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THE POSSIBILITIES OF BIOENERGY PRODUCTION FROM WHEY

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Abstract: The whey is used in dairy products or as a feed usually. In our work we focused on another way of its utilization: the biogas generating from membrane separated fractions i.e.: permeate and concentrate. The effect of thermal, the pH, the microwave pre-treatment and their combinations were investigated on the biogas yield. Our results show that the applied pre-treatments had significant effect on biogas production. In consequence of hydrolysis of large molecules the biodegradability of separated whey fractions enhanced therefore the biogas and methane production yield increased significantly.

*Keywords***:** Biogas, Methane, Whey, Thermal pre-treatments, Microwave

INTRODUCTION

The utilization of renewable energy sources and development of economical technologies has been come into the limelight by reason of reducing of available fossil energy sources. Nowadays the renewable energy generation can be often connected to waste management technologies. For example since an effective utilization of food industrial biomass waste has desired, the establishment and optimization of an efficient biogas production process from these waste materials is very important from perspectives of both energy and environmental issues. The wastes and by-products of food industrial technologies are suitable for bio-energy manufacturing because of their high organic matter content.

The anaerobic fermentation is a complex biological process developed in the absence of oxygen and in the presence of methanogenic bacteria, that transforms the organic substance into biogas (or biological gaseous mix), composed mainly from methane and carbon-dioxide. Digestion is the eldest technology for waste stabilization and however less final waste sludge production can be achieved by controlled anaerobic decomposition. With the permanent increasingly needs of concentrated liquid fuels of traffic and transportation the secondary and tertiary bioethanol technologies are hardly developed from technical and economical aspects also. It is verified, that the biological degradability of organic matter of processed raw materials – such as solid wastes, sludge, lignocelluloses contained by-products- has effect on the rate of digestion. Because of non-biodegradable components and large molecules (proteins, polysaccharides) of raw materials different kind of pre-treatments are required to achieve an appropriate and economic ethanol and biogas yield.

Whey is an important by-product of the dairy industry, in the case of conventional cheese technology the final volume of whey is about 85-90% of the volume of processed milk. Two main whey types are produces in dairy technologies, acid whey and sweet whey (or cheese whey) depend on the procedure of casein precipitation. The principal components of whey are lactose, proteins and mineral salts. Acid whey has higher ash and lower protein and fat content, typically. Approximately 150 million tons of whey disposed in the environment world-wide every year mainly in developing region (Leite et al., 2000, Saddoud et al., 2007). It represents a large-scale loss of resources and causes a strong environmental load because of the high organic matter content of whey and whey contained dairy wastewater. The conventional waste treatment process is itself not suitable for producing stabilized whey waste for direct disposal (Siso, 1996).

In Hungary the utilization of whey and membrane separated fractions of acid whey is used in whey based food industrial product. The whey is also could be appropriate as raw material for anaerobic digestion. Whey can be characterized by high chemical oxygen demand (COD) and biochemical oxygen demand (BOD) and more than 90% of 5 days BOD is caused by lactose content (Kisaalita et al., 1990).

In the case of cheese whey the average fat content is less than in the acid whey and therefore the specific biogas and methane product is less. Despite the many theoretical advantages, the anaerobic digestion is not widespread in the practice of dairy industry due to low dry matter content of whey, rapid acidification and the problems of slow reaction, which causes a longer hydraulic retention time in a continuous bio-system (Malaspina et al., 1996). But nowadays the membrane filtration technologies offer a rapid separation process for concentrating diluted whey or whey fractions and however there are many possibilities to accelerate the rate of hydrolysis and methanization (László et al., 2007). The whey digestion process usually is carried out two major stage, the first involves the conversion of complex compounds to simple materials (for instance lactose into volatile acids, or polymers into monomers), in the second stage the end-products of fermentation process are transformed into mainly methane and carbon-dioxide by methanogenic bacteria (Göblös et al., 2008; Cohen et al., 1994). The degree and the rate of hydrolysis and biodegradability have a significant effect on biogas production rate hereby on the influential and the economical parameters of digestion process (Beszédes et al., 2009).

Some investigated pre-treatments assist or accelerate the hydrolysis of macromolecules or enhanced volatilization. The most commonly used process is the mechanical and combined (thermal and acidic or alkalic) methods as pre-treatments of biogas and bio-ethanol technologies, but there are some experimental lab-scale and pilot scale intensive system (assisted by microwave and ultrasound) to rapid digestion. In last years the microwave irradiation was used as novel technology to enhance the rate and the extent of enzimatical hydrolysis of macromolecules (Neményi et al., 2008). In some cases the two-stage separated acidogenic and methanogenic reactors system gave an economical solution for accelerated anaerobic digestion (Ke and Shi, 2005).

The technology of ethanol fermentation from whey is developed in several countries. For instance several distillers producing ethanol from whey are in commercial operation in Ireland, the USA and New Zealand, where about 50% of cheese whey is used to ethanol production (Mawson, 1994; Siso, 1996). In most cases the ethanol producing from non-concentrated whey can be unprofitable, because of the low ethanol concentration in fermentation broth the distillation process demands a lot of energy and it is uneconomical. By the whey concentration the ethanol producing fermentation and distillation process can be more economical mainly due to higher alcohol yield and reduced distillation costs. In commercially one-step lactose-ethanol fermentation process the ethanol production is limited by inhibition effect and unfortunately the commonly used Saccharomyces cerevisiae yeast has not efficient lactose permease enzyme system therefore the direct reaction pathway of fermentation ethanol from lactose is not run (Castillo, 1990). The combined enzyme (β-galactosidase) and yeast two-step fermentation process could be more effective due to the enzymatic degradation of lactose which cause a higher accessible of carbon-source for yeast. But this process could not be widespread used in industrial practice by reason of high price of enzymes.

MATERIALS AND METHODES

Acid whey was used for our measurement, which is originated from a dairy works (Sole-Mizo Ltd., Szeged, Hungary). The original whey contains 0,16% fat, 0,93% protein and 4,2% lactose measured by Bentley 150 type infrared photometric milk analyzator.

The membrane separation was carried out by 30 kDa Berghoff type regenerated cellulose membrane. After separation the concentrate fraction contains 7,5 % lactose, 1,95% protein and 0,12% fat. The heat pre-treatment were performed in automatic temperature controlled laboratory heater equipment (Medline CM 307, UK) at 70 °C. In the case of combined acidic and heat pre-treatment the pH was adjusted by 1N HCl solution. For the combined acidic-microwave treatment a Labotron 500 type professional microwave equipment was used at 2450 MHz frequency, the magnetron power was 250W and the quantity of treated whey was 200 g.

For the rapid characterization of biodegradability(BD%) the BOD_5/COD ratio was used. The chemical oxygen demand (COD) was measured by photometric method using potassium-bichromate as oxidizer. The biochemical oxygen demand (BOD_5) measurements were carried out in a respirometric BOD meter (BOD Oxidirect, Lovibond, Germany), at 20 °C for 5 days.

The cumulative biogas production were measured in batch mode under mesophilic conditions, at 35°C for 30 day, in a temperature controlled anaerobic digester with Oxitop Control type pressure mode measuring system (WTW Gmbh, Germany). The tests were carried out duplicated; in one of reactor concentrated KOH was used as CO_2 absorber, in order to estimate the methane component of biogas.

The digesters were inoculated with an acclimated anaerobic sludge from an operating biogas reactor of municipal wastewater treatment plant (Hódmezővásárhely, Hungary) to eliminate the possible lag-phase of biological degradation process. After inoculation nitrogen gas was flowed through the reactor to prevent exposure to air and to ensure the consistency of the digestion tests the pH of suspension was adjust to 2.0.

RESULTS AND DISCUSSIONS

For the characterization of the accessibility for biological degradation of organic matter of raw and treated whey fractions the 5 days BOD/COD (BD %) ratio was used detecting the ratio of biodegradable part of organic matter refer to total organic matter content (expressed in COD).

Our results show that the whole whey has approximately 36% biodegradability but the concentrate fraction can be characterized a lower (25%) biological degradability. The biological degradation ability of permeate fraction is higher than the whole whey and concentrate due to the relatively higher concentration of lower molecule size and hereby easier decomposable components.

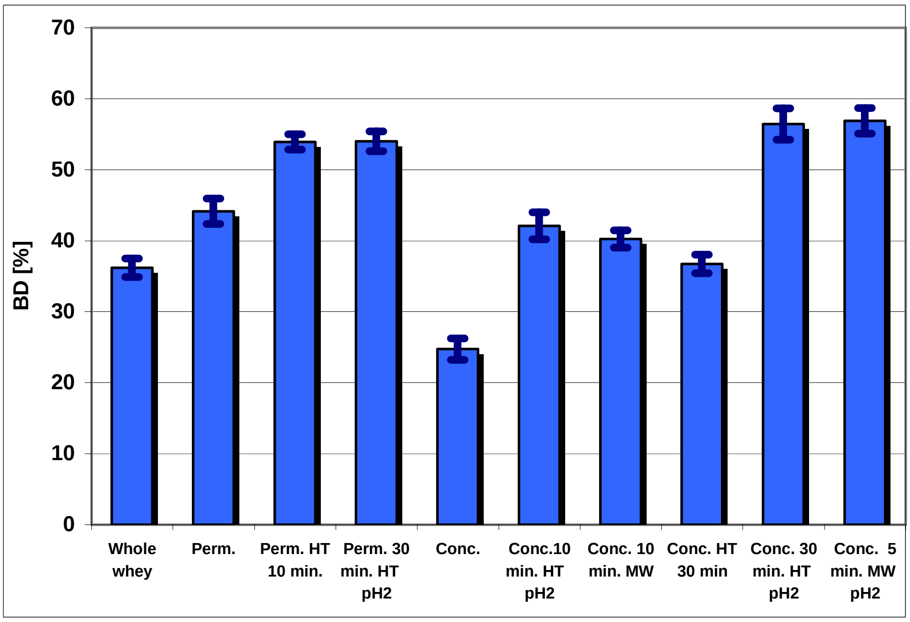

Fig. 1. Biodegradability (BD) of separated and pre-treated whey fractions
(HT-heat-treated, MW-microwave treated)

The applied convective heating (HT) and combined acidic-thermal pre-treatments could enhance the BD but for instance there was not found significant difference between the effect 10 minutes heat-treated and 30 minutes acidic heat treated permeate samples (Fig. 1.). Namely a simple 10 minutes heat treatment can reach the possible maximum biodegradability of organic matter. Longer heat treatment or added acid can not be able to enhance the degree of hydrolysis or the accessibility of organic matter for decomposing microbial enzymes.

In the case of concentrate fraction of whey the combined acidic-heat treatment and acidic - microwave treatment gave better results, and the growth of biodegradability was higher (from 25% to 56%) compare to permeate, where increment was 10%. The microwave pre-treatment alone cold enhance the biodegradability but slighter extent than applied combined acidic - microwave treatment. Comparing to the conventional 30 minute long heating the microwave irradiation was more effective.

The higher increment of biodegradability at concentrate folloed by the pre-treatment is due to the enhanced hydrolysis of whey proteins which concentrated in this separated phase. The main advantage of the application of microwave treatment comparing to the conventional heating is the less time demand. The effect of 5 minutes acidic pretreatment was equal as 30 minute long conventional heat-treatment on biodegradability.

Considering the results of mesophilic biogas production tests our data were similar to the results of biodegradability. The permeate - in spite of high original biodegradability - had a slight biogas and methane production (52 and 24 cm^3/g respectively) and by applying of combined pre-treatment the volume of fermented biogas could be enhance just above 80 cm^3/g.

In the case of concentrate the advantageous effect of pre-treatments could be manifested in higher increasing of biogas production and the percentage of methane component enhanced in biogas. Similar to the results of biodegradability examination there was no relevant difference between the biogas product of 10 minute long microwave irradiated and the 30 minute long conventionally heated whey samples.

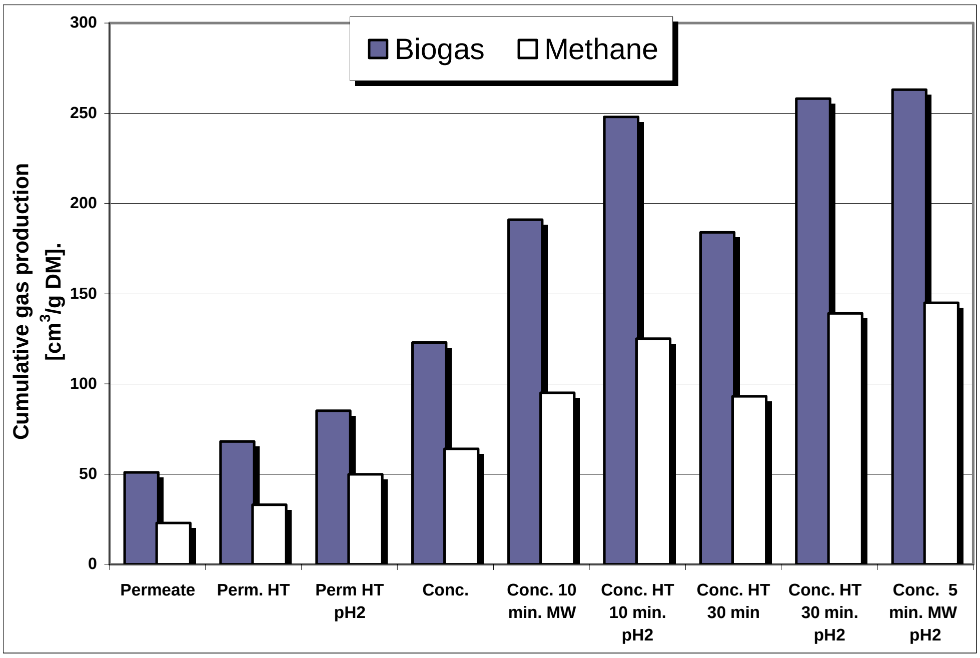

Fig. 2. Cumulative biogas and methane productions of pre-treated whey fractions

250 cm^3/g biogas and 150 cm^3/g methane yield was reached or exceed by combined acidic and classical or microwave heat treatments (Fig. 2.). There was just slightly difference between the 10 and 30 minute long combined acidic and classical heat treatment and the acidic and microwave treatment in reference to biogas and methane product

The specific biogas and methane production rate was also calculated refer to organic matter (COD) consumption during digestion process. The specific biogas production of permeate is higher than the concentrate, thanks to the more complex – less biodegradable - structure of concentrate components (Fig. 3.).

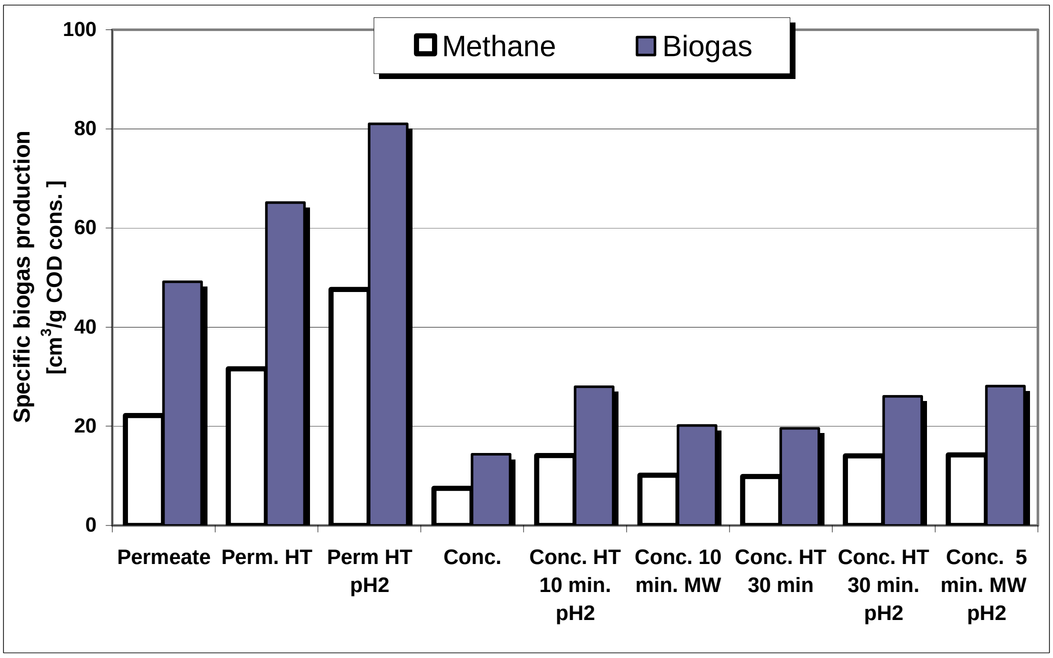

Fig. 3. Specific biogas and methane yield relate to COD consumption

However the applied pre-treatments could enhance the efficiency of bio-transformation of organic matter into biogas in both cases. In spite of better specific organic matter utilization; the total biogas and methane production is lower in the case of permeate than the biogas production of concentrate.

The advantages of pre-treatments were also shown in the rate of daily biogas production. The applied pre-treatments enhanced the maximum value of daily biogas production, for instance after acidic 30 minutes heat treatment and the acidic microwave treatment the maximum value of biogas product was twofold relate to untreated whey concentrate.

The adaptation period of anaerobic fermentation was shortened also by pretreatments beside the increased daily biogas production (Fig. 4.). Comparing to the untreated sample after combined acidic-heat treatment or acidic microwave treatment the gas producing started 3 days earlier (on the second day).

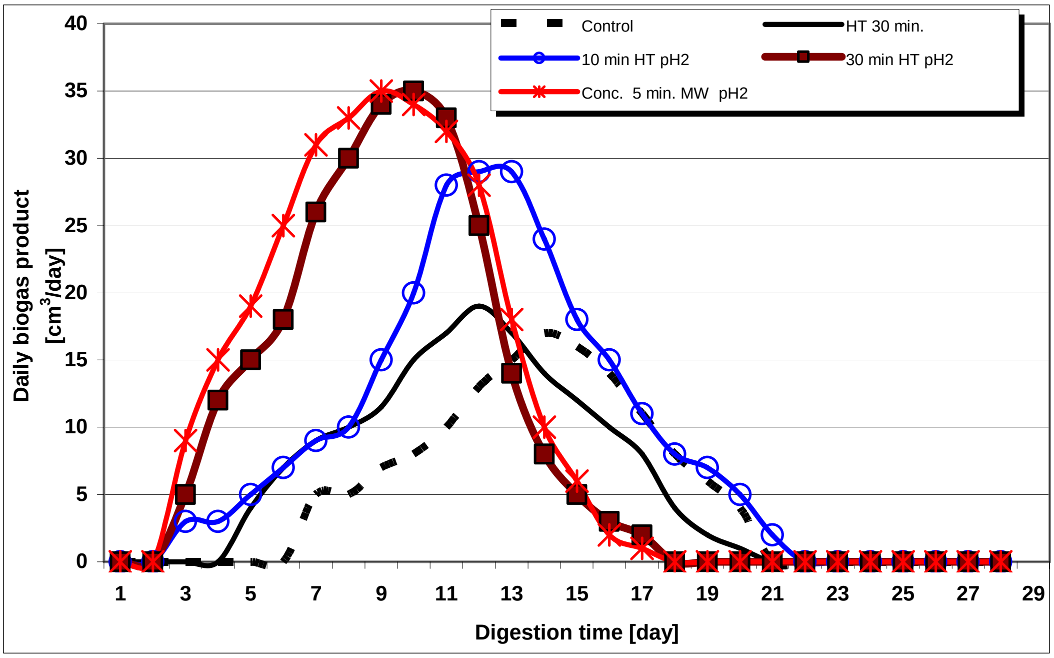

Fig. 4. Daily biogas production of pre-treated whey concentrate

The different pre-treatments reduced the overall time demand of digestion and increased the rate of anaerobic fermentation and the value of biogas production. In the case of a continuously running biogas reactor the reduced adaptation time demand can led to an easier maintain of equilibrium state.

CONCLUSION

In our work the effect of classical thermal, combined acidic and heat treatments and the acidic microwave treatments were examined on the biodegradability and digestibility of membrane separated whey fractions. Our results show that the thermal, combined acidic thermal and acidic microwave pre-treatments had significant effect on biogas product of concentrate and permeate of whey. The longer acidic heat treatment and the acidic microwave treatment could efficiently enhance the biodegradability and besides the increasing of biogas and methane production the adaptation period of anaerobic digestion could be shortened.

In the case of whey concentrate the specific biogas production was 250 cm^3/g after a longer heat treatment or 5 minutes microwave treatment. Based on our results we can say the concentrate is more applicable for biogas production than the permeate or the whole whey.

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