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Study on the effects of raw materials composition and pelletization conditions on the quality and properties of pellets obtained from different woody and non woody biomasses

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HIGHLIGHTS

- Higher lignin and lower extractives contents led to pellets with higher mechanical durability.
- Low lignin biomasses had a lower degree of deformation when pelletized.
- Pellets which exhibited lower mechanical durabilities also displayed a looser structure.
- 2 mm milling size produced pellets with higher mechanical durability for most materials.

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ABSTRACT

Different biomass types display very different characteristics relating to pelletization conditions and pellet quality. The aim of this study is to analyze the effect of biomass composition and milling size on pelletization parameters and the physical quality of the pellets obtained. Nine different woody and non woody biomass raw materials were pelletized in a bench scale pellet press. Materials were milled at 2 mm and 4 mm screen size and compositional analysis of all the tested biomasses was performed. Pellet mechanical durability and fines content were analyzed as well as the power demand of the press and temperature of the die reached during pelletization. In addition, scanning electron microscope images of the raw materials and the transverse fracture of the pellets were obtained.

Pellets obtained from 2 mm milled materials showed higher mechanical durability values. Pellets obtained from woody materials, which exhibited lower extractives and higher lignin contents, evidenced also a higher physical quality. Power demand and temperature of the die were also higher for woody materials, suggesting a higher friction inside the die channels. SEM images showed a closer agglomeration of the particles when materials were milled at 2 mm. Woody particles had a more evident deformation when pelletized while herbaceous materials preserved their shape. Different bonding interactions could be observed in pellets from different materials.

1. Introduction

Biomass raw materials often have some characteristics such as heterogeneous particle shapes and sizes, high moisture content and low energy density that make their use as a solid biofuel difficult. Pelletization has provided a technology to obtain a low moisture, dense and uniform biofuel which can be used in different applications, including household stoves, boilers and power plants.

The production of wood pellets has increased largely over the last years. In 2006 the worldwide wood pellet production excluding Asia, Latin America and Australia was between 6 and 7 million tons while in 2010 production of the same countries had increased to 14.3 million tons. Thus, production grew over 100% in that period [1].

Most of the world wood pellets are produced from sawdust obtained at sawmills. The crisis in the housing sector and the large growth of the pellet industry in the last years has decreased the availability of these traditional raw materials. Therefore there is a growing interest in the study of new materials which might be suitable for pelletization [1].

It is important that pellets from new materials reach a sufficient quality. Physical quality parameters of the pellets like mechanical durability, particle density and bulk density have to be controlled

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as well as their chemical composition and fuel performance. For this purpose, different quality standards have been developed, mostly in European countries.

Pelletization consists of the extrusion of the raw materials through a ring or flat hollowed die by the pressure of two or more rollers. The friction of the materials with the die hole walls produces an increase of pressure and temperature which leads to the material agglomeration. Pellets leaving the die are then cut down to a suitable length by the action of a blade.

The agglomeration of the lignocellulosic materials to form pellets occurs due to different inter-particle bonding mechanisms favored by the softening of different components at conditions of high pressure and temperature. In the field of hardboard manufacture, Back has found that at these conditions, hydrogen bonds between adjacent hemicellulose and amorphous cellulose play a major role in the inter-fiber bonding processes. According to his work, covalent bonds also occur in the inter-fiber bonding area of particles, lignin being the most reactive wood polymer in these autocrosslinking reactions [2].

Kaliyan and Morey described the creation of "solid bridge" type bonding between particles in corn stover and switchgrass pellets. According to their results, the potential natural binding components in these materials are water soluble carbohydrates, lignin, protein, starch and fat [3].

Other authors studied the bonding and failure mechanisms of pellets from beech, spruce and straw. In the case of wood pellets, they signaled van der Waals forces and hydrogen bonds being mainly responsible for agglomeration; solid bridge formation was observed in beech pellets but not in spruce ones. The presence of waxes on the straw surface produced a weak waxy boundary layer, resulting in a lower strength. Additionally, they found that temperature played an important role in the bonding mechanisms, obtaining in every case higher compression strength for pellets produced at higher temperatures [4].

Therefore, many factors play an important role in the results obtained in a determinate pelletization process. Raw materials composition, particle size or moisture content have proven to have an effect on the pellets physical quality and pellet press energy demand [5,6].

A better understanding of the reasons for quality differences among different materials is desirable.

In this study, different woody and non woody raw materials were selected to analyze their pelletization behavior: pine, eucalyptus, pyrenean oak, vine shoots, two different poplar biomasses, oats, triticale and rice. Materials were milled at 2 and 4 mm screen sizes to determine the effect of the particle size on the pelletization conditions and final pellets quality. Pellets mechanical durability and fines contents, temperature of the die and power demand were registered. Compositional analysis was developed and SEM images were obtained in order to study the influence of the biomass constituents and structure in the pelletization of the different biomasses.

2. Materials and methods

2.1. Raw materials

Nine different lignocellulosic materials were studied comprising softwood, hardwood and herbaceous species, as follows:

Softwood:
Logging residues from *Pinus pinaster* (PIN).
Hardwoods:
Chips from whole trees of *Eucalyptus camaldulensis* (EUC).
Quercus pyrenaica (Pyrenean oak) logging residues (OAK).
Two different poplar (*Populus nigra*) biomasses: Chips from short rotation coppice (SRP) experimental plots and from logs from a commercial crop (POP).
Vine shoots (*Vitis vinifera*) (VIN).
Herbaceous species:
Aerial parts of oats (*Avena sativa*) (OAT) and triticale (*X Triticosecale*) (TRI) collected before grain formation; and rice straw (*Oryza sativa*) (RIC).

All the woody species were first crushed in a knife mill equipped with a 20 mm screen. Pine, eucalyptus, oak, oats, triticale and rice biomasses were dried in a Trommel dryer at temperatures between 70 and 100 °C while poplar and oats were air dried. Then, all the materials were ground in a hammer mill at 2 mm and 4 mm to analyze the effect of the milling size. Milled materials were stored in air tight bags. The moisture content of the different materials prior to pelletization varied between 10% and 12%.

2.2. Pelletization

The different materials were pelletized in a bench scale pellet press (Kahl 14-175) equipped with a flat die. The specifications of the press can be seen in Table 1. The mass flow was set at 500-550 g/min by measuring repeatedly the weight of pellets produced in a minute for each material and adjusting the feeder drive accordingly. The rollers worked at 50–60 rpm.

The press was fed with each different material until the temperature did not vary more than 2 °C degrees over a period of 5 min. Then, five consecutive samples were collected, each one containing the pellets produced during 2 min. Samples were let cool down for an hour and bagged in air tight bags. The power demand and the temperature of the die were recorded by noting every 30 s the values displayed in the pellet press controller.

2.3. Laboratory samples preparation

The five samples obtained from each material were mixed to obtain a combined sample. Afterwards, laboratory samples for each test were obtained according to the EN 14780:2011 [7].

2.4. Property analysis

2.4.1. Durability

Five measures of mechanical durability for each batch were performed according to the Austrian ÖNORM M 7135 norm. Samples were analyzed in a Lignotester. With this method a sample of 100 g of pellets is introduced in a perforated chamber and then, exposed to a 70 mb air flow for one minute. The durability is defined as the remaining weight, divided by the initial weight and multiplied by 100. Mechanical durability data obtained by this method can lead to slightly different results and higher standard deviations when compared to those obtained according to the current European standard EN 15210-1:2009 [8–10].

Table 1
Pellet press specifications.

Property	Value
Die diameter	175 mm
Die channels length	24 mm
Die channels diameter	6 mm
Engine power	3 kW
Number of rollers	2
Roller linear speed	0.5–0.8 m/s
Rollers width/diameter	14.5/130 mm