Renewable Energy 55 (2013) 175–181

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Ultrasonic vibration-assisted pelleting for cellulosic biofuel manufacturing: Investigation on power consumption

Qi Zhang [a], Pengfei Zhang [a,*], Zhijian Pei [a,1], Donghai Wang [b]

[a] Department of Industrial and Manufacturing Systems Engineering, Kansas State University, 2037 Durland Hall, Manhattan, KS 66506, USA
[b] Department of Biological and Agricultural Engineering, Kansas State University, 150 Seaton Hall, Manhattan, KS 66506, USA

ARTICLE INFO

Article history:
Received 6 April 2012
Accepted 14 December 2012
Available online 20 January 2013

Keywords:
Biofuel
Biomass
Pelleting
Power consumption
Ultrasonic

ABSTRACT

Cellulosic ethanol produced from cellulosic biomass is an alternative to petroleum-based transportation fuels. Raw cellulosic biomass has low density, causing high costs in their storage, transportation, and handling. Ultrasonic vibration-assisted (UV-A) pelleting can increase the density of cellulosic biomass. Effects of UV-A pelleting variables on pellet quality (density, durability, stability, and strength) and sugar yield have been reported. However, power consumption in UV-A pelleting has not been fully investigated. This paper presents an experimental investigation on power consumption in UV-A pelleting of wheat straw. Effects of input variables (biomass moisture content, biomass particle size, pelleting pressure, and ultrasonic power) on power consumption are investigated. Results show that power consumption in UV-A pelleting increases as moisture content and particle size decrease, and as pelleting pressure and ultrasonic power increase.

1. Introduction

Liquid transportation fuels (including gasoline, diesel, and jet fuels) account for 70% of the U.S. petroleum consumption [1]. In 2010, the U.S. transportation sector consumed about 19 million barrels of petroleum every day, and about half of them were imported [2]. Use of petroleum-based liquid transportation fuels contributes to the accumulation of GHG (greenhouse gas) in the atmosphere. These conditions plus other concerns (finite reserves, non-uniform distribution, and volatile price of petroleum) make it critically important to develop domestic sustainable alternatives to petroleum-based liquid transportation fuels [3,4].

One such alternative is cellulosic ethanol made from cellulosic biomass (herbaceous, woody, and generally inedible portions of plant matter). Cellulosic biomass is abundant and relatively inexpensive. Land resources in the U.S. are sufficient to sustain production of enough cellulosic biomass (about 1.3 billion dry tons) annually to replace 30% or more of the nation's current consumption of liquid transportation fuels [5,6]. Cellulosic ethanol reduces GHG emissions by 85% over petroleum-based fuels [5,6]. In addition, a cellulosic ethanol industry would create jobs, increase farmers' income, and boost rural economy [6].

Fig. 1 shows major steps in manufacturing of cellulosic ethanol. A major challenge to cellulosic biofuel manufacturing is the high costs in storage, transportation, and handling of low density biomass. Pelleting of cellulosic biomass can significantly increase the density of cellulosic biomass and reduce the costs in biomass storage, transportation, and handling [9].

Traditional pelleting methods (e.g., using a screw extruder, a briquetting press, or a rolling machine [10,11]) usually involve high-temperature steam, high pressure, and binder materials. It is difficult to realize cost-effective pelleting at or near the fields where cellulosic biomass is available by using traditional pelleting methods. Ultrasonic vibration-assisted (UV-A) pelleting, without using high-temperature steam and binder materials, can produce pellets whose density is comparable to those produced by using traditional pelleting methods [12].

The literature on UV-A pelleting is focused on experimental investigations on pellet quality (density, durability, and stability) and sugar yield. However, power consumption in UV-A pelleting has not been fully investigated. The objective of this paper is to investigate the effects of input variables on power consumption in UV-A pelleting. The input variables include biomass moisture content, biomass particle size, pelleting pressure, and ultrasonic power.

* Corresponding author. Tel.: +1 785 532 3729; fax: +1 785 532 3738.
E-mail addresses: qizhang@ksu.edu (Q. Zhang), pengfei@ksu.edu, xyz8106@gmail.com (P. Zhang), zpei@ksu.edu (Z. Pei), dwang@ksu.edu (D. Wang).
1 Tel.: +1 785 532 3436; fax: +1 785 532 3738.

0960-1481/$ – see front matter
http://dx.doi.org/10.1016/j.renene.2012.12.015

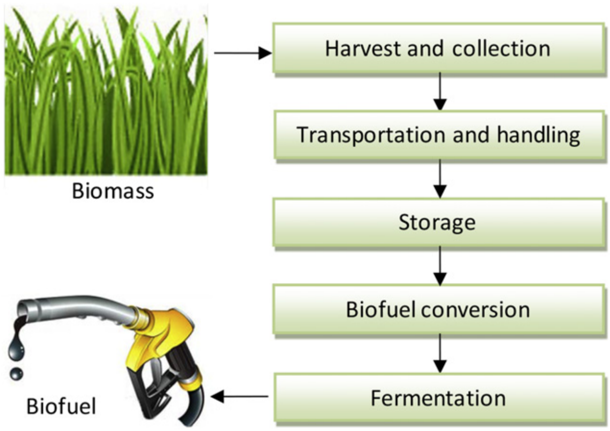

Fig. 1. Major steps in biofuel manufacturing (after Refs. [7,8]).

2. Materials and methods

2.1. Raw biomass material

The pelleting feedstock used in this study was wheat straw harvested in northwestern Kansas in July of 2010. The wheat straw had been run through a John Deere 9600 combine (that removed wheat grains from wheat straw and chaff) and collected. The collected wheat straw had an average length of 25 cm. After harvesting and collection, wheat straw was stored in bags before use.

2.2. Size reduction

The size of wheat straw was further reduced using a hammer mill (model 35, Meadows Mills, Inc., North Wilkesboro, NC, USA), as shown in Fig. 2. The hammer mill used a 240-V, 5-horsepower electric motor. The hammer mill had a steel drum containing a rotating shaft on which 24 hammers were mounted. The rotation speed of shaft was fixed at 3600 rpm and the hammers were free to swing. The size of hammers was 101.6 × 25.4 × 4.8 mm. The wheat straw was fed into the grinding drum from the top of the hammer mill. The rotating hammers impacted the wheat straw to reduce the size of wheat straw. The produced particles would pass through the sieve at the bottom of the grinding chamber when they were small enough [13]. The screen size of the sieve in the hammer mill was 2 mm.

Fig. 2. Size reduction by a hammer mill.

2.3. Separation of particle sizes

Wheat straw particles from hammer milling had a wide size distribution. The particles were then separated into different size ranges using a sieve shaker (model RX-29, W.S. Tyler, Inc., Mentor, OH, U.S.), as shown in Fig. 3. A series of sieves with different screen sizes were loaded on an agitation tray. Particles were put on the top sieve that had the largest screen size. A hammer stroke a cover located above the sieves at the rate of three times per second. Meanwhile, the agitation tray moved circularly at 200 rpm. The running time of the sieve shaker was 10 min.

Particle sizes were determined by the screen size of the sieves. Table 1 lists the screen sizes of the six sieves used to separate the wheat straw particles. Theoretically, particles should be separated into seven different size ranges with these six sieves. However, almost all particles fell through the 2.4 mm sieve, so the particle size range of >2.4 mm was excluded. Therefore, particles were separated into six different size ranges: <0.2, 0.2–0.3, 0.3–0.4, 0.4–0.6, 0.6–1.2, and 1.2–2.4 mm. These six particle size ranges were investigated in this study.

2.4. Adjustment of biomass moisture content

Biomass moisture content represents the amount of moisture (water) contained in a certain amount of biomass (wheat straw in this study). The initial moisture content was determined by drying about 25 g of wheat straw particles (after hammer milling) in an oven (Blue M Electric Co., Blue island, IL, USA) at 103 °C for 24 h according to ASABE standard S358.2 [14]. After drying, the dried particles were weighed by using an electronic scale (Ohaus, Pine Brook, NJ, USA). The initial moisture content was calculated as the ratio of the loss in weight during drying to the weight of pre-dried sample. In this study, the initial moisture content was determined as 5%.

Another four levels of moisture content were also investigated in this study: 10%, 15%, 20%, and 25%. The initial moisture content was adjusted to the higher levels by adding distilled water based on the ASABE standard [14]. Then, the wheat straw particles were stored in zip-lock bags until being pelleted.

2.5. UV-A pelleting

Pelleting was performed on a modified ultrasonic machine (model AP-1000, Sonic-Mill, Albuquerque, NM, U.S.). Fig. 4 is a schematic illustration of the experimental set-up for UV-A pelleting. The machine included a power supply (which converts 60 Hz electrical power into 20,000 Hz electrical power), a converter (which converts high frequency electrical energy into vibration), and a titanium tool (which was connected to converter). The tip of the tool was a solid cylinder (17.4 mm in diameter) with a flat end. The vibration frequency of the tool was fixed at 20 kHz.

The pneumatic cylinder was driven by compressed air provided by a 1.6 HP, 33 gallon air compressor (Sears, Roebuck and Co., Hoffman Estates, IL, U.S.). The pelleting pressure represented air pressure in the pneumatic cylinder. The air pressure was controlled by a pressure regulator. A higher air pressure in the cylinder would cause a higher pressure applied on the wheat straw particles in the mold by the tool.

Ultrasonic power was referred to the power provided by the power supply. It controlled the amplitude of the tool vibration. A larger ultrasonic power would result in larger vibration amplitude. Ultrasonic power was expressed as a percentage of the maximum ultrasonic power for the power supply. It could be adjusted from 0 (no ultrasonic power) to 100% (the maximum ultrasonic power).