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Torrefaction – the process for biofuels production by using different biomasses

D. Urbancl[*], J. Krope and D. Goričanec

University of Maribor, Faculty of Chemistry and Chemical Engineering, Smetanova street 17, SI2000 Maribor, Slovenia
[*]Correspondence: danijela.urbancl@um.si

Abstract. Torrefaction process is a mild pyrolysis, where biomass material is converted into solid fuel with higher heating value. The results of torrefaction at different temperatures in a range from 220 to 400 °C for three varied materials, oak wood, mixed wood and dehydrated, granulated sewage sludge are presented. The torrefaction process started with warm up stage, which took place for 30 minutes, after that sample was torrefied for 2 hours at constant temperature. The process continued with cool down stage. The energy demands were covered by electric power, while the flue gasses were not integrated in the process. The influence of the operating temperatures are analysed in order to determine optimal operation parameters to get the torrefied biomass with highest calorific value. Furthermore, the optimal operation time according to the largest increase in calorific value for each material is evaluated. The results of calorific value, mass drop and chemical compositions such as elemental analyses are also presented. Results show that heating values increase with raising temperature for both wood samples. The heating values for sewage sludge increases to approximately 320 °C, after that temperature are unchangeable. Torrefied oak wood samples were more fragile at higher temperatures in comparison to raw or torrefied oak wood samples at lower temperatures. At torrefied sewage sludge samples the changes in fragility are not detected due to pre-prepared granulates of sludge.

Key words: solid fuel, torrefaction, oak and mixed wood, sewage sludge, biomass, energetic evaluation.

INTRODUCTION

Biomass is one of the more important sources to produce energy and synthetic fuels, especially in Slovenia being one of the more forested countries in Europe with over 50% of its area covered by forests. Even though biomass is more expensive than coal, the carbon-trading laws are good motivation for greater usage of biomass. Tenacity of raw biomass is especially challenging, which prevents efficient pulverisation of biomass to use it in higher temperature gasifiers or in boilers of thermal power plants and heating plants. The torrefaction process (mild pyrolysis) is coming to the fore as a possible thermochemical conversion route that enhances the biomass properties obtaining ecologically acceptable energy source, which has similar properties as coal (Trop et al., 2014; Correia et al., 2017). Torrefied biomass is hydrophobic, resistant to biodegradation and is suitable for storage. Furthermore, the homogeneity and heating value of torrefied biomass is greater than that of wood. An important advantage of torrefied biomass is also its reduced tenacity. The grind ability of the product is higher and easier milling and application in industrial equipment is achieved (Iroba et al., 2017; L. Wang et al., 2017a).

Pyrolysis of wood is used mainly for the energetic exploitation, as the product can replace the fossil fuels (Van der Stelt et al., 2011). Pyrolysis is a thermal decomposition of organic materials at the inert conditions or at a limited inflow of air. This process leads to a release of volatile substances and the formation of product. Furthermore, waste can be converted to products with high heating value by using the pyrolysis process. It is difficult to achieve an atmosphere totally devoid of oxygen; therefore, oxygen is present in small concertation within every pyrolysis system, causing minor oxidation. The process takes place at a controlled concertation of oxygen, consequently careful reaction control is necessary with options for rapid cooling and heating (Yue et al., 2017).

MATERIALS AND METHODS

The comparison between three materials was performed to evaluate the influence of temperature on heating value of the torrefied biomass and to determine optimal operation time according to energy demands.

The materials were oak wood, dehydrated sewage sludge from waste water treatment plant and mixed wood. The calorific value and chemical composition for all raw materials are given in Table 1.

The ash content was determined according to the standard SIST EN ISO 18122: 2016, analytical humidity according to the standard SIST EN ISO 18134-3: 2015, heating value according to the test method of EN 14918: 2010. The total carbon, hydrogen and nitrogen content were determined according to the standard SIST EN ISO 16948: 2015. The sulphur content was determined using the test method ASTM D4239-14e2 by incineration in a tube.

The materials were processed in Bosio electric resistance furnace with nominal power of 2.7 kW. The container was field with the sample and covered with ceramic lid that the inert atmosphere conditions were reached and air inflow was limited. Ceramic lid was placed in the way that the combustion gasses could discharge. All samples were treated in three parallels.

Table 1. Properties of raw samples

Parameter	Oak wood	Sewage sludge	Mixed wood
GVC/LHV [kJ kg^{-1}]	19,074/17,793	15,520/14,421	19,722/18,405
Analytical moisture [%]	10.45	8.5	8.78
Nitrogen [%]	0.34	5.87	0.22
Volatiles [%]	79.12	61.14	78.54
Carbon [%]	48.53	36.59	49.6
Ash [%]	3.24	32.58	1.05
Hydrogen [%]	5.89	5.09	6.05
Sulphur [%]	0.02	0,.8	0.02

The temperature influence

The process started with warm up stage, which took place for 30 minutes, after that sample was torrefied for 2 hours at constant temperature. The process continued with cool down stage for 30 minutes when the temperature of the furnace reached 50 °C. At the end the sample was cool down to the room temperature. The energy demands were covered by electric power, while the flue gasses were not integrated in the process.

The experiments were done at 220 °C, 240 °C, 260 °C, 280 °C, 300 °C, 320 °C, 340 °C and 400 °C, according to previous research (Medic et al., 2012; Nanou et al., 2015; Barta-Rajnai et al., 2017; Białowiec et al., 2017; Wang et al., 2017b). The analyses of heating value were performed for each sample.

Optimal operation time

The torrefaction process was performed as it is described in previous sub-section. The materials were treated at 260 °C and for different time periods (0.5 h, 1 h, 1.5 h and 2 h) as it is presented on Fig. 1.

The invested energy was evaluated according to Eq. 1 and 2. The electricity (Eq. 1) was evaluated from furnace nominal power. The invested energy (Eq. 2) was than calculated per sample mass.

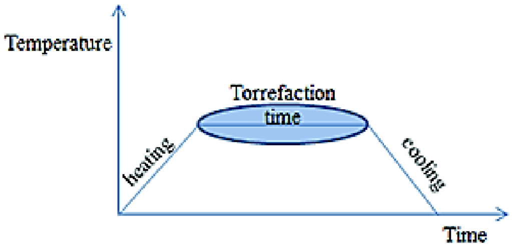

Figure 1. Schematic presentation of the process operation.

$$E_{electricity} = P_n \cdot t \qquad (1)$$

where $E_{electricity}$ – electricity (kWh); P_n furnace nominal power (kW), t – time (h).

$$E_{invested} = \frac{E_{\mathrm{electricity}} \cdot 3{,}600}{m_{\mathrm{v}}} \qquad (2)$$

where $E_{invested}$ – invested energy (kWh); m_{v} – mass of the sample (kg).

RESULTS AND DISCUSSION

The samples of oak wood, sewage sludge and mixed wood were processed at different condition. The sewage sludge particles were the same size, because they were previously dehydrated and granulated, while the wood particles were mixed. Optimal torrefaction temperature was determined at the beginning and in the next step optimal operation time was experimentally specified for each material.

Temperature

The comparison of higher heating values (GVC) and low heating values (LHV) for torrefied oak wood, sewage sludge and mixed wood at different temperatures are given on Fig. 2 and Fig. 3.

Fig. 2 presents the values of GVC and LHV for each sample, while on Fig. 3 the differences between torrefied and raw material are presented.

The heating values increase with raising temperature for both wood samples. The heating values for sewage sludge increases to approximately 320 °C, after that temperature are unchangeable or are lower than for raw sample.

Torrefied oak wood samples were more fragile at higher temperatures in comparison to raw or torrefied oak wood samples at lower temperatures. At torrefied sewage sludge samples the changes in fragility could not be detected due to pre-prepared granulates of sludge.

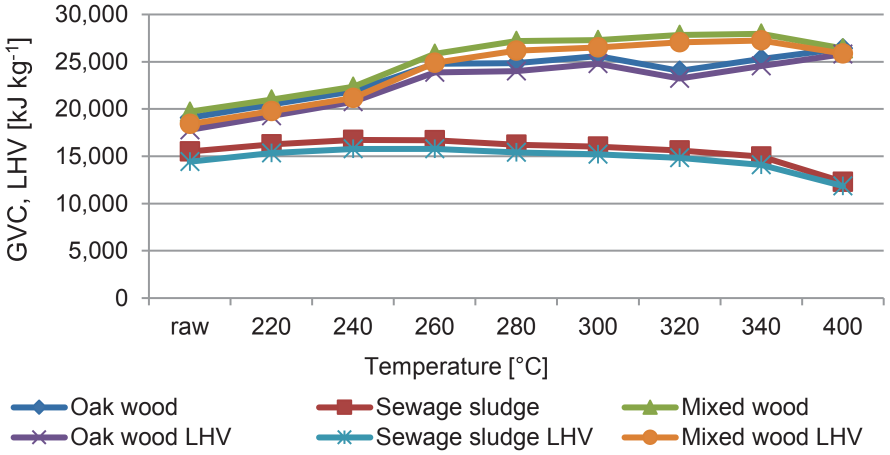

Figure 2. The GVC and LHV for torrefied materials depending on temperature.

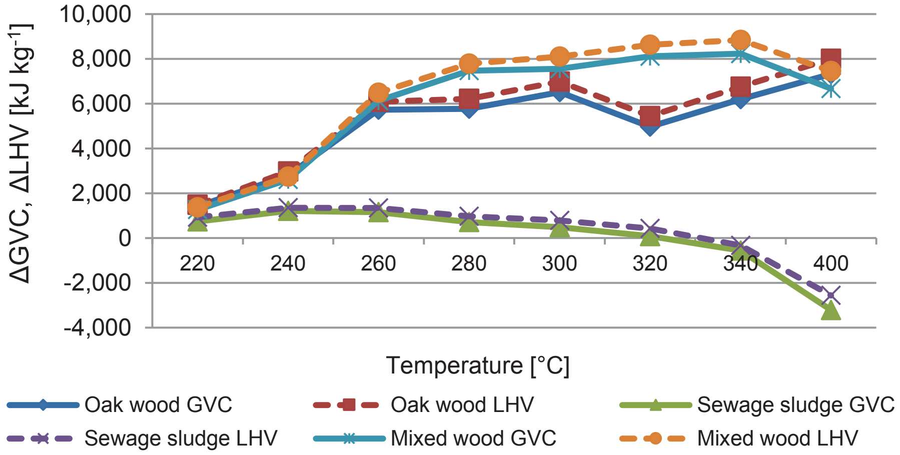

Figure 3. The difference in GVC and LHV depending on temperature.

Operation time

The experiments at different operation time of the torrefaction process were proceed at the constant temperature of 260 °C according to the results from previous sub-section. The temperature was chosen, according to the largest increase of GVC and according to the literature (Barta-Rajnai et al., 2017; Białowiec et al., 2017; Medic et al., 2012; Nanou et al., 2015; Wang et al., 2017a). The elemental analyses of torrifed samples at 260 °C are presented in Table 2.

Samples were torrefied for 0.5 h, 1 h, 1.5 h and 2 h at constant conditions and according to literature (Medic et al., 2012; Li et al., 2015; Nanou et al., 2015; Strandberg et al., 2015; Chen et al., 2016).

Fig. 4 presents the mass drop for all samples depending on operation time.

Table 2. Properties of torrified samples at 260 °C

Parameter	Oak wood	Sewage sludge	Mixed wood
Analytical moisture [%]	1.59	0.61	4.72
Nitrogen [%]	0.42	6.26	0.32
Volatiles [%]	47.94	50.75	46.85
Carbon [%]	65.01	39.9	66.66
Ash [%]	5.03	39.61	1.7
Hydrogen [%]	4.24	4.27	4.45
Sulphur [%]	0.01	0.79	0.03

The LHV and GVC are increasing with time for oak wood and mixed wood (Fig. 5), while the GVC and LHV for sewage sludge is almost the same for different operation time.

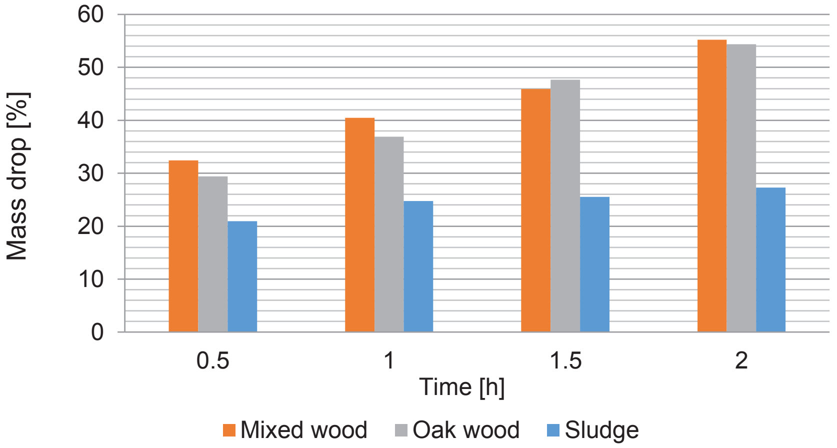

Figure 4. Mass drop for torrefied materials depending on operation time.

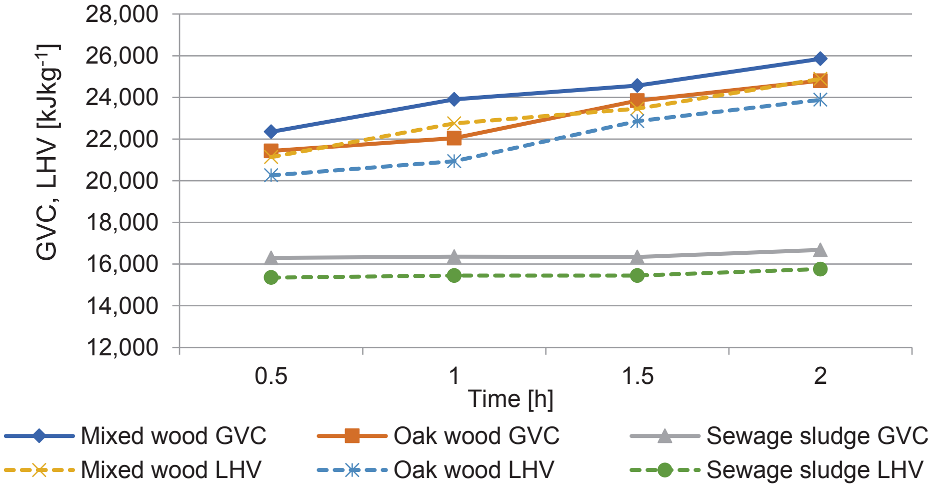

Figure 5. The GVC and LHV for torrefied materials depending on operation time.

The LHV and GVC are increasing with time for oak wood and mixed wood (Fig. 5), while the GVC and LHV for sewage sludge is almost the same for different operation time.

Fig. 6 presents the difference in calorific value between torrefied material and raw material. Also, the invested energy (Fig. 7.) is included, which was evaluated from furnace energy demands, the material mass and operation time according to equation 1 and 2.

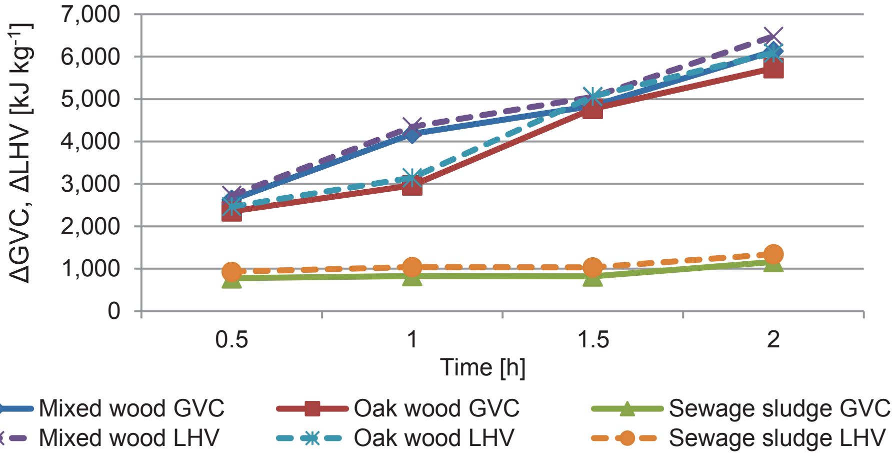

Figure 6. The difference in calorific value between torrefied material and raw material depending on operation time.

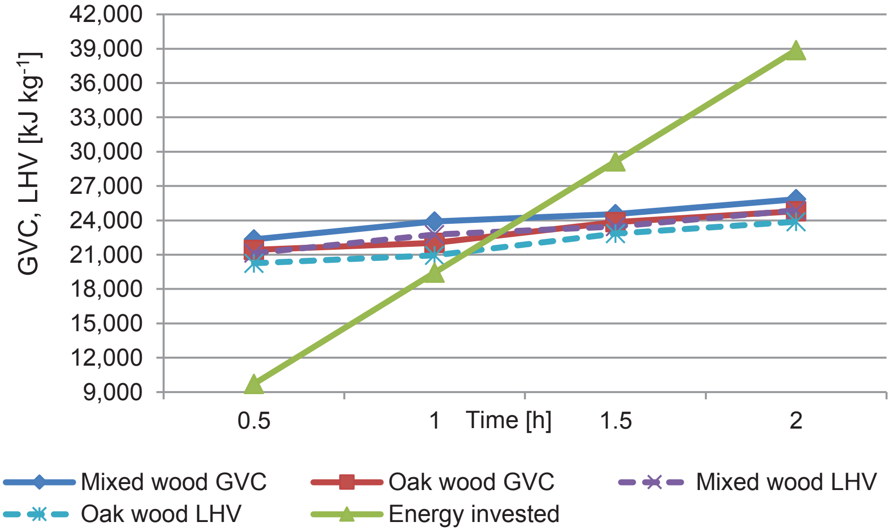

Figure 7. The invested energy, LHV and GVC for mixed and oak wood depending on operation time.

The results on Fig. 6 and Fig.7 show that the optimal operation time in case of oak and mixed wood is around 1.2 h, because till that time the solid fuel with higher heating value is gained. The operation time could be longer if the flue gases would be integrated for energetic exploitation.

CONCLUSIONS

The torrefaction of different biomasses was researched and optimal conditions were experimentally determined. Oak wood, dehydrated sewage sludge and mixed wood where processed at different temperatures, but for the same time (2 h) according to torrefaction conditions. The heating value of all materials increases with the temperature. According to the experimental results it was found out that for this material optimal operation temperature is at around 260 °C, where the higher increase of heating values is achieved. Similar results are presented in various literatures (Li et al., 2015; Strandberg et al., 2015; Chen et al., 2016).

The further research was purposed to determine the optimal operation time of the torrefaction process at previously determined optimal temperature of 260 °C. The results show that the torrefaction is favourable for both kinds of wood and it should take place for around 1.2 h, because there is the higher increase of heating values in comparison with invested energy. On the other hand, the results show that from invested energy point of view the sewage sludge torrefaction is not justified in case, if the flue gasses are not integrated in the process.

In a future work, the integration of flue gases in the process will be done and its influence will be evaluated. Also TGA analyses will be done.

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