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Clarifying sub-processes in continuous ring die pelletizing through die temperature control

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ABSTRACT

A pilot scale pelletizer with a custom-made die temperature control system was used for pelletizing of a typical Nordic softwood blend in an experimental design where die temperature, moisture content, and steam conditioning were varied independently. Steam conditioning, expressed as material temperature, showed a strong negative correlation with the pelletizer motor current, but had no significant effect on other responses. Die temperature was negatively correlated to bulk density and durability. This negative correlation is contradictory to results from a pilot scale study where die temperature co-varied with other factors, and to results from single pelletizing studies that do not mimic the friction originated pressure build-up that is required for pellet formation in a continuous process.

1. Introduction

Biomass has a key role in transforming the world's energy systems into orbits of renewable sources and energy carriers. The potential of biological materials is huge, and by suitable pre-treatment – i.e. drying, milling, and compaction – transportation, handling, storage and end-use are simplified [1]. Pellets are a standardized refined biomass product that is traded internationally. Standardized pellet quality parameters with a practical effect on handling and storage are described mainly in the following properties; bulk density, mechanical durability, and amount of fines. Bulk density should be high to ensure transport and handling efficiency. The mechanical durability is important as pellets should sustain being blown as bulk cargo and transported in screw conveyors, lifts and through burners without breaking into small pieces and dust that can block the supply chain. The amount of fines is restricted to be below a certain limit to ensure safe handling, thereby avoiding dust induced fire, explosion, and health hazards. Further, even though costs in pellet production are dominated by raw material, drying, and personnel, pelletizing itself constitutes around 10–15% of the pellet production costs [2] and guidance on how to reduce the energy required in the pelletizing process while sustaining high pellet quality is welcome to pellet producers.

Pelletizing research is typically performed in two distinctively different environments: i) lab scale single pelletizing [i.e. 3–6] and ii) pilot scale continuous pelletizing [i.e. 7–12]. Lab scale single pelletizing requires small amounts of raw material and provides a high degree of control over process parameters that can be varied independently. Raw material factors (material type, particle size, moisture content, etc.), die temperature, and compression force are varied and responses such as pellet density, pellet strength, and friction force when pushing the pellet out of the die, are measured. The abovementioned responses are interpreted as indirect measures of pellet bulk density, pellet durability, and pelletizing energy consumption. Single pellet studies are cheap, fast, and controllable, but have their challenge in providing an experimental setup that can produce data with relevance for the continuous ring die pelletizing process with industrial implication.

In pilot scale continuous ring die pelletizing, process parameters cannot be varied independently and thereby the range of settings is limited. Pilot scale operations require an infrastructure that can provide large amounts of raw material, and thus, research is costly and time consuming. However, pilot scale pelletizing research has a clear advantage in being performed within the actual process relevant for industrial applications.

In regular ring die pelletizing, die temperature and compression force cannot be controlled but are co-varying with material properties (i.e. moisture content) and process settings (i.e. die channel length). For each specific setting, the process will stabilize at a specific die temperature and motor current (the latter giving an indication of the applied compression force).

For this study, custom-made equipment for die temperature control in a ring die pelletizer was used to overcome the co-variation of die temperature with other process parameters. The setup had been used in

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two previous studies, showing that die temperature control is efficient for overcoming discontinuous production in straw material pelletizing [9] and that pellet quality can be improved by manipulating the die temperature [7]. In the present study, emphasis was put on using the benefit of die temperature control for evaluation of the true effects of moisture content, steam conditioning, and die temperature when die temperature was varied independently from other factors.

Further, the setup gave unique opportunities for gaining a deeper understanding of the effects of steam conditioning in fuel pelletizing. Through steam conditioning, both heat and moisture are added to the raw material and pre-conditioning of raw material by the use of steam is widely used in fuel and feed pelletizing [13]. Steam conditioning is in the fuel pelletizing process expressed in at least three vectors; material temperature, die temperature, and moisture content. The custom-made experimental setup made it possible to isolate the material temperature increment from the other factors, and to further investigate the impact of that vector.

For this study, a typical softwood blend was pelletized in an experimental design where die temperature, moisture content, and steam conditioning were varied independently. The aim was to 1) model the non-confounded effects of moisture content, steam conditioning, and die temperature on pellet quality and energy consumption in continuous ring die pelletizing and 2) make comparisons with results from lab scale single pelletizing studies and with previous continuous ring die pelletizing studies where die temperature co-varied with other factors.

2. Material and methods

2.1. Material

A sawdust mixture consisting of 50% Norway spruce (*Picea abies* L. H. Karst) and 50% Scots pine (*Pinus sylvestris* L.) was delivered at 10% wet base (w.b.) moisture content from the Neova pellet mill, Främlingshem, Valbo, Sweden to the Biofuel Technology Centre, Swedish University of Agricultural Sciences, Umeå, Sweden. The sawdust was hammer milled (Vertica Hammer Mill DFZK-1, Bühler AG, Uzwil, Switzerland) with a screen size of 4 mm. Moisture content after milling was around 9% w.b. For each point in the experimental design, approximately 150 kg of material was prepared. Moisture contents were adjusted according to the experimental design by adding water during mixing in a screw blender, and prepared materials were left overnight to reach moisture equilibrium.

2.2. Experimental setup

Pelletizing experiments were performed using an SPC PP300 Compact pelletizer (Sweden Power Chippers, Borås, Sweden), with a maximum capacity of 300 kg/h. The pelletizer is equipped with a steam generator (1 bar, 120 °C), and a cascade mixer for mixing steam homogenously into the material flow at ambient pressure. The die is stationary with drive on the roll suspension instead of the die. The experimental setup with die temperature control and measurement systems is described in detail by Larsson et al. [7]. Two circumferential slits (width: 12 mm, depth: 12 mm) are cut out at both sides of die channel rows in the die, into which copper coils (outer diameter: 12 mm, inner diameter 10 mm) for cooling and heating media are inserted. During cooling, water was used as the medium and circulated through a large tub where ice and snow were added continuously to keep a temperature of 0 °C. During heating, hydraulic oil was used as the medium and the oil was heated with an electrical heater to a maximum temperature of 155 °C. Throughout the experimental series, a die channel length/width of 52.5/8 mm was used, and the pellet production rate was adjusted towards a set point of 180 kg/h.

2.3. Experimental design

Controllable factors for the experimental design were; die temperature (°C), raw material moisture content (%, w.b.), and material temperature (°C). By using raw material temperature as a measure for steam conditioning, continuous logging of the parameter was made possible, and achieved factor settings could be followed up.

The experimental design chosen was a $2 \times 2 \times 2$ factorial design. Fixed levels were chosen according to the following; die temperature at 40 °C—representing a low level only achievable with die cooling, and 100 °C—representing a medium high biofuel pelletizing die temperature, raw material moisture content at 9.5 and 12.5% w.b. which is a typical moisture range for softwood pelletizing, and 23 °C and 55 °C for material temperature (equaling no steam conditioning and approximately 6 kg/h, which is a medium high steam conditioning level for softwood pelletizing). A center point for die temperature and moisture content was added at each of the low and high steam conditioning levels. Thus, the total number of runs was $2 \times 2 \times 2 + 2 = 10$. Because of the nature of the raw material, exact level settings were not achieved, and thus, factors could not be coded at -1 and 1. Instead, range scaling [14] was used. Studied responses were typical pellet quality responses; pellet bulk density (kg/m^3), pellet durability (%), and amount of fines (%). Pelletizer motor current (A) was used as a measure for energy consumption. Pellet temperature (°C) was also measured and modeled.

2.4. Data collection; measurements of factors and responses

Each experimental setting (run) was divided into three, two minute long, measurement periods (e.g. M1:1, M1:2, M1:3) when data and materials were collected. During two minutes, a sample amount of approximately 6 kg was produced, which was just enough for further pellet quality analyses, and the data sampling period was long enough to achieve representative data. For modeling, mean values of the data gathered at the three measurement periods were calculated to represent each of the 10 runs. Achieved settings for the experimental design and corresponding measured values are shown in Table 1.

Just before each measurement period, the milled raw material was sampled before and after the steam conditioner and hot pellets just as they came out of the die. Samples were immediately sealed in plastic bags and kept for moisture analysis. Sampling of the milled raw material after steam conditioning was difficult due to steam leakage and condensation of steam on the sampling equipment. Hence, values for raw material moisture content after steam conditioning should be treated with caution. Pellets produced during each two-minute measurement period were collected in 20 L open plastic trays and weighed to determine the production rate, then left overnight to cool down where after samples were sealed in plastic bags until further analysis (cool pellet moisture content and pellet quality analyses).

Die temperature and pelletizer motor current were measured and logged continuously (1 Hz) as described in [9]. Due to the die being stationary, and the pelletizer not running at maximum production capacity, pellets were not produced in all sections of the die. Pellet production was concentrated to the left side of the die, and thus, die temperature measured at the left side was used for modeling. Pellet temperature was measured throughout each measurement period with a hand held IR sensor (Optris CT laser 75:1, Optris GmbH, Berlin, Germany) directed towards the pellet surface at the outlet of a die channel. The IR sensor was directed towards one specific pellet channel outlet until a stable pellet temperature value was obtained. The IR sensor was calibrated according to the manual and special caution was taken to avoid measurement disturbing vapor formation on the sensor. Die temperature, pelletizer motor current, and pellet temperature (when applied) were logged continuously (1 Hz) with a data logger (PC-logger 3100i, Intab Interface-teknik AB, Stenkullen, Sweden). Moisture content analyses for determining raw material moisture content before and after steam treatment, hot pellet moisture content, and cool pellet moisture