Journal of Loss Prevention in the Process Industries xxx (2016) 1–6

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Thermal analysis and dust explosion characteristics of spent coffee grounds and jatropha

Masatoshi Todaka [a], Wasana Kowhakul [b, *], Hiroshi Masamoto [b], Mikiji Shigematsu [b]

[a] Department of Energy and Environment Systems, Graduate School of Engineering, Fukuoka University, Fukuoka, 814-0180, Japan
[b] Department of Chemical Engineering, Faculty of Engineering, Fukuoka University, Fukuoka, 814-0180, Japan

ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form
5 August 2016
Accepted 15 August 2016
Available online xxx

Keywords:
Spent coffee grounds
Jatropha
Biomass
Dust explosion
Thermal behavior
Flow properties

ABSTRACT

The relationships of fatty oil content in spent coffee grounds (SCG) and jatropha kernels (JK) with minimum explosible concentration (MEC), minimum ignition energy (MIE), cohesion, dispersibility and thermal analysis were investigated. Both SCG and JK are carbon-rich [> 50% by weight (wt.%)] with higher total calorific values than cellulose. The MEC values for absolutely dry 75–105 μm particles of oil-retaining and oil-extracted SCG were 35 g m^{-3} (high explosion hazard) and 120 g m^{-3} (low explosion hazard), respectively. The low MEC value of oil-retaining SCG was despite a high cohesion result, suggesting that the oil content increased the likelihood of a dust explosion. Conversely, the MIE values for all SCG and JK were sufficiently high to consider them a low-level risk. Behavior analysis showed that decomposition temperature of SCG did not differ to that for its oil-extracted form. However, exothermic peak temperature of JK was 76 °C higher than for its oil-extracted form. The SCG (20 wt% oil) was little affected by oil content; however, jatropha (60 wt% oil) was greatly affected. Thermogravimetric results for all samples showed that the decomposition temperature increased with the heating rate, although the overall behavior of decomposition was not affected by heating rate.

1. Introduction

Bioenergy is seen as one of the key options to mitigate greenhouse gas emissions and as a substitute for fossil fuels. Because biomass is a renewable form of energy, its large-scale introduction could contribute to sustainable development on several fronts: environmental, social and economic (Hamelinck and Faaij, 2006). However, biomass presents a substantial fire and explosion risk during storage, handling, processing and combustion. Thus, biomass explosibility characteristics need to be assessed for the design of safe systems and operations (Biomass Handling).

Table 1 shows some examples of fire and explosion incidents that occur every year in biomass manufacturing such as in June 2013, at Egger Hexham chipboard plant, the wood-burning biomass incinerator caught fire. In April 2013, an explosion at the Koda Energy CHP plant in Minnesota ignited a fire in two of its fuel storage silos that burned for a week. In May 2012, three people were injured from a wood dust explosion caused by a 'bang and clean' cleaning process using small explosions of oxygen and methane usually used to clean boilers but in this case used to unblock a plug of wood pellets.

However, the explosibility behavior of wood biomass powders have been little studied since these materials particularly in case of fatty oily contain biomass are difficult to characterize for explosibility using standard methods because of their bulky and fibrous nature. Research on explosions of dust biomass is shown in Table 2.

To evaluate the risk of biomass powders, it is very important to demonstrate dust explosion characteristics. The conditions for a dust explosion are summarized in a 'dust pentagon', which includes the five following elements (Amyotte and Eckhoff, 2010). (1) The dust must be explosible. (2) The dust must have a particle size distribution that will propagate a flame. (3) The atmosphere into which the dust is dispersed as a cloud or suspension must contain sufficient oxidant to support combustion. (4) The dust cloud must have a concentration within explosion range. (5) The dust cloud must be in contact with a source of sufficient energy to cause ignition (Barton, 2002).

In present work, properties of biodiesel fuels derived from inedible oils from spent coffee grounds (SCG), and jatropha (*Jatropha curcas*) kernels (JK) combined with various alcohols have been

* Corresponding author.
E-mail address: kowhakulw@fukuoka-u.ac.jp (W. Kowhakul).

http://dx.doi.org/10.1016/j.jlp.2016.08.008
0950-4230/

Table 1
Some examples of such incidences that take place every year on biomass manufacturing.

Year	Location	Country	Incidents
June 2013	Chipboard plant	Egger Hexham, UK	Their wood burning biomass incinerator caught fire
April 2013	Koda Energy CHP plant	Minnesota, USA	Igniting a fire in 2 of its fuel storage silos that burned for a week.
February 2012	Rwe's Tilbury Power station	Essex, UK	Biomass fire.
May 2012 December 2012	Amager Power station	Copenhagen, Sweden	Three people injured from wood dust explosion caused by a cleaning process
October 2011	The wood pellet storage facility	Port of Tyne, UK	A huge fire ripped through the wood pellet

Table 2
Physicochemical characteristics of SCG, jatropha, and cellulose and reference data.

Biomass sample	Elemental composition (wt.%)				Moisture content (wt%)	Total calorific value (MJ/kg)	Oil content (wt.%)	Ash (wt.%)	Particle size (μm)	MEC (g m^{-3})
	C	H	N	O						
Cellulose (Medina et al., 2015)	–	–	–	–	–	–	–	–	51	60
Biomass dust (forest ressidu and bark) (Japanese Standards Association, 2002)	47.8	6.3	0.3	45.5	6.0	18.48	–	2.9	275	30
Norway spruce (Wachter et al., 2015)	48.1	5.6	0	36.3	5.8	19.2	–	4.1	<60	–
Torrefied Norway spruce (Wachter et al., 2015)	54.8	5.2	0	30.7	2.7	20.6	–	5.8	<60	54
Lycopodium (Makkar et al., 1998)	–	–	–	–	–	–	–	–	35	35–45
Coffee (Ground coffee) (Medina et al., 2015)	–	–	–	–	–	–	–	–	–	100
Spent coffee ground (Yokoyama and Imou, 2009)	50.77	8.25	2.16	38.75	–	–	–	1.75	–	–
Cellulose	41.63	6.73	0.07	51.57	4.18	16.68	–	–	50	60
Spent coffee ground	55.86	7.02	2.33	34.79	3.67	23.56	21.27	2.17	75–105	35
Spent coffee ground (oil extraction)	49.90	6.19	2.53	41.38	7.08	20.85	–	2.47	75–105	130
Jatropha kernel	60.86	9.73	3.55	25.86	5.99	29.74	60.7	4.56	–	No explosion
Jatropha kernel (oil extracted)	44.14	7.65	6.90	41.31	5.06	20.38	–	9.61	75–105	50
Jatropha shell (not contained oil)	41.16	5.43	1.21	52.2	10.3	15.96	1.86	8.81	75–105	295

studied (Todaka et al., 2013). In the present study, thermogravimetric-differential thermal analysis (TG-DTA) was used to evaluate thermal and oxidation stabilities of SCG and JK. These two raw materials were chosen for study because they contain fatty oils. SCG contains approximately 20% by weight (wt.%) fatty oil and JK approximately 60 wt% (Caetano et al., 2012; Oliveira et al., 2008). The relationships between fatty oil content in SCG and JK and minimum explosible concentration (MEC), minimum ignition energy (MIE), cohesion and dispersibility were studied.

The layout of the paper is as follow. In Section 2 the experimental set-up and the experiment procedure are described. In Section 3 the experimental results and analytical predictions are given. Section 4 include the conclusions.

2. Experimental

2.1. Materials

SCG was supplied by a franchise coffee shop in Fukuoka University, while JK was purchased from IS Corporation Ltd in Japan. The n-hexane (1st Grade), as solvent to extract oil from SCG and jatropha seed was purchased from Wako Co., Ltd.; and cellulose Avicel PH-101 for use as a reference material from Sigma-Aldrich.

SCG was dried at 80 °C for 3 d. Jatropha seeds were descaled and JK milled using a mortar. Following these preparation steps, 500-g samples of dried SCG or milled JK were leached using 1 L of n-hexane for 1 h at room temperature. The leaching process was carried out three times. Extraction residues were subsequently filtered and the solvent removed by evaporation.

2.2. Particle size distribution

Particle size distribution of SCG was measured using sieves. The 50-g samples were placed in the upper sieve and separated for 30 min using a vibratory sieve shaker (AS200 basic, Retsch). The particle size distribution was calculated by the proportion of the sample remaining in each sieve.

2.3. Physicochemical characterization

The basic elemental composition of each sample was determined by a CHN analyzer (PerkinElmer-2400 II) according to the JIS M 8819 standard. The moisture and ash content were calculated according to the JIS M8812 standard by comparing the original sample mass with those after heating at 105 and 600 °C, respectively. Total calorific value was determined using an auto-calculating bomb calorimeter (CA-4PJ, Shimadzu, Japan) based on the JIS M 8814 standard.

2.4. Evaluation of dust explosion hazard

During this work, both MEC and MIE values were determined using a 1.2-L Hartmann tube apparatus (PIE-1200, Seishin Enterprises). MEC measurement conditions consisted of: electrode gap of 5 mm, compressed air at 0.075 MPa, charging voltage of 1000 V and ignition delay time of 0.1 s. Using these test parameters, MEC of a standard reference material composed of *Lycopodium* was 40 ± 5 g m^{-3}. During MIE measurements, the discharge energy was obtained by adjusting the ohmic value of the circuit with discharge time. MIE values were then calculated using the following equation, in accordance with the EN 13821 standard.

$$E_s = 10^{\left(\log E_2 - \frac{I[E_2](\log E_2 - \log E_1)}{(NI+I)[E_2]+1}\right)}$$

where E_1 is the highest energy at which ignition does not occur, E_2 is the lowest energy at which ignition is observed, NI is the number of non-ignitions observed at E_2 and I is the number of ignitions observed at E_2.

Please cite this article in press as: Todaka, M., et al., Thermal analysis and dust explosion characteristics of spent coffee grounds and jatropha, Journal of Loss Prevention in the Process Industries (2016), http://dx.doi.org/10.1016/j.jlp.2016.08.008