Waste Management 79 (2018) 22–29

Contents lists available at ScienceDirect

Waste Management

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

Experimental tests of co-combustion of pelletized leather tannery wastes and hardwood pellets

Jacek Kluska *, Tomasz Turzyński, Dariusz Kardaś

Institute of Fluid Flow Machinery, Fiszera 14, 80-231 Gdansk, Poland

ARTICLE INFO

Article history:
Received 27 February 2018
Revised 27 June 2018
Accepted 10 July 2018

Keywords:
Combustion
Leather tannery wastes
Thermogravimetric analysis

ABSTRACT

This study examines the possibility of using pelletized leather tannery wastes (LTW) in the co-combustion process with hardwood pellets (HP). The experiments were carried out in a small-scale combustion reactor and were followed by thermogravimetric analysis (TGA) of fuels in the nitrogen and air atmosphere. The experimental investigation has indicated that the leather tannery wastes can be an interesting fuel with a relatively high heating value (HHV), at the level of 16 MJ/kg, and the volatile content of about 68%. Thermal decomposition of the leather tannery sample occurs at temperatures ranging between 220 and 420 °C, with the maximum of intensity at 320 °C. The experimental results indicated that the averaged maximum temperatures obtained during the combustion reached similar values for all samples, which indicates that doping wood pellets with leather waste pellets does not have a significant impact on the temperature characteristics of the combustion process. However, decreasing the amount of hardwood pellets in the mixture reduces the bulk density of the fuel bed and the combustion front velocity. The emission of nitrogen oxides for combusting blends is twice as high as for combustion of pure HP, which is related to higher nitrogen content in leather waste as well as higher ash content.

1. Introduction

For many years, the amount of biomass used as an alternative source of energy is increasing. Biomass is used for heat and power generation on an industrial scale, often replacing fossil fuels like coal or oil. In many cases, co-firing of biomass with other solid fuels is also realized. Many kinds of waste material, such as Refuse Derived Fuel (RDF), sewage sludge and poultry litter, are becoming alternative sources of energy. For the purpose of thermal conversion, these kinds of waste fuels require specialized devices and technologies. Therefore, the combustion tests of these fuels are becoming more common. Magdziarz and Wilk (2013) indicated that co-combustion of biomass and sewage sludge may be a promising waste management alternative for sewage sludge utilization. This issue was also presented by Kijo-Kleczkowska et al. (2016). Whereas, Junga et al. (2017) showed the thermogravimetric analysis of co-combustion of coal and hen manure. The experimental investigation indicated the possibility of burning laying hen manure burned separately or blended with coal. The combustion characteristic of another widely used alternative fuel – RDF – was presented by Akdağ et al. (2016). The experimental investigation of co-combustion of RDF fraction with coal and petroleum coke showed that the increase of RDF fraction (above 10%) caused increase of CO concentration in the flue gas and decrease in the combustion efficiency. Among these new energy sources, LTW are particularly interesting. In this case there is a demand for immediate utilization of such waste because LTW cannot be stored. The amount of leather which was derived from bovine and equine animals for the tanning industry in Poland amounted to 21,140 tons in 2016. It is noteworthy that one tonne of raw leather material before tanning brings only about 200–250 kg of leather. The rest of it, i.e. about 75–80% of the weight of raw leather material composes the waste, partially in solid form, and can be used energetically. This aspect was analysed by Yılmaz et al. (2007) who presented results of experimental investigation of leather waste pyrolysis at temperatures of 450 and 600 °C under N_2 atmosphere. The authors have indicated that the pyrolyzed leather waste is attractive in the form of activated carbon. The aspect of utilization of the waste generated from leather industry in the form of hazardous chromium (Cr^{3+}) impregnated microfine solid particulate matter in the pyrolysis process coupled with oxygen incineration was also presented by Sethuraman et al. (2014). Priebe et al. (2016) showed the possibility of chrome-tanned leather waste utilization in the anaerobic digestion process for the biogas production.

* Corresponding author.
E-mail addresses: jkluska@imp.gda.pl (J. Kluska), tturzynski@imp.gda.pl (T. Turzyński), dk@imp.gda.pl (D. Kardaś).

https://doi.org/10.1016/j.wasman.2018.07.023
0956-053X/

The tanning industry in Poland consists of many small-scale installations, producing small amounts of waste. Therefore, LTW cannot be the main fuel for any continuous energy generation process and has to be combined with additional fuel. In Poland, the most accessible and the cheapest kind of fuel is wood. For this reason the present work describes the possibilities and characteristics of co-combustion pellets from leather tannery waste and hardwood pellets, to determine the characteristics and dynamics of the combustion process. The effect of doping wood pellets with pellets from leather wastes on temperature characteristics during the combustion process, as well as combustion front velocity and characteristic of flue gases presented in this work provide important guidelines in terms of boiler and grate constructions. In addition, the work presents a detailed exhaust gas analysis to characterize harmful substances and NO and NO_x emission, as well as characteristics of inorganic compounds found in the bottom ash from the LTW combustion.

2. Materials and methods

2.1. Materials

The results of the proximate and ultimate analyses are given in (Table 1). To conduct the analyses, wastes from leather tanneries situated in the north of Poland were first dried and then placed in a centrifugal grinder equipped with a 0.2 mm perforated plate to obtain small elements that could be easily fed into the reactor. The analysis were carried out on shavings from machining mixed with skin surface alignment. The moisture content was determined using a MAC moisture analyser (RADWAG), while the calorific value was determined and calculated using a calorimeter (EkotechLab). Characterization of elementary composition was carried out using a CHNS-O Flash 2000 analyser (Thermo Scientific) and a Fluorescence Spectrometer Dispersive X-ray Wavelength (Bruker Scientific Instruments).

Wastes from leather tanneries are characterized by high moisture content, ranging from 30 to 40%. The comparison of the proximate analysis results shows that while the fixed carbon content in tanning industry waste and HP may be assumed similar (about 21%), the amounts of volatiles and ash differ significantly. The volatile content in the LTW was about 68%, while in the HP it was about 76%. Whereas the tanning industry waste contained 11% of ash, the hardwood ash content was about 2%. Large differences were also observed in the ultimate analysis. The oxygen content reached about 28% for the LTW, while for the HP it was about 45%. As can be seen in the elemental analysis, the LTW has higher hydrogen content and lower carbon content than HP.

In order to carry out experiments related to co-combustion of wood pellets and tannery waste, the delivered tanning industry wastes were dried and formed into pellets with a diameter of 4 mm (Fig. 1).

The combustion experiments were carried out for fuel blends of HP and LTW pellets, with the participation of 50, 60 and 80% of HP by mass and, for comparison, only for HP. The analysis has shown that bulk density of LTW pellets was 388 kg/m^3 and increased with HP fraction to 646 kg/m^3 (Fig. 2). The HP particle is a cylinder with diameter of 8 mm and length of up to 15 mm. The LTW pellet consists of cylinder shaped particles with diameter of 5 mm and up to 25 mm in length. This implies that in cases of combined blends of hardwood and leather pellets, the average particle size decreases with the increase of leather pellet fraction.

Table 1
Proximate and ultimate analyses of tanning industry waste and hardwood pellets.

	TLW	HP
Heating value [MJ/kg]	16.6	19.6
Moisture [wt.%, as delivered**]**	**35.3**	**6.1**
Proximate	**[wt.%$_{db}$]**[a]	
Volatiles	67.9	76.3
Fixed carbon	21.2	21.4
Ash	10.9	2.3
Ultimate [wt.%$_{db}$][a]		
C	41.71	48.50
H	7.12	5.30
O	28.46	45.56
N	11.01	0.40
S	3.43	0.02
Cr_{total}	3.16	–
Na	1.77	0.08
Fe	0.99	0.01<
Ca	0.63	–
Si	0.59	0.03
Cl	0.57	0.01
Mg	0.21	0.02
K	0.14	0.06
Al	0.11	0.01
P	0.05	0.01<
Ag	0.02	–
Ti	0.02	–

[a] db = oven-dry basis.

2.2. Experimental methods

2.2.1. Thermogravimetric analysis

A thermogravimetric analysis was conducted under inert atmosphere to investigate the rate of thermal decomposition of solid waste generated from leather industry and the temperatures at which the decomposition occurred. The analysis was carried out with the SDT Q600 thermogravimeter (TA Instruments). The leather samples were heated from 30 to 800 °C at the rate of 10, 20 and 30 °C/min. The mass of the samples was 12 to 14 mg and the nitrogen (N_2) flow rate was 100 ml/min.

Moreover, in order to analyse thermal degradation of LTW in air atmosphere the TGA analysis (SDT Q600 thermogravimeter) was carried out. The mass of each sample was about 14 mg, the air gas flow rate was 100 ml/min, and the heating rate was 10 °C/min.

2.2.2. Combustion procedure

The combustion test stand consists of the combustion reactor, air supply, and the control and measurement system (Fig. 3). The combustion process propagates vertically from the top of the biomass bed to the bottom.

The combustion reactor is a half of an 80 mm diameter cylinder. The height of the reactor is 200 mm, the grate is placed at the bottom, with K-type thermocouples T1–T6 located above it. The thermocouples are installed along the combustion chamber height; the distance between them is 20 mm, except thermocouples T4 and T5 where it is 40 mm. The distance of the sensors from the inner wall is 20 mm. The grate is perforated, with twenty-six holes of 4 mm in diameter.

The upper surface of the fuel bed in the reactor was covered with burning cellulose cubes and then the air was supplied from the bottom of the reactor. After obtaining the combustion front across the entire width, the experiment was started. The combustion process was photographed every 60 s using a camera placed in front of the heat resistant glass. Since the glass used in the experiment is opaque to infrared wavelength, this provided an alternative method to analyse the combustion front velocity based solely on the fuel bed colour change.

The generated flue gases were directed upwards into the stack fitted with a gas analyser nozzle. The content of NO and NO_x in the flue gas was measured using a GA – 40 T plus gas analyser (Madur Electronics). For each experiment, a sample of produced