Industrial Crops and Products 63 (2015) 337–348

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Canola meal moisture-resistant fuel pellets: Study on the effects of process variables and additives on the pellet quality and compression characteristics

Ashwini Tilay[a], Ramin Azargohar[a], Mark Drisdelle[b], Ajay Dalai[a,*], Janusz Kozinski[c]

[a] Department of Chemical and Biological Engineering, College of Engineering, University of Saskatchewan, Saskatoon, SK S7N 5A9, Canada
[b] Evergreen BioFuels Inc., Montreal, QC, Canada
[c] Lassonde School of Engineering, York University, Toronto, ON M3J 1P3, Canada

ARTICLE INFO

Article history:
Received 11 April 2014
Received in revised form
28 September 2014
Accepted 5 October 2014
Available online 25 October 2014

Keywords:
Canola meal
Binder
Durability
Hardness
Gasification
Coating

ABSTRACT

This study focuses on pelletization of waste canola meal biomass to increase the bulk density, thereby reducing the transportation and storage costs, thus provide better material feeding in gasification reactors with less dust formation. The effects of feed constituents of canola meal such as protein, fiber, fat, lignin and feed moisture content as well as added binder, lubricant and densification process parameters on the strength and durability of the densified product are investigated. The increased durability (99%) of canola meal pellets was a result of added binder (5 wt%) and the inherent protein (40 wt%) and lignin (12 wt%) content in the feed. From the compression data at different temperature and pressure, Kawakita and Lüdde model (1971) was developed to classify the feed material into groups. The R^2 value ≥0.999 showed good model fit. It was found that at temperature >70 °C, the particle undergoes rearrangement followed by fragmentation and particle plastic deformation during the compression process. The effects of coating agent on pellet durability, hardness and moisture uptake were studied to produce moisture-resistant pellets. Finally, the pellets were gasified in a fixed bed reactor using different gasifying agents such as steam, oxygen (O_2) and carbon dioxide (CO_2) and their effects were assessed. Carbon dioxide was found to give maximum carbon efficiency (CE) up to 82.7% and 50.7 MJ/m^3 LHV of gas at a temperature of 750 °C and equivalence ratio (ER) of 0.4., whereas O_2 gave 66.5% of CE with 44.7 MJ/m^3 LHV of gas at 650 °C and 0.4 ER and steam produced gas with LHV 40.8 MJ/m^3 with CE 27.4% at 650 °C and 0.2 ER. Thus, by producing moisture-resistant canola meal pellets with reasonable fuel characteristics, pelletization of canola meal provides a promising alternative for the utilization of canola meal waste as an alternative source of renewable energy.

1. Introduction

Biomass residues are a valuable solution for generating power and can offset greenhouse gas emission, without being dependant on seasonal and weather changes which affect solar and wind power. Biomass can be stored and continuously utilized for heat, energy or power production (Wolfgang et al., 2012). Considering the energy resources such as fossil fuel, coal and oil in the world, agricultural residues or wastes were found to be as third largest energy resource (Bapat et al., 1997). The agricultural residues (wood, agricultural stovers, grasses and lignocellulosic material) are renewable and sustainable, and can help in reducing the carbon emission as compared to fossil fuel (Tumuluru et al., 2010).

The low bulk density of biomass (<150 kg/m^3), irregular shapes and different sizes limit their transportation, storage and utilization in actual form (Gilbert et al., 2009; Bowyer and Stockmann, 2001; Sokhansanj et al., 2006). To overcome these limitations, there is a need to develop more efficient methods for densification of biomass. The densification of biomass increases the density of biomass pellets typically >600 kg/m^3 and helps to reduce the transportation costs with convenient material handling and less dust formation (Gilbert et al., 2009). Densification of biomass into pellets, briquettes or cubes makes the material in uniform shape and sizes for easy handling, which can be directly used

* Corresponding author. Tel.: +1 306 966 4771; fax: +1 306 966 4777.
E-mail address: ajay.dalai@usask.ca (A. Dalai).

http://dx.doi.org/10.1016/j.indcrop.2014.10.008
0926-6690/

for thermochemical processes such as combustion, gasification, pyrolysis or co-firing with coal (Kaliyan and Morey, 2009). Increase in crude oil and gas prices led to rapid development in biomass pellet industries with more emphasis to reduce greenhouse gas emission (Peng et al., 2013). Commercial densification of biomass is typically carried out by conventional pressure driven processes such as extrusion, pelletization and briquetting (Li and Liu, 2000; Kaliyan and Morey, 2009). To prepare the densified quality biomass product, it is essential to study desirable and dependent parameters such as density and durability in relation to independent parameters such as moisture content (Adapa et al., 2007).

Pellets are more vulnerable to physical wear and tear during transport and storage. This leads to the formation of fine particles or dust which can create problems in the boiler or combustion systems (Carroll and Finnan, 2012). In addition, it can be a source of both health and fire hazard. As per the European Committee for Standardization (CEN), CEN/TS 15210 method defines the physical durability as the ability of pellet to remain undamaged during transportation. It means the ability of pellet to survive vibrations and shock. During the densification process, to a great extend the physical (thermal, mechanical or atomic) forces determine the strength of pellet produced (Adapa et al., 2002). Therefore, it is essential to understand the fundamental mechanism behind the biomass compression process, and to design energy efficient combustion process (Mani et al., 2004).

Continuous increase in demand for biomass pellets and the inadequate availability of agricultural resources has resulted in finding out new available raw materials for pellet production from various resources such as fibrous residue, straw, husks, stover, pulps, meal, grass and wastes from the food industry. The recent Canadian government directive to substitute 1.5 billion liters of petroleum based diesel per year (5%) with biodiesel by the year 2018 are projected to encourage biodiesel industries (Canola Council, 2012). The immense development of biodiesel industries in upcoming years will produce by-products in large quantity such as oilseed meal, for which their utilization will become uncertain. Particularly in Canada, biodiesel industries utilize canola as a common feedstock for the biodiesel production, resulting in abundant quantities of waste canola meal. Apart from being more widely used as an animal feed, canola meal can be used as alternative feedstock for biofuel/bioenergy production (Tilay et al., 2014; Azargohar et al., 2013). During 2013, Canada has 41 pellet manufacturing plants with total capacity of >3 million tons of annual production and has exported ~94% to overseas (Natural Resources Canada, 2013).

Biomass pellets offer ecological advantages over traditional fuels such as heating oil and natural burning gas. Biomass pellets in a pellet stove produce smaller volumes of hydrocarbons (methane) and CO_2. In general, pellet mills need a cheap and reliable source of waste materials due to rising competition for biomass. The competition and prices for renewable feedstock fluctuate as emerging applications such as alternative biomass, advanced biofuel, biochar from biomass, activated carbon made from the petcoke compete for these resources. Our previous study investigated that the waste canola meal can be successfully utilized as an alternative source for renewable energy (Tilay et al., 2014). The overall goal of this study is to develop quality fuel pellets from waste canola meal and to provide optimized operating conditions to produce more durable fuel pellets. The study was carried out as follows: (1) to study the effects of process variables (compressive force, temperature) and feedstock variables (moisture content and binder) on the quality of canola meal pellet; (2) to study the change in density and volume of pellets as a function of pressure followed by development of compression model; (3) to study effects of coating agent on the moisture-resistant property of pellets and (4) to study the effects of different gasifying agents on the quality of syngas produced using pellet gasification in a fixed bed reactor.

2. Materials and methods

2.1. Materials

The waste canola meal biomass from Milligan Biofuels Inc. (Saskatchewan, Canada) were used as raw materials for the present study. The proximate analysis of biomass was previously carried out using AAFCO (Association of American Feed Control Officials) standard (Tilay et al., 2014). The canola meal material was ground by means of knife mill (Retsch GmbH, 5657 HAAN, West Germany) and passed through 0.8 mm mesh. Further, the particle size distribution of the ground canola meal was determined using Mastersizer 9000 laser-scanning particle size analyzer (Malvern Instruments Ltd., Malvern, UK) which confirms that 80.3% particles were in the range of 100–800 μm. The volume of fine (<100 μm) and coarse (>1000 μm) particles was determined to be 14.2 and 5.5%, respectively. The moisture content of the ground canola meal was determined using ASTM 3173-87 method and was 5.19 ± 0.8% as received. Similarly, ash content of the manufactured pellet was determined as per ASTM 3174-04 in a laboratory muffle furnace (Holpack, USA) and was in the range of 5.5–5.7 wt%, depending upon the composition of feed and additives. The additives (binder, lubricant and coating agent) used in this study were procured from Evergreen BioFuels Inc. (Montreal, QC, Canada). All addetives used were provided by Evergreen BioFuels Inc. and their resources and chemical compositions were not disclosed. The elemental analysis of procured binder and pellet for carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) was performed using a Perkin–Elmer Elementar CHNSO analyzer (Vario EL III, Elementar Americas Inc., NJ) and the analyzer calibration was done using standard sulfanilic acid. The elemental analysis of binder showed 2.3 ± 0.05 wt% of N; 49.0 ± 0.2 wt% of C; 0.2 ± 0.07 wt% of S and 5.3 ± 0.07 wt% of H. In case of canola meal pellet using optimized formulation, the composition elements were found to be around 6.1 ± 0.07 wt% of N; 46.6 ± 0.8 wt% of C; 0.9 ± 0.3 wt% of S and 6.6 ± 0.2 wt% of H. The higher heating value (HHV) of produced canola meal pellet was measured by oxygen bomb calorimeter (Parr® 6400 Calorimeter, IL, United States) using ASTM D5865. The canola meal pellet sample was burnt in a Parr 1108, placed inside a Parr 1341 isothermal calorimeter. Approximately 1 mL of water was added to the bomb and pressurized to 2.5 MPa, before placing in an isothermal jacket filled with 2000 ml of water at room temperature (25 ± 1 °C). The electrical energy (40 V) was applied for ignition using a platinum wire. The test was carried in triplicates. All the produced canola meal pellets were found to have HHV of ~20.3 ± 0.18 MJ/kg.

2.2. Preparation of sample and densification

The desired quantity of moisture was added to the formulation to make the final moisture content in the range of 8–12 wt%. The additives (binder and lubricant) were added to the pre-adjusted moisture of canola meal, in the range of 2–5 wt% and 1–3 wt%, respectively and kept in air tight seal bags for 12 h. All samples were densified in a lab scale single-pelleting unit used in previous studies as described by Adapa et al. (2013) and Kashaninejad and Tabil (2011). The densification unit was composed of a plunger-die assembly. The internal diameter and length of a steel cylinder assembled on the Instron testing machine (3360 Dual Column Tabletop Testing Systems, Instron Corp., Norwood, MA) were 6.5 mm and 135.3 mm, respectively, and fitted with a 10,000 N load cell. The die was surrounded with a dual element heating tape (Cole-Parmer Instrument Company, Vernon Hills, IL) to maintain the desired temperature during the densification process. One thermocouple (type-T) was connected to the outer surface of the die and another to a temperature controller. The die was positioned on a raised base which consist of sliding gate at the bottom allowing the