Renewable Energy 111 (2017) 245–255

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Experimental tests of co-combustion of laying hens manure with coal by using thermogravimetric analysis

Robert Junga [a,*], Waldemar Knauer [b], Patrycja Niemiec [a], Mariusz Tańczuk [c]

[a] Department of Thermal Engineering and Industrial Facilities, Opole University of Technology, 5 Mikołajczyka St, 45-271 Opole, Poland
[b] NETZSCH-Gerätebau GmbH, 42 Wittelsbacherstrasse, 95100 Selb, Germany
[c] Department of Environmental Engineering, Opole University of Technology, 5 Mikołajczyka St, 45-271 Opole, Poland

ARTICLE INFO

Article history:
Received 15 December 2016
Received in revised form
22 March 2017
Accepted 31 March 2017
Available online 5 April 2017

Keywords:
Laying hens manure
Co-combustion
Coal and biomass mixtures
Thermogravimetric analysis (TG/DTA)
Kinetics

ABSTRACT

Waste from poultry farming, apart from good fertilizing properties, can be also a valuable source of energy. The article refers to the possibility of using laying hens manure burned separately or with gas-flame coal. In this research elemental and proximate analyses were used, as well as the heating values for characterization of the fuels properties. Furthermore, simultaneous Thermogravimetric and Differential Thermal Analyses (TG-DTA) were performed for separate biomass and coal samples and also for their blends containing 25, 50 and 75% by weight of poultry. The reaction regions as well as the ignition characteristics, burnout and maximal temperatures of analysed fuels were detected. The study demonstrates the significant differences in the composition and the character of combustion of both fuels. With the biomass content increase the reduction of the ignition temperature was observed, thereby increasing of the reactivity of the sample. The activation energy was calculated with the use of model-free isoconversional Ozawa-Flynn-Wall method (OFW). Average Activation Energy E_α was much higher for biomass (128.6 kJ/mol) than for coal (21.6 kJ/mol), whereas for blends E_α was increasing with the biomass content increase. Synergy exists between the two components in the main combustion region.

1. Introduction

Production and consumption of chicken meat and eggs constantly increases in Europe, while Poland is one of the leading manufacturers of these goods. Statistics demonstrate that the total population of chicken raised in Poland and exceeded 120 mln in 2014, wherein almost 46 mln were laying hens [1]. Breeding of such a large animal population requires relevant activities in the field of waste management, especially excrement disposal. Chicken manure, due to its high nutrients content, has been used as a fertilizer for many years. However, current regulations [2] prevent unrestricted use of this type of waste. This is mainly because of the ability to contaminate the ground water and water bodies, consequently leading to their eutrophication. Using poultry manure as a fertilizer may also cause emissions of greenhouse gases, due to the release of methane and ammonia [3].

As research shows [3] pre-treated chicken manure and litter can be thermally converted, due to the fact that their calorific values are equivalent to low rank coals [4]. There are many means for thermal conversion of biomass among which pyrolysis, gasification, combustion or co-combustion with coal can be distinguished. The last solution is becoming more and more popular nowadays, avoiding fossil fuels exhaustion. Furthermore, existing coal-fired power plants do not require a large capital investment to be able to be used successfully during simultaneous combustion of both substances [5]. The ability to reduce the carbon dioxide emissions through incineration of waste biomass should be also considered. Due to the European Commission Regulation No. 592/2014 of 3 June 2014, there are interesting perspectives of applications of chicken manure as a fuel for combustion directly onsite, i.e. on poultry farms [6]. In this case the addition of coal allows obtaining greater control and stabilization of the combustion process.

The experience in combustion and co-combustion of coal with waste biomass comes from two sources: the existing commercial solutions and laboratory research. The first power plants based on animal waste biomass were built in the United Kingdom [7]. Furthermore, there are several studies that analyse the combustion process of poultry litter in fluidized bed combustors which are considered being suitable for low calorific fuels [8]. It was observed

* Corresponding author.
E-mail address: r.junga@po.opole.pl (R. Junga).

http://dx.doi.org/10.1016/j.renene.2017.03.099
0960-1481/

Nomenclature

Variables

A	Ash content, %
A_α	Pre-exponential factor, 1/s
C	Carbon content, %
E_α	Activation energy, kJ/mol
H	Hydrogen content, %
HHV	Higher heating value, kJ/kg
k	Rate constant
LHV	Lower heating value, kJ/kg
m_i	Initial mass, mg
m_f	Final mass, mg
m_t	Mass at time t, mg
M	Moisture content, %
N	Nitrogen content, %
O	Oxygen content, %
R	Universal gas constant, = 8.314 J/(mol K)
S	Sulphur content, %
t	time, min
T	temperature, K
VM	Volatile matter content, %

Greek letters

α	Mass conversion degree
β	Heating rate, K/min

that combustion of manure makes sense only in the vicinity of poultry litter farms due to high transportation costs caused by their high moisture content. In addition, ash resulting from combustion process can be a valuable material used as a fertilizer. Attention is also drawn on high chlorine content of poultry waste which may lead to corrosion of boilers [8]. Abelha et al. [9] reported emissivity of low-scale atmospheric bubbling fluidized bed which combusts poultry litter alone or mixed with peat. It was presented that the amount of SO_2 in the flue gas was low which was additionally caused by the high calcium content in waste. NO_x, N_2 O and CO emissions can be reduced by the implementation of secondary air, especially increasing its turbulence. Moreover, combustion of poultry litter which moisture content is higher than 25% can affect negatively the screw feeding mechanism and therefore stability of the combustion process.

One of the techniques that can be used at laboratory scale to analyse the combustion process as well as their co-combustion is thermogravimetry. Burning profiles of raw fuels and their blends provide information about initial, final and maximum reactivity temperatures or total time of the process. This knowledge is essential for the combustion efficiency prediction, reaction (residence) time, air requirements or boilers design, also with regard to the existing one-fuel units at which the modernization to the co-combustion technology is planned [10]. There are numerous studies presenting thermogravimetric analyses of raw biomass fuels but the co-combustion subject of coal and biomass is less commonly treated. Moreover, there are only several publication that concern the coal and manure biomass blends. A short literature review of the co-combustion of different coal and biomass types is given in Table 1.

Yurdakul [11] studies the co-combustion of poultry litter with lignite coal with the use of thermogravimetry method and demonstrates significant differences in the burning profiles of both of the materials. The results show correlation between thermal properties of the mixtures and participation of the poultry litter in the blends. Calculated average activation energies of the blends increased with the biomass content increase. Activation energy for poultry litter sample reached the value of 127.84 kJ/mol, whereas for coal the result was one and a half lower. Moreover, synergistic effects between biomass and coal during combustion were also observed. Co-combustion of semi-anthracite coal with swine manure described in Otero et al. [10] demonstrates that a slight addition of manure (10%) reduced the differences between Derivative Thermogravimetric (DTG) curves evident for the fuels burned separately. Activation energies for both fuels, calculated by means of two different methods, were relatively consistent, but addition of manure into the blend increased the energy level to 125.8 kJ/mol for Vyazovkin method and 138.9 kJ/mol for OFW method, whereas activation energies for coal and biomass samples had the value of 106.4 kJ/mol, 114.4 kJ/mol and 107.0 kJ/mol, 119.6 kJ/mol, respectively.

In case of bituminous coal and sewage-sludge blends, Folgueres et al. [12] confirmed significant differences in combustion profiles and characteristic temperatures of the fuels. Blends reactivity is strongly related to the weight percentage (wt.%) of individual components. No interactions between coal and sludge in the blends were detected. However, similar values of activation energies for coal, sewage sludge and their blends were observed in each combustion stage. Otero et al. in Ref. [13] reported that differences between semi-anthracite coal and sewage sludge are significant, and addition up to 10% by weight of sewage sludge into the coal is slightly noticeable in reference to weight loss and reactivity. Moreover, small amount of biomass in the blends has a slight influence on the average activation energy increase. Otero et al. [14]

Table 1
Thermogravimetric analysis of coal-biomass co-combustion: examples of studies.

Coal-biomass mixtures	Sample mass	Method used	Temperature range	Heating rate	Gases, flow rate	Ref.
Lignite coal with turkey litter, chicken litter	10 mg	TG, DTG	30–900 °C	10, 40, 80 K/min	air 20 mL/min	Yurdakul [11]
Semianthracite coal with swine manure	25 mg	TG	up to 850 °C	5, 10, 25, 40 K/min	air 100 mL/min	Otero et al. [10]
Bituminous coal with sewage sludge	10 mg	TG, DTG	25–800 °C	10 K/min	air n.d.	Folgueras et al. [12]
Semianthracite coal with sewage sludge	25 ± 1 mg	TG	up to 1000 °C	5, 10, 25, 40 K/min	air 100 mL/min	Otero et al. [13]
Semianthracite coal with sewage sludge	25 ± 1 mg	DTG, DTA	up to 1000 °C	15 K/min	air 50 mL/min	Otero et al. [14]
Lignite coals with oak chips, olive cake and hazelnut shells	50 mg	TG, DTG	25–1100 °C	20 K/min	dry air, 40 mL/min	Varol et al. [15]
Subbituminous coal with oil palm biomass (PKS, PMF, EFB)	20 mg	DTG	25–1100 °C	10, 20, 40, 60 K/min	air, 50 mL/min	Idris et al. [16]
Bituminous coal with pine sawdust	5 mg	TG, DTG	Ambient temp. to 1000 °C	15 K/min	air, 50 cm^3/min	Gil et al. [5]