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Use of Two-stage Pyrolysis for Bio-waste Recycling

Vladimir F. Kosov, Vladimir A. Lavrenov, Olga M. Larina*, Viktor M. Zaichenko

Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS)
Address: Izhorskaya str. 13, 125412 Moscow, Russian Federation
umnova.olya@gmail.com

Currently a problem of human and animal bio-waste recycling is one of the immediate. This interest is explained by an environmental damage that bio-waste get to environment and by absence of areas for its disposal. The method of problem solution of sewage sludge and chicken litter utilization is considered. The method of two-stage pyrolysis is presented. It allows to get a gas fuel from there with calorific value more than 10 MJ/m^3.

Introduction

According to the World Health Organization (WHO), manure, chicken litter and sewage can be over one hundred factors of infectious agent transmission. Organic waste can be a favorable environment for the development and long-term survival of pathogenic organisms, can contain elevated levels of heavy metals, pesticides, pharmacological agents, radioactive materials, weed seeds and other impurities.

Around the cities of Russia, as well as near certain facilities a huge amount of untreated sewage sludge has accumulated. Only in the capital cities and megalopolises the sludge (initial relative moisture is 96-98%) is dried and burned in special energy-intensive and environmentally unsafe drying machine, and then it is storaged on landfill. This disposal of sewage sludge is carried out in the countries of Eastern and Western Europe, the advanced countries of Asia and America, and in some other countries. These processes may be preceded by conditioning, stabilization and other technological methods.

Russia is oversaturated with environmentally harmful sewage sludge (in conjunction with municipal solid waste this is really national tragedy for the country). Sewage sludge from some wastewater treatment facilities is collected and dumped in the landfill of municipal solid waste, which obviously does not solve problems.

Ecological situation is degraded when sewage sludge is stored in wastewater treatment facility territory. Dangerous liquid penetrates into underground waters and then in the rivers. Some organizations take sewage sludge (after dehydration) for using as organic or organic-mineral fertilizers in the cultivation of industrial, feed and vegetable crops.

However, the effect of such fertilizer is insignificant and often negative for the following reasons:

Sewage sludge with high content of unprocessed organic are gel state for a long time and unusable.

Sewage sludge is processed very limited or isn't treated in the most water treatment facilities, so that they contain 40-60% (sometimes up to 80%) unprocessed organics that is absorbed poorly by plant roots, and sometimes contains toxic ingredients.

Pathogenic microflora (especially eggs and larvae of helminth that are capable of reproduction under certain conditions) is contained in sewage sludge, which pollutes soil and food at using of such a fertilizer for cultivation of vegetables.

Technologies of sewage sludge treatment in many water treatment facilities in most countries are based on well-developed and reliable methods of anaerobic methane fermentation. The traditional methods are very energy intensive; their production cycle is longer (up to 20 days). Toxic gases are extracted in the atmosphere at methane fermentation. The technology does not provide high quality processing of sludge and therefore organics.

Chicken litter is a mixture of chicken manure with sawdust or straw. Its initial relative moisture is 70-75%. Chicken litter is a favorable environment for the development and long-term survival of pathogenic microflora, contains increased amounts of heavy metals, pesticides, weed seeds and other impurities. Often this toxic and

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biologically active material is stored in landfills for a long time. At air storage of chicken litter harmful substances penetrate the ground water and the smell spread over a large area.
The problems of sewage sludge and chicken litter treatment are very similar. At present time, there is not effective technology of bio-waste recycling. At this paper thermal convention method of bio-waste into gas fuel is studied.

1. Experimental setup

The experimental setup (Figure 1) consisted of a high-temperature two-chamber reactor and a system of extraction and analysis of gas and vapor forming as a result of heating an initial raw material. The reactor was a stainless steel tube which was placed within a two section furnace with independent heating for each section. Biomass sample was placed into the chamber 1 and was heated up from 20 to 1,000 °C. The rate of heating was 10 °C/min. Dried sewage sludge and chicken litter pellets were used as initial raw material. Characteristics of raw materials are shown in Table 1. The moisture and ash content were measured by method of thermogravimetric analysis (TGA) with SDT Q600 thermal analyzer. The higher calorific values were measured with the help of a combustion calorimeter. Chamber 2 was used for char filter. The reactor was purged by argon before experiments.

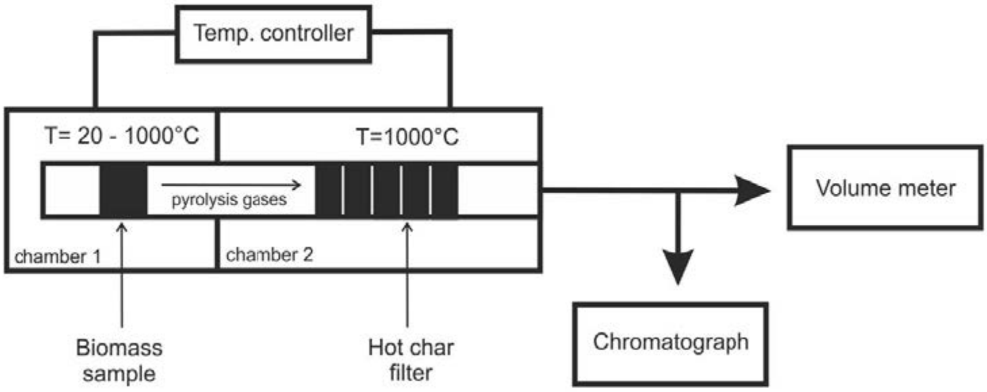

Figure 1: Experimental setup (Kosov et al., 2015).

Conventional pyrolysis was explored when chamber 2 was empty. The chamber 2 was heated up to 300 °C and this temperature was kept constant throughout the experiment. The obtained pyrolysis gases and vapors were caught in condenser where pyrolysis tar was condensed. The noncondensing pyrolysis gases came into the eudiometer. The samples of the noncondensing gases were chromatographed.
To study two-stage pyrolysis char obtained by pyrolysis of softwood pellets was placed in the chamber 2 and was used as hot char filter (it is heated up to 1,000 °C). The mass of char was equal the mass of initial raw material. Gases formed during pyrolysis of feedstock passed through the porous carbon bed in the chamber 2. As a result of homogeneous and heterogeneous chemical reactions in the high-temperature zone (chamber 2), the pyrolysis gases decomposed into synthesis gas. The volume of obtained gases was measured with eudiometer. The samples of obtained gases were chromatographed.

Table 1: Characteristics of initial raw materials

Kind of biomass	Relative moisture, %	Ash content, %	Higher Calorific value (daf), MJ/kg
Sewage sludge	2.7	22.7	25.0
Chicken litter pellets	16	13.8	20.4

2. Results and Discussion

The experimental data on the volume of the gas mixtures (per 1 kg of initial raw material) formed during conventional and two-stage pyrolysis of chicken litter and sewage sludge are shown in Figure 2.

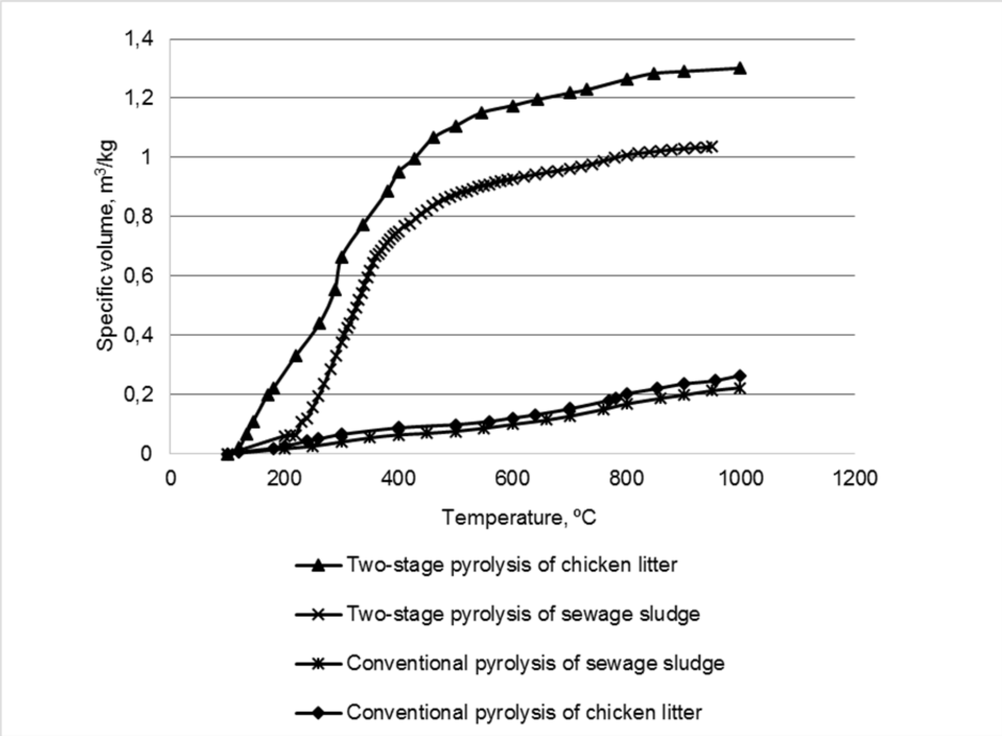

Figure 2: Volume of noncondensing pyrolysis gases per 1 kg of raw material.

From Figure 2 it is seen that the specific volume of produced synthesis gas was several times consequently higher than volume of noncondensing gases from conventional pyrolysis. In contrast to the conventional pyrolysis at two-stage pyrolysis the main gas generation occurs in the temperature range of 100-600 ºC. The produced gas volume was changed slightly in the range of 800 to 1,000 ºC. In this regard, to reduce energy costs it is expedient to heat up the raw material to 800 ºC.
The data on the composition change of gas mixture at the outlet of the reactor during the conventional and two-stage pyrolysis of sewage sludge are presented in Figure 3.

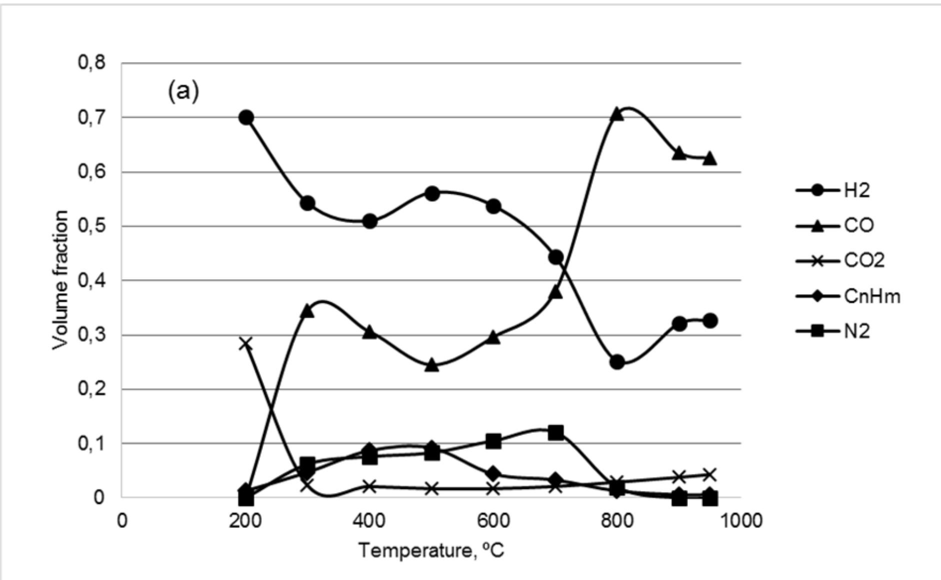

Figure 3: The composition of noncondensing gas mixtures obtained during the two-stage (a) and conventional (b) pyrolysis of sewage sludge.

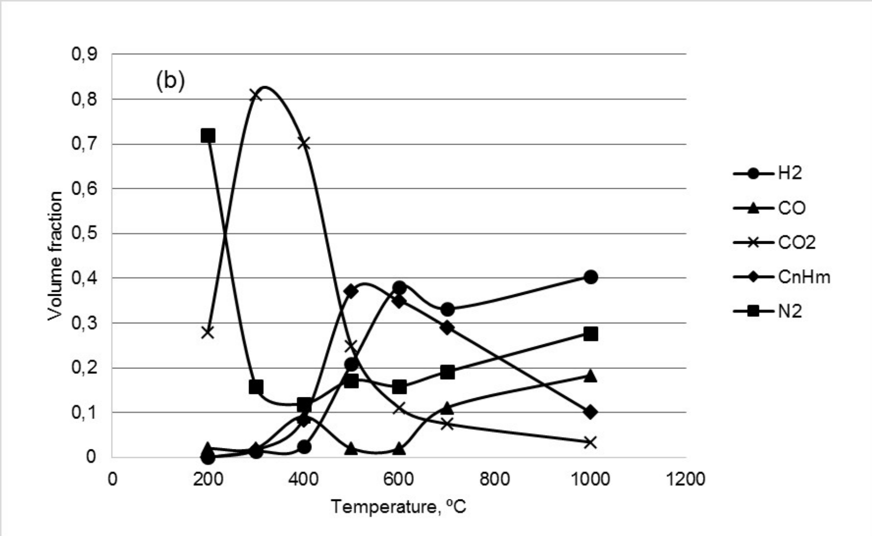

Figure 3: The composition of noncondensing gas mixtures obtained during the two-stage (a) and conventional (b) pyrolysis of sewage sludge.

From the data on Figure 3a, it is seen that the main components of the gas mixture at two-stage pyrolysis are CO and H_2. The composition of gas mixture is almost independent from the temperature of raw material heating. Carbon dioxide is contained in small amounts. A mixture with this composition is suitable for use in energy purposes. The gas mixture, formed during the pyrolysis of sewage sludge, has a non-uniform composition (Figure 3b) in comparison with the composition of the synthesis gas. The carbon dioxide and nitrogen are present abundantly, what complicates the use of pyrolysis gas.

The similar situation is observed during the conventional and two-stage pyrolysis of chicken litter (Figure 4). Sewage sludge and chicken litter are very similar in its properties, what explains the similarity of the behavior of these substances in the pyrolytic processing.

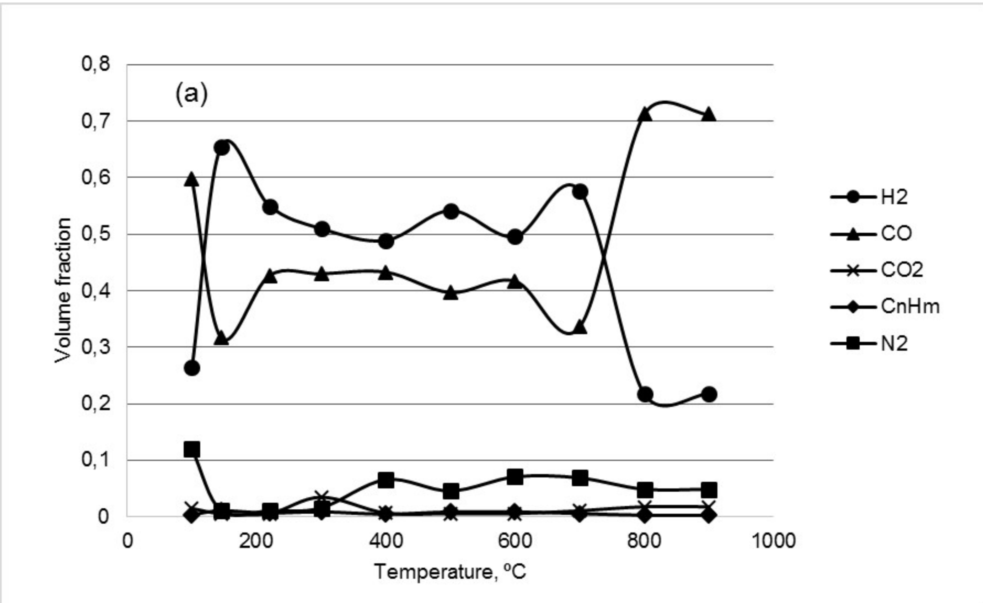

Figure 4: The composition of noncondensing gas mixtures obtained during the two-stage (a) and conventional (b) pyrolysis of chicken litter.

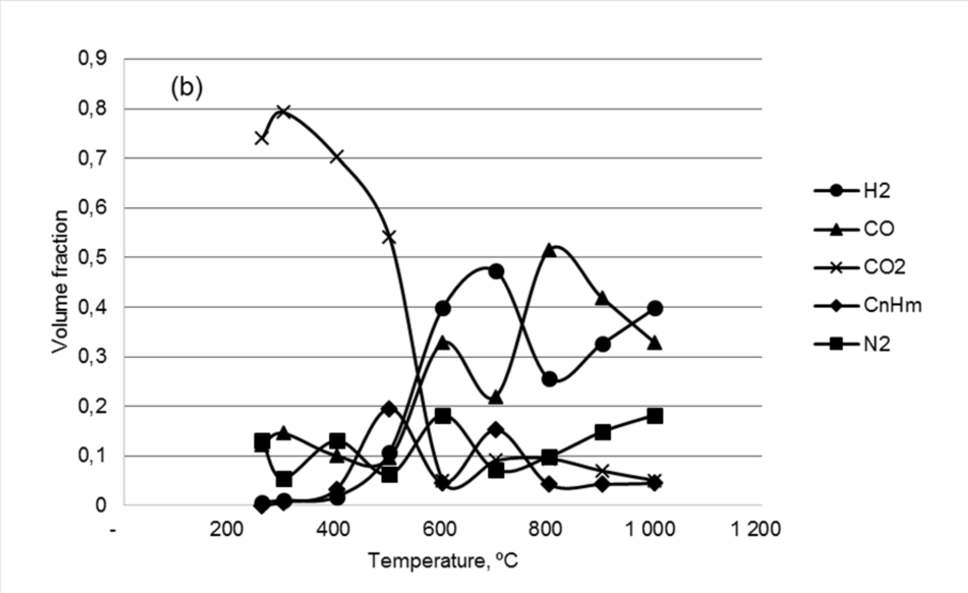

Figure 4: The composition of noncondensing gas mixtures obtained during the two-stage (a) and conventional (b) pyrolysis of chicken litter.

The characteristics of noncondensing gases that were obtained by conventional and two-stage pyrolysis of sewage sludge and chicken litter are presented in Table 2.

Table 2: Characteristics of noncondensing gas mixtures

Kind of biomass	Volume, m^3/kg	Volume fraction of combustible components, %			Calorific value MJ/m^3	
		H_2	CO	C_nH_m	Q_H	Q_L
Sewage sludge:						
- conventional pyrolysis	0.22	24.5	8.2	22.8	11.5	10.3
- two-stage pyrolysis	1.04	52.6	27.4	5.0	12.2	10.9
Chicken litter pellets:						
- conventional pyrolysis	0.27	22.5	27.4	5.6	8.5	7.9
- two-stage pyrolysis	1.30	51.0	42.6	0.8	12.1	11.1

From data on Table 2 it is seen that specific calorific value of the gas mixtures obtained by the conventional and two-stage pyrolysis is not much different. The complexity of the pyrolysis gas application lies in the considerably smaller volume and its non-uniform composition. A significant feature of the synthesis gas produced from the sewage sludge, is the ratio of CO:H2. It is close to the ratio of 1:2. It is unusual in comparison with the composition of the syngas obtained by the same method from wood and peat (Kosov et. al, 2009).

The investigations of pyrolysis and two-stage pyrolysis of sewage sludge and chicken litter were carried out on basis of biomass conversion technology (wood) to a gaseous fuel with a calorific value 10-12 MJ/m^3 (Batenin et. al, 2012; Batenin et. al, 2010). The large-scale setup of the thermal conversion of biomass into a gaseous fuel has been designed and constructed for the implementation of the proposed technology (Figure 5). The output of this setup was 50 kg/h of raw material. The initial raw material was wood. Electric power was generated in gas engine that can work with synthesis gas. The electric power of this setup was 50 kW.

Figure 5: The setup of two-stage pyrolytic conversion technology of biomass into a gaseous fuel (electric power is 50 kW).

3. Conclusions

The performed studies showed that in a combined process of thermal treatment of various bio-waste types (sewage sludge and chicken litter) that consists of a stage of pyrolysis of initial raw material and a stage of high-temperature processing of the pyrolysis gases and vapours by their filtration through a heated porous carbon material, gas mixtures with a lower calorific value about 10 MJ/m^3 and specific volume more than 1m^3 per kg of feedstock are produced. The volume of obtained synthesis gas is increased several times in comparison with volume of gas mixtures that can be generated by pyrolysis process. The pyrolytic treatment of sewage sludge and chicken litter allows to use all energy potential inherent these substances. The obtained synthesis gas can be used for generation of electric power for example in gas engine.
The next stage of investigations is creating experimental setup that is similar to large-scale setup of the thermal conversion of wood (Figure 5).

Acknowledgments

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