CONCENTRATION OF MEAT PROCESSING INDUSTRY WASTEWATER BY REVERSE OSMOSIS AND ANAEROBIC DIGESTION OF THE CONCENTRATE

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SUMMARY: The paper reports on reverse osmosis (RO) concentration of meat industry wastewater prior to treatment by anaerobic digestion (AD). Our primary aim was to optimize the RO process to achieve maximum recovery of organic matter with the highest permeate flux and the lowest total resistance. Secondly, AD experiments were conducted on the RO concentrate and appropriate pretreatment methods were sought after to achieve maximum biogas production. The optimal conditions for the RO process were determined at transmembrane pressure of 38.5 bar and recirculation flow rate of 1000 Lh^{-1} at 40°C. To find the best pretreatment method for highest biogas production, the effect of grease mixing, alkaline and acidic condition combining thermal pretreatment were evaluated. The AD tests showed good decomposition ability for the RO concentrate, and the highest biogas production was achieved by the combination of alkaline condition with heating at 70°C. The advantage of pretreatment was also manifested in higher rate of anaerobic decomposition into biogas and shorter LAG-phase of digestion.

1. INTRODUCTION

Biomass has the potential of becoming one of the major global primary energy sources in the next years, and the utilization of bioenergy sources could be an important contributor to a sustainable energy future in industrialized countries and in developing countries alike. In the 1st generation bioenergy sytems, energy crops are used as raw material. However, rising demand for energy crops generates a competition for the use of land and water resources, and thus increasing food prices and threatening the productibility of the agrifood sector. In the last

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decade, tertiary biomass has become a prime source of interest in bioenergy generation, and efforts are extended to ustilising the energy content of organic waste and effluents.

Rural areas in Northern Finland face unique challenges with respect to their economic development. Due to their remote location and long winters, these areas have been very resource intensive and have traditionally been dependent on fossil energy. The EU Waste Framework Directive has also created challenges for all countries in the handling of waste. The challenges weigh even heavier in remote Northern regions due to uneconomic scale and spread of waste amounts and long transportation distances. The European Spatial Development Perspective stresses the need for economic diversification in rural areas through strategies based on local resources and needs. There are several renewable energy sources which contribute to the achievement of EU policy targets. Among them, waste and biomass are considered the energy source with the largest unexplored potential. Exploiting resources in wastes for renewable energy through small-scale technical solutions also offers excellent opportunities for decentralized business innovation. Small-scale biomass and waste based energy solutions are able to answer the challenges of resource availability, while progressively reducing the impact of human activities on the environment.

This experimental work was conducted as part of a Northern Periphery Project ‘Micro Waste-to Energy Business: micro energy to rural enterprise (MicrE)’. The purpose of the project is to find solutions viable for Northern Periphery conditions for small and medium-sized enterprises to utilize the energy potential of their wastes. Anaerobic digestion (AD) was selected as one of the most promising technologies for wet organic waste widely generated in the area. The treatment of wastewaters with high organic content by AD could provide solution for both waste stabilization and a controlled decompositon the organic pollutants while also generating valuable bioenergy.

Compared to other agro-industrial sectors, food processing generates a great amount of wastewater due to the high water content of raw materials and the high water demand of flushing and cleaning procedures. Food processing companies face the demand for efficient wastewater purification and biowaste handling systems, while also an increasing need for sustainable energy. As well, because of the low average temperature in the northern regions, the efficiency of traditional biological wastewater treatment technology is low. Beside this, the fluctuating composition of the wastewater and the periodic operating nature of small- and medium-sized meat processing plants make the planning and optimization of biological purification processes challenging. However, the limiting factor is the high volume of wastewaters, and the fact that the wastewaters are too diluted to achieve profitable biogas production. Membrane operations are suitable for efficient wastewater purification and concentration in one stage process. Furthermore, membranes techniques are known to be easily adaptable for different flow rates and for fluids with diverse chemical compositions.

In our work, we investigated the reverse osmosis (RO) operation to find optimal process parameters for the purification and concentration of meat industry wastewaters. A unique feature in our work was that the tests were conducted on actual wastewaters delivered from a local meat processing company. Further, AD tests were conducted on the obtained wastewater concentrate, and the biogas production was determined with mesophilic anaerobic digestion tests.

2. THEORETICAL BACKGROUND

2.1 Reverse osmosis process

In the reverse osmosis (RO) process, where the fluid is forced through the porous membrane by the pressure difference, the permeate flow rate depends on the permeability of membranes (L), the physical properties of processed fluid (ρ, η) and the pressure gradient (d_p/d_x). However, RO process is additionally affected by the diffusion through the membrane (D). Based on the solution-diffusion transport model, the mass flux across the membrane depends on the permeability of membrane for water (L), the transmembrane pressure (Δp) and the osmotic pressure difference ($\Delta\pi$). If the thickness of membrane (l), the water solubility (S) and the water partial volume (V) are known, the water flux can be given by the formula of Wijmans and Baker (1995):

$$J = \frac{DSV}{RTl}(\Delta p - \Delta \pi) \tag{1}$$

Mass flow thorough the membrane and the permeate flux are affected by the transmembrane pressure and the temperature. Increasing the temperature decreases the viscosity of fluids and, therefore, increases the water and the salt permeability and the osmotic pressure as well (Greenlee at al., 2009). During the concentration process, the dissolved ions and solids form a thin layer on the membrane surface and cause local increasing in osmotic pressure. This concentration-polarization phenomena together with the fouling and the Donnan potential decrease can dramatically decrease the permeate flux (Kim and Hoek, 2005; Amiri and Samiei, 2007). During RO concentration at high pressure, the diffusion rate is reduced due to the more compact (less porous) deposited layer; furthermore, the resistance increases with the enhanced local osmotic pressure (Chong et al., 2008). In the formed cake-layer a complex flow pattern can be observed, moreover, the flow direction may even reverse the pressure gradient because of the inter-connectivity of the neighbouring pores (Yang et al., 2007)

The effect of fouling can be characterized by the flux decline versus operation time and, to examine the flux behavior and the fouling mechanisms, the resistance-in series model is used in various membrane processes. In the resistance-in series model the relationship between the permeate flux, transmembrane pressure and the total resistance can be described by the series resistance equation:

$$J = \frac{\Delta p}{\eta\ R_t} \tag{2}$$

where η is the viscosity of the feed fluid and R_t is the total resistance.

R_t can be defined by the sum of the is the hydraulic (intrinsic) membrane resistance ($R_{m)}$, the polarization layer (external fouling) resistance ($R_{p)}$ and the (internal) fouling resistance (R_f).

$$R_t = R_m + R_f + R_p \tag{3}$$

The model has been successfully adopted for the examination of flux behavior during the RO concentration of manure (Masse et al, 2010), separation of oil in water emulsion (Mohammadi et al, 2003) and for control of fouling phenomena in several ultrafiltration processes (Rai et al, 2006; Arora et al, 2009).

2.2 Anaerobic digestion

Anaerobic digestion has become a popular waste stabilization and bio-energy generating process. Theoretically, the solid and semi-solid phase of wastewater has great potential for biogas production, but the slow and incomplete hydrolysis of the extracellular polymeric substances

(EPS) and the other non-biodegradable components limit the rate and extent of anaerobic digestion (Higgins and Novak, 1997).

Microbial activity in the presence of organic compounds has a considerable effect on the physicochemical and biological properties, and it also plays a significant role in the bio-fouling and bio-corrosion phenomena (Flemming and Windgender 2001, Neyens et al., 2004). Additionally, the protein content of digested raw material originating from the dairy and meat industry can contain an extremely high level of EPS, which causes slower biogas production, because the enzymatic hydrolysis of the proteins is limited by the protection of the cell wall (Müller and Winter, 2004).

There are many possibilities to improve the digestibility and the aerobic biodegradability of biomass. The extent and rate of biological degradation can be enhanced by mechanical, ultrasound, chemical, thermo-chemical, and enzymatic pretreatment methods (Zhu and Beland, 2006, Climent et al, 2007). Thermal treatments are also suitable for sludge disintegrating, resulting increased solubilisation efficiency and enhanced degradation of the macromolecules to low molecular-weight compounds. Thermal treatment leads to the modification of the sludge flock and the opening of the cell walls of the bacteria; and in addition, the proteins can become more accessible to biological degradation. Moreover, applying it in order to pretreat wastes the initial lag-time of digestion can be shortened (Stasta et al., 2006; Houdkova et al., 2008).

3. MATERIALS AND METHODS

3.1 Wastewater sample

The wastewater samples originated from a meat processing plant, the sampling point was after the grease tap. The process water is originating from meat processing technology; mainly from flushing and rinsing of equipments (slicing and packaging machines, smoking chambers). The samples were fresh collected before measurements to avoid the altering of the organic matter structure under freezing and melting operations. To remove the grit and other large-size solids a cloth filter was used. The characteristic of wastewater is shown in Table 1.

TOC content was measured by a Sievers 900 portable TOC analyzer with membrane conductometric detector (GE Analytical Instruments, USA). The photometrical protein assay was based on the Lowry method (Lowry et al, 1951) using bovine serum albumin (BSA) standard. The samples were diluted to avoid the interference with lipids, ammonium ions and salts and to minimize the effect of the sample on the pH of reaction mixture. The lipid content of wastewater samples was determined by partition-gravimetric procedures after extraction according to modified Bligh and Dyer method (Smedes and Askland, 1999). For the viscosity measurements of wastewater samples glass capillary viscometer was used.

3.2 RO concentration

For the pilot scale filtration, a series flow B1 module of Paterson Candy International (PCI) was used, equipped by 18 AFC99 (ITT PCI Membranes Ltd.) tubular polyamide membranes (Nominal retention for NaCl 99%) with effective membrane area of 0.85 m^2. The temperature of feed was controlled by a heat exchanger. In all experiments, 30 L wastewater was concentrated to reach a volume reduction ratio (VRR) of 3.75, calculated by the Eq. (4)

$$VRR = \frac{V_f}{V_f - V_p} \tag{4}$$

where V_f is the volume of feed, and V_p is the volume of permeate.

Table 1 - Characteristics of raw wastewater.

Parameter	Mean value	STD
TS (mgL^{-1})	3210	296
TOC (mgL^{-1})	834.1	35.3
Lipid (mgL^{-1})	115.1	21.7
Protein (mgL^{-1})	379.4	21.2
pH	6.13	0.23
Conductivity* (μScm^{-1})	983.2	14.2
Density* (kgm^{-3})	1005.3	3.2
Viscosity* (mPas)	0.877	0. 009

* at 30°C

The retention (R) for total organic carbon (R_{TOC}), for fat (R_{fat}) and proteins (R_{prot}) were calculated using the following equation

$$R(\%) = \left(1 - \frac{c_p}{c_0}\right) \times 100 \tag{5}$$

where c_p and c_0 are the concentration of measured components in the permeate and feed, respectively.

To analyze the components of total resistances, the reistence-in-series model was applied. Hydraulic resistance of a clean membrane (R_m) can be calculated by the data obtained from permeate flux (J_w, $m^3m^{-2}s^{-1}$) measurement with deionized water at different transmembrane pressure (Δp, Pa) and from the dynamic viscosity ($\eta_{w,}$ Pas)

$$R_m = \frac{\Delta p}{\eta\ J_w} \ (\mathrm{m}^{-1}) \tag{6}$$

During the concentration process, the solid and dissolved components build up the polarization layer (cake layer) which can be removed by intensive flushing with water. From the pure water flux measured after flushing (J_f) and the prior calculated R_m the fouling resistance can be given by Eq. 7.

$$R_f = \frac{\Delta p}{\eta_w\ J_f} - R_m \ (\mathrm{m}^{-1}) \tag{7}$$

After knowing R_m an R_f and calculating R_t from the permeate flux of wastewater filtration, the polarization layer resistance can be determined by the combination of Eq. 2. and Eq. 3.

3.3 AD tests

Anaerobic digestion (AD) tests were carried out in continuously stirred laboratory scale reactors with 250 mL total volume, equipped with Oxitop C (WTW Inc.) barometric measuring heads under temperature controlled mesophilic conditions (35 ± 0.2°C) for 30 days. During our experiments, the cumulative biogas production was measured in batch mode and the pH of samples was adjusted to 7.2 prior to digestion.

The inoculums were collected from a wastewater treatment plant and they were acclimatized to the RO concentrate to reduce the initial lag-period of the anaerobic process. The dosage of seed sludge was 10 w/w%. The bottles containing only inoculums were used as a blank test. The biogas product was calculated according to the pressure increase, the normalized volume of the specific biogas product was given on a TS basis. The methane content was determined using gas chromatograph, TCD and FID detectors (Agilent 6890N) equipped with Agilent 19091N capillary and Porapak Q6 packed column, respectively. Helium was used as carrier gas with a flow rate of 25.0 mL min^{-1}. The temperature for detectors and for columns was 250 °C.

4. RESULTS AND DISCUSSION

4.1 Modeling and optimization of the RO process

To examine the possible interactions between the operating conditions and to optimize the influential parameters for RO concentration, central composite face centered (CCF) experimental design and response surface methodology (RSM) was performed using MODDE 8.0 statistical experimental design software (Umetrics, Sweden). For the modeling and optimization, the studied factors were the transmembrane pressure (p) of 25 and 45 bar, recirculation flow rate (Q_{rec}) of 600 and 1000 Lm^{-2}h^{-1} and the temperature of 30 and 40°C (Table 2).

The model was fitted by multiple linear regression (MLR). The values of pressure and the recirculation flow rate were chosen based on the membrane characteristics and considering the specification of RO unit and the membrane module. The operating temperatures were varied according to the temperature range of produced industrial process water. The selected responses were the average permeate flux (J), the organic matter retention ($R_{TOC)}$, the total resistance (R_tTo evaluate the reproducibility of the fitted model five center points was used in the experimental design (Qrec=800 Lh^{-1}, p = 35bar at temperature of 35°C). In order to reduce the systematic error the run of the experiments were randomized.

Our results indicate that the retention for TOC, lipids and proteins has not changed significantly because the retention of AFC99 membrane for different components was higher than 97% in all cases. The calculated value of R_m for the AFC99 membrane was 1.409×10^{14} m^{-1}, and it is independent from the pressure. In our case the range of R_f was obtained from 8.761×10^{13} to 1.034×10^{14} m^{-1} but the changing was not significant at 95% confidence interval. During the evaluation of process parameters on response functions, it was found that pressure and the temperature had considerable effect on the permeate flux R_t and R_p and, additionally, smaller influence of Q_{rec} was obtained on permeate flux and total resistance. The other factors and the interections between them have just a negligible effect on response parameters.

Our calculation based on the resistance-in-series model showed that the hydraulic resistance of membrane (R_m) was in all cases higher than the fouling resistance (R_f) and the ratio of R_m to R_t was from 39.3 to 51.9%, depending on the experimental conditions. The main part of R_m in R_t can be explained by the composition of the wastewater, the low amount of organic matter could not form thick polarization layer in the turbulent feed flow. Furthermore the concentration of low molecular size compounds was not high enough to increase significantly the internal fouling. Theoretically, the flow rate affects the thickness and the rate of building of polarization layer. However, in our case, the Re number was approximately 16200 at 600 Lh^{-1} of Q_{rec} and 27000 at 1000 Lh^{-1} of Q_{rec}, respectively, and in the turbulent flow range the effect of varying Re could not manifest in a large scale decrease of polarization layer.

Table 2. Factors and responses of experimental design

Exp. No.	Factors			Responses			
	Q_{rec} (Lh^{-1})	p (bar)	Temp.(°C)	J_{perm} ($Lm^{-2}h^{-1}$)	R_t ×10^{14} (m^{-1})	R_p ×10^{14} (m^{-1})	R_{TOC} (%)
1	600	25	30	54.35	2.604	0.716	99.28
2	1000	25	30	55.04	2.556	0.698	99.20
3	600	45	30	71.38	3.211	0.767	97.93
4	1000	45	30	72.27	3.102	0.749	98.04
5	600	25	40	60.21	2.652	1.036	98.77
6	1000	25	40	61.06	2.588	0.998	98.74
7	600	45	40	76.42	3.258	1.057	98.01
8	1000	45	40	78.13	3.189	1.091	97.96
9	600	35	35	69.99	2.954	0.936	98.86
10	1000	35	35	71.51	2.878	0.909	98.71
11	800	25	35	58.25	2.613	0.912	97.21
12	800	45	35	73.21	3.239	0.934	98.99
13	800	35	30	69.40	2.843	0.783	99.09
14	800	35	40	73.65	3.024	1.104	98.51
15	800	35	35	70.87	2.885	0.921	99.05
16	800	35	35	70.95	2.884	0.924	99.12
17	800	35	35	70.85	2.881	0.928	99.06
18	800	35	35	70.93	2.880	0.925	99.15
19	800	35	35	70.96	2.879	0.921	99.17

Using the fitted model, the mathematical relationship between the independent variables of pressure (p, bar), recirculation flow rate (Qrec, Lh^{-1}), temperature (t, °C) and the response function for permeate flux (J_p, $Lm^{-2}h^{-1}$) and total resistance (R_t, m^{-1}) are presented by Eqs. (8) and (9), respectively.

$$J_p = 71.0214 + 8.25p + 0.5659Q_{rec} + 2.711t - 4.989p^2 \tag{8}$$

$$R_t = 2.9009\times10^{14} + 2.986\times10^{13}\,p - 3.659\times10^{12}\,Q_{rec} - 3.95\times10^{12}\,t + 3.107\times10^{10}\,p^2 \tag{9}$$

The validity of the fitted model was tested with ANOVA at confidence level of 95% for each response and presented in Table 3.

The response function predictions were in good agreement with the experimental data, the R^2 for J_p and R_t was 0.996 and 0.994, respectively. In addition, the goodness of fit (Q^2) for J_p and R_t was 0.991 and 0.988 which indicate good predictive power of the models. The reproducibility was over 99.9% and the standard deviations of the fitted models were higher than the standard deviation of the residuals (R^2_{adj} >0.98 in both cases).

Table 3 - Results of ANOVA test on permeate flux (J_p) and total resistance (R_t).

Permeate flux	Degree of freedom	Sum of square	Mean of square	F value	Probability (p)	SD
Total Corrected	18	878.164	48.7869	-	-	6.9847
Regression	10	874.366	218.592	805.79	0	14.7848
Residual	8	3.79786	0.271276	-	-	0.5208
Lack of Fit	6	3.78818	0.378818	156.538	0	0.6154
Pure Error	2	0.00967	0.002419	-	-	0.0491
Total resistance						
Total Corrected	18	9.349E+27	5.194E+26	-	-	2.279E+13
Regression	10	9.205E+27	2.301E+27	224.239	0	4.797E+13
Residual	8	1.436E+26	1.026E+25	-	-	3.204E+12
Lack of Fit	6	1.434E+26	1.434E+25	214.072	0	3.787E+12
Pure Error	2	2.679E+23	6.699E+22	-	-	2.588E+11

Analysis of RSM data shows that the permeate flux is strongly dependent on the pressure and temperature. The difference of the operating pressure and osmotic pressure is decreasing during the concentration and, therefore, there was a non-linear correlation between the permeate flux and the pressure. (Figure 1).

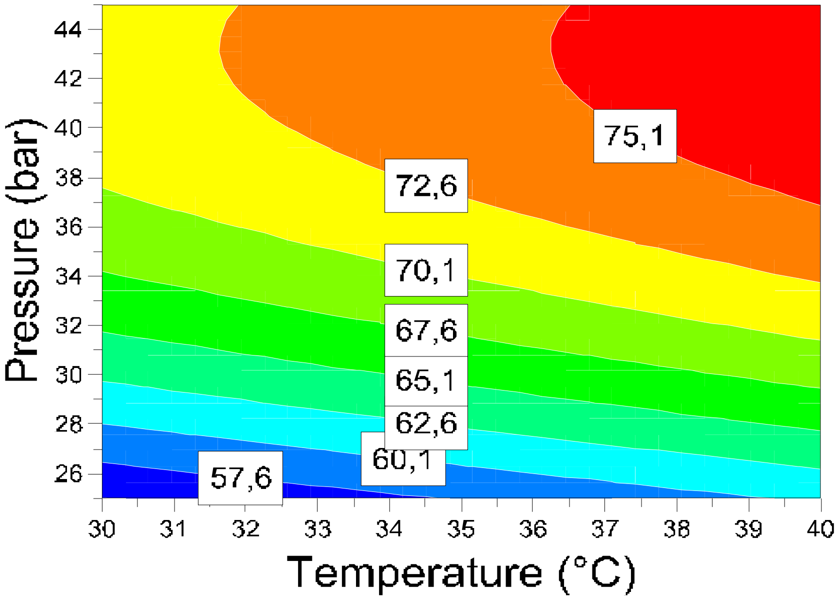

Figure 1. The combined effect of temperature and pressure on the permeate flux.

In addition, during the concentration process the deposited cake layer caused a slower diffusion (via longer diffusion path and lower diffusivity) and a higher hydraulic resistance. Increased temperature caused decreased viscosity, which predict higher permeate flux (Eq. 2.), but the higher temperature is also expressed in decreasing the driving force of the RO process (Δp-$\Delta\pi$). In our case, the highest permeate fluxes can be reach by applying the pressure of over 37 bar and at temperature over 36.5°C, however, to achieve the best permeate flux, the recirculation flow rate can be set a value over 750Lh^{-1}. In this region, the retention for TOC and protein was higher than 97% and 99%, respectively. On the other hand, the pressure increasing from 25 to 45 bar increased the total resistance by approximately 17% but this effect can be reduced by the application of elevated temperature and/or higher recirculation flow rate. This antagonist effect of the pressure increasing on total resistance and permeate flux can be explained by the altering of structure of polarization layer (Agashichev, 2004).

Using the fitted model (Eqs. 8-9), based on the date obtained from the response surface analysis, the optimal condition of RO process of meat industrial wastewater for highest permeate flux and the lowest total resistance were determined at transmembrane pressure of 38.5 bar and recirculation flow rate of 1000 Lh^{-1} at 40°C.

4.2 AD tests on RO concentrate

In the second phase of our experiments, the anaerobic digestion of concentrate was investigated to determine the biogas production potential and to examine the efficiency of different pretreatments. For the AD tests, the concentrate obtained from RO process (ROCC) with optimum parameters was used (Table 4.).

In the AD tests, the effects of grease addition (obtained from grease trap of wastewater line) in 5 and 10 w/w%, acidic (at pH2 for 60 minutes), alkaline (at pH12 for 60 minutes), and the combination of them with heat pretreatment of 70 °C were investigated on the biogas product. For comparison purposes, tests were also carried out with original wastewater (WW) samples. The experimental plan for AD is shown in Table 5.

As our results indicate that the concentration of wastewater can increase the volumetric biogas production from 1104 Lm^{-3} to above 3000 Lm^{-3}. With the RO concentration, the overall capacity of the AD process could be more profitable. The grease addition affected positively the biogas production; the grease addition in 5 w/w% with combination of alkaline pretreaetment could increase the volumetric biogas production by 73.3 % (Exp. No.11-12, in Table 5). To make comparable the efficiency of anaerobic digestion and transformation of organic matters to biogas, the biogas yields were also calculated.

Table 4 - Characteristic of raw wastewater.

Parameter	Mean value	STD
TS (mgL^{-1})	9102.3	241.5
TOC (mgL^{-1})	2405.8	153.2
Lipid (mgL^{-1})	328.2	17.9
Protein (mgL^{-1})	1083.4	22.6
pH	6.92	0.17

Table 5 - Experimental plan for AD tests (WW- original wastewater; ROCC- concentrate of RO process).

Exp. No.	Raw mat.	Grease (w/w%)	Acidic pret. (pH 12, 60 min)	Alkaline pret. (pH 12, 60 min)	Heat pret. (70°C, 60 min)	Biogas prod. (L·m^{-3})	Biogas yield (L·kg^{-1}TS)
1	WW	0	-	-	-	1104.1	345.02
2	ROCC	10	-	-	-	3079.4	581.57
3	ROCC	0	+	-	-	3560.8	391.50
4	WW	5	+	-	-	1716.3	536.12
5	WW	10	+	-	-	1398.2	436.95
6	ROCC	0	-	+	-	3017.6	331.59
7	ROCC	5	-	+	-	5227.1	574.34
8	WW	10	-	+	-	1904.3	595.08
9	WW	0	-	-	-	1088.2	339.41
10	ROCC	10	-	-	-	5292.6	581.59
11	ROCC	0	-	-	+	3462.6	360.51
12	ROCC	5	-	-	+	5166.7	538.13
13	WW	10	-	-	+	1401.4	439.15
14	WW	0	+	-	+	1309.1	409.68
15	ROCC	10	+	-	+	5601.9	615.68
16	WW	0	-	+	+	1186.7	370.84
17	WW	5	-	+	+	1927.4	602.23
18	ROCC	10	-	+	+	5765.8	633.29
19	ROCC	0	+	+	+	3363.9	366.73
20	ROCC	5	+	+	+	4897.6	538.19
21	WW	10	+	+	+	1386.3	432.82
22	ROCC	10	+	+	+	4886.4	536.95
23	ROC	10	+	+	+	4905.1	540.25
24	ROC	10	+	+	+	4845.4	531.43

The data obtained from biogas yield present that the specific biogas yield related to TS basis could be increased by pretreatments. Figure 2. present the biogas yield versus digestion time for original WW sample, the effect of grease addition in concentration of 5 w/w% and the specific biogas yield for heat pretreated ROCC with grease dosage of 5%.

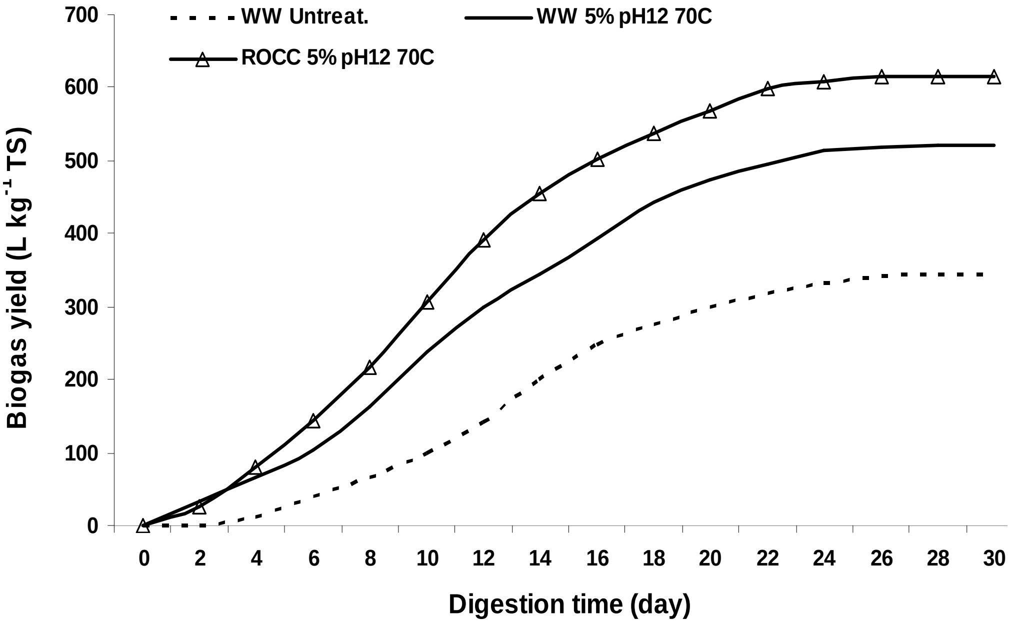

Figure 2. Biogas yield from WW and ROCC samples.

As the biogas yield curves show, apart from the enhanced total biogas production, the alkaline condition combined with heat pretreatment shortened also the initial LAG-phase of anaerobic digestion (Figure 2.).

In the case of ROCC sample added with grease in 10%, the lowest time demand for maximum biogas production was found by the alkaline (pH12) addition with combination of heat treatment. In this case the maximum biogas production was achieved during 17 days, and the biogas production rate was the highest compared to the other pretreatments. (Figure 3).

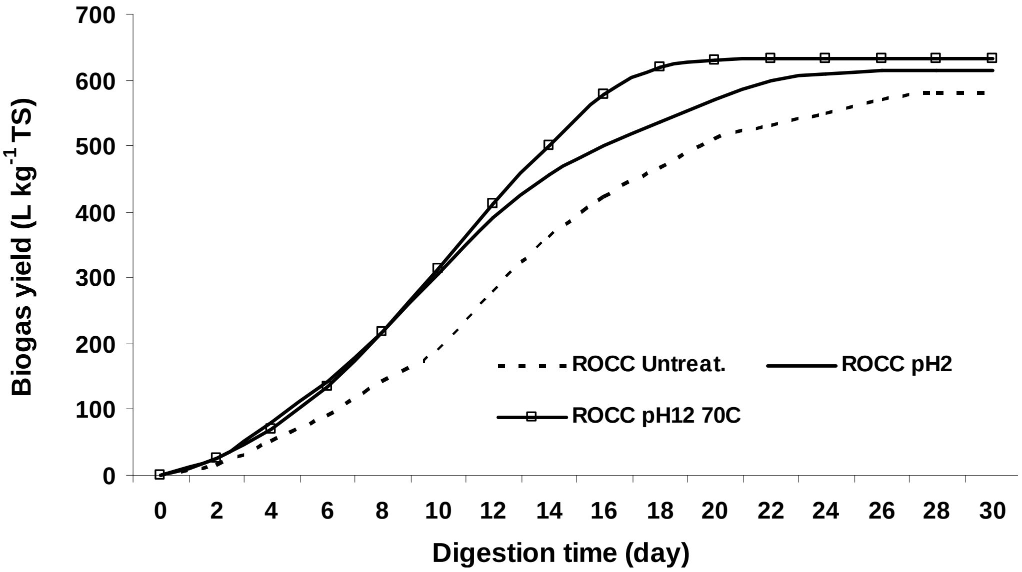

Figure 3. Biogas yield of ROCC samples with addition of 10% grease.

The maximum volumetric biogas production and the highest biogas yield on TS basis can be reached by grease addition in 10% and using alkaline condition with combination of heating as pretreatment. The results can be explained by the high specific biogas potential of lipids and the enhanced solubility of grease caused by alkaline condition. The GC analysis of biogas sample give a higher than 67% methane content for alkaline and heat preteated ROCC samples with added grease in 10 % and the pretreated RO concentrate samples in al cases had a higher methane content compare to the 33.6% methane content of untreated sample.

5. CONCLUSIONS

In our work, we investigated the applicability of reverse osmosis (RO) for the pretreatment of meat industry wastewater, to concentrate the waters prior to processing by anaerobic digestion (AD). The selected RO operation produced purified water with low organic matter content and, simultaneously, a concentrate suitable for the recovery of valuable organic compounds by AD. The data obtained from optimization by the response surface methodology (RSM) show that the recirculation flow rate, the pressure as well as the temperature have an impact on the efficiency of the RO process (permeate flux and total resistance); however, using AFC99 tubular membrane, the retention for lipids, proteins and organic matters are independent from these process parameters. The highest capacity of membrane operation (highest permeate flux) can be reached by 38.5 bar operating pressure with recirculation flow rate of 1000 L h^{-1}. The results of AD tests showed that the preconcentration could increase the overall capacity of digestion with the higher organic matter content of AD feed, moreover the specific biogas yield and the rate of AD process was improved by the applied pretreatment. Comparing to the untreated RO concentrate, the alkaline pretreatment with combination of heating at 70°C could enhance the biogas production by 70%, and the methane content of produced biogas improved. To summarize our results, the membrane process is applicable for purification of meat industry wastewater, and concentration of organic matters in one-step. With the application of RO process, low contaminated recyclable process water can be produced, and the biodegradable organic matter content of effluents can be utilizable in local bioenergy generation system for small-sized meat companies in rural areas.

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