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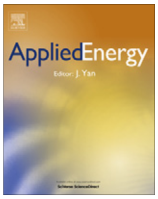

Effects of moisture content, torrefaction temperature, and die temperature in pilot scale pelletizing of torrefied Norway spruce

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HIGHLIGHTS

- Energy consumption in pelletizing of torrefied spruce is double as that for softwood.
- Pellet production rate showed a strong positive correlation with die temperature.
- Water addition worsened material flow properties severely.
- The amount of fines in pilot scale pelletizing of torrefied spruce was 10–30%.
- Bulk density of torrefied pellets was comparable to softwood pellets.

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ABSTRACT

Pilot scale pelletizing of torrefied Norway spruce was performed in a factorial design with controlled factors at two levels: material moisture content (11% and 15%) and torrefaction temperature (270 and 300 °C), and die temperature as an uncontrolled factor (60–105 °C). Compared to commercial wood pellets, produced pellets had comparable bulk densities (630–710 kg/m^3) but lower pellet durability (80–90%). Energy consumption for pelletizing of torrefied materials was approximately 100% higher than for softwood pelletizing, despite using a much shorter die channel length (35 vs. 55 mm:s), and the amounts of fines were high (10–30%). Die temperature showed a strong positive correlation with pellet production rate. Material moisture content had little influence on pellet quality and production rate, but addition of water created handling problems due to bad flow behavior.

1. Introduction

Due to superior handling characteristics compared to untreated biomass, wood pellets have become a world-wide trading commodity [1]. Pelletizing increases the energy density and improves the handling properties and the biofuel pellets can be used as energy carrier for a variety of conversion processes.

A major factor in biomass pelletizing is material moisture content [2]. The general functions of moisture when pelletizing thermally untreated biomasses are (i) process related – moisture is negatively correlated to wall friction/energy consumption [3,4] and (ii) pellet quality related – moisture is crucial for the binding properties of the compressed biomass and each pellet quality response is maximized at an optimum moisture content [5]. In practice, material moisture content is a versatile process parameter that is adjusted towards a minimum process friction that still maintains high enough pellet quality.

In single pelletizing studies, die temperature is negatively correlated to energy consumption and positively correlated to pellet density and hardness [4]. However, in ring die pelletizing, die temperature can be considered both as a factor – effecting energy consumption and pellet quality, and a response – as an effect of material properties and other process parameters.

Torrefaction is a pre-treatment method where biomass is heated to temperatures of 200–300 °C in inert atmosphere and the desired result is a material with low moisture content, high energy density and better grinding properties [6,7].

In single pelletizing of spruce and torrefied spruce, much higher forces were required to push pellets formed from torrefied materials through the die, and the pellets formed from torrefied materials showed substantially lower compression strengths [8]. Ring die pelletizing of torrefied materials has been performed by commercial or semi-commercial actors [9,10], but information on settings,

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process conditions, and pellet quality has not, to our knowledge, been published anywhere.

Prior to the present study, a few initial tests were performed for processing of various less well-defined torrefied materials. Pelletizing was performed using the pilot scale ring die pelletizer infrastructure at the Biofuel Technology Centre, Umeå, Sweden, where experience of various thermally untreated materials have been gained in previous studies, e.g. [5,11–13]. The main experience from initial tests with torrefied material was that, compared to untreated biomass, torrefied material required extremely high energy input, and that the amount of fines in the pellet production was unusually high. From these experiences the choice of settings in the present study were: the shortest available die channel length and material moisture contents at medium to high levels with reference to pellet production from thermally untreated wood. To reach desired material moisture contents, water was added to the milled torrefied material. The reasoning behind water addition was based on the previously described lubricating and particle bonding effects of water in biomass pelletizing process.

The present study is the first to systematically present process settings and conditions, pellet quality, and process performance in pilot scale ring die pelletizing of torrefied material. The objectives of the study was (1) to evaluate the influence of moisture content, torrefaction temperature, and die temperature on production rate and pellet quality parameters (bulk density, mechanical durability, and amount of fines) and (2) to spread knowledge on non-modeled measurements and experiences of process performance in ring die pelletizing of torrefied materials.

2. Materials and methods

2.1. Material

Norway spruce (*Picea abies* L.H. Karst) was chipped, sieved to a thickness below 10 mm, chips smaller than 8 × 8 mm was removed, and remaining chips was completely dried at 105 °C before torrefaction. Torrefaction was performed using a pilot scale torrefaction equipment (BioEndev, Umeå, Sweden) with a maximum capacity of 20 kg/h. The torrefaction setup is an electrical heated rotary drum in a continuous operating mode where rotary vane feeders in combination with a small nitrogen flow ensure an oxygen free atmosphere. The volatiles formed in the process are combusted in a gas burner. The rotation speed of the drum, which has a shaftless screw fixed on the inside, decides the residence time of the biomass and the electric heaters are controlling the temperature. For this study, two types of materials were produced at torrefaction temperatures of 270 °C and 300 °C and both at a residence time of 16.5 min. The torrefaction settings were chosen after initial screening studies in order to produce one light and one more severe torrefied biomass to enable a wide range of compaction properties without extremes. Further, a short residence time with corresponding high temperature was preferred to increase production rate. Torrefaction temperature was defined as the biomass surface temperature which was measured at the end of rotary drum with an IR-thermometer. Residence time was defined as the time the biomass was inside the rotary drum. Mass yield and energy yield was expressed on dry and ash free basis. Mass yield was measured on dry basis and during steady state conditions. See Table 1 for the torrefaction settings, chemical composition of the torrefied materials, lignin, cellulose, hemicellulose, extractives, and mass yields.

Cellulose consists only of glucose but part of the determined content of glucose is originating from hemicellulose. Mannose is only found in hemicellulose and in softwoods is mannose found in the ratio approximately 3:1 to glucose [14,15]. Therefore mannose was used as reference to determine the amount of glucose originating from cellulose. Cellulose content was thereby calculated by subtracting 1/3 of the mannose from the total amount of glucose. The amount of hemicellulose was calculated as the sum of arabinose, galactose, mannose, xylose and the remaining glucose. The xylose and arabinose amounts were multiplied by 1.05 to include compounds that degraded during the analysis. The method for lignin analysis is applied for determination of acid-insoluble lignin in wood and for all grades of unbleached pulps. However, when analyzing thermally treated biomass the degraded acid-insoluble components may be incorrectly determined as lignin. Thus, in Table 1, degraded components are specified together with lignin. The compounds were normalized to 100% by proportionally increasing cellulose and hemicellulose.

Torrefied wood chips were hammer milled (Vertica Hammer Mill DFZK-1, Bühler AG, Uzwil, Switzerland), screen size: 6 mm. After hammer milling, material moisture content was approximately 2%. For each point in the experimental design, 300 kg of

Table 1

Chemical composition of the torrefied materials (both with a torrefaction time of 16.5 min). DM = Dry Matter, DM in = Dry matter of raw material, LHV_{dry} = Lower Heating Value on dry basis, HHV_{daf} = Higher Heating Value on dry and ash free basis, $\eta_{m,daf}$ = mass yield on dry and ash free basis, $\eta_{E,daf}$ = energy yield on dry and ash free basis.

Term/name	Analysis method	Raw spruce	Torrefied spruce	Torrefied spruce	Unit
Torrefaction settings					
Biomass surface temp.		–	270	300	°C
Torrefaction residence time		–	16.5	16.5	min
Fuel analysis					
LHV_{dry}	SS-EN 14918	18.9	19.7	21.0	MJ/kg_{DM}
HHV_{daf}	SS-EN 14918	20.3	21.1	22.5	MJ/kg_{daf}
C	SS-EN 15104	50.4	52.5	56.0	$\%_{DM}$
H	SS-EN 15104	6.2	6.0	5.9	$\%_{DM}$
N	SS-EN 15104	0.1	<0.1	<0.1	$\%_{DM}$
S	SS-EN 15289	<0.01	<0.01	<0.01	$\%_{DM}$
O	Calculated	43.1	41.2	37.7	$\%_{DM}$
Ash (550 °C)	SS-EN 14775	0.3	0.3	0.4	$\%_{DM}$
Volatile matter	SS-EN 15148	85.4	82.5	75.4	$\%_{DM}$
Lignin	Tappi T 222 om-98	275 [275]	331[a][308[a]]	465[a] [349[a]]	g/kg_{DM} ($g/kg_{DM,in}$)
Cellulose	SCAN-CM 71:09	444 [444]	449 [417]	462 [347]	g/kg_{DM} ($g/kg_{DM,in}$)
Hemicellulose	SCAN-CM 71:09	269 [269]	201 [187]	44 [33]	g/kg_{DM} ($g/kg_{DM,in}$)
Acetone extractives	SCAN-CM 49:03	13 [13]	19 [17]	29 [22]	g/kg_{DM} ($g/kg_{DM,in}$)
Process/product analysis					
$\eta_{m,daf}$		–	93	75	$\%_{DM,in}$
$\eta_{E,daf}$		–	97	83	$\%_{DM,in}$

[a] Lignin + degraded components.