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Modelling anhydrous weight loss of wood chips during torrefaction in a pilot kiln

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ABSTRACT

Beech and spruce chips were torrefied in a batch rotating pilot kiln. For each torrefaction the temperature curve of the moving chips bed was recorded. The anhydrous weight loss (AWL) of each torrefaction was measured. Effect of torrefaction temperature and duration on the AWL was studied. In order to optimise short time torrefaction, models that can estimate the AWL from the chips temperature curve are required. Three phenomenological models were successfully applied. They all gave good correlations between experimental and calculated AWL. These three models can be employed to optimise industrial torrefaction. However, the more complex they are, the more difficult it is to understand their physical meaning. It is thus preferable to use simple model for the industrial control of torrefaction.

1. Introduction

Biomass, in particular wood and forest residues, is the largest source of renewable material and energy. Nowadays the use of wood as building material is promoted. Wood can store large amounts of carbon and its processing induces less CO_2 emissions than other materials [1,2]. Facing the decrease of fossil fuels resources, it becomes also crucial to enhance the use of biomass as a source of energy. To use biomass as a source of energy, different ways are considered such as direct combustion, co-firing in power plants, production of biomass based motor fuels. For example, diesel can be made from biomass by Fischer-Tropsch synthesis. Fischer-Tropsch synthesis requires a preliminary gasification. Gasification produces syngas (H_2 and CO) by heating biomass particles at temperatures between 800 °C and 1000 °C. In order to perform gasification at high yields, wood must be reduced to fine powder. However wood has viscous-elastic and plastic behaviours. Grinding wood requires a lot of energy, because a lot of energy is dissipated before failure [3,4].

Torrefaction is a heat treatment at low temperature, which may improve wood grindability [5]. Contrary to natural wood, torrefied wood has a brittle behaviour and a decreased mechanical strength. A lot of energy necessary for powdering wood may thus be saved [5]. Moreover torrefaction increases the carbon content of wood. Its energy content is consequently enhanced [6,7]. Heat treatments decrease biomass moisture content and hygroscopicity [8–10]. The advantages provided by torrefaction may also be useful for co-firing, or pellets manufacturing [11,12]. The torrefaction is energy-

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consuming, and therefore the energy balance "torrefaction – grinding" is reduced. However, the energy balance between energy gain made by grinding, the increase in the heat value of wood and energy consumption for torrefaction seems favourable [11–13].

In a more detailed way, torrefaction is a heat treatment of ligno-cellulosic material carried out at temperatures inferior to 300 °C. Torrefaction can be carried out under different gaseous atmospheres. Nitrogen or hot gases released during the thermal treatment are employed most of time. It avoids exothermic reactions that are likely to occur in presence of oxygen. When exothermic reactions take place, a fast and uncontrolled increase in temperature of the material occurs. However, chemical reactions involved during torrefaction as well as final properties of the material depend strongly on the temperature of the wood. To control the torrefaction process, it is consequently necessary to monitor the temperature of the material, and not only the temperature of the kiln that can be quite different. Kiln temperature is not adequate to estimate the advancement of torrefaction. To monitor correctly material temperature, a thermocouple has to be dived into the wood chips bed.

From the chemical point of view, wood is composed of three main structure constituents: cellulose (35 to 40 weight %), hemicelluloses (20 to 30 weight %) and lignin (20 to 30 weight %). It contains also 1 to 4 weight % of extractives compounds [14]. During torrefaction, slow pyrolysis prevails: wood is thermally decomposed at a slow rate [15,16]. This decomposition leads to an anhydrous weight loss (AWL) of the wood. AWL is representative for physical-chemical transformations of wood. AWL matches to the advancement of the torrefaction reaction. At temperatures below 300 °C, the main products of wood decomposition are water, carbon dioxide, carbon monoxide, formic acid, acetic acid and furfural. Many studies have shown that these products correspond mainly to hemicelluloses decomposition. Nevertheless, lignin and cellulose undergo also some decomposition, in particular when the temperature goes over 250 °C [17–19].

Properties of torrefied biomass depend on the AWL. Hence, controlling the torrefaction process means to control precisely the AWL of the material. It requires a model to estimate the AWL from the temperature record of the material. The purpose of this study is to examine different models that can be used as tools to predict the AWL. A large number of torrefactions were carried out. AWLs of each torrefaction were measured. The temperature of wood chips was recorded during torrefaction runs. According to these temperature records, different models were employed to predict the AWL. Parameters of each model were fitted, and the relevance of these models was examined.

2. Materials and methods

2.1. Torrefaction kiln

A pilot kiln designed at the Ecole des Mines de Saint Etienne was used to carry out torrefactions. It was an airtight rotating batch kiln with a volume of 30 litres. The kiln consisted of a cylindrical chamber made of stainless steel. When wood chips were introduced into the kiln, the chamber was closed to become airtight with outside. It rotated on itself in order to homogenize the wood charge. The whole (chamber and wood) was heated by electrical resistors located just below the rotating cage and regulated by a controller. Torrefactions were carried out under nitrogen flow (6 L/min). The temperature of the kiln was measured on the outer surface of the metal chamber of the reactor and used for control. The temperature of the material was measured in the moving bed of wood chips by the way of a thermocouple. Wood chips had to have a volume at least of 6 litres, to ensure a correct surrounding of the thermocouple. Fig. 1 presents typical curves of the temperatures recorded during a torrefaction run.

2.2. Samples

Forty three torrefactions were carried out on wood chips. Two kinds of wood species were used: spruce and beech. These species were chosen as typical European softwood and hardwood. The samples had been equilibrated at ambient temperature and humidity at least for 3 months. Table 1 summarizes the properties of the wood chip: wood density, chips bulk density, average particle sizes, moisture content and mass employed for one torrefaction. Owing to wood density and chips sizes, bulk density of beech chips was much higher than bulk density of spruce chips. Consequently, to ensure that the volume of chips was large enough to surround correctly the thermocouple, the mass of beech chips had to be 1.5 times higher than the mass of spruce chips.

2.3. Torrefaction parameters

For given chips size, species and gaseous atmosphere, the AWL depends only on two parameters: torrefaction temperature and duration. Tables 2 and 3 present the parameters of the forty three torrefactions carried out for this study. The nomenclature of each torrefaction is composed of three parts. The first part is the wood chips specie: S for spruce and B for beech. The second one is torrefaction temperature, and the third one is torrefaction duration. For example, a run labelled B-240-20, is a torrefaction of beech wood chips carried out at 240 °C during 20 min.

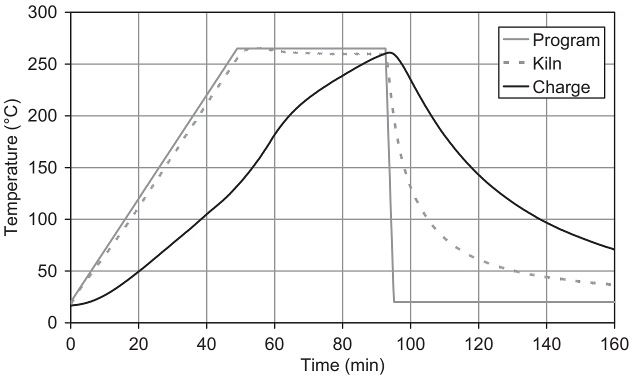

Fig. 1 – Typical curves of the temperatures recorded during a torrefaction run.