ON THE POSSIBILITY OF USING POULTRY LITTER AS A BIOFUEL FOR ELECTRICITY PRODUCTION

Dr. Rafail Isemin, Dr. Oleg Milovanov, Natalia Muratova[1]
Dr. Aleksandr Mikhalev[2]
Prof. Dr. Victor Zaichenko[3]

[1]Tambov State Technical University Tambov, **Russia** e-mail: risemin@gmail.com

[2]Clean Energy Ltd. Tambov, **Russia** e-mail: penergy@list.ru

[3]Joint Institute for High Temperatures of Russian Academy of Sciences (JIHT) Moscow, **Russia**
e-mail: zaitch@oivtran.ru

ABSTRACT

Waste from poultry farms represents the greatest danger to people and the environment among all types of bio waste. Approximate estimates show that in Russia up to 15 million tons of manure and a mixture of litter with sawdust or straw are formed annually. The original litter is a toxic substance; the main bacteria in the litter are E. coli and Salmonella. The process of torrefaction of a mixture of manure and sawdust was studied. The torrefaction proceeds in a reactor consisting of three sections with horizontal trays on which the processed material is moved with help of a two-bladed stirrer from the loading point to the discharge point from one plate to the other. The reactor has a jacket heated with a high-temperature oil. The analysis of content of pathogenic microflora after torrefaction shows that only low-temperature pyrolysis at 250 °C and treatment time of 60 min. allows full disinfection of this type of waste. To increase the outlet of gaseous products of low-temperature pyrolysis and to reduce the tar content in gaseous products, we proposed to pass the gaseous products obtained through a bed of carbonaceous particles heated to 800-1000 ° C. As a result of laboratory studies, the following characteristics of synthesis gas were obtained: H_2 content - 49.0%, CO content - 46%, net calorific value - 11.34 MJ/Nm^3, synthesis gas outlet - 0.9 Nm^3 per 1 kg of raw material. The results of preliminary calculations of the complex for manure with litter processing into biofuel pellets with a nominal capacity of 2 t/h for the final product (pellets).

Keywords: biomass, cracking, syngas, torrefaction.

Waste from poultry farms represents the greatest danger to people and the environment among all types of bio waste. Approximate estimates show that in Russia up to 15 million tons of manure and a mixture of litter with sawdust or straw are formed annually. The original litter is a toxic substance; the main bacteria in the litter are E. coli and Salmonella.

The cheapest and most common method of disinfection is composting. Composting is an aerobic process of decomposition of organic matter by microorganisms [1]. Microorganisms under the influence of oxygen begin to process the organic substances, as a result of microbial activity the temperature begins to raise up to 50-70 ºC. At this temperature, most of the pathogenic microflora is destroyed [2], but greenhouse gases CO_2 and water vapor are released. The disadvantage of composting the litter is the need for large land areas, the complexity of running the process in the autumn-winter period, the risk of pollution of the environment and groundwater.

The solution of the problem of utilization of all types of poultry litter remains in its processing into biofuel under the following conditions: 1) full and guaranteed decontamination of the litter, 2) elimination of recontamination of the litter, 3) minimization of energy costs and time for decontamination of poultry litter. These conditions can be realized in the case of treatment of the original poultry litter in the process of low-temperature pyrolysis of manure.

The process of torrefaction of a mixture of manure and sawdust was studied. The torrefaction proceeds in a reactor consisting of three sections with horizontal trays on which the processed material is moved with help of a two-bladed stirrer from the loading point to the discharge point from one plate to the other. The reactor has a jacket heated with a high-temperature oil. The lower section of the rector, through the jacket and the plate, is cooled by water, which allows the product to be emitted from the reactor at a temperature that excludes its ignition in air. The duration of pyrolysis can be regulated. The valves, preventing the spontaneous ingress of biomass from one section to another, are installed between the sections of the reactor. The reactor works as follows. A high-temperature coolant with a temperature of 230-260 °C is fed into the reactor's jacket (two upper sections) and jacket of the two upper sections plate. Cooling water is supplied to the lower section of the reactor (reactor jacket and plate jacket). After the high-temperature coolant is fed into the reactor, the internal volume of the reactor is heated. After reaching the temperature inside the reactor above 220 °C, manure can be loaded into the upper section of the reactor in an amount of 20 to 160 kg. After loading, its temperature begins to rise due to contact with the hot walls of the reactor. In this case, moisture is released from the litter and volatile substances, which, rising through the layer of manure, support the rapid warming of the upper layers of the litter.

Table 1. Content of pathogenic microflora in mixture of manure with sawdust before and after torrefaction (a. Mixture of manure with sawdust)

Microorganism	**Initial material[a]**	**Material[a] after torrefaction**			
		Torrefaction parameters			
		155 °C, 30 min	***155 °C, 45 min***	***155 °C, 60 min***	***250 °C, 60 min***
Mucor (colonies)	1,0	0,84	0.5	0,3	0
Penicillium (colonies)	1,6	1,6	1,2	0	0
Aspergillus (colonies)	0,3	0,3	0,3	0,2	0
Cladosporium (colonies)	5,5	5,5	1,3	0,2	0
Fusarium	0,2	0,2	0	0	0

Microorganism	Initial material[a]	Material[a] after torrefaction			
		Torrefaction parameters			
		155 °C, 30 min	*155 °C, 45 min*	*155 °C, 60 min*	*250 °C, 60 min*
(colonies)					
Trichoderma (colonies)	1	1	0,67	0	0
Bacterial microbiota	0,5	0,5	0,17	0	0
Average number of colonies	0,56	1,14	0,56	0,49	0
GBC in 1g of sample	5,7x10^5	5,7x10^5	2,8x10^5	2,5x10^5	0

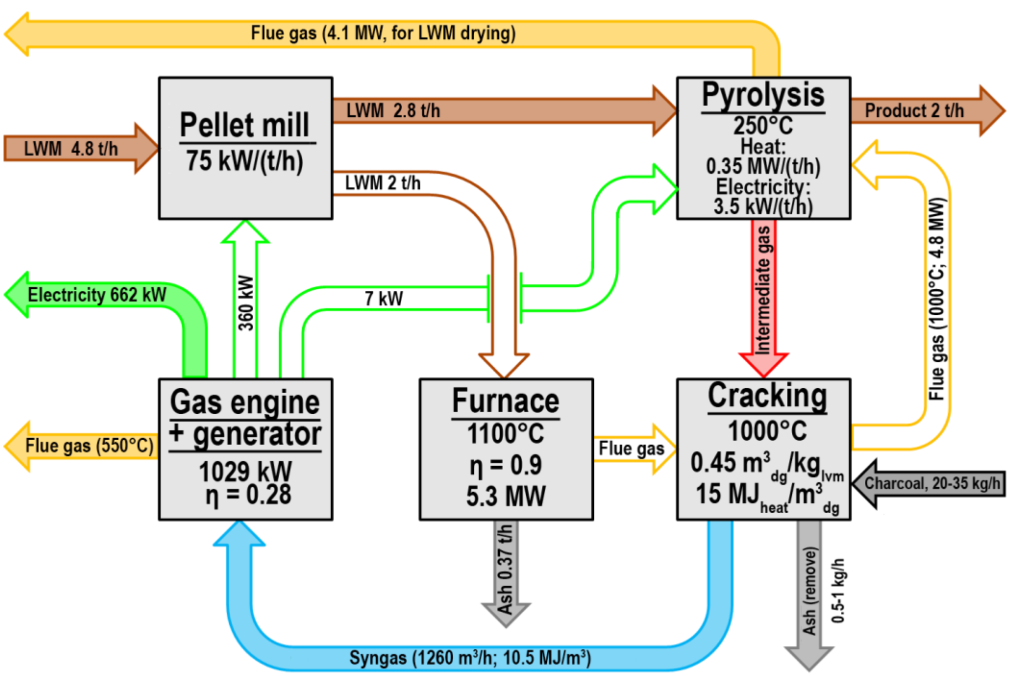

Figure 1. Scheme of mass and energy flows in electricity production from gaseous and liquid products of low-temperature pyrolysis of mixture of manure and litter. LWM – litter-wate mass, η – efficiency.

The analysis of data presented in Table 1 shows that only low-temperature pyrolysis of pellets from the litter waste mass at 250 °C and treatment time of 60 min. allows full disinfection of this type of waste.

In addition to the solid product, after a low-temperature pyrolysis some liquid (condensing) product and a gaseous (non-condensing) product are formed, the yield of which depends on the type of biomass, temperature and duration of heat treatment.

We propose liquid and gaseous products of low-temperature pyrolysis of manure to be processed into synthesis gas, suitable for combustion in gas piston engines of power generating plants. These requirements, in turn, will provide a set of equipment for the production of pellets.

However, the synthesis gas must be cleaned from high-molecular compounds (resins), the content of which should not exceed 50-100 mg/m^3.

The methods for suppressing the formation of resins and increasing the yield of gaseous products of gasification and pyrolysis (primary methods) and methods for purification of synthesis gas from resins are proposed (secondary methods) to solve the problems of pyrolysis gases purification [3, 4].

The process of pyrolysis and gasification in the fluidized bed of the catalyst, which is proposed to use the olivine sand, should be considered as the primary method [5, 6, 7, 8].

Secondary methods involve the treatment of synthesis gas at elevated temperatures (from 800 to 900 °C and above).

It is suggested, for example, to pass synthesis gas through a layer of activated carbon heated to 850-900 ° C [3].

Typical reactions of heterogeneous cracking of condensable and non-condensable volatiles to synthesis gas during interaction with hot activated carbon are given below:

$$CO_2 + C \rightarrow 2\ CO;$$
$$H_2O + C \rightarrow CO + H_2;$$
$$C_4H_4O_2 \rightarrow 2\ CO + 2\ H_2;$$
$$CH_2O_2 + C \rightarrow 2\ CO + H_2;$$
$$C_3H_6O_3 \rightarrow 3\ CO + 3\ H_2;$$
$$C_3H_6O \rightarrow CO + 3\ H_2 + 2\ C;$$
$$C_5H_4O_2 \rightarrow 2\ CO + 2\ H_2 + 3\ C.$$

Laboratory experiments were conducted on torrefaction of a mixture of bird droppings and sawdust, followed by thermal cracking of the resulted gaseous products.

The reactor for torrefaction is a stainless steel pipe of 142 mm in length and with an outer diameter of 60 mm with a wall thickness of 1.5 mm. Two tubes are welded to the wall of the reactor, through which the reactor is purged with argon and thermocouples are fed to measure the temperature of the processed raw material bed and reactor’s wall temperature.

The reactor for cracking is a stainless steel pipe of 337 mm in length with an outer diameter of 48 mm and with a wall thickness of 2 mm. A tube with a diameter of 6 mm is welded to the wall of the cracking reactor at a distance of 100 mm from the outside, into which a thermocouple is fed to measure the temperature inside the reactor.

During the experiments raw material (40 g) was placed inside the torrefaction reactor and heated to the required temperature at a rate of 4 °C /min. At the same time, the volumetric gas yield was measured, as well as its chemical composition with the help of the gas analyzer «Vario Plus Industrial Syngas».

For thermocracking of gaseous torrefaction products the charcoal was used, obtained from wood pellets with a diameter of 8 mm as a result of their pyrolysis at a temperature of 1000 °C. The reactor is loaded with 110 g of charcoal, which was heated to the required temperature at a rate of 10 ° C/min.

Element content and specific lower calorific value of bird droppings before and after torrefaction treatment are given in Table 2.

Table 2 – Element content and specific lower calorific value of bird droppings before and after torrefaction treatment

Indicator	Before treatment	After treatment by torrefaction
Element composition for the working mass (wt %):		
Carbon (C)	29,4	36,7
Hydrogen (H)	3,5	3,3
Nitrogen (N)	2,6	2,8
Sulfur (S)	0,6	0,7
Oxygen (O)	35,4	30,5
Humidity (H_2O)	10,0	0,0
Ash (A)	18,5	26,0
Lower heat of combustion, MJ/kg	9,5	12,6

After thermocracking the resulted synthesis gas had the following content: hydrogen content – 49,07 %, carbon monoxide content – 46,22 %, carbon dioxide content – 0,36 %, methane content – 0,67 %, nitrogen content – 1,23 %, other components – 2,45 %, net calorific value 10,5 MJ/Nm^3, specific yield of synthesis gas – 0,45 Nm^3/kg of initial material.

Analysis of the element content of condensed and non-condensable volatiles shows the possibility of their conversion to a synthesis gas consisting of hydrogen and carbon monoxide in practically equal proportions.

The degree of volatile heterogeneous decomposition depends on the temperature in the contact zone of volatile with carbon, and the period time of volatiles in the zone. It was shown that cracking at a temperature 1000°C, and typical reaction time of about 4 seconds is almost complete conversion of condensable volatiles in the synthesis gas. The reactivity of coal at such temperature is so high that practically the entire volume of CO_2 has been converted to CO. At a lower temperature an increase in the conversion factor can be achieved by increasing the thickness of the coal bed and increasing the period time of volatiles in this zone.

It should also be noted that due to thermal cracking, the yield of synthesis gas is increased by 4.5 times in comparison with the synthesis gas output in the classical (without thermocracking volatile) high-temperature pyrolysis.

The obtained experimental data made allowed estimating the possibility of using torrefaction and subsequent thermocracking of gaseous products for the production of synthesis gas and generation of electric energy for the needs of a complex for production of 2 ton/h granules from decontaminated manure in a mixture with wood sawdust.

As a result of the torrefaction (to a final temperature – 250°C) of a mixture of manure and sawdust (mass fraction of moisture in the feed – 10%) the weight loss makes up 29% of the original value. Thus, 2.8 t/h of untreated granulated litter is needed to ensure a nominal capacity of 2 t/h and 1260 m^3 / h of synthesis gas can be produced from 2.8 ton/h of litter mass entering the processing.

The process of high-temperature heterogeneous cracking proceeds with heat absorption (about 1.3 – 1.5 MJ per 1 m^3 of the formed synthesis gas). The operating temperature range of charcoal, at which heat is supplied to the reaction zone, is 850-1000 °C.

With regard to the heating of the reactor for high-temperature heterogeneous cracking through the wall by combustion products of granulated biomass, the energy consumption for the obtaining process of 1 m^3 of synthesis gas, in terms of the heat of combustion of the fuel, is approximately 15 MJ/kg and can vary over a wide range depending on the fuel combustion efficiency and the heat approach method from combustion products to the cracking zone. According to calculations, it will be necessary to burn 2.0 t/h of untreated granulated mnure to ensure the process of obtaining 1260 m^3/h of synthesis gas.

Energy content of combustion products at the outlet from the cracking zone with 950 - 1000 °C, will be about 4.8 MW. These combustion products can be used for the torrefaction process, as well as for drying the original waste and manure.

The specific heat consumption of the torrefaction process is 1.25 MJ per kg of final product (0.35 MW / (t / h)). At a nominal capacity of 2 t/h, the total thermal power required to provide the process is 0.7 MW, which can be provided with a margin due to the heat of the combustion products leaving the cracking reactor.

The amount of charcoal, necessary to ensure the process of high-temperature heterogeneous cracking, reaches 15-25 g per 1 m^3 of synthesis gas, which is equivalent to 20-35 kg/h at a nominal capacity of the complex.

Synthesis gas, formed during high-temperature heterogeneous cracking of pyrolysis products, has a lower calorific value of 10.5 MJ/m^3, the sum of volume fractions of hydrogen and carbon monoxide is 88 - 92%.

The average value of the conversion factor of the synthesis gas energy into electric power in the gas-piston electric aggregate, taken in the preliminary calculation, is 28%. With the burning of 1260 m^3/h of synthesis gas, the average generated electrical power is 1029 kW.

The main consumption of electric power for own needs consists of the power consumption of the pelletizing press (approximately 75 kW / (t/h)) and a torrefaction (3.5 kW / (t/h)). Thus, the total electric power consumption of the complex is 367 kW.

The total value of the generated electric power, taking into account the consumption for own needs at the rated capacity of the complex, will be 662 kW (331 kW / (t/h) of the final product).

The results of preliminary calculations of the complex for manure with litter processing into biofuel pellets with a nominal capacity of 2 t/h for the final product, exposed to disinfection by low-temperature pyrolysis, are reflected in the mass and energy flow diagram, shown in Fig. 1.

CONCLUSION

The process of torrefaction of a mixture of manure and sawdust was studied. The analysis of content of pathogenic microflora after torrefaction shows that only low-temperature pyrolysis at 250 °C and treatment time of 60 min. allows full disinfection of this type of waste. To increase the outlet of gaseous products of low-temperature pyrolysis and to reduce the tar content in gaseous products, we proposed to pass the gaseous products obtained through a bed of carbonaceous particles heated to 800-1000 ° C. After thermocracking the resulted synthesis gas had the following content: hydrogen content – 49,07 %, carbon monoxide content – 46,22 %, carbon dioxide content – 0,36 %, methane content – 0,67 %, nitrogen content – 1,23 %, other components – 2,45 %, net calorific value 10,5 MJ/Nm^3, specific yield of synthesis gas – 0,45 Nm^3/kg of initial material. Taking the average conversion efficiency of 0.28 for power generating units based on a gas piston engine and taking into account that at low temperature pyrolysis of the mixture of manure with litter at 250 ° C the loss of the mass of the raw material is 29%, we find that for the production of 2 t/h fuel pellets will require 2.8 t/h of raw material, but at the same time an amount of electricity, sufficient to provide the entire pelletizing process, can be obtained.

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