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The Development of Experimental Setups And Experimental Studies of The Process of Energy-Technological Processing of Wood

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Abstract. The paper describes the experimental setups for the study of the various stages of the process of energy-technological processing of wood waste with the production of synthesis gas. The systems for the study of conjugated processes of drying, pyrolysis and gasification, that are an integral part of energy-technological processing of wood wastes were developed. Experimental studies of the processes have identified their basic properties and optimum operating parameters, allowing to obtain a synthesis gas suitable for the chemical synthesis of various olefins.

1. Introduction

Millions of tons of waste wood are produced at the enterprises of a timber industry complex of Russia every year. The easiest way to dispose the wood waste is their thermal processing by direct combustion to produce heat energy. A more complicated but more effective are the methods of conversion of wood waste in to liquid or gaseous state to obtain the products demanded by the chemical and other industries. One of such products, which can be obtained by energy-technological processing of wood waste - is synthesis gas which is widely used in the chemical industry [1].

For implementation and intensification of energy-technological processing of wood waste from the timber industry, with receiving of synthesis gas and chemical products of a certain quality, it is needed to study heat and mass transfer, which is complicated by chemical reactions at all stages of energy-technological processing of wood waste. It is necessary to develop analytical and experimental methods for prediction of parameters of the waste wood state and products of their thermal decomposition at different stages of their energy-technological processing [2]. To control the chemical processes and obtain the desired product of energy-technological processing, it is necessary to study the kinetics of thermal decomposition of wood waste at different temperatures and conditions, considering the basic properties of wood species, chemical transformation mechanisms, and wood state parameters during thermal exposure.

Thus, the aim of the research is the development of equipment for the study of the processes occurring during the energy-technological processing of wood waste with the use of direct-flow gasification in consideration with modern representations about the effect of temperature on the wood properties [3], about heat and mass transfer being complicated by chemical reactions, as well as with sorption kinetic, heat and mass conductivity and chemical properties of the wood [4].

2. Materials and methods

The variety of processes occurring during energy-technological processing of wood waste of the timber industry, was investigated in a number of established experimental setups that allow for physical modeling of individual processes of drying, pyrolysis and combustion processes in the reduction zone [5]. To study the gasification stage, an experimental setup was developed and is described in schematic diagram in figure 1. The installation consists of a series-connected loading feeder of wood waste 11, the gasifier 13, post-combustion of gas generator chamber 14, heat exchanger 20 and flue gas cleaning system in the form of absorber 26. To measure the parameters and control the process the experimental unit is equipped with temperature sensors, devices for determining the flow of gases and liquids, valves and piping. Registration data from all sensors and devices is carried out by monitoring system 40.

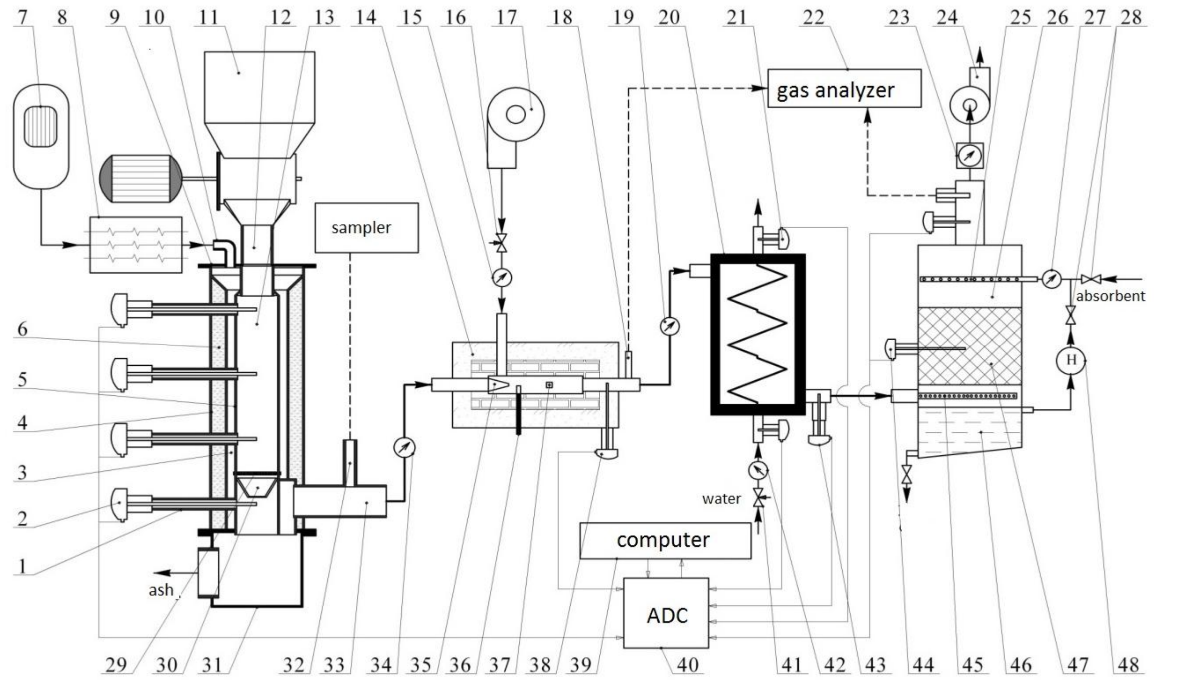

Figure 1. Experimental setup scheme for the research process of the direct flow gasification of wood waste

The gasifier 13 is a cylindrical reactor 4 on the inner surface lined with an inert, heat-resistant ceramic material. To ensure the thermal conditions of adiabatic approximation, the gasifier is thermally insulated from the outside with mineral insulator. The feeding in to gasifier is carried by air compressor 7 through a heater 8, which provides heating of the incoming air. The oxidant (air) is supplied to the afterburning chamber by blower 17. To control the generator gas flow the meter 34 is set up. The change of the temperature during the test is recorded at different levels of height of the gasification chamber by thermocouples, flow of the supply air (oxidant) to the combustion zone is controlled and is regulated by the sensors installed in the compressor 7. The consumption of produced generator gas is determined by using a flow meter 34. In order to determine the chemical composition of the product gas leaving the gasifier through the probe, there is a selection of gas samples and measuring of their temperature being done through the pipe 32. Determination of carbon monoxide gas, hydrogen, methane, carbon dioxide and water, is carried out to assess the quality and optimization of the gas generator mode parameters of the gasification process.

During the study of influence of wood waste moisture on gasification process the waste wood with the bulk density of 280 kg/m^3 and humidity of 10 % is used. Then for each subsequent experiment in this series the waste humidity is increased for 10 ± 1% to achieve the humidity values up to 70 % inclusive. When set humidity mass of wood waste is reduced to 0.4 kg. During the experiment the flow of gasified waste wood (GT) is 1.2 kg/h, with the oxidant flow in the combustion zone (Vvoz.) corresponding to the calculated value and equal to 1.5 m^3/h. The height of the reduction zone (HZ) is 100 mm.

To do a research of the influence of the oxidant flow in the combustion zone on the gasification process the flow of oxidant fed in to combustion zone of gasifier changes stepwise [6, 7]. The variation range of oxidant flow rate is from 1.25 to 0.5 m^3/h with a pitch variation of 0.25 m^3/h. Regulation and control of the oxidant supply to the combustion zone is carried out by the meter and valve located on the compressor 7.

An experimental study on the identification of the process parameters in the pyrolysis zone, such as the duration of the process, the kinetic temperature of the layer, and the mass loss was conducted. The experimental setup scheme for the study of the pyrolysis of wood waste is presented in figure 2.

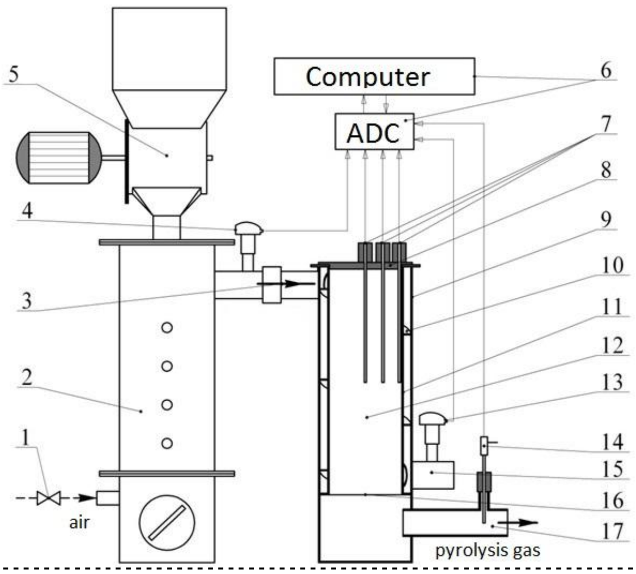

Figure 2. Experimental setup scheme for determining the process parameters of the pyrolysis of wood waste

The installation includes a furnace 2 with fuel feed hopper 5, waste conductive heating reactor 12, the gas sampler 14, thermocouples 4, 7 for temperature control, valve 1 for controlling the air supply to the furnace 2 and to the system of registration and data storage 6. The conductive heating reactor 12 has a cover 8 with thermocouples fixed on it 7, nozzles for supplying 3 and for removing 15 the heating flue gas generated during the combustion in the furnace 2, nozzle 17 for discharging the gas-vapour mixture from the heating chamber 11, which is a cylinder with the grate 16 on the bottom of it which prevents spillage of the material to the bottom of the reactor. Between the housing 9 and heating chamber 11 there is a helical guide 10 which serves to distribute the fuel gas and to wash the heating chamber's wall 11 by gas flow. The structural elements of the reactor are made of heat-resistant stainless steel. To prevent heat losses the unit has a double layer of insulation [8].

Experiments to determine the weight loss dependence on the temperature in the pyrolysis zone are carried out at temperatures ranging from 350 to 650 °C in increments of 50 °C on the samples having an initial moisture content of 10 %. During the pyrolysis process changing the temperature of the flue gases at the inlet and outlet of the reactor, respectively is controlled by thermocouples 4 and 7. The temperature of flue gases entering the reactor 12 is controlled by changing the air flow in the blast furnace 2. At the time of the parameters stabilization of the pyrolysis process by the probe 14, the pyrolysis gas being selected by samples, measured on the temperature and determined on chemical composition. Coal samples are subjected to chemical analysis to determine the content of the amount of volatile materials and pyrolysis gas concentrations in the coal.

An experimental installation was developed and built for the physical modeling and the study of heterogeneous chemical reactions occurring in the reduction zone of the gasification reactor which is shown in diagram of figure 3. The experimental installation consists of a loading hopper 26, the reactor 28, isolated from each other by vane feeder 27, gas supply system 11. Measurement of parameters and the management of the experimental installation are carried out via temperature sensors, devices for determining the gas flow, pressure reducers, closing and regulatory insert. Registration of data from all sensors and devices is done by the system of collection and storage of information, the gas analyzer 3, a calorimetric bomb 43.

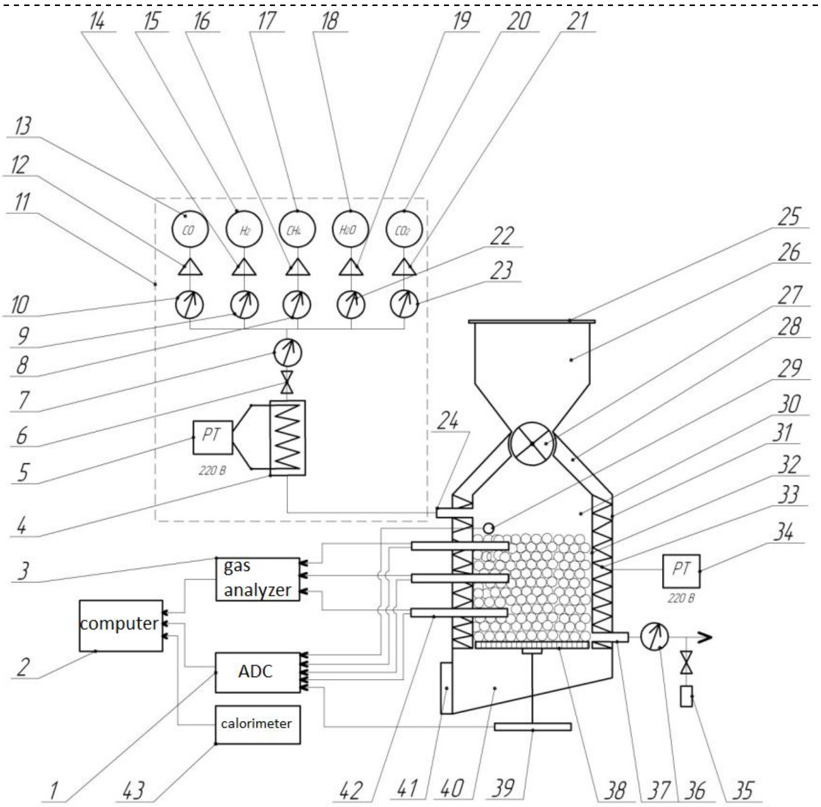

Figure 3. Installation of the study of reduction processes.

A gas supply system 11 is a system with a gas cylinder 13 (*SB*) 15 (H_2), 17 (CH_4) 18 (H_2O) 20 (CO_2), where the gas of predetermined pressure and composition is supplied to the heating element 4. The volume of the gas fed in to heating element is regulated by a flow meter 7 and a locking

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mechanism 6. The temperature of the heating element is regulated by a temperature controller 5. The heated gas with the temperature of 400-900 °C is sent into the reactor 28 and is determined by a pressure sensor 29. The gas selected from the sampler 35 for research of calorific value is sent in to the calorimetric bomb 43. The weight change of the material due to its response is fixed by means of strain gauge 39. Continuously recorded sample weight change during the experiment allows to determine the kinetics of thermal decomposition. The feed rate of gas into the chamber is regulated by the locking mechanism 44 and 48. The number of inlet and exhaust gas is fixed by flowmeters 43 and 47. During the study of dependance on the composition and quantity of gas from the particle diameter and the porosity of the layer the charcoal various fractions are prepared.

3. Results and Discussions

At a result of data obtained during the experiments, characteristic curves describing the process of energy-technological processing of wood waste at various regime parameters and at different stages of processing are constructed. The results are shown for wood waste of different fractional composition with different initial moisture content.

In the study of pyrolysis experimental data of layer's loss in weight, change in the layer's temperature, process time, the content of volatile substance in the coal residue.

The dependence of the specific gravity decrease on the process temperature in the pyrolysis zone, shown in figure 4 which shows that during the increase of process temperature the coal mass yield drops. This is due to higher degree of release of volatile substances contained in the coal mass [9]. The dependences on the mass loss of cellulose and hemicellulose in the pyrolyzed material on the temperature [10, 11], obtained by treatment of experimental data are also displayed in this figure.

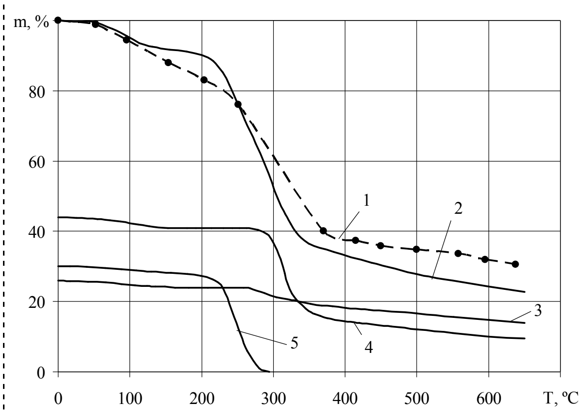

Figure 4. Dependence of loss of specific weight on the heating temperature: 1 - material (e); 2 - material (p), 3 - lignin (p) , 4 - cellulose (p), 5 - hemicellulose (p)

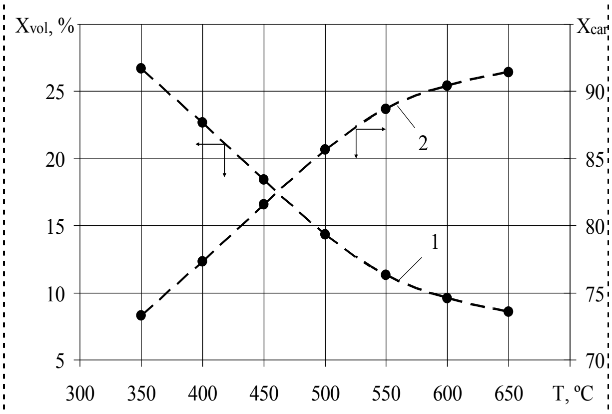

Figure 5. Dependence of volatile substances (curve 1) and carbon (curve 2) in the coke residue on the temperature in the pyrolysis zone

The experiments also revealed the dependence of volatile substances and carbon in coal on the temperature in the pyrolysis zone, as reflected in figure 5. The data show that with increasing of the processing temperature the mass of coal output decreases, and the proportion of carbon contained therein increases. This is explained by a greater degree of thermal degradation of lignocellulosic complex at high temperatures and, consequently, the release of more volatile substances contained in the pulp. During the analysis of pyrolysis gas sample the dependence of the effect of temperature on the pyrolysis process on the pyrolysis gas composition which is shown in figure 6 was also obtained. This relationship shows that within an increase in temperature a significant increase of methane formation occurs [12]. It is associated with a great increase in the reaction rate of methane formation in relation to the other components [13]. However, methane growth rate decreases at temperatures above 550 °C . The content of hydrogen also increases slightly with increasing of temperature, and its quantity increases intensively at temperatures above 550 °C. This happens because of formed char burning and mainly excreted hydrogen. Also, there is a decrease in carbon dioxide, which is explained by the relatively low temperature of pyrolysis process flow and a comparative increase in the content of the other components of the pyrolysis gas.

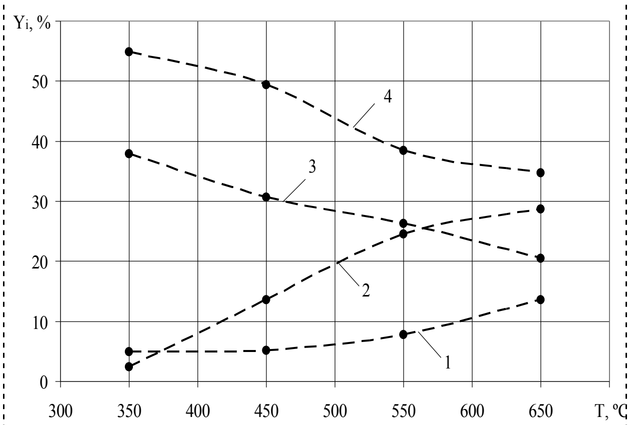

Figure 6. The composition dependence on the temperature of pyrolysis gas in the pyrolysis zone 1 - H_2; 2 - CH_4; 3 - CO; 4 - CO_2

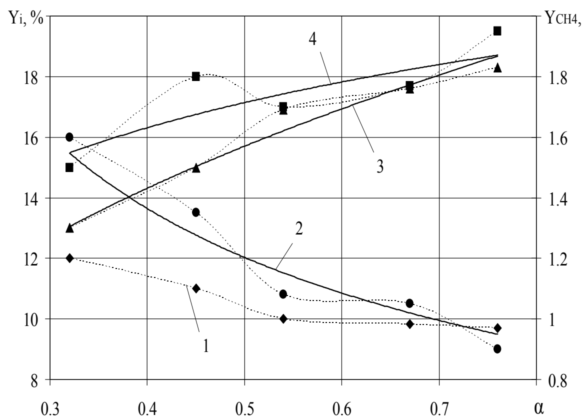

Figure 7. The dependence of the produced gas composition on oxidizer flow in the combustion zone of the gasifier 1 - CH_4; 2 - CO_2; 3 - SO; 4 - H_2

Experimental dependence of figure 7 shows that increasing the supply of oxidant into the combustion zone leads to a significant increase in temperature. This is because when the oxidizer flow rate and its outflow through the tuyere changes i.e. the gas flow rate in the combustion zone, rising the temperature on the surface of the waste layer in the incoming oxidant stream increases. In this case the reaction rates of interaction between the waste and the oxidant significantly increase. The intensity of the gasification process also has an impact on the composition and calorific value of the produced gas. The intensification of the process by increasing the oxidant flow results in an increase of the combustible components of carbon monoxide and hydrogen and the reduction of not recovered carbon dioxide, due to displacement of the equilibrium constants of the endothermic reduction reactions of carbon dioxide and the decomposition of water in the direction of increasing the content in the produced gas of carbon monoxide and hydrogen, connected, as it was noted above, with the increasing of the temperature and the rate of chemical reactions in combustion and reduction zones [14]. Furthermore, an increase in temperature in combustion and reduction zones leads to almost complete decomposition of the resulting resin, which improves the quality of the produced gas, but it increases the amount of ablative dust and the pressure resistance of the gas generator [15].

The study of the effect of reduction zone height on the parameters of the produced gas showed a significant value of this parameter during the gasification process, as it determines the contact time of gases and water vapour with coal made red-hot by carbon, which has a significant impact on the quality of the product gas [16].

The study results, shown in figure 8 indicate that with increasing the height of the reduction zone to 125-135 mm the content of combustible part of produced gas increases, and hence its calorific value. However, further increase in the height (over 135 mm) is followed by reduction of the quality of the produced gas, due to reducing the amount of carbon dioxide associated with the drop in temperature at the end of the reduction zone and the flow of reverse reactions. The quantity of hydrogen increases slightly. The reason is that the height of the reduction zone depends on the temperature at the end of the reduction zone. In addition, the gas flow rate substantively affects on the value of the height of the reduction zone. Thus, with increasing gas flow rate there is an increase in the height of the reduction zone. This is due to inadequate hold-up time of the gas stream in the reduction zone, which leads to its increase. It is also noted that the particle size influences at the increase of temperature and reaction ability of the waste. The smaller the particle size, the lower the height of the recovery zone, which provides the completion of reduction reactions.

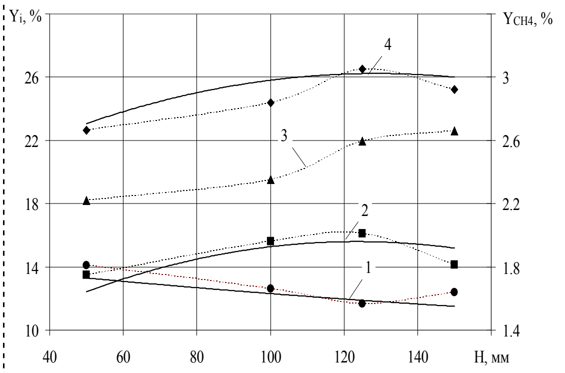

Figure 8. The dependence of composition of the produced gas from the height of the recovery zone 1 - CO_2; 2 - H_2; 3 - CH_4; 4 - CO

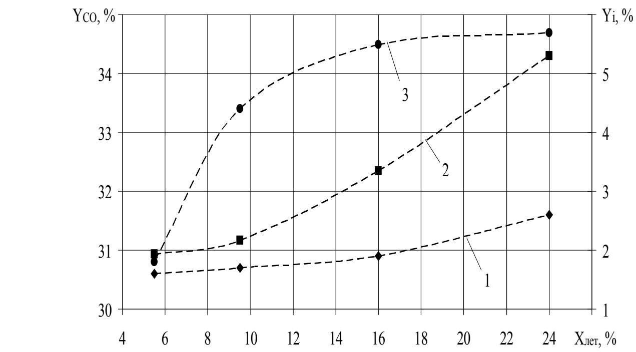

Figure 9. A produced gas composition dependence on the content of volatile substances in coal in the reduction zone 1 - CH_4; 2 - CO; 3 - H_2

The obtained results let us to suggest that the volatile substances contained in the coal in the reduction zone can influence on the quality of the produced gas. To confirm the hypothesis the study was conducted to determine the effect of volatile substances' content in coal in the reduction zone on the component composition and the quality of the produced gas. The obtained data are reflected in figures 9. The graphs show that the main combustibles content of the produced gas, with an increase of volatile substances in coal from 5 to 24 %, increases. As a result, the calorific value of the produced gas is also increased. However, the experience shows that a further increase in the content of volatile substances in the coal leads to the formation and growth of undecomposed tar content in the produced gas.

A generalized analysis of these dependences shows that even at a temperature of 400 °C in the pyrolysis zone, there is an achieved optimum value of the content of volatile substances produced in coal mass, but due to minor changes in the limits of the produced gas composition it was concluded that this option has no significant effect on the entire process of gasification. It is also noted that this option is difficult to manage and almost impossible to control.

4. Conclusions

Analysis of the results of physical modeling process of energy technological processing of wood waste showed that the volatile substances' content in the coal, the oxidant flow in the combustion zone and the height of the reduction zone are the main parameters that affect the work efficiency of the gasifier unit. The height of the reduction zone in co-current gasification depends on the flow rate, concentration and the oxidant temperature in the combustion zone and the amount of volatile substances in coal in the reduction zone. Increasing the height of the reduction zone, first, helps to increase in calorific value of produced gas, however, further increase reduces the calorific value of the produced gas. The duration of the thermochemical decomposition in the pyrolysis zone depends on the fractional composition of wood waste.

As a result of physical modeling are determined the following points: the optimum height of the drying zone and the pyrolysis depending on the initial humidity of wood waste, coal supply and pyrolysis gases generated during pyrolysis, the optimal parameters of the combustion zone, the effective height of the reduction zone and the parameters of the produced gas at the outlet of the installation.

An overall analysis of the data reveals the optimal modes of process of energy-technological processing of wood waste with the use of direct-flow gasification to develop the technology of thermochemical processing of wood waste using the gasification method and the project the gas generators' constructions, ensuring high quality of the received synthesis gas.

References

[1] Hu G., Li G., Zheng Y., Zhang Z., and Xu Y. 2015 Euler–Lagrange modeling of wood chip gasification in a small-scale gasifier. *Journal of the Energy Institute* **88**(3): 314-322.
[2] Sadrtdinov A.R., Safin R.G., Gerasimov M.K., Petrov V.I., and Gilfanov K.K. 2016 The mathematical description of the gasification process of woody biomass in installations with a plasma heat source for producing synthesis gas. *IOP Conference Series: Materials Science and Engineering* **124**(1), 012092. IOP Publishing. DOI:10.1088/1757-899X/124/1/012092
[3] Saravanakumar A., Haridasan T.M. and Reed T.B. 2010 Flaming pyrolysis model of the fixed bed cross draft long-stick wood gasifier *Fuel Processing Technology* **91**(6): 669-675. DOI:10.1016/j.fuproc.2010.01.016
[4] Janajreh I. and Al Shrah M. 2013 Numerical and experimental investigation of downdraft gasification of wood chips. *Energy Conversion and Managemen*, **65**: 783-792.
[5] Timerbaev N.F., Safin R.R., Safin R.G. and Ziatdinova D.F. 2014 Modeling of the process of energy-technological treatment of wood waste by method of direct-flow gasification *Journal of Engineering and Applied Sciences* **9**(5): 141-146
[6] Tuntsev D.V., Filippova F.M., Khismatov R.G., and Timerbaev N.F. 2014 Pyrolyzates: Products of plant biomass fast pyrolysis. *Russian Journal of Applied Chemistry*, **87**(9): 1367-1370.
[7] Pakdel H. and Roy C. 1991 Hydrocarbon content of liquid products and tar from pyrolysis and gasification of wood. *Energy & Fuels* **5**(3): 427-436.
[8] Saravanakumar A., Haridasan T.M., Reed T.B., and Bai R.K. 2007 Experimental investigation and modelling study of long stick wood gasification in a top lit updraft fixed bed gasifier. *Fuel* **86**(17): 2846-2856.
[9] Mahapatra S., Kumar S. and Dasappa S. 2016 Gasification of wood particles in a co-current packed bed: Experiments and model analysis *Fuel Processing Technology* **145**: 76-89.
[10] Bui T., Loof R. and Bhattacharya S.C. 1994 Multi-stage reactor for thermal gasification of wood *Energy* **19**(4): 397-404.
[11] Sadrtdinov A.R., Sattarova Z.G., Prosvirnikov D.B. and Tuntsev D.V. (2015, December) Modeling of thermal treatment of wood waste in the gasifiers. In *2015 Int. Conf. on Mechanical Engineering, Automation and Control Systems (MEACS)* pp 1-5. DOI:10.1109/MEACS.2015.7414914
[12] Dasappa S., Paul P.J., Mukunda H.S. and Shrinivasa U. 1994 The gasification of wood-char spheres in CO2 N2 mixtures: analysis and experiments *Chemical Engineering Science* **49**(2): 223-232.
[13] Bui T., Loof R., and Bhattacharya S.C. 1994 Multi-stage reactor for thermal gasification of wood. *Energy* **19**(4): 397-404.
[14] Lashkov V.A., Sattarova Z.G., Taymarov M.A., Gerasimov M.K. and Halitov R.A. 2016 Modeling of a reduction zone of the gasifier installation *IOP Conference Series: Materials Science and Engineering* **124**(1), 012111. IOP Publishing. DOI:10.1088/1757-899X/124/1/012111
[15] Palmer E.R. 1984 Gasification of wood for methanol production *Energy in agriculture* **3**: 363-375.
[16] Prosvirnikov D.B., Safin R.G., Ziatdinova D.F., Timerbaev N.F., and Lashkov V.A. 2016 Multifactorial modelling of high-temperature treatment of timber in the saturated water steam medium. *IOP Conference Series: Materials Science and Engineering* **124**(1), 012088. IOP Publishing. DOI:10.1088/1757-899X/124/1/012088