THE USE OF ANAEROBIC MEMBRANE BIOREACTOR AND REVERSE OSMOSIS SYSTEM FOR WASTEWATER TREATMENT

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Domestic wastewater from Ramnicu Valcea town are treated by anaerobic membrane bioreactor (AMBR), followed by reverse osmosis (RO). The main studied objectives were the reduction of organic matter and the nutrient recovery, as well as the production of gas. The results confirmed the reduction of organic matter, nitrogen and phosphorous. However, it is necessary to add acid to prevent the precipitation / fouling of the RO unit. The total use of electricity for running the system is estimated at 4-7 kWh / m^3.

Keywords: Anaerobic, domestic wastewater, nutrient recovery, reverse osmosis

1. Introduction

Various approaches for the use of recycling nutrients from wastewater have been tested. A first approach is to use 'end of pipe' wastewater treatment. The wastewater treatment station in a town using an anaerobic membrane bioreactor (AMBR) and reverse osmosis (RO) was studied. The results will be used to design a treatment plant for this area. The domestic wastewater is conducted through mechanisms pipeline directly into the treatment plant. The wastewater will be treated in the local sewage plant, thus excluding water drainage and rainwater [1,2]. Results from the analysis showed that this concept will reduce the potential for eutrophication and increase the potential for nutrient recycling. The use of a MBR is very beneficial for both anaerobic and aerobic processes [3], one of the advantages being the possibility of an efficiently retention of the solids. The

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membrane unit is of vibratory shear enhanced processing (VSEP) type, implementing a vibration amplitude in order to achieve transverse flow across the membrane for a high efficiency of separation [4]. The main objective was to assess the effectiveness and performance of an AMBR coupled with a RO unit. It was monitored the reduction of organic matter, nitrogen and phosphorous, as well as the production of methane gas. The aim was to obtain a product with a high content of nitrogen and phosphorus, but with no or very low content of heavy metals, which can be used in agriculture [5,6].

2. Materials and Methods

The system consisted of a pilot scale AMBR and RO unit. Their characteristics and system components are shown in Table 1 and Fig. 1, respectively [7]. The complete mixed anaerobic bioreactor had a total volume of 1.5 m^3. The volume of liquid in the reactor was 0.75 m^3, resulting a hydraulic retention time of about 0.5 days. The reactor was operated at 23°C. The temperature in the feed tank of the RO was kept constant at 23°C with a water cooling system. The two filters are positioned between the pump with wastewater pre-treated and pump for sludge. The bioreactor was fed with wastewater pre-treated in a filter with a 3 mm-pore size diameter. The sludge was pumped through a filter of 0.5 mm diameter prior to entering the membrane and the filtrate was automatically returned to the bioreactor [8]. The membrane unit consisted of a VSEP containing 15 double membrane plates with a total area of 1.20 m^2. Before the trial period, an extensive membrane experiment was performed in order to obtain the maximum hydraulic capacity. The membrane chosen for the period of evaluation was a PTFE Teflon membrane, with a pore size of 0.45 mm. Diaphragm clogging is prevented by the shear forces which are induced near the surface of the vibration membrane VSEP unit, allowing the hydraulic capacity to be maintained during a relatively long period. Hydraulic capacity of the membrane is affected by the characteristics of the feed, the amplitude of the vibration membrane pore size and type of membrane [9,10]. RO unit consisted of a feed pump, a reverse-osmosis, an open feed tank (0.5 m^3) and a closed permeation tank (1.0 m^3), a cross-flow spiral membrane with a surface area of 2 m^2 and a saline reduction capacity of 99%.

Mainly, there were applied two phases of operation: recirculation and concentration. During the concentration phase, the permeate was collected in the permeate container and in the phase of recycling both concentrate and permeate were directed to the feed tank [11]. This process is discontinuous.

Table 1

The technological characteristics of AMBR and RO unit

Characteristics	**Value**
Total volume of the bioreactor	1.5 m^3
Volume of liquid in the reactor	0.75 m^3
Temperature °C	23°C
Bioreactor filter	3 mm
Filter sludge pump	0.5 mm
Total surface membrane plates	1.20 m^2
PTFE membrane pore	0.45 mm
Chemical substances used:	- hydrochloric acid; - phosphoric acid; - nitric acid

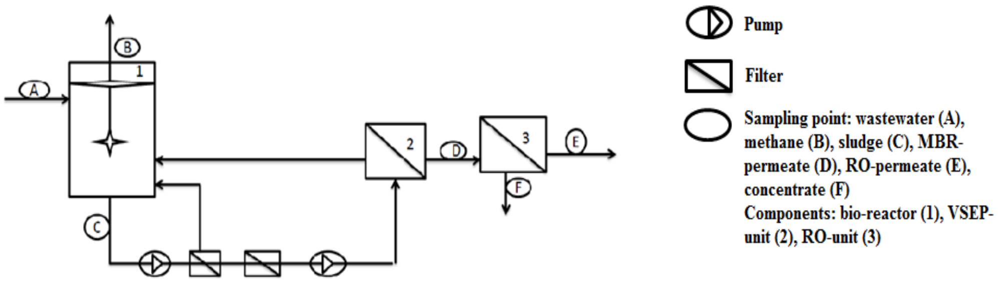

Fig. 1. Schematic representation of the system

The reverse osmosis was used four times in four different experiments. Acid was added to the feed to prevent fouling and evaporation of ammonia. In order to evaluate the fouling of the membrane caused by precipitation, the first experiment was conducted without adding any acid. The second and third experiments were conducted with hydrochloric acid. A mixture of nitric and phosphoric acids was used in the fourth experiment. The use of nitric acid and phosphoric acid increases the nutrient concentrations in the concentrate and makes it more attractive as a fertilizer, whereas the use of hydrochloric acid might generate a concentrate that could be unsuitable for some crops [12,13]. The total cost of all chemicals used is no more than 25 euro. The samples of wastewater were sampled every day and finally mixed together at the end of each week in order to be analyzed. This method was used for influent and effluent from the AMBR. The RO experiments were analyzed separately.

3. Results and discussion
3.1 AMBR operation

The bioreactor was fed with wastewater pre-treated in a filter with a 3 mm-pore size diameter. The characteristics of the wastewater are presented in table 2, where are presented the annual mean and standard deviation values.

Membrane and VSEP unit required frequent cleaning. The cleaning process required hot water tap, a commercial liquid detergent to dissolve organic matter and sodium hydroxide to improve the dissolution of organic matter or hydrochloric acid to solve the clogging due to chemical precipitation [14,15]. Each cleaning cycle lasts 30 minutes at temperatures above 23°C and it was followed by a wash cycle, in which VSEP unit was supplied with clean water.

Table 2

The physico-chemical characteristics of wastewater

Parameter	Value (min - max)
Temperature °C	22 ± 0.9
TOC, mg/L	210 ± 16.5
COD-tot, mg/L	650 ± 20.6
NH_4-N, mg/L	65 ± 3.7
Kj-N, mg/L	85 ± 3.5
Tot-P, mg/L	12 ± 1.3
Ni, μg/L	6.5 ± 0.4
Cu, μg/L	40 ± 2.4
Zn, μg/L	70 ± 4.0
Cd, μg/L	0.1 ± 0.002
Hg, μg/L	0.04 ± 0.0007
Pb, μg/L	3.5 ± 0.5

3.2 RO-unit operation

The highest volume reduction factor (VRF) reached was 60, which means >98% reduction of the volume. The effluent from the AMBR did not contain any suspended solids; thus, it could be treated by RO without any further treatment. The procedure of RO cleaning was similar to the procedure used for the VSEP. However, other chemicals were used: liquid detergent and citric acid - to resolve chemical precipitation. The cleaning procedure of the RO resulted in a high recovery of the hydraulic capacity of the membrane.

There is a reduction of suspended solids in the pre-filter leading to only about 2% for chemical oxygen demand (COD) and smaller for phosphorus and nitrogen species. The organic load on the bioreactor has been relatively constant, around 0.6 kg COD/day. The membrane unit contributed to the reduction of organic matter by filtration of suspended solids, a relative constant accumulation of organic matter (about 0.10 kg COD/day) in the reactor being observed. No excess sludge has been withdrawn from the reactor, except a small insignificant amount due to sampling. The anaerobic process was stable and a continuous production of methane gas amounting to 0.2–0.6 m^3 /week being achieved. The experiments showed a good anaerobic activity in the sludge at a temperature of 23°C. The low gas production is explained by the accumulation of COD in the reactor (17% of the influent) and the dissolved methane concentration in the permeate is very low [16,17]. The solubility of methane in water was evaluated as 2.657×10^{-5} at 23°C, according to Fig. 2 [18].

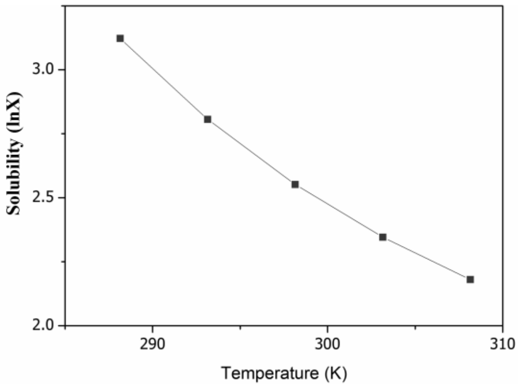

Fig. 2. Methane solubility in water

Table 3 describes the average change in concentrations over the system throughout the period of investigation and also the reduction over the AMBR and RO. Organic matter was mainly reduced in the AMBR, whereas nutrient reduction mainly was achieved in the RO.

Table 4 shows the change in concentrations of the nutrients and organic matter over the RO for each experiment. In the first experiment, no acid was added and only VRF of 10 was reached. The membrane was fouled, probably due to precipitation, to the point where the permeate flow reached zero. For the second, third and fourth experiments, the specific flow decreased relatively linearly with increasing VRF as an effect of increased salinity (measured as electrical conductivity). Thus, the reduction in specific flow for experiments 2–4 was probably due to increased osmotic pressure and not due to fouling and/or precipitation. In the experiment 4, the concentrations of nitrogen and phosphorus species in the concentrate are relatively high because of the added acid. It could be estimated that the effluent concentration of nitrogen would be about 10 mg /L N, resulting in an overall nitrogen removal efficiency of 86%. Thus, the addition of acids such as HNO_3 will result in a concentrate having a relatively high concentration of nutrient, which would probably be suitable for agricultural use. However, the addition of acids containing nitrogen and phosphorus species will reduce the overall removal efficiency. There could be an accumulation of nutrients, mainly phosphorus, in the RO due to precipitation. At higher pH, there is also a risk of ammonia gas evaporation.

Table 5 shows the heavy metal species content found in the concentrate as mg/kg P from four experiments using the RO-unit. For comparison, data for urine approved for agriculture use are listed. Low Me/P ratios for most metals are mainly explained by a high removal performance of heavy metals in the AMBR.

However, they are also explained by a relative low Me/P ratio in the influent. The influent consists only of domestic wastewater, with low concentration of heavy metals, with heavy metals presumably mostly bound in suspended solids. The VSEP-unit produces a permeate containing no suspended solids, thus minimizing the concentration of heavy metals fed into the RO-unit. The electricity consumption is relatively high. Based on the operational data and experiments from full scale treatment plants concerning specific energy consumptions, the total electricity used for operation for the entire system, including the energy demanding RO-unit, is estimated to be 3–6 kWh/m^3.

Table 3

Reduction over the AMBR and RO

Sample for analysis	**TOC (mg/L)**	**K_j-N (mg/L)**	**Tot-P (mg/L)**
Influent	210	85	12
AMBR permeate	20	55	8
RO permeate	<5	≤5	≤0.5
Reduction, AMBR	95%	6.5%	6.66%
Reduction, Total	>98%	>90%	>99%

Table 4

Results from RO experiments

	Exp 1	**Exp 2**	**Exp 3**	**Exp 4**
VRF	10	30	60	60
Acid type used	No acid used	HCl	HCl	H_3PO_4+HNO_3
	TOC (mg/L)			
AMBR permeate	20	20	20	20
Concentrate	150	300	500	600
Permeate	<5	<5	<5	<5
	Tot-P (mg/L)			
AMBR permeate	12	12	12	12
Concentrate	50	250	400	1200
Permeate	≤0.5	≤0.5	≤0.5	≤0.5
	K_j-N (mg/L)			
AMBR permeate	55	55	55	55
Concentrate(tot-N)	550	1500	2500	10000
Permeate	≤5	≤5	≤5	≤5

Table 5

Metal species content in RO concentrates, in mg/kg

Experiments	**Cu**	**Zn**	**Ni**	**Cr**	**Cd**	**Hg**	**Pb**
Exp 1 (VRF 10)	50	300	400	40	<0.1	0.6	7
Exp 2 (VRF 30)	250	1800	220	75	0.3	0.2	40
Exp 3 (VRF 60)	400	160	340	55	0.1	0.3	3
Exp 4 (VRF 60)	100	100	170	20	0.3	<0.1	1
Urine	101	45	7	-	0.7	0.8	0.7

The VSEP-unit has an estimated energy consumption of 0.5–1.5 kWh/m^3. Thus, it is important to reduce the amount of wastewater treated [19]. One way of doing this is to treat only the wastewater from toilets and possibly kitchen waste disposers.

4. Conclusions

The concept of using the anaerobic membrane bioreactor (AMBR) and reverse osmosis (RO) is well suited for the purpose of nutrient recovery from domestic wastewater. The end product is water that meets high effluent requirements and a concentrate ready to be used as nutrient on agricultural farmland. The studied system did not require any heating and the high temperature of the influent made production of high energy methane gas possible.

Due to mentioned performances, the integrated system has been able to recycle a significant proportion of the total water usage, saving the water supply and effluent discharge costs. It can recycle up to 45%, yielding annual net savings of approximately 100,000 Euro. The AMBR technology has provided a compact and reliable biological process, and in combination with RO can allowed recycling to potable water standards, delivering a potential commercially attractive water treatment and re-use solution.

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