The Partial Replacement of Diesel Fuel in Hot Water Boiler with Syngas Obtained by Thermal Conversion of Wood Waste

O.M. Larina, V.A. Lavrenov and V.M. Zaitchenko

Abstract This paper presents experimental results on the use of syngas produced from waste wood by two-stage pyrolytic conversion method, in the implementation of heating system on a basis of hot water boiler. The method of two-stage pyrolytic biomass processing, combining the waste wood pyrolysis, and subsequent heterogeneous cracking of volatile pyrolysis products in charcoal bed, provides a high degree of energy conversion of raw material into syngas with a lower calorific value of 10–11 MJ/m^3. The possibility of partial replacement of diesel fuel in hot water boiler with syngas was shown.

Keywords Biomass · Gasification · Heating systems · Hot water boiler Pyrolysis · Syngas · Thermal conversion · Wood waste

Introduction

Development of technologies that allow efficient use of wood waste for energy purposes is an important task in terms of rational use of natural resources. During processing of wood, only 28% of the original weight of wood turns into a lumber, the rest becomes waste. An alternative to the direct combustion of waste wood is processing into gas suitable for use as fuel for the boilers of the existing heating systems. Methods of thermal conversion of the wood biomass into gas can be divided into two main types: gasification and pyrolysis.

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Gasification is a partial oxidation process to yield a syngas, the main combustible components are carbon monoxide, hydrogen and methane. It also contains large amount of ballast gases: nitrogen (air gasification), carbon dioxide and water vapor. Furthermore, syngas contains various impurities, such as tars and particles of ash and carbonaceous substance [3]. Air, oxygen, steam, or mixtures thereof may be used as the oxidant in the gasification process. Syngas obtained by air gasification has a lower calorific value of not greater than 6 MJ/m^3 [7]. This gas can be burned in boilers.

Pyrolysis is the thermal decomposition of the raw material without oxidant access. The products of the pyrolysis are a gas mixture (consisting mainly of H_2, CO, CO_2, CH_4, C_nH_m, and N_2), liquid fraction (mixture of water and pyroligneous liquor) and solid carbon residue. The gas mixtures produced from biomass, have a lower calorific value of 20 MJ/m^3 [4]. The ratio of the masses of liquid and gaseous products is about 1.5, and most significantly depends on the heating rate [5]. The main disadvantages of pyrolysis from the viewpoint of obtaining gas mixtures are relatively low specific gas yield which does not exceed 0.3–0.4 m^3 per 1 kg of raw material and high carbon dioxide content (up to 30% vol.). This causes a low efficiency of energy conversion of the feedstock into gaseous products: the ratio of the energy content of the pyrolysis gas to the calorific value of the feedstock does not exceed 0.3.

Increasing the degree of the raw material conversion can be achieved by processing of the liquid fraction in the gas. There are catalytic [6] and noncatalytic methods [5]. In this paper, to produce gas from waste wood used a method similar to that proposed for the processing of wood chips in [8] and then studied in detail in [1, 2]. It is based on the cracking of the pyrolysis products formed during the heating of raw material, in the bed of porous carbon residue maintained at a fixed temperature of about 1000°C. This scheme has been adopted as the basis for creating a pilot plant, allowing to obtain a syngas with enhanced characteristics (more than 90% vol. of H_2 and CO, the lower calorific value of about 11 MJ/m^3, the almost complete absence of tar in the gas). Obtained syngas can be effectively used as a substitute for diesel fuel in existing boilers.

The Experimental Technique

Experiments on the waste wood processing into syngas and its further use in boiler were carried out on the area of Energonezavisimost Ltd. (city of Nizhny Novgorod).

The heating system was used floor cast iron boiler “RIELLO RTT 93” with nominal thermal power of 100 kW with the diesel fuel burner “CUENOD NC12H101”. The heaters “KEV-36T3W2” set in the heated rooms were used as a heat load of the heating system. Syngas produced in the thermochemical conversion module was accumulated in the elastic polymeric gas holder, from which it was fed through a pressure regulator into the special co-combustion nozzle of burner (Fig. 1).

Fig. 1 Combustion head of the fuel-oil burner with a nozzle for co-combustion of gaseous fuels

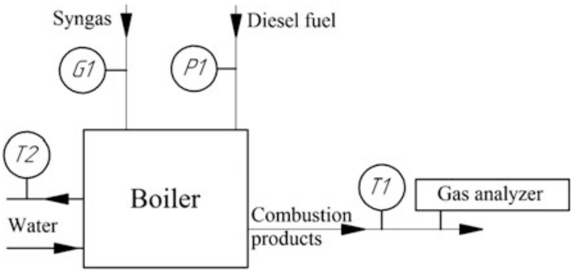

Fig. 2 Scheme of the measurement system of the boiler and burner parameters: G1—syngas volume meter; P1—the diesel fuel pressure meter; T1—temperature of the combustion products; T2—temperature of water

Scheme of the measurement system of the boiler and burner parameters is shown in Fig. 2. The measurement system of the boiler and burner allows to determine the following parameters:

– the diesel fuel consumption (calculates based on the diesel fuel pressure);
– the syngas consumption (gas flow meter "SGMN-1 M-G6");
– the oxygen volumetric content (O_2) in combustion products (gas analyzer "Askon-02");
– the combustion products temperature (chromel-alumel thermocouple (type K), connected to thermometer "Aktakom ATT-2004").

Each experiment included two main stages. The first stage is obtaining of syngas and its accumulation in the elastic polymer gas holder. At the second stage, obtained syngas is fed to the burner. For testing of the synthesis gas and diesel fuel co-combustion five operation modes have been selected. Three operation modes on the diesel fuel only (modes 1, 2, and 3) and two operation modes of partial substitution of diesel fuel with syngas (modes 4 and 5). The first mode is intended to work at the nominal diesel fuel consumption and the base air flap setting.

In all other modes, the air flap setting remained unchanged from the nominal mode 1. In the second mode, the diesel fuel consumption decreased to reduce the thermal power of the burner by about 10% and in the third mode—by 20%. In the fourth and fifth operation modes the diesel fuel consumption corresponds to the second and third operation modes, but the syngas consumption was adjusted so that the thermal power of the boiler reaches value corresponding to the nominal mode 1.

Results and Discussion

The feedstock and syngas characteristics, obtained in elemental analyzer “Elementar Vario Macro Cube”, gas flow analyzer “MRU Vario Plus Industrial «Syngas»” (O_2, H_2, CO, CO_2, C_nH_m, N_2) and gas chromatograph “Chromos GH-1000” (hydrocarbons) are shown in Table 1.

The measurement results of the combustion products parameters and the calculated values of power and efficiency of the boiler in the five operation modes are shown in Table 2.

Table 1 The feedstock and syngas characteristics

Parameter	Dimension	Value
The feedstock type		Pine shavings
The feedstock consumption	kg/h	5.0
The feedstock composition (on the wet /dry /dry ashless basis)		
Moisture content	% mas.	8.80/0/0
Ash content	% mas.	0.48/0.53/0
The elemental composition:		
Carbon (C)	% mas.	47.68/52.28/52.56
Hydrogen (H)	% mas.	5.54/6.07/6.10
Oxygen (O)—as a residual	% mas.	37.43/41.04/41.26
Nitrogen (N)	% mas.	0.05/0.06/0.06
Sulfur (S)	% mas.	0.02/0.02/0.02
Volatiles at 700°C	% mas.	84.5/83.0/−
The syngas volume	m^3	6.5
The syngas specific volume	m^3/kg	1.3
Chemical composition of dry syngas		
Hydrogen (H_2)	% vol.	49.2
Carbon monoxide (CO)		40.8
Carbon dioxide (CO_2)		5.0
Nitrogen (N_2)		1.8
Oxygen (O_2)		0.0
Hydrocarbons (C_nH_m), among them:		3.2

(continued)

Table 1 (continued)

Parameter	Dimension	Value
– methane (CH_4)	% vol. of C_nH_m	88.9
– ethane (C_2H_6)		1.1
– этен (C_2H_4)		1.0
– propane (C_3H_8)		4.7
– пропен (C_3H_6)		0.3
– i-butane (C_4H_{10})		1.2
– n-butane (C_4H_{10})		0.9
– i-pentane (C_5H_{12})		0.4
– n-pentane (C_5H_{12})		1.5

Table 2 Key parameters of the burner and boiler in the different operation modes

Parameter	Dimension	The operation mode				
		1	2	3	4	5
The diesel fuel consumption	kg/h	8.76	7.92	6.98	7.92	6.98
The syngas consumption	m^3/h	0	0	0	3.6	7.4
	kg/h	0	0	0	2.29	4.72
The substitution degree	%	0	0	0	10.7	21.9
Parameters of the combustion products (boiler outlet):						
Temperature	°C	297	292	286	299	303
Oxygen concentration (O_2)	% vol.	3.2	4.74	6.20	3.12	3.08
Excess air ratio	–	1.20	1.32	1.46	1.19	1.19
Boiler parameters:						
Thermal power	kW	90.4	80.9	70.5	90.7	90.4
Efficiency	%	87.2	86.3	85.3	87.2	87.1

The presented data show that the boiler efficiency decreases in modes 2 and 3 compared to nominal mode 1 because of the excessive dilution of the combustion products with air. The boiler thermal power value recovers in modes 4 and 5 due to the syngas supply. The efficiency value in operation modes 4 and 5 is equal to the corresponding value in the nominal operation mode 1, which indicates that the partial replacement of the diesel fuel not deteriorated the combustion conditions. These results confirm the possibility of replacing the diesel fuel in existing hot water boilers to syngas obtained by two-stage thermal conversion of waste wood.

Conclusions

In this paper, the results of the syngas application obtained by the method of two-stage pyrolytic biomass conversion, combining the feedstock pyrolysis, and subsequent heterogeneous cracking of volatile pyrolysis products in charcoal bed.

The possibility of partial substitution of the diesel fuel with syngas obtained from wood waste by two-stage pyrolytic conversion method is shown. It is experimentally confirmed that the substitution of 10.7 and 21.9% of the diesel fuel with syngas obtained from waste wood occurs without reducing the thermal efficiency of the boiler.Research are carried out with the financial support of the state represented by the Ministry of Education and Science of the Russian Federation. Agreement no. 14.607.21.0073 20.Oct 2014. Unique project Identifier: RFMEFI60714X0073.

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