

THE NEW TECHNOLOGY OF COMPLEX THERMAL CONVERSION OF BIOMASS

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ABSTRACT

Torrefaction is an up to date technology of biomass thermal conversion that allows obtaining solid organic fuel with improved properties. The one of the main disadvantage of the torrefaction is necessity of volatile products utilization. Thermal conversion of volatiles into synthesis gas is the promising way to solve this problem.

The results of experimental investigations of different kinds of torrefied biomass properties are presented. The quantity of gases obtained by high-temperature cracking of condensable and non-condensable volatiles formed during the torrefaction of wood, straw and peat at temperatures of 230°C, 250°C, 270°C are presented. It is shown that high-temperature conversion of the volatiles into synthesis gas is very effective method of utilization the torrefaction by-products.

INTRODUCTION

For several years in Joint Institute for High Temperatures of Russian Academy of Sciences, new technological processes of production bio-carbon of various modifications from wood and other biomaterials has been developed. This paper bases on the technology described in [1, 2] and shows the two-stage method of thermal conversion of biomass and its volatiles products.

It is well-known that torrefaction is a promising process to improve the properties of biomass. During the torrefaction moisture and low weight organic volatile components is removed and the hemicellulose fraction of biomass is decomposed that made hydrophobic solid product which is referred to as “torrefied biomass” or “bio-coal” [3-5]. Torrefaction combined with granulation (so-called TOP-process) increases the energy density of fuel pellets from 19 to 22 MJ/kg and bulk density - from 14 to 18.5 GJ/m³ [4]. Non-condensable torrefaction volatiles mainly consist of carbon dioxide and carbon monoxide while the main liquid torrefaction products are acetic acid and water with smaller quantities of methanol, formic acid, lactic acid, and furfural [5]. High-temperature conversion of the volatiles into synthesis gas is a

way to increase the overall efficiency of torrefaction and a green solution for torrefaction technology [6].

HYDROPHOBIC PROPERTIES OF TORREFIED BIOMASS

During the torrefaction process then the biomass heated up to the temperature 250 – 270°C the moisture and quantity of the volatile matter leaves, in result calorific value of biomass increased, an average, from 19 to 22 MJ/kg, and volume density - from 14 up to 18,5 g/cm³. During the torrefaction process biomass gets waterproof properties that simplify and reduce the logistics costs.

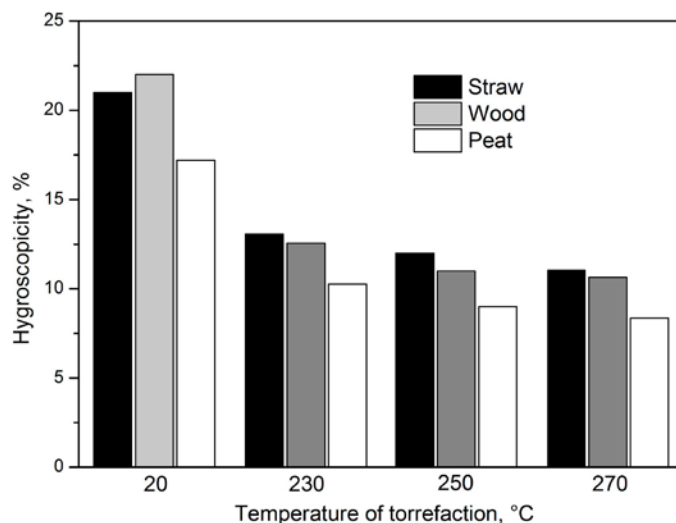


Figure 1. Hydrophobicity of various kinds of biomass torrefied at 230°C, 250°C and 270°C.

On the Figure 1 the hydrophobicity, as a function of torrefaction temperature for pellet from wood, straw and peat is

presented. Initial wetness of preliminary drying biomass was near 5 - 6%. Apparently that preliminary thermal processing of various kinds of the granulated fuel from a biomass allows reducing substantially their ability to absorb the atmospheric moisture that considerably simplifies process of their storage. Finding of waterproof properties for biomass granulated fuel in many cases is determinant because some kind of biomass granulated fuel, for example, pellets from wood, during its storage on air may destroy on account of adsorption the water from the air.

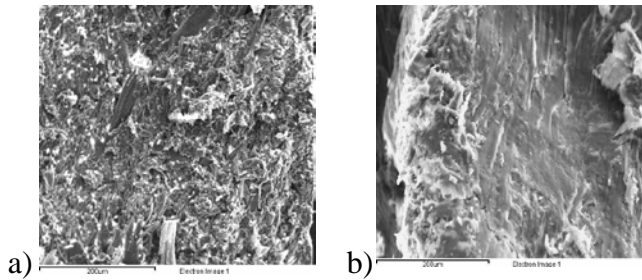


Figure 2. Electron microscopy image of original (a) and torrefied (b) biomass.

The changing of biomass structure during torrefaction is supported by an electron-microscope image of a section of torrefied biomass and original raw biomass (Figure 2). The structure of original biomass is porous whereas the structure of torrefied biomass is solid that follows to its higher hydrophobic properties. This solid structure formed during torrefaction by melting of biomass material components, mainly lignin.

VOLATILES PRODUCTS OF TORREFACTION

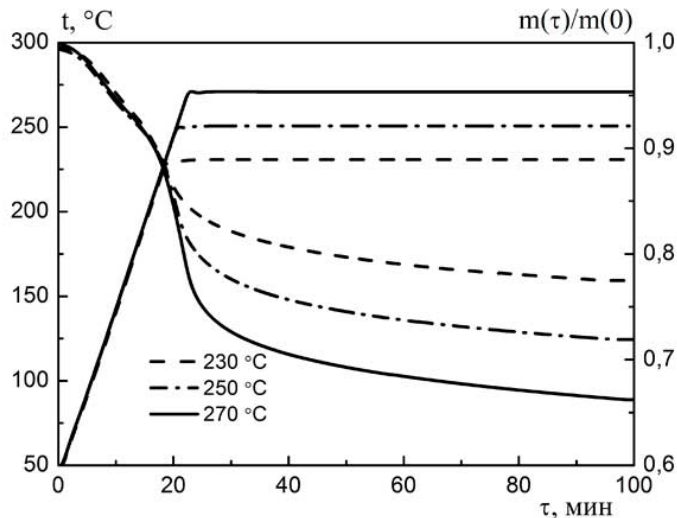


Figure 3. TGA of peat at 230°C, 250 °C and 270 °C and the heating curve. Heating rate 10°C min⁻¹.

Figure 3 shows the weight loss curves of peat at 230, 250 and 270°C and time of torrefaction up to 100 min obtained from isothermal TGA experiments. From this figure it can be

seen that peat start decomposing around 200°C and has the highest weight loss in the time period between 20 and 30 min after the start of heating. Overall weight loss after 100 min of experiment was 22% for 230°C, 28% for 250°C and 34% by weight for 270°C torrefaction temperature.

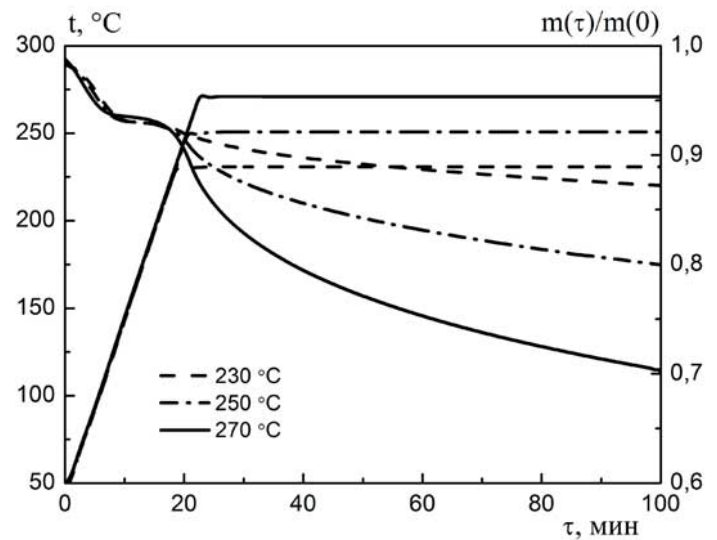


Figure 4. TGA of wood at 230°C, 250 °C and 270 °C and the heating curve. Heating rate 10°C min⁻¹.

Figure 4 shows the weight loss curves of wood at 230, 250 and 270°C and time of torrefaction up to 100 min obtained from isothermal TGA experiments. From this figure it can be seen that wood start decomposing around 200°C and has the highest weight loss in the time period between 20 and 30 min after the start of heating. Overall weight loss after 100 min of experiment was 12% for 230°C, 20% for 250°C and 30% by weight for 270°C torrefaction temperature. Independently of kind of biomass the weight loss occurs by volatiles outgoing. These volatiles can be effectively converted into synthesis gas by heterogeneous cracking over hot char bed [7].

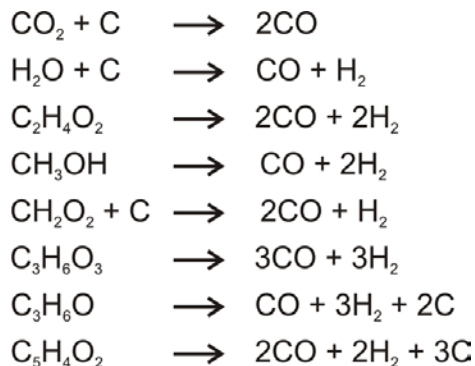
CRACKING OF VOLATILES INTO SYNTHESIS GAS

The technology of biomass (peat, wood and agricultural waste) thermal processing with production of power gas with increased calorific value developed in the JIHT RAS is based on high-temperature processing of the pyrolysis gases and volatiles. The method is similar to the one suggested in [7] and used in [1, 2] for processing of wood waste and peat. Products of biomass pyrolysis are char, non-condensable pyrolysis gases (CO₂, CO, H₂) and liquid fraction.

Carbon, hydrogen and oxygen content of condensable and non-condensable volatiles allows them to be converted into synthesis gas consists of hydrogen and carbon monoxide in practically equal parts.

Table I shows typical reactions of heterogeneous pyrolysis of condensable and non-condensable torrefaction volatiles [8] on surface of hot char. Initial and final states are shown only.

Table 1. Typical reaction of heterogeneous decomposition of condensable and non-condensable volatiles into synthesis gas



According to these reactions the volume of output gases considerably increases on account of decomposition of condensable volatiles. Volume of non-condensable volatiles also increases nearly twice because of Boudouard reaction of conversion of 1 mol of CO₂ which is the main non-condensable output gas into 2 mol of CO.

For condensable and a noncondensable fractions, the amount formed torrefaction gases increases with torrefaction temperature. Therefore volume of output gases after hot char filter increases subsequently (Figure 5 and Figure 6). Chemical interaction of torrefaction gases with char was confirmed by char mass loss in the char bed.

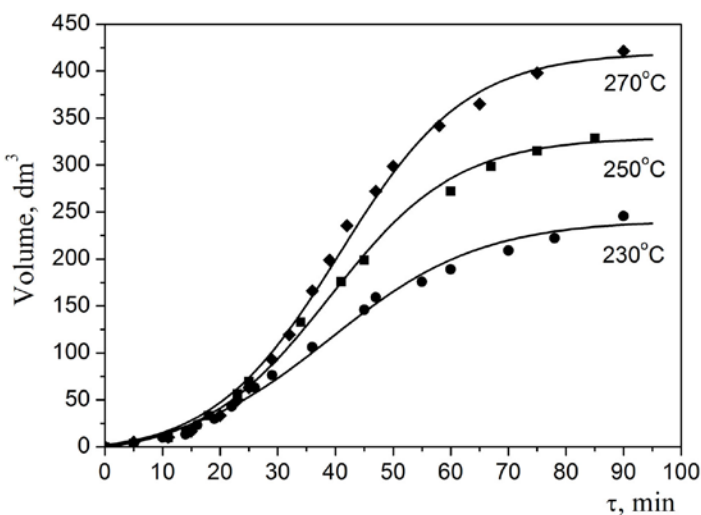


Figure 5. Gas yield per one kg of raw material during torrefaction of peat

The volume of gas in torrefaction of peat pellets higher than for wood pellets, and this difference increases with increasing torrefaction temperature.

The main fraction reacting in the torrefaction temperature range is hemicellulose, so that the difference in the dynamics and the volume of output gas can be explained by differences in the hemicellulose of wood and parts of plants, forming peat. However, in terms of the technology of torrefaction volatiles conversion into synthesis gas is the difference between the

types of biomass are not too large. The composition of the gas at the reactor outlet after the cracking of volatiles is more important.

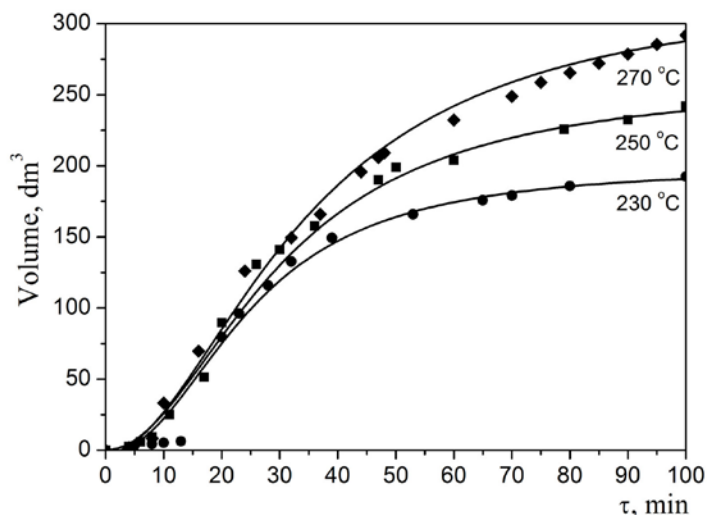


Figure 6. Gas yield per one kg of raw material during torrefaction of wood

The content of hydrogen and carbon monoxide are shown in Table II. The data presented show that the total content of hydrogen and carbon monoxide at the outlet reaches 93%, which indicates a high degree of conversion of torrefaction volatile products. The composition of the gas remains virtually unchanged for the different modes and different types of pyrolysis of biomass, while the volume of gas produced depends on the source material. Thus, the volume of gas produced from 1 kg of peat pellets, almost 1.5 times the volume of gas produced from the same amount of wood pellets.

Table 2. The composition of the synthesis gas produced by cracking of torrefaction volatiles of wood and peat pellets.

T, °C	Wood pellets		Peat pellets	
	H ₂	CO	H ₂	CO
230	38%	45%	39%	45%
250	40%	46%	43%	50%
270	45%	47%	45%	43%

CONCLUSIONS

1. The complex experimental researches demonstrated the possibility of improving properties of biomass fuel by the way of carrying out preliminary thermal processing of biomass fuel.

By this way can be increased calorific value of biomass fuel, density and provided water-resistant proprieties.

2. High-temperature conversion of torrefaction volatiles allows to obtain up to 0.4 m³ of synthesis gas consists of CO and H₂ in practically equal parts with calorific value approximately 10.9 MJ/m³ from one kg of original raw material. In consideration of 30% efficiency factor of gas-engine power station, this quantity of syngas is enough to obtain about 0.4 kW•h of electric energy.

REFERENCES

- [1] Kosov V.V., Kosov V.F., Maikov I.L., Sinelshchikov V.A., Zaichenko V.M., "High calorific gas mixture produced by pyrolysis of wood and peat", *The Proceedings of 17th European Biomass Conference and Exhibition*, 29 June - 3 July 2009, Hamburg, Germany. pag. 1085 – 1088
- [2] Kosov V.F., Sinelshchikov V.A., and Zaichenko V.M., "New Teechnology for Integrated Processing of Biomass and Natural Gas with Production of Hydrogen and Pure Carbon Materials", *Proc. of 16th European Biomass Conference and Exhibition*, Valencia, Spain, 2008, pp. 1171 – 1175.
- [3] Bergman, P.C.A.; Kiel, J.H.A., 2005, "Torrefaction for biomass upgrading", *ECN report*, ECN-RX—05—180
- [4] Bergman, P.C.A., 2005, "Combined torrefaction and pelletisation – the TOP process", *ECN Report*, ECN—C—05-073
- [5] Mark J. Prins, Krzysztof J. Ptasinski, Frans J.J.G. Janssen, "Torrefaction of wood. Part 1. Weight loss kinetics", *J. Anal. Appl. Pyrolysis* 77 (2006) pp. 28–34
- [6] Antropov A.P., Isyemin R.L., Kosov V.V., Kosov V.F., Sinelshchikov V.A., "Synthesis gas production as a result of biomass torrefaction", *Alternativnaya energetika*, N 10, 2011, pp. 42-46 (in Russian)
- [7] Snehaltha K Chembukulam, Arunkumar S. Dandge, Narasimhan L. Kovilur, Rao K. Seshagiri, and R. Vaidyeswaran, "Smokeless Fuel from Carbonized Sawdust", *Ind. Eng. Chem. Prod. Res. Dev.*, vol. 20, 1981, pp. 714-719.
- [8] Mark J. Prins, Krzysztof J. Ptasinski, Frans J.J.G. Janssen, "Torrefaction of wood. Part 2. Analysis of products", *J. Anal. Appl. Pyrolysis* 77 (2006) pp. 35–40