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EXPERIMENTAL STUDY OF FEATURES BIOGAS PRODUCTION BY PYROLYSIS OF CORN PELLETS

The material in the article contains useful information for studying and analyzing the production processes of biogas with a low tar content by pyrolysis and gasification of corn straw pellets in a composite fixed bed of a pilot plant. The results show good adaptability of the installation to this fuel, the ability to ensure optimal temperature distribution in each zone. Temperature control in the resin cracking zone is carried out by supplying the required volume of secondary air, which can significantly reduce the presence of resin in biogas while maintaining the calorific value of the gas at 4700 kJ /nm^3.

Key words: biomass; pellets; pyrolysis; gasification; resin cracking; biogas, environmental cleanliness.

Introduction

The modern world challenge is that mankind needs to move to sustainable development with a stable rate of energy production in compliance with the basic principle of development of the fuel and energy complex - the principle of ecological balance [1]. Recently, the world has formed the opinion that energy facilities should not use organic (fossil) fuel and nuclear energy for the subsequent increase in energy capacities in connection with negative environmental consequences. As an alternative energy source, it is advisable to consider the use of biomass for these purposes.

Table 1. Data on the energy use of biomass (BM) in different countries [4]

Indicators	USA	Denmark	Austria	Sweden	Finland
BM share of total energy resource consumption	3,2	6,0	12,0	18,0	23.0
Share of different types of BM in total energy production from BM.%:					
- Firewood	85	37,0	74,2	83,0	73
- Straw	-	24,7	-	-	-
- Liquid fuel	5,5*	-	-	-	-
- Peat	-	-	-	4,8	25,2
- Solid household waste	9,5	40,5	18,9	5,2	1,8
- Biogas	5,5*	0,33	-	-	-

* – This figure is a combined indicator for biogas and liquid fuel.

Table 2. Energy potential of biomass in Ukraine [4]

Type of biomass	Croppage, million tons	Waste coefficient	Accessibility coefficient	Amount of wastes, million tons	$Q^{р}_{н}$, MJ/kg	Amount of BM, accessible near energy receiving		Energy potential of BM, accessible to energetics	
						%	million tons	PJ	million tons
Cereals	28,53	1,771	0,85	42,95	15,7	20	8,59 ,	134,8	4,6
Corn for grains	5,34	1,2	0,7	4,49	13,7	50	2,24	30,72	1,05
Sugar beet	17,66	0,4	0,4	2,83	13,7	50	1,41	19,36	0,66
Sunflower	2,31	3,7	0,7	5,97	13,7	50	2,99	40,94	1,39
Wood	5,94	0,55	0,9	2,94	15,0	40	1,18	17,65	0,60
Manure (dry substance)	7,39	–	0,62	4,58	15,0	100	4,58	68,7	2,34
Total	–	–	–	63,76	–	–	20,98	312,15	10,64

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At the same time, the sustainable development of industrial potentials of various countries should be based on the stable development of energy production at a pace that should outpace the pace of energy consumption of all sectors combined [2]. A promising paradigm for the development of the energy industry, it is advisable to name the New energy-ecological paradigm [3], which reads: "Sustainable development in harmony with nature."

In this sense, it is advisable to pay attention to renewable energy sources. Solar and wind energy can not be fully used as stable sources of energy production to satisfy axioms, principles and development paradigms [1-3] of energy industry. In this regard, the most favorable is the possibility of a more rational use of biomass for energy production as one of the types of renewable energy sources [4].

Recently, more and more attention has been paid to this type of energy source, since the use of biomass in the process of production of heat and electric energy solves a set of problems: obtaining energy and processing agricultural waste. Table 1 shows data on the level of bioenergy development in developed countries [4].

Table 2 presents the energy potential of biomass (BM) in Ukraine [4], which is now actively considered as an alternative to using fossil fuels in energy production processes [5].

The purpose and objective of the study

The aim of the research is to study the process of pyrolysis of biomass fuel pellets obtained from corn straw using an experimental gasification unit in a composite fixed layer with determination of the structure and optimal conditions for the pellet gasification to produce biogas with a low resin content.

The objective of the research is to study the gasification characteristics of corn pellets in the gasifier of a composite fixed layer depending on the amount of primary and secondary air supplied, determine the temperature and depth of the pyrolysis reaction, determine the temperature distribution in the furnace and in the cracking zone of the resin, the effect of temperature on the depth of cracking of the resin, and the effect of the volume of secondary air on the thermal value of the obtained biogas.

Compared with other energy production technologies, the use of biomass energy has two technological routes: direct combustion and gasification, which can use biomass on a large scale [6]. Power plants with direct biomass burning, in which coal is replaced by agricultural and forest waste, significantly contribute to the use of biomass energy [7,8].

However, the efficiency of using direct biomass burning is low due to its low specific gravity, inconvenient collection, storage and transportation [9-11]. Moreover, biomass energy is the only material energy with carbon among all types of renewable energy, so it's a pity to use it directly as coal.

The technical route of gasification utilization can realize the co production of biomass gas, biomass carbon and wood vinegar according to the regional resource status. It can also realize the combined power supply of electricity, gas, cold and heat according to the regional energy demand. According to the investment scale, the technical route of gasification can further extend the development of biomass chemical industry, such as hydrogen production from biomass, methanol production from biomass and dimethyl ether production from biomass. With the development of biomass gas tar removal and purification technology, the tar problem in gasification utilization has been solved gradually. The utilization of gasification technology for the comprehensive utilization of agricultural and forestry wastes has attracted more and more attention of researchers. Ukraine and China has a wide corn planting area and rich corn straw resources. It is widely used to compress corn straw into pellet fuel by pelletizer to improve its bulk density and energy density. In this case, it is possible to widely use the compression of corn straw into granular fuel using a granulator in order to improve its bulk density and specific calorific value.

Corn straw pellet fuel

To create effective technological processes of energy conversion based on the use of pellet fuel, it is necessary to take into account its characteristics for the management of gasification processes based on pyrolysis. Element analysis, industrial analysis, heat value and ash fusibility test were carried out for corn straw pellet fuel according to relevant test standards. The analysis results are shown in Table 3. According to the results of element analysis of fuel, the theoretical air quantity is calculated, and different gasification equivalence ratio is selected to determine the sum of primary and secondary air volume. The results of industrial analysis can be used to determine the ratio of primary and secondary air volume. The heat value analysis can provide a basis for determining the raw material treatment capacity according to the volume load of the gasification unit. The ash fusibility of pellet fuel can be used to guide the determination of the upper temperature limit of the combustion zone in the test run, so as to avoid excessive fuel slagging.

Table 3 - Comprehensive analysis of the properties of corn straw fuel pellets

Elemental analysis (%)		Component composition (%)		Thermal dynamics (°C)		Low heat value (kJ/kg)
C	31,19	Volatile matter	54,68	Deformation temperature	1030	11680
H	4,24	Fixed carbon	13,31	Softening temperature	1050	
O	31,31	Moisture content	3,93	Hemisphere temperature	1080	
N	0,96	Ash content	28,07	Flow temperature	1100	
S	0,29	Volatile matter	0,01	Flow temperature	1100	

Introduction to the pilot plant of low tar gasification in composite fixed bed

The traditional biomass fixed bed gasification devices are mainly divided into two types: up draft and down draft [12,13]. The up draft gasifier has high gasification and thermal efficiency, but it has the disadvantages of high tar content of crude gas and. The quality of gas produced by the down draft gasifier is stable, and the amount of tar formed by the down draft gasifier is lower than that of the up draft gasifier. However, the down draft gasifier has the disadvantages of low gasification efficiency and thermal efficiency. In the process of biomass pyrolysis and gasification, tar components are formed in the stage of fuel pyrolysis and decomposed in the stage of high temperature oxidation [14,15]. The thermal decomposition of tar components is mainly related to temperature [16,17]. However, in the traditional fixed bed gasifier, no matter up draft or down draft, the reaction stages of pyrolysis, combustion and reduction are not clearly separated in the furnace space which makes the two forms of gasifier difficult to provide a stable high temperature environment for tar cracking in physical space. The composite fixed bed low tar gasifier involved in this study integrates the advantages of the up draft fixed bed and the down draft fixed bed. In the composite gasification unit, the internal pyrolysis tube is used to separate the space in the furnace, and the three stages of the gasification process, namely dry pyrolysis, combustion reduction and tar cracking, are relatively separated in the same unit.

The pilot plant of this study is shown in Figure 1. The inner diameter of the gasifier is 1,5 m, the height is 4m, and the raw material processing capacity is 0.4 t/h. The diameter of corn straw pellet fuel is 8 mm, its length is 20-50 mm, and its bulk density is about 650 kg/m^3.

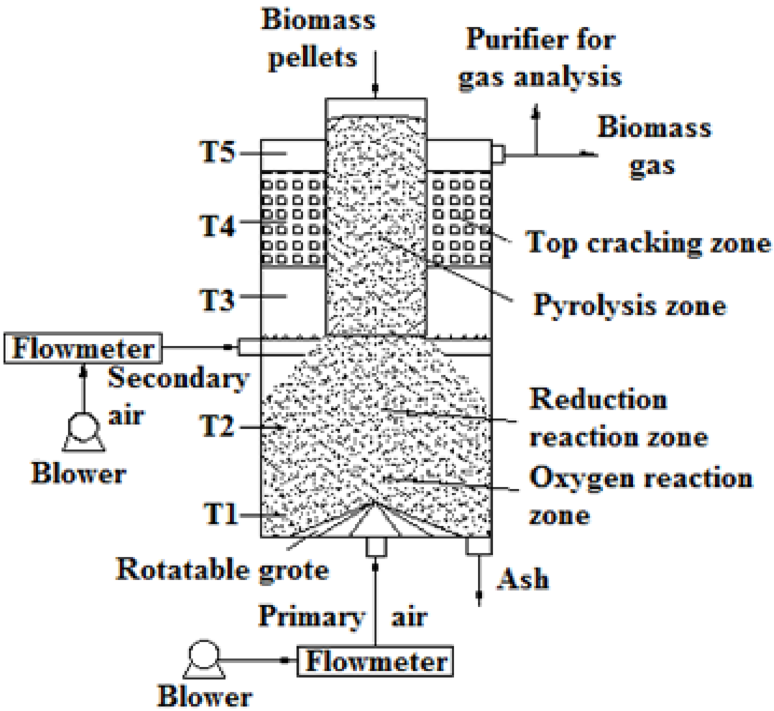


Fig. 1 - Scheme of experimental setup for studying biomass gasification processes in a composite stationary layer

The pellet fuel is uniformly and continuously fed into the gasifier from the top of the gasifier. Firstly, the fuel is indirectly heated by high temperature gas at about 1000 ºC in the pyrolysis zone to carry out pyrolysis reaction. The generated pyrolysis gas is led to the middle of the gasifier by the induced draft fan and burns with the secondary air. A small part of the pyrolysis gas is burned through the control of the secondary air volume. A slight decrease in the heat value of the pyrolysis gas causes the combustion temperature to remain around 1100 ºC. After partial combustion, the pyrolysis gas heated up the tar cracking area in the gasifier. The tar cracking area is built with heat storage bricks. The cracking zone absorbs the sensible heat of the pyrolysis gas and forms a high temperature field to crack the tar in the pyrolysis gas into small molecule non condensable gas, so as to remove the tar in the furnace. The fuel is pyrolyzed in a pyrolysis tube to produce semi coke. Under the action of gravity, semi coke forms a carbon layer about 1.8m high above the grate. The primary air at the bottom of the furnace is evenly distributed through the annular gap of the tower grate and then sent into the furnace. Under the action of primary air, the carbon in the upper part of the grate is completely burned, and the generated ash is discharged out of the grate continuously by the rotary grate and then cooled by the slag cooler. The generated flue gas will go up through the carbon layer to generate carbon monoxide, which will be discharged from the top of the gasifier together with the pyrolysis gas.

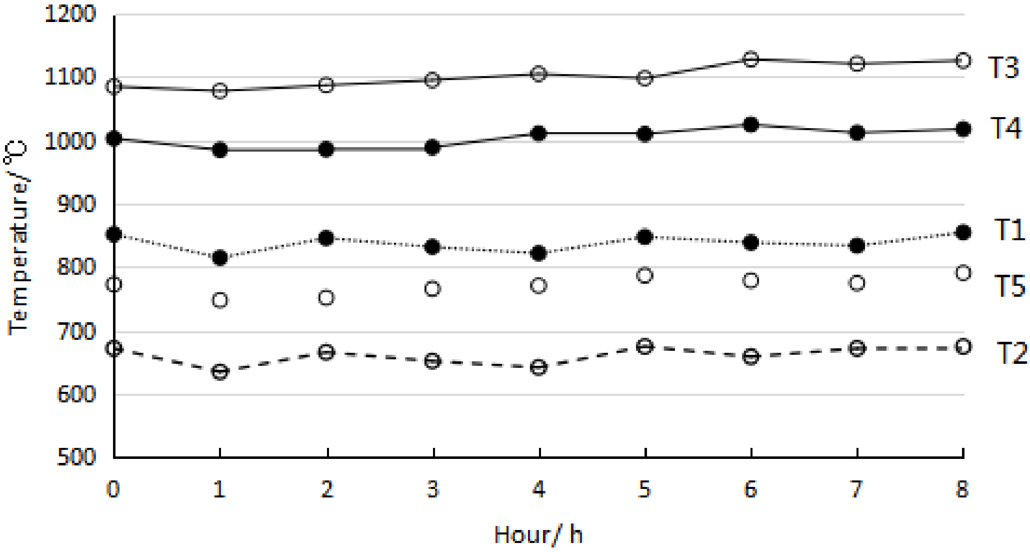
The speed of induced draft fan, primary fan and secondary fan can be adjusted by frequency conversion. The gasifier body is equipped with five temperature measuring points, and the temperature of five areas, including combustion area, reduction area, gas combustion area, tar cracking area and gas outlet area, is detected respectively from T1 to T5. The gas sampling port is connected by the infrared gas analyzer (Gasboard-3100p), and the gas composition is detected and recorded online.

Experimental results and their analysis

Through the experiment, the gasification characteristics of corn straw pellet fuel in the composite fixed bed gasifier were studied. By adjusting the parameters of primary air quantity, secondary air quantity and feed quantity, the temperature and reaction depth of each reaction zone are controlled. The temperature distribution in the furnace, the influence of secondary air volume on the temperature of tar cracking zone, the influence of temperature of tar cracking zone on tar cracking and the influence of secondary air volume on the heat value of gas were studied.

Temperature distribution in the furnace

During the operation of biomass gasification plant, the change of temperature in the furnace is a direct characterization of chemical reaction. With corn straw particles as fuel, the gasification unit has reached a stable operation state after a period of start-up. The temperature of each zone in the furnace is shown in Figure 2.



T_1-temperature of the oxidation zone; T_2 - temperature of the reduction zone; T_3 - temperature gas oxidation zone; T_4 - temperature of tar cracking zone; T_5- temperature of biomass gas outlet point

Fig. 2 - Temperature distribution in the furnace during the study period

When the temperature T_1 of the oxidation zone at the bottom of the installation (Fig.1) is between 810 ºC and 860 ºC, the biomass carbon is oxidized by the action of primary air. The reaction rate depends on the rate of chemical reaction of the interaction of oxygen and carbon on the surface of carbon particles. In other words, oxidation is largely controlled by dynamic factors. In the experiment, the temperature of the oxidation is controlled in a reasonable range by adjusting the primary air volume. On the one hand, overtemperature T_1 above 800 ºC can provide enough heat for reduction zone. On the other hand, it should be below 900 ºC to avoid slagging. The temperature of the reduction zone T_2 is between 640-690 ºC, which means that the temperature of the reduction reaction between C and CO_2 remains high after the completion of the reduction reaction, so as to ensure that the reduction reaction can be carried out normally. The temperature T_3 of gas oxidation zone is in the range of 1080-1130 ºC. The temperature of tar cracking zone T_4 ranges from 980 ºC to 1025 ºC. By controlling the air intake of the secondary air burner, a small part of the pyrolysis gas is burned to provide the heat needed to maintain the high temperature in the tar cracking area. The outlet temperature T_5 is between 750 ºC and 790 ºC. The temperature difference between T_5 and T_4 within 200 ºC indicates that the heat is continuously supplied to the new fuel entering the pyrolysis drum and the cracking heat of the tar components in the tar cracking zone.

Influence of secondary air volume on temperature of tar cracking zone

The volatile content of corn straw pellet fuel is 54,68 %. After the fuel is indirectly heated in the pyrolysis tube, the volatilization analysis goes into the gas combustion area. The pyrolysis gas can react with the secondary air quickly when the ambient temperature is higher 300 ºC. As shown in Fig. 3, under the condition of stable feed and ash output, the secondary air intake is adjusted to 130 Nm^3/h, 200 Nm^3/h and 270 Nm^3/h respectively by motor frequency conversion, and the temperature changes of tar cracking zone T_4 is investigated. With the increase of secondary air volume, the combustion share of pyrolysis gas transported from pyrolysis cylinder is increasing, and the temperature T_4 of tar cracking zone is increasing. This shows that the design of the secondary air burner is reasonable and the method of adjusting T_4 by adjusting the secondary air volume is feasible.

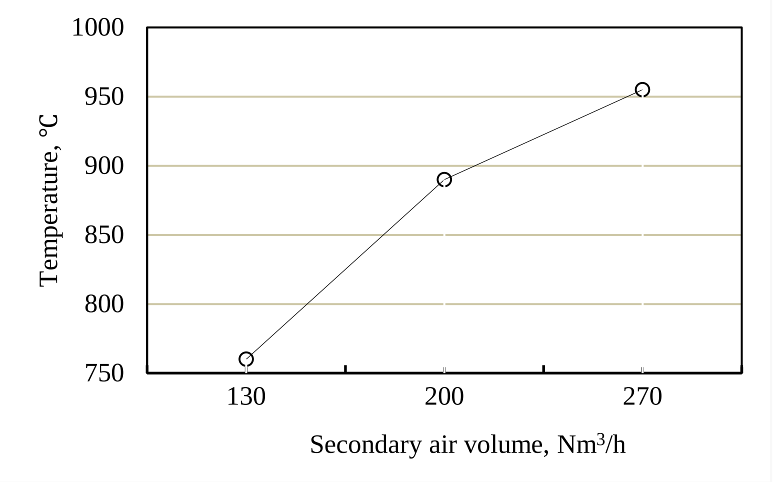


Fig. 3 - The influence of secondary air flow on temperature T_4 of tar cracking zone

Effect of temperature in tar cracking zone on tar cracking

As shown in Table 4, after high temperature cracking at 1060 °C, the hydrogen content in the biomass gas increased from 16,77 % to 20,82 %. Other components in the biomass gas such as CO, CH_4 and C_mH_n all decreased in varying degrees. In particular, the content of light hydrocarbon gas C_mH_n decreased from 4,03 % to 0,49 %.

Table 4 - Biogas composition data

Sample number	Temperature in tar cracking zone (°C)	H_2 volume percent (%)	CO volume percent (%)	CH_4 volume percent (%)	C_mH_n volume percent (%)	Tar content (mg/Nm^3)
1	750	16,77	19,26	5,17	4,03	1875,41
2	1060	20,82	18,03	2,24	0,49	19,56

This is because the tar group of larger molecules is split into light hydrocarbon components, and the light hydrocarbon is further split into CH_4 and H_2. The significant decrease of the proportion of light hydrocarbon gas indicates the almost complete cracking of tar components in the furnace. The tar content in the gas is detected by sampling. The test results are shown in Table 4. When the temperature of tar cracking zone is 750 °C, the tar content is 1875,41 mg/Nm^3. When the temperature of tar cracking zone increased to 1060 °C, the tar content decreased to 19,56 mg/Nm^3.

Influence of secondary air volume on heat value of gas

As shown in Figure 4, when the secondary air volume is 130 Nm^3/h the heat value of gas is as high as 7266 kJ/nm^3. As the volume of secondary air increases, more pyrolysis gases participate in the oxidation reaction and the flue gas mixes with the not yet oxidized combustible components so that the calorific value of the biomass exhaust gas decreases.

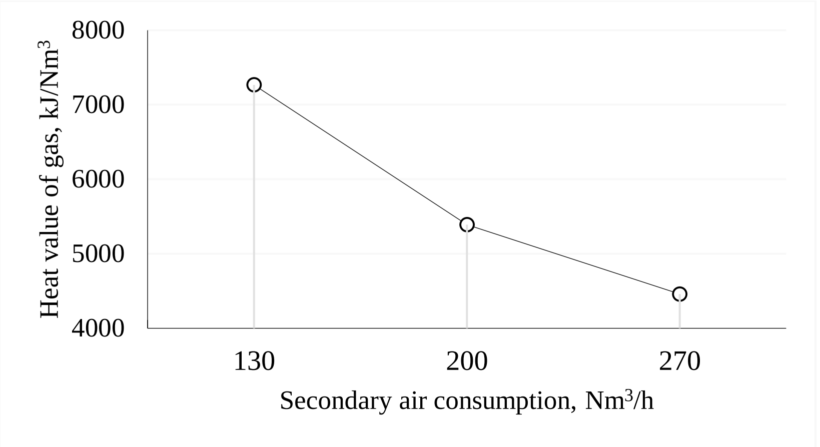


Fig. 4 - Influence of secondary air consumption on the heat value of biogas

When the secondary air volume increases to 270 Nm^3/h the heat value of gas decreases to 4460 kJ/Nm^3. The constancy of gas oxidation zone T_3 temperature about 1060 ºC and tar cracking zone T_4 temperature about 955 ºC provides a relatively stable high temperature environment for the cracking zone of tar components. It is feasible to use the energy of pyrolysis gas to create a high temperature field in the cracking zone of tar in order to remove the tar components in the gas.

Conclusions

1. The use of energy from burnt fossil fuels and nuclear fission in nuclear reactors for energy production at energy facilities has recently been limited for a number of reasons, one of which is a negative impact on the environment.
2. As an alternative source of energy, it is advisable to consider the use of biomass for these purposes.
3. The study of the gasification characteristics of fuel pellets from corn straw was carried out using an experimental gasification unit in a composite fixed bed and allowed to obtain positive results.
4. The results of the study provide useful information for the production of biogas for energy purposes by pyrolyzing biomass and producing biogas without burning tar.
5. A stable equilibrium of the chemical reaction in the installation was achieved in the pyrolysis zone, the reduction zone, the gas oxidation zone and the resin cracking zone by optimizing the temperature distribution in each of these zones.
6. The 1000 ºC high-temperature cracking zone of the resin can be adjusted in the furnace by adjusting the secondary air supply. This zone can separate almost all groups of resins in biogas.
7. Flexible adjustment of the secondary air supply for the gasification of pellets in a gas generator with a composite fixed bed allows optimizing the high-temperature medium for cracking the resin while maintaining the calorific value of biogas at 4700 kJ / nm3.
8. The ability to control the volume of secondary air supply allows you to accurately maintain the required temperature in the cracking zone of the resin with a decrease in its content in biogas.
9. The results obtained make it possible to achieve high gasification of corn pellet granules for biogas production with high ecological purity, which contributes to the increase in their use in energy production processes with the simultaneous utilization of agricultural waste.

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УДК 620.952

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ЕКСПЕРИМЕНТАЛЬНЕ ВИВЧЕННЯ ОСОБЛИВОСТЕЙ ВИРОБНИЦТВА БІОГАЗУ ПІРОЛІЗОМ КУКУРУДЗЯНИХ ПЕЛЕТ

Матеріал статті містить корисну інформацію для вивчення та аналізу виробничих процесів отримання біогазу з низьким вмістом смоли шляхом піролізу і газифікації гранул кукурудзяного соломи в композитному нерухомому шарі експериментальної установки. Результати показують хорошу пристосованість установки до цього палива, можливість забезпечення оптимального розподілу температури в кожній зоні. Контроль температури в зоні крекінгу смоли здійснюється шляхом подачі необхідного обсягу вторинного повітря, що дозволяє значно зменшити присутність смоли в отриманому біогазі при збереженні теплотворної здатності газу на рівні 4700 кДж / нм^3.

Ключові слова: *біомаса; пелети; піроліз; газифікація; крекінг смоли; біогаз, екологічна чистота.*

Надійшла 15.11.2019
Received 15.11.2019