

## Influence of Torrefaction on the Fuel Characteristics of Different Biomass Materials

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**Abstract**—Possibilities of use of low-temperature pyrolysis (torrefaction) for improvement of heat engineering characteristics of biomass granulated fuel are considered. The data on hygroscopic properties, content of volatile matter and specific combustion heat of the torrefied fuel, produced under various conditions of processing of such types of biomass as wood, peat and agricultural waste, are presented. It is shown that the high-temperature conversion of gases and vapors, escaping during torrefaction, into synthesis gas is an effective method of their environmentally friendly utilization and, at the same time, increases the energy efficiency of biomass processing to granulated fuel.

**Keywords** - biomass; solid fuel; torrefaction; pyrolysis; synthesis gas

### I. INTRODUCTION

At present biomass are widely used in the power purposes. It is caused by development of self-sufficient power units, increasing attention to ecological aspects of warm and the electric power production, availability and renewable character of biomass as a fuel, tendency to energy safety of regions and countries. Methods of power utilization of biomass can be divided into two main groups, namely, direct use as a solid fuel and processing into gaseous or liquid fuel. In spite of distinctions in the properties of wood, agrowaste (sunflower and rice husk, straw) and peat, the production of granulated solid fuel (for example, pellets) from mentioned types of biomass obtains a wide spread occurrence. One of the main disadvantages of the granulated biomass fuel is bad hygroscopic property that complicates its storage and transportation and results in need to use of a moisture-proof package. Decrease in the hygroscopicity of biomass pellets can be achieved by their thermal processing. The thermal processing in the range of temperatures up to 300°C, carried out in the inert gas environment (low-temperature pyrolysis), leads to an improvement of consumer properties of solid fuel from biomass. In scientific literature this process is known as a torrefaction and can be used both as a prior operation before pelletisation [1, 2], and as processing of the solid granulated (briquetted) fuel from biomass [3]. In course of torrefaction not only the moisture removal from an initial raw material, i.e. its drying, occurs but also partial thermal decomposition of an organic constituent of biomass takes place. As a result a solid hydrophobic product is formed. In addition its specific

combustion value  $Q_f$  surpasses a similar value for initial raw material. In case of use of wood waste as initial raw material the value of  $Q_f$  can reach 19-23 MJ/kg depending on conditions at which the torrefaction is carried out [1]. Note that the combustion value of a dry wood and wood pellets doesn't exceed 18 MJ/kg. The present paper is devoted to investigation of influence of the torrefaction conditions on such properties of end product as devolatilization, specific combustion value and hygroscopicity.

### II. EXPERIMENTAL CONDITIONS

As raw materials there were used such types of biomass as wood, straw and peat. Thermal processing of pellets from the mentioned biomass materials consisted in their heating in the inert gas environment (nitrogen) to the torrefaction temperature  $T_f = 230, 250$  and  $270^\circ\text{C}$  at the rate of  $10^\circ\text{C}/\text{min}$  and holding at this temperature during some time.

When heating biomass there is its thermal decomposition and as a result a residual char and volatile products are formed. The volatile products consist of noncondensable gases, namely  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{H}_2$ ,  $\text{N}_2$  and  $\text{C}_n\text{H}_m$  (among gaseous hydrocarbons the basic is  $\text{CH}_4$ ), and condensable gases and vapor forming the liquid fraction under the normal conditions. Composition of each fraction and a quantitative ratio between them depend both on the final temperature of heating and on the heating rate. The yield of volatile products defines the mass loss of a raw material during its thermal processing. For measurements of the quantitative characteristics concerned with mass loss of raw materials during heating the thermogravimetric analysis were carried out. For this purpose the thermogravimetric analyzer SDT Q600 was used. The SDT Q600 allowed also to make the differential calorimetric analysis and it was used during investigations of the influence of torrefaction on the combustion value of granulated biomass fuel.

### III. RESULTS AND DISCUSSION

#### A. Torrefaction Process

Mass loss observed at the initial stage of heating (up to the temperature about  $150^\circ\text{C}$ ) is caused by release of physically bound water, i.e. drying of material, and characterizes its initial moisture content. In our case the moisture content of the samples was equal to 5.4% for wood pellets, 6.6% for peat pellets and 5.6% for straw pellets.

Further mass loss is caused by a thermal decomposition of organic constituent of raw material. Hydrocarbon raw materials of a phyto genesis consist of organic and mineral components. In turn organic part falls into hemicellulose, cellulose and lignin. Hemicellulose is the least thermostable organic component. According to [4] thermal decomposition of hemicellulose accompanied with mass losses occurs in the temperatures range of 200-270°C (with maximum rate at 245°C), cellulose – in the temperatures range of 280-370°C (with maximum rate at 330-335°C). Thermal decomposition of lignin follows more uniformly in comparison with two other components, and is characterized by a temperature interval 200-540°C.

Time history of the mass loss rate of wood pellets during torrefaction is well seen from the differential thermogravimetric curves (DTG) presented in Fig. 1: the first peak characterizes the drying rate of the sample, the second peak – the rate of thermal decomposition of the material. The maximum rate of mass loss is observed when the sample temperature reaches the value of  $T_t$  whereupon the rate decreases because of reduction of sample mass. As appears from Fig. 1 in 100 minutes after the onset of heating the rate of mass loss falls off practically on an order of magnitude. Based on this fact during investigations of the influence of torrefaction on the thermotechnical characteristics of granulated fuel from biomass the time of thermal processing was limited by the specified value.

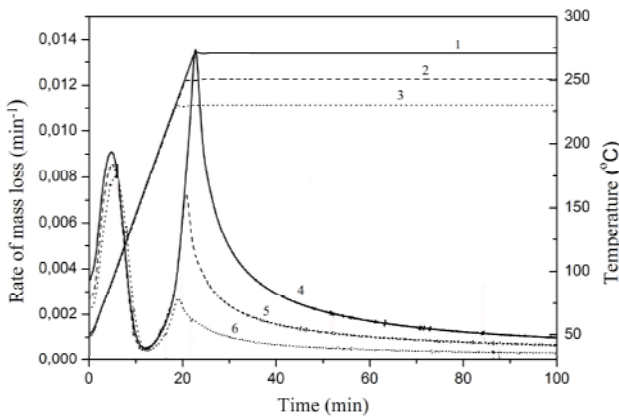


Figure 1. Change of temperature (1, 2, 3) and rate of mass loss (4, 5, 6) of wood pellets during torrefaction at  $T_t = 270^\circ\text{C}$  – 1, 4;  $250^\circ\text{C}$  – 2, 5;  $230^\circ\text{C}$  – 3, 6.

DTG curves describing dynamics of mass loss during pyrolysis (heating up to  $1000^\circ\text{C}$  at the rate  $10^\circ\text{C}/\text{min}$ ) of the original and torrefied wood pellets are presented in Fig. 2. In DTG curve, corresponding to the original sample, one can see three representative knees (are marked by arrows) associated with thermal decomposition of hemicellulose, cellulose and lignin. In DTG curve, corresponding to the sample subjected to torrefaction at  $T_t = 270^\circ\text{C}$ , the knee attributed to thermal decomposition of hemicellulose

disappears that is evidence of practically complete absence of it in the sample.

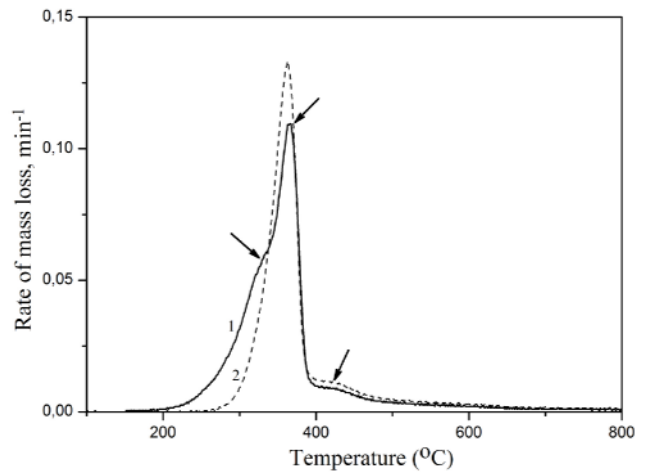


Figure 2. DTG curves of original wood pellets (1) and wood pellets torrefied at  $T_t = 270^\circ\text{C}$  (2) (heating rate  $-10^\circ\text{C}/\text{min}$ ).

In Table 1 the data on mass loss for different types of initial raw materials as a result of torrefaction at different temperatures  $T_t$  are submitted. From these data one can see that the smallest mass loss at torrefaction is observed for wood pellets, the greatest – for pellets of straw that is mainly concerned with the various content of hemicellulose in these raw materials. Note, that the maximum mass loss, re-counted on a dry state, as a result of pyrolysis of initial raw materials (heating up to the temperature of  $1000^\circ\text{C}$ ) accounts for 82, 64, 72 % for pellets of wood, peat and straw, respectively.

TABLE I. MASS LOSS AS A RESULT OF TORREFACTION, RE-COUNTED ON DRY STATE (%)

Torrefaction Temperature, $T_t$ (°C)	Raw material		
	Wood pellets	Peat pellets	Straw pellets
230	6.4	18	17
250	14	23	27
270	25	30	43

Decomposition of an organic part of a raw material, occurring during torrefaction, leads to change of its internal structure that is verified by electron micrographs. As a result of release of the volatile products the ratio between carbon, hydrogen and oxygen in a raw material changes that leads to change of its combustion value. Thus in consequence of torrefaction an initial raw material changes the thermotechnical properties, important at its use as a solid fuel.

#### B. Devolatilization

The ratio between the content of volatile and solid matters in a solid fuel has essentially influence on process of its burning. In particular, the rate of combustion is generally

defined by the rate of combustion of a solid carbon residue. Solid carbon residue makes main contribution to the combustion value of solid fuel also. In Table 2 the data on content of volatile matter in the initial raw materials and in the raw materials torrefied at different temperatures are submitted. From the presented data it follows that an increase in the torrefaction temperature  $T_t$  leads to a decrease of the content of volatile matter and, therefore, to an increase of mass fraction of solid carbon residue. The greatest difference between initial and torrefied raw materials is observed for pellets of straw. It is necessary to note that decrease of the volatile matter content leads to decrease of soot content in combustion products of a solid fuel. Soot is formed as a result of thermal decomposition of hydrocarbon components contained in the volatile products and responsible for smoke emission.

TABLE II. MASS FRACTION OF THE VOLATILE MATTER IN THE INITIAL AND TORREFIED RAW MATERIALS, RE-COUNTED ON DRY STATE (%)

Torrefaction Temperature, $T_t$ (°C)	Raw material		
	Wood pellets	Peat pellets	Straw pellets
230	81	60	66
250	79	57	62
270	76	53	51
Starting state of raw material	82	64	72

C. Hygroscopicity and Combustion Value

Other important properties characterizing a solid fuel are the combustion value  $Q$  and the limit moisture content  $W$ . In Fig. 3 and 4 there are shown the data on influence of the torrefaction temperature  $T_t$  on the above-mentioned properties. The limit moisture content  $W$  was measured as the ratio of the equilibrium mass of water retained by a material in the air with 100% humidity at the temperature of 26°C to the mass of dry material.

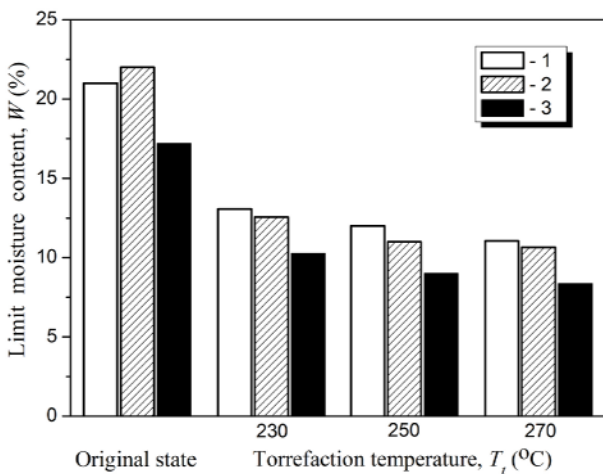


Figure 3. Effect of torrefaction temperature  $T_t$  on limit moisture content  $W$  for pellets of straw – 1, wood – 2 and peat – 3.

From the data presented in Fig. 3 one can see that the torrefaction allows essentially to improve the hygroscopic property of granulated fuel of the different biomass materials: the limit moisture content of pellets torrefied at  $T_t = 270^\circ\text{C}$  halves practically in comparison with untreated pellets. It is necessary to note, that untreated wood pellets swelled and collapsed after holding during 24 hours in the air with 100% humidity at the temperature of 26°C. The torrefied wood pellets kept the form in the similar conditions.

In Fig. 4 there are shown the data on influence of torrefaction on the combustion value of pellets from different biomass materials. From the presented data it follows that an increase of torrefaction temperature results in appreciable increase of specific combustion value. The maximum growth is observed for peat pellets.

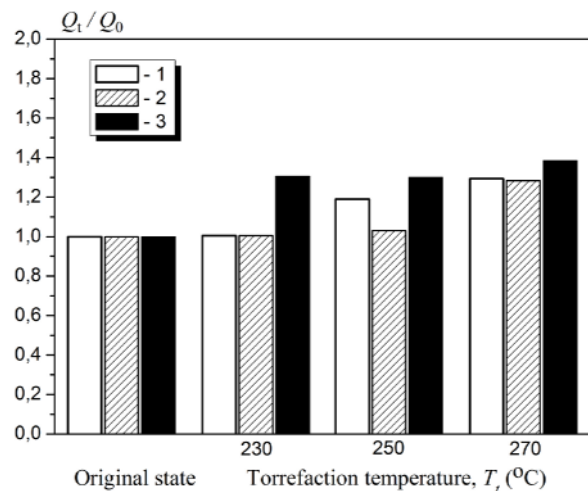


Figure 4. Effect of torrefaction temperature  $T_t$  on the ratio of combustion value of torrefied pellets  $Q_t$  to combustion value of original pellets  $Q_0$  (re-counted on dry state): pellets of straw – 1, wood – 2 and peat – 3.

IV. CONVERSION OF VOLATILE TORREFACTION PRODUCTS INTO SYNTHESIS GAS

In torrefaction of a biomass the perceptible amounts of volatile products is evolved (see Table 1). Usually the mass fraction of condensable volatiles is several times as much as noncondensable one. According to [5] the condensable fraction of volatile products consists mainly of acetic acid and water with modest quantities of methanol, formic acid, lactic acid, furfural and hydroxyl acetone. It is natural that the question of their utilization is very important from the ecological point of view. For this purpose the technology of thermal conversion of pyrolysis gases and vapour, suggested in [6] and considered in [7] as applied to torrefaction, can be used. In conformity with this technology, the volatile products forming during heating the treated organic raw materials are filtered through a porous carbon medium maintained at a constant temperature. The coal residue obtained by pyrolysis (heating in the inert gas environment up to the temperatures of 600-1000°C) of the same raw material can be used as a porous carbon material. Owing to

its well-developed surface, a rapid heating of volatile products and intensive decomposition of the high-molecular organic components entering into their composition take place. In addition as a result of interaction of water vapor and carbon dioxide with a carbon surface a formation of hydrogen and carbon monoxide (the water gas reaction) and reduction of carbon dioxide to carbon monoxide (the Boudouard reaction) occur. At the temperature of the carbon medium about 1000°C and suitable time of interaction of volatile products with a carbon surface practically complete conversion of the last into synthesis gas, i.e. a mixture of hydrogen and carbon monoxide, takes place.

In Fig. 5 there are presented the data on the volume content of hydrogen and carbon monoxide in gas mixture, which can be obtained as a result of high-temperature conversion of the volatile products forming during torrefaction of various biomass materials. Note that admixture of other gases, from which the basic is carbon dioxide, doesn't exceed 10 % (by volume).

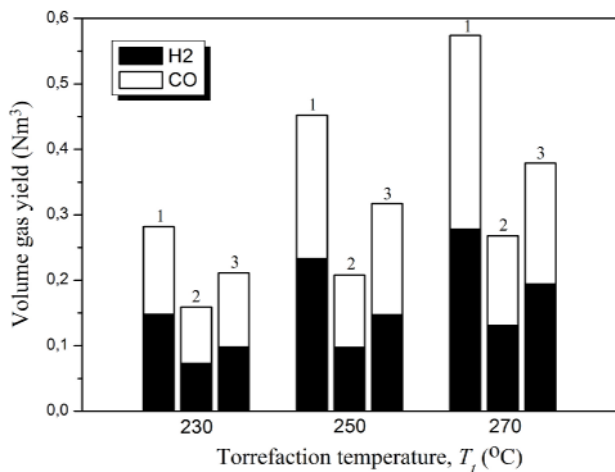


Figure 5. Volume yield of hydrogen and carbon monoxide per one kg of initial raw material vs. torrefaction temperature  $T_t$  for pellets from: straw – 1, wood – 2 and peat – 3.

The combustion value of the product synthesis gas is about of 11 MJ/m<sup>3</sup> that allows to consider it, as a quite acceptable gaseous fuel for power installations based on gas-piston engines. Let an average efficiency of transformation for electrogenerating installations on the basis of gas-piston engine is equal to 30 %, and the volume yield of the synthesis gas, which can be produced by high-temperature processing of the volatile products formed as a result of torrefaction of 100 kg of pellets, ranges between 20 and

55 m<sup>3</sup>, depending on types of raw material and torrefaction temperature (see Fig. 5). In this case the use of the synthesis gas, produced on torrefaction of 100 kg of pellets per hour, will permit to maintain an electrogenerating installation with power of 18-50 kW in operation. At the same time the electrical power of plant for wood pellitization with productivity of 100 kg per hour doesn't exceed 7,5 kW and with a large supply can be provided at the expense of thermal processing of the torrefaction volatile products into synthesis gas.

## V. CONCLUSION

As a result of performed experimental investigations it is shown that thermal processing of the granulated fuel from different biomass materials (wood, peat, straw) allows to improve its consumer properties, namely, to reduce the limit moisture content practically in half and to increase the specific combustion value noticeably. The volatile products obtained in the course of torrefaction can be converted into synthesis gas that allows to solve the problem of their utilization and simultaneously to increase the power efficiency of biomass processing. The considered approach can be used during engineering and creation of self-contained plants working directly in places of biomass production and intended for processing of different biomass materials (wood and agricultural waste, peat) into the granulated solid fuel with improved consumer properties and.

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