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Emission of pollutants from torrefaction of wood

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ABSTRACT

The torrefaction of biomass is carried out in order to obtain homogenous material with a low water content. This process can also be called mild pyrolysis. The paper focuses upon an experimental study of emissions released in the torrefaction process of deciduous wood types beech (*Fagus sylvatica*) and linden (*Tilia cordata*). Torrefaction was carried out in a reactor from Parr Instrument Company, USA. The reactor was heated to a temperature of 300ºC which was maintained for three hours. Concentrations of pollutants CO, CO_2 and CH_4 were ascertained in the emissions. For beech, concentrations of CO and CH_4 increased with temperature up to a concentration of 12500 ppm and 2.59% at a temperature of 300ºC. For linden, concentrations of CO_2 decreased with increasing temperature to 2.63% at a temperature of 300ºC.

Keywords: Emissions • Pyrolysis • Torrefaction • Wood

1. Introduction

Due to worldwide excessive use of fossil fuels and related global warming, the use of renewable resources is become more and more interesting. From a CO_2 viewpoint, the CO_2 process in the burning of biomass is neutral. Biomass fuel has worse properties in comparison with fossil fuels. Unlike fossil fuels, they have a low bulk density, a high humidity content and low calorific value. These biomass properties therefore cause technical problems when processing biomass and such operations are then less competitive. Therefore, before using as energy, various methods of pre-preparation of biomass are recommended. One method is the torrefaction of biomass.

Torrefaction is the thermal processing of biomass for 10 - 60 minutes at a medium-high temperature of 200 - 300ºC at atmospheric pressure, without the access of oxygen. It is carried out in order to obtain homogenous material with a low water content. The whole process consists of drying, torrefaction and cooling phases. This process can also be called mild pyrolysis during which approximately 70% of the original weight and 80 to 90% of the original energy content remains [1-2].

During torrefaction, we distinguish between three temperature phases depending upon time. The torrefaction reaction time is defined as the sum of the heating time from 200ºC to the required temperature, the time for which torrefaction temperature is maintained (torrefaction phase of approximately 30 minutes) and the time necessary for cooling from torrefaction temperature to 200ºC [3-4].

During the pyrolytic process, we may observe a range of processes depending upon the achieved temperature. For simplification, we may divide these processes into three temperature intervals:

1. Within a temperature of up to 200 ºC, there is a process of drying and the creation of water vapour via the physical separation of water. These processes are strongly endothermic.
2. Within temperatures from 200 to 500 ºC, there is an area of so called dry distillation. Here there is a major separation of side chains from high molecular organic compounds and transformation of macromolecular structures into gas and liquid organic products and solid carbon.
3. In the gas creation phase within 500 to 1200 ºC, products created by dry distillation are further split and transformed. Then, stable gases such as H_2, CO, CO_2 and CH_4 are created from the solid carbon as well as from liquid organic compounds.

The aim of the work is an experimental study of emissions released in the low temperature pyrolysis process of deciduous wood types beech *(Fagus sylvatica)* and linden *(Tilia cordata).*

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2. Material and methods

The torrefaction of two types of deciduous wood, linden and beech, was carried out under laboratory conditions using a 4570/80 reactor from Parr Instrument Company, USA. Twenty blocks with dimensions of 8 x 2 x 2 cm of the appropriate wood type, with a total mass of approximately 380 g, were placed into the reactor. The material was placed in the vessel in the shape of a grid so a sensor for measuring temperatures could be placed in the centre.

Torrefaction took place without air access and the temperature in the reactor was gradually increased to 320 ºC. The temperature in the reactor was read from the display on the reactor's control unit. After fitting and sealing the reactor head, the gas was transferred via an outlet to apparatus consisting of Erlenmayer glass flasks through a closing valve and a high pressure hose.

Pach et al. [2] observed the creation of emissions from Birch, Pine and Bagasse in an N_2 inert atmosphere at temperatures of 230 °C, 250 °C and 280 °C. This temperature was kept for various time intervals (1, 2 or 3 hours). The gas was extracted through a cooler where the tar and water condensed. The gas was then led through a cotton filter through a gas gauge and was gathered in collection sacks for gas. The gas content was analysed using gas chromatography for CO_2, CO, N_2, CH_4, and C_2, carbohydrates (ethane, ethene and acetylene) content.

In our case, the first Erlenmayer flask was filled with water, the second contained a 1M HCl solution and the third contained 1M $NaHCO_3$. After the apparatus, there was a filter for trapping humidity and a three-way valve via which it was possible to redirect the gas mixture to individual measuring sensors.

The following types of sensors were used for measuring the gas components from low temperature pyrolysis:

- Detcon Model IR-700-CO_2 sensor designed to detect and monitor carbon dioxide gas in air using miniature non-dispersive Infrared Optical (NDIR) sensor technology. The sensor is calibrated by the producer for measuring a concentration range from 0 to 5% CO_2.
- An MQ7 semiconductor sensor for measuring CO, by Sandbox Electronics. The sensor is calibrated by the producer for measuring a CO concentration range from 10 to 10000 ppm.
- A MadIR D01 is a single-chamber infrared sensor designed for continuous measurement of methane (CH_4) in gas mixtures. The range of measuring the methane concentration in gas mixtures is 0 - 5% of CH_4.

3. Results and discussion

Concentrations of the pollutants CO, CH_4 and CO_2 were measured at temperatures of 230, 250, 280 and 300 °C. Concentrations of pollutants found for beech and linden at individual temperatures are shown on Fig. 1 to 3.

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Concentrations of CO and CH_4 increased with increasing temperature (Fig. 1 and Fig. 3) in both tested types of wood. Fig. 2 shows that, on the other hand, CO_2 concentration decreased with increasing temperature. The highest concentration of CO - 12500 ppm - was found during torrefaction of beech at 300ºC and the lowest for linden - 6700 ppm.

The intensity in the creation of pyrolysis gases and their development during low temperature pyrolysis differed for individual types of wood. The development of pyrolysis gases as well as the intensity of their development could also be monitored visually in Erlenmayer glass flasks.

As shown when measuring the concentration of individual gases, the semiconductor sensors are not the suitable for monitoring gas components of low temperature pyrolysis, where often the semiconductor sensor range was exceeded and its saturation took place at low temperature in the reactor during the drying phase. Exceeding the range of a particular type of sensor at a certain temperature depended upon the type of wood used and also perhaps upon its humidity.

Kiel [5] states the following content of gas emissions from the torrefaction of willow in a nitrogen atmosphere at 260 ºC for 32 minutes: CO 0.1%, CO_2 3.3%, H_2O 89.3%, acetic acid 4.8%, furfural 0.2%, methanol 1.2%, formic acid 0.1%, remainder (CH_4, C_xH_y, toluene and benzene) 1%. Analysis of the content of emissions was carried out using gas chromatography.

Pach et al. [2] monitored emissions from the torrefaction of birch in a nitrogen atmosphere at various temperatures and various torrefaction times. The greatest amount of CH_4, C_2 and CO_2 was created at 280 °C and two hours of torrefaction, which were 0.3%, 0.13% and 24.5%. On the other hand, the greatest amount of CO_2 was created at 250 ºC and a torrefaction time of one hour, which was 81.2%.

To date, there have only been a few studies on the influence of pressure upon the creation of gas emissions. Mok and Antal [6] investigated pyrolysis at a pressure of 0.6 MPa and at a temperature of 500 ºC. They discovered that an increase in pressure results in an increase in the yields of biochar and CO_2. On the other hand, a decrease in the production of CO, CH_4, C_2H_6 a C_3H_6 was discovered.

The woody biomass used in study autors [7] was *Leucaena leucocephala*, the fast growing tree which normally considered as one of the most potential energy crops in Thailand. Leucaena has been torrefied at low temperature at atmospheric pressure and under pressure up to 4 MPa in inert atmosphere. The torrefaction temperature is an important factor influencing coal yield. It was discovered that the solid proportion of the yield decreases with an increasing calcination temperature. For example, at atmospheric temperature, the coal yield was 88. %, 82.2% and 73.9% at temperatures of 200 °C, 225 °C and 250 °C. With an increase in pressure, coal yield increased, e.g. 88.2% at *t* = 200°C and with a pressure of 4 MPa it increased to 89.9%. On the other hand, at 225 and 250 ºC, it was discovered that the coal yield had already decreased when increasing pressure by 1 MPa [7].

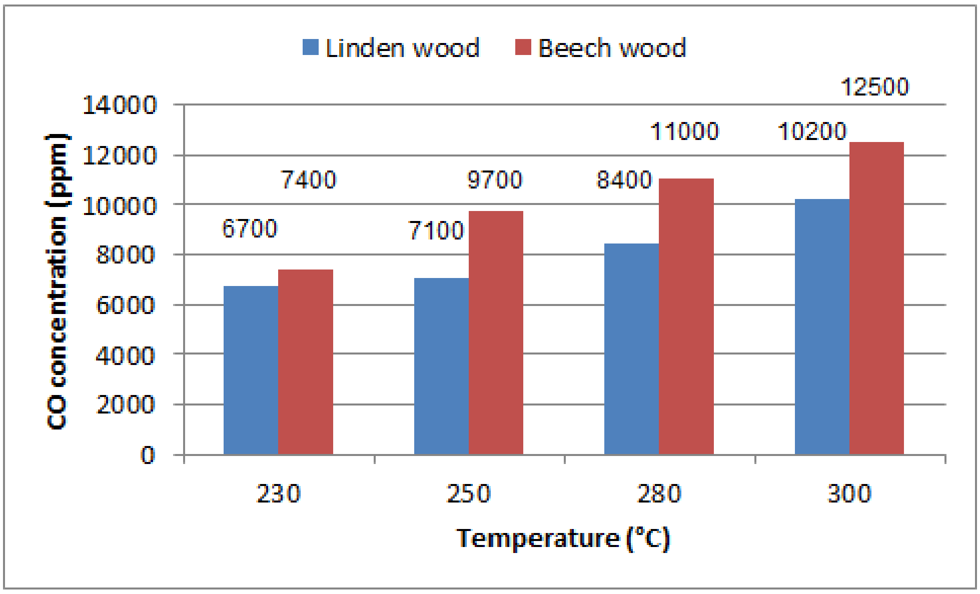

Figure 1 Dependence of carbon monoxide concentration on the temperature

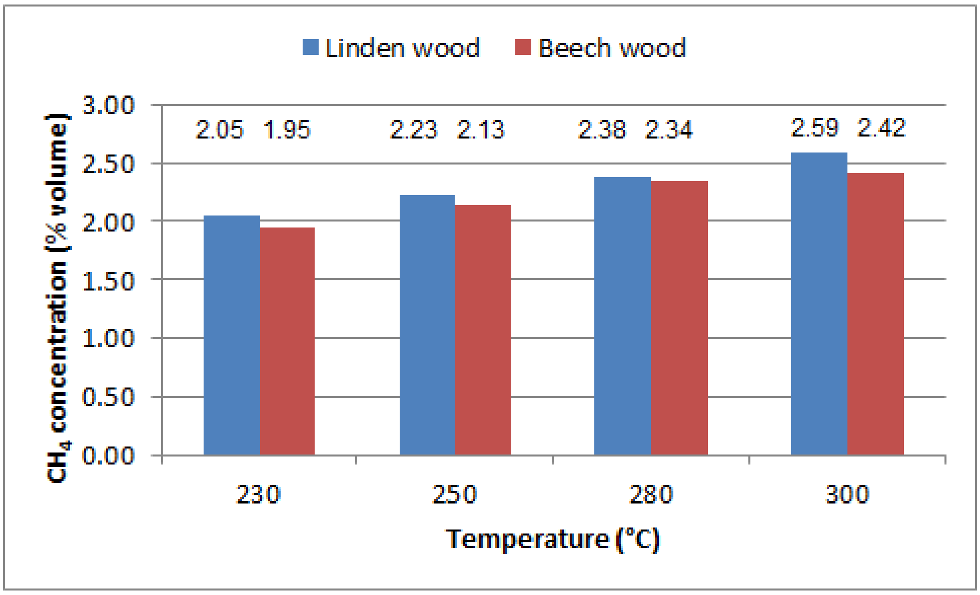

Figure 2 Dependence of methane concentration on the temperature

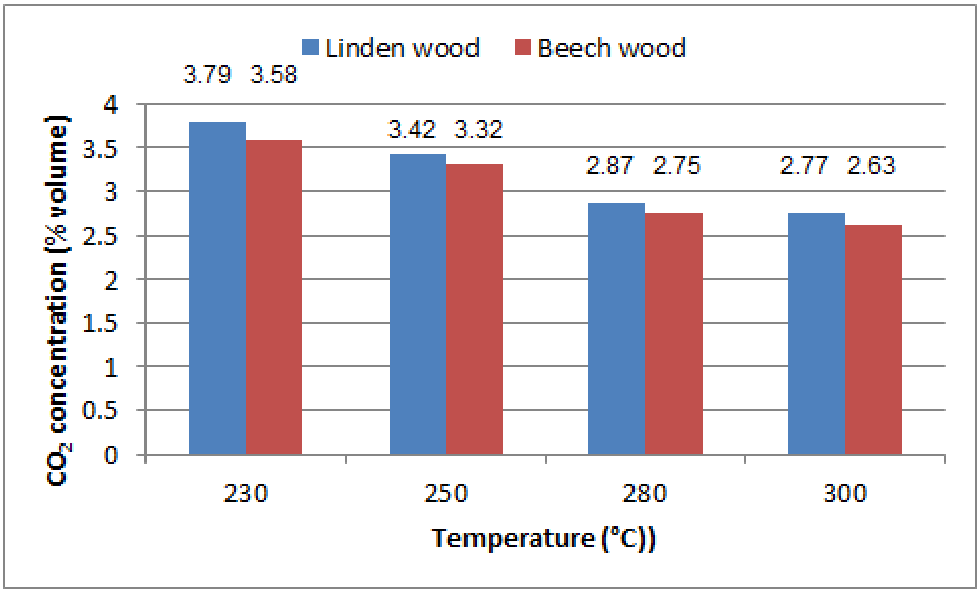

Figure 3 Dependence of carbon dioxide concentration on the temperature

4. Conclusion

Torrefaction is currently considered to be attractive technology. It takes place at relatively low temperatures, resulting in lower emissions of potential pollutants in comparison with pyrolysis or total incineration of biomass. The produced charcoal has hydrophobic properties, thanks to which it can stored for a long period, it is easier to crush in order for further pressing, e.g. into pellets. Pellets obtained in this way have lower seasonal changeability in terms of their physical and energy properties. It was discovered within the work that infrared sensors are suitable for measuring concentrations of pollutants. The following concentrations of CO were measured at 230, 250, 280 and 300 °C for beech at 7400, 9700, 11000, 12500 ppm and 6700, 7100, 8400 10200 ppm for linden. Concentrations of CO_2 at 230, 250, 280 and 300 °C for beech at with % of: 3.58, 3.32, 2.75, and 2.63 and for linden with % of: 3.79, 3.42, 2.87 and 2.77. Concentrations of CH_4 for 230, 250, 280 and 300 ºC were measured for beech *(Fagus sylvatica)* with % of: 1.95, 2.13, 2.34 and 2.42 and for linden *(Tilia cordata)* with % of: 2.05, 2.23, 2.38 and 2.42.

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