Effect of torrefaction on grinding energy requirement for thin wood particle production

Alexandre Govin, Vincent Repellin, Mathieu Rolland, Jean-Luc Duplan

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Effect of torrefaction on grinding energy requirement for thin wood particle production

GOVIN Alexandre[(1)] *, REPELLIN Vincent [(2)], ROLLAND Mathieu[(2)], DUPLAN Jean-Luc[(2)]

[(1)] *Ecole Nationale Supérieure des Mines de Saint Etienne, Centre SPIN – Département PMMC ; LPMG -UMR CNRS 5148, 158 Cours Fauriel - 42023 Saint-Étienne Cedex 2, France*

[(2)] *IFP-Lyon, Rond-point de l'échangeur de Solaize, 69390 Solaize, France*

Abstract:

The second generation biofuels exploits the lignocellulosic materials. The main advantage is to not compete with food chain. In the case of thermochemical means (gasification in an entrained flow reactor followed by Fischer-Tropsch synthesis), a grinding step is necessary to inject particles into the burner. The targeted particle size is about 200µm to reach a total conversion and to improve gas quality. Due to the plastic behaviour of the biomass, this step is strongly energy-consuming. Biomass torrefaction (thermal treatment lower than 300°C) is a way to decrease the grinding energy and to standardize materials (composition and moisture). Contrary to natural wood, torrefied wood has a brittle behaviour and a less mechanical strength. The aim of this study is to investigate the interest of torrefaction on wood grinding energy diminution. The torrefactions were carried out on beech and spruce, in an airtight rotating batch kiln under nitrogen. The effect of torrefaction temperature (160-300°C) and duration (5-60min), on weight loss, grinding energy and powder particles size were examined. The grinding energy was calculated by integration of the electric power of the grinder, which was measured by the means of a wattmeter. A grindability criterion, which took into account both grinding energy (E) and the volume fraction (X) of particles lower than the targeted size (200µm), was defined. Results showed a strong interest of torrefaction on the decrease in energy required for fine wood particle grinding. The grindability criterion could be reduced by 93% for treatments beyond 260°C. However, the global energy balance becomes less favourable. It is necessary to reach a compromise between the consumed energy by torrefaction and the decrease in grinding energy. According to the wood species, an optimum could be established around 10% of weight loss and around 85% of the grindability criterion diminution.

Keywords:

torrefaction ; grinding ; wood ; energy ; particle size distribution

I. Introduction

In recent years, worldwide interest in the conversion of biomass into biofuels is growing. Researchers are working on second and third generation biofuels, which do not compete with the food chain. This scope aimed to exploit the renewable lignocellulosic materials from several plant sources such as wood, straw, agriculture residues, wastes… One way to produce synthesis fuel is the thermochemical conversion processes of biomass. Among thermochemical processes, gasification of biomass followed by Fischer Tropsch process is promising (Claudet *et al.*, 2004). However, a grinding step is necessary to improve reaction rates and gas yield. Indeed, several authors revealed the effect of the heating rate of the sample, pyrolysis temperature, and particle size and distribution, on the products evolved and their distribution during pyrolysis (Li *et al.*, 2004; Wei *et al.*, 2006; Tinaut *et al* 2008).

* Auteur à qui la correspondance devait être adressée : govin@emse.fr

According to (Simmons and Gentry, 1986) and (Wei *et al.*, 2006), the fast pyrolysis of biomass is mainly controlled by reaction kinetics, for particle sizes smaller than 200µm, while for particle sizes above 200µm, the process is mainly controlled by mass and heat transfer within the particle. However, grinding wood or biomass is very energy consuming. To obtain aspen wood powder with a d50 between 500 µm and 250 µm, (Himmel *et al.*, 1985) found typical net grinding energies values around 120kWh/t. Straw required grinding energies inferior to 50kWh/t. Moreover, they showed that for similar particles size reduction, energy requirement is higher with a hammer mill than with a knife mill. Other studies showed that higher energy consumption is necessary with attrition mill or explosion depressurisation than with knife mills (Holtzapple *et al*, 1989). For coarser grinding (d50 around 840µm), energy requirements were 453kWh/t for explosive depressurisation and 783kWh/t for attrition mill. Fine grinding with attrition mill (d50 close to 105 µm) required 1900kWh/t. Optimising grinding process with hammer mills, (Esteban and Carrasco, 2006) obtained 130kWh/t for poplar and 170kWh/t for pine, for a d50 approximately around 500µm. For comparison, typical coal grinding energy ranges between 7kWh/t and 36kWh/t.
Biomass torrefaction could be a way to decrease the grinding energy (Bergman and Kiel, 2005) and to standardize materials (composition and moisture). The torrefaction is a thermal treatment of lignocellulosic materials carried out at temperatures lower than 300°C (mild pyrolysis) under inert atmosphere (Bourgeois, 1989 and 1990). Contrary to natural wood, torrefied wood has a brittle behaviour and a decrease in mechanical strength (Rapp *et al.* 2006). As wood grinding is very energy consuming, the objective of this study is to investigate the interest of wood torrefaction on the grinding energy.

II. Materials and Methods

The experimental procedure followed for this work is presented in Figure 1. Natural wood chips were torrefied at several temperatures and durations and then pre-grinded with a first knife mill. Afterwards, pre-ground material was sieved. For each batch, the same sieved fraction (2-4 mm) was collected and used for fine grinding. During fine grinding, the energy measurements were carried out. The particle size of the resulting fine powder was analysed by laser diffraction.

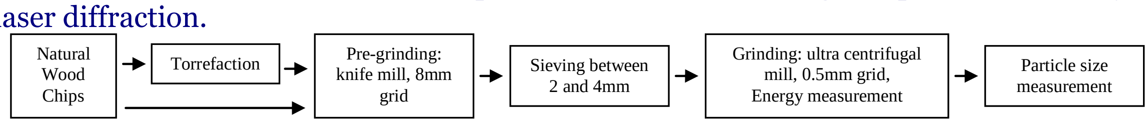


Figure 1: Experimental procedure.

II.1. Torrefactions

The torrefactions were carried out in a pilot kiln designed at the Ecole des Mines de Saint Etienne. The kiln was an airtight rotating batch kiln with a volume of 30L. All the torrefactions were carried out under nitrogen. The temperature of the kiln was measured on the outer part of the envelope of the reactor and used for regulation. The temperature of the material was measured in the moving bed of wood chips. The temperature of the treatment was defined as the maximum of temperature reached by wood chips. Temperatures and durations of torrefaction ranged, respectively, from 160°C to 300°C and from 5 to 60 minutes. Two kinds of wood species were used in this study: spruce and beech. For each treatment, the Anhydrous Weight Loss (AWL) was estimated as follow:

$$AWL = \frac{m_{nat0\%} - m_{tor0\%}}{m_{nat0\%}} \times 100 \qquad (1)$$

With $m_{nat0\%}$ and $m_{tor0\%}$ corresponding respectively to the mass of anhydrous natural wood (before torrefaction) and to the mass of anhydrous torrefied wood.

II.2. Fine grinding and energy measurement

Natural chips and torrefied chips of each batch were pre-ground in a knife mill Retsch SM1 equipped with an 8mm grid. The material was collected and automatically sieved between

2mm and 4mm. For natural wood and torrefied wood, four samples of 30g of well defined size particles (2-4mm) were employed for fine grinding. They were finely ground in an ultra centrifugal mill (Retsch ZM 1). We selected the grid that produced most particles inferior to 200µm and the least grinding energy. The 500µm grid was chosen for this aim. It allowed relevant observation of the influence of torrefaction on the volume fraction of particles smaller than 200µm. The mill was fed with a vibrating feeder type Retsch D100. The feeding rate was adjusted according to the material to ensure a power of the mill motor close to its nominal value (400W). A numerical wattmeter ISW 8350 from IeS (Instruments and Systems) was employed to record the electrical power during grinding with the ZM1 mill. The power of the mill under no-load conditions was measured (280W) and subtracted to the power obtained during the grinding of wood. Then, the grinding energy (E) was evaluated by integration of the power curve during the duration of grinding, divided by the sample mass. It counted only the energy necessary to grind wood particles.

II.3. Particle size

Each powder sample was analysed by laser particle size analysis (Malvern Mastersizer 2000 and sirocco 2000(A) cell). Disperser pressure was set to 3.5 bars. We defined X<200µm as the volume fraction (%) of particles of diameter inferior to 200µm.

III. Results and discussion

III.1. Effect of torrefaction temperature on mass losses

The Figure 2 shows the Anhydrous Weight Loss of beech and spruce vs. torrefaction temperatures. In these cases, the treatment durations have been fixed to 5 minutes. We could notice that for both species, up to 200°C, no AWL was observed. In this temperature range, only drying and physical transformation of the lignin occurred. After that, as expected, the AWL increased sharply with the torrefaction temperature. For both species, the AWL ranged from 0.4 to 30% for temperatures ranging from 200 to 300°C. However, from 220°C, the AWL was higher for beech than for spruce. In order to have the same AWL, beech needed to be treated 20°C lower than spruce. For example, AWL of about 28% was obtained at 280°C for beech and at 300°C for spruce. This phenomenon could be due to heat transfer or chemical composition. Indeed, we noticed that the torrefaction temperature was reached faster for spruce than for beech. The time to reach 260°C was about 85 minutes for spruce and 105 minutes for beech. This means that beech was exposed to temperature for a longer period of time than spruce. Moreover, according to (Sjöström, 1993), the content of xylan is higher for beech (27.5%) than for spruce (8.6%). Several authors showed that xylan is the most heat-sensitive among hemicelluloses (Degroot *et al.*, 1988 ; Weiland *et al.*, 1998 ; Repellin and Guyonnet, 2005). Then, a higher AWL was expected and observed for beech than for spruce.

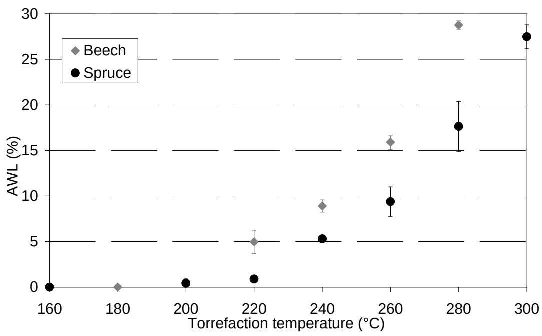


Figure 2: AWL vs. torrefaction temperature for beech and spruce.

III.2. Effect of torrefaction temperature on grinding energy

The effect of thermal treatment on the grinding energy for beech and spruce is shown on Figure 3. It corresponded to the energy required for grinding wood species through a grid of

500µm. As described above, the grinding energy plotted here, did not take into account the energy of the mill under no-loading conditions. Only the energy required to grind wood particles was plotted.

For natural (non-treated) woods, the grinding required a lot of energy. For beech, when the torrefaction temperature exceeds 180°C, the grinding energy decreased gradually (250 to 27 kWh/t). The grinding energy could be reduced by a factor of 10 when the temperature rises from 180 to 280°C. For spruce, from 200°C, the same tendency was observed. However, the slope is lower than for the beech. Indeed, the grinding energy was only divided by 5 for temperatures ranging from 200 to 300°C (127 to 26kWh/t).

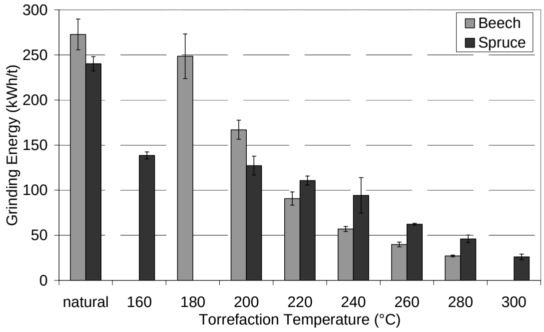
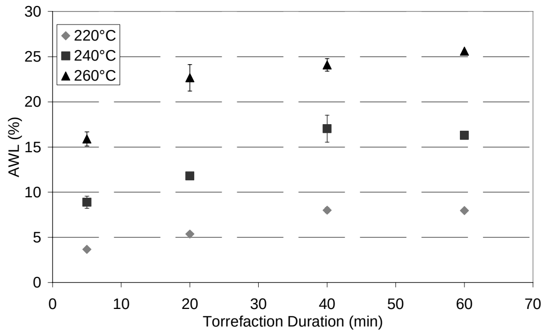


Figure 3: Grinding energy for beech and spruce vs. torrefaction temperature.

For both wood species, the thermal decomposition of wood begins from 200°C, and increases with temperature. The thermal decomposition of wood resulted in, a progressive and general, embrittlement and degradation of wood cell walls. Consequently, grinding becomes easier and then the required energy is lowered. By comparing beech and spruce, two remarks can be made. Firstly, as the AWL, beyond 200°C, spruce needed to be treated 20°C higher than beech to obtained similar grinding energy. Secondly, an effect of temperature on grinding energy could be noticed at 160°C for spruce. It indicated that a soft thermal treatment could drop off, of about 40%, in the energy required to grind spruce. However, as shown on Figure 2a, the AWL was equal to 0% for torrefaction at 160°C, which means that only drying and overtaking of the glass transition temperature of lignin occurred during this treatment. These phenomena could induce shrinkage and a relaxation of the internal stress of wood, which could favour the creation of defects and cracks. The material could become more brittle and therefore easier to grind after heat treatment.

III.3. Effect of torrefaction duration on the mass losses and the grinding energy

The effect of torrefaction duration on the AWL for beech is shown on Figure 4a. The experiments were carried out at 220, 240 and 260°C. Whatever the temperature, the AWL drops rapidly with durations of 5 to 20 minutes and then increases slightly. For example, at 260°C, the AWL reached 23% during the first 20 min and then only augmented of 3% during the 40 minutes following.



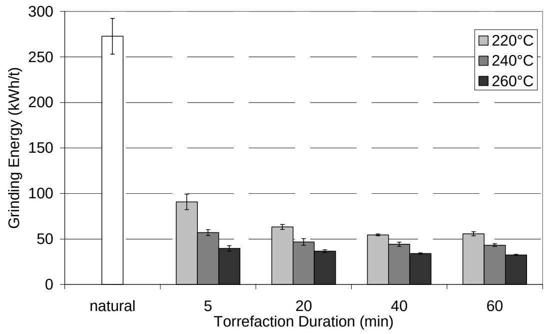


Figure 4: (a) AWL vs. torrefaction duration for beech; (b) Grinding energy vs. torrefaction duration for beech

The Figure 4b shows the effect of torrefaction duration on grinding energy. For each temperature, grinding energy decreased with the duration of torrefaction up to 20 minutes. Then, the grinding energy was constant. This means that with the considered treatment and technology, a duration higher than 20 minutes, was not necessary.

III.4. Effect of torrefaction temperature on particle size

After each grinding, the powder was analyzed by laser particle sizer. The Figure 5 shows the cumulative volume fraction vs. particle diameter for each treatment and for both wood species. It highlighted that the diameter of the particles, obtained after grinding, is dependant of the torrefaction temperature. Indeed, the higher the temperature the thinner the particles are. For example, the volume fraction of particles smaller than 200µm was about 45% for natural beech and about 65% for beech treated at 280°C. From the point of view of particle size, spruce seemed to be more thermally sensitive than beech. Indeed, for the same parameters as above, the volume fraction reached 75%. This value may exceed 85% for treatment at 300°C. This could be explained by the fact that spruce particles, after torrefaction, may be harder than those of beech, and then they require a little more energy to be grinded (Figure 3). Moreover, the centrifugal grinder could be more efficient with harder particles, leading to greater fragmentation of particles and hence to a finer diameter.

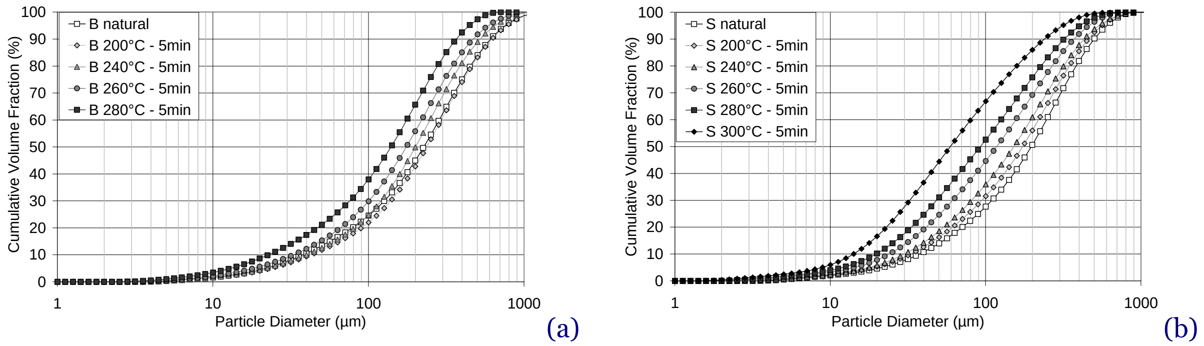


Figure 5: Particle size distribution of fine powder of beech (a) and spruce (b) (natural and torrefied at different temperatures).

These results emphasized that in addition to lowering the energy of grinding, the torrefaction reduced the particle size obtained after grinding. In order to compare both materials and treatments, we proposed a grindability criterion inspired from Sokolowki's work (Sokolowki 1996). The grindability criterion, noted G (in kWh/t), was defined as follow:

$$G = E/X_{<200\mu m}$$

With E and X corresponding respectively to the grinding energy, and to the volume fraction of wood particles lower to 200µm.
G took into account, on the one hand, the grinding energy, and on the other hand, the volume fraction of particles less than a threshold. In our case, the threshold was fixed to 200µm. For each torrefaction (wood species, temperatures and durations) the grinding criterion vs. the anhydrous weight loss, which characterized the treatment, was plotted on Figure 6.

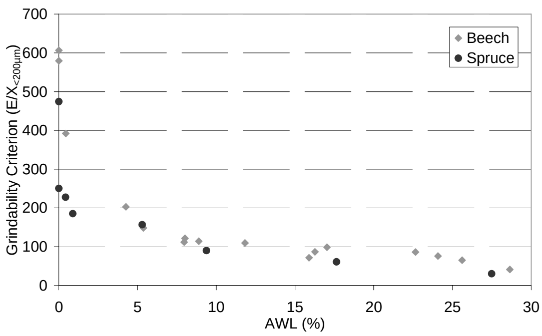


Figure 6: Grinding criterion vs. anhydrous weight loss for beech and spruce.

G trends to follow a hyperbolic curve. In the first 10% AWL, G decreased dramatically from 600 to 100 kWh/t. Beyond 10% AWL, G diminished very little. Indeed, for an interval from 10% to 30% in AWL, G varied only of 60 kWh/t. For beech, the grindability criterion could be reduced by 93% by treatments at 280°C. However, the energy balance becomes less favourable. Indeed, the grinding is strongly enhanced by heat treatment, but the gain of energy is annihilated by the energy required by the treatment. It is necessary to reach a compromise between the consumed energy by torrefaction and the decrease in grinding energy. In addition, to maximize the carbon yield, the torrefaction should not be too drastic. According to the wood species, an optimum could be established around 10% of weight loss and around 85% of decrease in grindability criterion.

IV. Conclusion

Biomass torrefactions were carried out in an airtight rotating kiln on beech and spruce. For both wood species, the mass losses increase with temperature and duration of torrefaction. Results on energy measurements and particle size highlight a strong interest of torrefaction. Indeed, torrefaction reduces significantly the energy required for grinding on one hand and, on the other the particle size. Then a grindability criterion (G), which takes into account these two parameters, was proposed. It allows comparing each treatment and wood species. G declines sharply up to 10% mass loss. This range of mass loss corresponds to “soft” torrefaction. When treatment exceeds 260°C or 20 minutes, G decreases very slowly. In some cases, it was possible to reduce G by 93% but the energy required for heating and the mass loss could annihilate the gain. According to the evolution of G vs. mass loss, we propose treatments, which induce a maximum mass loss of 10%.

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