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Biofuels Production by Torrefaction Process Supplied with Different Biomasses

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Abstract Solid fuel production from different biomass sources become a very challenging area. The paper presents the torrefaction process, mild pyrolysis, where biomass material is converted into solid fuel with higher heating value. The material is processed in inert atmosphere or in the atmosphere with very low oxygen concertation. The study is done for three varied materials, oak wood, mixed wood and dehydrated, granulated sewage sludge. The influence of the temperature is examined, and the optimal temperature is determined. Furthermore, the optimal operation time for each material is evaluated. The experiments were done without flue gases integration. The results show that from energy point of view the optimal operation time for oak and mixed wood is around 1.2 h at 260°C. The torrefaction of sewage sludge is energetically unjustified.

Keywords: • solid fuel • torrefaction • oak and mixed wood • biomass • energetic evaluation •

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1 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 a 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 (Correia, Gonçalves, Nobre, & Mendes, 2017; Trop, Anicic, & Goricanec, 2014). 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, Baik, & Tabil, 2017; L. Wang et al., 2017).

Pyrolysis of wood is used mainly for the energetic exploitation, as the product can replace the fossil fuels (van der Stelt, Gerhauser, Kiel, & Ptasinski, 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, Singh, Singh, & Mani, 2017).

2 Experiment

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 first material was oak wood, the second material was dehydrated sewage sludge from waste water treatment plant and the third material was mixed wood. The calorific value and chemical composition for all materials are given in table 1 for raw samples.

Table 1. Properties of raw oak wood

Parameter	Oak wood	Sewage sludge	Mixed wood
GVC/LHV [kJ/kg]	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	49.6
Carbon [%]	48.53	36.59	1.05
Ash [%]	3.24	32.58	6.05
Hydrogen [%]	5.89	5.09	0.02
Sulfur [%]	0.02	0,.8	19,722/18,405

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. Ceramic lid was placed in the way that the combustion gasses could discharge.

2.1 The temperature influences

The process started with warm up stage, which took place for 30 minutes, after that stage 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 (Barta-Rajnai et al., 2017; Białowiec, Pulka, Stępień, Manczarski, & Gołaszewski, 2017; Medic, Darr, Shah, Potter, & Zimmerman, 2012; Nanou, Carbo, & Kiel, 2015; Z. Wang, Lim, Grace, Li, & Parise, 2017)]. The analyses of heating value were performed for each sample.

2.2 The optimal operation times

The torrefaction process was performed as it is described in chapter 2.1. The materials were proceeded at 260°C and for different time periods (0.5 h, 1 h, 1.5 h and 2 h) as it is presented on figure 1.

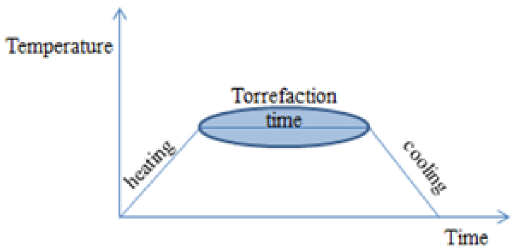

Figure 1: Schematic presentation of the process operation, source: own.

3 Results and discussion

The samples of oak wood, sewage sludge and mixed wood were processed at different condition. The optimal torrefaction temperature was determined at the beginning and in the next step optimal operation time was experimentally specified for each material.

3.1 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 figure 2 and figure 3.

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

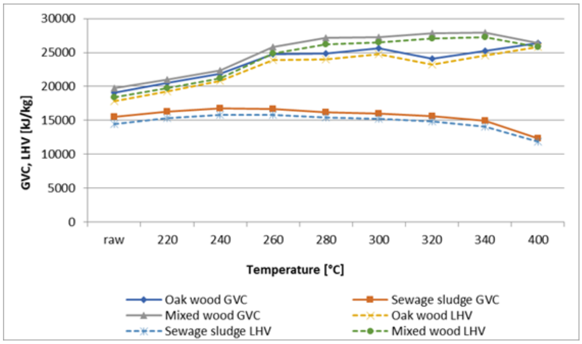

Figure 2. The GVC and LHV for torrefied materials depending on temperature, source: own

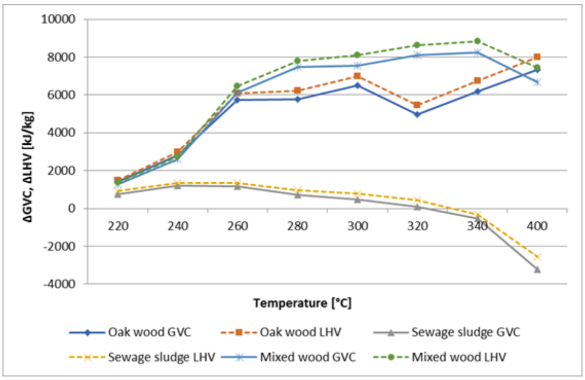

Figure 3. The difference in GVC and LHV depending on temperature, source: own

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.

3.2 Operation time

The experiments regarding different operation time of the torrefaction process were proceed at the constant temperature of 260°C according to the results from section 3.1. The temperature was chosen, because of 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; Z. Wang et al., 2017). The samples were torrefied for 0.5 h, 1 h, 1.5 h and 2 h at constant conditions and according to literature (Chen, Cao, & Atreya, 2016; Li et al., 2015; Medic et al., 2012; Nanou et al., 2015; Strandberg et al., 2015).

Figure 4 presents GVC and LHV for torrefied materials depending on operation time.

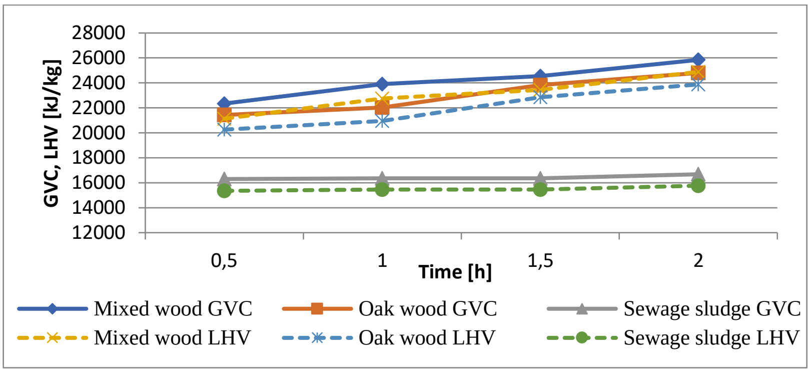

Figure 4. The GVC and LHV for torrefied materials depending on operation time, source: own

The LHV and GVC are increasing with time for oak wood and mixed wood (Figure 4), while the GVC and LHV for sewage sludge is almost the same for different operation time.

Figures 5 present the difference in calorific value between torrefied material and raw material. Also, the invested energy is included, which was evaluated from furnace energy demands, the material mass and operation time.

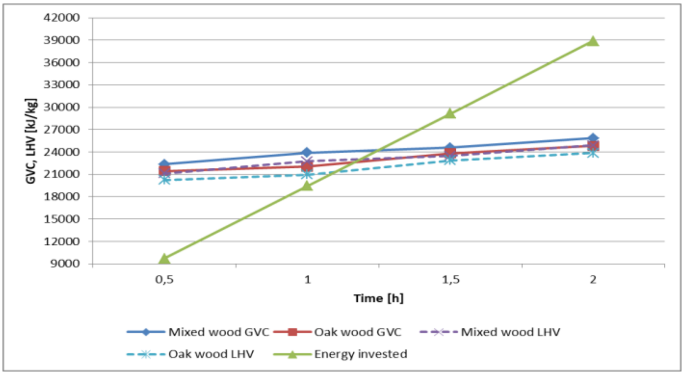

Figure 5: The invested energy, LHV and GVC for mixed and oak wood dependng on operation time, source: own

The results on figure 5 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.

4 Conclusion

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 literature (Chen et al., 2016; Li et al., 2015; Strandberg et al., 2015).

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.

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