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In-situ torrefaction and spherical pelletization of partially pre-torrefied hybrid poplar

Dan Nicksy [a], Andrew Pollard [a,*], David Strong [b], Jason Hendry [c]

[a] Department of Mechanical and Materials Engineering, McLaughlin Hall, Queen's University at Kingston, Canada
[b] Faculty of Engineering and Applied Science, Beamish-Munro Hall, Queen's University at Kingston, Canada
[c] PARTEQ Innovations, Biosciences Complex, Queen's University at Kingston, Canada

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ABSTRACT

A novel compacted, spherical, torrefied biomass pellet is discussed. Pellets were pressed in a heated mould and die, and torrefied in-situ (at 280 °C) from both untorrefied and pre-torrefied (at 250 °C) hybrid poplar sawdust prior to pelleting. Spherical pellets were successfully produced from both input materials. The calorific value of these pellets, referred to as "Q'Pellets", is 20.78 MJ kg^{-1}–21.60 MJ kg^{-1} on a moisture and ash free basis, which compares favourably with lignite coal. The ash content of Q'Pellets was as high as a mass fraction of 2.07%–5.08%. Q'Pellets are demonstrated to be uniquely durable, as they did not abrade in a tumbling can test or fracture in an impact resistance (drop) test.

1. Introduction

Most biomass pellets, known as "white" pellets, are made from raw biomass using an extrusion process. Woody biomass, such as poplar, willow and grasses, such as hemp, switchgrass, miscanthus are examples of feedstocks. To produce white pellets, raw biomass is typically hammer-milled to pass a 4 mm screen, and conditioned to a moisture content of mass fraction 8%–12% [[1], p. 57] prior to pelletization. Pelletization involves a press that forces material through a friction-heated extrusion die, which has multiple holes of approximately 6 mm diameter. Cylindrical pellets approximately 2–5 cm long with smooth sides and rough ends are thereby formed. The gross calorific value (GCV) and energy density of woody white pellets are approximately 19.8 MJ kg^{-1}–20.7 MJ kg^{-1} (dry basis) and 8.7 GJ m^{-3}–11.4 GJ m^{-3}, respectively [[1], p. 56–57]. Fig. 1 shows an example of typical white cylindrical biomass pellets.

White pellets have a number of deficiencies that limit their acceptance in a variety of commercial jurisdictions. For example, Duncan et al. [2,3] have identified a number of problems that prevent the adoption of biomass pellets as a fuel for large scale thermal electricity generation. These have been re-interpreted as follows:

a) Low energy density

Wood has a low calorific value compared to coal. For example, lignite and anthracite contain 20 MJ kg^{-1} and

* Corresponding author.
E-mail addresses: nicksyd@me.queensu.ca (D. Nicksy), pollard@me.queensu.ca (A. Pollard), strongd@appsci.queensu.ca (D. Strong), jhendry@parteqinnovations.com (J. Hendry).
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Fig. 1 – Modern cylindrical biomass pellets. Top-left: usual mode of fracture. Top-right: fines produced by scraping a fingernail across the end of the pellet. Bottom: bulk pellets. Grid paper is 6.35 mm for scale.

25 MJ kg^{-1} to 30 MJ kg^{-1}, respectively, whereas wood pellets contain only 17 MJ kg^{-1}–19 MJ kg^{-1} [[2], p. 2–3]. Thermal generating stations are designed to operate optimally with a specific fuel, and if substituted with a fuel that is "off-specification" then thermal efficiency will be altered.

b) Cost of transportation

Raw logs and wood pellets have high moisture content and low packing density compared to coal. Thus, it is comparatively expensive to transport biomass.

c) Storage

Biomass is hydrophilic; if left in an uncontrolled atmosphere will achieve equilibrium moisture content of mass fraction 4% to 25% [[1], p. 143] (depending on relative humidity) where higher moisture content correlates with lower energy density (i.e. lower heating value). White pellets that become sufficiently moist will disintegrate. Pellet piles can experience self heating due to microbial activity or moisture absorption, ultimately leading to spontaneous combustion [[1], p. 164–167]. Thus, storage of biomass in large quantities can be difficult and dangerous.

d) Grinding

Hemicellulose and cellulose, held together with lignin, form a rigid chemical structure that gives wood its strength. Where coal is brittle, biomass is malleable and "stringy". Biomass material adheres to the ball bearing-type environment found in typical coal pulverizers. Thus, woody biomass presents unwanted side effects to existing infrastructure.

e) Mechanical durability and fines production

Modern wood pellets have exposed ends, which flake and produce fines and dust. Airborne dust is a workplace health concern, and an excess of suspended particles in the air can lead to dangerous dust explosions. Fines production is a risk when transporting and handling wood pellets. Fig. 1 presents evidence of the typical issues with durability and fines.

1.1. *Benefits of torrefaction*

Torrefaction is a mild pyrolysis heat treatment that is accomplished in the temperature range 200 °C–300 °C. Torrefaction is performed in an inert atmosphere, often by nitrogen gas (N_2) flood, in order to prevent combustion. During the torrefaction process molecules are released in gaseous and condensable vapour forms, such as carbon mono- and dioxides, water vapour, acetic acid, and various other volatile organic compounds (VOCs). The result derived from torrefaction is characterized by an increase in energy density, decrease in particle size, and darkening the colour of the biomass.

There exists a prevalent notion in the biomass literature that states that the heating rate during torrefaction must not exceed 50 °C min^{-1} [4–6]. Other research has been conducted with heating rates in excess of 50 °C min^{-1} and no ill effects were noted [7]. Steam treatment of biomass as a means of torrefaction routinely features cool material inserted into a pre-heated vessel and rapid heating rates [8].

Given the five issues noted above, torrefaction addresses these through an increase in energy density and associated decrease in transportation costs, safer storage and an increase in friability.

Off-gassing molecules constitute roughly 30% the mass of the original sample, but only 10% the energy thereof. As such, the remaining solids contain 90% of the energy in only 70% of the original mass, and the ratio of energy density of the torrefied biomass compared to the original biomass is significantly increased to approximately 1.28 [[5], p. 94]. The energy density of torrefied biomass is similar to that of coal, thereby enabling co-firing or generating station conversion.

The breakdown of hemicellulose reduces the presence of hydroxyl (OH–) groups that absorb water molecules through hydrogen bonding, and non-polar molecules are formed that prevent the condensation of water. The hydrophobicity of torrefied biomass reduces its equilibrium moisture content to a mass fraction of 3% (compared with approximately 8.5% for white pellets) [[5], p. 119], and reduces self-heating through water absorption. Torrefaction also removes most of the chemically and biologically active solid, liquid and gaseous products, thereby significantly reducing the risk of spontaneous combustion [[5,9], p. 117].

Raw biomass exhibits plastic behaviour during grinding, while torrefied biomass is brittle and does not adhere to, say, pulverizer balls used to grind coal. The electrical energy required to grind biomass to a particle size suitable for co-firing with coal is reduced by up to an order of magnitude when the biomass is torrefied [[5,10], p. 116].

Torrefaction of biomass does not mitigate the production of fines or the danger of dust explosions. Material that is