Original Research

Application of Ultrafiltration and Reverse Osmosis to the Treatment of the Wastewater Produced by the Meat Industry

J. Bohdziewicz*, E. Sroka, I. Korus

Institute of Water and Wastewater Engineering, Silesian University of Technology
ul.Konarskiego 18, 44-100 Gliwice, Poland

Received: 14 November, 2002
Accepted: 14 January, 2003

Abstract

The meat industry is characterized by high water consumption. Since this wastewater is highly loaded, it should be thoroughly pre-treated prior to its discharge into receiving water. Our investigations revealed that a hybrid system of ultrafiltration and reverse osmosis is a promising purification method. Its application resulted in a 100% and 98.8% removal of phosphorus and nitrogen compounds, respectively. The efficiency of COD and BOD removal exceeded 99%.

Keywords: membranes, ultrafiltration, reverse osmosis, coagulant, wastewater produced by the meat industry

Introduction

One of the branches of the food industry which has the greatest impact on the degradation of the natural environment is the meat industry. Over 90% of the water taken for production needs is discharged as wastewater characterized by considerable content of organic matter, high COD and BOD_5, high concentration of etheric extract, suspension, biogenic and dissolved substances. For this reason, the wastewater should be thoroughly treated prior to its discharge into receiving water. This process, however, requires an application of several complementary technologies which enable the wastewater to be purified to the extent that will allow it to be reused in industry or discharged into receiving water.

It should be emphasized that most meat-processing plants are equipped only with grease catchers, grates, sieves and floatation machines, and those which have a mechanical, chemical and biological wastewater treatment plant discharge wastewater which does not meet the standards [1].

For the last few years, a lot of attention has been focused on the development of unconventional methods for wastewater treatment, such as pressure driven membrane operations, namely ultrafiltration which helps remove colloids, suspended and macromolecular matter, and reverse osmosis, which helps eliminate mineral substances and low-molecular organic compounds.

This research dealt with the treatment of wastewater by means of two hybrid systems employing the following processes:

1 - fat separation - floatation - filtration through a sand filter - ultrafiltration - reverse osmosis;
2 - fat separation - floatation - coagulation - filtration through a sand filter - reverse osmosis.

*Corresponding author; e-mail: jolaboh@zeus.polsl.gliwice.pl

Material and Methods

Apparatus

Ultrafiltration was carried out applying a SEPA CF-HP pressure apparatus equipped with a plate-frame module produced by Osmonics, membrane active area - 155 cm^2. The system operated in the cross-flow mode.

Reverse osmosis was conducted in a GH 100-400 high-pressure apparatus, capacity – 400 cm^3, produced by the same company. The system operated in the dead-end mode on flat membranes whose active area was 36.3 cm^2.

Materials

The wastewater was sampled from the Meat-Processing Plant "UNILAG" in Wrzosowa (southern Poland) whose activity covers the slaughter and processing of pigs. It was characterized by considerable pollutant load, substantial amounts of suspended matter and high concentrations of total nitrogen and phosphorus. The values of the basic and eutrophic pollution indexes ranged widely during the whole production cycle. The characteristics of the wastewater are presented in Table 1.

Coagulant

Our research employed the technical coagulant PIX-113 (Fe_{og} - 12.8%, Fe^{2+} - 0.7%, H_2SO_4 - 1%) which was added to the wastewater in the form of 1% wt. aqueous solution. The basic reagent dosage of 6.5 g coagulant / g phosphorus in the wastewater was calculated on the basis of a chemical reaction of phosphates. The process of coagulation with the basic dosage of the coagulant as well as its 100% and 200% excess was carried out at 18^0C - 20^0C, pH of the wastewater being 6.4-7.6. The fast stirring time was 45 s, while the time of slow stirring and sedimentation was 30 min each. The degree of the wastewater purification was assessed on the basis of a decrease in COD and phosphorus concentration.

Membranes

The membranes used in the pressure-driven membrane operations are as follows: flat polysulfone ultrafiltration membranes SEPA-H designated by HN and HZ, DS-CQ cellulose membrane, two DS-GH 2K and DS-GH 8K composite membranes, and one SS-10 membrane for reverse osmosis made of cellulose acetate. Table 2 shows the operating conditions and separation characteristics recommended by the manufacturer of the membranes.

Methods and Analysis

In the first system which combined ultrafiltration with reverse osmosis the raw wastewater pre-treated in a fat separator, floatation machine and subsequently filtered through a 0.2 mm - 0.4 mm sand filter was subjected to ultrafiltration treatment which aimed at removing suspended and macromolecular matter. The processes, which used the HN, HZ, DS-GH 2K and DS-GH 8K membranes, were carried out at the transmembrane pressures recommended by the manufacturer, while in the case of the DS-CQ membrane it was 0.3 MPa. The linear flow velocity of the filtered medium over the membrane surface was 2m/s each time. The next stage was reverse osmosis. The operating parameters of the process were: transmembrane pressure - 2.0 MPa, stirring rate - 200 rpm. The effectiveness of both processes was assessed based on the removal degree of the contaminants from the wastewater and the values of permeate fluxes.

In the other system, ultrafiltration was replaced with coagulation followed by reverse osmosis carried out at the transmembrane pressure of 2.0 MPa and stirring rate of 200 rpm. The transport characteristics of the membranes were determined describing the dependence of the volume deionized water flux on the transmembrane pressure applied.

The concentrations of total nitrogen, phosphorus and COD were determined by means of the tests which used

Table 1. Pollution concentration in raw wastewater.

Pollution indices	Concentration of pollution in raw wastewater [mg/dm^3]		Load pollution [kg/d]	Permissible standards [mg/dm^3]
	Range	Mean value	Mean value	
COD	2780 – 6720	4584	309.2	150
BOD_5	1200 – 3000	19721	126.8	30
Total nitrogen	49 – 287	198	13	30
Total phosphate	15 – 70	32	2.1	5*
Total suspension	112 – 1743	396	26.1	50
Detergents	7 – 21	11.3	0.75	5

*For a wastewater treatment plant whose daily flow is below 2000 m^3.

Table 2. Characteristics of membrane SEPA-CF firm Osmonics.

Membrane type	Retention (0.2% NaCl) R, [%]	Nominal molecular weight Cut-off	Operating pressure ΔP, [MPa]		Recommended pH range	Max. temp. T, [°C]
			Recommended	Maximum		
HN	-	20,000-70,000	0.35	2.07	0.5-13	100
HZ	-	80,000-100,000	0.17	1.38	0.5-13	100
DS-GH 2K	-	2,000	-	2.7	2-11	90
DS-GH 8K	-	8,000	-	2.7	2-11	90
DS-CQ	-	15,000-30,000	-	0.35	2-8	30
SS-10	98*	-	2.76	6.90	2-8	50

* Value coefficient of retention appoint for $\Delta P = 27.6 \times 10^6$ Pa

an SQ118 photometer produced by Merck [4]. BOD_5 was assayed employing the respiratory measurement method with OxiTOP measuring cylinders produced by WTW [5], the dry matter of the deposit was determined by means of the gravimetric method whereas oxygen concentration, pH and temperature were measured with a CX - 315 microcomputer pH/oxygen meter produced by ELMETRON.

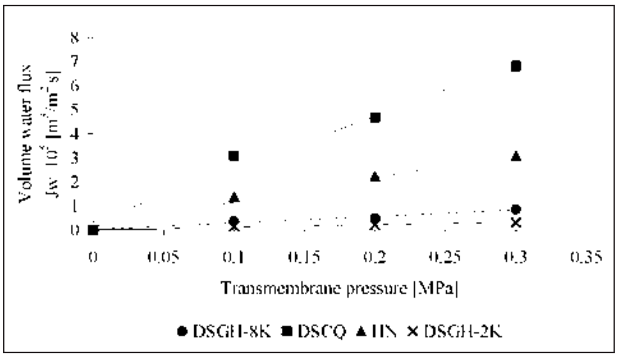

Fig. 1 Dependence of volume water flux on transmembrane pressure for ultrafiltration membranes.

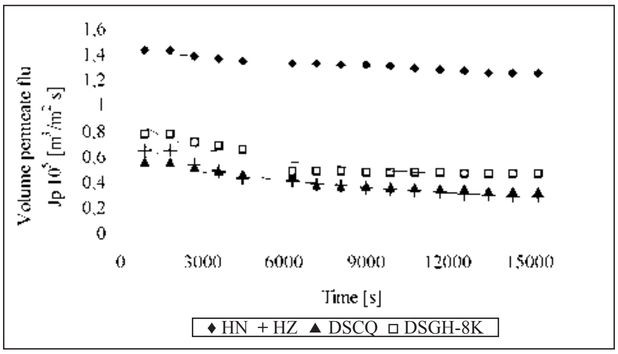

Fig. 2. Dependence of volume permeate flux on ultrafiltration time.

Results and Discussion

Treatment of Wastewater in the Hybrid System of Flotation, Filtration through a Sand Filter, Ultrafiltration and Reverse Osmosis.

The first stage of the investigations dealt with the treatment of wastewater in the system of ultrafiltration and reverse osmosis.

Raw wastewater was introduced into an ultrafiltration module after fat separation, flotation and filtration through the sand filter. Ultrafiltration was carried out on four ultrafiltration membranes which differed in the polymer type they were made of and the compactness of the structure, and thus different cut-off values ranging over 2,000-100,000.

At the beginning of our research, the transport characteristics of the membranes were determined by establishing the dependence of the volume deionized water flux on the transmembrane pressure. It was found that the volume water fluxes increased with increasing transmembrane pressure for all the cases, and the correlations observed were rectilinear (Fig.1).

The highest increase in membrane performance over the pressure range of 0.1 MPa - 0.3 MPa was observed for the ultrafiltration DS-CQ membrane whose volume water flux increased 2.2-fold under these conditions. The DSGH-2K membrane was characterized by the slowest filtration velocity for which the volume water flux was $0.31 \cdot 10^{-5}$ $m^3/m^2 \times s$ at $\Delta = 0.3$MPa.

Dependences of the volume permeate fluxes on filtration time are presented in Fig. 2.

Table 3 presents equations describing the dependence of the volume permeate flux on the time of the process. They are of logarithmic nature.

The HN membrane was the most efficient. Its permeate flux decreased by 12%, recovery being 30%. However, it was three times lower in comparison with the water flux. Decisively lower filtration velocities were found for the HZ and DS-CQ membranes. The volume permeate fluxes

Table 3. Equations describing the dependence of volume permeate flux on ultrafiltration time of raw wastewater.

Membrane type	J_w=f(t) J_w[m^3/m^2•s], t [s]	Coefficient of correlation	Standard deviation
HN	J_w=-0.0678ln(t)+1.9169	0.9326	0.06
HZ	J_w=-0.1419ln(t)+1.6446	0.9726	0.12
DSGH-8K	J_w=-0.1432ln(t)+1.8052	0.8965	0.08
DSCQ	J_w=-0.098ln(t)+1.2625	0.9336	0.12

Table 4. Pollution indexes of wastewater after treatment by the combination of ultrafiltration (HN membrane) and reverse osmosis (SS-10 membrane).

Pollution indices	Concentration of pollution in raw wastewater [mg/dm^3]	Wastewater after UF process [mg/dm^3]		Wastewater after RO process [mg/dm^3]	
		Concentration [mg/dm^3]	Retention R [%]	Concentration [mg/dm^3]	Retention R [%]
COD	2284	355.0	84.6	4.0	99.8
BOD_5	1900	350.0	81.5	3.9	99.8
Total phosphate	25.5	10.6	58.4	0.0	100
Total nitrogen	285	40.0	85.9	2.5	99.1

Table 5. Equations describing the dependence of volume permeate flux on reverse osmosis time applying SS-10 membrane.

Membrane type	J_w=f(t) J_w[m^3/m^2•s], t [s]	Coefficient of correlation	Standard deviation
Wastewater after membrane HN	J_w=-0.0272ln(t)+0.7001	0.956	0.02
Wastewater after membrane HZ	J_w=-0.0158ln(t)+0.573	0.8597	0.02
Wastewater after membrane DSGH-8K	J_w=-0.0206ln(t)+0.5889	0.7804	0.01
Wastewater after membrane DSCQ	J_w=-0.0224ln(t)+0.555	0.8951	0.02

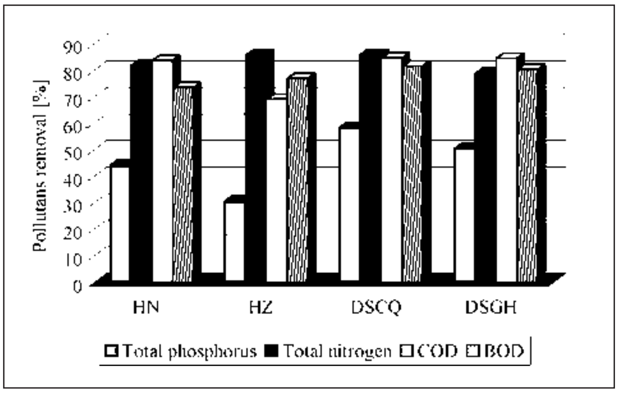

Fig. 3. Effect of ultrafiltration membrane type on the degree of pollutant removal from wastewater.

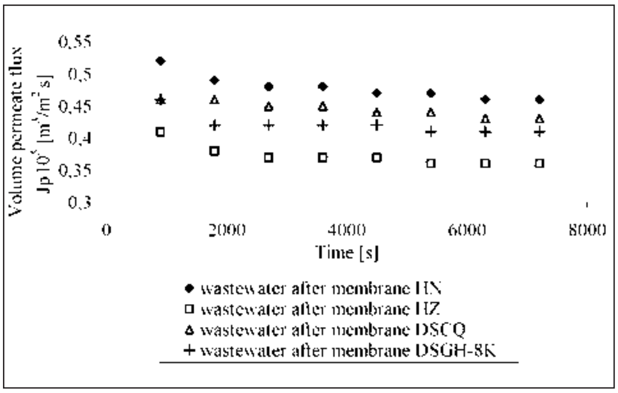

Fig. 4. Dependence of volume permeate flux on the time of reverse osmosis of the wastewater that underwent prior ultrafiltration.

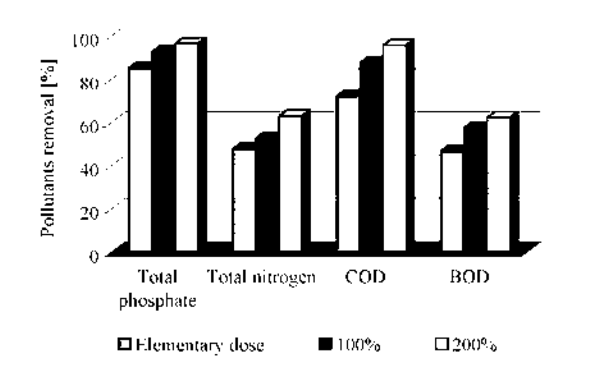

Fig. 5. Dependence of pollutants removal degree on coagulant dose.

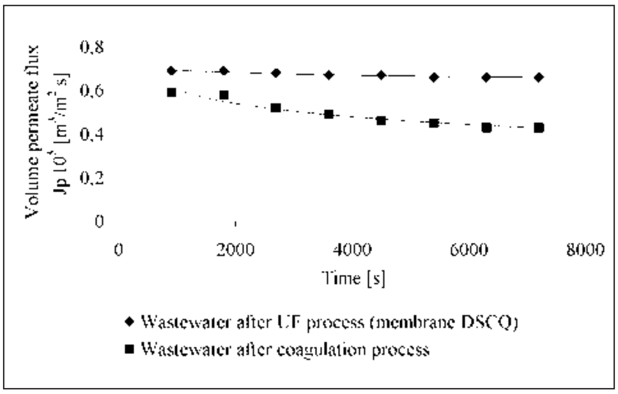

Fig. 6. Dependence of volume permeate flux on the time of reverse osmosis of the wastewater additionally treated by means of combined coagulation and ultrafiltration (nz - concentration below detection threshold).

obtained after 4 hours of the process were approximately 3.9 times lower than for the HN membrane.

However, the effectiveness of the processes depends not only on membrane performance but also the degree of contaminant removal. Depending on the type of a membrane applied, different degrees of a decrease in particular pollution indexes (i.e. COD, BOD_5, phosphorus and total nitrogen) (Fig. 3) were found.

The highest retention coefficients of nitrogen and phosphorus, and the highest COD and BOD_5 were obtained when the DS-CQ membrane was applied. They were 58%, 85.9%, 84.6% and 81.5%, respectively. A similar degree of wastewater purification was obtained in the ultrafiltration carried out on the HN membrane. Nevertheless, the degrees obtained in both cases were not sufficient to allow the wastewater to be discharged into receiving water, let alone be returned into the production cycle. For this reason, the ultrafiltration permeates obtained were subjected to additional purification applying reverse osmosis. Table 4 shows the final characteristics of the wastewater treated in the hybrid system of both processes.

The results obtained indicate that the wastewater additionally treated during reverse osmosis can be reused in the production cycle.

Fig. 4 illustrates dependences of the changes in the volume permeate fluxes on the time of reverse osmosis after ultrafiltration treatment carried out on the membranes tested. The decrease in filtration velocity for the HN, HZ and DS-GH 8K membranes was similar and reached 12%, while for DS-CQ it decreased almost two-fold and equalled 6.5%.

As far as reverse osmosis is concerned, the dependences of the volume permeate flux on time were of logarithmic function, similarly to the ultrafiltration of raw wastewater (Table 5).

Treatment of Wastewater in the Hybrid System of Coagulation and Reverse Osmosis

Since ultrafiltration did not produce a satisfactory degree of wastewater purification, it was replaced with coagulation. The most favourable results were obtained for the 200% excess of the basic coagulant dosage i.e. PIX concentration of 13.5 g coagulant/g phosphorus. It enabled a decrease in pollution indexes COD and BOD_5 by 92.6% and 87.5% respectively. The concentrations of phosphorus and total nitrogen in the purified wastewater decreased by 91% and 64% (Fig. 5).

Subsequently, following the coagulation, the wastewater was additionally passed through a sand filter prior

Table 6. Effectiveness of wastewater treatment in the system combining coagulation and reverse osmosis.

Pollution indices	Concentration of pollution in raw wastewater [mg/dm^3]	Wastewater after coagulation process [mg/dm^3]		Wastewater after RO process [mg/dm^3]	
		Concentration [mg/dm^3]	Retention R [%]	Concentration [mg/dm^3]	Retention R [%]
COD	2700	662.0	87.5	4.00	99.9
BOD_5	5318	200.0	62.6	3.98	99.2
Total nitrogen	420,0	150.0	49.0	1.16	98.8
Total phosphate	27,8	2.5	91.0	0.0	100

to its introduction into the osmotic module. The effectiveness of the wastewater treatment in the system discussed is shown in Table 6.

Fig. 6 illustrates a comparison of the volume osmotic permeate fluxes obtained during the final stage of wastewater purification after its initial treatment in the process of coagulation.

After six hours of reverse osmosis in which the feed was the wastewater that underwent prior ultrafiltration, the permeate flux was higher by 43% compared to the flux obtained in the process in which the pressure filtration dealt with the wastewater that underwent prior coagulation. In this case, a smaller decrease in the volume permeate flux during reverse osmosis was also observed. It reached 4.3% and was lower by 22.7% than the decrease in the permeate flux for the wastewater after prior coagulation. This rapid drop in filtration velocity could be explained by the presence of suspended matter which was not removed sufficiently during the filtration through the sand filter.

Conclusions

The investigations proved that the pressure driven membrane operations can be applied to the treatment of the wastewater from the meat industry. It has been found that the degree of wastewater purification, both after ultrafiltration and coagulation, is too low to discharge the wastewater into receiving water. Only the application of reverse osmosis enables it to be reused in the production cycle.

References

1. KRAJEWSKA, Treatment of the wastewater from the Meat Plant FARM FOOD S.A.. Czyżewo Branch, Conference handouts of the Polish Scientific and Technological Conference entitled „Achievements and problems concerning the treatment of industrial wastewater" (in Polish), Politechnika Śląska, pp. 49-58, **1998**
2. Regulation of the Ministry of Environmental Protection, Natural Resources and Forestry dated 5 November **1991** on the classification of waters and conditions the sewage discharged to waters and soil should satisfy, Journal of Law No. 116, item 501.
3. Performance characteristic of reserve osmosis, nonfiltration and ultrafiltration spiral wound permeates – Osmonics.
4. *User's manual*, Photometer SQ 118, Merck.
5. *User's manual*, Determination of BZT using respirometric method, Oxi Top, firm WTW.
6. HERMANOWICZ W (Edit.), *Physicochemical testing of water and sewage*, Arkady, Warsaw **1998**.