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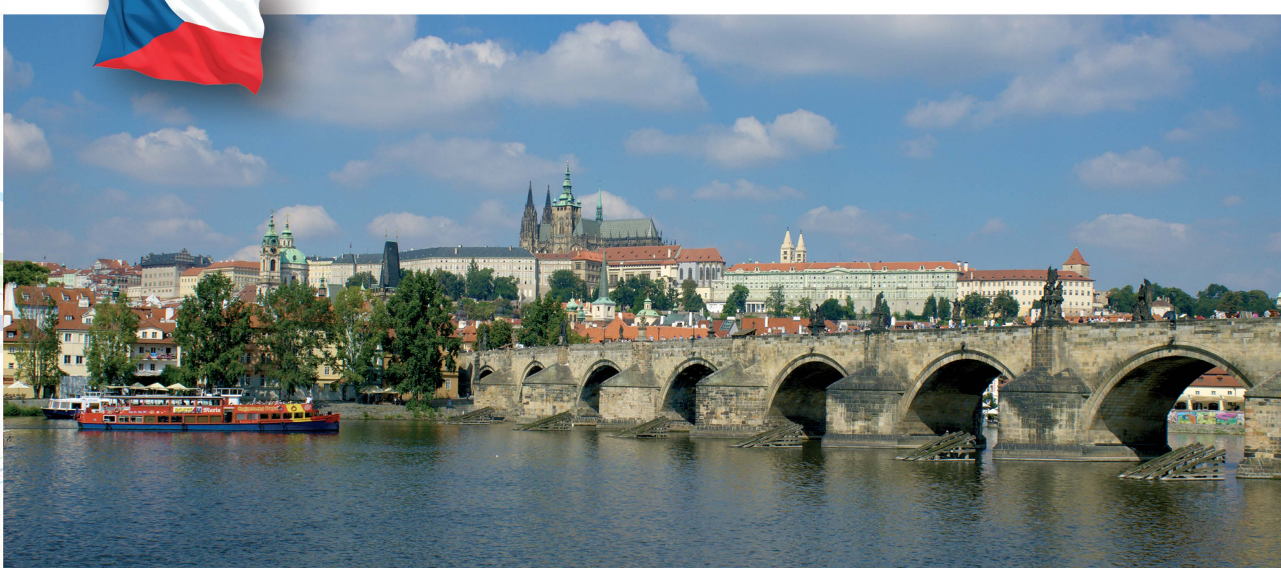

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CONTENTS

OPTIMISATION OF BIOMASS TORREFACTION

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Abstract: In this paper, our last results about the research of the torrefaction is introduced. The torrefaction is a heat treatment process to increase the energy density of any kind of biomass. The most important technology conditions are the inert atmosphere, the temperature, which is necessary to be below 300°C and the residence time. The final product of the process is a solid fuel, which has a higher heating value. As the process needs external heat energy to heat up the system so that amount of energy is increasing along the residence time. However the energy demand is increasing the heating value increment is not so significant. During that research, the torrefaction, as a heat treatment process, was optimised according to residence time and input energy. The different residence times have been examined, which means different amount of external energy, in the function of the final heating value. In our research three different biomasses have been examined, wheat straw, rapeseed straw, and vine so in that investigation we would like to find the answer for the following question: which is the optimal point between the heating value increment and input energy?

Introduction

The principle of Torrefaction (in order to release the fragrance or flavour of certain goods) has been known for more than 5 centuries now (Maillard reaction). On the other hand, when it comes to Torrefaction of biomass (for energy purposes) the concept is much more recent and the purpose of the treatment process is not the same. Actually, the objective is not to release the flavours and fragrance, but rather to degrade the fibres contained in the biomass. Torrefaction (also referred to as depolymerisation) of biomass is a “soft” thermo-chemical treatment usually between 200 and 300° C in order to eliminate water and to modify a part of the organic matter of the biomass so that the fibres are broken. During the process of Torrefaction, the light organic matter is extracted and the structure of the biomass is depolymerized and modified which leads to the cracking of the fibres. This modification leads to a significant change of the physical properties of the biomass: the biomass becomes crumbly, (easy to break) which facilitates and enhances its shaping and compacting. The biomass becomes moderately hydrophobic, which allows longer duration storage without distortion of the product quality (no biological degradation, no fermentation).

About Torrefaction

Torrefaction of the biomass is different from the classical roasting of some edible goods (coffee, cacao, etc…) it consists of a thermo-chemical treatment allowing the elimination of water along with a transformation of a part of the organic matter. The biomass is not “grilled” but rather is heated uniformly from the outside inwards to the core.[1]

If we take the particular case of wood, it is composed of hemicellulose, cellulose, lignin and other organic substances in lower quantities (polysaccharides, pentosanes, hexosanes, resins, tannins, colorants, alkaloids, etc…) these organic substances are often referred to as extracts.

During torrefaction, the molecular structure of the wood is modified, which leads to a change in its properties. Torrefaction releases water and evaporates volatile organic matter by decomposition of the hemicellulose and the extracts.

Lignin undergoes a minor modification though, more like softening and weakening, while cellulose is not affected at all by the temperature. Since the hemicellulose serves as a linkage for the cellulose, its suppression weakens the general structure and makes it fragile. Thus the material becomes friable. The degradation of the hemicellulose allows the elimination of the water and makes the wood irreversibly hydrophobic [2]. So when the water is evaporated, it can no longer be absorbed by the wood.

From the point of view of energy, the energy contained in the biomass is almost totally preserved: for example, for the wood, 95% of the initial energy is conserved when the torrefaction is done at 240°C (specific torrefaction temperature of this material).

Laboratory measurements

At the University of Miskolc, in the laboratory of the Chemical Machinery Department the torrefaction process was analyzed. According to an early research, the torrefaction was occurred at 240°C for different residence time. During that research the correlation between the torrefaction residence time and heating value was analyzed. After 15 minutes the heating value increment was not significant. So in our recent research 1, 2, 3, 4, 5 minutes were investigated.

The measurements were executed with the equipment which can be seen on the 1. Figure. The laboratory furnace has a heating surface (1) which can be controlled by the PID device (8) with temperature control (6). The (7) cylinder is a closable part of the device, which is the container of the premade biomass. The (5) nozzle is for the gas evacuation, the internal temperature (3) and the pressure (4) were measured by two sensors.

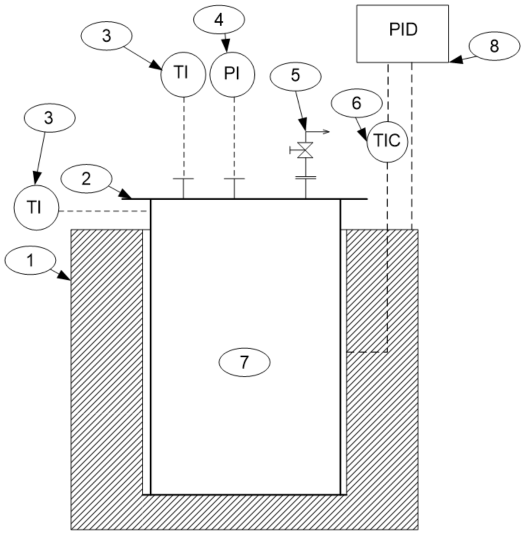

Fig.1 The laboratory scale furnace [3]

The objective of this experiment is to measure the amount of the heat energy required for the torrefaction of wheat straw and its heating value for different residence times. From previous experiments, the oven temperature of 370°C is needed to obtain the corresponding torrefaction temperature of the wheat straws which is around 240°C.

Two measurements have been conducted:

- The results of the first measurement the power consumption required to maintain the oven and the empty container at the required temperatures (370°C and 240°C respectively) for the desired residence times.
- The second measurement will have the power consumption required to maintain the oven and the container loaded with the biomass at the required temperatures (370°C and 240°C respectively) for the desired residence times.
- The power consumption required to maintain the biomass alone at the torrefaction temperature 240°C will be equal to the difference of the two above mentioned measurements.

In order to do this, the biomass is to be heated up in the laboratory oven up to a certain temperature and then left at this temperature for the desired time duration (residence time). This allows us to measure the power consumption required to heat up and maintain both the oven and the biomass at the desired temperatures.

Note that because of an independent container is used, heat must be transferred from the heating surface to the container which will result in a difference in temperatures. Thus, the working temperature of the oven is higher than the desired torrefaction temperature (the temperature inside the container).

Before starting the heating process, the container must be purged by sealed well to avoid any interference with the power consumption and the heating process. The container must be sealed off by using a high temperature rubber gasket to improve the isolation of the system.

Then, while heating, the working pressure must be kept at around 1.1 bar_a. Pressure build up inside the container (due to evaporation of water and volatile material) must be avoided; the container has a manual valve which allows pressure control. By opening this valve more water vapour is allowed to escape and thus pressure will decrease inside.

Measurement procedure

The power consumption of the furnace as the energy was electricity a power consumption measurer was used (Voltcraft Plus) to determine the energy demand of the process. The measurement steps were the followings: when the temperature of the oven reaches 370°C, the power consumption meter was reset to zero and the timer was started. When all the measurements were taken, the oven was switched off and was let it cool down to room temperature. The same procedure was repeated at least three times for consistency. Now proceed with measuring the power consumption required for the furnace and the biomass together, first 40g of biomass and was weighted then inserted it into the container. The container was taken into the preheated oven. The oven and container were insulated well to minimize the heat losses. When the internal temperature reaches the 240°C the power consumption was recorded. After each measurement the heating value of the biomass was determined in a calorimeter bomb in Parr 6200 type calorimeter (see on Fig. 2.).

Table 1. Results of the higher heating value measurements

Residence time [min]	H_a [MJ/kg]	H [m/m%]	W [m/m%]	H_u [MJ/kg]
0	16,3630	4,98	7,2	15,100
1	20.6978	5.22	4.41	19.4505
2	22.0945	5.28	4.23	20.8385
3	22.7005	5.35	4.05	21.4336
4	23.0454	5.4	3.67	21.7769
5	23.3204	5.6	3.52	22.0119

To determine the lower heating value of the biomass, according to the DIN standard [4] the following equation should be used:

$$H_u = H_a - 24.42 \cdot (8.94 \cdot H + W) \quad (1)$$

where: H_u: heating value [J/g], *24.42* correction factor adequate for 1% moisture content on 25°C, H_a higher heating value [J/g], *H* the hydrogen content of the sample [m/m %], *8.94* the calculation coefficient of the hydrogen to water, *W* the moisture content of the sample [m/m %].

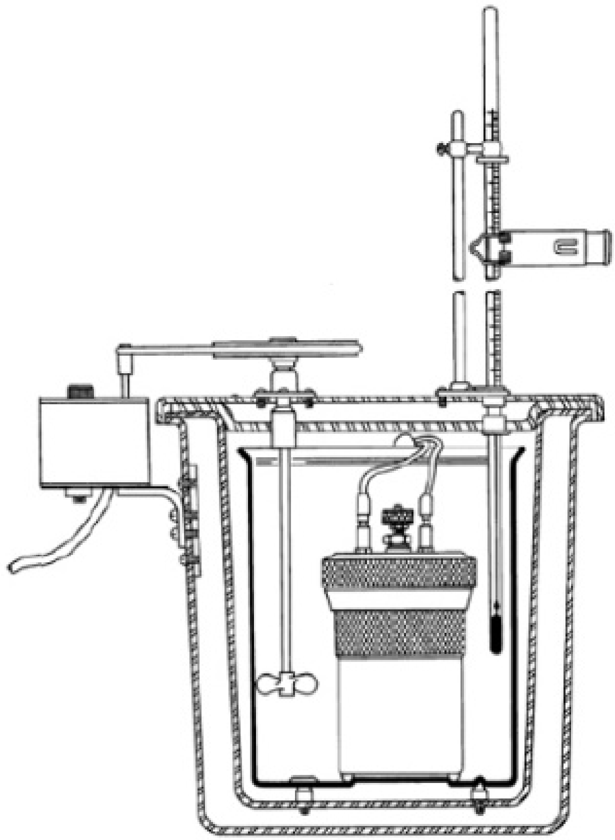

Fig. 2 The schematic drawing of the calorimeter

As one can see according to the calorific measurements the increment of the heating value is significant if we compare to the initial heating value. The initial date is in the first line, the residence time „0“ means the untreated biomass, the raw wheat straw.

In the Table 2 one can see the results of the two measurements. According to the different residence time the initial heating value (15,1 MJ/kg) of the wheat straw increased to the value which can be seen in the 4th column of the table. While 40 grams were taken into the container the 2nd column shows the energy demand of the heat treatment. The 3rd column shows the calculated values to unit mass of kilograms. The 5th column (name “Increment”) shows the energy increment from the initial heating value. The 6th column contains the difference between the heating value increment and the energy demand of the process. These are average values.

Table 2. Results of the measurements

Residence time [min]	**Energy demand [MJ/40g]**	**Energy demand [MJ/kg]**	**Heating value H_u [MJ/kg]**	**Increment [MJ/kg]**	**Increment-energy demand [MJ/kg]**	**Gradient**
1	0.0216	0.54	19.4505	4.3505	3.8105	-
2	0.036	0.9	20.8385	5.7385	4.8385	1.3879
3	0.0432	1.08	21.4336	6.3336	5.2536	0.5951
4	0.0504	1.26	21.7769	6.6769	5.4169	0.3433
5	0.054	1.35	22.0119	6.9119	5.5619	0.2350

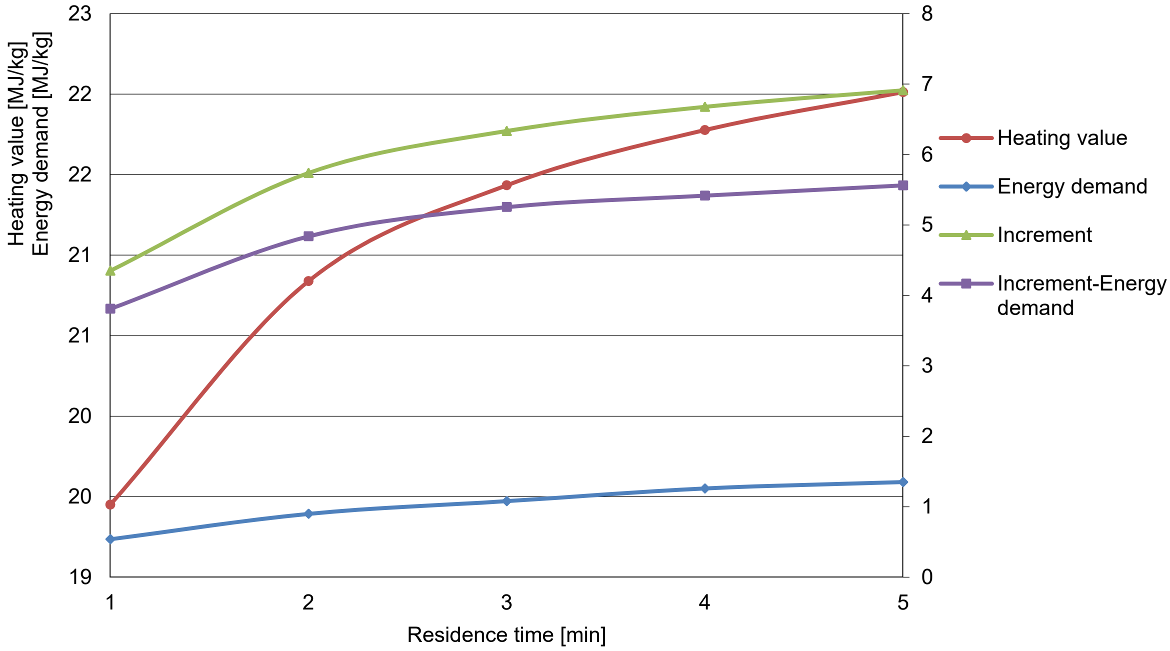

Fig. 3 The correlation of the residence time and the energy flow of the process

In the above mentioned table one can see in the last column, the gradient, which means the gradient of the energy increment. That gives us the maximum recommended residence time, which is maximum 2 minutes.

Conclusion

During our research we try to find the optimum residence time of the torrefaction process. At the beginning we thought there will be a minimum of the energy increment decreasing the energy demand of the process, because of the endothermic reactions [5] which occurs during the heat treatment. In the comparison of the energy demand of the heat treatment, we have only taken into account the external heating energy. When that process would occur in a pilot plant, or in industrial scale plant there would be further energy demands (screw conveyors, gas system etc…) of the torrefaction which would be examined in a further research.

Acknowledgment

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