Biomass Torrefaction and Co-firing, Processes Modeling

I. INTRODUCTION

Poland is in the group of fife countries in European Union with the biggest biomass resources (68 thousands m3) which can potentially use for energy production. This biomass is coming mainly from forests and wood waste. Ligninocellulose biomass is a unique fuel and will play a important role in near future energy mix in Poland [1]. Compare to the rest of renewable energy sources, biomass provide continuous electricity generation, and is the only widespread source of renewable heat. Biomass co-firing and biomass combustion will contribute except to the reduction of CO2 and SO2 emissions also in support sustainable development, increase energy security and regeneration of rural areas, due to the increased of forestry and agricultural activity and the provision of small scale heat and electrical energy production schemes. There are a number of barriers to overcome in order to expand the biomass sector. Some of them includes economics and bureaucracy and fragmented approaches from national and regional authorities but some also limitations connected to biomass fuel characteristics [2].

When we would like to compare coal with wooden biomass, which both are still the dominant solid fuels in heat and electricity production in Poland, often reveal inferior properties of biomass. When we look closely on wooden biomass fuel properties we see that biomass has in most cases a high moisture content, resulting in storage complications such as self heating and biological degradation, lower energy densities, is a bulkier fuel (with poorer transportation, handling characteristics), more tenacious (fibrous nature of biomass makes it difficult to reduce to small homogeneous particles). Biomass properties mentioned above have negative impacts during energy thermal conversion such as gasification system design limitations and lower combustion and co-firing efficiencies [3].

To improve the properties of wooden biomass and make it more coal-liked material a torrefaction (biomass carbonization) process is necessary to by apply which is also called biomass roasting process. Torrrefaction is a thermal treatment technique that occurs in a inert atmosphere. Carbonization or torrefaction is a thermal degradation of biomass structures by heating it without air contact under atmospheric pressure. It removes low weight organic volatile components and moisture as well as depolymerises the long polysaccharide chains of biomass. This kind of process of wood carbonization is quite complex research subject due to the fact that wood contains different fractions. When we look in microscopic scale, wood cells are build from microfibrils, bundles of cellulose molecules ‘coated’ with hemicellulose. Another component of wood biomass is lignin which is deposited between microfibrils and in some types of biomass in the amorphous regions of the microfibril. All of those three fractions represents different thermal behavior [4]. As a torrefaction product we get a hydrophobic solid fuel with greatly increased grindability and energy density (on a mass basis). What is more important we lower requires energy to process the torrefied biomass and it not longer requires additional separate handling facilities when we co-combusted new fuel with coal in operating power plants. It is suggested that torrified biomass can be compacted into high grade pellets with substantial superior fuel properties compared with standard wood pellets from un-treated biomass. Carbonization process can be combined together with drying and pelletisation process, with both energy end economy benefits. Biomass torrefaction process has been suitable feedstock for flow gasification, which was not before considered feasible for raw biomass. Due to the fact that carbonized biomass forms more than raw biomass solid fuel spherical shaped particles during milling or grinding. In the group of negative aspects of torrefaction process we can distinguish: requirements for separate plant, an input of additional energy for biomass carbonization and the production of volatile streams, increasing the capital, operating and emission control costs. Only the optimum balance between these new process costs plus energy consumption as well as energy benefits and costs from a higher caloric value, better grindable are therefore important factors for the future of torrefaction process. There are few publications presents evaluation of wooden biomass torrefaction and concluded that the heating value and environmental positive aspects and corresponding benefits thanks to carbonization are not much greater than additional capital costs and the extra energy consumption, but it did indicated that biomass torrefaction has potential in fuel densification. In this paper is presented the first results on torrefaction of four kinds of wooden biomass, straw, pine, deciduous and coniferous wood. In the second half of this paper a technical barrier of biomass co-firing is presented and advantages of torrifed biomass co-combusted with coal is described. Torrefaction is a thermal pre-treatment step for biomass co-firing which takes places in relatively low temperature range of 225-350 ºC to produce a fuel with bigger energy density by decomposition of hemicellulose fractions mainly. During biomass decomposition a three zones can be distinguished on the weight loss curves of wood: first one correspond to the most reactive component – hemicellulose which decomposition starts at 225°C and finished at 325°C, second one is cellulose which decomposition temperature rate is 300°C up to 375°C and last one – lignin which represents the widgets temperature rate of 250-500°C [5]. Carbonization process of lignocellulosic biomass can be described by the weight loss kinetics by using different experimental devices. Among those many devices are: fluidized bed reactors, thermogarvimetric analyzers Fig.1. and tube furnaces.

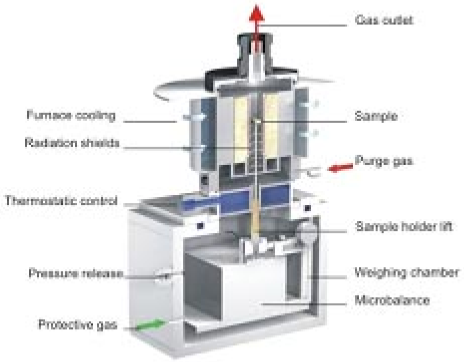

Figure 1. TG analyser 209 T3 (Netzsch)

II. EXPERIMENT ON BIOMASS TORREFACTION, USING TGA, DTA ANALYSIS,

In this paper a method with thermogravimetric analyser (TGA) was chosen to determined the weight loss kinetics of wood torrefaction. By using this kind of experimental method we can obtain dynamic conditions, in which the sample with biomass is placed to an specific heating rate, but it is important to known that experimental heating rates are very often slower than those in real process equipment such as combustors, reactors or gasifiers. Because of the variations in ash content of different samples, the measured weight where corrected using equation placed below:

$$\left(\frac{M_t}{M_O}\right)_{\exp} = \frac{W_{TGA} - W_{ash}}{W_{initial} - W_{ash}} \qquad (1)$$

Where, $W_{initial}$ is the solid weight of the dry sample, W_{ash} is the weight of the ash in the dry sample, and W_{TGA} is the solid weight that is measured as a function of time.

In the firs stage of this paper a none – static conditions where carry on, in which the samples where heated up from ambient temperature to 400°C with assigned heating rate 10°C/min in nitrogen atmosphere. In second part a isothermal conditions were applied after the maximum mass loss ratio in time was found from the data obtained in first experiments and after dynamic heating of the samples (the samples stays 10 minutes in isothermal conditions in temp. range from 330 up to 350°C) in argon atmosphere. In this kind of procedure, the heating rate is very important too, due to the fact that the biomass must be heated from laboratory temperature to the temperature at which the torrefaction reaction takes place and the weight loss kinetic is observed. When the heating rate is too high, the results may be affected by heat transfer limitations within the specific sample with biomass [6]. In the opposite situation when heating rate is too slow, the weight lost which occur during warming up is big enough to influence on deduction and proper interpretation of experimental kinetics data. Fortunately, for the low temperatures which are uses in biomass carbonization (225-320°C), the warm-up phase is not so long, even compare to low heating rates uses in TGA method (10-50°C/min) and the error which appear due to the weight loss in this phase is acceptable.

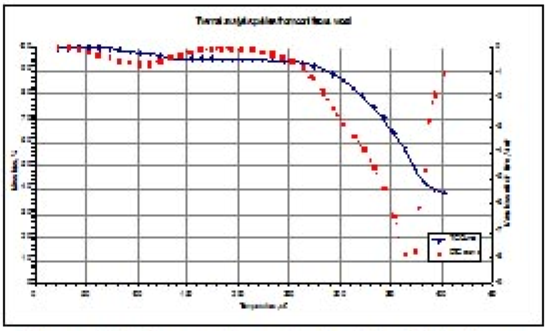

Figure 2. Thermal analysis of pellets from deciduous wood (nitrogen atmosphere, none-isothermal conditions)

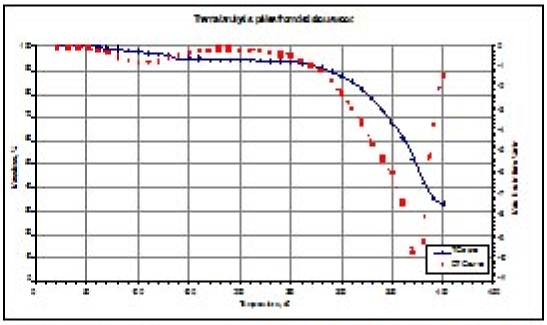

Figure 3. Thermal analysis of pellets from coniferous wood (nitrogen atmosphere, none-isothermal conditions)

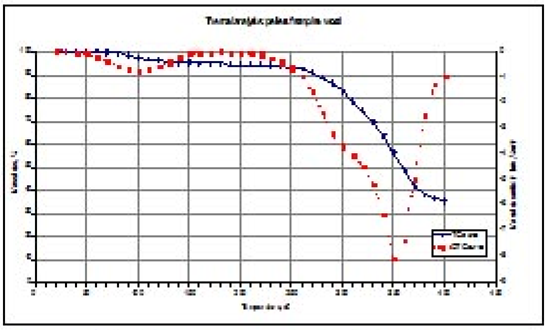

Figure 4. Thermal analysis of pellets from pine wood (nitrogen atmosphere, none-isothermal conditions)

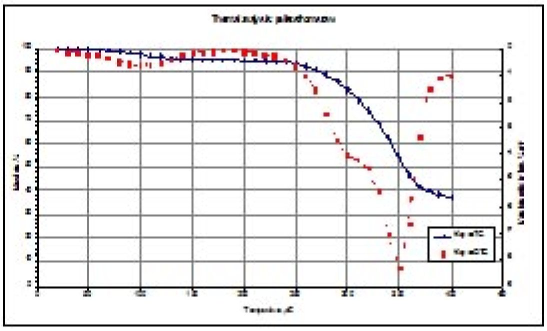

Figure 5. Thermal analysis of pellets from straw (nitrogen atmosphere, none-isothermal conditions)

Composition of biomass determines its behavior during carbonization process. In my research I have chosen four different types of wooden biomass: pellets from deciduous wood, pellets from coniferous wood, straw pellets and willow. All of those four types are coming from central part of Poland (province of lodzkie) and were pre-dry to obtain moisture content in the range of 5-10%.

Table 1. Fuel characteristic of four wooden pellets from:

No.	Decid--uous	Conif--erous	Pine	Straw
C,%				
H,%				
N,%	<0,3	<0,3	<0,3	
O,%				
Zn mg/kg	<100	<100	-	-
Pb mg/kg	<10	<10	-	-
Ash, %	<0,5	<1,5	<1,0	<0,5
Mois--ture, %	8,1	6,3	8,2	4,2
LHV	18,5	17,5	18,0	16,0

MJ/kg				

Table 2. Analysis

Properties	Deciduous	Coniferous
Cellulose	55%	45%
Lignin	30%	25%
Hemicellulose	10%	20%
Resin, Gum	4,5%	9,5%
Minerals	0,5%	0,5%

These four types, except straw and willow, are not much different in the distribution of three wood fractions. Coniferous wood types and deciduouse wood type are considered as a soft wood and hard wood respectively. The first one, coniferous wood can contain little less cellulose (35-50 wt% versus 40-55 wt%), slightly more lignin (25-35 wt% versus 18-30 wt%) and similar on average amount of hemicellulose (20-32 wt% versus 15-35 wt%). Anyhow, the composition of the polysugars from which hemicelluloses fractions are formed is much different. Hemicelluloses from coniferous wood contain 60-70 wt% of glucomannan and 15-30% of arabinogalactan whereas they contain 80-90 wt% of 4-O methyl gluconoroxylan (referred to as xylan) for deciduous wood [7]. So, it is important question whether thermal behaviour of coniferous and deciduous wood types is the same, and if they react with similar rates in the carbonization temperature range.

The area closed by DTA curve given in fig.5 is described by the following equation:

$$\frac{m \cdot \Delta H}{g \cdot k} = \int_{t_1}^{t_2} \Delta T \cdot dt \qquad (2)$$

Where, m is the mass of sample (mg); ΔH is the heat of reaction (kJ mol-1); g is the geometric shape constant for the apparatus (4πh or 8πa; h is the height of sample, a is the radius of sample holder) (m); k is the thermal conductivity (Wm-1K-1); ΔT is the differential temperature (K); t1 and t2 are the integral limits of differential curve (K) [8].

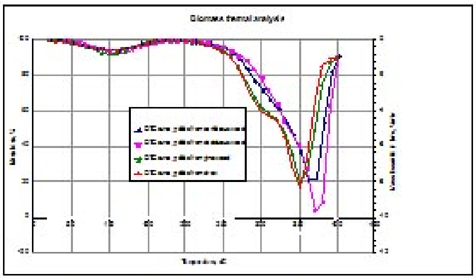

Figure 6. Mass loss in time curves represents four types of torrified wooden biomass

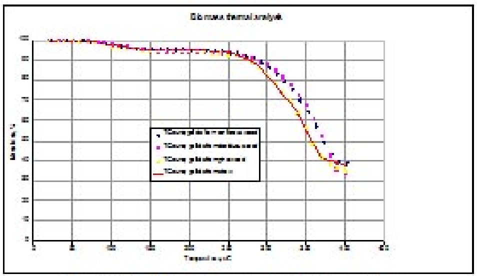

Figure 7. Mass loss in time curves represents four types of wooden biomass

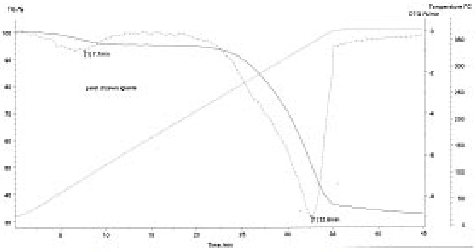

Figure 8. Thermal analysis of pellets from deciduous wood (argon atmosphere, isothermal conditions)

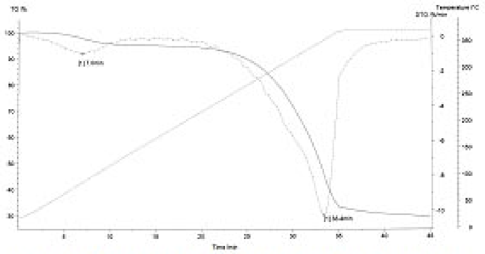

Figure 9. Thermal analysis of pellets from coniferous wood (argon atmosphere, isothermal conditions)

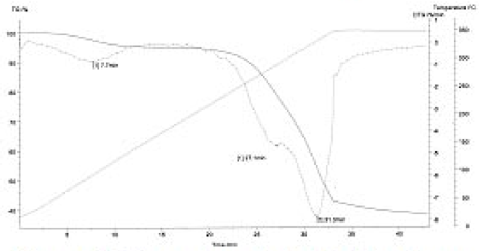

Figure 10. Thermal analysis of pellets from straw wood (argon atmosphere, isothermal conditions)

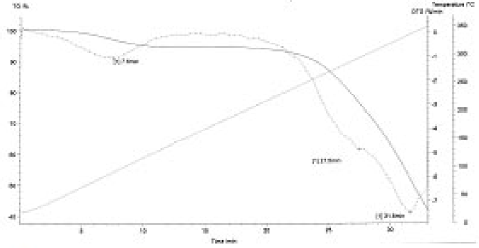

Figure 11. Thermal analysis of pellets from pine wood (argon atmosphere, isothermal conditions)

III. BIOMASS CO-FIRING

Biomass co-firing with coal in conventional power plants is the main direction of polish and European energy sector development. Biomass has the biggest potential from all kind of renewable energy sources in Poland. Unfortunately combustion of untreated biomass (which has significant amount of water and organic and mineral matter) cause series of technical and exploitation problems in pulverized boilers and other equipment [9]. Negative impact of biomass on ash deposition and ash sintering on the surface of the heat exchangers and other co-firing problems are listed below:

1. Adding fuel with lower caloric value and with high humid content like wooden biomass makes that it is necessary to use more water in the main stream of water injected. When we use 20% of biomass in the main fuel stream the stream of injected water to the burners increase 50% compare with the normal operating conditions. To solve that problem it is common to uses heat from biomass for the burners in the lower part of boilers.

2. When we combust straw with coal together we need to take into account fact, that straw characterize with low mineral matter content which makes that during co-firing we get less ash

formations,

- Straw co-firing has slightly influence on heat transfer inside the boiler
- Straw co-firing together with coal causes chloride corrosion. To solve those problems it is important to match proper coal characteristics
- Nearly all kind of wooden biomass has bigger than coal tendency to char formation which influence on the boiler efficiency – higher flue gases losses and lower efficiency [10]
- Ash formation and it residue on the heat exchangers surface is solve by mechanical removing or ash blowing

During co-combustion we can observe a significant increase in ash formation which is streaming with flue gases. Due to that fact thermal effectively of boiler heating surface decrease with increasing the biomass/coal fuel ratio. In addition the pollution emission is rising because of adding to fly ash volatiles with very small granulation which are formed during condensation and fusion of mineral volatile fractions. Especially during co-firing with biomass rich in sodium and phosphorus it has big influence [11].

All of problems during biomass co-firing which were described above can be solve after co-combustion process by mechanical removal of the ash deposition, mineral matter deposition on hex's surface or by cleaning mills or replacing them with the new one. This rise the operational and exploitation costs drastically and do not solve the sources of those problems. A promising biomass pre-treatment technology which is cost-effective and soon will be commercialize is called torrefaction.

During biomass carbonization process a high reduction of oxygen and hydrogen amount occur compare to reduction of carbon because biomass is transform to more coal liked fuel called biocoal. Average caloric values of torrifed biomass is in the range of 18 to 23 MJ/kg, low humid content (1-6%) makes from biocoal a potential substitute fuel for organic coal [12]. Biocoal is not perfect product which does not any disadvantages, a still low energy density is the main problem of torrefaction products, this mean that in practice torrefaction should be combined together with pelletisation. Thanks to those two processes combined together we can get a torrefied pellets which are characterize with high energy density, low humidity, high humidity resistance and do not need a any special storage facilities. Comparing biocoal pellets to standard pellets from un-treat biomass which was not produced during biomass carbonization, torrefied pellets have strong hydrophobic nature because of OH groups degradation and are more stronger and much more easier to transport and store [13]. Torrefied pellets are more compact and can be directly combust in fluidized bed combustor or pulverized boiler and represents faster ignition time of volatile matter and char. Biomass torrefaction solves co-firing barriers in the sources and soon will be less expensive for commercialization and easier from technical point of view to implement in industrial scale.

IV. CONCLUSIONS AND FURTHER IMPROVEMENTS

The first results on biomass torrefaction which was done in different condition: dynamic heating rate and static (isothermal conditions) and in different inert atmosphere: nitrogen and in argon shows that lower temperature under which maximum mass loss ration in time is observed in argon atmosphere (20°C lower temperature than in nitrogen atmosphere). Additional research will need to be done to explain if the different torrefaction atmosphere has exactly this influence on optimum temperature under which the highest mass loss ratio occur. Also a quantity analysis of torgas (gas evaporating during biomass torrefaction from heated samples) and this gas content analysis will be done. The quantity analysis will be perform using FTiR spectroscopy analysis (Fourier Transform Infrared Spectroscopy). After detail analysis of pellets from deciduous, coniferous, straw and pine wood a different kind of grass (like miscanthus) will be analysis.

The data obtained from biomass thermal conversion will be use for preparation a model which will simulate the biomass particles behavior during torrefaction process and co-firing with coal in one of the existing and operating boiler in local CHP plant. The last stage on my research will be related to create a model of co-combustion and heat transfer processes in a combustion chamber of fluidized bed combustor feed with torrified biomass.

V. REFERENCES

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