A new method for energy gas producing from biomass

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Abstract. Biomass is known to be an alternative source of energy due to its availability and less environmental impacts in comparison with fossil fuels. Widespread of biomass allows us to solve the problems associated with development of local energy production. The developed at the Joint Institute for High Temperatures of the Russian Academy of Sciences technology for biomass energy utilization let to reduce energy consumption. It is achieved through the use of energy released during exothermic reactions, which is accompanied by heating of various types of biomass, which, as it follows from the literature, is realized for the first time in the processes of gas fuel producing. The second energy-saving factor of the developed technology is that the heat source is the gas piston power unit (GPU) combustion products. In this case, a cogeneration scheme is implemented. The results of experiments on the biomass conversion in GPU combustion products medium and numerical calculations in a one-dimensional non-stationary approximation are presented. The method of biomass thermal conversion under development will make it possible to obtain gas fuel or energy supply systems at local fuel and energy resources.

1. Energy gas producing from biomass

Biomass is a renewable natural resource with great potential to be clean, renewable and CO2-neutral energy source. The widespread use of biomass will solve both the energy supply issues of settlements remote from traditional energy sources and environmental problems associated with carbon dioxide emissions into the atmosphere, global warming and uncontrolled accumulation of various types of waste. Biomass includes peat, wood, agricultural waste and waste of various kinds. Biomass resources in Russia are large: 69% of the territory of the Russian Federation is made up of lands of the forest fund and lands of other categories on which forests are located, 46.5% is covered by forests, which share in global reserves is about 24%. About 40% of the territory of Russia does not have a centralized energy supply [1].

Settlements remote from centralized heat and energy supply often receive electricity through diesel power generation, which is one of the most difficult segments of the energy industry, since it is characterized by many difficulties created by significant territorial fragmentation, complicated by the seasonal nature of energy supplies, as well as price regulation. All this determines the relevance of developing new highly efficient methods for generating energy based on biomass, which is often available in places where there are no traditional energy sources. Gasification is a process of partial oxidation of carbon-containing raw material for generator gas production,
which is composed of hydrogen, carbon monoxide, methane, carbon dioxide, a small amount of higher order hydrocarbon compounds, contains water vapor, nitrogen (during air blasting) and various impurities, such as resins, particles of carbonaceous matter and ash [2]. Air, oxygen, water vapor, carbon dioxide or mixtures of these substances can be used as an oxidizing agent during gasification.

There are two known methods for producing energy gas in the thermal conversion of carbon-containing materials: pyrolysis and gasification [3]. In relation to existing, the developed technology allows to obtain gas with higher efficiency. Energy consumption reducing is achieved through the use of energy released during exothermic reactions, which is accompanied by heating of various types of biomass, which, judging by the literature, is realized for the first time in the processes of producing gas fuel. The second energy-saving factor of the developed technology is that the heat source is the products of combustion of a gas piston power unit (GPU). In the proposed method, a cogeneration scheme is implemented, initially, when fuel is burned, electricity is generated, and the combustion products of this process are used to heat the processed raw materials. This approach, in contrast to the known gasification methods, makes it possible to obtain generator gas by thermoconversion of various types of biomass practically without using external heat sources.

2. Experimental research

An experimental plant for biomass thermal conversion was created at the Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS) is shown in figure 1. The reactor is a vertical heat-insulated steel cylinder 1-meter-high and 325 mm in diameter, which is filled with the initial granular biomass raw material and blown out by the GPU combustion products. Thermocouples are located along the height of the reactor to control the temperature in the reaction zone. An afterburner is installed at the outlet of the reactor, in which the resulting gas burns under the action of the ignition torch.

The temperature of the hot coolant at the reactor inlet did not exceed 400 °C. The oxygen volume concentration in the combustion products varied due to the depletion of the fuel mixture of the internal combustion engine from 0.8 to 4%.

The graph in figure 2 shows that the temperature in the pyrolysis zone significantly exceeded the temperature of the coolant at the reactor inlet (due to exothermic reactions). Heating up at a cross section of 200 mm occurs more intensively because a fresh gas stream first comes here. The reference point in this graph is the point in time at which the temperature of the processed raw material exceeded the operating temperature of the process provided by the flow of heating coolant. The first peak in the temperature at 10 min after is due to the reverse discharge from the afterburner. The temperature in the afterburner at this moment exceeded 1100 °C. At 28 min, the oxygen concentration was brought to 2%, 47 min O₂ concentration reached to 3.7%. The temperature in the pyrolysis zone rose to almost 700 °C.

3. Numerical modeling of the processes of thermochemical conversion of biomass

Numerical analysis of the processes of biomass thermochemical conversion is based on the laws of conservation of mass and energy in the one-dimensional non-stationary approximation taking into account the stoichiometric balance of chemical elements and the equilibrium of the main reactions of thermochemical transformations [3]. The program for calculating the pyrolysis reactor [4] is supplemented by the procedure for determining the composition and heating value of the generator gas, taking into account the internal energy of endothermic and exothermic reactions. The gasification reaction of one mole of biomass in the products of combustion with
excess oxygen can be written in the following general form:

\[
H_aO_bN_c + dH_2O + eCO_2 + fN_2 + gO_2
= mC + xCO + yCO_2 + zH_2 + uH_2O + nN_2 + hCH_4,
\]  

(1)

where \(a\), \(b\) and \(c\) are the atomic ratios \([H]/[C]\), \([O]/[C]\) and \([N]/[C]\) obtained from the analysis of the initial biomass composition; \(x\), \(y\), \(z\), \(u\), \(n\) and \(h\) are the number of moles of components of
Figure 2. Change in the temperature of the heating gas at the inlet to the reactor (1) and the temperature in the pyrolysis zone at a height of 200 (2) and 400 mm (3).

the generator gas; \( n \) is the number of moles of carbon remaining; \( d, e, f \) and \( g \) are the relative composition of the GPU combustion products. To determine the composition of the resulting generator gas, the atomic balance of the reaction components is recorded for carbon:

\[
1 + e = x + y + h + m; \tag{2}
\]

hydrogen:

\[
a + 2d = 2z + 2u + 4y; \tag{3}
\]
oxygen:

\[
b + d + 2e + 2g = x + 2y + u; \tag{4}
\]

and nitrogen:

\[
c + 2f = 2n. \tag{5}
\]

The system of equations (2)–(5) is supplemented by the equilibrium equations of the main reactions of gasification [3]:

\[
k_1 = \frac{x^2}{y}, \tag{6}
\]

\[
k_2 = \frac{xy}{u}, \tag{7}
\]

\[
k_3 = \frac{hu}{x^2y^2}, \tag{8}
\]

where \( k_1, k_2 \) and \( k_3 \) are the equilibrium coefficients of the Boudouard reactions, water gas and hydrogasification; empirical temperature dependences were used [5]. The system of nonlinear
algebraic equations (2)–(8) with respect to unknown $x$, $y$, $z$, $u$, $n$, $h$ and $n$ is solved by the Newton’s iterative method.

The chemical composition of the original biomass (wood pellets):

$$a = 0.13; \quad b = 0.89; \quad c = 0.002.$$  \hfill (9)

The composition of the combustion products at the inlet to the reactor:

$$d = 0.24; \quad e = 0.13; \quad f = 1.19; \quad g = 0.021.$$  \hfill (10)

The results of calculations of volumetric concentrations of the main components of the generator gas are presented in figure 3.

Based on the calculated concentration of the composition of the generator gas, its heating value was obtained (figure 4).

The studies carried out at the JIHT RAS to develop a hydrogen engine [6] showed that the main obstacle to using hydrogen as a fuel is its reduced knock resistance. In this connection, the calculated design composition of the generator gas (see figure 3), in which the hydrogen concentration is about 20%, allows the use of such gas in a gas engine instead of natural gas without modernizing the engine. The heating value of the produced gas is significantly lower than methane, so the consumption of generator gas to produce the same amount of electricity will be two, three times higher. Compressed natural gas is used to start the installation.
4. Conclusion
The method of thermal conversion of biomass under development allows high energy efficiency through the use of internal heat of chemical reactions and a cogeneration scheme to obtain gas fuel and electricity for energy supply systems at local fuel and energy resources. In future, it is planned to optimize the developed approaches in terms of reducing energy consumption for the process, determining the process parameters for obtaining a given composition of reaction products, and obtaining various ratios of gaseous reaction products components. Studies conducted at the JIHT RAS will reveal the features of producing energy gas from various types of biomass and give practical recommendations on the creation of industrial installations.

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