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# Moisture content and storage time influence the binding mechanisms in biofuel wood pellets

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## HIGHLIGHTS

- ▶ Pellet bulk density and energy consumption is mainly determined by moisture content.
- ▶ Durability and fines are determined by moisture and storage time in a complex model.
- ▶ A qualitative model for binding mechanisms in wood pellets is suggested.

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## ABSTRACT

In a pelletizing experiment the three factors sawdust moisture content, steam conditioning of the sawdust, and storage time of the raw material, were varied in a full factorial design with a total of 34 experiments to evaluate the influences on the pelletizing process and the pellet quality when producing biofuel wood pellets from pine sawdust. Moisture content of the sawdust was found to be the dominant factor for the bulk density and for the pelletizer motor current, both showing low values at high moisture contents due to the lubricating property of water that lowers the friction in the pelletizing process. More complex models were obtained for mechanical durability and the amount of fines, where all factors and most interactions and squared terms were significant. In order to explain the effect of the sawdust moisture content and the storage time on these response factors, a qualitative model for the binding mechanism is suggested. In this model water is supposed to be actively involved in the binding mechanism as hydrogen bonded bridges. The increase in binding strength with storage time is explained by the reduction of extractive content which contain molecules that can block binding sites on the material surface. Optimum pellet quality was obtained when the storage time exceeded 120 days and within a range of sawdust moisture content of 11–13%.



## 1. Introduction

Biofuel pellet quality is a result of used feedstock and process settings in the pelletizing process. The industrial pelletizing process is partly quite rigid when it comes to process control. Process settings such as particle size distribution, die channel length, gap between rollers and die, cannot be altered without interrupting the production for adjustment. In most cases, the only real-time process controlling parameters, besides blending of raw materials, are feeding rate, raw material moisture content, and steam conditioning.

Bulk density, mechanical durability and fines are among the most important quality parameters for fuel pellets. Bulk density is a measure of the extent of the compaction of the particles in the pellet, while the durability and the fines is a result of the bonding strength between the particles in the pellet. The latter are strongly correlated where high durability results in low amount of fines.

Bonding mechanisms have been widely discussed in the literature [1–6]. Rumpf [1] was the first to describe possible mechanisms of bonding in granules and agglomerates and he proposed the following five mechanisms: (i) attraction forces between solid particles; (ii) interfacial forces and capillary pressure in movable liquid surfaces; (iii) adhesion and cohesion forces; (iv) solid bridges; (v) mechanical interlocking between particles.

Attraction forces between solid particles, i.e. hydrogen bonds and van der Waals forces, are short range forces that are active only when particles are close together and the attraction decreases rapidly when the distance is increasing. Interfacial forces and capillary pressure in movable liquid surfaces are results of surface tension and capillary forces between the liquid and the particles. These forces create strong bonds between particles but disappear when the liquid evaporates. Cohesion is the attraction between

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molecules of the same substance, while adhesion is the attraction between molecules of different kind. Solid bridges are formed by different mechanisms basically at high pressure and temperature by crystallization of dissolved substances, hardening of binders, and melting and sintering of various pellet components. Mechanical interlocking is a bonding mechanism where the particles fold about each other to form interlocking bonds.

Water has a crucial role in the pelletizing process [3–5]. It is found to be the most important factor influencing the pellet quality and it can act as both a binding agent that affect mechanical durability and fines, and as a lubricant that lower the friction in the die resulting in low bulk density and energy consumption [5].

Inherent physical and chemical properties of raw materials can be manipulated to tailor the fuel pellet feedstock. An example is how process operators in plants producing wood pellets have found that seasoning of pine sawdust in piles for a period of time before pelletizing improves the pelletizing properties. It is well known that seasoning of softwood sawdust reduces the concentration of extractives and that of the two major Scandinavian softwood species Scots pine has higher extractive content than Norway spruce [7]. Since fresh pine sawdust show very different properties in the pelletizing process compared to stored pine sawdust and spruce sawdust it has been suggested that the extractive content is influential on pelletizing properties and pellet quality [8–10]. However, detailed studies have not been performed to quantify the influence of different process settings on pine sawdust with varying seasoning time and the effect of sawdust moisture and extractive content. In this study, the three factors sawdust moisture content, steam conditioning of the sawdust, and storage time of the raw material, were varied in a full factorial design with a total of 34 experiments to evaluate the influences on the pelletizing process and the pellet quality when producing biofuel wood pellets from pine sawdust. The objectives were (1) to determine the influences and interactions of these factors on pellet quality responses, (2) to quantify a required seasoning time for optimum pellet quality and (3) to develop a qualitative model for the binding mechanisms in pellets with different moisture and extractive contents.

## 2. Materials and methods

### 2.1. Biomaterials

Scots pine (*Pinus sylvestris* L.) sawdust originating from latitude 64 °N in Sweden was delivered from a sawmill (SCA Timber AB in Holmsund, Sweden). About 18 tons of sawdust was transported and stacked on asphalt at the end of June at the Swedish national pilot plant Biofuel Technical Center (BTC), Swedish University of Agricultural Sciences (SLU), Umeå, Sweden.

The pile (3 m high, 5 m wide at the bottom, and 10 m long) was stored for 160 days, during which extractive content and content of Klason lignin were monitored. At specific storage times (0, 46, 81, 117 and 160 days) batches were taken from the short end of the pile after removal of a protecting sawdust layer of about 2 m along the pile. The protecting sawdust layer was put back again after each sampling occasion. This was done to ensure that the batches were taken from the inside of the pile with a similar environment each storage time.

### 2.2. Experimental

All pelletizing experiments were performed at the SLU BTC national pilot plant and the experimental set-up consisted of a horizontal batch drier, a combined mixer wagon and balance, conveyor systems, mill, steam treatment equipment, pelletizer and pellet cooler. The full system is described in detail in [10]. The pelletizer (SPC PP300, Swedish Power Chippers, Borås, Sweden) with a capacity of 300 kg/h, was equipped with a fixed die (outer diameter 540 mm, press channel lengths of 55 mm) and two rotating press rollers (200 mm in diameter). The mill had a 4 mm sieve, and saturated steam was generated by a steam boiler to a temperature of 111.0 ± 0.76 °C. The steam conditioning of the sawdust material was carried out during 2 min just before reaching the pellet press. The pelletizer was controlled by a programmable logic controller (PLC) (Swedish Power Chippers, Borås, Sweden).

Drying of the raw sawdust with approximately 50% moisture content was executed on a ventilated batch drier with a capacity of about 400 kg/batch and the temperature of the in going ventilating air was about 40 °C. The drying process was continued until the moisture content of the material was close to the design value, which was controlled by repeated moisture content measurements using a moisture balance (Sartorius MA30, Tillquist, Sweden).

A drying cabinet (1600 × 800 × 700 mm) (Elvärmedetaljer, Sweden) calibrated to 105 ± 2 °C was used for oven drying of the samples collected from the pelletizing trials. Temperature calibrations were carried out using a thermometer (Technoterm 9300, Nordtec Instrument AB, Sweden) calibrated at an accredited laboratory (AREPA Mätteknik AB, Sweden). The size of the drying trays was 750 × 600 mm and the samples were weighed to 0.1 g accuracy with a balance (Mettler PE 16, instrument TEKNIK, Sweden).

### 2.3. Experimental design

Pelletizing of the sawdust was executed in a full factorial design with three parameters: storage time at the five levels: 0, 46, 81, 117 and 160 days, moisture content at the three levels: 8.4 ± 0.48%, 10.7 ± 0.38% and 13.1 ± 0.38%, and steam treatment at the two levels: 2 and 6 kg/h. There were some difficulties to reach the intended design values of 8%, 11% and 14% for the moisture content, especially for the upper level, probably due to loss of moisture after the drying process was completed. For determination of experimental precision, three replicates of the experiments with moisture contents of 11% and storage time of 160 days were carried out for both steam levels, respectively. In all, the design for pelletizing consisted of 34 experiments in a randomized order except for storage time. About 75 kg of sawdust was milled and compressed into pellets in each experiment. The response factor parameters measured during each experiment were: bulk density and mechanical durability of produced pellets, the share of fines generated during the pelletizing process, and the energy consumption of the pelletizer recorded as the mean current during a 2 min measurement period. Each experiment lasted for about 30 min at a production rate of 154 ± 11 kg/h, where the first 20 min were used to stabilize the process and obtain a fairly constant die temperature. During the last 10 min of each experiment, pelletizer motor current was monitored and samples of 1 L milled sawdust, and 5 kg pellets were collected during two different measurement periods.

All samples of sawdust and pellets were analysed for moisture content according to the CEN standard [11]. In Fig. 1 the correlation between sawdust moisture content and pellet moisture content for the 2 kg/h steam treatment is shown. The content of fines produced in the pelletizing process was quantified by manual sieving of an 8 L sample of pellets through a 3.15 mm sieve, and calculated as the percentage of the loss of the fine material to the total sample weight. Pellet bulk densities were determined using the CEN standard [12]. Mechanical durability of the pellets was measured by use of a pellet tester (Q-tester, Simon Heesen BV, Netherlands) according to the CEN standard [13]. The pellet length distribution was determined by subsequent dividing of the pellet sample until about 10 pellets remained followed by a length determination using a calliper.