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Reprint of: Pelletizing properties of torrefied wheat straw

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ABSTRACT

Combined torrefaction and pelletization are used to increase the fuel value of biomass by increasing its energy density and improving its handling and combustion properties. However, pelletization of torrefied biomass can be challenging and in this study the torrefaction and pelletizing properties of wheat straw have been analyzed. Laboratory equipment has been used to investigate the pelletizing properties of wheat straw torrefied at temperatures between 150 and 300 °C. IR spectroscopy and chemical analyses have shown that high torrefaction temperatures change the chemical properties of the wheat straw significantly, and the pelletizing analyses have shown that these changes correlate to changes in the pelletizing properties. Torrefaction increase the friction in the press channel and pellet strength and density decrease with an increase in torrefaction temperature.

1. Introduction

Biomass from wood and agricultural residues is increasingly important for sustainable heat and power production at industrial scale [1]. Political decision makers have set ambitious goals to push forward renewable energies, and power producers have identified biomass utilization as a potential way to increase their share of renewable energy relatively fast and cost efficient when using it in their existing coal power plants [2]. However the physical properties of biomass have been identified as a challenge for power producers due to its poor handling properties and combustion related problems. Biomass as a material is inhomogeneous in structure and composition and its bulk and energy density is low when compared to conventional fossil fuels. Furthermore is it necessary to bridge long distances between biomass production sites and power plants and that require expensive logistics [3]. There are different technologies to improve the physical properties of solid biomass. Mechanical treatment such as pelletization and briquetting results in a homogeneous biomass product of high density [4]. Thermal treatment i.e. torrefaction removes moisture, volatiles and degrades parts of its carbohydrate fraction, resulting in a product with higher energy density and better moisture resistance [5]. Both processes have been studied extensively and recent efforts have been made to combine both processes where biomass is thermally

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treated (torrefied) and subsequently pelletized [6–8] The resulting product is a “coal like” product that is expected to be used as replacement and/or supplement for coal in existing heat and power plants [8]. The properties of pellets made from torrefied biomass are in many ways similar to coal as shown in Table 1.

Major advantages are their high energy density hydrophobic nature and good grindability, and it is expected that torrefied pellets can be handled similar as coal. Another major advantage of torrefied pellets pointed out by the pellet industry is that they are an ideal fuel to be used in coal fired power plants since only few changes have to be made to the existing power plant design. A recent study has shown that it is possible to fire 100% torrefied biomass in a pulverized coal boiler without decrease of the boiler efficiency and fluctuation of boiler load [14].

Torrefaction is a mild pyrolysis process at about 200–300 °C in the absence of oxygen that changes the biomass properties significantly [5,8]. Due to thermal depolymerization and degradation a large fraction of the biomass carbohydrate fraction is removed from the biomass, especially the hemicelluloses that account for about 25–35% dry matter of lignocellulose type biomass. Its natural function in biomass is to crosslink the cellulose fibers and the lignin matrix and thereby providing the biomass with its tenacious and flexible structure which is crucial for the mechanical stability of each plant.

It has been shown that hemicelluloses start to degrade at low torrefaction temperatures of about 230 °C and that the rate of degradation increases strongly with an increasing torrefaction temperature [15]. Cellulose and lignin have been shown to be more resistant to thermal decomposition and significant degradation occurs at higher temperature than for hemicellulose. Chen and Kuo [15] found that at a torrefaction temperature of 260 °C almost 40% of the hemicellulose has been removed from the biomass compared to less than 5% of the cellulose and about 3% of the lignin.

The degradation of hemicelluloses results in the loss of the biomass’s tenacious and flexible properties resulting in a brittle material with poor mechanical properties. The heating value increases from about 10 to 17 MJ kg^{-1} to about 12–24.5 MJ kg^{-1} depending on species, torrefaction temperature and residence time [5,8,16]. Biomass torrefaction processes have been reviewed in great detail recently by van der Stelt et al. [5] and others [17–19].

Biomass densification has been an established process to improve the handling properties of biomass for several decades [4]. The raw materials are mainly softwood but also hardwoods are being used and recently agricultural residues i.e. straws and husks from various crops and pulps are gaining interest. Straw is available in large quantities and a low value by product of the agricultural industry. It is already used in large scale heat and power plants [20] but the handling and transportation of straw have remained an issue. Therefore several studies have been made to investigate the pelletizing properties of agricultural residues [21–23].

The pelletizing process consists out of multiple steps that are shown in Fig. 1.

The working principle of a pelletizing process has been explained in detail in one of our earlier studies [24]. In general the process can be subdivided into different steps: compression, flow and friction component as shown in Fig. 2.

Every time the roller approaches the surface of the die, the biomass is compressed and forms a temporary layer on the die surface (compression component). The flow component represents the energy required to force the compressed layer into the press channels and the friction component stands for the energy required to press the compressed saw dust in the channels. The work required for the three components can be determined experimentally for different raw materials and process parameters. The resulting data provides and estimation for the energy consumption of the pelletizing process that can be used for process design and optimization [24].

Turning torrefied biomass into pellets has so far shown to be a challenging step in completing the full production chain for torrefied biomass pellets [6,25]. The problems are two-fold in the sense that both good pellet quality and acceptable pellet production capacities have been difficult to achieve. In terms of quality, the pellet durability and density are often low in comparison to conventional natural wood pellets, and high energy consumption in the pellet mill causes lower production capacities and high costs.

Using a standardized single pellet press method has shown that the pelletization of torrefied biomass requires more energy due to the high friction between the torrefied biomass and the metal surface of the press channel within a pellet mill. Furthermore it was shown that the resulting pellets are less stable compared to conventional wood pellets [6,7]. The lower strength has both advantages and disadvantages. On the one hand lower pellets strength increases the risk for fines and dust formation during handling and transportation but on the other hand it has been shown that torrefied pellets are easier and less energy intense to grind into a fine powder (e.g. prior to co-firing in a coal boiler) [26].

It has been shown that pelletization of torrefied biomass requires higher energy and results in lower crushing strength and density of the pellets compared to untreated biomass.

Table 1 – Benchmark of torrefied pellets with selected bio- and fossil-fuels [8–13].

	Torrefied pellets	Wood pellets	Charcoal	Lignite coal	Bituminous coal	Anthracite coal
Moisture [g kg^{-1}]	10–50	70–100	10–50	65–400	20–160	20–160
Fixed carbon [g kg^{-1}]	280–350	200–250	850–870	314–410	340–780	800–860
Bulk density [kg m^3]	750–850	550–750	ca. 200	560–865	670–910	800–930
Energy density [GJ m^3]	15–18.5	7.5–10.4	6–6.4	14–19	19–30	18–24
Hydroscopic properties	Moderate hydrophobic	Hydrophilic	Hydrophobic	Hydrophobic	Hydrophobic	Hydrophobic
Biological degradation	No	Yes	No	No	No	No
Milling requirements	Classic	Special	Classic	Classic	Classic	Classic