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Poster C01

Influence of the heating rate on energy consumption of the biomass torrefaction process

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Context and objectives

Wood constitutes a renewable and sustainable material usable in construction, energy production or to provide chemical feedstock. However, raw wood utilization is limited because of its weak durability and dimensional stability, low energy density, high moisture content and compromised grindability. Wood torrefaction (temperature ranging between 200°C and 300°C in oxygen free atmosphere) is a thermal modification process with great ecological and economical importance to improve the shortcomings of the raw material (Esteves and Pereira 2009, Candelier et al. 2016, Chen et al. 2015, Kumar et al. 2017, Chen et al. 2018).

Many technologies for wood thermochemical modification have been developed in Europe and all over the world since the 1980's. In spite of the huge industrial development, torrefaction processes are lead in an empirical manner (Bergman and Kiel 2005, Sun et al. 2011, Acharya et al. 2012). The interest of the scientific community has been triggered and numerous investigations have been developed to deeply understand the relationships between treatment intensity, reaction atmosphere, and final properties. A significant lack of knowledge persists in the initial stages of the process, where temperature is raised from the ambient to the treatment one (Fig. 1). Low heating rate (0.2 to 1°C.min^{-1}) is usually practiced when thermal treatment process is applied as preservation method improving dimensional stability and fungi resistance. A slow temperature increasing allows to avoid the appearance of crack, the alteration of mechanical properties and dimensional collapse. Even though this start-up phase is necessary, it induces longer time for the total process and immobilization of the production unit.

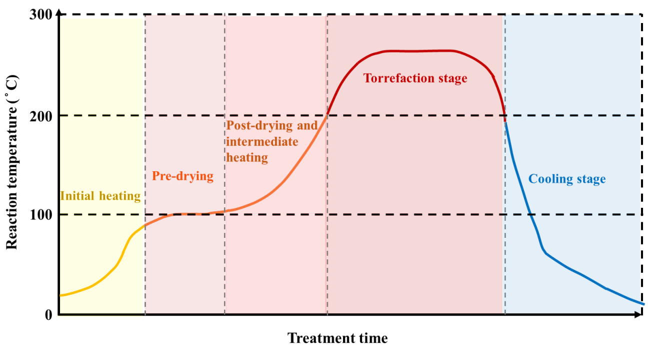

Fig. 1: Stages in the heating of most biomass.

On the other hand, when torrefaction process is used as pretreatment phase in energy production industry, heating rate is much higher (going from 20 to several hundred°C min^{-1}). Consequently, the total process is faster but requires the use of powerful heaters which can represent an important investment.

In order to elaborate an optimal business plan, companies need to evaluate the compromise between investment and process duration. For this reason, the investigation of the total energy consumption of the torrefaction process could be an important key for industrial process control.

Thus, the purpose of this study is to investigate the influence of the heating rate on the biomass thermo-degradation pathway and the final properties of the material.

Material and methods

Thus, experiments of thermal degradation were carried out on poplar (*Populus nigra*) woody powder by thermogravimetric analysis (TGA) with an analyzer TGA 2 (LF), Mettler Toledo. The heating rate has been varied between 0.2°C.min^{-1} and 20°C.min^{-1}. Prior to the experiments, the powdered woody samples were dried under 103°C in the oven for 24 h. The isothermal experimental plate is characterized by 5 hours duration under 220°C. In each run, around 25 mg of sample were loaded into an Al_2O_3 crucible (600 µL), and then the crucible was inserted into the TG furnace. The N_2 at a flow rate of 100 mL min^{-1} was used as the carrier gas to provide an inert atmosphere.

Results

Dynamic solid yield curves are shown on Fig. 2. A clear difference can be observed in the first stage of the torrefaction process when different heating rates are employed. At the end of the thermal treatment, this disparity starts to be less significant. Table 1 summarizes the occurred mass loss during the total heat treatment process composed by the heating stage (different heating rates) and a 5 hours isothermal plate. Mass loss is defined as follows:

$$Mass\ Loss\ (\%) = \frac{M_i - M_{treated}}{M_i} \times 100 \qquad (1)$$

Where M_i is the initial mass of the wood panel, $M_{treated}$ is the mass of the panel after the thermal treatement.

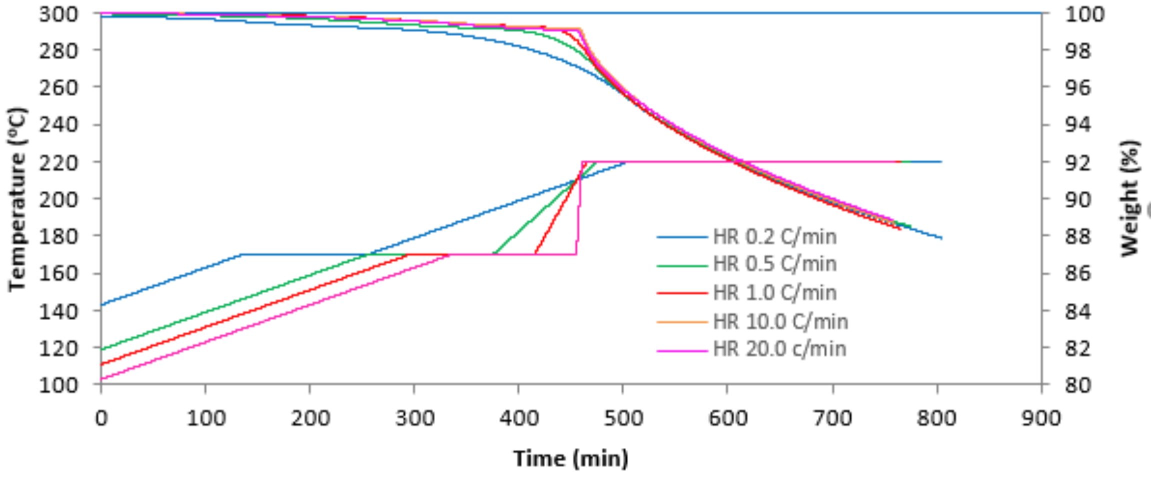

Fig. 2: Dynamic weight and temperature profiles for 6 different heating rates (0.2; 0.5; 1.0; 5.0; 10.0 and 20.0°C min^{-1}) followed by 5 hours isothermal plate.

Tab. 1: Mass loss (%) measured for the total torrefaction process.

Heating rate (°C/min)	0.2	0.5	1	5	10	20
Mass loss (%)	12.12	11.50	11.64	11.32	11.30	11.12

A deeper analysis of results has been proposed in order to investigate the influence of the heating rate on degradation pathway. For each heating rate, a new experiment has been performed. Thermal process starts with the studied heating rate. When solid yield reaches 98% (Fig. 3), the process is set to pyrolysis process till 800°C under 20°C min^{-1}.

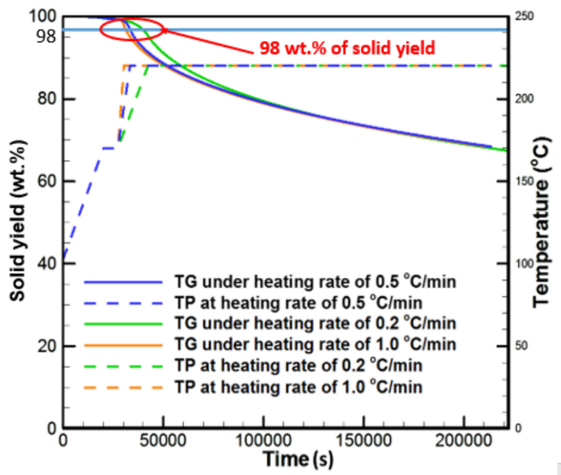

Fig. 3: Strategy of investigation of the influence of the heating rate on thermodegradation pathway.

The derivative thermodegradation analysis (DTG) of pyrolysis are shown on Fig 4. This method is used as indirect way to determine the chemical composition of the biomass.

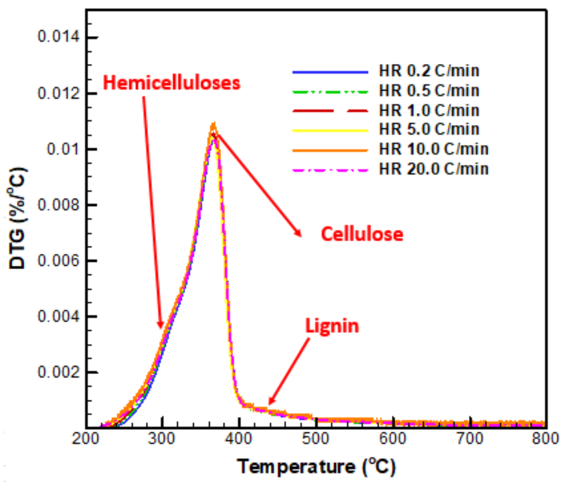

Fig. 4: Derivative thermodegradation analysis.

It can be seen on Fig.4 that for samples obtained after a low heating rate, the shoulder of hemicelluloses is less present. Hemicelluloses are more sensitive to the temperature. The time to reach the treatment temperature (220°C) is longer for low heating rate and this constituent is more degraded. The biomass chemical composition is significantly similar for cellulose and lignin.

Discussion

Chemical aspect: The DTG curves derived from pyrolysis of heat-treated products (2 % Mass Loss) overlap. It is indicating that the heating rate has no effect on the thermal degradation of the poplar when they achieve the same weight loss.

Energy aspect: Among cases with 2 % Mass Loss, using heating rate of 0.2°Cmin^{-1} is much energy-saving or cost-saving, since it can reach the 2 %Mass Loss at lower temperature. This may be due to the low heating rate having enough time to transfer heat homogeneously, and thus enhancing the thermal degradation.

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