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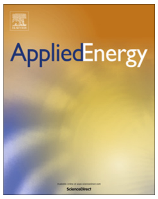

New tool for improved control of sub-process interactions in rotating ring die pelletizing of torrefied biomass

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HIGHLIGHTS

- New concept for controlling feed layer formation when pelletizing torrefied biomass.
- Softwood forest residues and a hardwood species torrefied at 308 °C for 9 min were pelletized.
- Two ring die pelletizers were used. One with a stationary and one with a rotating die.
- Lower initial moisture content enabled better flow properties.

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ABSTRACT

A new concept was developed for feed layer formation control and to obtain continuous pellet production when pelletizing torrefied biomass. The materials pelletized were softwood forest residues and a hardwood species which both had been torrefied at 308 °C for 9 min. The torrefied wood chips were milled over a screen size of 6 mm and the torrefied feedstock moisture content was adjusted to about 9% before pelletizing. Two types of pelletizers were used; one with a stationary ring die and one with a rotating ring die. With a traditional, non-cooled die configuration, the die temperature increased to 75–78 °C. During temperature increment, pellet production deteriorated and finally ceased at approximately 80 °C. This phenomenon was caused by a breakdown of the feed-layer formation between the free rolling rollers and the die. However, continuous production could be sustained when the die was cooled. A new tool was developed based on nozzle injection of water directly onto the feed layer. By this course of action pellet production was sustained at temperatures well above 80 °C. This proof-of-concept for a new tool to control sub-process interactions in ring die pelletizing also includes use of low initial moisture content to utilize the flowability of torrefied particulates and, thus, avoid problems connected to feeding, conveying and silo discharging which frequently occurs at higher feedstock moisture contents.

1. Introduction

White pellets from wood is a fast growing standardized [1] bioenergy commodity. The world's fuel pellets production is now at about 30 Tg y^{-1} and is expected to reach 100 Tg y^{-1} by the year of 2020 [2,3]. By using carbonized biomass as feedstock in pelletizing, so called black pellets (with higher energy density) can be produced. Such pellets have the potential to additionally lower costs for handling, transport and in down-stream energy conversion. Torrefaction is now developed for carbonization of lignocellulosic biomass. In this process, conducted at low oxygen partial pressures and temperatures ranging from 200 to 350 °C [4–8], torrefied materials are produced that have a reduced oxygen content, are less hydrophilic [7,8], have lower equilibrium moisture content [9], are more homogenous, and show less resistance to grinding [10]. These features are of importance for the thermal, thermochemical and biochemical process routes [11,12].

However, before being able to reach the market, carbonized pellets still face challenges e.g. regarding: energy consumption in pelletization [13–15]; binding properties of torrefied particles [9,16,17] followed by low pellet durability [18–20]; and narrow production windows for production of high quality pellets [14,21,22].

In addition to these challenges Larsson et al. [19] found that feeding and conveying properties, and silo discharge behaviour for (hammer milled) torrefied Norway spruce powder was much worse, compared to when handling non-treated wood powders. It was also concluded that problems were increasing with torrefaction severity. Falk et al. [23] showed no significant differences in

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angle of repose between torrefied and non-treated hammer milled Norway spruce wood powder. When the same materials were cutting milled, non-treated wood powder had significantly higher angle of repose (53° resp. 47°). Strandberg et al. [24], found that only severely torrefied (310 °C) cutting milled Norway spruce powder differed from non-treated material with a lower angle of repose. The, by Larsson et al. [19], observed packing, blocking, and bridging that repeatedly interrupted feeding of the pelletizer when pelletizing torrefied materials was therefore unexpected. However, these problems also occurred for the higher moisture contents used in a pilot pelletization study by Rudolfsson et al. [22]. Feeding problems was hypothesized to be due to the decreasing equilibrium moisture content (EMC) with increasing thermal treatment severity as reported by Kymäläinen et al. [25]. Feed material with a low EMC will, at the same moisture content as a material with a higher EMC, have a larger proportion of less bonded water. At high moisture contents wet surfaces of particles in the bulk build cohesive strength which impairs flow properties and silo discharge.

Rudolfsson et al. [14] showed a moisture content optimum at approximately 5% (w.b.) in bench scale single pelletizing of woody materials torrefied at temperatures ranging from 250–300 °C when raw material moisture content was varied from 0 to 10% and die temperature between 125 and 180 °C. However, obtaining a pellet moisture content of 5% in industrial scale ring die pelletizing of torrefied materials is complicated due to moisture evaporation in the pelletizing process. In the study by Larsson et al. [19], moisture contents of pellets varied between 0.6 and 5.0% and levels were controlled by torrefaction severity, not by the torrefied feedstock moisture content (in this case 11% and 15%). Similar pellet moisture levels (<5.0%) were found in another pilot scale pelletizing study [22], with materials torrefied at 290–315 °C and moisture contents between 9 and 14%. Larsson et al. [19] also measured average temperatures for pellets just leaving the press: 109 and 138 °C for materials torrefied at 270 and 300 °C, respectively, i.e. almost one degree (°C) in increased pellet temperature per increased degree (°C) in torrefaction temperature. The positive correlation for torrefaction temperature and pellet temperature is caused by friction in the press channels which, according to Rudolfsson et al. [14], increases with torrefaction degree (lower mass yield).

Larsson et al. [19,26] and Rudolfsson et al. [14] have previously reported discontinuous pellet production at higher die and pellet temperatures. They discuss this behaviour as being due to drying of the compressed feed layer inside the die and a simultaneous loss of lateral adhesion forces which results in intermittent loss of the feed layer. To better interpret the role of moisture in pelletizing, it can be useful to divide the process into three different phases: (i) when feeding material from silo through conveyers to the press die; (ii) at the very moment when the feed layer is formed; and finally, (iii) when the pellet is pressed through the press channel. The functionality of moisture in each of these phases differs a lot and so does the optimum moisture content in each phase. Today's pellet plants do not consider the differences in moisture content optima throughout the pelletizing process. The common principle is to adjust moisture content in the drier and, if necessary, add steam in the material stream before pelletizing. However, due to the fundamental impact of moisture in each of the pelletizing phases, it is advantageous to optimize the moisture content throughout the production process.

In this study we present and evaluate new approaches for controlling feed layer formation to obtain continuous pellet production and improve pellet quality when pelletizing torrefied biomass. For pellet mills with rotating ring dies, the aim is to maintain feedstock flowability and add water at a late state to obtain cooling and lubrication of the pelletizing process. For pellet mills with fixed dies, cooling is done by circulation cooling media in the die as has been shown earlier by Larsson et al. [27]. If these approaches are successful, process control may be improved and production of torrefied biomass pellets considerably simplified.

2. Materials and methods

2.1. Biomaterials

Two types of biomaterials were used as biomass models in the study: one mixed forest residue assortment including bark, needles and branches consisting of 17% Scots pine (*Pinus sylvestris* L.), 69% Norway spruce (*Picea abies* Karst. (L.)), and 14%. deciduous trees, and one pure willow (*Salix ssp.*) assortment as an example of hardwood. Both materials were chipped to a size of <40 × 30 mm and then dried, in a flatbed dryer at around 40 °C, to moisture contents of around 4–8%, at the Biomass Technology Centre, Swedish University of Agricultural Sciences (SLU), Umeå, Sweden. Dried materials were stored under roof until torrefaction.

2.2. Torrefaction

Torrefaction was performed by Bioendev in a second generation pilot scale plant (200 kg h^{-1}) as described by Strandberg [28]. The process is continuous and consists of a pre-heating rotary drum (220 °C) step followed by a heated auger screw where torrefaction takes place at desired temperature and residence time. The reactor was operated in inert atmosphere with N_2 as a purge gas. Torrefaction of both willow and forest residues was performed at a temperature of 308 °C and a residence time of 9 min, with resulting mass yields of 83% and 80%, respectively. Torrefaction temperature was measured continuously with a IR-thermometer at the outlet of the rotating torrefaction drum as described by Strandberg et al. [24]. The material was excluded if the temperature exceeded the tolerance of ±2 °C.

2.3. Pelletizing

Torrefied materials were hammer milled with a screen size of 6 mm (Vertica Hammer Mill DFZK-1, Bühler AG, Uzwil, Switzerland). Moisture content for both assortments was adjusted to about 9% w.b. in a screw type mixer by adding water during mixing. Prepared materials were left in silos for 16 h to reach equilibrium before pelletizing.

2.3.1. Pelletizing with pilot scale stationary ring die equipment

Torrefied forest residues was pelletized with a SPC PP300 Compact pelletizer (Sweden Power Chippers, Borås, Sweden) equipped with a fixed ring die and free rolling press rolls. The fixed die of the SPC pelletizer was equipped with two cooling circuits for die temperature control (see Larsson et al. [27] for a detailed description). Press channel dimensions were: 52.5 mm press length and 8 mm diameter, resulting in a press channel ratio of 6.5:1. Pelletizing was initially performed with a cooled die under steady state conditions. Subsequently, cooling was turned off and die temperature was allowed to increase (Fig. 1).

2.3.2. Pelletizing with pilot scale rotating ring die equipment

Torrefied willow was pelletized with a Bühler DPCB pelletizer (Bühler AG, Uzwil, Switzerland) which, contrary to the SPC pelletizer, has a set of fixed but free rolling rolls and a rotating die. The die has no temperature control system. In the Bühler pelletizer, cooling of the process was performed via direct injection of water to the die. A hose with a nozzle was installed so the water was injected right into the space inside the die where the actual feed