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Physical quality and surface hydration properties of wood based pellets blended with waste vegetable oil

Nevena Mišljenović [a,*], John Mosbye [a], Reidar Barfod Schüller [b], Odd-Ivar Lekang [a], Carlos Salas-Bringas [a]

[a] Department of Mathematical Sciences and Technology, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway
[b] Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O. Box 5003, N-1432 Ås, Norway

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A B S T R A C T

To satisfy the demand of reducing extensive usage of wood as a raw material for pellets production, application of alternative raw materials, particularly residues, is necessary. The purpose of this paper is, therefore, to study feasibility of alternative wood pellets with addition of waste vegetable oil and to examine how the oil affects pellet's physical quality, surface properties and pelleting process. Furthermore, a novel approach for estimation hydrophobic properties of biomass pellets was presented. Pellet surface hydrophobicity and water drop absorption rate were assessed by measuring contact angle along time. Oil addition was 2.2% and 5.8% based on dry solids. Pellets were produced by single pellet press method under four compacting pressures (75, 150, 225 and 300 MPa) at three pelleting temperatures (60, 120 and 180 °C). The results show that oil addition significantly increases energy content in wood pellets ($p < 0.05$). Energy content was increased from 19.69 MJ/kg (control) to 20.05 MJ/kg (2.2% of oil) and 20.64 MJ/kg (5.8% of oil). Strength of pellets, as well as sawdust compressibility, was reduced when adding oil. The oil caused lower friction on the pellet–die wall contact area.

1. Introduction

Waste vegetable oil (WVO) is a residual biomass available in large quantities with high potential for usage as a raw material in solid biofuel production. WVO is non-fossil oil, has high calorific value, low heavy metal content, and low moisture content and does not require any pretreatment [1]. The main focus of this paper is valorisation of waste vegetable oil (WVO) by using it as a raw material in production of wood based pellets. The aim of paper is to examine how the WVO addition will influence physical pellet quality, pellet surface properties and pelleting process. In addition, a novel approach to assess pellet hydrophobicity by contact angle measurements is presented. The paper answers in detail how the oil addition changes compressibility of sawdust, strength of pellets, where are the limits of densification, how the pellet hydrophobicity changes by adding WVO and how hydrophobicity can be more quickly evaluated by measuring contact angle on compacted powder. The main challenges related to pelleting of oily sawdust are discussed.

The EU is currently a leader in world pellet consumption (70% of world consumption) [2]. Demands for pellets in Europe have already exceeded their production; thus significant amounts of pellets have been imported mainly from US and Canada, although the production capacities in EU are not fully used [2–5]. Moreover, European Commission predicts that pelleted solid biofuels will play an important role in meeting renewable energy targets in Europe [4]. All of these indicate a further growth in pellet production. Forest biomass is almost exclusively used as a feedstock for pellet production. In order to provide sustainable production, the goal is to use new and cheap raw materials available in large quantities, which will partially replace wood. The usage of by-products or waste from industry, agriculture or households is the best way to achieve environmentally and economically sustainable fuel production. Utilization of bio-residues is preferable not only from the aspect of using these materials for energy generation, but also from the aspect of avoiding the problems related to waste disposal.

WVO is discarded by restaurants, food manufacturers (potato chips, breaded fish sticks, doughnuts, etc.) and other facilities (schools, hospitals, households, etc.) because it cannot be further used in human or animal nutrition. Estimation is that total EU potential is 3.55 million tonnes per year which is about 8 l per capita/year [6]. Inappropriate disposal of WVO can be environmentally hazardous; therefore its further utilization is preferable. Until 2002 most of the collected WVO was used as a feed component, but EU banned its application because of harmful components formed during frying which can return into the food chain trough the animal meat [7]. Thus the application of WVO for energy generation would be a good form of its utilization.

WVO addition can improve wood fuel properties, but densification of wood with added oil can be more challenging due to inhibition of the main binding mechanisms for densification and lowering friction in the die [8]. Vegetable oils are reported in literature as an additive

* Corresponding author. Tel.: +47 6496 6427; fax: +47 6496 5401.
E-mail addresses: nemi@nmbu.no (N. Mišljenović), john.mosbye@nmbu.no (J. Mosbye), reidar.schuller@nmbu.no (R.B. Schüller), odd-ivar.lekang@nmbu.no (O.-I. Lekang), carlos.salas.bringas@nmbu.no (C. Salas-Bringas).

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which reduces die wall friction and energy consumption for pelleting process due to lubricating effect [9]. To our knowledge, blending waste vegetable oil with wooden biomass has not been previously reported in pellet production. A recent work of Shang et al. [10] showed that rapeseed oil addition reduces static friction on the die wall and strength of pellets produced from torrefied wood chips. Ståhl and Berghel [11] studied how the addition of different amounts of rapeseed cake which contained 18% of oil affects energy consumption and some mechanical properties of wood based fuel pellets. The authors concluded that energy consumption, durability and bulk density of pellets were reduced with increased amount of rapeseed cake. Some commercial pellet producer has already started with production of pellets covered with thin oil layer aiming to reduce dust content [12].

Surface characteristics and water absorption rate of pelleted solid biofuels are important quality parameters especially when it comes to outdoor and indoor humid storage conditions. A common method for evaluating biomass fuel hydrophobicity is based on measuring the material moisture absorption capacity, when surrounding temperature and humidity are constant [13–15]. The method is reliable, but time consuming, because it requires equilibration of moisture in the material and surrounding atmosphere, which can take several days. The method presented in this paper is based on measuring contact angle (θ) and absorption rate of a water drop placed on a compacted wood powder. The method is fast and particularly convenient for densified biomass like pellets or briquettes. Also this method can give an information about material/pellets behavior in direct contact with water which can replicate outdoor (rain) and indoor (condensation) storage situations. Similar measurements have been performed in compacted powders of soy and wheat flour [16,17] and pharmaceuticals [18,19], but this approach, to our knowledge, has never been used for testing the surface properties of densified solid biofuels.

In order to study the effect of WVO on pelletability and pellets physical properties the oil has been added in two different amounts (2.2 and 5.8% on dry solids). Blends and control pellets (no oil addition) were produced by single pellet press method at three different temperature (60, 120 and 180 °C) under four compacting pressures (75, 150, 275 and 300 MPa). Pellets for the θ measurements were produced at 120 °C under a pressure of 300 MPa.

2. Material and methods

2.1. Preparation of the raw materials

Spruce stumps (*Picea abies*) were selected as raw material and cut from a local forest in Ås, Norway in December 2012. In order to preserve woods physicochemical properties the stumps were stored in a freezer until further usage. Prior to the pelleting the wood was defrosted, the bark was removed, stumps were cut in smaller pieces, pre-dried and grinded in a hammer mill (Brabender, Duisburg, Germany) with screen opening size of 1.5 mm. Wood pieces were pre-dried at 105 °C in order to make material more brittle and thus easier to grind by hammer impact. Adopting literature recommendation for pelleting process [20], the wood powder was afterwards moisturized to 10 ± 1% moisture content by spraying water in an intensive laboratory mixer (Diosna P1/6, Germany). The final moisture content in spruce powder was 10.8 ± 0.3% (Table 2). This material served as control sample and as a base raw material for the blends with WVO. The moisturized powder was stored in vacuum packed plastic bags at ambient conditions until further usage (1–2 weeks).

The WVO was obtained from McDonald's restaurant in Vestby, Norway. Before spaying, the WVO was filtrated trough filter paper. Basic physicochemical properties of the WVO are presented in Table 1.

Two levels (L_1 and L_2) of WVO were added to the powder by spraying in a high shear mixer having three impellers and a tulip-form chopper (Diosna P1/6, Germany). An intensive mixing (mixer 250 rpm; chopper 500 rpm), manipulating oil drop size in the spraying lance (Düsen-Schlick GmbH, Germany, Model 970) and a preheating of the WVO to 60 °C were used to facilitate an even distribution of the oil in sawdust. Final content of oil in sawdust was calculated from the difference in the higher heating value (HHV) of control powder and powder with oil. Blended powders L_1 and L_2 contained 2.2% and 5.8% of WVO based on dry solids, respectively. The materials were pelletized at least 48 h after the mixing in order to allow an eventual penetration of WVO into pores.

Table 1
Properties of WVO.

Property	Value
HHV (MJ/kg)	37.60 ± 0.07
Density[a] (kg/m^3)	910.7
Dynamic viscosity [21] (Pa s)	0.117 (at 20 °C)
	0.026 (at 60 °C)
	0.007 (at 120 °C)
	0.004 (at 178 °C)
Ash content [22] (%)	0.006

[a] Measured at room temperature.

2.2. Characterization of the raw materials

Following analyses on raw materials were performed:

- The particle size distribution of spruce sawdust was measured by Mastersizer 3000 optical unit combined with Aero S dry dispersion unit (Malvern Instruments, U.K.).
- The bulk density was determined by measuring the mass of a known volume of material that has been loosely poured into a graduated cylinder. The density of oil was determined by measuring the mass of know volume of oil in a graduate cylinder (±0.2 ml) on analytical balance (±0.0001 g)
- The water activity value (a_w) was measured by a Rotronic HygroLab C1 (Switzerland) instrument. Average temperature during the a_w measurements was 20.16 ± 0.1 °C. a_w value describes availability of free water in different products (typically food and feed). Free water affects products microbiological, enzymatic and chemical stability.
- The moisture content was determined by drying in an oven for about 20 hours (Termaks, Norway) at 105 °C (EN 14774-1).
- The content of ash and volatile matters was determined in a muffle furnace (Nabertherm D-2804, Germany) according to EN 14775 and EN 15148 standard procedure, respectively.
- The fixed carbon ($\%_{d.b}$) was calculated by difference between 100 and the sum of the volatile matter and ash content.
- The HHV was calorimetrically determined (Parr 1341 Oxygen Bomb Calorimeter, Moline IL) following the EN 14918 standard procedure.

2.3. Pellet production

Pellets were produced by single pellets press method in a pelleting unit that consists of a steel cylinder with a concentrically positioned compressing channel of 8 mm in diameter. A jacket heater (450 W) is temperature controlled by a PID (proportional-integral-derivate). A tungsten carbide pressing rod was used for compression. The compressing force was applied to the rod using an Instron 5800R 100 kN universal compression-tension testing machine (England). Pelleting unit was designed and built at the Norwegian University of Life Sciences (Ås, Norway). Pellets were produced following the same procedure as described in Mišljenović et al. [14], based on previous work of Salas-Bringas [23]. Briefly summarized, when set temperature was reached, the die channel was filled with material and the pressing rod was placed into the die. After 3 min of tempering, the biomass was compressed at a rate of 2 mm/min until the set pressure was reached. Afterwards the pressure was released, the bottom rod

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