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Faculty of Chemistry and Chemical Engineering

7TH INTERNATIONAL CONFERENCE ON SUSTAINABLE SOLID WASTE MANAGEMENT

Torrefied biofuels production using different biomasses

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INTRODUCTION

- Biomass - important sources to produce energy and synthetic fuels
- Tenacity of raw biomass is especially challenging,
- The torrefaction process is possible thermochemical conversion route that enhances the biomass properties obtaining ecologically acceptable energy source, which has similar properties as coal.
- Torrefied biomass is hydrophobic, resistant to biodegradation and is suitable for storage.
- The homogeneity and heating value of torrefied biomass is greater than that of wood.
- The comparison between three materials is performed to evaluate the influence of temperature on heating value of the torrefied biomass and to determine optimal operation time.
- The first material is oak wood, the second material is dehydrated sewage sludge from waste water treatment plant and the third material is mixed wood.

THE SEWAGE SLUDGE CHARACTERISTICS

- Activated sludge contain 5 heavy metals fraction

- Most of the EU countries adopted stringent limits for heavy metals in comparison with EU directive.

Table 1. Properties of activated sludge in Slovene WWTP and EU directive of heavy metals in sewage sludge intended for agricultural application

	12	20-40
	481	2500-4000
	94	1000-1750
	51	-
	26	750-1200
	24	300-400

MATERIALS AND METHODS

- Three materials (oak wood, dehydrated sewage sludge and mixed wood)

- 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.

- **METHODS**

ash content SIST EN ISO 18122:2016

total moisture SIST EN ISO 18134-3:2015

heating value SIST EN 14918:2010.

the total carbon, hydrogen and nitrogen contents SIST EN ISO 16948:2015

sulphur content as per ASTM D4239-14e2 by burning in tube furnace.

EXPERIMENT

- ***The temperature influence on torrefaction***

- ***The determination of optimum time***

Table 1. Properties of raw samples

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	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.

- The analyses of heating value were performed for each sample.

Optimal operation time

- The materials were treated at 260°C and for different time periods (0.5 h, 1 h, 1.5 h and 2 h).

- Temperature was chosen on basis of preliminary results. It was shown that higher temperature does not affect the heating value.

- The temperatures of torrefaction as well as the time of heating and cooling wer whole experiment.

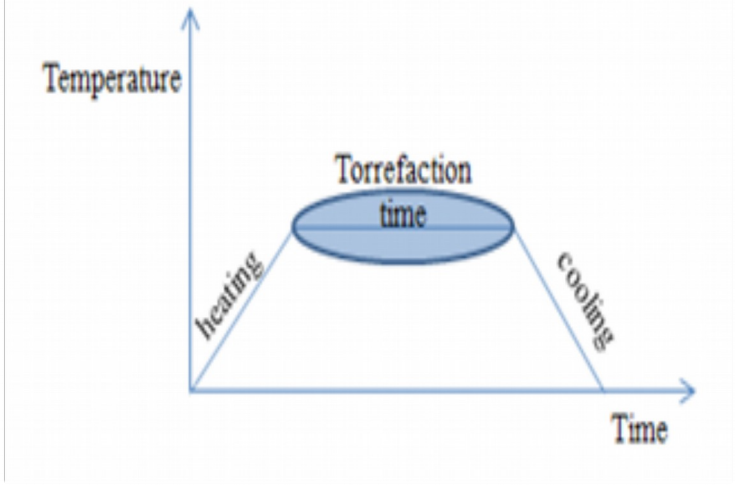

Figure 1. Schematic presentation of the process operation

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.
- The wood particles were mixed size.

Temperature

- Mass loss

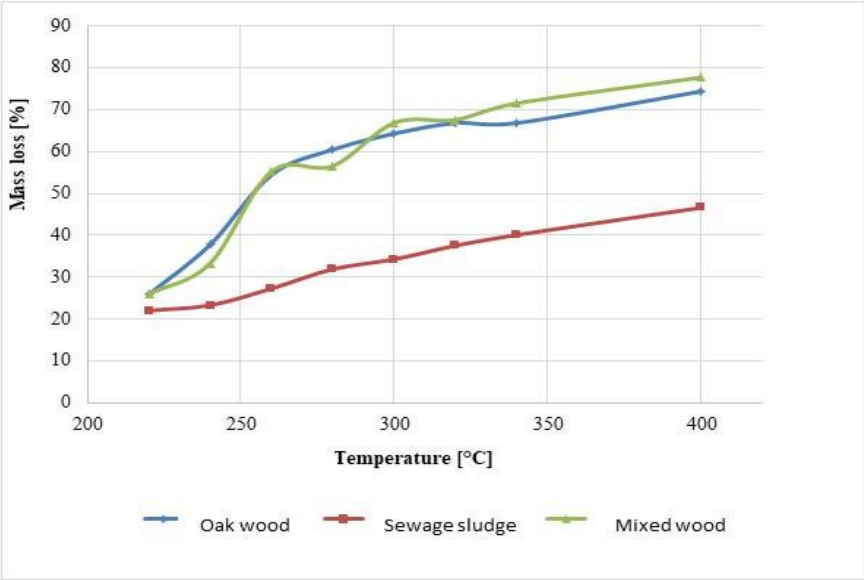

Figure 2: Mass loss of torrefied material in temperature dependence

Mass losses increase with temperature.
The most losses are due to moisture loss.
Between wood samples the losses are comparable.
Those are much higher compared with municipal sewage sludge.

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Ash and volatile matter contents, elemental analysis

- The most ash is present in torrefied municipal sludge, the content is increasing with increasing temperature.
- More volatile compounds -in wooden material at lower temperatures,
- Above 280°C the content of volatile compounds is similar as in municipal sludge
- With increasing temperat
  decreasing.
- The share of carbon is th

Table 3: The properties of torrefied oak wood in temperature dependence

Parameter	Temperature [°C]							
	220	240	260	280	300	320	340	400
Ash [%]	2.9	4.67	5.03	7.56	5.63	8.02	8.25	6.22
Moisture [%]	1.38	2.13	1.59	2.07	2.77	3.25	3.35	3.86
Volatile compounds [%]	73.59	64.44	47.94	42.96	40.23	39.38	35.96	34.1
Carbon [%]	52.27	56.56	65.01	65.93	68.35	67.13	68.75	72.43
Hydrogen [%]	5.58	5.1	4.24	3.87	3.75	3.72	3.34	2.77
Nitrogen [%]	0.34	0.39	0.42	0.54	0.53	0.55	0.6	0.71
Sulphur [%]	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01

Table 4: The properties of torrefied municipal sewage sludge in temperature dependence

Parameter	Temperature [°C]							
	220	240	260	280	300	320	340	400
Ash [%]	37.9	37.5	39.61	42.85	43.99	45.89	48.58	55.32
Moisture [%]	1.16	0.58	0.61	0.66	1.24	0.6	1.12	0.9
Volatile compounds [%]	51.2	53.06	50.75	45.09	43.16	40.74	37.2	27.98
Carbon [%]	39.2	39.57	39.9	39.57	39.33	38.73	37.54	33.82
Hydrogen [%]	4.21	4.45	4.27	3.9	3.71	3.5	3.23	2.1
Nitrogen [%]	6.31	6.36	6.26	5.94	5.81	5.63	5.38	4.92
Sulphur [%]	0.87	0.88	0.79	0.7	0.66	0.61	0.55	0.46

Table 5: The properties of torrefied mixed wood material in temperature dependence

Parameter	Temperature [°C]							
	220	240	260	280	300	320	340	400
Ash [%]	1.17	1.38	1.7	1.77	2.18	2.63	3.28	4.65
Moisture [%]	2.32	2.59	4.72	4.11	6.2	5.71	6.45	9.25
Carbon [%]	53.79	56.91	66.66	68.35	71.61	72.26	73.61	72.4
Hydrogen [%]	5.58	5.43	4.45	4.63	3.58	3.66	3.27	2.47
Nitrogen [%]	0.22	0.29	0.32	0.34	0.43	0.42	0.54	0.64
Sulphur [%]	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.01

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Heating value

- The comparison of higher heating values (GVC) and low heating values (LHV) 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.

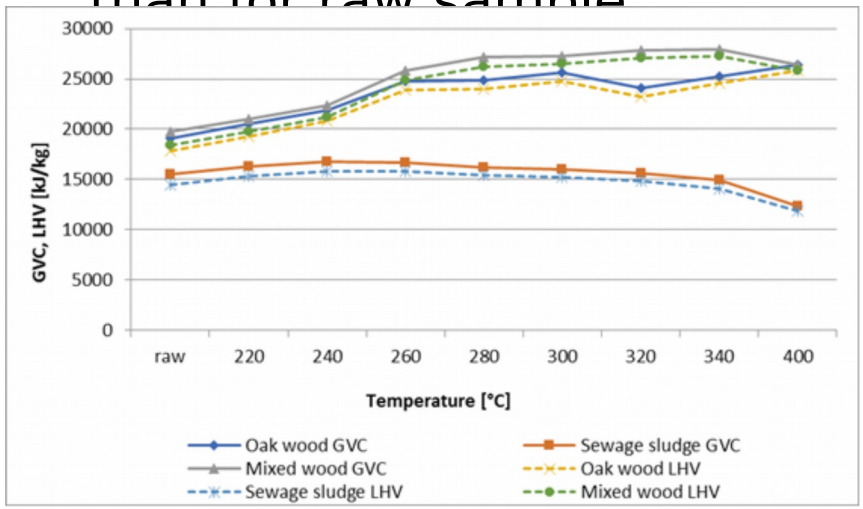

Figure 2. The GVC and LHV for torrefied materials depending on temperature

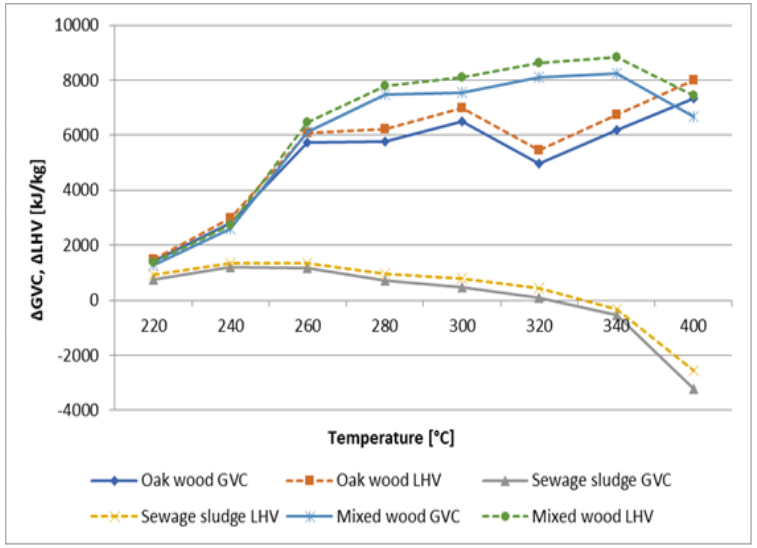

Figure 3. The difference in GVC and LHV depending on temperature

Operation time

- The experiments at different operation time of the torrefaction process were proceed at the constant temperature of 260°C.

- **Mass loss**
  - longer time the mass losses increased
  - the highest mass loss was determined with mixed wood material, followed by oak wood and municipal sludge

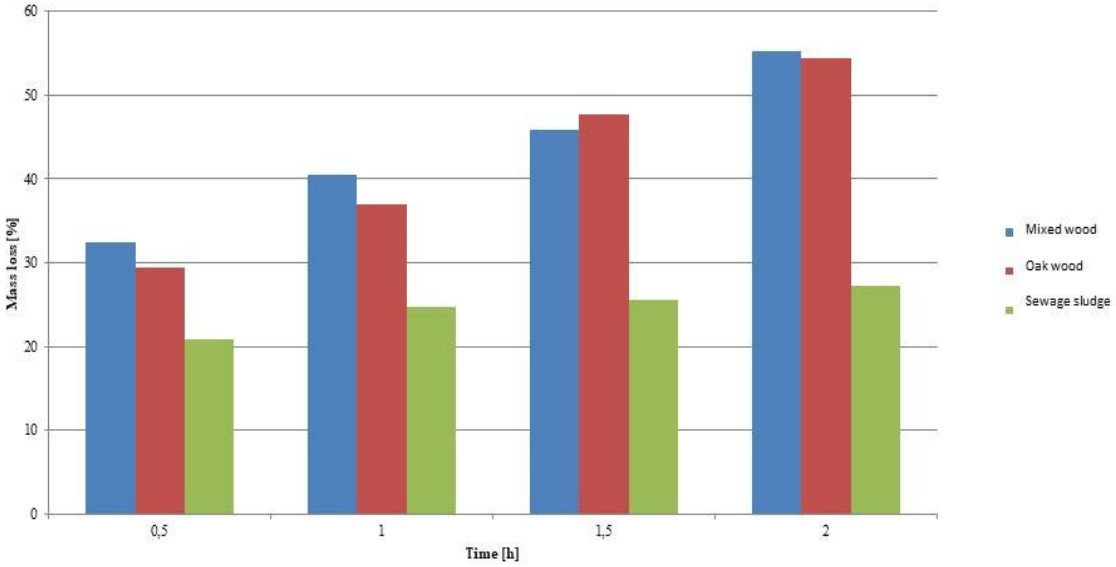

Figure 5: Mass loss of material upon operation times of torrefaction

Chemical analyses of biomaterial

Table 6: The properties of torrefied oak wood at different operation times

Parameter	Time [h]			
	0.5	1.0	1.5	2.0
Moisture [%]	3.37	4.2	4.22	1.59
Nitrogen [%]	0.24	0.29	0.35	0.42
Carbon [%]	55.19	57.26	61.67	65.01
Ash[%]	2.31	3.34	3.96	5.03
Hydrogen [%]	5.39	5.03	4.53	4.24
Sulphur [%]	0.02	0.02	0.02	0.01

Table 7: The properties of torrefied municipal sewage sludge at different operation times

Parameter	Time [h]			
	0.5	1.0	1.5	2.0
Moisture [%]	2.68	1.81	2.35	0.61
Nitrogen [%]	6.17	6.24	6.22	6.26
Carbon [%]	38.73	39.29	39.29	39.9
Ash [%]	35.83	38.24	38.47	39.61
Hydrogen [%]	4.39	4.15	4.14	4.27
Sulphur [%]	0.83	0.8	0.76	0.79

Table 8: The properties of torrefied mixed wood material at different operation times.

Parameter	Time [h]			
	0.5	1.0	1.5	2.0
Moisture [%]	4.21	3.98	3.77	4.72
Nitrogen [%]	0.21	0.27	0.27	0.32
Carbon [%]	56.36	59.51	61.48	66.66
Ash [%]	1.06	1.36	1.26	1.7
Hydrogen [%]	5.57	5.3	5.1	4.45
Sulphur [%]	0.02	0.02	0.02	0.03

- ash content is increasing with operating time.
- the total carbon content is increasing with increasing operating time.
- the hydrogen content is decreasing with the operational time.

Heating value

- The LHV and GVC are increasing with time for oak wood and mixed wood while the GVC and LHV for sewage sludge is almost the same for different operation time.

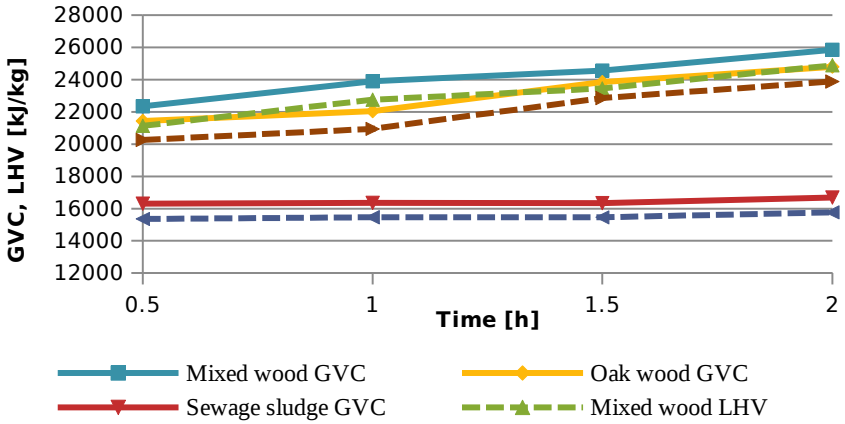

Figure 6. The GVC and LHV for torrefied materials depending on operation time

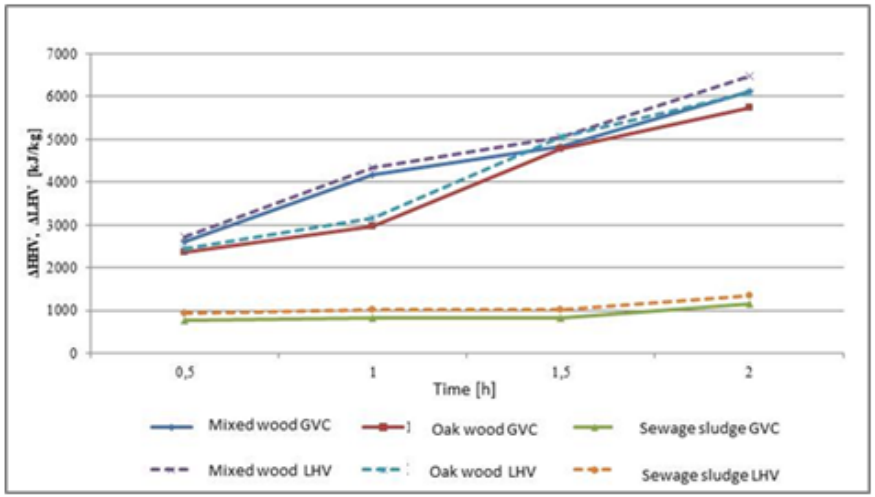

Figure 7. The difference in calorific value between torrefied material and raw material depending on operation time

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CONCLUSIONS

- 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 mass loss was higher for oak and mixed wood, mainly due to the higher moisture content of wood samples than sewage sludge
- 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.
- The materials became more hydrophobic after torrefaction, and the fragility of wood samples was also visibly improved.
- Furthermore, at optimum temperature (260 ° C), the optimum time of the toreffaction process was determined.
- The optimum process time is about 1.2 hours, because till this time the increase in heating value is the largest. It can be concluded that solid biofuels with similar properties to coal can be produced through the process of torrefaction.
- Presented work will be upgraded by determining the energy efficiency and the process improvement factor, also the degree of decarbonisation and dehydrogenation will be evaluated.
- TGA and DTG analyses.
- Comparison with inert atmosphere.

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Thank you !

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