Biomass and Bioenergy 98 (2017) 8–14

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Biofuel pellets made at low moisture content – Influence of water in the binding mechanism of densified biomass

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ARTICLE INFO

Article history:
Received 15 January 2016
Received in revised form
2 November 2016
Accepted 4 January 2017

Keywords:
Biofuel pellets
Moisture content
Temperature
Pressure
Density
Strength

ABSTRACT

In order to find the optimum moisture content for strength and density for pellets produced in a laboratory single pellet press, three different materials were prepared, birch *(Betula pendula)*, spruce *(Picea abies)* and reed canary grass (*Phalaris arundinacea)*. Pellets were produced at different process settings. Density and strength of the produced pellets were analyzed. Both pressure and temperature had a positive effect on pellet density and strength, while raw material moisture content was the dominant factor for pellet density and compression strength.

For all raw materials, a maximum moisture content for pellet density and strength could be found. For birch at all compression pressures, maximum pellet density and maximum strength coincided at 6.1% moisture content. For reed canary grass, optimal pellet density occurred at 5.2% moisture content, the maximum pellet strength was at 8.5% moisture content for compression pressure of 300 MPa and 400 MPa. For spruce, maximum pellet density was found at 5.1% moisture content, and maximum pellet strength at 8.3% moisture content for compression pressure of 300 MPa and 400 MPa and at 10.7% for 200 MPa. When the process temperature was increased to 80 °C, the optimal moisture content for pellet strength shifted to a lower value. The moisture content for monolayer coverage was 6.2%, 7.7%, 7.5% for birch, RCG and spruce, respectively. Optimal moisture content coincided with monolayer coverage at room temperature when the compaction pressure was sufficient high, in the case of spruce and RCG, the pressure should be above 300 MPa.

1. Introduction

In order to mitigate climate change, the use of renewable energy is getting increasingly popular, aiming to substitute the use of fossil fuels. The so called 20-20-20 targets were set by the European Commission as well as countries outside the EU to increase the share of renewable energy sources to the total energy stating that the EU should produce 20% of their energy from renewable sources, including bioenergy, by 2020 [1]. The global annual production of wood pellets was recently estimated by the International Energy Agency (IEA) to be at about 6–8 million tons, with a net potential of about 13 million tons [2].

Moisture content of the material is found to be the most important factor that affects the pellet quality [3]. Water plays a significant role in the pelletizing process, in terms of pellet quality, it can act as both a binding agent that affect mechanical durability and when it comes to the process, moisture is negatively correlated to wall friction as it function as a lubricant that lowers the friction in the die of the pelletizer [4]. Studies from industrial scale pellet production showed that strength and durability of the densified products increased with increasing moisture content until an optimum is reached [4]. Among the factors that have been affected by the moisture content of the feedstock of the wood pellet, a negative correlation has been reported between moisture content and pellet strength [5], compression strength [6], bulk density [7,8] and energy consumption [5,7,8]. While a positive correlation of moisture content and durability was reported [7,9].

Optimum moisture content of feedstock materials is required in order to produce stable and durable pellets. The optimal moisture

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http://dx.doi.org/10.1016/j.biombioe.2017.01.002
0961-9534/

varies for different feedstock types and production settings [8]. Samuelsson et al. [3] reported that optimum pellet quality of Scots pine (*Pinus sylvestris*) was obtained when the storage time exceeded 120 days and within a range of sawdust moisture content of 11–13%. According to Obernberger and Thek [10], a moisture content of the feedstock between 8.0% and 12.0% gives high quality of the pellets; otherwise, lower quality pellets would occur.

Besides moisture content, pellet quality can also be affected by content of extractives. Extractives consist of low molecular weight compounds such as fatty acids, waxes, sterols and terpenes, etc. When wood is freshly cut, these substances are concentrated at the wood surface creating a layer that prevented binding between wood particles [11]. The study from nonextracted and acetone-extracted Scots pine pellets showed that pellets made from extracted sawdust had higher density and compression strength than pellets made from fresh (nonextracted) sawdust [12]. Stelte et al. [13] studied inter-particle adhesion binding and failure mechanism of pellets made from beech (*Fagus sylvatica*), Norway spruce (*Picia abies*) and wheat straw (*Triticum aestivum*), representing hardwoods, softwoods and grasses, respectively. The results showed that compression strength were much higher for wood pellets than straw pellets at both 20 °C and 100 °C. They interpreted this to be due to the fact that the amount of extractives in the straw was much higher than in the wood species, because of the high amounts of waxes found in the protective cuticula of straw. Nielsen et al. [14] reported that the pellet strength could be connected to the extractives content and pellet strength significantly decreased with increasing extractives content, because extractives seem to prevent close contact between the bonding sites of the lignocellulose particles, thus decreasing the pellet strength. Samuelsson et al. [3] studied the effect of storage time on Scots pine pellet and stated that the increase in binding strength with storage time was due to the reduction of extractives content.

In addition to raw material moisture content and extractive content, the production variables in the pelletizing process, e.g. compression pressure and die temperature, significantly affect the pellet mechanical properties [4–6,12]. Bergstrom [12] reported that pressure and temperature had a positive effect on both pellet density and compression strength. In the study of Norway spruce pellets, Rhen et al. [6] reported that high temperature and low moisture content are the most important factors to increase the compression strength and dry density of pellets. Nielsen et al. [5] studied the importance of temperature on the pelletizing process of European beech (*Fagus sylvatica*) and Scots pine (*Pinus sylvestris*) sawdust into pellets, showing that increasing temperature decreased energy requirements and created stronger pellets.

In order to improve the industrial pellet production, a lot of researches have been done to find optimal raw material properties and process settings. However, in the industrial pellet production conditions, it is difficult to analyze how the pelletizing parameters affect individual pellet properties, for example, to measure the prevailing pressure and die temperature [6]. Therefore, this paper was performed using a laboratory scale single pellet press, where individual pellet properties could be analyzed. The aim of the work was to investigate how the moisture content and densification parameters affect pellet strength and density for birch, reed canary and spruce. The goals were: 1) to find the optimal moisture content for each material for maximum pellet density and pellet strength; 2) to determine the influence of process settings, pressure and temperature, on pellet density and pellet strength; 3) to see how the optimum moisture content for pellet density and strength fit the moisture content for monolayer coverage.

2. Materials and methods

2.1. Biomaterial

Three kinds of biomaterials, birch (*Betula pendula*), spruce (*Picea abies*) and reed canary grass (*Phalaris arundinacea*) (RCG) were prepared for comparison of compaction behavior. These materials were collected in June 2012 in the Umea region of northeastern Sweden. The chips had been stored outdoors in a pile for about 8 weeks before being used in this experiment. The materials were ground in a hammer mill (Kamas BAC-50, Malmö, Sweden) using 1 mm screen, and then sieved using 0.5 mm and 0.25 mm screen with a sieve shaker (FRITSCH, analysette3, Germany) for three minutes per batch and each time approximately 30 g of the material was sieved. A 5 kg sample of each kind of material was collected for further treatment. The sawdust of size distribution between 0.25 and 0.5 mm was utilized in this study. The mass distribution of the sieved material is given in Table 1.

2.2. Extractives and ash content

Fatty and resin acids in the samples were extracted using an extraction system (Universal extraction system B-811 from Büchi Labortechnik AG, Flawil, Switzerland). The extraction solvent was a mixture of petroleum ether (bp 40–60 °C) and acetone (90–10 v/v). The extraction time was 1 h and the extractions were repeated twice for each material. Ash content was analyzed according to standard [15]. Table 2 shows the result of extractives and ash content of the three raw biomaterials, birch, spruce and reed canary grass.

2.3. Moisture adjustment

The evaluation of the effect of the raw material moisture on the properties of the pellets was carried out at seven moisture levels. The initial moisture content of the birch, reed canary grass and spruce was 2.9%, 7.3% and 4.9% respectively on wet basis. The materials were thereafter conditioned to a desired moisture content of approximately 8% by adding an appropriate amount of water using a spray bottle, and then were stored in sealed plastic bags for equilibrium for one week. To adjust the moisture content of the materials to the desired levels, which were about 8%, 7%, 6%, 5%, 4%, 3% and 2%, the samples were placed in an environmental chamber (CLIMACELL, CLC 111-TV, MMM Medcenter Einrichtungen GmbH, Planegg, Germany) set to operate at 25 °C and 20% relative humidity. The moisture content was quickly checked every day using a moisture scale (Mettler Toledo, HR 83 Halogen, METTLER-TOLEDO AG, Laboratory & Weighing Technologies, CH-8606 Greifensee, Switzerland). The materials were removed from the chamber after gaining the desired amount of moisture and placed in sealed plastic bags. Moisture content of the materials and pellets were analyzed according to the standard method by drying of 1–2 g sample ma-

Table 1
Mass distribution of raw materials.

Fraction (mm)	Mass		
	Birch	[a]RCG	Spruce
>0.5	10.4%	8.7%	17.7%
0.25–0.5	56.3%	40.4%	39.1%
<0.25	33.3%	50.9%	43.2%

[a] RCG: reed canary grass.