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# Energetic investigation of microwave treatment

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## Abstract

Microwave (MW) irradiation as a method for sludge treatment has gained widespread popularity, mainly due to enhance biodegradability and increase yield of biogas. In this study energetic investigation of MW treatment was carried out using whey as test substance. Treatment was performed in a continuous flow treating system at different irradiation power levels, whey concentrations and flow rates. Experiments indicated that pre-treated whey gave higher yield of biogas compared to untreated whey. Moreover, the results of this study demonstrated that the flow rate and the duration of treating caused perceptible difference in yield of biogas. The most energy-efficient treatment was at low flow-rate, low power of magnetron, low treating time.

## Keywords

microwave pre-treatment, biogas production (BP), anaerobic digestion

## 1. Introduction

Anaerobic digestion is an effective way of treating wastewater for yielding profitable biogas and alleviating environmental concerns. It consists of several processes in which the biodegradable materials are broken down in oxygen-free environment. The main features of AD process are mass reduction, biogas production and improved dewatering properties of the treated sludge.

Wastewater sludge has theoretically high biogas yield, but the degree and the rate of anaerobic digestion is limited by macromolecules and other chemical components. In order to access the energy potential of the materials, large organic polymers must firstly be broken down to their smaller components. Due to this fact however, anaerobic digestion has a great future amongst the biological technologies of sludge treatment, the low overall biodegradation efficiency of the sludge solids and long retention times result in only moderate efficiencies.

Most soluble organic materials which can be converted into biogas are produced during hydrolysis process, but it is identified as the rate-limiting step (Ghyoot and Verstrate, 1997). Consequently, the biogas production depends for the most part on the biodegradability and hydrolysis rate (El and H.E., 2003).

Pre-treatment of sludge to break down its complex structure can be used for enhancing anaerobic digestibility in order to lyse sludge cells further to facilitate hydrolysis. Thermal, chemical, biological and mechanical processes as well as different combinations of them have been studied as possible pre-treatments. Thermal treatments can be highlighted as no additional chemicals needed and they can be controlled easily. Microwave pre-treatment was found to be superior over the thermal treatment with respect to sludge solubilization and biogas production. (Beszédes et al, 2011)

## 2. Methods

*Whey samples*

Whey is a by-product of cheese production. It is one of the components that separates from milk after curdling. Cheese whey can be used in many ways; supplied as feed for animals is the most common practice because of its nutritional value. Lactose and whey protein can be recovered separately and be further used for other applications. High value-added products or nutrients that can be derived or recovered from cheese whey, there are certain disadvantages inhibiting these practices to be fully applied. The major disadvantages are its high content in water that must be removed and the high energy cost to process and dry and the competitive products already available in the market. However, markets are developing continuously, there is still a surplus of whey produced above and beyond the market for whey products. In this respect, the anaerobic digestion of cheese whey is a cost-effective configurations for the cheese producers who owe to dispose the wastewater safely and, at the same time, could benefit directly from the energy recovered in the form of biogas. (Antonopoulou G., et. al.)

Two concentrations of whey were examined. One of these is the original whey (whey) coming from a milk-processing factory (Szeged, Hungary), and the other is concentrated by membrane separation (concentrate). The ingredients of the samples can be found in Table 1.

*Table 1.* Ingredients of examined whey

| | Protein [%] | Lactose [%] | Fat [%] | Total solids [%] |
|---|---|---|---|---|
| Whey | 0.47±0.13 | 2.61±0.04 | 0.18±0.01 | 3.24±0.07 |
| Concentrate | 0.73±0.16 | 3.59±0.09 | 0.34±0.08 | 5.36±0.24 |

*Microwave pre-treating system*

Microwave pre-treating system contains a water-cooled, variable-power magnetron operating at 2450 MHz. High-voltage power supply feeding the magnetron consists of two transformers, one of them produces cathode heating voltage and heating current, the other produces the anode voltage which can be controlled by the primary circuit of an external auto-transformer. With this device the power of the magnetron can be set as well. Electromagnetic energy of the magnetron spread over a resonant slot. Getting through this slot the energy gets in the toroidal resonator. (Kovács et al, 2012). During the operation of toroid resonator energy is given to the treated material. As a result of energy transmission the temperature of the material rises and the dielectric properties change continuously. The effect of the microwave energy intake, variable power, impedance and dielectric relationships are formed in the microwave resonator. Some of these can be measured (eg. power dissipation, reflected power), some of them can only be determined by calculation, knowledge of the other parameters (J. Zhu et al, 2007). Material is transferred in the continues-flow microwave treating system by a membrane pump with variable flow.

There is a dielectrometer attaching to the system. The material can flow through the waveguide of this measuring equipment in a Teflon tube. Electric signal of the dielectrometer, the inlet and outlet temperature of the material are received by the measurement data collector and recorded on-line by software and displayed in the computer screen. (Kovács et al, 2013)

*Microwave pre-treatment*

Treatments were carried out at different powers of magnetron, at different flows, and different treating numbers. Three levels from these parameters were used and combined (Table 2.).

Table 2. Microwave pretreatment conditions

| **Number of sample** | **Treated material** | **Flow [l/h]** | **Power of magnetron [W]** | **Number of treatings** | **MW irradiation time [s]** | **Energy demand [kJ]** |
|---|---|---|---|---|---|---|
| **1** | **Whey** | 6 | 350 | 1 | 300 | 105 |
| **2** | **Whey** | 6 | 600 | 1 | 300 | 180 |
| **3** | **Whey** | 6 | 850 | 1 | 300 | 255 |
| **4** | **Whey** | 15.5 | 350 | 1 | 120 | 42 |
| **5** | **Whey** | 15.5 | 600 | 3 | 702 | 421,2 |
| **6** | **Whey** | 15.5 | 850 | 1 | 120 | 102 |
| **7** | **Whey** | 25 | 350 | 5 | 1080 | 378 |
| **8** | **Whey** | 25 | 600 | 1 | 72 | 43,2 |
| **9** | **Whey** | 25 | 850 | 5 | 1080 | 918 |
| **10** | **Concentrate** | 6 | 350 | 5 | 4500 | 1575 |
| **11** | **Concentrate** | 6 | 850 | 1 | 300 | 255 |
| **12** | **Concentrate** | 25 | 350 | 1 | 72 | 25,2 |
| **13** | **Concentrate** | 25 | 850 | 5 | 1080 | 918 |

The energy demand of whey pretreatments was calculated from the power of the magnetron and the time of irradiation.

$$E = P_M \cdot t \qquad (1)$$

*Fermentation process, biogas measurement*

Digestion was performed at mesophilic temperature range (35 °C). Whey samples were inoculated with anaerobic sludge, the whey: fire sludge volume ratio was 4:1.

BOD OxiTop PM manometric measuring system with 12 mini continuously stirred digesters was used for measuring biogas yield. (Fig.1.)

*Figure 1.* BOD OxiTop PM

## 3. Results and discussion

*Biogas production*

In our experiments the effect of intensity of microwave irradiation, volumetric flow and concentration on anaerobic digestion was investigated, which were characterized by cumulative biogas production.

Cumulative biogas production with pretreated and untreated whey is shown in Fig.2.

Biogas production rate was higher for all pretreatment conditions compared to the controls. Concentrates gave the highest biogas yield, but as we can see later, the specific energy demand was worse in these cases, not to mention the energy demand of membrane separation.

For having clearer picture effects of the parameters were investigated. Biogas yield wasn't particularly affected by the power of magnetron, although the higher level was more than double the lower level (Fig.3.).

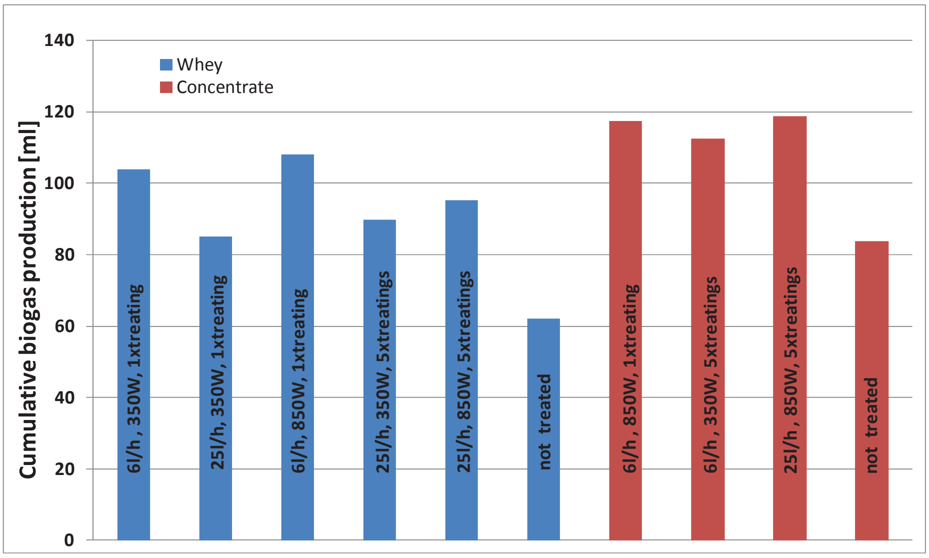
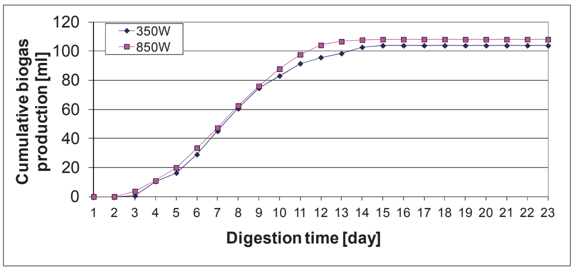


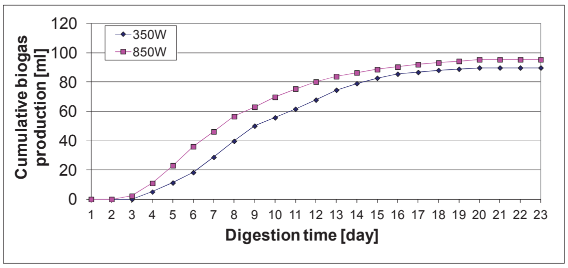

*Figure 2.* Cumulative biogas production under different conditions

In contrast, changing of flow rate caused perceptible difference in yield of biogas. (Fig.4.)

And as we could see in Fig.2. the difference in concentration also caused differences in the yield of biogas. (Fig.5.)




a)




b)

*Figure 3.* Biogas production of MW pretreated whey
a) 6 l/h, 1x treating, b) 25l/h, 5x treatings

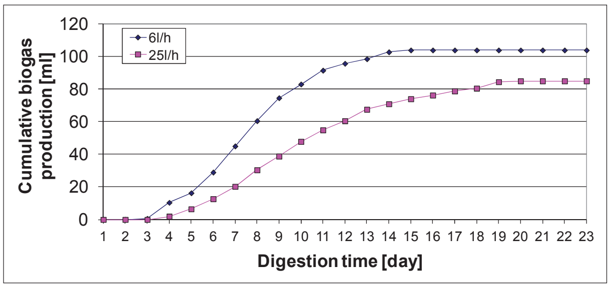
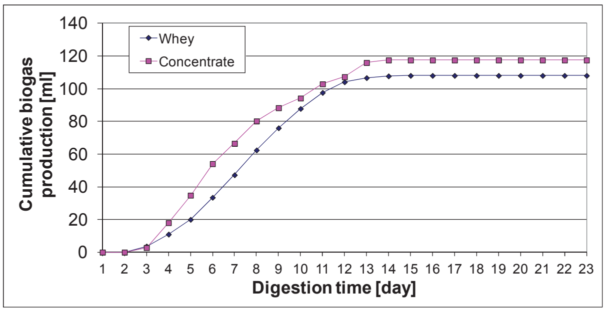
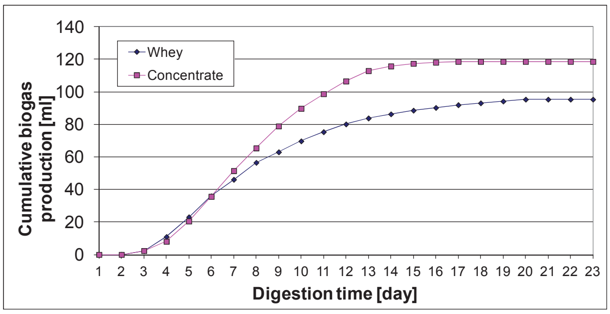



*Figure 4.* Biogas production of MW pretreated whey (350W, 1x treating)




a)




b)

Figure 5. Biogas production of MW pretreated whey and concentrate
a) 6l/h, 850W, 1x treating, b) 25l/h, 850W, 5x treatings

*Specific energy consumption*

In fact, previous investigations only provide information on effects of various parameters, however they are useless without energetic analyzes.

Pretreatment conditions and accordingly energy demand were very different, therefore specific energy demand was determined.

$$SED = \frac{E}{BP} \tag{2}$$

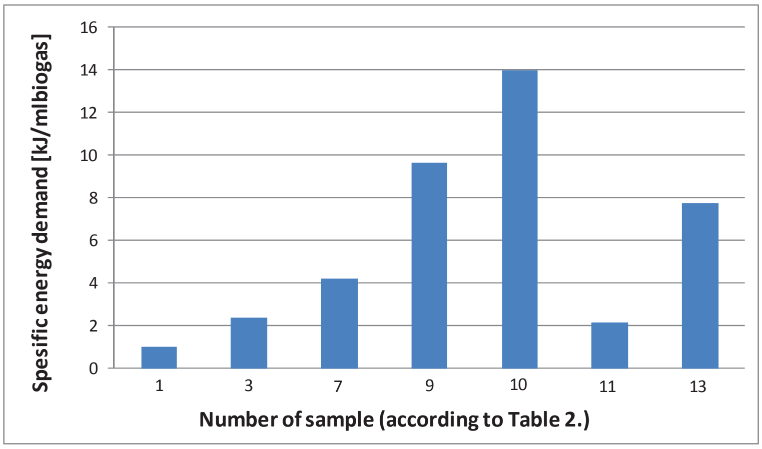



*Figure 6.* Specific energy demand at different conditions

From energetic investigation of the effect of MW pre-treatment we could identify that the effect of flow rate is the most significant. At sample 1., 3., 11. were the three lowest SEP and at these samples the flow rate was 6 l/h. At only one other sample was the flow rate 6 l/h (at sample 10), but the long treating time (5x treatings) resulted higher SED. This trend can be observed at the other three samples (Sample 7., 9., 13.) treated 5 times.

Thus conclude that the microwave treatment is most effective energetically when low flow rate, low power of magnetron and a small number of treatments are used.

## Conclusions

Based on the measurement results we can determine that the biogas yield itself doesn't characterize a pretreatment process, amount of energy investment must be taken to consideration with the use of biogas quantity can be reached.

## Nomenclature

| | | |
|---|---|---|
| E | energy demand of pretreatment | J |
| P | power | W |
| t | MW irradiation time | s |
| Subscripts | | |
| M | magnetron | |

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