meat and bone meal is based on slow soluble nitrogen and phosphorous and in addition to these, MBM includes also huge amount of calcium. Also soil properties like for example moisture content and the amount of organic substances must be taking into consideration, when using MBM as a fertilizer in soils /1/.

Picture 5. MBM fertilizer Viljo from Elosato Oy /9/.

4. REGULATIONS CONCERNING USAGE OF MBM

This chapter defines regulations, which influence the usage of meat and bone meal. These regulations are Fertilizer Product Act, EU animal by-product regulation and Waste Incineration Directive.

4.1 Fertilizer Product Act

Fertilizer Product Act comes into effect in 1.1.1994. The Act defines and classifies all suitable fertilizers and suitable substances, which can be used for soil enhancement. What is new in the Act is that it also defines the utilization possibilities of organic fertilizers and animal by-product fertilizers for farming purposes. For this matter, it is also possible to use meat and bone meal as a fertilizer. The purpose of the Act is to promote beneficial usage of by-products for fertilizers, when they are not causing any kind of problems to people, animals, plants and to environment /10, 11/.

4.2 EU animal by-product regulation

European Parliament and Council have done regulation, which concerns the possibilities for animal by-product utilization. This regulation (2002/1774/EY) lays down to health rules, which are concerning animal by-products not intended to human consumption. Primary purpose of the regulation is to prevent spreading of animal diseases to animals and people via animal feeds and by-products. So this means that for example, exploitation of waste or recycling are not main concerns of this regulation. The regulation concerns wastes, which are originated from destruction or somehow usable wastes, like dead animals and former animal-based foodstuff. It almost completely denies feeding of animal waste to those species, which it originates from /11/.

According to by-product regulation, by-products are classified to three classes. These classes are defined in a way of how great disease risk they cause and this lead to the fact that different by-product classes are handled in different ways. By-products, which are classified to class 1, have the greatest potential disease risk (TSE risk materials) and they are handled in Honkajoki Oy. Honkajoki Oy also handles class 2 and 3 products. Findest Protein Oy handles class 2 and 3 products, which are not as dangerous as class 1 products /11/.

4.3 Waste Incineration Directive

Waste incineration directive (2000/76/ETY) concerning burning of waste comes into effect in Finland with government decision concerning of burning waste (362/2003). It is applied to burning- and co-firing plants, which are burning solid or liquid wastes. The regulation is not applied to burning- or co-firing plants, which are burning following wastes like for example plant-based forest and agricultural residues or cork waste. Pilot plants, which are used for research and testing applications for development of burning process, are excluded from the regulation /7/.

Waste Incineration Directive gives rules, which are attempting to reduce risks and problems to human health and to environment. It gives instructions for several issues like:

- burning conditions (850 °C, 2s)
- burners
- waste feeding to the burner
- emission measurements

- And exceptional using conditions /11/.

Industrial emissions directive (2010/75/EU) will come to force in 6.1.2011. It updates the IPPC-directive (96/61/EY, coded 2008/1/EY). In addition to this, IE directive covers present so called LCP directive (2001/80/EY), waste incineration directive (2000/76/EY), titanium dioxide industry directive (78/176/ETY, 82/883/ETY, and 92/112/ETY) and industrial VOC directive (1999/13/EY), which all will be integrated together to be one directive. The general goal of the directive is to promote air pollution control, soil protection and implementation of sustainable development resource strategies. Other goals of the IE directive are improvement of cost-effective environmental protection and promotion of new technical solutions. As a general estimation we can say that, nowadays the YSL permit procedure follows the requirements of the IE directive in issues which concerns controlling of emissions and environment. When coming into force, it will require major changes to regulations which are based on YSL /53/.

5. POSSIBLE COMBUSTION AND BOILER TECHNIQUES FOR MBM

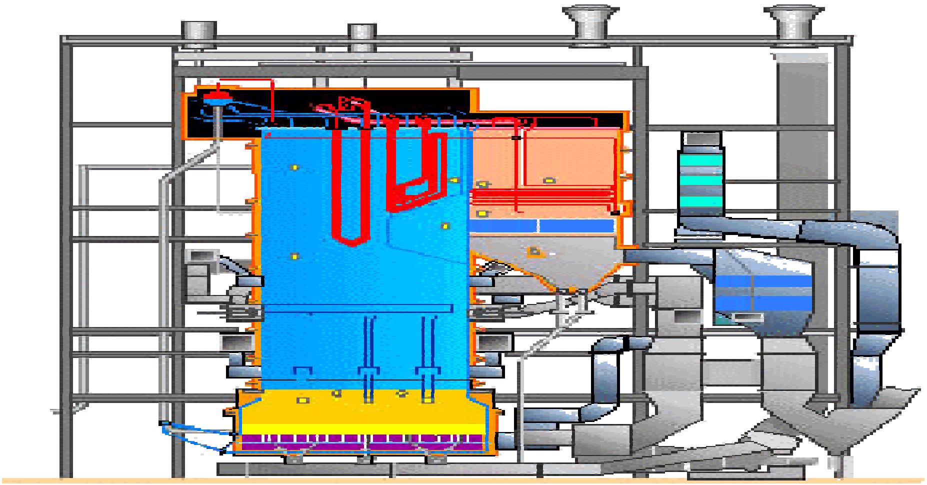
This chapter introduces possible combustion and boiler techniques for MBM. Introduced techniques are fluidized bed combustion, grate firing and gasification.

5.1 Fluidized bed combustion

Since 1970´s fluidized bed combustion has been one of the most important combustion techniques to burn solid fuels in an environmentally friendly way. Since the beginning, Finland has been one of the leading developers in fluidized bed combustion. Fluidized bed combustion is based on a technology, where fuel is burnt with the help of inert material. Sand, ash or similar can be used as an inert material /12, 13, 14, 15/.

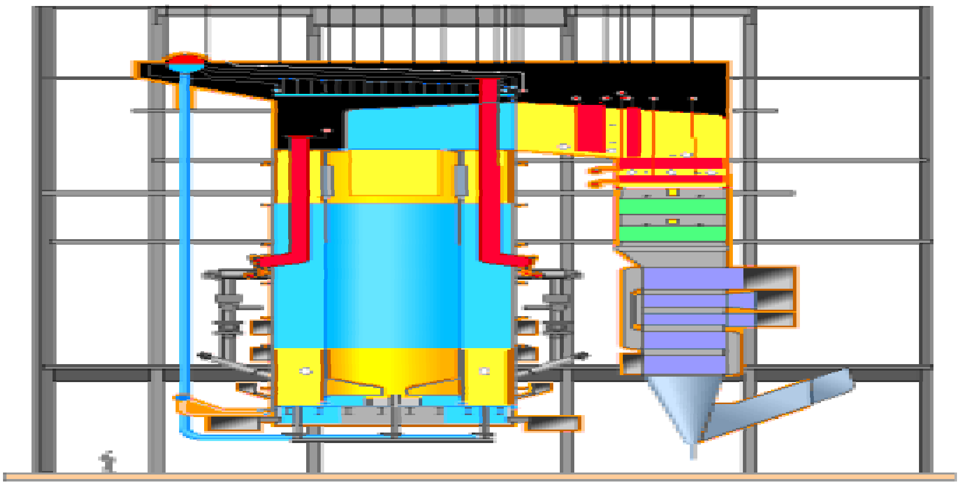
With the help of large heating capacity of the sand bed, fluidized bed combustion can be used especially for low quality fuels (wet fuels); because these fuels do not need any separate drying process. These kinds of fuels are for example bark, woodchips and forest –and sewage industry residues. Wet fuel blends dries quickly, when they mix with hot sand bed. Because of effective mixing with hot sand bed, burning temperature of the wet fuel blends can be achieved very quickly, which leads to high combustion efficiency. Large heating capacity of the sand bed also evens out quality changes of the fuels, which leads to the fact that fluidized bed combustion is suitable for waste incineration purposes. In addition to these properties, fluidized bed combustion has low burning temperature, which leads to low NO_x-emissions compared to for example traditional dust combustion. The bed temperature in fluidized bed applications varies between 750…950°C. The upper temperature limit of the fuel must be lower than ash melting point, so that bed agglomeration cannot occur. Removal of agglomerated sand from the boiler is a difficult process, which usually means that boiler must be shutdown so that it is possible to remove agglomerated sand from the boiler. There exits two main boiler types, which can be used in fluidized bed combustion. These boilers are: Bubbling fluidized bed boiler (BFB) and Circulating fluidized bed boiler (CFB) /12, 13, 14, 15/.

The velocity of the air is low in bubbling type, which means that medium particles are not carried among the bed. This leads to the fact that combustion in bubbling type happens in the bed with the help of oil and gas burners. The bed material starts to flow and expand, when air applied through the grate has enough velocity. Primary air content from needed combustion air is about 35 – 40%. The secondary air is fed to the upper part of the post-combustion chamber. The upper part of the freeboard is called post-combustion chamber. The fuel is fed mechanically to the bed from the fuel silo with the help of conveyor. Even distribution of the fuel to the bed is secured with several feeding pipes. Also secondary air, which is fed to the feeding pipes, can help even distribution of the fuel inside the boiler. The typical particle size in bubbling type is between 1…3 mm. The fluidization speed is approximately from 0,7 m/s to 2,0 m/s and the height of the bed is between 0,4…0,8 m. The ash is removed so that part of the sand is dropped through the bottom grate. This operation guarantees that coarse particles from the bed, which affects the fluidization capacity of the bed, can be removed. Cleaned sand can be returned back to the boiler /12, 13, 14, 15/.



Picture 6. Bubbling fluidized bed boiler /16/.

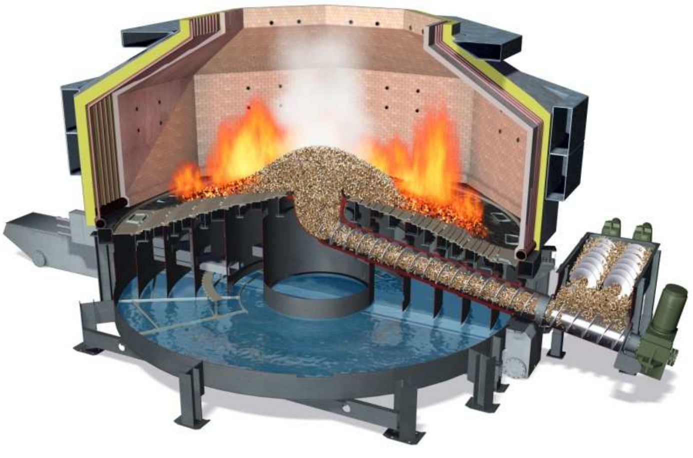
The velocity of the air in circulating type is higher than in bubbling type, which means that fuel and bed material moves along with the gas. This means that higher fluidization velocities and finer bed materials can be applied in circulating fluidization bed boilers. The usual particle size in circulating type is between 0, 1…0,5mm and the velocity of the gas is between 3…10 m/s. The typical characteristics for CFB boilers are high turbulent flow and effective mixing of the particles. This means that exact layer of the fluidization cannot be seen because the density of the bed lowers as the function of the height. The fuel is fed to the boiler either through the front wall or mixing it with hot sand from the cyclone. The first method is more often used than latter method. Burning of the fuel happens in furnace along with hot solid materials. Same burning methods are used in CFB and in BFB for solid materials. The main exception is that burning conditions can change a lot in CFB, because of the turbulent flow. Combustion air is fed to the boiler as primary and secondary air. Primary air is fed through the bottom nozzles and secondary air is fed from several different stages of the upper part of the grate. Primary air amount from all air is around 40- 60 % depending on the fuel properties. The suitable solid content and particle size is kept in the boiler so that removal of solid particles happens through the bottom ash removal equipment /12, 13, 14, 15/.



Picture 7. Circulating fluidized bed boiler /17/.

5.2 Grate firing

Grate firing is usual method for small and medium-sized furnaces (15 kW – 30 MW) to burn solid fuels since the beginning of the industrialization. It can be also used for waste incineration purposes. Nowadays in Finland, fluidized bed combustion applications has replaced grate firing in unit sizes over 5 MW. Main types of grate furnaces consist of grates, which can be horizontal, sloping or conical. Chain conveyors are located in the grate furnace to transport the fuel forward. The grate can consist of parts, which are movable or fixed. In fixed grate, fuel is transported to the furnace by its own weight. The fuel is fed to the furnace from the hopper and after that, it is moved forward or downward sequentially within the furnace and the combustion of the fuel happens in the grate furnace. Combustion methods in grate firing consist of removal of moisture, pyrolysis and combustion of volatile matter and combustion of the char. In grate firing, ash removal of the fuel happens mainly through the grate /14, 18, 19, 20/.



Picture 8. Wärtsilä BioGrate /21/.

5.3 Gasification

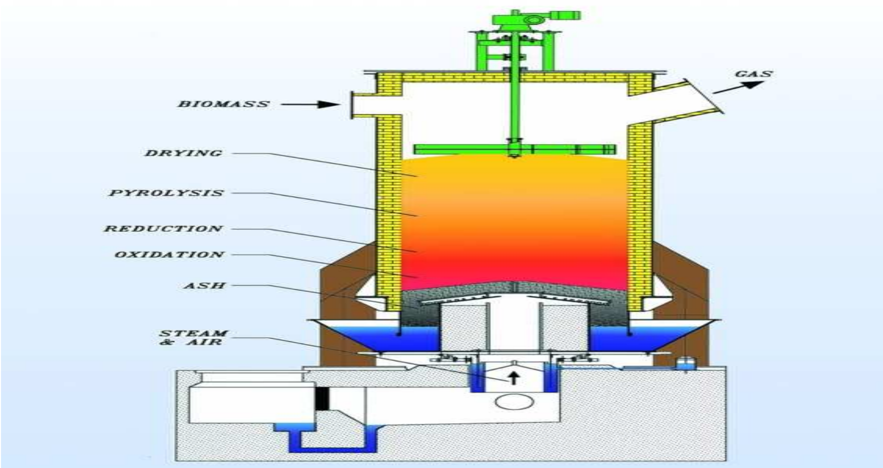
In gasification process carbon based fuels are burnt with under stoichiometric air amount. The purpose of the fuel gasification is to produce combustible gas, which contains carbon monoxide, hydrogen, methane and hydrocarbons. Combustion methods in gasification consist of drying of fuel, pyrolysis and gasification – and burning reactions of carbon residues. The reactions, which produces main components of the gasification process, are highly endothermic, which means that heat must be transported either with co-combustion or in a way of external heat material. Gasification processes can be divided in a way of used gas or in a way of is the process atmospheric or pressurized. In power plant applications, typical gasification methods are based on air- and oxygen gasification /19/.

Typical air amount, which is used in air gasification process, is between 20 – 50 % from the stoichiometric air amount. Fuels, which contains large amounts of volatile matter, can be gasified in rather low temperature (800 - 1000°C) when the air amount is between 20- 30% from the stoichiometric air amount. The product gas in air gasification contains usually approximately 50 weight percent of nitrogen. At this point we can speak about low heating value gas, which heating value is from 3 MJ/m^3_n to 7 MJ/m^3_n /19/.

In oxygen gasification solid fuels are gasified with mix, which contains oxygen and water vapor. With this method, it is possible to achieve product gas which heating value is between 7 - 15 MJ/m^3_n. Oxygen gasification is mainly used in large-scale power plants /19/.

Indirect gasification process is carried out with water vapor, flue gas or with recyclable product gas. This method can be used for biofuels, where gasification process can be carried out with temperatures lower than 800°C /19/.

Different kinds of reactor types can be used in gasification process. These reactors can be divided to three main types: solid-layer gasifiers, dust gasifiers and fluidized bed gasifiers. For waste incineration purposes there is used solid-layer gasifiers and fluidized bed gasifiers. Solid-layer gasifiers can be divided to cross-flow, counter-flow or co-current flow. Only differences between these methods are direction of the flow and solid content of the material. Fluidized bed gasifier consists of reactor part, where gasification happens and cyclone. Return pipes are also part of the fluidized bed gasifier, which are used to return the separated solid content from the gas flow to the reactor. In circulating fluidized bed gasifiers the delay time of the gas is smaller and power to heat ratio bigger than compared to bubbling fluidized bed gasifiers. For this reason, CFB gasifiers are suitable for biofuels /19/.



Picture 9. Illustration of gasification process /22/.

6. DETERMINATION OF FUEL PROPERTIES

Fuels can be classified to high- or low quality fuels. Definition of fuel properties consists of determination of:

- heating value
- moisture content
- elementary analysis
- volatile matter
- ash content and ash melting point

From environmental reasons, it is often necessary to determine heavy metal content of the fuels, which can cause problems to the species after burning. These heavy metals are for example, chromium, cadmium and vanadium. Also fluorine and mercury can cause same kind of problems to the environment than heavy metals /23, 24, 25/.

6.1 Heating value

The most important property of the fuel is heating value, which is determined by using of a bomb calorimeter. It defines released heat amount during burning of the fuel. Heating value can be classified to higher-, lower- and to gross heating value. Higher heating value takes into account the latent heat of vaporization of water which is formed during combustion. In Finland heating value is usually determined as lower heating value. Lower heating value is achieved by subtracting it from higher heating value and taking into account the heat of vaporization of the water which is formed during combustion of hydrogen and also taking into account the heat of vaporization of the water. The third option is to utilize gross heating value, which is the lowest heating value. It is defined as MJ/kg /23, 24, 25/.

Picture 10. Bomb calorimeter /26/.

6.2 Moisture content

Moisture content affects to the amount of heat released during combustion of the fuel. There is no exact way to determine water content of the fuel, because water can bind in different ways to the fuel. Typically water content of the sample can be determined by drying the fuel sample for constant temperature (105 °C) and time (24 h) and by determining the weight loss of the sample /23, 24, 25/.

6.3 Elementary analysis

Chemical composition of combustion part of the fuel can be determined with elementary analysis. Main combustion elements of the fuel are carbon, hydrogen, oxygen, sulfur and nitrogen. These components can be defined with analyzers (atomic absorption spectroscopy) or with different chemical standard methods like for example ISO 334 /23, 24, 25/.

Picture 11. Atomic absorption spectroscopy /27/.

6.4 Volatile matter

Volatile content of the fuel can be defined from that part of the fuel, which vaporizes, when it is heated up. Typically volatile content of fuel can be defined by putting the sample to the oven for constant temperature

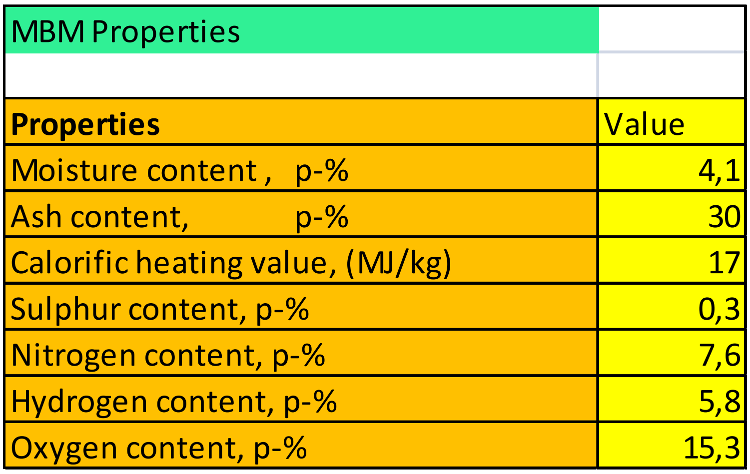
(900°C) and time (7min) and by defining the weight loss of the sample. In real combustion process, the volatile content of the fuel can differ a lot compared to the results from laboratory analysis /23, 24, 25/.

6.5 Ash content and ash melting point

Usually ash content of the fuel is determined by heating up the sample in furnace (575 °C or 850°C) and by monitoring temperature behavior of the sample, when temperature rises. With this method, it is possible to determine fusion- and melting point for the ash. The ash content of the fuel can cause slagging and fouling problems to the boiler /23, 24, 25/.

7. PROPERTIES OF MBM AS A FUEL

Due to the BSE crisis, safe disposal of MBM is required to prevent the expansion of diseases from stock breeding. According to the Waste Management Hierarchy, the most potential alternative for safe disposal of MBM is thermal disposal, particularly incineration with energy recovery. Another thermal disposal option for MBM is the co-incineration in cement kilns. Before starting to use MBM as a fuel in energy production, lots of research must be done concerning the composition and behavior of MBM as a fuel, because its composition is not similar with that of coal or wood. MBM is characterized as a high volatile and high ash containing fuel (30 %-w/w) with lower heating values from 17 to 20 MJ/kg. It contains alkali and alkaline earth metals due to its bone content, particularly calcium, phosphorus and chlorine. From this point of view, there exist two types of energy generation applications to use MBM as a fuel in energy production. These two types are utilization of MBM as a secondary fuel in combustion process (co-combustion) and utilization of MBM as a primary fuel in stand-alone combustion process. At this point I am going to evaluate the possibilities to utilize MBM as a secondary fuel in co-combustion process with coal, peat and olive bagasse /28, 29, 30/.



MBM Properties	
Properties	Value
Moisture content , p-%	4,1
Ash content, p-%	30
Calorific heating value, (MJ/kg)	17
Sulphur content, p-%	0,3
Nitrogen content, p-%	7,6
Hydrogen content, p-%	5,8
Oxygen content, p-%	15,3

Table 1. Properties of MBM /31/.

7.1 Co-combustion of coal with MBM

Nowadays MBM producers are facing new kinds of situations concerning the utilization of MBM. The landfilling legislation and the market situation are forcing producers to think about other options like, for example combustion of MBM in power plants. At this point, fluidized bed co-combustion applications (CFB) fulfill the technical and administrative requirements to provide viable solutions to use coal and meat and bone meal in combustion applications. In terms of both cost and the environment, co-firing of MBM and coal can be carried out with fluidized bed technology, which is one of the best methods of MBM disposal, because fluidized bed plants already have integrated installations for gas cleaning and ash handling. At this point, fuel savings and extra profit as residues disposer are ways of profit for power producers /32, 33/.

Picture 12. Co-firing of coal and MBM in Essent power plant at Borselle, Netherlands /34/.

Understanding the behavior of MBM during combustion process is also important, so that it is possible to avoid problems during combustion process. According to the inorganic nature of MBM, it can be classified as sticky and granular material which contains bone fragments. Bone fragments have high volatile and ash content, because they consist of calcium, phosphorus, chlorine and kalium. The presence of P and K can increase the bed agglomeration problems, which means that bed temperature must be closely monitored. Unfortunately, presence of chlorine (may exceed 0, 5 wt %) and alkali concentrations can increase fouling and corrosion formation in boilers. At this point, thick deposit can hinder the heat transfer rate in heat exchangers. In addition to this, it is important to consider deposit-related corrosion, which can cause damage for superheaters. These two factors can lead to unscheduled shut downs and extra maintenance costs /32, 33/.

There has been performed several pilot scale co-combustion studies for coal and MBM which have shown, that most often used technology for co-combustion process is circulating fluidized bed technology. Nowadays also industrial scale applications for co-firing of coal and MBM are used in central Europe. Performed studies have shown that MBM has good fuel properties compared to other conventional fuels. Combustion temperatures around 780 °C can be used when MBM is co-combusted with coal so that it is possible to avoid bed agglomeration. Usually quartz is used as bed material in combustion process of MBM and coal. Addition of high mineral matter MBM at low temperatures to coal mixtures can increase the reaction rate of combustion. At high temperatures reaction rate of combustion is reduced because of the fact that mineral content of MBM undergoes major transformation reactions such as crystallization of calcium to hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$). Addition of high volatile MBM fuel to coal increases CO emissions and this means that use of secondary air is essential to meet the regulations. It can be also noticed from pilot scale studies, that SO_2 emissions were higher, when the amount of coal in the mixture was increased. At this point, the high Ca content of MBM can help to reduce SO_2 emissions because calcium can act as SO_2 scavenger. Co-combustion of MBM with coal also creates NO_x and N_2O emissions. NO_x emissions can be reduced by increasing the share of MBM in the coal mixture. The reduction of N_2O emissions can be achieved due to the catalytic effect of the char and CaO rich ashes. Formation of PCDD/F during combustion of MBM alone is high, but the levels of PCDD/F emissions can be reduced by co-combustion process of coal and MBM. The ash content of MBM is higher than compared to coal.

Performed studies have shown that total amount of ash can be reduced, when amount of MBM in the mixture is less than 20 %. It must be also said, that increasing the amount of MBM in the mixture has led to production of ashes with higher content of heavy metals. On the other hand, leaching rates of these chemical species has not increased. It seems that, produced ashes can be characterized as ecotoxic. Recent studies have also shown that MBM produces finer fly ashes. This means that, in addition to cyclone installations in industrial applications, the use of bag filters is necessary to bring down ash levels so that it is possible to meet limits of EU regulations /35, 36, 37, 38, 39, 40/.

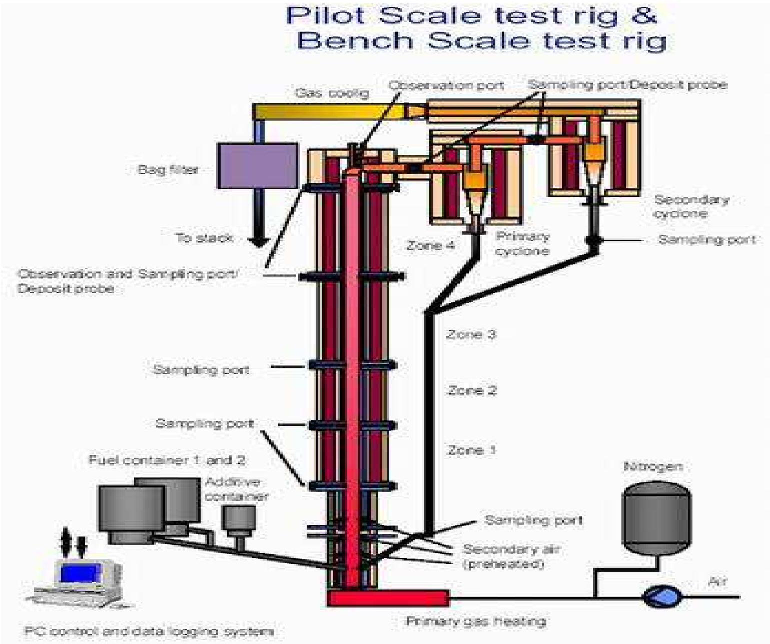
Picture 13. Co-firing of coal and MBM in E-ON power plant at Maasvlakte, Netherlands /41/.

7.2 Co-combustion of peat with MBM

Co-combustion of peat with MBM is a new way to utilize MBM in combustion process. At this point, bubbling fluidized bed and circulating fluidized bed technologies offers solutions for co-firing of peat and meat and bone meal. These technologies have ability to combust efficiently fuels which have low operating temperatures. Typical operating temperature of BFB is from 750°C to 900°C and also NOx emission reduction is possible to achieve with bubbling fluidized bed technology. It must be also said, that utilization of BFB technology offers advantage to operate with higher residence times with lower fluidization velocity. Utilization of BFB technology also gives opportunity to improve on accuracy of assessment of flue gas emissions and quality of ash in biofuel applications. The typical characteristics for CFB boilers are high turbulent flow and effective mixing of the particles. The velocity of the air in circulating type is higher than in bubbling type, which means that fuel and bed material moves along with the gas. This means that higher fluidization velocities and finer bed materials can be applied in circulating fluidization bed boilers. Same burning methods are used in CFB and in BFB for solid materials. The main exception is that burning conditions can change a lot in CFB, because of the turbulent flow /42, 43, 44, 45/.

There has been made only few pilot-scale studies for combustion of peat with MBM in Ireland. These studies are performed with CFB and BFB technologies. One reason to do co-fuelling experience of peat and MBM is due to the fact that, these fuels have same kind of physical properties. Even though the physical properties of these fuels are same, MBM as a fuel has different properties than peat. This is due to the fact, that MBM has high ash, sulphur, calcium and chlorine content /42, 43, 44, 45/.

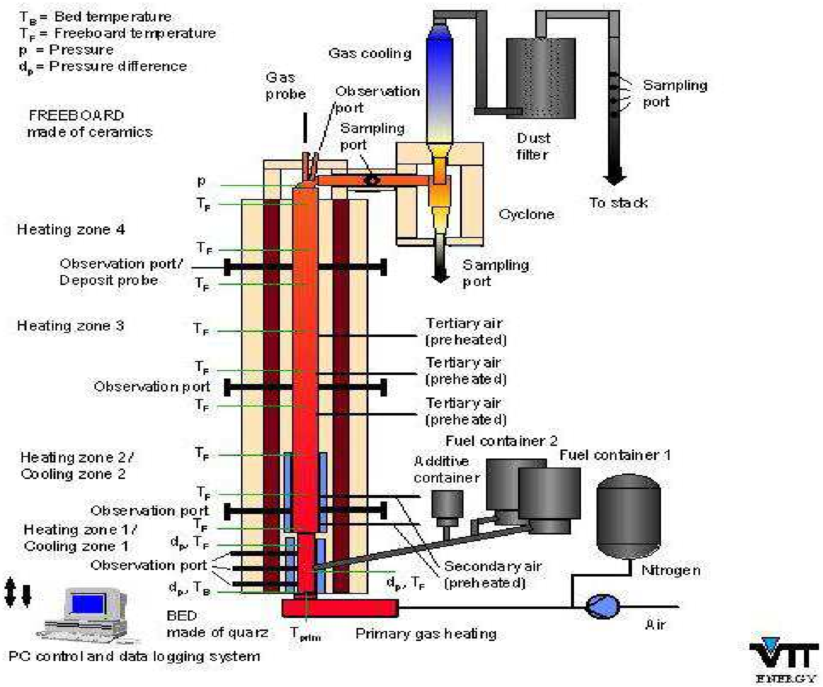
Pilot-scale combustion studies for MBM have been done with several blends of milled-peat in circulating fluidized bed boiler. These results have shown that the temperature during combustion of MBM and peat is good to keep around 850 °C with minimum residence time of 2 seconds, because of the demand of Waste Incineration Directive. In that way it is possible to meet legislative requirements for all atmospheric emissions. Combustion studies also indicate, that fluidization and bed agglomerations problems can be avoided, when combustion of MBM-peat mixture was steady /44/.



Picture 14. VTT Energy´s circulating fluidized bed reactor /46/.

Pilot-scale combustion studies have also been performed to bubbling type with several blends of peat-MBM pellets. During the test trials, the temperature was kept 880 °C or 820 °C because of the variation of LHV of the different fuels due to the fluidization of the material at varying temperatures. The tests indicate that emissions were below the regulatory limits. Bed agglomeration and ash melting occurs, when temperature was

880 ° C and fuel mixture contains 35% of MBM. These problems can be avoided, when temperature of the bed is around 850 °C and the share of MBM in the mixture is not more than 20 % /45/.



Picture 15. VTT Energy´s bubbling fluidized bed reactor /45/.

7.3 Co-combustion of olive bagasse with MBM

A pilot scale experience has also been made for olive bagasse and MBM. High amounts of K, Ca/Mg, Si and some Cl and Al can be found from olive bagasse ash. On the other hand, MBM contains high amounts of Ca, P and Cl in the ash. According to above mentioned ash contents, it is well known that K and Cl, as well as P in combination with Si and S are known to cause sintering and agglomeration problems. The experiment was done with 20 and 40 % w/w MBM. The co-combustion process shows that total defluidisation occurred rapidly after combustion experiments. This means that steady state combustion cannot be achieved and this leads to the fact that emission measurements are not trustworthy even though they were measured during the combustion process. This experience shows that it is not viable to use this application in industrial scale /47/.

8. EXPERIMENTAL PROCEDURE AND METHODS

This chapter defines materials and methods which have been used in burning trials of meat and bone meal. Burning trials have been carried out with VETO grate boiler at Energy laboratory of Lappeenranta University of Technology. The purpose of trials is to define different kinds of fuel properties concerning meat and bone meal /48/.

Picture 16. VETO grate boiler at Energy laboratory of LUT /49/.

8.1 VETO stoker boiler

Veljekset Ala-Talkkari Oy manufactures VETO grate boilers for heating applications. The size of the VETO grate boilers varies from 30 to 700 kW. The experiments of my thesis are carried out with 80 kW VETO grate boiler at Energy laboratory of LUT. This particular boiler is used for burning of wood pellets. It uses vertical convection which means that cleaning periods of the furnace does not have to be done so often. Standard model of VETO grate boiler includes large and isolated ash room and efficient water spiral.

Picture 17. Side picture of VETO boiler at Energy laboratory of LUT /50/.

Picture 18. Front picture of VETO boiler at Energy laboratory of LUT /51/.

VETO keskuslämpökattila

MALLI	VETO 80K	MODELL
VALMISTUS	80429	TILLV. N:O
VALMISTUSVUOSI	2007	TILLV. ÅR
SARJA N:O	2	SERIE N:O
RS-PÄÄTÖS N:O	4109-96	RS-ANTAG. N:O
SUURIN KÄYTTÖP.	1.5 bar	DRIFTTRYCK MAX.
KORKEIN LÄMPÖT.	110 °C	DRIFTTEMP. MAX
ALIN LÄMPÖTILA	0 °C	DRIFTTEMP. MIN
TEHO PUU/ÖLJY	80 kw	EFFEKT VED/OLJA
TILAVUUS	0.41 m³	VOLYM

VELJEKSET ALA-TALKKARI OY
HELLANMAANTIE 619, 62130 HELLANMAA
PUH.+358 6 433 6333 FAX.+358 6 437 6383

Picture 19. Basic properties of VETO boiler /52/.

8.2 Experimental procedure

The experimental procedure consists of combustion trials, which purpose is to define fuel- and ash properties for class 2 MBM and also test how milled peat and MBM can be combusted together. MBM, which is used in combustion trials, has the form of granulated fertilizer (80 % MBM and 20 % grain) and also powder form of MBM (100 %) is used. The combustion trials are carried out with 80 kW VETO boiler at Energy laboratory of LUT.

The first combustion trial consists of burning 100 % MBM mixture. The purpose of this trial is to define fuel- and ash properties for class 2 MBM such as heating value, moisture content and ash content. Emissions from flue gases are measured with FTIR-spectrometry which can measure gaseous emissions. Also heavy metals and PCDD/F compounds are measured from flue gases and they are analyzed with chemical methods. Ash properties of meat and bone meal like melting behavior of MBM (melting point °C, hemisphere °C, and liquefaction °C), heavy metals and PCDD/F compounds are measured and analyzed with chemical methods. This combustion trial also includes installation of sampling plate to the furnace, which gives opportunity to visually observe is any kind of corrosion or fouling reactions happening in the furnace.

The second combustion trial consists of burning milled peat and MBM blend. This blend consists of 80 % milled peat and 20 % MBM on a dry material basis. The purpose of this combustion trial is to observe, how the largest possible milled peat and meat and bone meal mixture reacts in the boiler. Also emissions measurements are carried out from flue gases with FTIR-spectrometry. This combustion trial, like above mentioned combustion trial, includes installation of sampling plate to the furnace, which gives opportunity to visually observe is any kind of corrosion or fouling reactions happening in the furnace.

Picture 20. Milled peat /54/.

9. THE BURNING TESTS

The burning tests were carried out in two separate dates. The first day consists of burning test of 100% granulated MBM and mixture of 90 % peat and 10 % MBM. The second day consists of six different burning tests with mixtures of peat and MBM.

9.1 The first burning test day

The first day consists of burning test of 100% granulated MBM and mixture of 90 % peat and 10 % MBM.

9.1.1 Burning test of 100% granulated MBM

The first burning test consist of burning 100 % granulated MBM. The purpose of this trial is to define fuel- and ash properties for class 2 MBM. The granulated MBM was loaded to the fuel silo, where it was transported to the boiler with screw conveyor.

Picture 21. Fuel silo with screw conveyor /55/.

At this point ignition of the boiler was carried out. When granulated MBM reached the boiler furnace, it extinguished the flame. The flame was so low and weak, that it extinguished immediately. Also a pile of MBM was formed in front of the flame, which didn’t burn. The temperature of the flame was only 100°C and the temperature of water was 30 °C. Also large amount of ash was formed, which also affects the burning process of the 100 % granulated MBM. At this point, the burning test of 100% granulated MBM was stopped.

Picture 22. The flame of the 100% granulated MBM /56/.

9.1.2 Burning test of 90 % peat and 10 % MBM mixture

At this point it must be said, that this burning test was planned to be done in second burning test day. The reason why this test was carried out in first burning test day was that 100 % granulated MBM didn’t burned. At this point I made a decision that we can continue the testing day by burning of 90 % peat and 10 % granulated MBM mixture and we can start to measure different kinds of properties of this mixture with the help of different kinds of measurement devices. The purpose of this trial was to define fuel- and ash properties for 90 % peat and 10 % granulated MBM mixture, which includes measurements of heating value, moisture content and ash content. Emissions from flue gases were measured with FTIR-spectrometry which can measure gaseous emissions. Also heavy metals and PCDD/F compounds were measured from flue gases and they were analyzed with chemical methods. Ash properties of this mixture like melting behavior (melting point °C, hemisphere °C, and liquefaction °C), heavy metals and PCDD/F compounds were measured and analyzed with chemical methods.

Picture 23. FTIR-spectrometry probe /57/.

At first we started to make the burning mixture so that we were weighing 9 kg of peat and 1 kg of granulated MBM with different scales and then we mixed them together. After that the mixture was poured to the fuel silo, where it was transported with screw conveyor to the furnace. At this point also little bit of lighter fluid was poured to the furnace, which purpose was to facilitate the ignition process.

Picture 24. Mixture of 90 % peat and 10 % granulated MBM in the fuel silo /58/.

The ignition process of the furnace was done so that the air input was shut off and the mixture start to burn. After a while, the air input was turned on again and the burning process continued. It must be also said that, we changed boiler adjustments from pellet adjustment to peat adjustment. At first the temperature varies from 550 °C to 600 °C. The feeding of the fuel was adjusted in a way that the feeding time was 2 seconds with 9 seconds break. With this feeding adjustment, the temperature of the flame start to increase rapidly from 730 °C to over 800 °C and the mixture was burning very well. At this point, the flow rate of the mixture varies from 21, 9 liters per seconds to 22, 5 liters per seconds. The temperature of the water was 73, 5 °C.

Picture 24. Ignition of the furnace /59/.

When the temperature reaches over 800° C, we started to measure emissions from flue gases. Gaseous emissions were measured with FTIR-spectrometry and PCDD/F and heavy metal measurements were measured with their own measurement devices. The measurement interval of the gaseous emissions with FTIR-spectrometry was 1 minute.

Picture 25. Heavy metal and PCDD/F measurement devices from flue gases /60/.

When the temperature inside the furnace was stabilized to around 800 °C, the mixture burned very well. At this point, we also started manual mixing of the fuel inside the silo with a spade to ensure even proper mixing of the fuel mixture. With the help of this procedure, it can be clearly seen from the furnace, that the mixture continued to burn very well.

Picture 26. Flame inside the furnace /61/.

The final step in the first burning test day was to evaluate how much ash was created to the ash collection chamber. The assumption was that the ash content of MBM is over 30%, which means that there should be lots of ash inside the ash collection chamber. After the cooling and shut down of the boiler, we opened the ash collection chamber and we noticed the fact that, burning of this mixture creates lots of ash. Visual evaluation of the ash showed that the assumption was correct and there can be seen two different types of ash particles. The ash of the peat looks like brown powder and the MBM ash looked like white granulates.

Picture 27. Ash of 90 % of peat and 10 % granulated MBM mixture /62/.

9.2 The second burning test day

The second burning test day includes several different experiments with peat and MBM mixture. Emissions measurements with FTIR-spectrometry were also carried out to different mixtures of peat and MBM. These mixtures were:

- 80 % of peat and 20 % of granulated MBM
- 70 % of peat and 30 % of granulated MBM
- 50 % of peat and 50 % of granulated MBM

- 90 % of peat and 10 % of powder MBM
- 80 % of peat and 20 % of powder MBM
- 100 % of powder MBM

9.2.1 Burning test of 80 % peat and 20 % granulated MBM

At first we started to weigh 8 kg of peat and 2 kg of granulated MBM with different scales. After that we mixed them together and poured them to the fuel silo, where it was transported with screw conveyor to the furnace. The fuel feeding adjustment was same as yesterday (2 seconds feeding and 9 seconds break). The starting temperature was greater than yesterday and the mixture starts to burn. The temperature rapidly rises to over 800 °C and we started to measure gaseous emissions with FTIR-spectrometry. The temperature of the water was 73 °C. We also used manual mixing operation at some point and noticed the same fact than yesterday that the burning operation gets better when there was proper mixing of the mixture. The burning operation was stable and after burning works well.

Picture 28. Burning process of 80 % peat and 20 % granulated MBM /63/.

9.2.2 Burning test of 70 % peat and 30 % granulated MBM

When the above mentioned burning test was finished we changed the mixture in the fuel silo to be 7 kg of peat and 3 kg of granulated MBM. The adjustments were the same as in the last experiment (2 seconds fuel feeding and 9 seconds break). At this point it must be said that, the fuel consumption rises a little bit compared to previous measurement, because of increase of MBM amount in the mixture. The temperatures of the experiment were stable and the mixture burnt well.

9.2.3 Burning test of 50 % peat and 50 % granulated MBM

The last test with granulated MBM consists of mixture of 5 kg peat and 5 kg granulated MBM. At first the fuel adjustment was the same as in previous experiments. This adjustment was too fast so we have to change it to be 2 seconds fuel feeding and 25 seconds break so that the mixture has time to burn inside the furnace, not just go through the furnace. At this point we also noticed that a big pile of mixture was formed to the front of the flame which didn’t burnt. This means that this mixture didn’t burn as well as other previous mixture and lots of ash was also formed.

Picture 29. Pile of mixture inside the furnace /64/.

9.2.4 Burning test of 90 % peat and 10 % powder MBM

When we finished the last test with granulated MBM, we started to use powder MBM. The first mixture includes 9 kg of peat and 1 kg of powder MBM. This mixture was mixed properly and poured to the fuel silo, where it was transported to the furnace with screw conveyor. At first the fuel feeding was 2 seconds and the break was 20 seconds. We noticed that it was possible to decrease the break time and we adjusted it to be 11 seconds. The flow rate of the mixture was 22.8 l/min. At first the temperature was around 700 °C, but increased very rapidly to over 800 °C. The MBM was totally mixed with peat and the burning was very well.

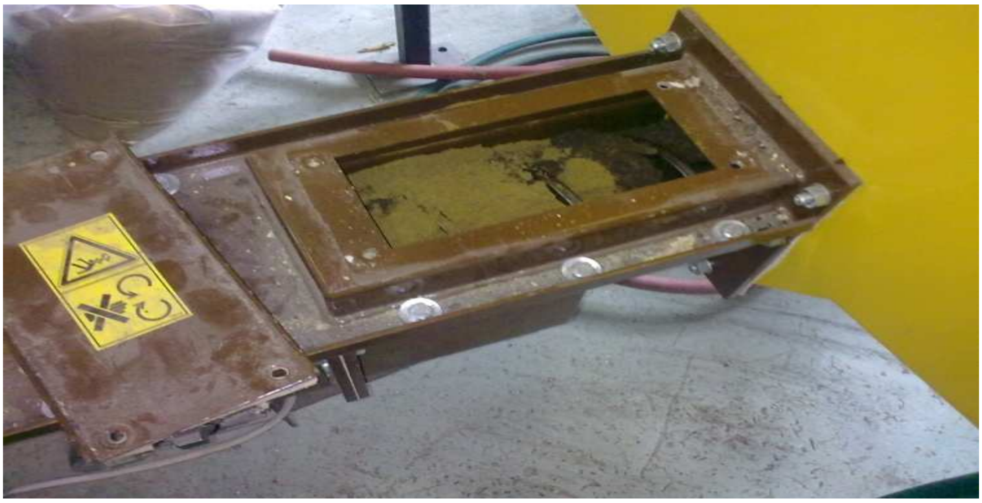
Picture 30. Powder MBM /65/.

9.2.5 Burning test of 80 % peat and 20 % powder MBM

The final mixture test with powder MBM was carried out with 80 % of peat and 20 % of powder MBM. Temperature of the mixture was same as in previous experiment with same fuel feeding adjustment. The burning operation of this mixture was even better than with previous mixture and the total mixing of MBM with peat was reached. The flame was also stable.

9.2.6 Burning test of 100 % powder MBM

The final experiment of the second burning test day consist of burning 100 % powder MBM. We decided to do this experiment because we wanted to know is it possible to burn 100 % powder MBM when the boiler has been operated whole day. At first we opened the cover of the conveyor and poured few hundred grams of pure powder MBM to the screw. We waited a while so that the fuel has chance to reach the furnace. At first the temperature was stable due to the fact that there was small amount of peat left in the screw, but after a while when there was only pure powder MBM left in the screw the temperature decreases very rapidly. Also formation of big pile was noticed in front of the flame, which didn't burnt and the experiment was finished after that.



Picture 31. Feeding of pure powder MBM /66/.

10. RESULTS

In this chapter I am going to evaluate results from burning experiments. At first there is evaluated first burning day results and then second burning day results.

10.1 Results from the first burning day

The first burning day was the main experiment day, because purpose of this day was to evaluate emission and ash properties for 100 % MBM mixture. This mixture was put to the fuel silo where it was moved forward to the furnace with screw conveyor. When this mixture arrives to the furnace, it immediately shut downs the flame and this shows to us that this mixture cannot be burned with this boiler. The temperature of the flame was only 100 °C and water temperature was 30 °C. It also forms lots of ash to the ash chamber and even to the furnace. At this point, I made a decision that this experiment must be stopped and we have to change original plan in a way that every key measurements must be now done with 90 % of peat and 10 % of MBM mixture.

Picture 32. 100% MBM inside the furnace /67/.

Like mentioned before, I changed the original plan and the main experiments are now taken from mixture, which consists of 90 % of milled peat and 10 % of MBM. Purpose of this experiment was to evaluate results concerning emission- and ash properties of this mixture, because this kind of mixture might be also used in a real power plant.

First part of this experiment consists of installation of sample plate to the furnace. The sample plate was first cleaned and after that installed to the furnace. Purpose of this sample plate was to evaluate possible corrosion and fouling problems, which can be seen when burning high volatile content fuel like MBM. The sample plate was taken off after the final experiment in the second burning test day. The visual inspection of the sample showed, that no corrosion and fouling can be seen from the sample plate. Only some burnt fuel particles where attached to the plate which can be seen from the sample plate. Reason for this was that the sample time was too short, because the experiments only last two days which was too short to visually detect corrosion or fouling problems inside the furnace.

Picture 33. Sample plate before the burning experiments /68/.

Picture 34. Sample plate after the burning experiments /69/.

Burning test of 90 % of peat and 10 % of MBM includes online temperature monitoring with Yokagawa DX2030. This device can measure temperatures from flame, flue gases and glycol. The measurement interval was 1 minute.

Picture 35. Temperature measurement device Yokogawa DX2030 /70/.

At first the temperature variation was quite large from 500 °C to 800 °C. This was due to the fact that the boiler was shut down before the experiment and it takes time to achieve stable burning of the fuel mixture. The stable burning temperatures were achieved, when the burning experiment was lasted 30 minutes. The temperature was now from 700 °C to 800 °C. This means that because the temperature variation is about 100 °C it can be considered a stable burning state. When this state was achieved it means, that emission measurements can be also started. The flue gas temperature was from 110 °C to 180 °C. The water temperature was from 54°C to 73, 5 °C.

Flow rate of the test was also measured with online measurement device. The variation of the flow rate was from 15, 9 l/min to 22, 5 l/min. The stable flow rate was achieved after a while to be 22, 5 l/min.

Picture 36. Universal flow meter /71/.

This experiment also includes evaluation of the heating value, moisture content and ash content to the mixture of 90 % peat and 10 % MBM and to the mixture of 100 % MBM. The experiment was done with bomb calorimeter. The 90 % peat and 10 % MBM mixture has heating value of 12, 61 MJ/kg, ash content of 11, 9 % and moisture content of 31, 5 %. The 100 % MBM mixture has heating value of 16, 83 MJ/kg, ash content of 24, 7 % and moisture content of 4, 6 %. Temperature of glycol in was 18 °C and glycol out 52 °C. Also boiler power was calculated according to the formula, where:

$$qv = 22{,}5\,\frac{l}{min} = \frac{22{,}5}{60}\frac{l}{s} = 0{,}375\,\frac{l}{s} = \frac{0{,}3750\frac{l}{s}}{1000} = 0{,}000375\,\frac{m^3}{s}$$

$$\rho, monopropylene\ glycol = 1030\ \frac{kg}{m^3}$$

$$qm = 0{,}000375\,\frac{m^3}{s} * 1030\,\frac{kg}{m^3} = 0{,}38625\,\frac{kg}{s}$$

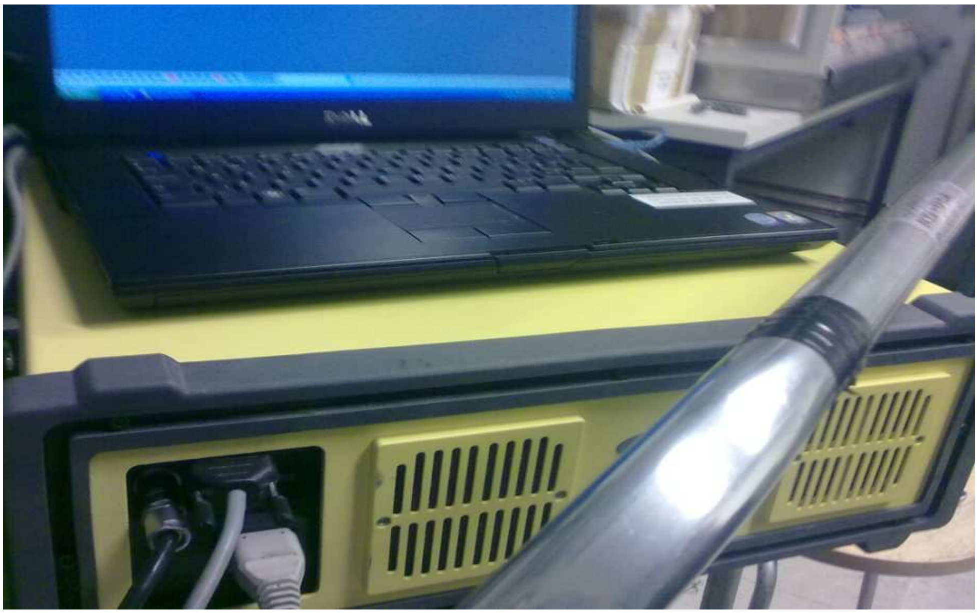
$$cp, monopropylene\ glycol = 3800\,\frac{J}{kgK} = 3{,}8\,\frac{kJ}{kgK}$$

$$T1, glycol\ out = 52\ ℃$$

$$T2, glycol\ in = 18\ °C$$

$$\phi = q\dot{m} * cp * \Delta T = 0{,}38625\,\frac{kg}{s} * 3800\,\frac{J}{kgK} * (52 - 18)°C \quad = 49903{,}5\ W$$
$$= 49{,}9\ kW$$

Online emission measurement for gaseous emissions where also done during the burning experiment. These emissions where measured with FTIR-spectrometry from flue gases. At the same time also heavy metal and dioxins and furans where measured from flue gases. These measurements were carried out by analytical laboratory company called Ramboll Analytics and they are not analyzed in Thesis.



Picture 37. Gasmet Technologies FTIR measurement device /72/.

FTIR-spectrometry can measure gaseous emissions like for example SO_2, CO, CH_4 and so on. During the burning experiment it can be seen, that lots of carbon monoxide was formed. This can lead to the fact that the mixture is not properly mixed inside the fuel silo, which means that proper mixing of the mixture can lead to lower carbon monoxide emissions. One reason might be that, the mixture goes straight through the furnace so that only small amount of mixture was burning. But on the other, the flame inside the furnace was clear and stable, so this can lead to the fact that the mixture burnt well. Also high amount of SO_2 was formed during the burning experiment. This is due to the fact that peat contains lots of SO_2, which increases the SO_2 emission amounts. These emissions can be reduced with calcium, which can be found from MBM, because calcium can bind the sulfur and this way it can reduce SO_2 emissions during burning operations. Also lots of NO_x emissions were also formed. These emissions can be reduced with proper scrubbers. On the other hand HCl and HF emissions were quite low. This kind of mixture can be used in power plant applications.

Gas	ppm	mg/m3
Carbon dioxide, CO2	16,82785359	33,27016337
Carbon monoxide,CO	2111,310966	2640,081257
Sulfur Dioxide, SO2	175,3374468	513,1964467
Nitrogen monoxide, NO	356,3690351	477,6522886
Nitrogen dioxide, NO2	3,94144517	8,094039189
Nitrogen oxide, N2O	29,62861703	58,19906917
Methane, CH4	32,468225	23,19158928
Ethane C2H6	3,630598137	4,862408219
Ethylene, C2H4	6,545295278	8,181619097
Hydrogen chloride, HCl	2,885107922	4,636780589
Hydrogen fluoride, HF	0	0
Gas O2 %	10,03	14,3354592

Table 2. Emission results of 90 % peat and 10 % MBM

10.2 Results from the second burning day

The purpose of the second experiment day was to evaluate which kinds of possible peat and MBM mixtures can be burned. For this purpose several mixtures of peat and MBM were made and temperature and emission measurements with FTIR were also performed.

The first experiment consists of burning 80 % peat and 20 % of MBM. The temperature at the start was around 650 °C, but after a while it increases to 750 °C. At this point stable temperature inside furnace was achieved and emission measurements can be started. Also flow rate was measured and it was around the same as in previous experiment. The emissions were measured with FTIR. The burning of the mixture was stable and the flame was clear. Carbon monoxide, sulfur dioxide and nitrogen monoxide emissions were again high like they were also in previous experiment. Hydrogen chloride and hydrogen fluoride emissions were low like they were in previous experiment. According to this it seems, that also this mixture can be used in real power plant applications, if proper flue gas and ash devices are installed to the boiler.

Gas	ppm	mg/m3
Carbon dioxide, CO2	20,44416772	40,41993807
Carbon monoxide,CO	1924,719087	2406,758109
Sulfur Dioxide, SO2	188,1965372	550,8338116
Nitrogen monoxide, NO	632,3904668	847,6122335
Nitrogen dioxide, NO2	3,069064372	6,302542907
Nitrogen oxide, N2O	30,67180413	60,24818669
Methane, CH4	24,18275811	17,27339865
Ethane C2H6	3,874196915	5,188656583
Ethylene, C2H4	6,130337867	7,662922333
Hydrogen chloride, HCl	3,652777746	5,870535663
Hydrogen fluoride, HF	0	0
Gas O2 %	15,92459679	22,75958452

Table 3. Emission results of 80 % peat and 20 % MBM

When previous experiment was finished, we change the mixture to be 70 % of peat and 30 % of MBM. Same measurements were carried out like in last case. The temperature was stable immediately when we started this experiment due to the fact that the boiler was warmed up with mixture containing 80 % of peat and 20 % of MBM. At this point temperature was from 720 °C to over 800 °C. The flow rate was same (22, 5 l/min). The flame inside the furnace was still quite good and stable. Carbon dioxide, sulfur dioxide and nitrogen monoxide emissions were again high and hydrogen chloride and hydrogen fluoride emissions were low.

Gas	ppm	mg/m3
Carbon dioxide, CO2	19,05827906	37,6799129
Carbon monoxide,CO	1985,603878	2482,891278
Sulfur Dioxide, SO2	222,5563844	651,401898
Nitrogen monoxide, NO	525,1916651	703,9304096
Nitrogen dioxide, NO2	1,331287369	2,733893704
Nitrogen oxide, N2O	27,55342767	54,12280435
Methane, CH4	23,01908209	16,44220149
Ethane C2H6	3,375828118	4,521198373
Ethylene, C2H4	3,031169525	3,788961906
Hydrogen chloride, HCl	5,938569301	9,544129234
Hydrogen fluoride, HF	0	0
Gas O2 %	15,64380092	22,3582684

Table 4. Emission results of 70 % peat and 30 % MBM

The third experiment consists of 50 % of peat and 50 % of MBM mixture. Again temperature and emission measurements were carried out according to the research plan. Temperature was immediately stable and the flame was clear. But after a moment, there can be noticed a big pile of mixture in front of the flame, which affects the burning of the mixture. At this point also increased ash formation can be seen and this affects also the burning conditions of the mixture. For a result, we stopped this experiment to this point and it can be said that this kind of mixture cannot be used in power plant applications.

Gas	ppm	mg/m3
Carbon dioxide, CO2	20,89660533	41,31444747
Carbon monoxide,CO	1958,077796	2448,471387
Sulfur Dioxide, SO2	356,4354446	1043,253492
Nitrogen monoxide, NO	750,977837	1006,558503
Nitrogen dioxide, NO2	0,715525033	1,469381764
Nitrogen oxide, N2O	39,20325618	77,00639608
Methane, CH4	20,80246593	14,85890424
Ethane C2H6	5,397636127	7,228976955
Ethylene, C2H4	4,382128997	5,477661246
Hydrogen chloride, HCl	11,8377876	19,02501579
Hydrogen fluoride, HF	0	0
Gas O2 %	16,8569211	24,09207125

Table 5. Emission results of 50 % peat and 50 % MBM

After burning 50 % of peat and 50 % of MBM, we changed the mixture to be 90 % of peat and 10 % of powder MBM. Temperature was around 700 °C and 800 °C. Again the burning was good and stable. Emissions of carbon monoxide, sulfur dioxide and nitrogen monoxide were high like they were in case of 90 % peat and 10 % granulated MBM. Hydrogen chloride and hydrogen fluoride emissions were also low like they were in granulated 10% MBM case. At this point it is also good to notice that, because we are burning powder MBM which mixes well with peat, so it might be also a case that only peat is now burning. This kind of mixture is possible to use in power plant applications.

Gas	ppm	mg/m3
Carbon dioxide, CO2	20,44888481	40,42926418
Carbon monoxide,CO	2178,728502	2724,383274
Sulfur Dioxide, SO2	241,9036365	708,0295106
Nitrogen monoxide, NC	625,0718635	837,8028862
Nitrogen dioxide, NO2	1,624932128	3,336914191
Nitrogen oxide, N2O	41,13847105	80,80771099
Methane, CH4	24,65060513	17,60757509
Ethane C2H6	4,798587884	6,426680201
Ethylene, C2H4	4,792691831	5,990864789
Hydrogen chloride, HCl	10,61586403	17,06121006
Hydrogen fluoride, HF	0	0
Gas O2 %	16,56371283	23,67301521

Table 6. Emission results of 90 % peat and 10 % powder MBM

The last experiment consists of burning 80 % of peat and 20 % of powder MBM. Again temperature variation was stable and the flame was clear. The mixture was also burning well. Carbon monoxide, sulfur dioxide and nitrogen monoxide emissions were high and hydrogen chloride and hydrogen fluoride emissions were low. As a result this kind of mixture can be used in power plant applications.

Gas	ppm	mg/m3
Carbon dioxide, CO2	22,31636791	44,12144437
Carbon monoxide,C	1954,094643	2443,490667
Sulfur Dioxide, SO2	220,6346871	645,7772682
Nitrogen monoxide,	735,8041999	986,2208146
Nitrogen dioxide, NC	3,792924414	7,789041207
Nitrogen oxide, N2O	47,96300487	94,21304528
Methane, CH4	19,088008	13,63429143
Ethane C2H6	3,761588408	5,037841618
Ethylene, C2H4	4,139378349	5,174222936
Hydrogen chloride, H	12,09290636	19,43502809
Hydrogen fluoride, H	0	0
Gas O2 %	16,88304028	24,12940103

Table 7. Emission results of 80 % peat and 20 % powder MBM.

11. CONCLUSIONS

Purpose of the Thesis was to evaluate possibilities to utilize MBM in energy production by performing burning tests in Energy laboratory of LUT. The test were performed with 80 kW VETO grate firing boiler, which can be used to fire wood and peat. The main purpose of the burning tests was to evaluate emission- and ash properties for MBM. The first test includes burning of 100 % MBM with grate firing method. The results from this burning tests show, that MBM cannot be burnt as a primary fuel in combustion applications, because ignition of the MBM is rather difficult and demands high technology applications. Perhaps it can be burned in a boiler if it is heated up for a very long time, but at this point we didn't test this possibility, because of tight time schedule. It also forms lots of ash, which hinders the possibility to burn MBM as a primary fuel. Also risk for corrosion and fouling is very high, because MBM contains lots of chloride and other substances, which can increase the risk of corrosion or fouling. The experiment was stopped, because of the reason that MBM cannot be used as a primary fuel in this type of boiler.

Because the first experiment shows, that MBM cannot be burnt as a primary fuel, I changed the plan and we started to take emission- and ash properties from co-firing of peat with MBM. The mixture, what we used, contains 90 % peat and 10 % of granulated MBM. When this mixture enters to the furnace it burned well and the flame was clear. At this point it is good to mentioned, that co-firing of peat with MBM goes to under waste incineration directive. Waste incineration directive demands, that end burning of the waste must last 2 seconds in 850 °C, so that every harmful emissions can be avoided. It is pretty obvious, that flue gas cleaning equipments must be installed to this kind of boiler. The laboratory boiler didn’t have flue gas cleaning equipments or any other sophisticated equipment, because this type of boiler is usually used for warming applications only. Also temperature in this kind of boiler is not as high as it should be, so this also effects for the results. If grate boilers are going to be used, they need to have special installations like separate after burning space, so that it is possible to meet requirements of the Waste incineration directive. This was also one reason, why emissions in this experiment were quite high, which can be seen from the result part of the Thesis. But anyway, the purpose was to show, that it was possible to burn peat with MBM, which was the main purpose of this work. The mixture, which contains 90 % of peat and 10 % of granulated MBM, seems to be good combination, which can be also used in real power plant applications. At this point it is good to mentioned, that fluidized bed burning offers the best solutions for burning peat with MBM. The mixture can contain maximum 20 % of MBM, so that it possible to avoid corrosion and fouling problems. It can be burned on the sand bed as suspension burning and the boiler must also contain flue gas cleaning applications. Burning of peat with MBM creates also lots of ash, so good ash handling equipments must be also installed to the boiler. Proper and even mixing of the mixture also ensures that burning is stable and emissions are not so high.

The other tests with different mixtures of peat with MBM were performed, because we wanted to know the maximum possible combination of peat with MBM, which can be used in burning applications. The mixture which contains 80 % of peat and 20 % of granulated MBM burned well and the temperature was stable inside the furnace. Even though the emissions were quite high and lots of carbon monoxide and sulfur dioxide were formed. At this point it is good to mentioned, that MBM contains lots of calcium which can bind sulfur and in that way, the emissions of sulfur dioxide can be decreased. Even though the mixture which contains 70 % of peat and 30 % of MBM burned rather good, it is not recommended to use this kind of combination in burning applications, because of the risk of corrosion and fouling. We also burned mixture which contains 50 % of peat and 50 % of MBM. This mixture forms a big pile in front of the flame, which didn’t burnt and ash problems were also occurring at same time. Also corrosion and fouling risk inside the boiler at this point is high. But again it was good to notice that how different kinds of mixtures can be burned with same boiler. We also tried two mixtures which contains powder MBM. These mixtures were 90 % of peat and 10 % of powder MBM and 80 % of peat and 20 % of powder MBM. These mixtures burned very well and the tests shows that also powder MBM can be used in co-firing applications.

Performed burning tests showed, that MBM can be considered to burn as a secondary fuel in co-firing applications with peat. The most promising burning technology for burning peat with MBM is fluidized bed firing. These applications can provide high technology equipments and process conditions to meet the demands of Waste incineration directive.

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56. The flame of the 100% granulated MBM. Picture. Mobile phone camera
57. FTIR-spectrometry probe. Picture. Mobile phone camera
58. Mixture of 90 % peat and 10 % granulated MBM in the fuel silo. Picture. Mobile phone camera
59. Ignition of the furnace. Picture. Mobile phone camera
60. Heavy metal and PCDD/F measurement devices from flue gases. Picture. Mobile phone camera
61. Flame inside the furnace. Picture. Mobile phone camera
62. Ash of 90 % of peat and 10 % granulated MBM mixture. Picture. Mobile phone camera
63. Burning process of 80 % peat and 20 % granulated MBM. Picture. Mobile phone camera
64. Pile of mixture inside the furnace. Picture. Mobile phone camera
65. Powder MBM. Picture. Mobile phone camera
66. Feeding of pure powder MBM. Picture. Mobile phone camera
67. 100% MBM inside the furnace. Picture. Mobile phone camera
68. Sample plate before the burning experiments. Picture. Mobile phone camera
69. Sample plate after the burning experiments. Picture. Mobile phone camera
70. Temperature measurement device Yokogawa DX2030. Picture. Mobile phone camera
71. Universal flow meter. Picture. Mobile phone camera
72. Gasmet Technologies FTIR measurement device. Picture. Mobile phone camera

APPENDICES 1

POLTTOKOE SUUNNITELMA (laboratorio)

Määritetään 2-luokan (ei riskiaines) lihaluujauholle (100 % ajo, toimitetaan rakeina, koe toteutetaan 80 kW VETO stokerikattilalla):

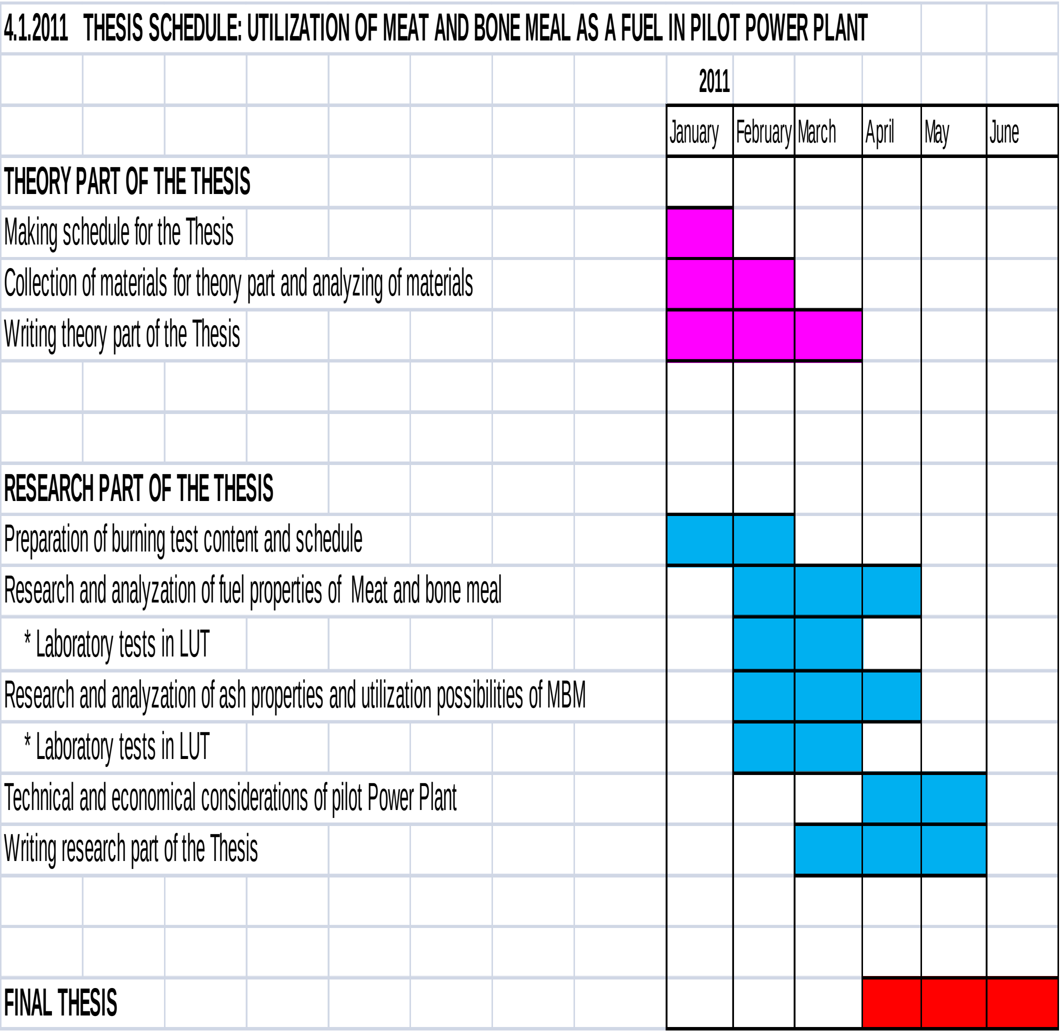
- Lämpöarvo MJ/kg (LUT)
- Kosteus % (LUT)
- Tuhka % (LUT)
- Kaasumaisten päästöjenmittaus (FTIR-mittaus) savukaasuista (LUT)
- Näytelevyn laitto (korroosio, likaantuminen→visuaalinen tarkastelu) (LUT)

- Raskasmetallit ja Dioksiinit/Furanit (savukaasuista) (Ramboll Oy; mittaaja paikalla)
- Tuhkan sulamiskäyttäytyminen (pehmenemispiste, puolipallo, nesteytyminen) (Ramboll Oy)
- Tuhkan PCDD/F (Ramboll Oy)
- Tuhkan metallipaketti HF-hajotus ja ICP-OES (mod. CEN/TS 15290) : Na, K, Ca, Mg, Si, P, Fe, Al, Ti, Pb, Sn, Zn, Cd, Sb, As, Cr, Co, Cu, Mn, Ni, V (Ramboll Oy)

sekoitus ajo: 80 % turve ja 20 % lihaluujauho

- Mitataan kaasumaiset päästöt (FTIR-mittaus) (LUT)
- Tarkastellaan tapahtuuko tulipesän tai lämmönvaihdinpintojen korroosiota tai likaantumista näytelevyn avulla visuaalisesti (LUT)

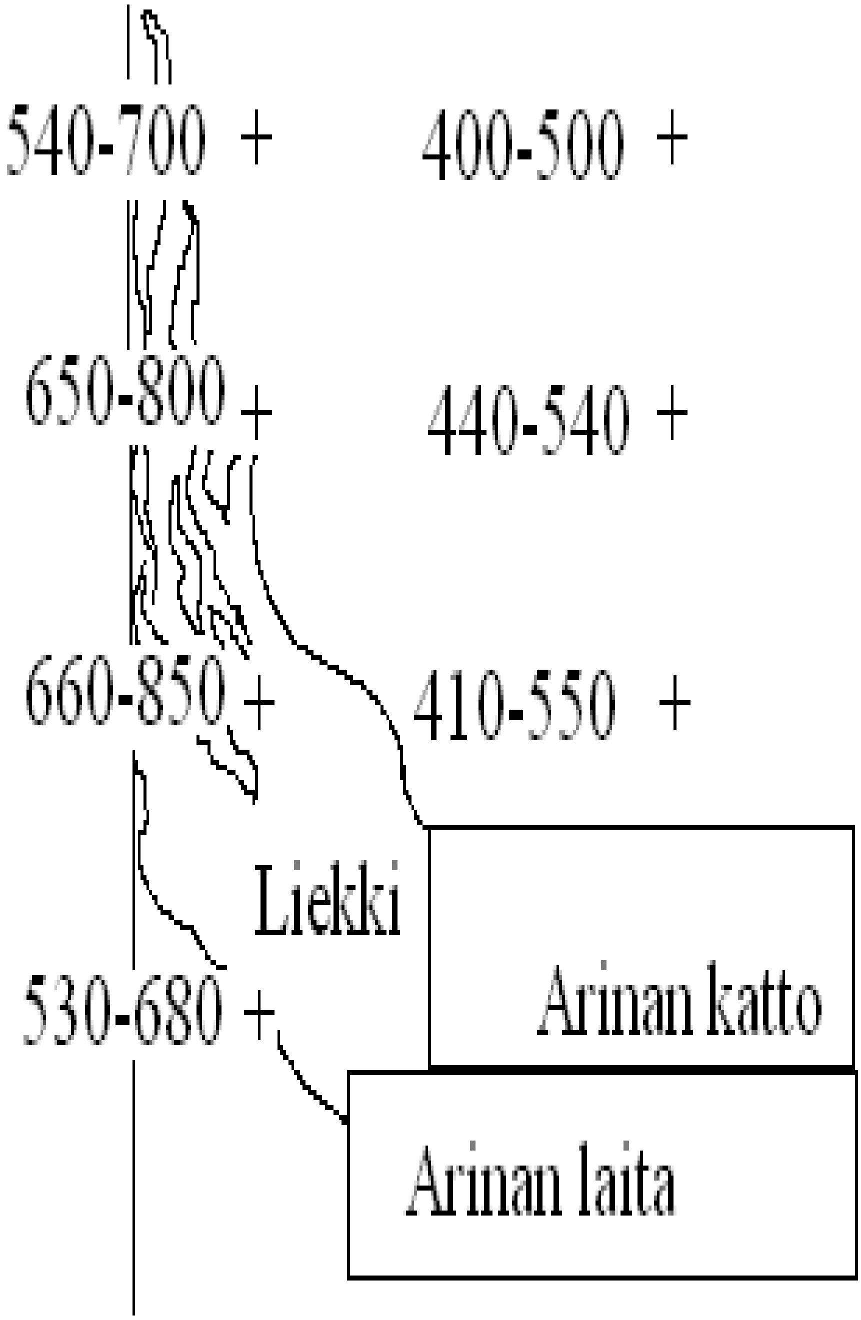
APPENDICES 2



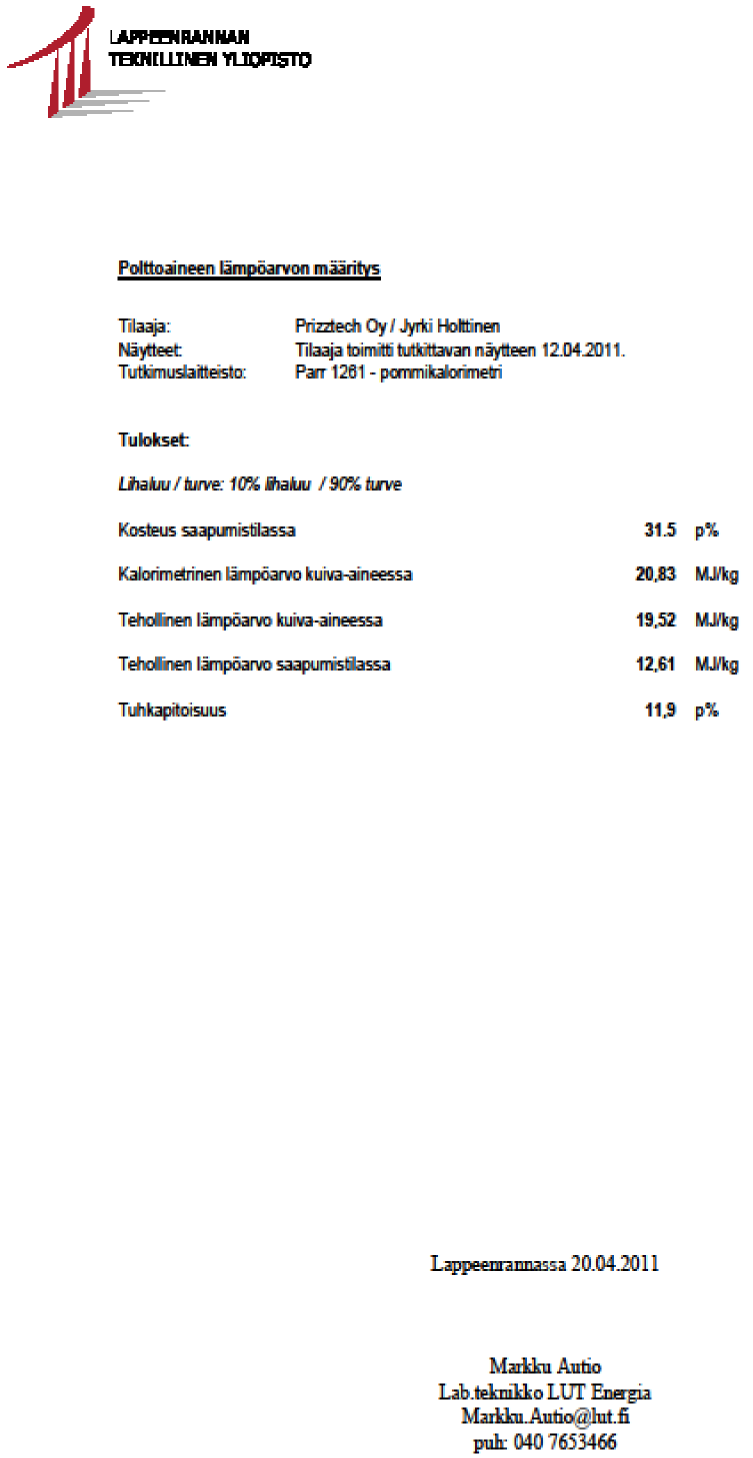
4.1.2011 THESIS SCHEDULE: UTILIZATION OF MEAT AND BONE MEAL AS A FUEL IN PILOT POWER PLANT

	2011					
	January	February	March	April	May	June
THEORY PART OF THE THESIS						
Making schedule for the Thesis	🟪					
Collection of materials for theory part and analyzing of materials	🟪	🟪				
Writing theory part of the Thesis	🟪	🟪	🟪			
RESEARCH PART OF THE THESIS						
Preparation of burning test content and schedule	🟦	🟦				
Research and analyzation of fuel properties of Meat and bone meal		🟦	🟦	🟦		
* Laboratory tests in LUT		🟦	🟦			
Research and analyzation of ash properties and utilization possibilities of MBM		🟦	🟦	🟦		
* Laboratory tests in LUT		🟦	🟦			
Technical and economical considerations of pilot Power Plant				🟦	🟦	
Writing research part of the Thesis			🟦	🟦	🟦	
FINAL THESIS				🟥	🟥	🟥

APPENDICES 3



APPENDICES 4



LAPPEENRANNAN
TEKNILLINEN YLIOPISTO

Polttoaineen lämpöarvon määritys

Tilaaja: Prizztech Oy / Jyrki Holttinen
Näytteet: Tilaaja toimitti tutkittavan näytteen 12.04.2011.
Tutkimuslaitteisto: Parr 1261 - pommikalorimetri

Tulokset:

Lihaluu / turve: 10% lihaluu / 90% turve

Kosteus saapumistilassa	**31.5**	**p%**
Kalorimetrinen lämpöarvo kuiva-aineessa	**20,83**	**MJ/kg**
Tehollinen lämpöarvo kuiva-aineessa	**19,52**	**MJ/kg**
Tehollinen lämpöarvo saapumistilassa	**12,61**	**MJ/kg**
Tuhkapitoisuus	**11,9**	**p%**

Lappeenrannassa 20.04.2011

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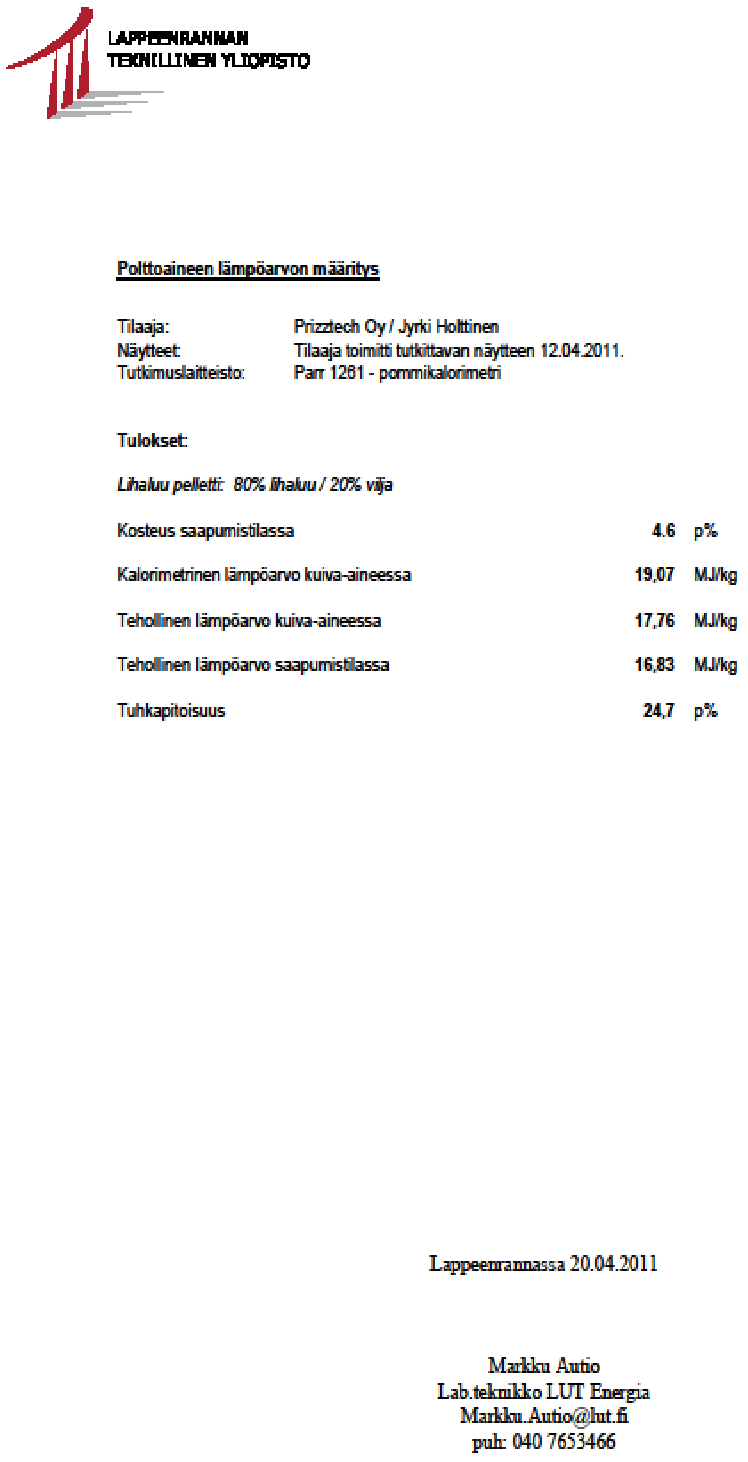
APPENDICES 5



LAPPEENRANNAN
TEKNILLINEN YLIOPISTO

Polttoaineen lämpöarvon määritys

Tilaaja:	Prizztech Oy / Jyrki Holttinen
Näytteet:	Tilaaja toimitti tutkittavan näytteen 12.04.2011.
Tutkimuslaitteisto:	Parr 1261 - pommikalorimetri

Tulokset:

Lihaluu pelletti: 80% lihaluu / 20% vilja

Kosteus saapumistilassa	**4.6**	p%
Kalorimetrinen lämpöarvo kuiva-aineessa	**19,07**	MJ/kg
Tehollinen lämpöarvo kuiva-aineessa	**17,76**	MJ/kg
Tehollinen lämpöarvo saapumistilassa	**16,83**	MJ/kg
Tuhkapitoisuus	**24,7**	p%

Lappeenrannassa 20.04.2011

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