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Research paper

Effect of process parameters and raw material characteristics on physical and mechanical properties of wood pellets made from sugar maple particles

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ABSTRACT

The aim of the current study was to investigate the influence of process parameters and raw material characteristics on physical and mechanical properties of wood pellets made from particles of sugar maple trees of different vigor. Pellets were made in a single pelletizer while controlling temperature (75, 100 and 125 °C), moisture content (8.1, 11.2 and 17.2%), compression force (1500, 2000 and 2500 N) and particle size (<0.25, 0.25–0.5 and 0.5–1.0 mm). Particle size was the most important factor influencing friction in the die, followed by moisture content, compression force and temperature. Moisture content was the most important factor affecting pellet density, followed by temperature, compression force and raw material particle size. Temperature was the most important factor for pellet compression strength, followed by compression force, particle size and moisture content. Friction in the die decreased with increasing particle size and moisture content of the material and increased with increasing compression force. It decreased initially with increasing temperature from 75 °C to 100 °C, and then increased with temperature. Density and strength of pellets increased with temperature and compression force, decreased with increasing particle size, and decreased with increasing moisture content. Pelletizing should be performed at 100 °C to minimize friction and a moisture content of 11.2% to maximize density and compression strength of the pellets. Wood particles from sugar maple trees of low vigor were more suitable for making wood pellets in terms of friction in the pelletizer and compression strength than those from vigorous trees.

1. Introduction

The Northern hardwood forests of Québec, Canada, are composed largely of sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britton). Several decades of subjecting these hardwood forests to selective harvesting where the most valuable high quality trees were removed, left the productive hardwood stands with low commercial value [1]. The restoration of more productive and ecologically desirable conditions through appropriate silvicultural practices requires the ability to gradually remove low vigor trees, with retention of vigorous growing stock of the desired species. However, the cost of harvesting low vigor trees rapidly becomes an obstacle because they often have low commercial value for traditional products such as lumber or pulp [2]. In such situations, wood energy markets can provide the economic incentive for removal of low value trees from forests.

Provided the existence of a suitable market, harvesting priority can be given to low vigorous trees in partial cuts as a means to restore depleted hardwood forests. Among tree classification systems that have been developed to assess tree vigor prior to harvesting, the MSCR classification system proposed by Boulet [3] is used as tree marking guide for selection cuttings in the province of Québec, Canada. Based on pathological symptoms (e.g. presence of cankers and fungi), mechanical damage (e.g. cracks, leaning) and other visible features (e.g. improper branch shedding, crown openness), it defines more than 200 vigor codes, which are then grouped into four vigor classes: trees of reserve stock (class R) are free of any symptoms of disease or damage and are considered as healthy trees with highest probability of survival; growing trees (class C) have minor defects but are not biologically declining and are expected to survive until the next harvest without risk of

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imminent wood decay; low quality or defective trees (class S) are considered to be declining in terms of vigor, wood quality and volume increment, and are not expected to survive until the next harvest; and moribund trees (class M) show signs of either lethal pathological infection or severe damage with high risk of trunk breakage. Moribund trees are biologically declining and are assumed to have a high probability of mortality before the next harvest entry. According to Hartmann et al. [4], typical fungal infections for sugar maple involve the northern tooth fungus *(Climacodon septentrionalis* P. Karst.), which causes severe crown dieback. Sugar maple trees showing signs of this fungal infection are classified as moribund. The unused available annual forest biomass in the Province of Québec, Canada, is estimated at 6.4 million anhydrous metric tons including 3.5 million tons in the form of tree trunks and 2.9 million tons in the form of crowns and branches. More than half (55%) of this volume is coming from low vigor trees not suitable for lumber production [5]. The availability of these unused low quality trees could thus represent a significant source of feedstock for the production of biofuel.

In recent years, a clear interest arose for the use of forest biomass as biofuels. This was motivated not only by its low environmental impacts and carbon emissions, but also because meeting the global increase in energy consumption may not be achievable without the contribution of biofuels [6,7]. It has been argued recently that a better use of biomass would be to burn it in the form of solid fuel for the generation of electricity to power electric vehicles [8]. Particularly, modern solid fuel combustion technology has been developed with much cleaner and efficient combustion than in the past. Solid biomass fuel, e.g. in the form of pellets, could thus become a more important energy commodity [9]. The CEN/TS 14588 standard [10] defines wood pellets as densified biofuel made from pulverized woody biomass with or without additives, usually with a cylindrical form in diameter of 6–10 mm and a random length of typically 5–40 mm with broken ends. The homogeneity in size, shape and quality of pellets makes them well-suited for fully automated feed systems [11]. Pellets could be used as fuel directly in several applications from residential heating stoves to central heating boilers [12]. They can even be used as a fuel source in large-scale power plants [13], or as part of the process to produce liquid fuels [14]. Wood pellets are standardized and traded at both national and international levels. These features combined with their advantages such as environmental benefits, high energy content due to their high density and low moisture content, and relative convenience of transportation and storage explain the rapid growth of the global wood pellets market, both in terms of production and consumption.

In Canada, the wood pellets industry is well developed. It produced more than 1.5 million tons in 2011 and continues to be one of the world leaders in wood pellet production. In the beginning of 2012, Canada had 39 operational wood pellets plants with a capacity of 3.2 million tons per year [15]. The production capacity has grown significantly in recent years. However, wood pellets producers are facing a shortage of the traditional raw material supply (i.e. sawdust and wood chips) due to the recent downturn in the commodity wood products industry. This has increased the interest in finding new raw material sources from forests in sufficient volumes and in a sustainable manner. With the increase in fossil energy prices and environmentally efficient technologies such as those used by St-Pierre et al. [16] and Ngueho Yemele et al. [17] for the extraction of wood and bark, the harvesting of low quality sugar maple and/or yellow birch trees from high-graded hardwood forests as new sources of raw material for biofuel pellets production is likely to become a viable option.

Hardwood particles are difficult to use for pellets production because the frictional forces in the compression channels of the die are high compare to softwoods and other biomass. Consequently, the pellet mill is prone to blockage when hardwoods are used [18,19]. According to Obernberger and Thek [12], the process of densification in the pellet mill depends on the friction between the compression channel and the raw material, which is largely determined by the moisture content of the raw material. This is why the optimal moisture content has to be determined according to the pelletizing technology and the raw material used. Moisture contents in the range of 5–10% are usually optimal for woody raw material. Moisture contents of 6–10% for beech wood [20], of 5% for olive tree wood [21], and of 6–8% for pine wood [22] have been reported as appropriate. Tumuluru [23] reported that it is possible to produce corn stove pellets from feedstock at high moisture content in the range of 28–38% (w.b.) by varying other process parameters. Gunnerman [24] found that the moisture content of organic fibrous material in pelletization can be within the range of 16–28% but the best results were obtained for moisture content between 20% and 24%. Both Tulumuru [23] and Gunnerman [24] suggested that high moisture content pellets can be dried to safe storage moisture content by using cost and energy efficient drying systems.

Another problem occurring during pelletization is overheating. Heat is generated during pelletization due to friction between the ground material and the walls of the pellet mill. Serrano et al. [25] studied the heat distribution in a pellet press and found that under operation at stable conditions, the temperature of the die is about 90 °C, while the temperature of the biomass is about 70 °C. Nielsen et al. [22] reported that the pelletizing process generates heat that maintains the temperature of the operating die at 110–130 °C. The results conducted by Holm et al. [18] showed that the pellet mill was blocked after a few minutes of pelletizing a mixture of 40% (by dry weight, wt) pine shavings and 60% (wt) beech dust. The temperature of the pellets in the matrix was recorded at approximately 120 °C in this case. However, a mixture of 80% (wt) pine shavings and 20% (wt) beech dust could be pelletized without problems with pellets temperature of approximately 105 °C while the pellets temperature of pure pine shavings was approximately 90 °C.

A single pelletizer cannot simulate all aspects of a large-scale pelletizing process; for example, the flow of feedstock into the openings of the press channels [26,27]. However, using a large-scale pellet mill to study the effects of various parameters on pelletizing characteristics and pellets quality is time and material consuming, and some process parameters such as temperature and friction in the channels of the die cannot be easily controlled because of their interaction effects [28]. A single pelletizer is therefore widely used method for testing the pelletizing characteristics of a new type of biomass. The effect of die temperature, pressure, raw material moisture content, and other parameters can be quickly tested and screened with the single pelletizer before scaling up to an industrial pellet mill.

The objectives of this study were (i) to investigate the effect of compacting temperature, moisture content of the particles, compression force, and particles size on the physical and mechanical properties of pellets pressed from raw material obtained from low and high vigor sugar maple trees; (ii) to determine which combinations of these independent variables provide the best pelletizing process in terms of friction force and pellets quality.

2. Experimental

2.1. Raw material

Pelletizing experiments were conducted only from material obtained from the sugar maple trees sampled in this study. The trees were harvested in July 2010 from two mixed hardwood stands