Thermotechnical Characteristics of Granulated Fuel Made of Chicken Litter: Researching and Ways of its Upgrading

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***Abstract*— Experimental data on the effect of heat treatment (torrefaction) on thermotechnical properties of chicken litter pellets are presented. Initial raw material was heated in a nitrogen atmosphere with the rate of 10°C/min up to the torrefaction temperature T_t and then was held at this temperature during some time. Process of heat treatment lasted 60 minutes. Experiments were carried out at three temperatures T_t = 230, 250 и 270°C. To investigate the properties of the initial and torrefied materials the thermogravimetric analysis and differential scanning calorimetry were used. As a result, the data on the influence of torrefaction on devolatilization, ash content and combustion value of the granulated chicken litter were obtained. In addition hygroscopic properties of initial and torrefied material was measured. Listed thermotechnical characteristics were compared with similar characteristics of granular fuel made of wood. As a result of executed investigations it was shown that the torrefied granulated chicken litter can be used as a solid fuel for autonomous heating systems.**

Keywords - biomass; solid fuel; torrefaction; pyrolysis

I. INTRODUCTION

Agricultural waste, both vegetable and animal origin, are renewable hydrocarbon resources and relate to one of the most promising and environmentally friendly substitute of fossil fuel. Usage of agricultural waste for energy purposes would solve not only the problem of their utilization, but also significantly increases the power availability of agricultural industry by domestic resources. In addition, utilization of agricultural waste will contribute to solving a number of environmental problems associated with agricultural production. Last circumstance is primarily concerned with waste of livestock and poultry breeding.

Average chicken farm produces up to 300 tons of litter (consisted of manure and wood sawdust) per day. Simple storage of chicken litter leads to pollution of ground, water and air. The composition of the chicken manure is as following: water - 50-70%, organic matter - about 25%, nitrogen – 0.7-1.9%, phosphoric acid - 1.5-2.0%, potassium oxide - 0.8-1.0%, lime - 2.4%, magnesium - 0.8%, sulfur - 0.5%. Chicken manure contains valuable microelements such as copper, manganese, zinc, cobalt, boron, as well as active ingredients. Fresh chicken manure, usually, contains hazardous pathogenic bacteria, as well as in large amounts contains nitrogen, phosphorus, and sulfur. Content of nitrogen and phosphorus in chicken manure is 4-5 times more than in cattle manure [1]. The upper layer of the ground, on which litter is stored, contains about 4950 kg/ha of mineral nitrogen (including 2500 kg/ha of the nitrate), which is in 17 times higher in comparison with uncontaminated soil.

There are two ways of chicken litter utilization: to use it as fertilizer and as raw stock for fuel production.

Biogas and bio-fertilizer are two products of technology of the chicken litter processing, based on anaerobic fermentation. Such kind of technologies are widespread. If satisfied all specific process parameters such as optimal fermentation temperature, continuous mixing of raw materials, and well-timed loading and unloading of the raw material in reactor it is possible to produce up to 6 m^3 biogas from 1 m^3 of reactor. Biogas, produced a result of action of bacteria, consists of methane (60-70%), carbon dioxide (30-40%), hydrogen sulfide (0-3%) and hydrogen impurities, nitrogen oxides and ammonia. Calorific value of biogas reaches 25 MJ per cubic meter that is equivalent to combustion of 0.6 liters of gasoline, 0.85 liters of spirit, 1.7 kg of wood or use 1.4 kWh of electricity.

Besides energy generation, the bioconversion process allows to solve another problem. Fermented chicken litter, when used in agriculture as fertilizer, helps increasing crop yield a 10-15% compared with the unfermented chicken litter. This is explained by the fact that during the anaerobic treatment, the mineralization and nitrogen fixation occur [1].

Chicken litter can also be used as a solid fuel. Production of solid fuel from chicken litter requires preliminary pelletization. Chicken litter pellets can be used as an intermediate product for further processing, or directly as a solid fuel. In the first case gasification of chicken litter pellets can be proposed for the production of gaseous fuel. This technology allows to convert chicken litter pellets into gaseous fuel with combustion value about 5000 kJ/m^3 [2]. Composition of gaseous fuel, received by this technology is shown in Table I.

TABLE I. COMPOSITION OF GASEOUS FUEL, PRODUCED FROM CHICKEN LITTER PELLETS

Gas component	Volume content, %
CO	15-22
H_2	16-22
CH_4	1.0-2.5
CO_2	11-15
N_2	45-48

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The main drawback of this technology is the high content of nitrogen and carbon dioxide in the produced gas mixture that lead to decrease of it combustion value.

As a solid fuel chicken litter pellets can be used for burning in the pellet boilers. It is also possible to use them for co-firing with straw, wood chips or coal. The main disadvantage of chicken litter pellets is its low heating value. So we encounter the need to raise the combustion heat of chicken litter pellets. One way of solving this problem is thermal treatment of pellets in neutral gas environment. This process is well known as a torrefaction and is widely used for processing different types of vegetable biomass into solid fuel [3][4]. In course of torrefaction not only the moisture removal from an initial raw material, i.e., its drying, occurs but also partial thermal decomposition of an organic constituent of biomass takes place. As a result a solid hydrophobic product is formed. In addition its specific combustion value surpasses a similar value for initial raw material [4].

The present paper is devoted to investigation of influence of the torrefaction conditions on such properties of chicken litter pellets as devolatilization, specific combustion value and hygroscopicity.

II. EXPERIMENTAL CONDITIONS

Thermal processing (torrefaction) of pellets consisted in their heating in the inert gas environment (nitrogen) to the torrefaction temperature T_t = 230, 250 and 270^{o}C at the rate of 10^{o}C/min and holding at this temperature during some time. Total time of the process of heat treatment was equal to 60 min. In Fig.1, one can see the temperature profile during torrefaction.

When heating the mass change of pellets takes place as a result of devolatilization. For measurements of the quantitative characteristics associated with mass loss of raw materials during heating the thermogravimetric (TGA) analysis was carried out. For this purpose, the thermogravimetric analyzer SDT Q600 was used. The SDT Q600 was capable also to perform the differential scanning calorimetry (DSC) and it was used during investigations of the influence of torrefaction on the combustion value of granulated biomass fuel.

As raw materials there were used chicken litter pellets. Moisture content of the pellets was equal to 4.6%, ash content in terms of the dry basis – 13.7%, the yield of volatile matter in terms of the dry basis – 73.5%. Results of ultimate analysis in terms of the dry ash free basis were as follows: carbon – 48%, hydrogen – 6.4%, nitrogen – 5.9%.

III. RESULTS AND DISCUSSION

A. *Heating in neutral gas environment (nitrogen)*

As mentioned above, in the process of torrefaction the release of volatile matter, caused by thermal decomposition of the organic constituents of raw material, takes place. In Fig. 1, the TG curves describing mass losses of samples during torrefaction at different torrefaction temperatures are presented. Ibid the TG curve describing the mass loss when heated up to 800°C is shown. After the sample temperature reaches the value of T_t the rate of mass losses decreases because of reduction of sample mass. As it appears from Fig. 1, mass losses account for 27, 34 and 37 % at torrefaction temperature 230, 250 and 270^{o}C, correspondingly. From a comparison of curves, shown in Fig. 1, follows that these losses are noticeably less than total content of volatile matter in the initial sample.

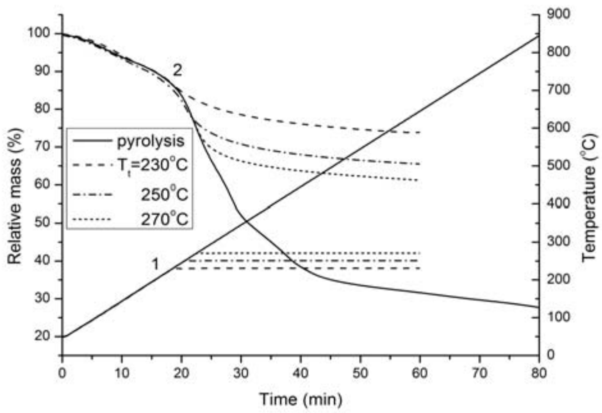

Figure 1. Change of temperature (1) and ralative mass (2) of chicken litter pellets during pyrolysis and torrefaction at different temperatures T_t.

Since wood sawdust is a part of chicken litter it is natural to compare the yield of volatile matter from them and from chicken litter pellets. As mentioned above, content of volatile matter in the chicken litter pellets is 73.5% (in terms of the dry basis). A similar parameter for sawdust is 82%. Fig. 2 presents data on the rate of mass loss as function of temperature (so-called DTG curves) for wood sawdust and chicken litter pellets.

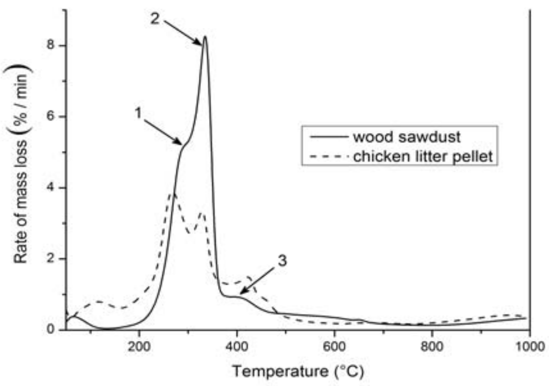

Figure 2. Rate of mass loss of wood sawdust and chicken litter pellets during heating in nitrogen at the rate of 10^{o}C/min.

The DTG curve, corresponding to wood sawdust, has three representative knees (are marked by arrows) associated with thermal decomposition of hemicellulose (1), cellulose (2) and lignin (3). On the DTG curve, corresponding to the chicken litter pellets, the beginning of devolatilization is shifted to lower temperatures. The representative knees, associated with thermal decomposition of hemicellulose, cellulose and lignin, are persisted, although their amplitudes are varied considerably.

Noticeable qualitative and quantitative differences are observed for the DSC curves that describe the heat flow required to maintain a given heating rate of wood sawdust and chicken litter pellets (see Fig. 3). The first endothermic effect for chicken litter pellets is observed in the temperature range 120-270^{O}C. For sawdust the maximum of the first endothermic effect, associated with the decomposition of cellulose (see Fig. 2), falls on temperature of about 360^{O}C. In the temperature range 390-480^{O}C exothermic effect, caused by decomposition of lignin, results in change of sign of heat flow in the case of sawdust. At temperatures above 650^{O}C, DSC curves for wood sawdust and chicken litter pellets coincide practically.

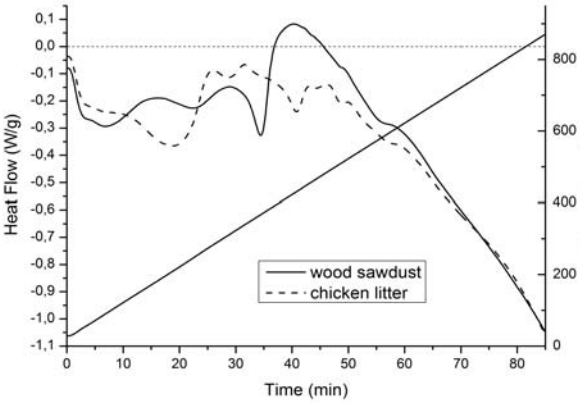

Figure 3. DSC curve of wood sawdust and chicken litter pellets in nitrogen at the heating rate of 10^{O}C/min.

B. Heating in oxidizing gas environment (air)

DTG curves, measured in oxidizing gas environment and in particular in air, differ considerably from similar curves, measured in a neutral gas environment. This difference is primarily due to the fact that heterogeneous oxidation reactions go in air. In Fig. 4, DTG curves measured in air for initial and torrefied chicken litter pellets are shown.

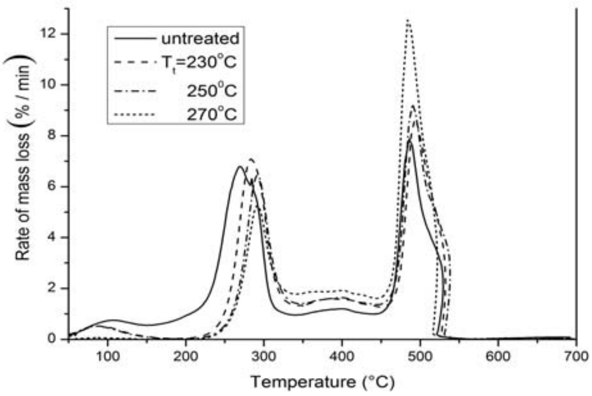

Figure 4. Rate of mass loss of untreated and torrefied chicken litter pellets during heating in air at the rate of 10^{O}C/min.

On the DTG curve measured in nitrogen, the basic mass loss is observed only in the temperature range 200-450^{O}C and is connected with devolatilization (see Fig. 2). On the DTG curve, measured in air, in the temperature range 450-530^{O}C there is observed the second peak of mass loss that is associated with the oxidation of char residue. Shift of first maximum towards higher temperatures for the DTG curves corresponding to the samples, processed at higher torrefaction temperatures (see Fig. 4), is explained by decreasing content of least thermostable organic component, namely hemicellulose, in their composition.

DTG curves, shown in Fig. 4, correlate well with the DSC curves describing the heat generation caused by oxidation reactions proceeding during heating pellets in the air (see Fig. 5).

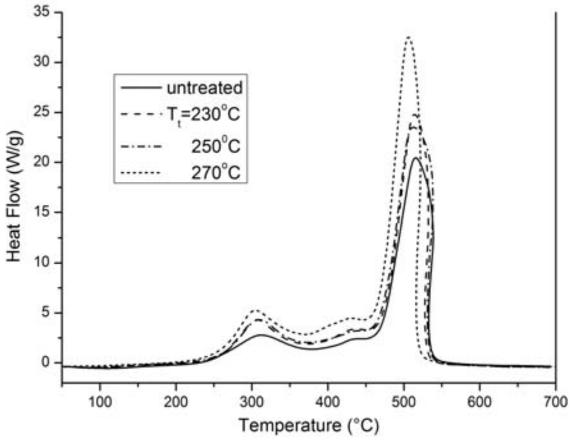

Figure 5. DSC curve of untreated and torrefied chicken litter pellets in air at the heating rate of 10^{O}C/min.

The first maximum in the DTG curves shown in Fig. 5 is associated with the oxidation of the volatile matter, the second – with oxidation of the char residue. As seen from Fig. 5, an increase of torrefaction temperature leads to an increase in the amplitude of both peaks. This behavior is explained by the fact that with increasing T_t the combustion value of volatile matter (the first peak) and the relative fraction of the char residue (the second peak) are increasing also. As a result the combustion value of torrefied pellets exceeds the combustion value of initial pellets and increases with increasing the torrefaction temperature.

C. Thermotechnical characteristics of torrefied chicken litter pellets

Table II presents the main characteristics of the initial chicken litter pellets and the pellets torrefied at different temperatures, which are important if we discuss the usage them as a solid fuel. From the presented data it follows that an increase of torrefaction temperature results in appreciable increase of specific combustion value. Unfortunately, at the same time the ash content, that in chicken litter pellets is several times greater than in peat and especially in wood pellets, increases also. Decrease of the volatile content in torrefied pellets (see Table II) leads to decrease of soot

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content in combustion products and decrease of smoke emission.

TABLE II. THERMOTECHNICAL CHARACTERISTICS OF UNTREATED AND TORRIFIED CHICKEN LITTER PELLETS

Characteristics	Untreated pellet	Pellet torrefied at		
		230˚C	*250˚C*	*270˚C*
Relative combustion value	1	1.32	1.41	1.65
Ash content (dry basis), %	13.7	16.6	18.6	20.8
Content of volatile matter (dry basis), %	73.5	63	58.7	56.6

Other important characteristic of any solid fuel is its hydrophobic properties. To determine the effect of torrefaction on these properties the corresponding measurements were carried out. During measurement a test sample was placed into a desiccator, in which 100% humidity at a temperature of 26^{o}C is maintained. Periodically measurements of mass of test sample were carried out. Results of experiments are presented in Fig. 6.

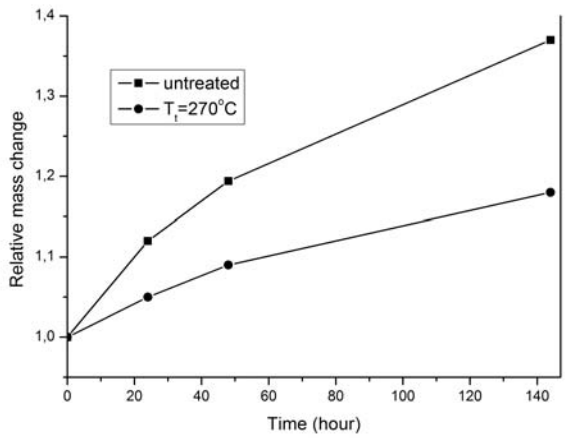

Figure 6. Relative mass change of initial and torrefied (at temperature 270^{o}C) pellets as a result of water vapour uptake.

The presented data show that the initial sample absorbs water vapor from the air considerably faster than the sample torrefied at temperature of 270^{o}C. It is necessary to note that untreated chicken litter pellets swelled and fell apart after 140 hours presence in a desiccator with the abovementioned conditions. At the same time, pellets torrefied at temperature of 270^{o}C, conserved their shape and hardness. Such a behavior simplifies storage and transportation of torrefied pellets.

From these data one can see that the torrefaction allows to improve essentially the hydrophobic property of granulated biomass fuel. The limit moisture content of pellets torrefied at T_t = 270^{o}C is practically half in comparison with untreated pellets. It is necessary to note, that untreated wood pellets swelled and fell apart when in contact with water. The torrefied wood pellets kept the form in the similar conditions.

IV. CONCLUSION

Experimental investigations of influence of thermal treatment (torrefaction) on the properties of chicken litter pellets were fulfilled. Measurements were carried out by methods of the thermogravimetric analysis and the differential scanning calorimetry in neutral and oxidizing gas environment (nitrogen and air, respectively). As a result of performed experimental investigations it is shown that thermal processing of chicken litter pellets allows to improve its consumer properties, namely, to increase the specific combustion value and to improve hydrophobic properties. Thus torrefied chicken litter pellets can be recommended for using as a solid fuel.

V. REFERENCES

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