Torrefied Pellets As Fuel For Two-stage Technology Of Biomass Conversion Into Synthesis Gas

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***Abstract*— One of the most important properties of the torrefied pellets, along with high calorific value, is their hydrophobicity. Inability to absorb moisture and self-destruct under its influence determine possibility of using of pellets in the pyrolysis reactor. For the technology of two-stage thermal processing of biomass, developed at the Joint Institute for High Temperatures, the amount of synthesis gas which can be obtained from one kilogram of torrefied pellets is also important. A construction of the pilot torrefaction reactor powered by flue gas is shown. The results of experimental investigations of hydrophobicity of torrefied pellets produced by the reactor and quantity of synthesis gas which can be obtained by two-stage thermal processing of the pellets are presented. It is shown that torrefaction allows simplifying the process of conversion of pellets into synthesis gas without significant reduction in the volume of the gas.**

Keywords - biomass conversion; torrefaction; pyrolysis; syngas.

I. INTRODUCTION

The most effective way to convert biomass is its conversion into combustible gas. However, the existing conversion technologies of solid hydrocarbon raw materials in gaseous fuel have several disadvantages.

Air gasification is the easiest method to convert biomass into the gas. However, the resulting gas contains up to 60% nitrogen and 40% carbon dioxide. The calorific value of the gas is generally around 4 - 5 MJ/m^3, which is too low for efficient use. Overall efficiency of gasification gas power plant is limited to 20% [1].

Oxygen and steam gasification allow increasing the calorific value of the gas which contains no nitrogen and small amount of carbon dioxide. The maximum gas yield reaches 1.3 nm^3 per kg of raw material and its calorific value is about 11 MJ/m^3 [2]. Steam gasification is the widespread process because of its simplicity. The main disadvantage of the process is concerned with necessity of steam generation, which reduces overall effectiveness of power plant. Use of oxygen for the purpose of gasification demands an air separation unit in technological chain that leads to rise in price of end product. It should also be noted that purification of the gas from tar and ash is an urgent problem for all methods of gasification.

For several years, in the Joint Institute for High Temperatures of Russian Academy of Sciences, the two-stage technology of biomass processing has been developing [3, 4]. The technology is based on pyrolysis of biomass as the first stage. The second stage is high-temperature conversion of liquid fraction of the pyrolysis on the surface of porous charcoal matrix. Synthesis gas consisted from carbon monoxide and hydrogen is the main products of the technology.

Our experiments have shown a significant increase of the volume of gas in the outlet of the reactor due to decomposition of condensable and non-condensable pyrolysis products. In comparison to pyrolysis, the volume of gas increased nearly 10 times at cracking temperature 1000 ° C. At this temperature, the gas consists almost entirely of hydrogen and carbon monoxide in approximately equal parts in the zone of maximum gas release.

To implement this technology at the Joint Institute for High Temperatures, an experimental model of power station of electric power up to 5 kW was created. The power station consists of a thermochemical reactor, control and measurement system, and a gas-diesel engine with an electric generator.

Figure 1. Experimental power station of electric power up to 5 kW.

During the test of the power station, a problem with the high hygroscopicity of wood pellets was detected. Pellets that are in the low-temperature zone of the reactor absorbed water vapor rising from the high-temperature zone. As a result of swelling of the pellets, the gas-tight stopper formed that blocked operation of the reactor. Preliminary drying of pellets allowed to improve the situation only insignificantly, but did not remove the main problem. To solve the problem, it was suggested to use torrefied pellets as fuel for the thermochemical reactor.

The second section describes construction of the torrefaction reactor that was created in Joint Institute for High Temperatures of the Russian Academy of Sciences and characteristics of produced torrefied pellets. The third section describes the technology of two-stage thermal processing of biomass that use torrefied pellets as a raw material for synthesis gas production.

II. TORREFACTION REACTOR

It is known that torrefaction allows reducing substantially the ability of biomass to absorb the atmospheric moisture. During the torrefaction process biomass heated up to the temperature 250 – 270ºC, the moisture and quantity of the volatile matter leaves, in result calorific value of biomass increased from 19 to 22 MJ/kg and biomass gets waterproof properties.

To achieve these goals, the torrefaction reactor using as a heat source exhaust gases of power station engine was created. The reactor is shown at the Figure 2.

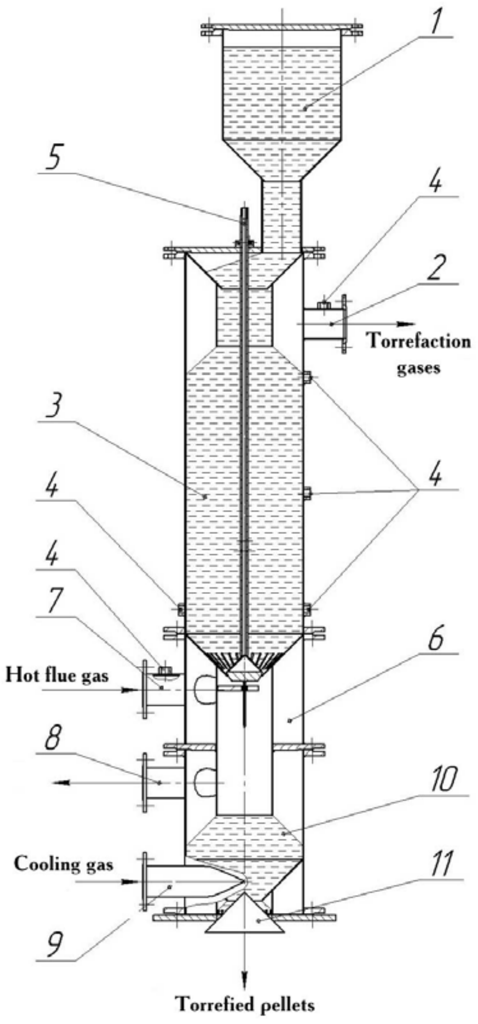

Figure 2. Torrefaction reactor

Raw material is loaded into the reactor through the feed tube 1 and fills the volume of the top of the reactor tank 3. Hot gases flow through the pipe 7 in average tank 6, passing through the perforated cone, heat pellets and leave through the pipe 2. The flow rate of the hot flue gases was 242.5 nm3 per hour. The temperature of the hot flue gases was regulated by temperature control system (is not shown at the Figure 2) consisted of a gas-water heat exchanger and a mixer.

With the rod 5 with closing sphere, the hot pellets are discharged into the lower tank 10, where they are cooled by cold gases. Cooled Pellets unloaded from the reactor when the cone-unloader is open.

The main feature of the proposed scheme is the use exhaust gas of the internal combustion engine as gas coolant. Thus, two problems are solved. Firstly, due to the high heat transfer coefficient an efficient heating processed raw material provides in comparison with schemes in which the heat input through the reactor wall. Secondly, the proposed scheme, in essence, is a co-generation unit which allows generating electricity and utilizing the heat produced by in order to improve the properties of the solid biomass fuel. This approach significantly improves the economics of the whole process of processing of pellets into synthesis gas.

For the purpose of using the obtained torrefied pellets as a fuel or raw material for further processing, it is important to know their properties of hygroscopicity and calorific value. Figure 3 shows the change of hygroscopicity of torrefied wood pellets obtained in the reactor at three temperatures of torrefaction 230°C, 250°C and 270°C, in comparison with original raw material. The total torrefaction time for all cases was 60 min.

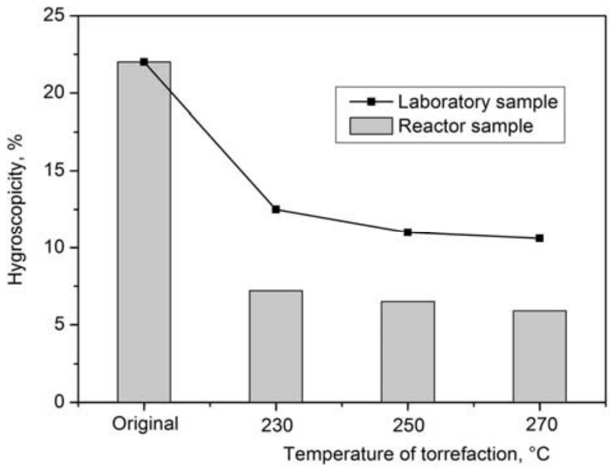

Figure 3. Hygroscopicity of wood pellets obtained in the torrefaction reactor in comparison with laboratory sample.

The figure also presents the values hygroscopicity of torrefied pellets obtained in the laboratory at the same temperatures. From the data above, it follows that hygroscopicity of the torrefied pellets is significantly lower than hygroscopicity of the original pellets. In this case, hygroscopicity of pellets obtained in the reactor even lower than that of laboratory samples. Long-term experiments

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(about 72 hours) showed that the torrefied pellets are not destroyed under the influence of moisture and retain their structure.

The results of measurements of the relative increment of the calorific value of wood pellets in comparison to the original material are shown in the Figure 4. Calorific values of samples torrefied in the laboratory are shown as well.

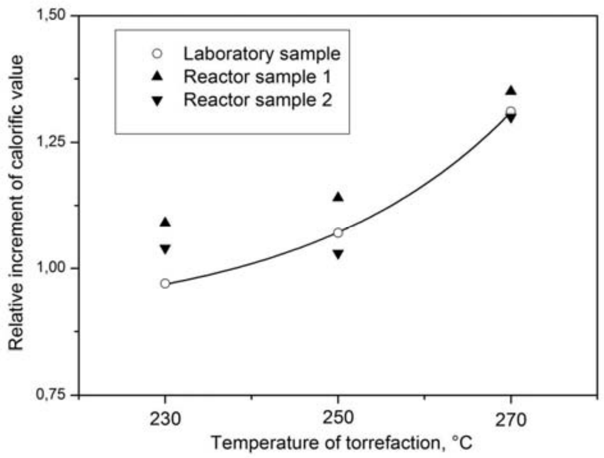

Figure 4. Relative increment of the calorific value of wood pellets obtained in the torrefaction reactor in comparison with laboratory sample.

From the data presented, it follows that pellets obtained in the torrefaction reactor have similar properties of calorific value as the laboratory samples. Small variations in the relative increment of the calorific value of pellets obtained in the torrefaction reactor can be explained by differences in the properties of the original material and the non-uniformity of the thermal field inside the reactor.

In general, it can be concluded that the proposed construction of the reactor allows obtaining torrefied pellets of high quality suitable for use as fuel and as raw material for further processing.

III. TWO-STAGE THERMAL PROCESSING OF TORREFIED WOOD PELLETS

The technology of biomass thermal processing with synthesis gas production 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 [5] and used in [3, 4] for processing of wood waste and peat. Products of biomass pyrolysis are char, non-condensable pyrolysis gases (CO_2, CO, H_2,) 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.

During torrefaction some part of volatiles leave the biomass reducing the total amount of biomass synthesis gas that can be obtained from it and lowering the total effectiveness of the technology. It was important to determine the amount of synthesis gas that could be obtained from the torrefaction volatiles and compare it to the amount of gas is produced from torrefied pellets.

The experimental set-up (Figure 5) was similar to one described in [3] and consisted of a high-temperature two-chamber fixed-bed reactor and a system of extraction and analysis of gas and vapor forming as a result of heating an initial raw material.

The reactor was a stainless steel tube with an inside diameter of about 37 mm, which was placed within two-section furnace with independent heaters for each section. The chambers were 300 mm length each. Raw material was placed into the bottom chamber. Char obtained by pyrolysis of the same raw material was placed in the top chamber. The depth of char bed was equal to 50 mm. Before experiments the top chamber was heated up to temperature 1000°C that was held further at the constant level. After that the temperature of the bottom chamber was raised at the rate 10°C/min.

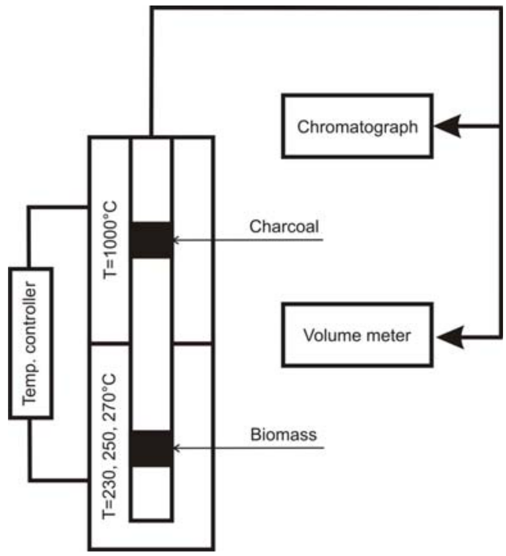

Figure 5. Scheme of the experimental reactor

Pyrolysis gases formed during pyrolysis of initial raw material passed through the porous carbon bed with the fixed temperature. As a result of homogeneous and heterogeneous chemical reactions in the high-temperature zone, a decomposition of torrefaction gases took place. Conversion degree depended both on the temperature in the top chamber and on the residence time in a high-temperature zone. Non-condensable gas came into the volume meter (eudiometer). The samples of the gas were chromatographed.

There were two series of experiments. In the first series of experiments the amount of synthesis gas that can be produced by thermal decomposition of volatiles formed during torrefaction was determined. In the second series of experiments, the amount of synthesis gas that can be produced by thermal decomposition of volatiles formed during pyrolysis of the preliminary torrefied pellets was determined. There were also carried out experiments on the

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production of synthesis gas from the initial non-torrefied pellet.

The data on gas volume (per kg of initial raw materials) obtained in the process of wood pellets torrefaction at constant temperature of the top chamber are shown in Figure 6. It can be seen that high-temperature conversion of torrefaction volatiles allows obtaining from 0.2 м^3 to 0.3 м^3 of synthesis gas consisted from hydrogen and carbon monoxide in practically equal parts.

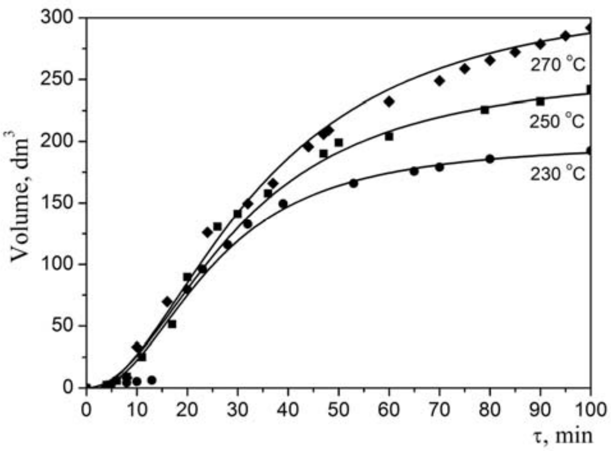

Figure 6. Gas yield per one kg of raw material during torrefaction of wood pellets.

Based on the material balance, it can be assumed that the decrease in the volume of gas produced from torrefied pellets will be less than gas volume produced from the initial non-torrefied pellets on a comparable value.

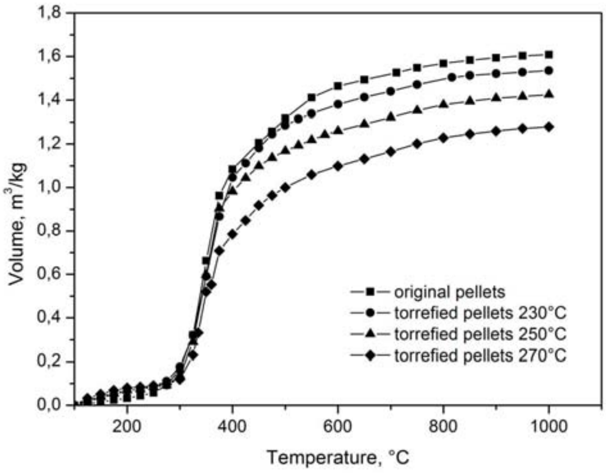

Figure 7. Gas yield per one kg of torrefied wood pellets during its thermal processing.

Experimental results on the two-stage thermal treatment of torrefied wood pellets into synthesis gas showed the validity of this assumption. Figure 7 shows the dynamics of the yield of synthesis gas during the thermal treatment of torrefied pellets. In this case the synthesis gas also consisted from hydrogen and carbon monoxide in practically equal parts. Reducing the amount of the resulting synthesis gas compared to initial raw pellets was from 0.1 м^3 to 0.3 м^3.

Thus, the inclusion in the technological scheme the torrefaction reactor for pretreatment of wood pellets allowed to solve the problem of the destruction the pellet during the pyrolysis process and did not significantly reduce the resulting volume of synthesis gas.

IV. CONCLUSION AND FUTURE WORK

Preliminary heat treatment of pellets from biomass can solve the problem of the destruction of moisture. Even the low-temperature torrefaction at 230°C allows reducing the hygroscopicity of wood pellets more than twice.

The proposed construction of the torrefaction reactor which is used as the heat source of gas-diesel exhaust gases provides production the torrefied pellets with desired properties. Hygroscopicity of wood pellets obtained from the reactor was lower than that of the sample obtained in the laboratory.

Increased calorific value of the torrefied wood pellets allows using them not only as raw material for a two-stage processing into synthesis gas, but also as a source of heat for ensuring thermal regime of the process.

Optimal mode of torrefaction of wood pellets is a low-temperature heat treatment at the temperature of 230°C that allows the process implementation without significant reduction in the volume of product gas.

Future work will include an elemental analysis of the biomass torrefied at different torrefaction temperature to determine the H/C and O/C ratio. Also it will be determined the energy balance for the technology.

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