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Investigation on thermochemical conversion of pelletized Jatropha residue and glycerol waste using single particle reactivity technique

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ABSTRACT

Adverse environmental effects resulting from fossil fuel usage as well as foreseeable conventional energy depletion lead to the exploration of alternative fuel materials especially the renewable ones. In this work, characterization of synthetic fuel material formed by pelletization of Jatropha residue (physic nut) using glycerol waste as a binder was carried out in order to investigate the feasibility of utilizing these waste materials which are by products from biodiesel manufacturing process as another renewable energy source. Jatropha residue mixed with 0–50% glycerol waste were formed to length of 11.1 mm and diameter of 13.2 mm under pressure of 7 MPa in a hydraulic press. Maximum compressive stress (2.52×10^5 N/m^2) of the fuel pellet occurred at 10% glycerol waste. Thermal conversion characteristic of solid fuel was studied by using single particle reactivity testing scheme at temperature of 500–900 °C under partial oxidation atmosphere. In general, higher glycerol content in solid fuel as well as oxygen concentration in reacting gas resulted in greater decomposition rate from 0.006 to 0.110 g/s. Burning started with a relative short drying phase, followed with a longer pyrolysis time and thereafter the dominated char combustion time which took around 35–57% of total conversion time. The average total conversion time varied from 26 to 288 s, depending mainly on reaction temperature. Higher glycerol content resulted in char with lower density and higher shrinkage with greater porosity. Greatest changes in pellet diameter, height, and density of 75.6%, 89.2%, and 91.5%, respectively, were exhibited at 5% oxygen atmosphere and 900 °C. The results suggested that pelletized Jatropha residue mixed with glycerol is suitable for utilization as quality solid fuel.

1. Introduction

Solid fuel pellets and briquettes are normally generated from bark, cutter shavings, saw dust, dry chips. Compacting of these bulky and low density residues improves physical handling (storage and transport) as well as chemical property (energy content) of the materials. Pelletized fuels also provide possibilities for process automation and optimization which may lead to superior overall burning efficiency and lower residues [1,2]. In addition, other potential raw materials such as bagasse, grape pomace, paper, plastic, textile, and wood wastes were also compacted to form densified logs and tested for their potential usage as solid fuels by several researchers [3–5]. Greater use of these mostly renewable resources would lessen dependency on conventional fuel as well as ease associated environmental problems while accomplish waste management scheme. The biowaste readily available from the bio-oil industry is one of the attractive renewable energy sources. In this work, Jatropha (physic nut) waste and glycerol, both from biodiesel industry, are of interest. Jatropha waste, obtained from bio-oil extraction process, is typically used for fertilization and animal feed or incinerated in case of oversupply. Glycerol is also a by-product obtained during the production of biodiesel. Biodiesel and glycerol are produced from the transesterification of plant oils and fats with alcohol in the presence of a catalyst. About 10 wt% of plant oil is converted into glycerol during this process [6]. The investment required for purification process of waste glycerol is considerably high. One option for conversion of Jatropha residue and glycerol into value added products is to pyrolyze, gasify or combust these wastes to useful products or energy. However, research on converting these wastes into value added products using thermochemical conversion processes are limited. Valliyappan et al. [6] pyrolyzed glycerol in N_2 at 650–800 °C using a tubular reactor while thermal decomposition of crushed Jatropha waste was studied by Sricharoenchaikul and Atong [7] using thermogravimetric analysis and a fixed bed reactor. Fast pyrolysis experiments of the nut shell of Jatropha were carried out in a continuous bench scale pyrolyzer

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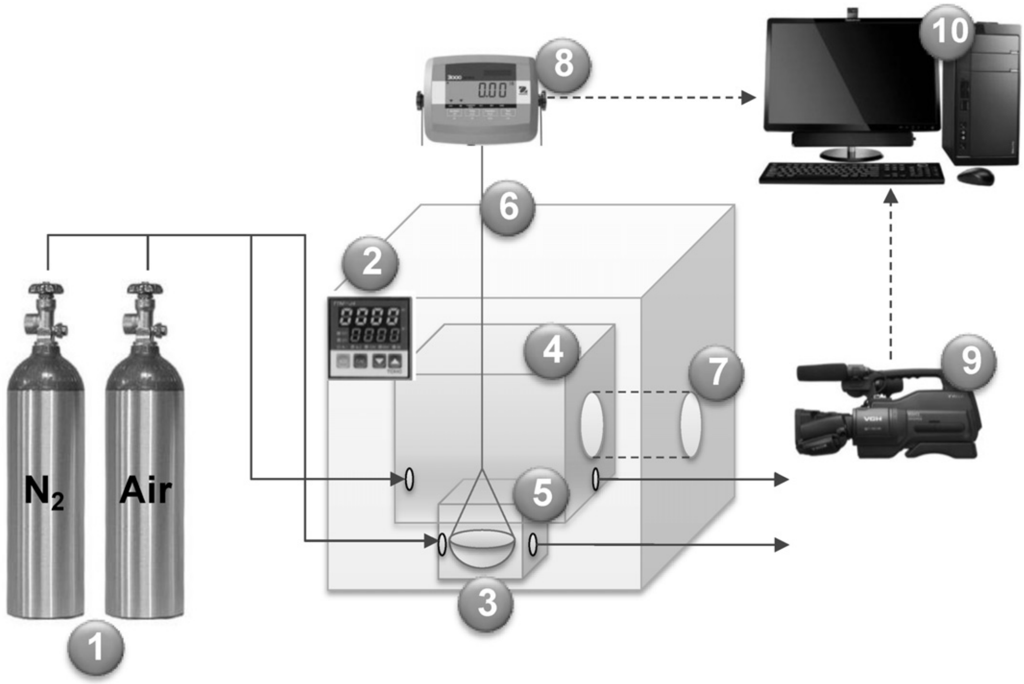

Fig. 1. Schematic of single particle reactivity testing apparatus showing: (1) gas cylinders, (2) temperature controller with thermocouple, (3) quartz sample holder, (4) furnace chamber, (5) staging chamber, (6) nichrome wire, (7) quartz window, (8) digital balance, (9) camcorder, and (10) data logger.

at 480 °C by Manurung et al. [8]. However, these reports mainly focus on single raw material or conversion of smaller waste particle, which may not be suitable for application to large scale operation. Data on physical and burning characteristics of these mixed wastes, especially for pelletized one, are important for designing of proper equipment to efficiency utilize them. For example, diameter and length of the pellets are important combustion factors. Thinner pellets are usually undergone a more consistent combustion rate than thicker ones [9]. For continuous flow operation, shorter pellets are more suitable due to their superior feeding properties. Burning properties of solid fuels are also vital to the successful design and operation of thermal conversion processes. These properties including char yield and char combustion rate are highly related to the chemical composition of raw materials. Lignin was found to yield a higher char than cellulose and hemicellulose [10]. Rhén et al. [2] reported longer char combustion time for pellets with higher density and larger portion of stem wood. Though the data on typical densified solid fuels mentioned earlier are relatively extensive, it is not a case for crushed Jatropha and glycerol wastes. Hence, the objective of this work is to prepare and characterize solid fuels from mixture of Jatropha and glycerol wastes as well as investigate their thermal conversion properties. The densification of loose waste material into solid fuel pellet is aimed to improve the fuel handling, transportation, storage, and also combustion properties. Their thermal conversion properties were studied by using single particle reactivity testing scheme. The conversion behavior during pyrolysis and partial oxidation of mixed solid fuel was compared. The effects of mixture composition on combustion behavior, density, shrinkage, burning rate, as well as char structure were also studied.

2. Experimental

2.1. Raw materials

Jatropha waste used was collected from oil extraction process using twin screw extruder, dried, crushed and sieved to particle size of 0.43–0.50 mm. Glycerol waste was obtained from a local biodiesel company. Prior to mixing, removal of methanol from glycerol was performed using evaporator. The proximate analysis was performed followed ASTM to classify the sample in terms of moisture, ASTM E871 [11], volatile matter and fixed carbon, ASTM E872 [12], and ash, ASTM D1102 [13]. The elemental analysis (C, H, O, N, and S) was carried out using Leco TruSpec® CHNS (micro) analyzer. The oxygen content was calculated by difference. Bomb calorimeter (Leco model AC-350) was used to determine the higher (gross) heating value of raw material following ASTM D240 [14]. High heating value can be converted to LHV by Eq. (1). Results of elemental, proximate, and thermal analyses of raw materials are presented in Table 1. Additional chemical components of Jatropha waste sample were also identified using TAPPI T203 [15] and T222 [16] standard

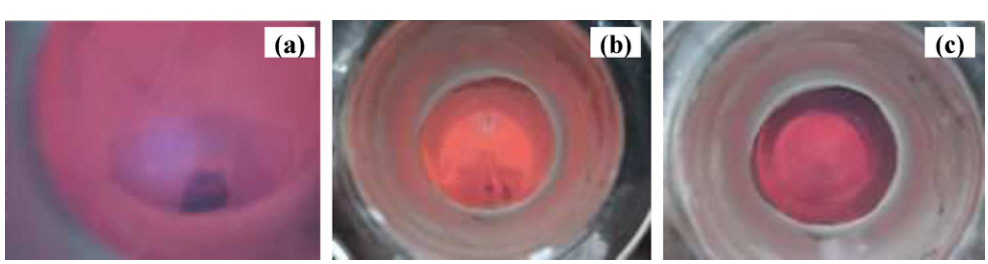

Fig. 2. Photos of mixed solid fuels inside oven during (a) drying (b) devolatilization and (c) char buring period.