The Optimization of the Gasifier Recovery Zone Height When Working on Straw Pellets

Gennadii Golub*, Savelii Kukharets**‡, Oleh Skydan***, Yaroslav Yarosh****, Vyacheslav Chuba*, Victor Golub*****

*Department of tractors, automobiles and bioenergy systems, National University of Life and environmental sciences of Ukraine, Heroev Oborony str., 15B, Kyiv, 03040, Ukraine

**Department of mechanical and engineering agroecosystems, Zhytomyr National Agroecological University, Staryi blvd., 7, Zhytomyr, 10008, Ukraine

***Department of Innovative Entrepreneurship and Investment Activities, Zhytomyr National Agroecological University, Staryi blvd., 7, Zhytomyr, 10008, Ukraine

****Department of processes machinery and equipment in agrarian engineering, Zhytomyr National Agroecological University, Staryi blvd., 7, Zhytomyr, 10008, Ukraine

*****Research and testing department, Ivan Cherniakhovsky National Defense University of Ukraine, Povitroflotskiy ave., 28, Kyiv, 03049, Ukraine

(gagolub@ukr.net, saveliy_76@ukr.net, skydanolegv@ukr.net, yaroslav.yarosh76@gmail.com, vvchuba@ukr.net, victor-golub@meta.ua)

‡ Corresponding Author; Savelii Kukharets, Zhytomyr National Agroecological University, Staryi blvd., 7, Zhytomyr, 10008, Ukraine, Tel: +38 067 665 3548, saveliy_76@ukr.net,

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Abstract- Analysis of studies of the process of generator gas obtaining from straw allows us to draw a conclusion about the suitability of using straw as a fuel for a gasifier. However, the main obstacle to producing generator gas from straw is the formation of solid agglomerates in the process of producing generator gas. In order to avoid the formation of agglomerates, the researchers went through the creation of complex designs of gasifiers. In addition, it was not possible to completely avoid the formation of agglomerates on the working surfaces of gasifiers, in particular on grates. The article discusses the design of the gasifier, which does not have a grate, and gas is extracted through grooves in the side surface of the recovery zone. The article also presents the results of experimental studies of such a gasifier operation. The influence of the air supply to the gasifier and the height of the recovery zone on the concentration of carbon monoxide in the generator gas was established. It was determined that when the air supply is 3.8 l/s, the optimal height of the recovery zone, at which the maximum output of CO is reached, is 100±2 mm. When the air supply is 8.3 l/s, the optimal height of the recovery zone is 90±2 mm, and when the supply is of 12.8 l/s – 70±2 mm. Experimental studies of the operation of the power plant using generator gas obtained from straw were also carried out.

Keywords Straw, gasifier, generator gas, electric generator.

1. Introduction

To reduce greenhouse gas emissions, it is necessary to increase the use of renewable energy sources [1, 2]. In this case, it is a good idea to use pellets, briquettes, rolls of straw from grain crops, sunflower husks and other plant biomass [3] as a renewable fuel for gasifiers [4, 5]. In particular, the use of straw pellets to produce generator gas can provide energy autonomy of agricultural production [6].

The experimental studies demonstrated that the use of straw pellets when compared to wood, they are observed: the increase in concentration of CO in the obtained generator gas by 44.3 %, increase in total output of the generator gas by 7.7 % and increase in the duration of operation of the gasifier at boot by equal weight portions of fuel (2 kg of fuel) by 2.8 % [7]. However, the gasification of straw pellets is complicated by the low melting point of the ash. In particular, in [8], a study of the formation of generator gas from a mixture of coal and wheat straw was carried out. The results of the study showed that increasing the straw content to 75 % increased the volume of the produced gas by 15 %. With an increase in the content of straw in the fuel mixture by more than 75 %, the temperature in the recovery zone of the gasifier decreased, and the formation of solid agglomerates proceeded intensively. In studies [7] of the operation of a downdraft gasifier with a solid fuel layer and a wheat straw content of more than 60 %, active formation of solid agglomerates was observed on the working surfaces of the gasifier placed horizontally. With a lower content of straw in the fuel, agglomerates were also formed, although with a lower intensity.

To disable the formation of agglomerates, they were made attempts to use the steam supply [10] or the supply of a mixture of steam and oxygen at normal and high pressures [9]. During the supply of steam or oxygen-enriched air, there was a significant slowdown in the formation of agglomerates. The disadvantages of this technology are the high water vapor content in the resulting generator gas and the use of complex equipment for preparing and supplying gases for blowing. It is effective to obtain generator gas from a mixture of sewage sludge and straw in a fluidized bed gasifier [11]. The disadvantage of this method is that it also requires the use of complex equipment. In addition, it is not possible to use fuel with 100 % straw content. The article [12] presents the results of a study of agglomeration processes during the production of generator gas from wheat straw in a small fluidized bed gasifier. These studies have shown that changing the operating modes of the gasifier does not actually affect the formation of agglomerates, but significantly affects the efficiency of the gasification process. Another method for reducing the formation of agglomerates is to obtain generator gas in two stages [13] using oxygen. At the second stage, the formed agglomerates are removed from the gasifier through the water barrier. This method helps to reduce the number of the formed agglomerates, but the design of the plant is difficult to use. Studies [14] have shown that the use of fluidized bed gasifiers improves the quality of the resulting generator gas, but does not allow to get rid of the formation of agglomerates. The only advantage is that fluidized bed gasifiers can mechanically remove agglomerates. A study was also conducted on the effect of the height of the recovery zone on the quality of the resulting gas and the number of the formed agglomerates during the production of generator gas [15, 16]. The study has shown that the height of the zone significantly affects the composition of the generator gas, in particular the CO content. However, the height of the recovery zone did not significantly affect the number of the formed agglomerates.

The analysis of the conducted research on the production of generator gas from straw shows that the researchers went through the creation of complex designs of gasifiers. Such gasifiers allow you getting generator gas from straw quite efficiently, but the complexity of the technological process does not allow them to be used effectively. In addition, it was not possible to completely avoid the formation of agglomerates on the working surfaces of gasifiers. For designs of downdraft gasifier, using the solid fuel layer technology, the study of the straw gasification process is complicated by the intensive formation of agglomerate deposits on the working surfaces of gasifiers [7]. For example, a study [17] of small downdraft gasifier was conducted and it was concluded that the formation of agglomerates in them causes grate blocking, channeling, and bridging.

The classic design of a downdraft gasifier for biomass gasification includes a housing, a fuel hopper, a fuel combustion (oxidation) zone, a combustible gas recovery zone, a zone for supplying the oxidizer to the combustion zone, a bunker for ash accumulation, and a horizontal grate [18]. The disadvantage of such gasifiers is the formation of ash and slag agglomerates on the surface of the grate because of its horizontal placement. As a result, the area of the grate openings decreases, the efficiency of removing gas from the recovery zone decreases, which causes the decrease in the efficiency of the gas formation process. In addition, the oxidizer supply to the combustion (oxidation) zone of the gasifier decreases and the stability of thermochemical transformations in the reduction zone deteriorates. It should be noted that the study of the process of agglomerates formation during biomass gasification is difficult for theoretical substantiation due to the variety and transience of processes occurring in the working zones of the gasifier [19, 20]. This prevents theoretical models of agglomerate formation from achieving the necessary accuracy to optimize the gasification process [21]. Therefore, the establishment of rational design parameters of gasifiers and optimization of technological parameters of the process of obtaining generator gas is carried out on the basis of experimental data [22, 23].

Analysis of the study of the process of straw gasification allows us to draw a conclusion about the suitability of straw as a fuel for generator gas production. Analysis of technical solutions of straw gasifiers has shown that effective use of straw in gasifiers is possible only when using complex equipment. In addition, the issue of operating modes of gasifiers without agglomerate formation has not been resolved. Therefore, for efficient use of straw as fuel, it is necessary to develop simple designs of gasifiers that will avoid the formation of agglomerates on working surfaces. The design of gasifiers for generator gas production from straw must be reliable, technological, easy to operate and maintain.

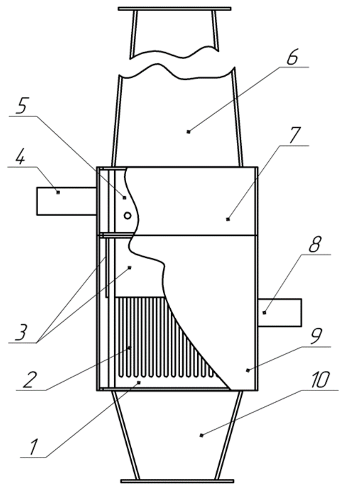
The aim of the study was experimental determination of the influence of the gasifier parameters without grate and with selection of gas through the slots in the side surface recovery zone on the quality of the generator gas and checking the possibility of stable generation of generator gas from the straw pellets.

2. Materials and Methods

To test the process of generator gas production from straw pellets, we offer the original design of the gasifier (Fig. 1 and Fig. 2). The gasifier consists of a combustion (oxidation) zone 5, a recovery zone 1, a fuel hopper 6, a bunker for ash 10, an oxidizer supply chamber 7, a generator gas offtake manifold

9, oxidizer supply 4 and generator gas offtake 8 pipes. In the side surface, evenly spaced vertical grooves 2 are made in the recovery zone of the generator gas 1. The side of the cross section of the gasifier in the area of the oxidation and reduction zones is 200 mm. On the outside of the surface of the generator gas recovery zone 1, valves (special plates) 3 are installed. The valves can be moved vertically. Moving the valves allows reaching the required height of the recovery zone and coordinating the useful area of generator gas offtake with the modes of oxidizer supply to the combustion (oxidation) zone.

The removal of gas from the recovery zone takes place through the vertical grooves 2 of the side surface of the recovery zone 1. Therefore, there is no need to install a horizontal grate, which mainly causes the formation of ash and slag agglomerates.



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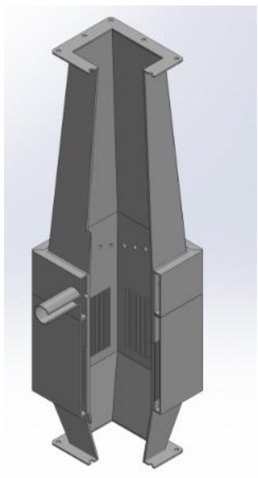
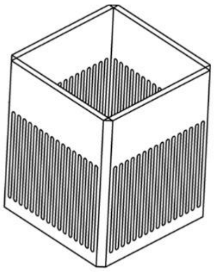


b)

c)

Fig. 1. Diagram and appearance of equipment used in the research: a - diagram of the gasifier; b -layout; c - general appearance; 1 – recovery zone; 2 – vertical grooves; 3 – valves (special plates); 4 – oxidizer supply; 5 – combustion (oxidation) zone; 6 – fuel hopper; 7 – oxidizer supply chamber; 8 – generator gas offtake pipes; 9 – generator gas offtake manifold; 10 – bunker for ash.



a)

b)

Fig.2. Diagram and appearance of the recovery zone of the generator gas with a plate for adjusting the height of the recovery zone: a - schematic image; b - appearance.

The influence of the design and operation parameters of the gasifier on the concentration of carbon monoxide (CO) in the generator gas was studied in the laboratory using the developed plant (Fig. 3). The plant consisted of a gasifier 5 with an adjustable height of the recovery zone, a centrifugal discharge fan 2 with an adjustable air supply capacity to the combustion (oxidation) zone of the gasifier, a mixer 10 equipped with a centrifugal discharge fan, and other components.

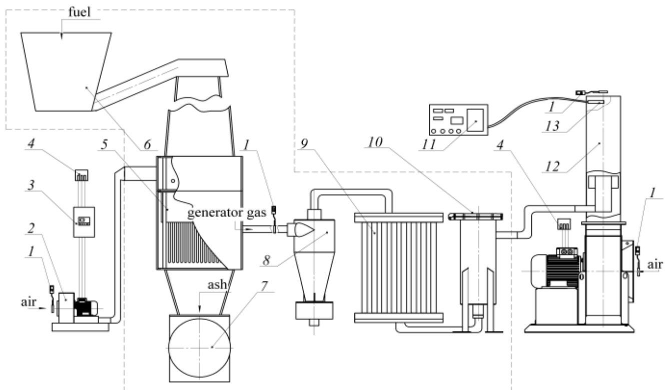


Fig. 3. Research plant scheme: 1 – wind meter; 2 – a fan for supplying air to the gasifier; 3 – the frequency converter; 4 – source of electric current of 0.4 kV; 5 – gasifier GG-2; 6 – bunker with a screw for fuel; 7 – ash discharger; 8 – filter; 9 – cooler; 10 – fine filter; 11 – gas analyzer; 12 – mixer; 13 – gas analyzer sensor.

To identify the relationship between the effect of air supply to the gasifier (q_g) and the height of the recovery zone (h_r) on the concentration of carbon monoxide in the generator gas (n_{CO}), the appropriate experimental studies were conducted. Straw pellets were used as raw materials, the quality indicators of which met the standards DIN 51731 and ONorm M 7135. The research methodology is described in detail in [16].

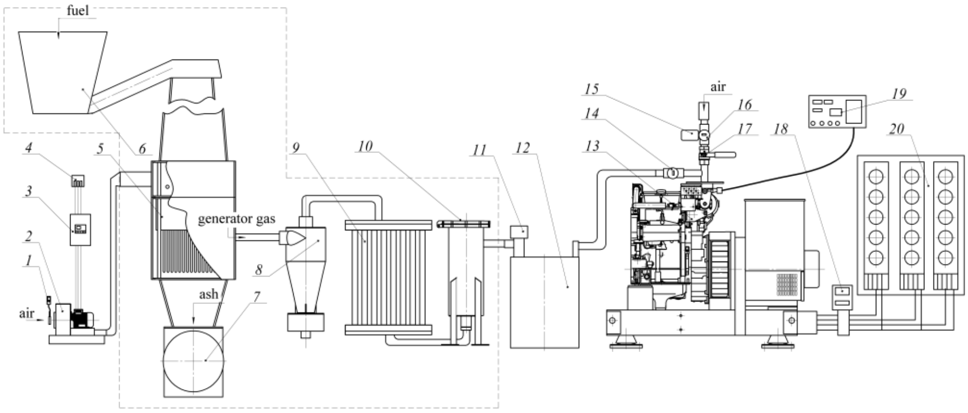
The height of the recovery zone was adjusted using special plates (Fig. 2, b). The ranges of values and levels of variation of the studied factors are shown in table. 1.

A special pilot plant (Fig. 4, a, b) was used to conduct the experimental studies of the operation of the power plant fuelled by generator gas obtained from straw. It was conducted the check of parameters of generator gas power plant operation with a fixed air supply level of 12.8 l/s into the gasifier combustion zone, and the height of the recovery zone corresponded to the maximum concentration of CO in the gas.

Table 1. Ranges of values and levels of variation of the studied factors when conducting studies of the combustible gas gasifier

Name of factors	Unit	Symbol	Factor levels			Variation intervals
			-1	0	+1	
Air supply to the gasifier	l/s	q_g	3.8	8.3	12.8	4.5
The height of the recovery zone	mm	h_r	50	100	150	50

a)



b)

Fig. 4. Plant appearance and diagram for the study of the working process of the generator gas power plant: 1 – anemometer; 2 – a fan for supplying air to the gasifier; 3 – the frequency converter; 4 – source of electrical energy 0.4 kV; 5 – gasifier GG-2; 6 – bunker with a screw for fuel; 7 – ash discharger; 8 – prime filter; 9 – cooler; 10 – fine filter; 11 – valve; 12 – receiver; 13 - power plant; 14 – gas meter; 15 – blower; 16 – air counter; 17 – air supply regulator; 18-device for measuring current consumption parameters; 19 - exhaust gas analyzer; 20 - electric load.

During the experiments, a receiver 12 with a safety valve was used. The receiver provided a uniform flow of generator gas to the power plant engine.

3. Results and Discussions

When performing experimental studies of the influence of gasifier parameters on the quality of generator gas, the results shown in table 2 were obtained.

Multivariate regression analysis of the values shown in table 2 allowed us to obtain equations describing the dependence of the CO content in the generator gas depending on the height of the recovery zone and on the air supply to the gasifier:

$$n_{CO}=-24.4339+3.6892q_a+0.4568h_r-0.0445q_a^2-$$
$$-0.0138q_ah_r-0.002h_r^2, \quad (1)$$

where: n_{CO} – CO content in the obtained gas, %; q_a – air supply to the gasifier, l/s; h_r – the height of the recovery zone, mm.

Table 2. Results of experimental studies on optimizing the height of the recovery zone

Experiment number	Height of the recovery zone, mm	Air supply to the gasifier, l/s	The CO content in the gas, %
1	50	3.85	2.38
2	50	8.33	17.71
3	50	8.33	13.98
4	50	12.82	24.99
5	100	3.85	7.14
6	100	3.85	11.91
7	100	8.33	19.57
8	100	8.33	17.71
9	100	8.33	16.78
10	100	12.82	20.62
11	100	12.82	21.87
12	150	3.85	4.76
13	150	8.33	4.66
14	150	8.33	8.39
15	150	12.82	14.99

A graphical interpretation of the equation (1) is shown in fig. 5.

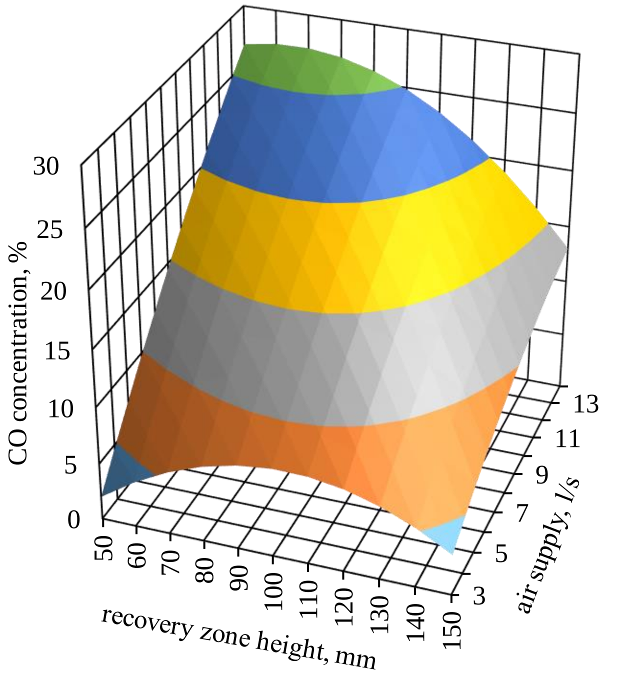


Fig. 5. Yield surface of the dependence of the CO content in the generator gas on the height of the recovery zone and the air supply.

Analysis of the response surface in Fig. 5 allowed us to obtain graphical dependencies of the CO content on the height of the recovery zone at the minimum, average, and maximum air supplies (Fig. 6).

The analysis of the graphs in Fig. 6 demonstrated that at the minimum air flow of 3.8 l/s, the optimum height of the recovery zone with the maximum CO concentration is 100±2 mm. At an average air flow of 8.3 l/s, the optimal recovery zone height is 90±2 mm, and at a maximum flow of 12.8 l/s, the optimal recovery zone height is 70±2 mm.

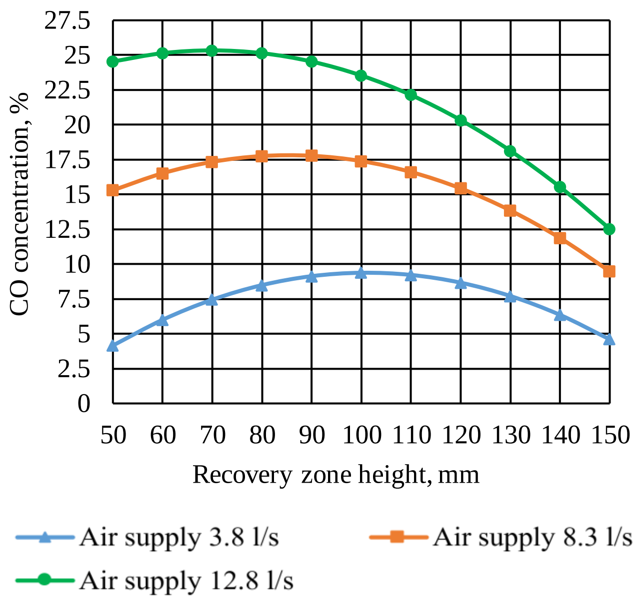


Fig. 6. Graphs of the dependence of the CO concentration on the recovery zone height.

When the gas flow passes through the material layer in the recovery zone, carbon monoxide (CO_2) reacts with carbon, and as a result, carbon monoxide (CO) is formed. If the recovery area is not high enough, the recovery process is partially completed, and if the height is too high, the temperature regime deteriorates and the resistance to gas passing through the recovery zone increases significantly. A similar effect was also obtained during the gasification of wood [16]. This leads to a decrease in the content of combustible substances in the generator gas. In addition, it is important to coordinate the speed of gas passing through the recovery zone and the height of the recovery zone. The optimal height of the recovery zone decreases as the air supply increases, which can be explained by the high speed of gas passing through the recovery zone, and as a result, the increased temperature in the recovery zone. At the same time, if the recovery zone is too high, the generator gas is re-oxidized, which also reduces the content of combustible substances in the gas. A similar effect was also obtained during experimental study of the influence of straw content in fuel on parameters of generator gas [7].

Analysis of the results of the power plant engine and gasifier in the pilot plant shown in Fig. 4 is shown in table 3.

Table 3. Results of experimental studies of the operation of power plant on generator gas

Electric power, kW	Supply of generator gas to the power plant engine, m^3/min	Air supply to the power plant engine, m^3/min	Air supply to the gasifier, m^3/min	Power plant engine emissions	
				CO, %	CH, ppm
0.24	0.18	0.312		2.02	68
0.46	0.186	0.330		1.9	70
0.72	0.186	0.336		1.82	65
1.17	0.192	0.342		1.27	62
1.92	0.198	0.348	0.011885	0.99	64
2.16	0.204	0.348		0.94	60
2.43	0.21	0.354		0.39	46
2.73	0.216	0.354		0.27	52
3.15	0.222	0.360		0.24	62

Analysis of table 3 data allowed us to obtain empirical dependences of gas consumption (with a coefficient of determination R^2=0.97) and air consumption (with a coefficient of determination R^2=0.86) by the power plant engine on the generated electric power:

$$q_{sg} = 0.014W + 0.177, \quad (2)$$

$$q_a = 0.013W + 0.321, \quad (3)$$

where: q_{sg} – generator gas consumption, m^3/min.; q_a – air consumption, m^3/min.; W – produced electric power, kW.

A graphical representation of equations (2) and (3) is shown in fig. 7.

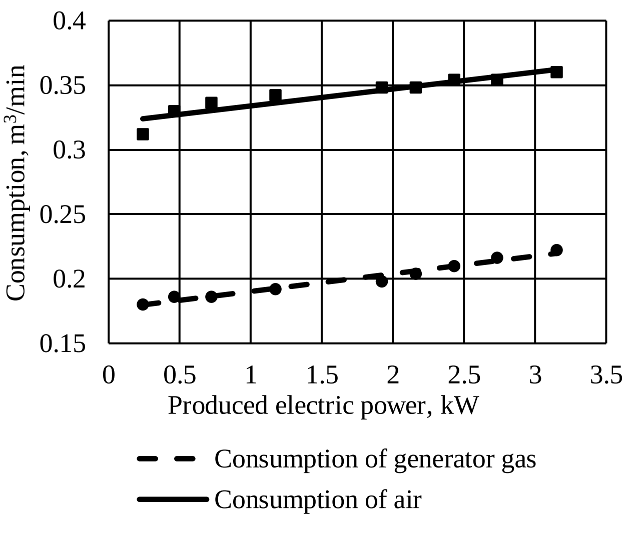


Fig. 7. Consumption of generator gas and air depending on the produced electrical power.

From the analysis of the graph in Fig. 7 it was found that with an increase in electric power by 13 times (from 0.24 to 3.15 kW), there is a linear increase in generator gas consumption by 1.23 times (from 0.18 to 0.22 m^3/min) and air consumption by 1.15 times (from 0.312 to 0.36 m^3/min). At the same time, there was a linear increase in the ratio of consumed gas to consumed air from 0.58 to 0.62. In addition, when using generator gas as a fuel, there was observed the CO emissions reduction in the power plant engine by 25 times, and CH emissions – by 4 times, when compared to the use of gasoline.

Using of the gasifier without grate and with selection of gas through the slots in the side surface recovery zone allowed to avoid formation of ash and slag agglomerates on the surface of the grate because of its horizontal placement, that was also obtained during the gasification of straw and wood [7, 17, 18]. New gasifier design allows constantly receive generator gas from the straw pellets, which has not been achieved in known studies [7, 8].

4. Conclusion

The full scale straw pellet gasifier was used for the research. The side of the cross section of the gasifier in the area of the oxidation and reduction zones is 200 mm. The height of the recovery zone was adjusted using special plates from 50 mm to 150 mm. The height of the combustion (oxidation) zone was 100 mm.

Due to the fact that evenly spaced vertical slots are made in the side surface of the gasifier recovery zone, and valves are installed on the outside of the side surface of the generator gas recovery zone with the ability to move them vertically and set the specified working height of the vertical slots, gas is removed from the recovery zone through vertical slots in the side surface of the recovery zone. In this case, there is no need to install a horizontal grate, on which ash and slag agglomerates are formed.

From the analysis of experimental studies of the operation of gasifier on straw pellets, it was found that with a minimum air supply of 3.8 l/s, the optimal height of the recovery zone, at which the maximum CO content is reached, is 100±2 mm. With an average air supply of 8.3 l/s, the optimal height of the recovery zone is 90±2 mm, and with a maximum supply of 12.8 l/s, the optimal height of the recovery zone is 70±2 mm.

It was found that with an increase in electric power from 0.24 to 3.15 kW, there is a linear increase in generator gas consumption from 0.18 to 0.22 m3/min and air consumption from 0.312 to 0.360 m3/min. The ratio of consumed gas to consumed air is from 0.58 to 0.62, and the reduction in engine emissions of the power plant is by 25 times for CO, and by 4 times for CH, compared with the use of gasoline.

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