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Towards manufacturing the "ideal pellet"

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ABSTRACT Wood pellet production and its use for heat and power have become common practice in North America and in Europe. The current global trade in pellet exceeds 30 million tonnes annually. Canada is a major producer and exporter of pellets at about 3 million tonnes every year and increasing. Pellets have the characteristics of high mass density and good flow properties. But pellets easily break and disintegrate upon absorbing water or mechanical abrasion. International standards (ISO 17225) define the properties of several grades of tradable pellets. Most of the pellets produced today achieve this standard and are generally considered a high quality product. However, in order to stay competitive on the global pellet market, it is crucial to improve the product 'pellet' constantly. Research towards optimizing the pelletization process parameters, such as temperature, moisture content or die geometry show improvements in mechanical durability and density. Additionally, steam treatment, torrefaction, and the coating of pellets can further improve the pellet properties with respect to density, calorific value, and hydrophobicity. This study highlights the recent progress in enhancing pellet quality and the impact of various parameters and technologies towards the production of higher quality pellets. A first step towards an improvement of the current product is to define a new level of quality for an "ideal pellet".

Keywords: Wood pellets, biomass, quality, process parameters, sustainability

INTRODUCTION Biomass is becoming a preferred feedstock for production of sustainable fuels and bio products due to its availability and its neutrality in carbon dioxide emission. Biomass is characterized by its variety in physical and chemical properties. This makes it difficult to handle and to predict the performance of biomass conversion to useful products. Other unfavorable properties are associated with biomass, mainly low energy density, high moisture content and heterogeneity (Obernberger et al. 2010).

Mani et al. (2006) showed that by densifying biomass into fuel pellets, the storage and transportation costs would be significantly reduced. The bulk density of woody biomass increases from values as low as 50 kg/m^3 to over 700 kg/m^3 (Sokhansanj and Torhollow, 2004). The pellets are low in moisture content and much easier to store and transport than wood chips. Different densification parameters such as die temperature, pressure, and the use of binder can affect the quality of the pellets.

High quality biomass is important in producing high standard bioenergy and bio-products. The international standard, ISO 17225-2, is widely accepted as the standard for residential and industrial pellets. In other words, the majority of the pellets in the market meet the ISO 17225-2 standard. Although this is a big step forward, there is room for improvements in wood pellet quality.

In the search for the “ideal pellet” for bioenergy and bio-products, a number of common criteria are found in the literature. These ideal criteria are discussed below and summarized in Table 1. It should be noted that achieving one criterion may result in the downgrading of pellet quality in another criterion. Different technologies proposed in this study may aid the necessary improvements towards an “ideal pellet”. As stated by Tumuluru et al. (2010), the optimum pelletizing conditions vary depending on process variables (die temperature, pressure, and die geometry), feedstock variables (moisture content, particle size, and shape) and biomass composition (protein, fat, cellulose, hemicellulose, and lignin).

CRITERIA FOR PELLET IMPROVEMENT A number of criteria are crucial for improving the commonly existing pellets. Chemical compositions such as chloride and sulphur content are dependent of the pellet feedstock and therefore not mentioned in this paper. Other factors, as discussed below, are related to the manufacturing process. Those can be improved by changing a variety of parameters and applying different technologies. The properties of the pellets are summarized in Table 1.

Durability is often a top quality criterion of wood pellet producers and suppliers. To minimize fine production during storage, handling and transportation, pellets should have high mechanical durability, e.g. more than 98.5%. This value relates to the tumbler test widely accepted by the industry. The level of durability is achieved by the majority of the wood pellet producers in British Columbia (Oveisi, 2011). Unfortunately, a recent study showed that the resolution of the tumbler is not high enough to differentiate pellets from each other (Schilling et al. 2015). Figure 1 shows that other methods such as the Dural Tester or the Single Pellet Shaker would be more suitable to measure the durability of pellets (Oveisi, 2011). To achieve an increase in durability it is crucial to adjust the pelletization parameters such as moisture content, die temperature and particle size for the specific material. Shahrukh et al. (2015) also showed that steam treatment of feedstock material can increase pellet durability.

Ash content Low ash content is important as ash removal after combustion in residential settings can be a hazardous process. Bottom ash may contain high concentration of heavy metals. Raw materials with low ash content, like, clean stem wood, are preferred as they have an ash content of less than 0.5% (d.b.). In industrial settings, however, a higher ash content (up to 3% according to ISO 17225-2) is tolerated. This is due to built-in mechanisms to safely remove the ash. In a manufacturing point of view, the removal of ash is limited to a prewashing of the material. In specific cases it is beneficial to mix high calorific bark materials, which have a higher ash content, with clean stem wood to reduce the overall amount of ash.

Aspect ratio The ideal aspect ratio of pellets has been the focus of recent studies at the University of British Columbia. Schilling et al. (2015) showed that longer pellets are more durable compared to smaller pellets. Most of the fines of pellets are produced by the rougher surface of the ends of a pellet. As longer pellets have less ends per mass compared to shorter pellets, they provide a higher durability (Figure 2). However, the highest bulk density of pellets can obviously be achieved by the smallest size of pellets. The minimum size of pellets is 6mm according to ISO 17225-2. Therefore, the ideal aspect ratio lies in between those two parameters.

Hydrophobicity Due to challenges in transport, handling and storage of material, it is highly desirable to develop pellets with an increased hydrophobicity. This would allow open storage with less danger of off-gassing and fine particle hazards. Additionally, the loading of ships during rainy periods would be possible. Improvements in hydrophobicity can be achieved by torrefaction of either feedstock or pellets. Another possibility is the coating of pellets (Hashemi et al. 2013).

Calorific value Since the majority of pellets are currently used for combustion purposes such as coal-biomass co-firing and domestic heating application, the calorific value of pellets should be as high as possible. For co-firing applications the calorific value should be as high as the one for coal. This could increase the ratio of pellets that could be added to the coal combustion process. Two major technologies seem to be promising to improve the calorific value, torrefaction as well as steam explosion (Shahrukh et al. 2015).

MANUFACTURING CRITERIA

The Pelletization pressure was the objective of many studies in the past. The overall conclusion of the conducted research shows an increase in durability and density of pellets resulting from increased pelletization pressure (Figure 3). The tested pressures ranged from as low as 50 MPa to over 600 MPa (Stelte et al 2012). Increasing pelletization pressure also directly correlates with an increase in energy consumption of the pelletization process (Stelte et al. 2011b). Hence, another challenge in biomass pelletization is to keep the pelletization pressure low to reduce the energy consumption but at the same time still produce high quality pellets at a high capacity.

Die temperature Another parameter that can influence the energy requirement for pelletization and pellet quality is the die temperature. Nielsen et al. (2009) observed that increasing the temperature up to 105°C would minimize the compression energy and resulted in more durable pellets (Figure 4). For temperatures higher than 105°C, the energy consumption rises because of drying. Several studies (Gilbert et al. 2009; Kaliyan and Morey 2010b; Stelte et al. 2011d) recommended that increasing the temperature up to lignin glass transition point may result in improved contact area and consequently to durable pellets. Also, by increasing die temperature, hydrophobic extractives tend to move to the surface of pellets. Those can act as lubricants and reduce the friction between biomass and die wall surface. Therefore the pelletizing pressure and energy required decrease when the die temperature increases (Stelte et al. 2011, Nielsen et al. 2009).

Moisture content Samuelsson et al. (2012) reported that moisture content has a great impact on the energy consumption for pelletization and the density of pellets. Water in high moisture feedstock material act as a lubricant and decreases the friction between materials and die surface (Figure 4). Stelte et al. (2011b) observed that for woody samples, the pelletization pressure decreases with increasing moisture content. He also reported that pellets are more stable with a feedstock moisture content in the range of 5% to 15% (Stelte et al. 2011b). An increase in moisture content above the optimum has a negative impact mechanical properties of pellets (Kaliyan and Morey 2009d; Nielsen et al. 2009a; Serrano et al. 2011; Stelte et al. 2011b). Andrejko and Grochowicz (2007) discovered that the energy consumption for making pellets of lupine seeds was ideal within the range of 9.5 to 15% (w.t.) and the energy input decreased. Nielsen et al. (2009a) observed that an increase in moisture content for pine and beech resulted in less required energy for pelletizing.

Particle size Smaller particle size results in higher friction and higher pelletizing pressure but increases the durability. The fine content should not exceed 10-20% (Stelte et al. 2012). It is important to find a suitable particle size distribution for each material to produce a durable pellet with low energy requirements. Figure 5 displays a recent study conducted at the University of British Columbia and shows the influence of particle size on energy consumption for single pelletization and pellet durability. This indicates an optimum particle size for low energy consumption which differs from an ideal particle size for increased durability.

Binder addition can be beneficial especially for feedstock that is difficult to pelletize as for example agricultural materials. Lu et al. (2013) used different binders to pelletize wheat straw. He showed that the mechanical and chemical properties of pellets with binder improved compared to pellets without binders. Wood waste as a binder decreases the ash content while the addition of glycerol increased the calorific value significantly from 17.98 ~ 18.77 MJ/kg. Further, both, the density and tensile strength improved when adding various binders.

Torrefaction Another way of improving the properties of pellets is to add another process to the existing system. Torrefaction is one way to improve the pellet quality, especially in terms of calorific value and hydrophobicity as shown in Table 2 and Figure 6. During torrefaction, the biomass is heated in an oxygen-free atmosphere of up to 300ºC. This results in a further decrease in moisture content and volatiles, which leads to an overall increase in carbon content. The net calorific value increases based on the improved carbon to oxygen ratio (Tumuluru et al. 2010). After torrefaction, the material shows an increased hydrophobicity which allows outside storage of biomass. On the other hand the densification of torrefied materials is more difficult as the feedstock loses part of the lignin during the process. However, Peng et al. (2012) observed that by decreasing the particle size and increasing the severity of torrefaction pretreatment, the quality of torrefied pellets (hydrophobicity and hardness) could be improved. Ghiasi (2013) investigated the possibility of torrefying pellets itself. He concluded that this approach, although consuming slightly more energy, produces more durable and denser pellets as shown in Table 2 and Figure 7. He also stated that the slightly lower energy consumption of pelletizing torrefied material was at the expense of using binder to pelletize the material. However, it is still unknown whether the additional process of torrefaction adds more value to the product than it adds cost to the production process.

Steam explosion Another pre-treatment for biomass material is steam explosion. Shahrukh et al. (2015) showed that pellets made from steam-exploded wood required less energy to be compressed and pushed out of the die compared to pellets made from untreated wood. Tests with the produced pellets also showed an increase in density as well as durability. Recent studies at the University of British Columbia confirmed those results (Figure 8). Apart from steam explosion, a mild preconditioning of feedstock materials can also improve the mechanical properties of the pellet and decrease the die wear on pelletizer. This method is commonly used by various pellet manufactures. However, the process of steam explosion itself requires higher investments and presents a technical challenge when conducted in a continuous system. As with the torrefaction process it is still unknown whether the product benefits will overcome the higher investments for producing steam exploded pellets.

Coating pellets has been focus of a recent study at the University of British Columbia. Hashemi et al. (2013) showed that the encapsulation of wood pellets with liquid solutions such as canola oil, linseed oil or wax could improve the hydrophobic character of a pellet. In case of wax coating, the rate of moisture adsorption from humid air decreased by more than half compared to untreated pellets. The overall moisture content after 72 hours decreased from 16% for untreated pellets to 2.5% for wax coated pellets. Figure 9 shows the results for moisture uptake and final moisture content after 72 hours for 9 pellets coated with different materials and an untreated pellet.

CONCLUSIONS

The current standard for high quality pellets represents pellets which are now widely produced by manufactures around the world. Unfortunately, this also reduces the challenge and the effort of improving the pellet itself. With new technologies such as torrefaction and steam explosion, it is possible to produce pellets with higher calorific value, hydrophobicity and improved physical quality. Further fine-tuning in die-hole geometry, die temperature and moisture content may allow another way of improving the properties of pellets. Lately conducted research shows very promising results for torrefied pellets produced from steam exploded material. However, often times the improvement in one characteristic results in the deterioration of another pellet property. Additionally, the industry must be able to work in a cost effective manner in order to keep its operation sustainable. But with rising prices on the energy market, it is likely that these technologies will be implemented in the future to provide pellets, which come closer to what is described as the “ideal pellet”. Challenges also lie in the feedstock availability. With less suitable pelletization materials it will be more challenging to produce good pellets. Different applications in the future might also call for different properties of pellets. A pellet for bio-conversion for example, could have different requirements as those for combustion applications.

Nonetheless, due to the limitation of biomass feedstock characteristics compared to fossil fuels it is up to the producers and researchers to develop a method to produce improved pellets in a sustainable way to compete on the worldwide market. Defining an “ideal pellet” is already a first step. Implementing a new standard for pellet quality by developing a realistic optimum pellet regarding each pellet characteristic could be the next one.

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Table 1: Proposed values for the “ideal pellet” orientated on the international standard of ISO 17225 (2013)

“The Ideal Pellet”	
Parameter in ISO standard	*Proposed Ideal values*
Raw material type	Any biomass materials
Diameter	6.35 mm
Length	>6.35 mm, <40 mm
Moisture	As low as possible or $\leq 5\%_{ar}$
Total ash	$\rightarrow 0\%_{ad}$
Ash melting behavior	As high as possible ≥ 2000 ºC
Mechanical Durability	$\rightarrow 100\%_{ar}$
Fines content	$\rightarrow 0\%_{ar}$
Particle size distribution	→ 100% > 3.15mm
Additive content	$\rightarrow 0.0\%_{ad}$
Net calorific value	≥ 20 MJ/kg_{ar}, towards the calorific value of coal
Bulk density	≥ 750 kg/m^3
Bulk temperature	≤ 60.0 ºC
Nitrogen	→ 0%, to minimize NO_x emissions
Sulphur	→ 0%, to minimize SO_x emissions
Chlorine	→ 0%, to minimize corrosion
Minor elements	→ 0 ppm

Table 2: Physical properties of pellets made from untreated and torrefied wood chips (Ghiasi et al. 2015)

Pellet type	**Diam. (mm)**	**MC (%)**	**Particle density (g/cm^3)**	**Bulk density (kg/m^3)**	**High heat value (MJ/kg)**	**Durability DURAL (%)**
Pellets made from untreated wood chips	6.43	6.7	1.16	674	18.82	80.7
Pellets made from torrefied woodchips mixed with 7% wheat flour binder , Temp 260ºC	6.47	8.6	1.21	-	-	85.0
Regular white pellets torrefied at 260ºC	6.28	1.9	1.14	614	21.08	63.9
Regular white pellets torrefied at 280ºC	6.12	1.7	1.04	579	21.97	62.0
Regular white pellets torrfied at 300ºC	6.12	1.5	0.96	510	23.00	60.9

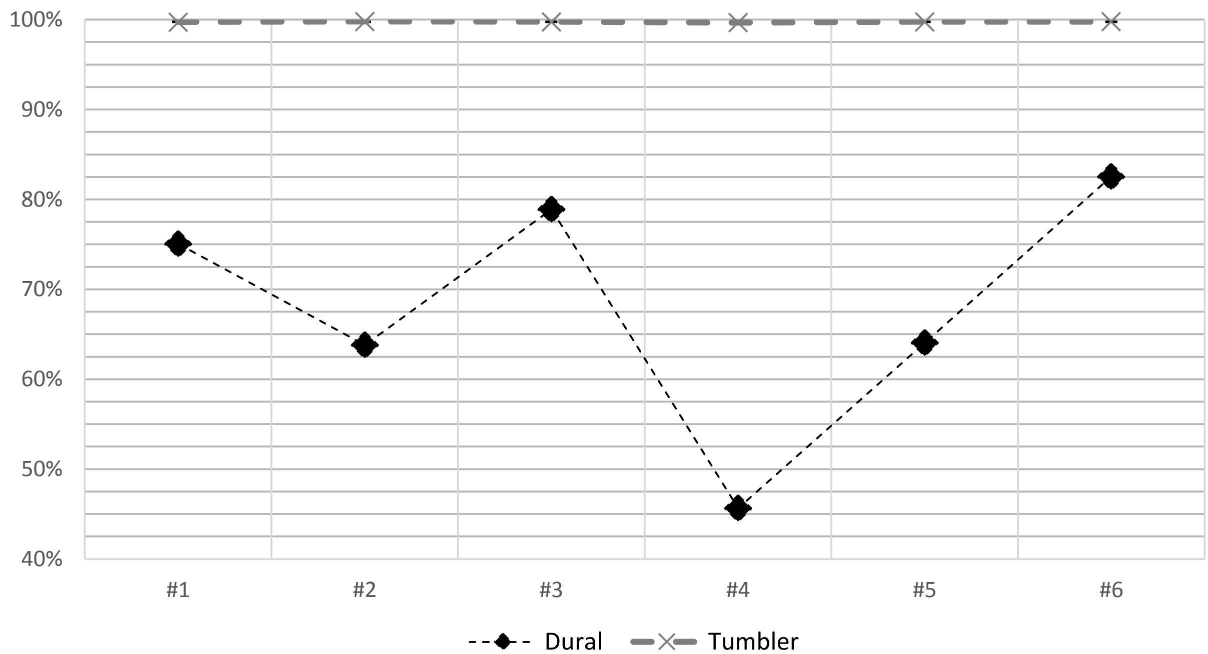

Figure 1: Durability measurements of 6 different pellet samples produced in British Columbia, compared results for durability tested with the 'Tumbler' tester and 'Dural' tester.

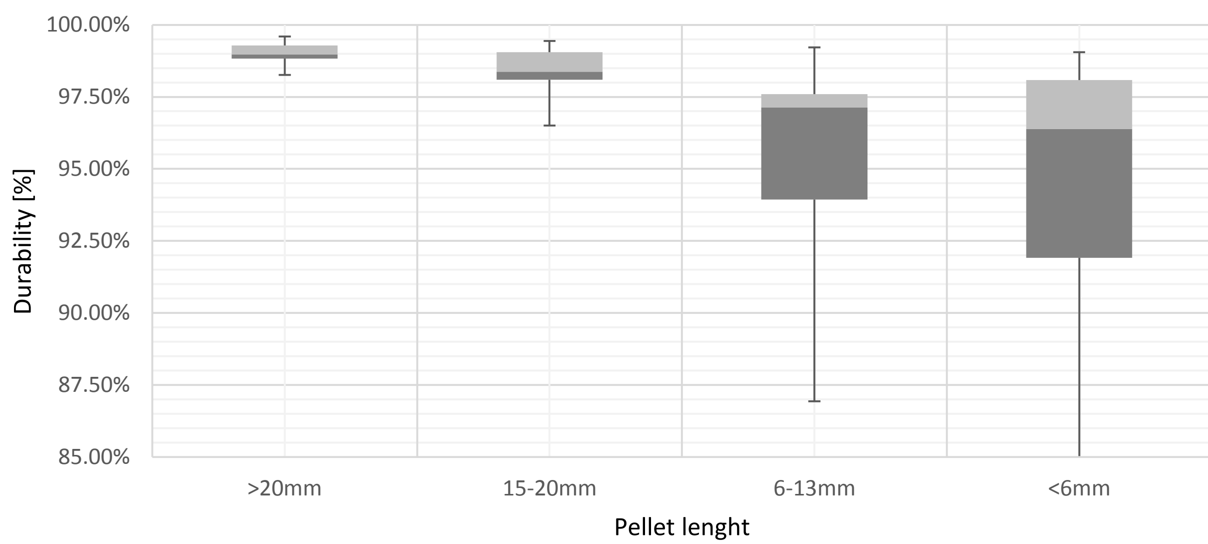

Figure 2: Influence of pellet length on durability of single Douglas Fir Pellets (Schilling et al. 2015)

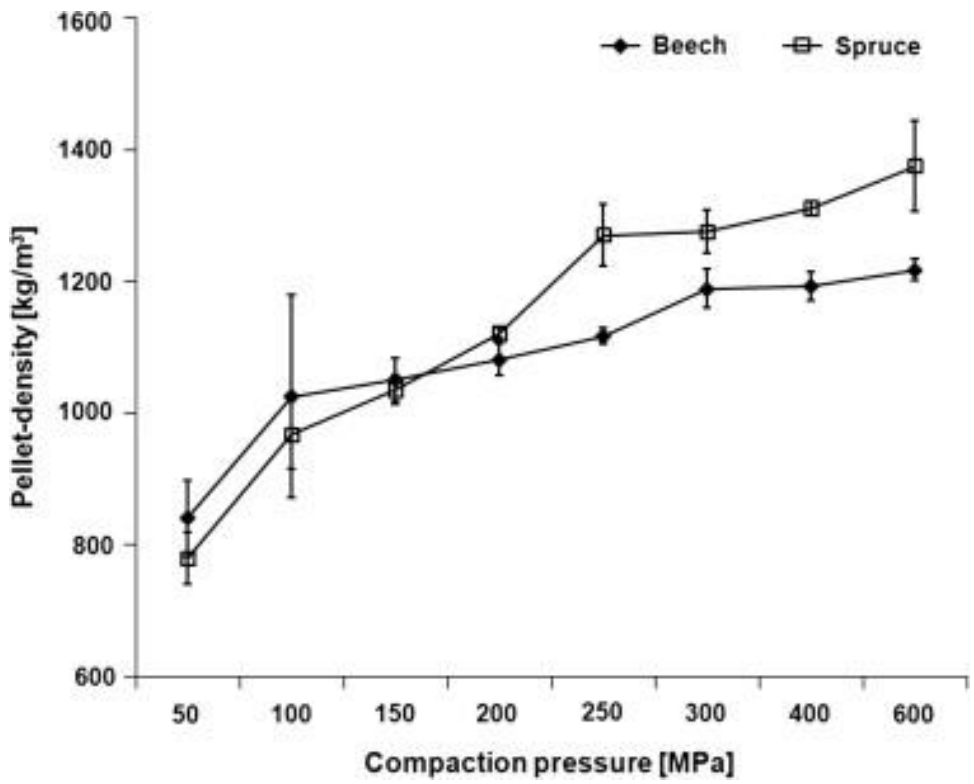

Figure 3: Density vs. compaction pressure (Stelte et al. 2011b)

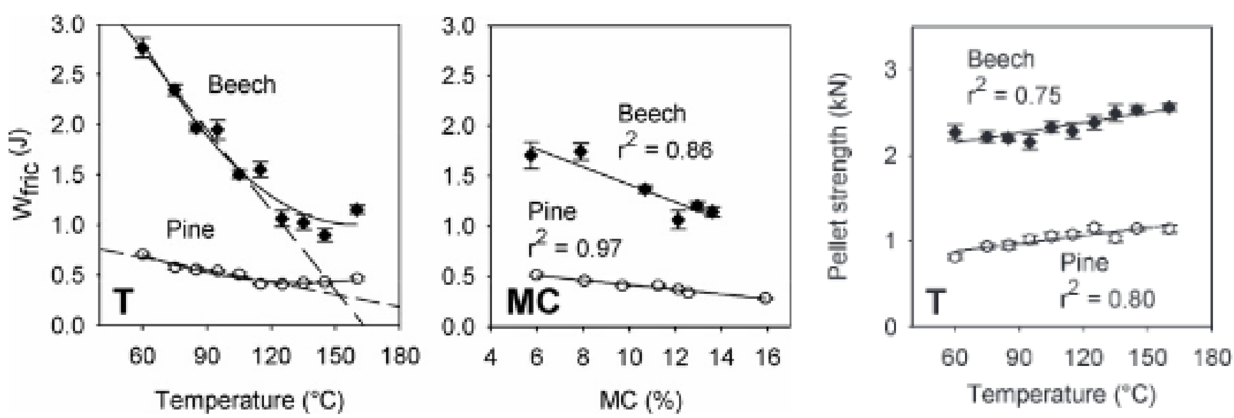

Figure 4: Influence of temperature on the pelletization process (Nielson et al. 2009)

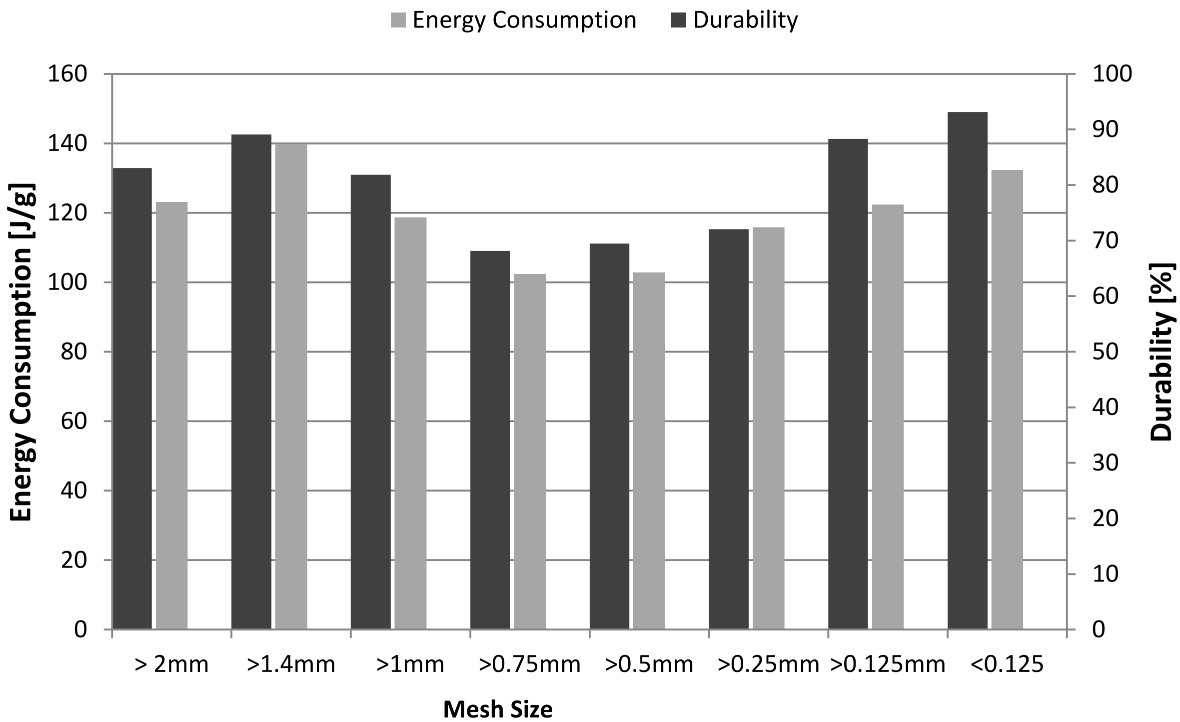

Figure 5: Influence of particle size on energy consumption for pelletization and on durability for Douglas Fir feedstock ground on hammer mill and pelletized on a single pelletization unit. Durability was obtained using the ‘Shaker’ durability tester (Schilling et al. 2015).

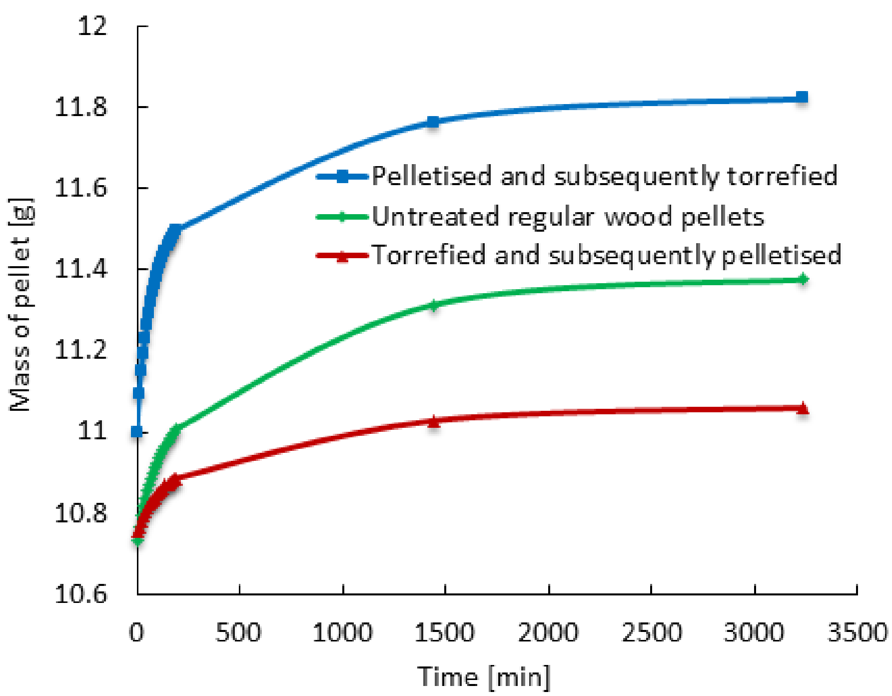

Figure 6: Moisture absorbtion of torrefied and raw pellets (Ghiasi et al. 2015)

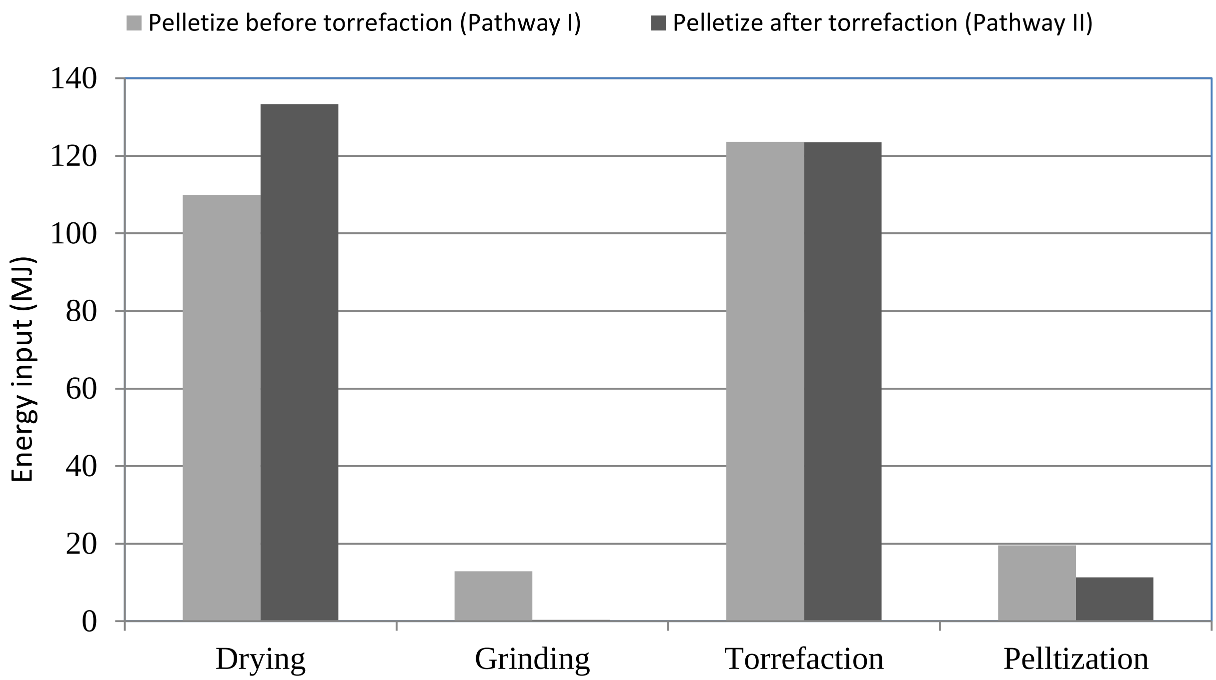

Figure 7: Energy input to major unit operations for the two pathways of pelletize before torrefaction (Pathway I) and Pelletize after torrefaction (Pathway II) (Ghiasi et al. 2015)

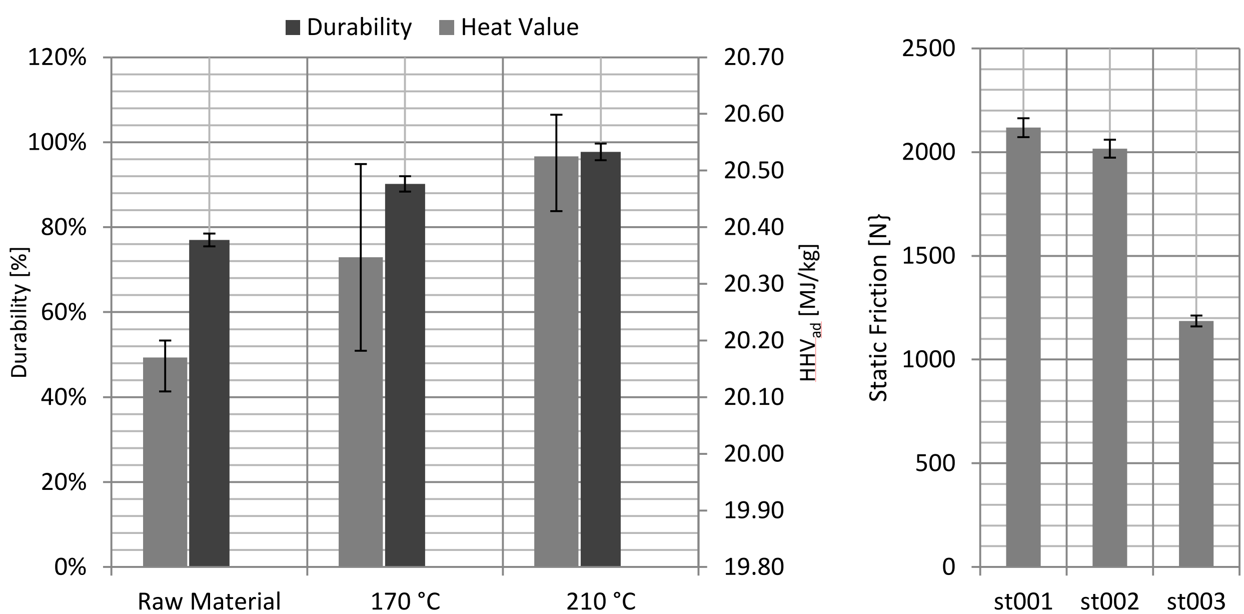

Figure 8: Influence of steam explosion on pellet quality and die friction, the diagrams show results of Douglas Fir Pellets produced from steam exploded material. The research was recently conducted with the University of British Columbia

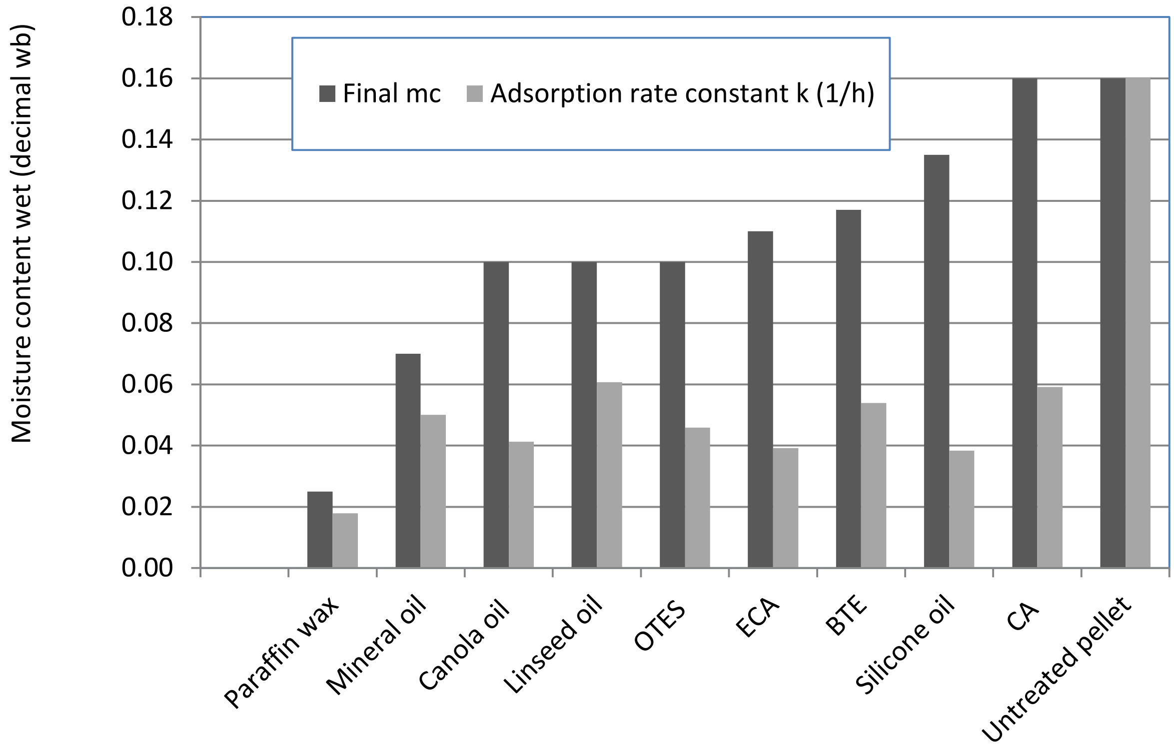

Figure 9: Final moisture content and the rate of adsorption for untreated and treated wood pellets (Hashemi et al. 2013).

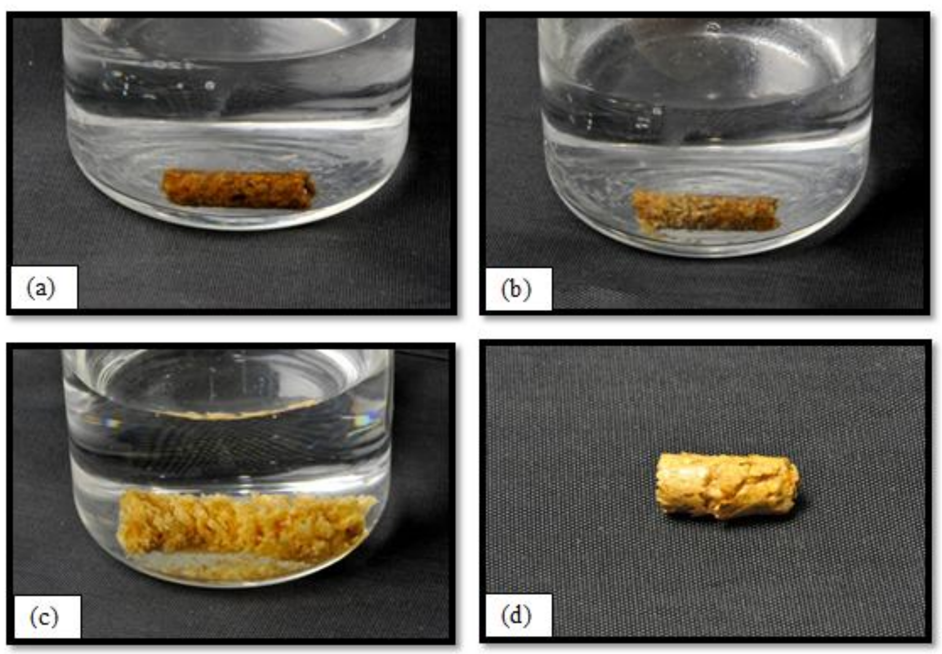

Figure 10: Categorizing pellets dipped in water. (a) no change on the pellets; (b) wood particles separate from the wood pellet surface; (c) 4 & 6: cracks on the surface of pellets appear and pellets disintegrate; (d) cracks on the surface of pellets are visible and pellets swell