The Influence of Different Operation Atmospheres on the Produced Biochar Quality

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Biological wastewater treatment plants are used to purify water, but they also generate large quantities of sewage sludge and other solid residues. Sewage sludge and the residues on screens have a promising energy content. The article deals with the characterization of two different samples from small wastewater treatment plants, the dewatered sewage sludge and the material remaining on a fine screen after the removal of sand particles and mineral oils. The added value of the waste produced is studied using the torrefaction process. To establish torrefaction, a pilot process was developed in which various waste materials were processed and the effects of different process parameters, such as the influence of different atmospheres and temperatures on the quality of the biofuel, were studied. The raw samples and the solid products of the thermal treatment were analyzed.

Keywords:
torrefaction,
wastewater treatment plant,
sewage sludge,
CO_2 atmosphere,
N_2 atmosphere,
biofuel

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1 Introduction

Wastewater treatment is a major challenge, and it is important that wastewater treatment plants function properly in order to reduce water pollution. Biological treatment of wastewater also produces a by-product, namely sewage sludge and residues on screens. Sewage sludge and screen residues have a promising energy content (Petrovič et al. 2023).

Nowadays, the question often arises as to how this sludge can be treated efficiently. One promising method is torrefaction, a low-temperature pyrolysis process that produces products with a higher energy density that can be used for energy purposes. The process of torrefaction is one of the thermochemical conversion routes that improves the properties of the feedstock, eliminates pathogenic organisms and produces an environmentally acceptable energy source with similar properties to coal (Ivanovski et al. 2022).

Therefore, torrefaction of activated sludge (SS2) and cellulosic material (RS) was performed. Mass and energy yield (MY, EY), energy density (EF), energy- mass co-benefit index (EMCI) and high heating value (HHV) were determined.

2 Methodology

Two samples were analyzed during the torrefaction process. The sewage sludge sample (SS2) was taken after the dewatering process. The second sample (RS) is waste collected with fine rakes and contains mainly cellulosic and biological waste. This waste is collected in a special container and separated from the sludge. The sample of sludge and cellulosic waste was dried in a dryer at 50 °C to a constant mass before starting the experimental work. The dried samples were then grinded in a water-cooled MultiDrive basic M 20 mill from IKA to achieve homogeneity of the samples.

The torrefaction analyses were carried out in a Carbolite tube furnace (Figure 1a) with a tube diameter of 90 mm. The sample was weighed and placed on a special tray as shown in Figure 1b. The tray has four zones separated by perforated metal. Torrefaction was performed at 250 °C and 350 °C under N_2 atmosphere with a flow rate of 1 l/min. The inert gas was previously heated to 50 °C. The temperature was measured in four zones during the experiment. The concentrations of the exhaust gases, such as methane, carbon dioxide, carbon monoxide and oxygen, were measured at the exit of the furnace. After torrefaction, the samples were cooled and weighed. The experimental calorific value of the raw and processed samples was determined using an IKA C 6000 calorimeter.

Figure 1: a) Carbolite tube furnace b) The tray with material
Source: own.

The torrefication efficiency (MY, %) was calculated by Eq. 1:

$$\text{MY}\ (\%) = \frac{m_{\text{t}}}{m_0} \cdot 100 \tag{1}$$

m_t–torrefied sample mass (kg)
m_o– non torrefied sample mass (kg)

Energy yield (EY, %), energy efficiency (EF) and energy co-benefit index (EMCI) were determined by Eq. 2-4:

$$\text{EY}\ (\%) = \left(\text{MY} \cdot \frac{\text{HHV}_\text{t}}{\text{HHV}_\text{o}}\right) \tag{2}$$

HHV_t–torrefied sample (MJ/kg)
HHV_o– non torrefied sample (MJ/kg)

$$\text{EF} = \frac{\text{HHV}_\text{t}}{\text{HHV}_\text{o}} \tag{3}$$

$$\text{EMCI} = \text{EY} - \text{MY} \tag{4}$$

3 Results

Samples SS2 and RS are shown in Figure 2. From left to right are the samples SS2 in N_2 atmosphere torrefied at two different temperatures (250 °C and 350°) and the raw sample (Figure 2a). The same order applies to the RS samples (Figure 2b). Sample SS2 is dark after treatment as well as the raw dewatered sludge, while samples RS have a light color as well as the raw sample (Figure 2b), due to cellulose residues content.

The temperature is a very important parameter in the torrefaction process as it influences the mass and energy yield as well as the energy efficiency. When the torrefaction temperature was increased from 250 °C to 350 °C, the mass and energy yields decreased for all samples. It follows that the higher the torrefaction temperature, the lower the MY and EY. In terms of energy efficiency, however, better results were obtained for the RS samples.

a)

b)

Figure 2: a) SS_2 and b) RS after treatment and raw material

Source: own.

Figure 3 shows the changes in temperature and gas composition during torrefaction. The temperature was constant during the experiment and fluctuated slightly around 250 °C and around 350 °C. It was found that the SS2 samples extracted the most CO_2 in N_2 atmosphere. This suggests that the fluctuations in CO_2 concentration are a measure of the progress of torrefaction, while the time between the increase and decrease in CO_2 concentration corresponds to the time during which the torrefaction process takes place in the material. The extraction of the individual gases from the sample was not affected by the temperature fluctuations. However, the RS sample showed that temperature affects the extraction of organics, with more CO and CO_2 extracted at higher temperatures. The oxygen contained in the material is released during torrefaction in the form of volatiles and other organic compounds

(Doddapaneni et al., 2022), which explains the high content of CO_2 in the gas phase. The content of other gases was negligible.

The mass yield was influenced by the temperature in such a way that a better torrefaction yield was achieved at lower temperatures than at higher temperatures.

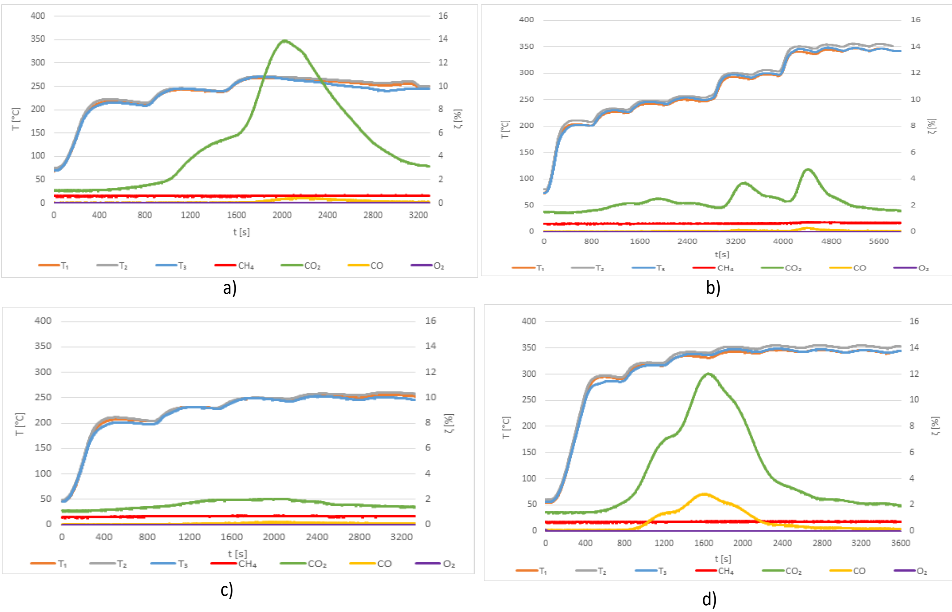

Figure 3: Measurements of temperature and exhaust gas composition during the torrefaction for sample a) SS2 at 250 °C, b) SS2 at 350 °C, c) RS at 250 °C and d) RS at 350 °C
Source: own.

Table 1 shows all calculated indexes. The highest MY and EY were achieved at 250°C, while EMCI was higher at 350°C for both samples. Other studies have reported a wide range of mass yields up to 80 %, depending on feedstock type, composition, and operating conditions (Huang et al., 2017).

Table 1: Calculations for mass yield, energy yield, energy efficiency and factor EMCI

	sample, atmospehere, T, volumne flow	MY [%]	EY [%]	EF [/]	EMCI [%]
1	SS_2			1.00	
2	SS_2, N_2, 250 °C, 1 L/min	75.33	92.24	11.79	16.91
3	SS_2, N_2, 350 °C, 3 L/min	57.44	85.04	10.86	27.60
4	RS			10.00	
5	RS, N_2, 250°C, 1 L/min	80.95	92.30	11.40	11.35
6	RS, N_2, 350 °C, 1 L/min	35.44	47.93	13.52	12.49

Figure 4 shows that the highest mass yield was calaculated at 80.95 % at 250 °C with 1 L/min flow for RS samples treated in N_2 atmosphere.

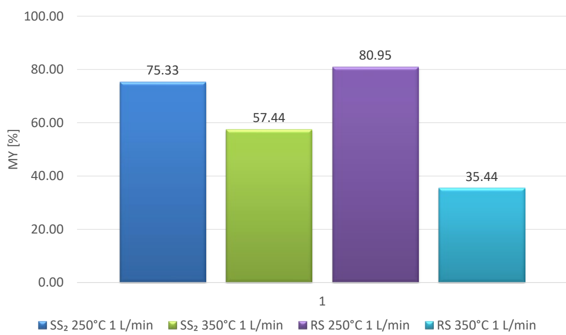

Figure 4: Mass yield (%) for SS2 and RS in N_2 atmosphere
Source: own.

Figure 5 shows the calculated values for all treated SS2 and RS samples. Regarding HHV the highest HHV was calculated at 23.32 MJ/kg for RS sample in N_2 atmosphere at 350° C and 1 L/min flow and 17.81 MJ/kg for SS2 sample.

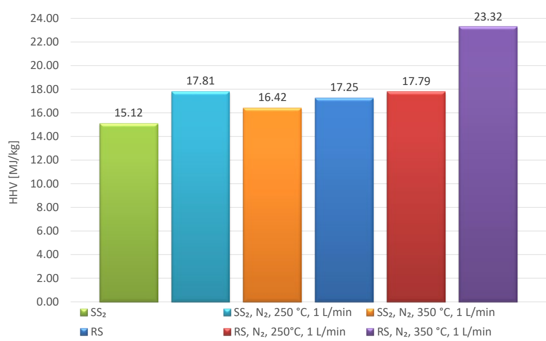

Figure 5: High heating values for SS2 and RS samples
Source: own.

4 Conclusions

Based on the results obtained on the heating values, we concluded that sludge and RS are suitable for combustion and could be used as biofuel. Both samples have high HHV values, but the cellulosic material has even higher values.

This is an important finding as more sludge and waste are produced each year and are simply disposed of in landfills. It is important that the resulting products are properly used as a secondary resource in wastewater treatment. Given the problems, these resources are underused and demand more attention.

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