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TORREFACTION OF BEECH AND SPRUCE SAWDUST

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Abstract:
This paper aims to apply a thermal treatment of beech and spruce sawdust dried to 10% moisture in order to determine the mass loss and to obtain pellet sets. This paper considers the colour change of the treated material during the treatment, as function of time and temperature increase. It also highlights the changes in the chemical composition of sawdust connected with the mass loss. The paper also studies the physical integrity of the obtained pellets, using the method of free fall, with the results showing that spruce sawdust pellets appear to be more stable. The optimal temperature of thermal treatment proves to be 260^{0}C and the duration of treatments are 5 and 10 minutes, when the sawdust has dimensions between 0.4-1mm. Regarding the pellets formed at the temperature above 260^{0}C, it should be noted that their stability is low, in particular that one of beech, which is difficult to compress and compact.

***Key words**: torrefaction; sawdust; beech; spruce; pellets.*

INTRODUCTION

Thermal treatments are used more widely in the process of improving the mechanical and physic-chemical characteristics of biomass. These treatments modify the chemical composition, providing carbon content enrichment. Nowadays there are two main types of heat treatment processes, they are dry torrefaction and wet torrefaction. Dry torrefaction presupposes the treatment of biomass at the temperatures of 200-300^{o}C, the reaction time is about 5-30min, depending on the size of the biomass particles (Chen *et al.* 2010, Brostrom *et al*. 2012). Wet torrefaction, which is called hydrothermal carbonization in scientific researches, occurs at the temperatures of within 180–260^{o}C, with biomass immersed in pressure 4.6MPa (Chen *et al*. 2011, Chen *et al.* 2012). Another research concerning rapid thermal processing is the fast pyrolysis which is the thermal treatment of biomass at the temperature of 500^{o}C in the absence of oxygen (Brigwater 2011, Duncan *et al.* 2013).

Rapid heat treatment or torrefaction has been widely analyzed recently. Torrefaction process provides superior energy properties of solid fuel received from biomass, similar to those of fossil fuels. Torrefaction is considered a modern method of drying and handling of material and it has two main advantages: lowering the moisture content of the fuel and creating a hydrophobic fuel which absorbs only small amounts of moisture (Bridgeman *et al.* 2010, Pelaez-Santiago *et al*. 2013, Mendes *et al.* 2013). Moreover wood biomass is sterilized due to high temperature treatment, what increases its calorific value. The furnace used for dry torrefaction processes in comparison with other methods of drying was closed hermetically, controlling the temperature of the treatment, measuring the oxygen content and the quantity of material. It was possible to provide inert environment inside the furnace by the use of nitrogen introduced in order to control the amount of oxygen in the interior, which is referred to by different researchers (Almeida *et al.* 2010, Tsyganova 2013).

Regarding the processes of biomass thermal treatment there can be distinguished five main intervals of woody biomass thermal treatment, namely:

- The first treatment interval with the temperature up to 100^{o}C and the atmospheric pressure causes the elimination of water content from the wood.
- The second phase occurs at the temperature range of 100-250^{o}C, the heat is absorbed and the degradation of the wood chemical composition takes place.
- The third phase that occurs within the temperatures of 250-330^{o}C involves the complete degradation of hemicelluloses. At this stage, with significant changes of the hemicelluloses content, the oxygen bonds decrease and others, more resistant, links are formed.
- The fourth stage is assumed to take place in the temperature range of 330-370^{o}C producing cellulose destruction.

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- The fifth stage occurs at the temperature over 350°C, it is the period of the formation of charcoal which is a degradation product of lignin eliminated from the wood.

The temperature range is very important, because it determines the changes of the physical properties and thermal ones. According to the researches conifer species from America experience mass loss within the temperature range of 200-400°C, with cellulose and hemicellulose is having a lower resistance than lignin. Other researches in the given field prove a greater resistance of the cellulose and lignin of Eucalyptus species at the temperature of 300°C. The studies have revealed that hemicellulose and cellulose degrade 2 times faster than the lignin in the wood (Almeida *et al*. 2010). The processes of heat treatment described by many authors (Brigwater 2011, Ohliger *et al*. 2013) provide complex energy products, in a short period of time, compared to the biological decomposition through fermentation. During the thermal treatment of biomass hemicellulose decomposes in the temperature range of 200°C and 280°C, while cellulose decomposes in the temperature range of 240°C and 350°C, while lignin decomposition takes place starting with 280°C up to 500°C and after a longer period of time, according to the researches (Pienkos and Zhang 2009).

Weight loss is an important indicator of the effects of the wood torrefaction. This result is due to the degradation of the chemical elements composition, in particular, the hemicellulose which is the most sensitive to thermal effects and produces volatile substances. Thermal instability of hemicellulose being compared with cellulose is explained by crystal structure of hemicellulose, which is fine and easily decomposable. The recorded decomposition of the analyzed species was decreasing from 16.4% (untreated material) to 10.2% (180°C, the material treated during 1h). Mass and energy efficiency of wood untreated and wood torrefied is largely dependent of treatment temperature, treatment time, type of biomass used for treatment (wood or bark) and sizes of work samples (Almeida *et al*. 2010, Hu *et al.* 2011). It is a fact that the mass decrease is accompanied by the increase of the biomass calorific value, due to the increased content of carbon, which is the main component of all fuels (Bates and Ghonlem 2013, Li *et al.* 2012, Chaouch *et al*. 2013). The thermal treatment or thermal pretreatment is very important and in the field of bioethanol production involving degradation processes of hemicellulose, cellulose and lignin. It is obvious that these questions are also studied in terms of ecological aspects and environmental protection (Chiaramonti *et al.* 2010).

The main objective of this paper is to apply dry thermal treatment of beech and spruce sawdust in order to determine mass loss and to obtain pellet sets with good physical integrity and a better calorific power.

MATERIAL AND METHOD

We used beech and spruce sawdust obtained by processing with circular saws by ripping and cutback. For this purpose two sieves were used, eliminating the sawdust bigger than 1×1mm and less than 0.4×0.4mm. Such a small fraction of sawdust was taken as the torrefaction heat action was supposed to penetrate rapidly around the sawdust mass. Taking into consideration the size of the sieve meshes (Fig. 1), there appears the range of diameters 0.4-1mm.

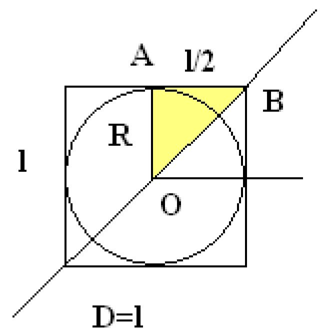

Fig. 1.
Sawdust diameter in relation to the sorting sieve sizes.

The furnace (Fig. 2) is prepared for heat treatment of sawdust. After being weighed, a certain amount of sawdust is placed in a crucible, being put on 2 rows of particles, so that to provide a good contact with the furnace temperature. This crucible is inserted into the furnace, previously set for each of the following temperatures: 200, 220, 240, 260, 280 and 300°C.

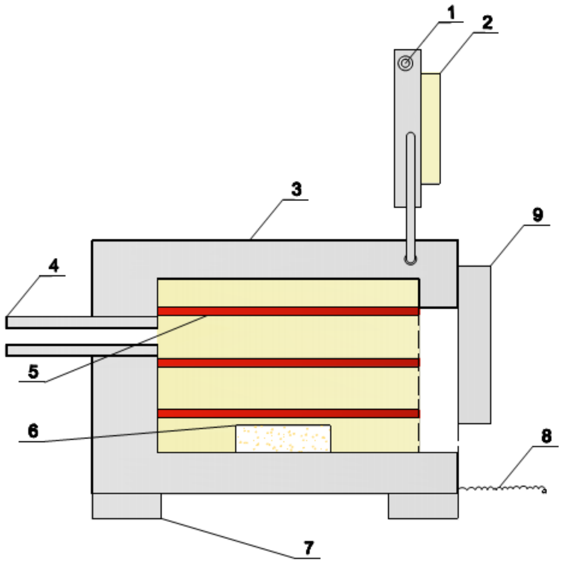

Fig. 2.
Furnace of sawdust heat treatment:
1 - element of opening and closing the door; 2 - pivot door; 3 - body of the thermal oven; 4 - gas chimney and fresh air intake; 5 - electrical resistance of heating; 6 - crucible with sawdust; 7 - furnace supports; 8 - power cable with plug; 9 - furnace programmer.

Thermal treatment is supposed to last correspondingly 5 and 10 minutes, which aims to find out the best time of torrefaction. The furnace is set for the desired period, the crucible is placed into the furnace and the crucible with the treated material is removed at the end of period. Then, this material is reweighed and the data are introduced in the tables. The following formula is necessary to calculate the mass losses (P_m) after torrefaction:

$$P_m = \frac{m_i - m_f}{m_i} 100 \quad [\%] \tag{1}$$

where: m_i is the initial mass, in g;
m_f - final mass, in g.

After cooling, the torrefied material is kept in the laboratory at the temperature of 20^0C and relative humidity 50% over 48 hours in order to obtain moisture content of 8-9%. At this period the torrefied sawdust is analyzed from the point of view of color changes. Then a hand press is used to produce pellets with the diameter of 12mm and length of 8-20mm. These pellets are kept over 1-2 hours, after which their physical integrity is checked by freefall from the height of 30cm on a hard, flat surface. Depending on what happens to the pellets in contact with the hard surface the qualification "yes- resist" or "no- break" can be estimated.

RESULTS AND DISCUSSION

The results of mass loss are presented in Table 1 for both species, at different treatment temperatures and times.

Table 1

Mass loss of torrefied beech and spruce

T, ^{0}C	Mass loss of beech sawdust, % after		Mass loss of spruce sawdust, % after	
	5 min	10 min	5 min	10 min
200	8.5	9.4	8.2	9.6
220	8.5	9.5	9.6	9.7
240	8.6	10.2	10.3	11.3
260	9.2	10.4	10.3	13.0
280	11.7	11.9	12.1	14.7
300	13.3	18.1	13.3	19.4

Total mass loss obtained after torrefaction is between 7.8-18.1% for beech and slightly higher between 9.5-19.4% for spruce. The influence of treatment temperature on the mass loss of beech and spruce is presented as well in the graph in Fig. 3.

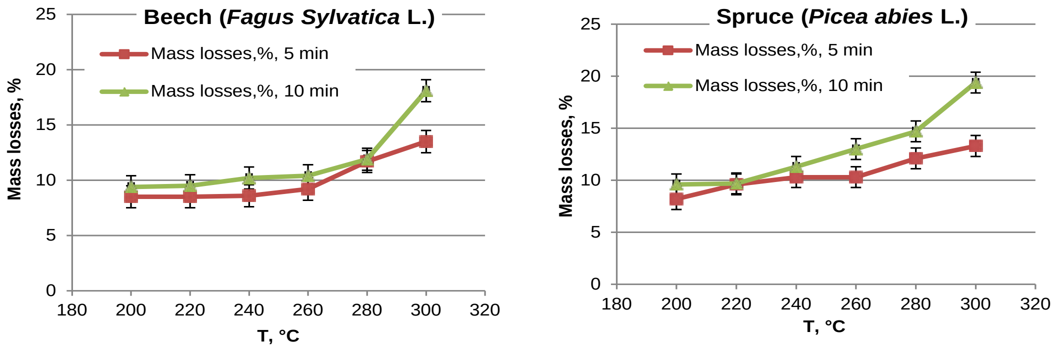

Fig. 3.
Influence of thermal treatment temperature on mass losses P_m.

Visible color changes of the sawdust were observed, and namely the spruce changes its color from pale yellow to dark brown and the beech from light to dark reddish brown (Fig. 4). The black color or the dark gray color denotes intense degradation of sawdust.

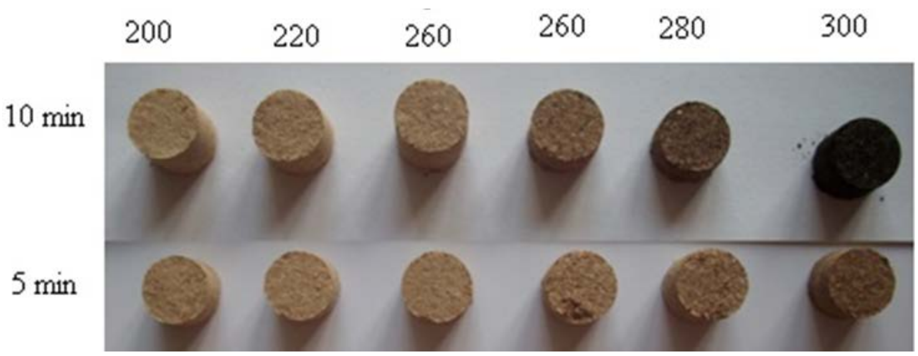

Fig. 4.
Color change of beech sawdust pellets under the influence of treatment temperature and duration.

The analysis of mass loss after torrefaction can be regarded also from the point of view of the major chemical components of wood, which are cellulose, hemicellulose and lignin. Their average proportions in wood are: cellulose 50%, hemicellulose 15%, lignin 30% and others 5%. The order of their decomposition during thermal treatment is the following: first decomposes hemicellulose, then cellulose, and finally lignin. The time and temperature of the heat treatment should be chosen so as to obtain only the thermal degradation of hemicellulose (in percentage of maximum 15%).

The physical integrity of the obtained pellets, determined by free fall shows that while the temperature and the duration of the treatment increase, the physical integrity of the pellets decreases (Table 2).

Table 2

Physical integrity of the pellets

T, ^{0}C	Beech pellets, after time of torrefection:		Spruce pellets, after time of torrefection:	
	5 min	10 min	5 min	10 min
200	Yes	No	Yes	Yes
220	No	No	Yes	Yes
240	No	No	Yes	Yes
260	No	No	Yes	Yes
280	No	No	Yes	No
300	No	No	No	No

So, from this point of view, the optimum torrefaction conditions for beech pellets are: 200ºC/5min and for spruce pellets: 280ºC/5min, so as to preserve the physical integrity of the pellets. Beech pellets are less compact after torrefaction and they break easily; consequently, they may require natural addings in their composition (starch, molasses etc.), in order to enlarge the particle adhesion. Since the compactness degree and the calorific value of the torrefied biomass are in a close relationship, this issue is of outmost importance for the use of pellets as fuel and the authors intend to continue their research in this direction.

CONCLUSION

In accordance with the main objective of the paper, beech and spruce sawdust was thermally treated in order to determine the mass loss depending on the duration and temperature of the treatment. Dry torrefaction of wood biomass is a method of heat treatment with visible results, such as the color change of the treated material and especially mass loss of the treated sawdust. Mass loss increases with temperature and with the duration of treatment. These values do not exceed the maximum percentage of hemicellulose in the wood, which means that only hemicelluloses are decomposed through this treatment. However, the temperature and duration must be limited since the physical integrity of the pellets is seriously affected by growing temperature. According to the obtained results, the optimum torrefaction conditions for beech pellets are: 200ºC/5min and for spruce pellets: 280ºC/5min, so as to preserve their physical integrity. The research is going to be continued and extended.

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