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The Possibilities of Bioenergy Production from Whey

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Abstract: The wastes and the by-products of food industrial technologies are suitable for bioenergy generating because of the high organic matter content. Anaerobic digestion is the eldest technology for waste stabilization and however by controlled decomposition a high value and marketable energy source can be produced. Whey is normally used as a component of dairy products or as an additive for food product. In our work we focused on another utilization method: biogas generating from membrane separated fractions i.e.: permeate and concentrate of whey. The effect of the pH, thermal, microwave pre-treatment and their combinations on the biogas yield were investigated. Our results showed that the applied pre-treatments had significant effect on biogas production. In consequence of the hydrolysis of large molecules the biodegradability of the pre-treated whey fractions was enhanced, therefore the biogas and methane production yield increased significantly.

Key words: Biogas, methane, whey, thermal pretreatments, microwave.

1. Introduction

The utilization of the renewable energy sources and the development of economical processing technologies have been come into the limelight by the reason of the reducing of available fossil energy sources. Nowadays the renewable energy generation is often connected to the 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 bioenergy generating since their high organic matter content.

The anaerobic digestion is a complex multistage 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. Compare to thermophilic anaerobic digestion, the mesophilic processes are more widely used because of the lower energy demand and higher stability but it can be remarked that the destruction of pathogenic micro-organisms and weed seeds is more effective and faster in the thermophilic digester. It is verified, that the biological degradability of organic matter of processed raw materials such as solid wastes, sludge, lingo-cellulostic by-products-has effect on the rate of digestion. During the hydrolysis step of anerobic digestion the organic matters are solubilized and the organic polymers are decomposed to monomers. Therefore the one of the most important aim of the pre-treatments is to increase the degree of hydrolysis and to enhance the methane production rate. Different kind of pre-treatments are required to achieve an appropriate and economic ethanol and biogas yield because of the non-biodegradable components and large molecules (proteins, polysaccharides) of raw materials.

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Whey is an important by-product of the dairy industry. At the conventional cheese making technology the final volume of whey is about 85-90% of the volume of processed milk. Two main whey types are produced 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. Approximately 150 million tons of whey disposed in the environment world-wide every year mainly in developing region[1, 2]. 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 containing dairy wastewater. The conventional waste treatment process is itself not suitable for producing stabilized whey waste for direct disposal[3].

In Hungary the utilization of whey and membrane separated fractions of acid whey is used mainly in food and feed industry. 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 BOD_5 is caused by lactose content[4].

In the case of cheese whey the average fat content is lower than in the acid whey and therefore the specific biogas and methane product is lower. Despite of the many theoretical advantages, the anaerobic digestion of whey is not widespread used in practice 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[5]. But nowadays the membrane filtration technologies offer a rapid separation process for concentrating diluted whey and however there are many possibilities to accelerate the rate of hydrolysis and methanization[6].

The whey digestion process usually is carried out two major stage, the first involves the conversion of complex compounds into 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[7, 8]. 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[9]. In some cases the separated two-stage-acidogenic and methanogenic system gave an economical solution for accelerated anaerobic digestion[10].

Some investigated pre-treatments assist or accelerate the hydrolysis of macromolecules or enhanced the volatilization. The most commonly used processes are mechanical and/or combined (thermal and acid or alkaline) methods, but there are some experimental lab-scale and pilot scale systems assisted by microwave radiation and ultrasonic technique. In the last years the microwave irradiation was used to enhance the rate and the extent of hydrolysis of macromolecules[11]. The controlled microwave process has many advantages comparing to the conventional heating process, for example the rapid, uniform and volumetrically heating and the selective energy absorption of different organic and inorganic compounds. Whey is a multiphase with high water content therefore it can absorb efficiently the irradiated microwave energy.

The technology of ethanol fermentation from whey is developed in many countries. For instance several distillers are worked in Ireland, in the USA and in New Zealand, where about 50% of cheese whey is used to ethanol production[12]. The ethanol production from non-concentrated whey is unprofitable, because of the low ethanol concentration in fermentation broth; therefore the distillation processes need a lot of energy. After whey concentration the ethanol fermentation and distillation process can be economical due to higher alcohol yield and reduced distillation costs. In the simple lactose-ethanol fermentation process the ethanol production is limited by the inhibition of the produced ethanol. 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[13]. The combined enzyme (β-galactosidase) and yeast using 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.

2. Materials and Methods

Acid whey was used for our measurement, which is originated from a local 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 analyzer.

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 convective heat pre-treatment (HT) were performed in automatic temperature controlled laboratory heater equipment (Medline CM 307, UK) at 70 ℃. For the microwave treatment (MW) 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. To measure the effect of pH on the hydrolysis, we made the heat pre-treatments at pH 2. The pH was adjusted by 1N HCl solution.

For the rapid characterization of biodegradability (BD%) the BOD_5/COD ratio was used. The organic matter content-expressed in COD was measured by colorimetric method according to the dichromate standard method (5250D, APHA 1995). The biochemical oxygen demand (BOD_5) measurements were carried out in a respirometric biochemical oxygen demand meter (BOD Oxidirect, Lovibond, Germany), at 20 ℃ for 5 days. To ensure the consistency of the experiments BOD microbe capsules (Cole Parmer, USA) were used for measurements.

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

3. Results and Discussion

For the characterization of the accessibility for biological degradation of organic matter the BOD/COD (BD %) ratio was used. It shows the ratio of the biodegradable part of organic matter (BOD_5) refer to the total organic matter content (expressed in COD).

Our results showed that the BD% of the whole whey was approximately 36% but the whey concentrate can be characterized by a lower (25%) value. The biological degradability of the permeate fraction is higher than the whole whey or the concentrate due to the relatively higher concentration of smaller molecules and hereby easier decomposable components.

The applied convective heat treatment (HT) and the convective heat treatment in acidified medium could enhance the BD, but for instance there was not significant difference between the 10 minute long heat-

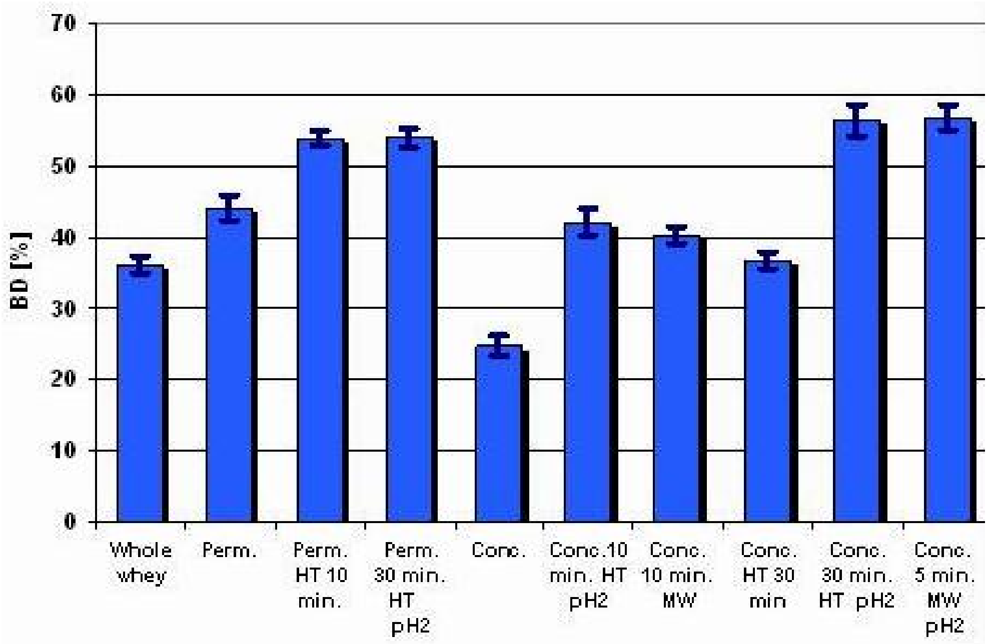

Fig. 1 Biodegradability (BD%) of separated and pre-treated whey fractions.

HT-heat-treated, MW-microwave treated.

treated and 30 minute long treated permeate samplesat pH2 (Fig. 1). Because with a simple 10 minutes heat treatment can be reach the maximum biodegradability. Longer heat treatment or added acid could not enhance the degree of hydrolysis or the accessibility of organic matter for decomposing micro bial enzymes.

In the case of concentrate fraction of whey the combined acidic - heat treatment and acidic-microwave treatment gave better results, and the increasing of biodegradability was higher (from 25% to 56%) compare to permeate, whereby the increment was 10%. The microwave pre-treatment alone could enhance the biodegradability just in a slighter extent than applied combined acid-microwave treatment. But the micro-wave irradiation was more effective comparing to the conventional 30 minute long heating.

The higher biodegradability of pre-treated concentrate is due to the enhanced hydrolysis of whey proteins which concentrated in this separated phase. The main advantage of the microwave treatment is the less time demand comparing to the conventional heating. The effect of 5 minutes acid pretreatment was similar to the 30 minutes long conventional heat-treatment.

For the examination of the biological decom-position and the transformation of organic compounds into biogas, the total biogas production of pretreated whey fractions were also measured during 30 day long mesophilic digestion. The results of mesophilic biogas production tests were similar to the results of biodegradability measurements. The permeate-despite of the high original biodegradability-had a slight biogas and methane production (52 and 24 cm^3/g, respectively). After the combined pre-treatment the volume of fermented biogas could be enhanced above 80 cm^3/g.

In the cases of concentrate fractions the advantageous effect of pre-treatments could be manifested in a higher biogas yield and in a higher percentage of methane component in biogas. Similar to the biodegradability there was no relevant difference between the biogas product of 10 minutes long microwave irradiated and the 30 minutes long conventionally heated whey samples.

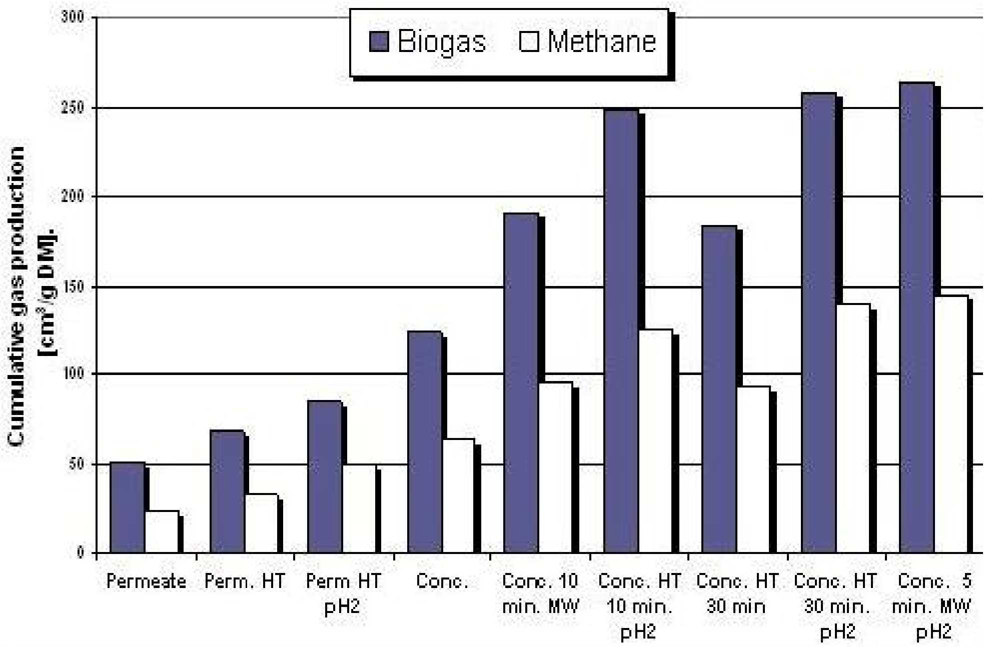

Fig. 2 Cumulative biogas and methane productions of pre-treated whey fractions.

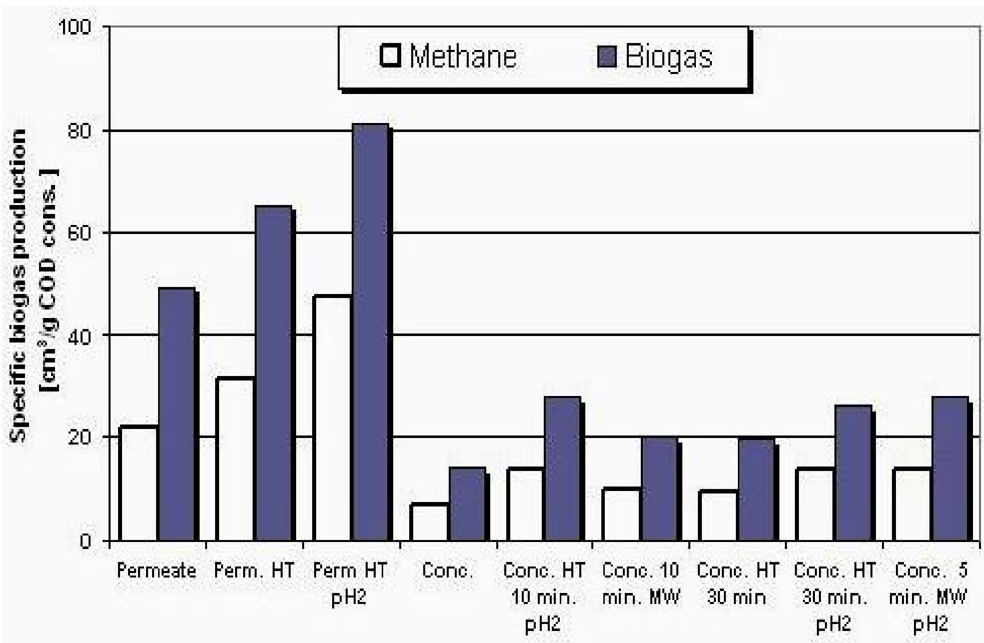

Fig. 3 Specific biogas and methane yield relate to COD consumption.

Approximately 250 cm^3/g biogas and 150 cm^3/g methane yield was reached after combined acidic and microwave heat treatments (Fig. 2). There was just a slightly difference in biogas product between the 10 and 30 minutes long combined acidic - convective heat treated sample and the acidic-microwave treated sample. So, in this field the heating- or irradiation time can be reduced. The biogas product of our pre-treated samples were not high itself, but in our work the main aim was the examination of the efficiency of applied pretreatments

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 was higher than the the biogas production from concentrate,due to the more complex-less biodegradable structure of concentrate components (Fig. 3).

The total produced biogas of permeate is lower than the biogas product of concentrate despite of better specific organic matter utilization. However the applied pre-treatments could enhance the efficiency of bio-transformation of organic matter into biogas

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 30 minutes combined acidic-heat treatment and the acidic microwave treatment the maximum value of biogas product was twofold (35 cm^3/g per day) related to non-treated whey concentrate (17 cm^3/g per day).

The adaptation period of anaerobic fermentation was also shortened after pretreatments beside the increased daily biogas production (Fig. 4). The gas production started 3 days earlier (on the second day) in the case of the combined acidic and convective heated or the microwave irradiated samples.

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

4. Conclusions

In our work the effect of different pretreatments, i.e.: classical thermal heating, microwave irradiation and the combined acidic and heat treatments on the biodegradability and anaerobic digestion of membrane separated whey fractions were examined. Our results showed that the thermal, combined acid thermal and acidic microwave pre-treatments had also significant effect on biogas production of concentrate and permeate fractions of whey. The long-time classical heat treatment and the microwave irradiation in acidic medium could efficiently enhance the biodegradability and besides the increasing of the biogas and methane production, the adaptation period and the initial lag-phase of anaerobic digestion could also be shortened. Based on our results we can say the concentrate is more applicable for biogas production than permeate or the whole whey. The specific biogas production of concentrate fraction increased from 130 to above 250 cm^3/g after a longer i.e. 30 min. long-classical heat treatment or 5 minutes long micro-

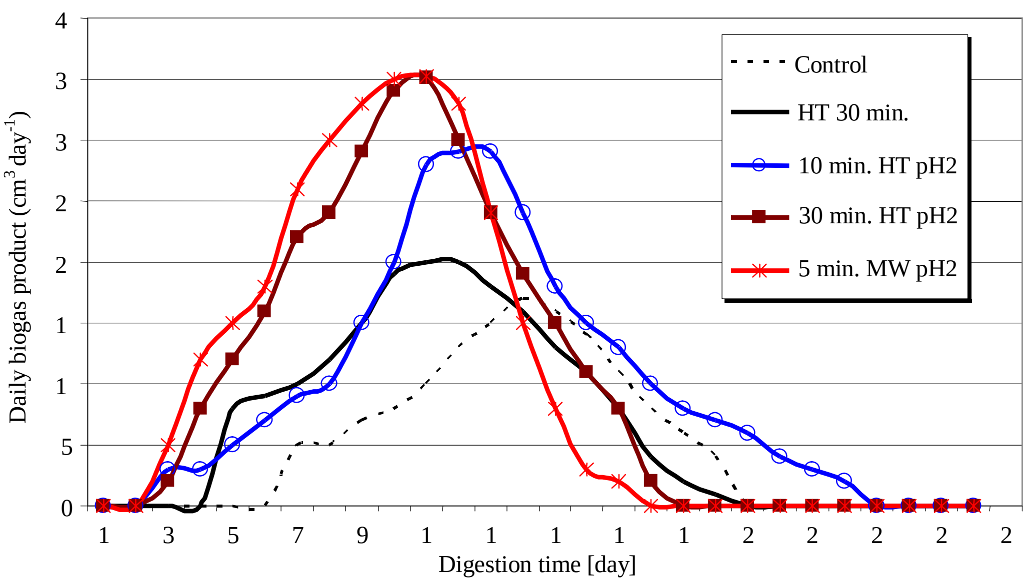

Fig. 4 Daily biogas production of pre-treated whey concentrate.

wave irradiation.

Acknowledgments

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