Renewable Energy 92 (2016) 312–320

Contents lists available at ScienceDirect

Renewable Energy

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

Investigating pellet charring and temperature in ultrasonic vibration-assisted pelleting of wheat straw for cellulosic biofuel manufacturing

Yuzhou Li [a, b], Fuda Ning [b], Weilong Cong [b, *], Meng Zhang [c], Yongjun Tang [a]

[a] School of Electromechanical Engineering, Guangdong University of Technology, Guangzhou, Guangdong 510006, China
[b] Department of Industrial Engineering, Texas Tech University, Lubbock, TX 79409, USA
[c] Department of Industrial and Manufacturing Systems Engineering, Kansas State University, Manhattan, KS 66502, USA

A R T I C L E I N F O

Article history:
Received 12 October 2015
Received in revised form
28 January 2016
Accepted 4 February 2016
Available online xxx

Keywords:
Charring
Temperature
Ultrasonic vibration-assisted pelleting
Biofuel
Cellulosic biomass

A B S T R A C T

Biofuels are only alternative solution for liquid transportation fuels among different kinds of renewable energy. To avoid the competition with the food, cellulosic biomass has been proposed as feedstock for manufacturing of cellulosic biofuels. Costs associated with collection, transportation, and storage of cellulosic biomass account for more than 80% cost of the feedstock. By processing cellulosic biomass into high density pellets, handling efficiency of cellulosic feedstocks can be improved, leading to costs reduction in transportation and storage. Ultrasonic vibration-assisted (UV-A) pelleting is a recently developed pelleting method, which can not only produce higher density but also break the lignin shell, to some extent, to increase cellulose accessibility and then increase sugar and biofuel yield. The reported investigations on UV-A pelleting provided little information about the relationship between charring and pelleting temperature under different input variables of pelleting. In this paper, effects of different input variables of pelleting on both charring ratio and pelleting temperature were studied. This paper, for the first time, reported the relationship between charring ratio and pelleting temperature. The obtained results will be helpful in understanding the mechanism of UV-A pelleting and providing guide to control pellet charring for a higher biofuel yield.

1. Introduction

The most commonly used transportation fuels are petroleum-based fuels, whose supplies are expected to decline in the future [1,2]. Biofuels including bioethanol and biodiesel alternatives to petroleum-based transportation fuels can potentially dampen price volatility in transportation fuels, reduce economic and security concerns related to importing oil from other countries, and reduce the greenhouse gas (GHG) emissions along with associated risks of global climate change [1–3]. Currently, primary feed materials for biofuels manufacturing are sugarcane (in Brazil), corn (in U.S.), and rapeseed (in Europe). The use of edible crops for biofuels manufacturing may result in increasing of food price. Therefore, it is crucial to utilize no-food crops for biofuels manufacturing, and cellulose biomass feedstock. Cellulosic biomass includes agricultural residues, forestry and wood pulp wastes, and energy crops [5,6]. The U.S. government expects that annual production of cellulosic biofuels will reach to 16 billion gallons by 2022, and cellulosic biomass can be available in the U.S. for biofuels manufacturing to meet 30% of the current transportation fuel consumptions [4,7].

Fig. 1 shows major steps for cellulosic biofuels manufacturing [8,9]. The low density of cellulosic feedstocks is a main barrier hindering large-scale and cost-effective manufacturing of cellulosic biofuels [10–13]. Under certain conditions, costs of biomass collection, transportation, and storage account for more than 80% of feedstock cost [14]. Cellulosic biomass densification will increase density, improve handling efficiency [15,16], and reduce transportation and storage costs [17–19]. Pelleting is a popular process to process cellulosic biofuels into pellets.

Traditional pelleting methods (for example, using a screw extruder, a briquetting press, or a rolling machine [18,20–23]) generally require high-temperature steam, high pressure, and/or binder materials, making it difficult to realize cost-effective pelleting on or near the field where cellulosic biomass is available. Ultrasonic vibration-assisted (UV-A) pelleting, without using high-temperature steam and binder materials, can produce pellets whose density is comparable to that processed by traditional

* Corresponding author.
E-mail address: weilong.cong@ttu.edu (W. Cong).

http://dx.doi.org/10.1016/j.renene.2016.02.006
0960-1481/

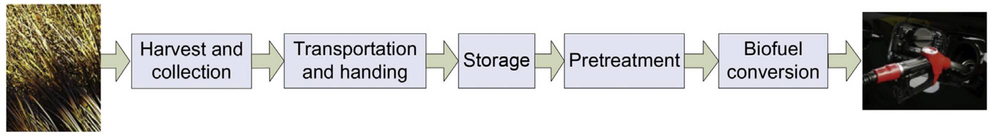

Fig. 1. Major steps for manufacturing of cellulosic biofuels (after [8,9]).

pelleting methods [24–26]. Moreover, biomass (switchgrass) processed by UV-A pelleting has approximately 20% higher sugar yield (approximately proportional to biofuel yield) than biomass pelleted without ultrasonic vibration [24].

The reported experimental investigations in UV-A pelleting include effects of pelleting parameters on pellet quality, pelleting temperature, charring, and sugar yield [24,27–38]. Under certain UV-A pelleting conditions, charring occurs inside pellets produced. As shown in Fig. 2, charring occurred inside the pellet, and outside of the pellet might appear to be normal before pellet being separated into halves. An experimental study on charring of cellulosic biomass in UV-A pelleting has been carried out by Feng et al. [27], however, it is still unclear about the reasons of pellets charring generation. The pellets charring may be resulted from high pelleting temperature generated by ultrasonic vibration in UV-A pelleting. Currently, there are no reported studies on the relationship between charring ratio and pelleting temperature. Therefore, it is necessary to explore the optimal pelleting temperature for a low charring ratio with further obtaining a high biofuel conversion yield.

In this paper, effects of various input parameters (pelleting duration, ultrasonic power, pelleting pressure, pellet weight, and moisture content) on charring ratio and temperatures at three different locations (at the center, on the top and bottom of a pellet) were studied. In addition, the relationship between charring ratio and pelleting temperature in UV-A pelleting was explored. The obtained results will contribute to the understanding of the influences of pelleting parameters on both charring ratio and temperature for obtaining decreased charring with high yield of biofuel.

2. Experimental conditions and procedures

2.1. Biomass material and feedstock preparation

The cellulosic biomass used in this study was wheat straw collected from a farm in western Kansas. The wheat straw was run through a combine (9600, John Deere, Moline, IL, USA). The wheat straw and chaff exited through the back of the combine. The straw chopper on the combine was disconnected to allow the straw to be baled. The longest pieces of wheat straw coming out from the combine were 28 cm long.

Before pelleting, wheat straw was milled into powder by a knife

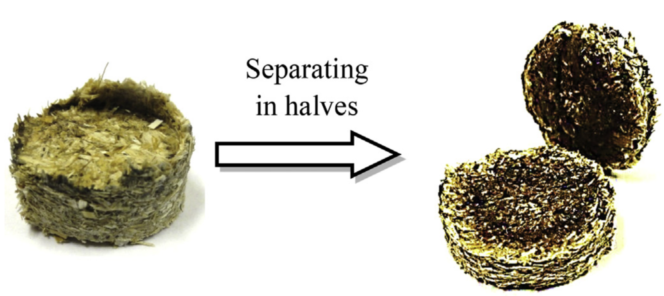

Fig. 2. Charring occurred inside pellets in UV-A pelleting.

mill (SM 2000, Retsch, Germany). The particle size of wheat straw powder was controlled by a sieve with 2 mm in size in the knife mill. The mill used a three-phase, 240 V, and 3 horsepower electric motor with fixed rotation speed of 1720 rpm.

Moisture content of cellulosic biomass was determined according to ASABE standard S358.2 DEC1988 [28] and National Renewable Energy Laboratory (NREL) technical report [29]. After measuring the initial moisture content of wheat straw powder, a certain amount of distilled water was sprayed on the wheat straw powder to adjust the moisture content to a desired level.

2.2. Experimental setup

Fig. 3 illustrates the experimental setup. A modified ultrasonic machine (Model AP-1000, Sonic-Mill, Albuquerque, NM, USA) was used to conduct pelleting. The experimented setup included an ultrasonic system, a pneumatic loading system, and a data-acquisition system. The ultrasonic system consisted of a power supply (which converted 60 Hz line electricity to 20 kHz high-frequency electrical energy) and an ultrasonic transducer (which converted high frequency electrical energy into ultrasonic vibration). An aluminum mold with a cylindrical cavity at its center was used to hold wheat straw powder and shape the pellets. A pellet was compressed by solid cylindrical tool. Diameter of the tool (17.4 mm) was slightly smaller than that of the mold cavity (18.6 mm). In addition, the pneumatic loading system provided the pelleting force. A double acting pneumatic cylinder was mounted on the top of the aluminum protecting tube which was in conjunction with the ultrasonic transducer and protected the spindle. The pneumatic cylinder was driven by compressed air provided by a 1.6 horsepower air compressor (Sears, Roebuck and Co., Hoffman Estates, IL, USA), and its movement was controlled by a two-position and five-way manual valve. The air pressure in the cylinder was controlled by a pressure regulator.

2.3. Experimental conditions

Experimental conditions were shown in Table 1. One combination of pelleting input variables was used at a time. Pelleting duration was the period of time from the beginning to the end of a pelleting test, during which the tool was in contact with the wheat straw powder inside the mold. Pelleting time referred to the time between the beginning of a pelleting test till a point of interested time. Pelleting time could be any value between starting point and pelleting duration in this paper. The frequency of ultrasonic vibration was set at 20 kHz. Vibration amplitude was controlled by the setting of ultrasonic power. Higher ultrasonic power led to higher amplitude of ultrasonic vibration. A higher pelleting pressure meant a higher pressure applied through the tool on wheat straw powder in the mold. Pellet weight was the weight of wheat straw powder in the mold cavity for each pellet.

2.4. Measurement procedure for charring ratio

Charring severity of pellets was evaluated by charring ratio (the ratio of the weight of charred biomass to the initial weight of the