Environment Protection Engineering

Vol. 29 2003 No. 3–4

JOLANTA BOHDZIEWICZ*, EWA SROKA*,
WACŁAW KUSZNIK*

AEROBIC MEMBRANE BIOREACTOR IN THE TREATMENT OF WASTEWATER FROM THE MEAT INDUSTRY

The wastewater produced in meat processing factories should be treated before its discharge into receiving water or sewage system due to marked COD and BOD, high fat content, large quantity of suspended matter and microbiological contamination. Our research aimed to assess the effectiveness of the process carried out in an oxygen membrane bioreactor. The values and correlations determined were: the most favourable substrate loading of activated sludge, the quantity of resulting excess sludge in respect of the loading of activated sludge, and the contribution of the activated sludge and capillary membranes to the treatment of wastewater.

1. INTRODUCTION

The processes of pressure-driven separation which utilize micro- and ultrafiltration membranes have been used in the technology of biological wastewater treatment since the early 1970s. They were to replace secondary tanks in the then used systems of wastewater treatment by activated sludge. Suitably selected membranes were characterized by high retention coefficients of biomass, and their separation properties were not affected by the characteristics of activated sludge, such as flock size or age. The purified wastewater was of high quality which did not depend on the loading of raw wastewater [1].

Over the last few years, a rapid development in the new generation of more effective and less costly UF and MF membranes has taken place. The term *membrane bioreactor* (MBR) has been known in the literature since the 1960s. It is usually defined as a system in which a biological process takes place simultaneously with the separation of products from a refractory mixture applying low-pressure membranes. This

* Institute of Water and Wastewater Engineering, Silesian University of Technology, ul. Konarskiego 18, 44-100 Gliwice, Poland, tel.: +48(32) 2371698, fax: +48(32) 2371047, e-mail: jolaboh@zeus.polsl.gliwice.pl, ewasroka@zeus.polsl.gliwice.pl

new technique has taken precedence over the traditional methods for wastewater treatment and offered better quality of purified wastewater and reliability. One of its advantages is the possibility of using membrane bioreactors in the treatment of industrial wastewater.

The aim of this research was to treat the wastewater produced in the Meat Processing Plant Uni-Lang in Wrzosowa. The process was conducted in an oxygen membrane bioreactor which combined activated sludge and microfiltration.

2. EXPERIMENTAL

2.1. MATERIALS

The treated wastewater taken from the Meat Processing Plant Uni-Lang in Wrzosowa was degreased. Table 1 shows the extreme values of contamination indices for the wastewater which were compared with permissible standards that allow wastewater to be discharged into a sewage system or receiving water.

Table 1

Physicochemical characteristics of meat industry wastewater generated by Meat Processing Plant Uni-Lang in Wrzosowa

Assays	Unit	Contamination indices for meat wastewater	Permissible values of contamination indices for wastewater discharged into sewage system[1)]	Permissible values of contamination indices for wastewater discharged into receiving water[2)]
pH	pH	6.9–7.3	6.5–9.0	6.5–9.0
COD	g O_2/m^3	1100–6300	1000	150
BOD_5	g O_2/m^3	700–3700	700	30
Ammonia nitrogen	g $N\text{–}NH_4/m^3$	2–150	6	6
Total nitrogen	g $N_{tot.}/m^3$	100–582	–	30
Total phosphorus	g $P_{tot.}/m^3$	18–51	–	5

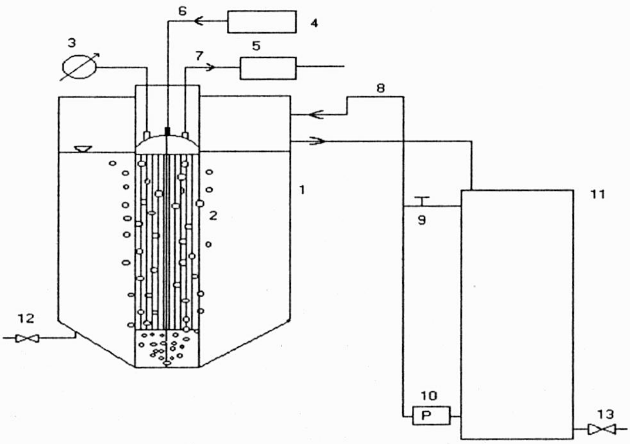
[1)] Instructions issued by the Cabinet, dated 19th May 1999, concerning the conditions for the discharge of wastewater into the apparatuses of sewage systems, the values for COD, BOD_5, ammonia nitrogen, total nitrogen and phosphorus will be determined on the basis of the current load of wastewater treatment plant.

[2)] Instructions issued by the Minister of Environmental Protection, Natural Resources and Forestry, dated 5th November 1991.

The wastewater was of red and brown colour, had strong unpleasant odour and displayed a tendency to foam and putrefy.

2.2. APPARATUS

The apparatus contained an averaging tank and membrane bioreactor with a microfiltration capillary module installed inside. The raw wastewater degreased mechanically was pumped from the averaging tank into the bioreactor containing activated sludge. The capacity of the reaction chamber was 45 dm^3. The membranes operated under a negative pressure of 2.5×10^{-4} MPa–11.0×10^{-4} MPa, induced by a filter pump. The bottom part of the bioreactor was filled with air whose bubbles floating along the capillaries made them vibrate, thus preventing the sludge from depositing on their surface. Such chamber aeration ensured a complete mixing of its content. A schematic of the system is given in figure 1.



1. membrane bioreactor
2. capillary module
3. manometer
4. compressed air blower
5. pump
6. supply of compressed air
7. permeate discharge
8. supply of raw wastewater
9. control valve
10. raw wastewater pump
11. averaging tank
12. bioreactor drain
13. tank drain

Fig. 1. Schematic of apparatus

2.3. CAPILLARY MEMBRANE MODULE

The polymer capillary membranes manufactured in Canada were purchased in Zenon System Ltd., in Tychy. They were of high mechanical strength and chemical durability [2].

The membrane module consisted of 1 m capillary fibres fixed in heads at both ends and sealed with epoxy resin. The structure of the upper head made it possible to install a manometer, pump in compressed air and discharge purified wastewater. The membrane effective area was 0.929 m^2 and pore diameter ranged from 0.035 μm to 0.1 μm. The active layer of the membranes was located on their outer side and had a direct contact with the treated wastewater. Figure 2 shows a schematic of the capillary module and its operation. Until now, this type of capillary module has been used in ZeeWeed® process to treat surface waters of various degrees of contamination [2].

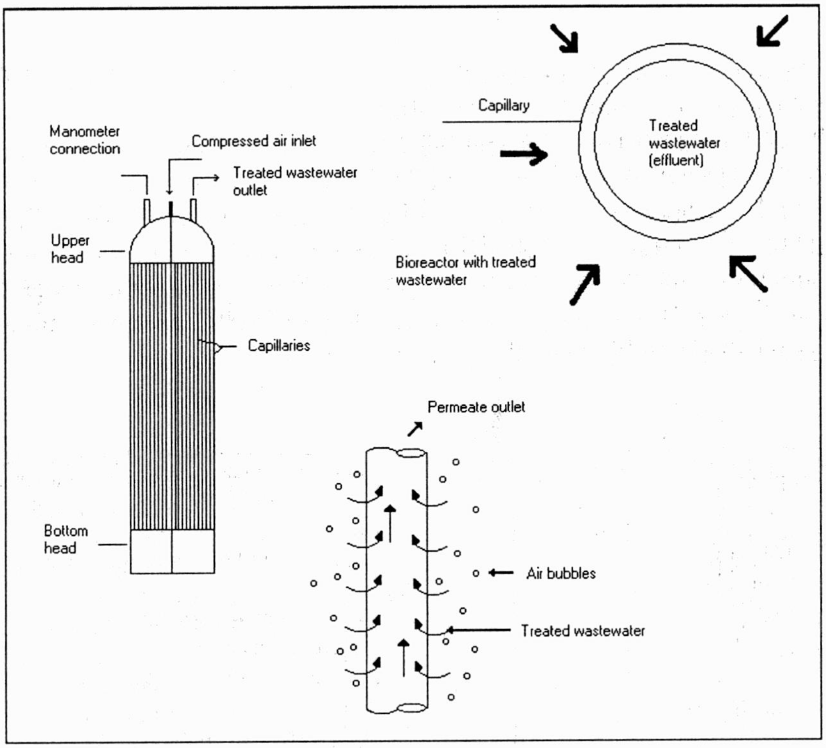


Fig. 2. Schematic of the capillary module

2.4. METHODS

The tests were carried out in a hybrid system combining the biological process of activated sludge and microfiltration. The operation of the membrane bioreactor was based on the assumption that the activated sludge absorbed and oxidized the contaminants present in treated wastewater, and the membrane retained biomass and macromolecular refractory compounds which did not undergo biodegradation in a fixed time.

The research cycle had the following two basic phases:

– determination of transport and separation properties of the capillary membranes installed in the bioreactor;

– assessment of the effectiveness of wastewater treatment in the oxygen membrane bioreactor (determining the most favourable substrate loading for activated sludge, finding the correlation between the quantity of the resulting excess sludge and substrate loading for activated sludge, and estimating the effect of activated sludge and capillary module on a decrease in COD).

The determination of the characteristics of the capillary membranes consisted in identifying their transport and separation properties. Hence, tap water was filtered through the capillary fibres at different negative pressures. The results obtained enabled us to describe the correlation between the volume water flux and the pressure applied. The efficiency of the membranes was calculated using the equation:

$$J_w = \frac{V_w}{s \times t} \, [\text{m}^3/\text{m}^2 \times \text{s}], \tag{1}$$

where:

J_w – volume water flux; $\text{m}^3/\text{m}^2 \times \text{s}$,
V_w – water volume; m^3,
s – membrane area; m^2,
t – time; s.

The subsequent phase of the research focused on the determination of separation properties of the membranes which were tested with a 4 g/dm^3 dextran solution, molecular weight of 200 kDa (Polfa S.A. Kutno). The concentrations of dextrans (specific molecular weights) in particular microfiltration fluxes were assayed using gel permeation chromatography (GPC), a gel permeation chromatograph manufactured by Schimadzu. It was equipped with a NUCLEOGEL-OH50-8 column (Machery-Nagel), refractometric detecting device RID-6A (Schimadzu) and integrator C-R4A Chromatopac (Schimadzu) used for data processing. Dextran concentrations in permeates were determined through assays of total organic carbon (TOC) using an analyzer manufactured by Beckman Ind. (model 915B Tocamaster™) [3].

The main research cycle dealt with the treatment of wastewater in the membrane bioreactor. In order to find the most favourable substrate loading of activated sludge, its values were being changed from 0.002 g $\text{COD/g}_{\text{TS}} \times \text{d}$ to 0.063 g $\text{COD/g}_{\text{TS}} \times \text{d}$. Since the activated sludge was sampled from the biological treatment plant in the Meat Processing Plant Uni-Lang, Wrzosowa, the bacterial microflora had already been adapted to the type of treated wastewater. The operating parameters of the membrane bioreactor are shown in table 2.

The loadings of the activated sludge were calculated using the following formulas:

$$A_x = \frac{A_v}{X_v} \, [\text{g BOD}_5/\text{g}_{\text{TS}} \times \text{d}], \tag{2}$$

where:

A_x – sludge loading with contaminants; g $\text{BOD}_5/\text{g}_{\text{TS}} \times \text{d}$,
X_v – concentration of sludge suspension in aeration chamber; $\text{g}_{\text{TS}}/\text{m}^3$,
A_v – loading of aeration chambers with organic contaminants; g $\text{BOD}_5/\text{m}^3 \times \text{d}$.

$$A_v = \frac{Q \times c_o}{V} \, [\text{g BOD}_5/\text{m}^3 \times \text{d}], \tag{3}$$

where:

A_v – loading of aeration chambers with organic contaminants; g $BOD_5/m^3 \times d$,

Q – flow rate; m^3/d,

c_o – concentration of organic compounds in inflowing wastewater expressed as BOD_5; g BOD_5/m^3,

V – capacity of aeration chamber; m^3.

Table 2

Operating parameters of membrane bioreactor

Parameter	Unit	Value
Biomass concentration	g/dm^3	2.2–3
Biomass fraction	%	45–67
Oxygen concentration	mg O_2/dm^3	~3
Flow rate	dm^3/d	0.04–0.2
Sludge loading with contaminants	g $COD/g_{TS} \times d$	0.002–0.063
Sludge age	days	10–30

While treating the wastewater at a fixed sludge loading, we tried to determine the increase in excess activated sludge and assess the impact of activated sludge and capillary module on a decrease in COD. Therefore, at the same time, COD of the wastewater from the bioreactor (filtered wastewater) and purified wastewater (permeate) was assayed.

The effectiveness of wastewater treatment was evaluated on the basis of the decrease in contamination indices, i.e., BOD_5 and COD, and the concentrations of biogenic substances.

2.5. ANALYTICAL PROCEDURES

The determination of COD, concentrations of phosphorus, total and ammonia nitrogen was performed on a photometer SQ 118 (MERCK) [4], while BOD_5 was measured using Oxi Top cylinders manufactured by WTW [5]. The mass of the sludge was assayed by means of the gravimetric method [6].

3. RESULTS AND DISCUSSION

3.1. TRANSPORT PROPERTIES OF CAPILLARY MEMBRANES

The correlation between the water flux and the negative pressure applied was determined by filtering tap water through the capillary membranes at negative pressures of 0.22×10^{-3} MPa–1.6×10^{-3} MPa. The results are shown in figure 3.

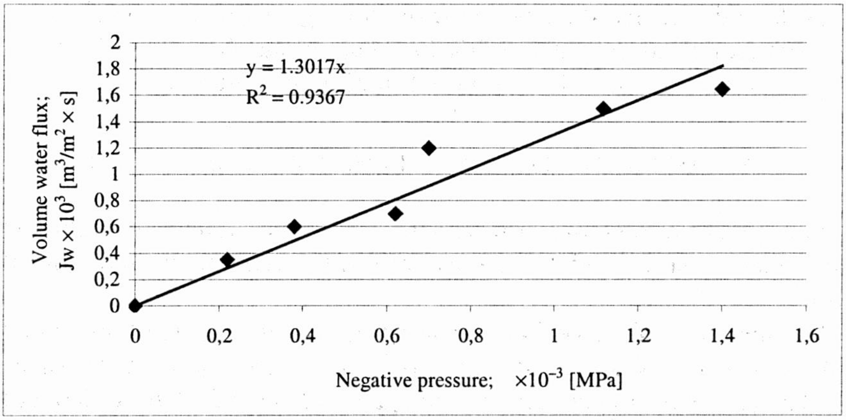


Fig. 3. Correlation between volume water flux and negative pressure

It was found that the correlation was a linear function over the whole range of pressures applied and the permeate flux increased approximately 5-fold (from 0.32×10^{-3} $m^3/m^2\times s$ at a pressure of 0.22×10^{-3} MPa to 1.74×10^{-3} $m^3/m^2\times s$ at a pressure of 1.4×10^{-3} MPa).

3.2. SEPARATION PROPERTIES OF CAPILLARY MEMBRANES

The determination of separation properties of the capillary membranes was performed by filtering a dextran solution (nominal molecular weight 200 kDa) through them. Table 3 shows particular molecular fractions of dextrans and their concentrations in the testing solution.

Table 3

Molecular fractions of dextrans in testing solution

Fraction	Contribution of molecular fractions [%]	Fraction	Contribution of molecular fractions [%]
> 300000	3.4	70000–60000	7.75
300000–200000	3.85	60000–50000	10.13
200000–150000	5.36	50000–40000	11.77
150000–120000	5.00	40000–30000	12.06
120000–90000	7.26	30000–15000	14.66
90000–70000	10.70	< 15000	8.06

Dextran concentration in testing solution – 4.0 g/dm^3.

The results indicate that the membrane did not retain dextran particles, even those of the highest molecular weight > 300 kDa. Thus, it may be assumed that the membrane displayed the density typical of microfiltration membranes.

3.3. WASTEWATER TREATMENT IN MEMBRANE BIOREACTOR

The purpose of the wastewater treatment in the membrane bioreactor was to decompose organic matter and to remove biogenic compounds, i.e., nitrogen and phosphorus.

The determination of the optimum loading of activated sludge with contaminants consisted in putting raw wastewater of various flow rates into the activated sludge chamber. The concentration of activated sludge was from 2.2 g/dm^3 to 3.0 g/dm^3. The raw and purified wastewater was analyzed chemically and the concentrations of nitrogen and phosphorus as well as COD and BOD_5 were assayed for different loadings of activated sludge.

Figure 4 gives a correlation between the decrease in COD for the purified wastewater and the loading of activated sludge. It was found that COD (the values tested herein) depends upon activated sludge loading. The highest COD removal was observed for the loading of 0.063 g COD/$g_{TS}\times$d. It was 98.1%, i.e. 73 g O_2/m^3 for the purified wastewater (raw wastewater 3880 g O_2/m^3). The lowest degree of contaminant removal of 93.2% was obtained for the sludge loading of 0.004 g COD/$g_{TS}\times$d.

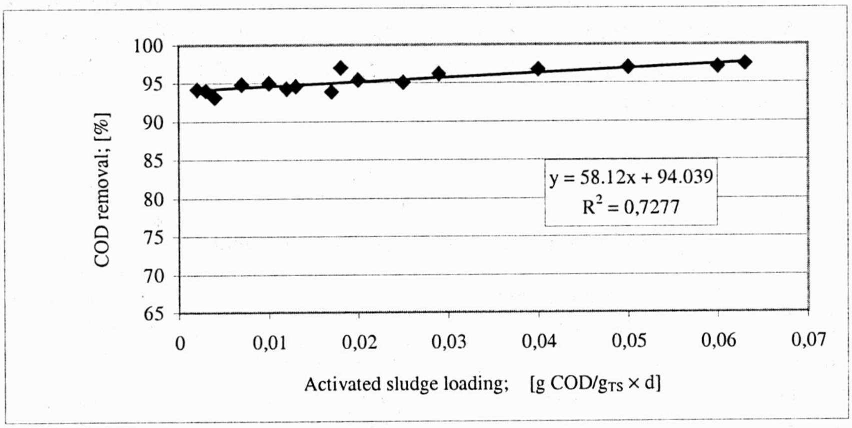


Fig. 4. Correlation between COD removal and activated sludge loading

The reduction in BOD_5 in the treated wastewater depended on activated sludge loading, similarly to COD (figure 5).

Its maximum removal reached 99.4% for the sludge loading of 0.063 g COD/g_{TS}×d. This enabled a decrease in BOD_5 from 1600 g O_2/m^3 for the raw wastewater to a level of 10 g O_2/m^3 for the purified wastewater. The lowest removal of organic matter was observed at the sludge loading of 0.004 g COD/g_{TS}×d and reached 97.6% (BOD_5 of purified wastewater – 20 g O_2/m^3).

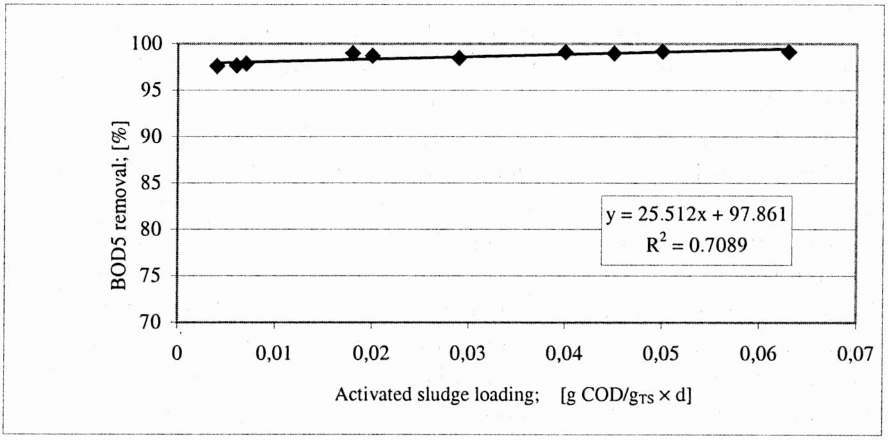


Fig. 5. Correlation between BOD_5 removal and activated sludge loading

The change in total nitrogen removal in respect of the substrate loading of sludge is illustrated in figure 6.

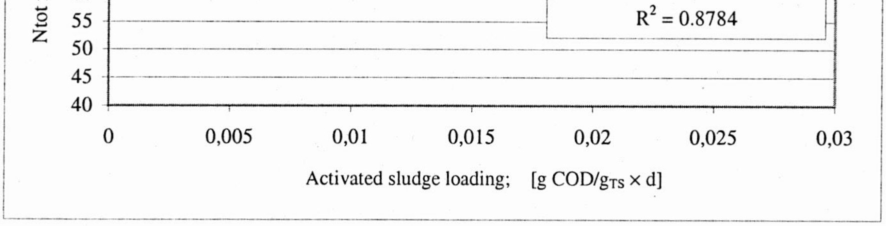


Fig. 6. Correlation between N_{tot} removal and activated sludge loading

Also in this case, a strong influence of this parameter on N_{tot} concentration in the treated wastewater has been observed. The highest reduction in nitrogen concentration of 82.1% was achieved for the activated sludge loading of 0.017 g COD/g_{TS}×d. This corresponds to the decrease in total nitrogen concentration in the raw wastewater from 162 g N_{tot}/m^3 to 29 g N_{tot}/m^3 in the purified wastewater. The lowest total nitrogen removal was 65.7% for the loading of 0.004 g COD/g_{TS}×d (purified wastewater – 55.6 N_{tot}/m^3).

Phosphorus was another biogenic compound whose removal was assayed. The correlation between its removal and activated sludge loading is shown in figure 7.

The data indicate that the most favourable result obtained over the range of activated sludge loadings tested was achieved for 0.063 g COD/g_{TS}×d. This enabled a 89.6% removal of phosphorus, which corresponded to the change in its concentration from 29 g P/m^3 in raw wastewater to 3.0 g P/m^3 in purified wastewater. The lowest phosphorus removal of 67.9% was obtained for the loading of 0.003 g COD/g_{TS}×d (treated wastewater – 9.3 g P/m^3). The data obtained point out that not all determined values of contamination indices had the lowest values for the same activated sludge loading (table 4).

Table 4

The most favourable substrate loading of activated sludge for particular contamination indices characterizing purified wastewater

Contamination indices	Units	Raw wastewater [g/m^3]	Activated sludge loading [g COD/g_{TS}×d]	Purified wastewater [g/m^3]
COD	g O_2/m^3	3880	0.063	73
BOD_5	g O_2/m^3	1600	0.063	10
Total nitrogen	g $N_{tot.}/m^3$	162	0.017	29
Ammonia nitrogen	g $N\text{–}NH_4/m^3$	48	0.017	0.6
Total phosphorus	g $P_{tot.}/m^3$	29	0.063	3.0

Since the concentration of N_{tot} in the purified wastewater for activated sludge loading of 0.017 g COD/g_{TS}×d was only slightly lower than the permissible one, this value was selected as the most favourable to carry out the process.

The remaining contamination indices, i.e., COD and BOD_5, and the concentrations of phosphorus and ammonia nitrogen did not exceed the permissible values at higher substrate loadings of activated sludge. Table 5 shows the values of contamination indices which characterize the purified wastewater for the activated sludge loading of 0.017 g COD/g_{TS}×d.

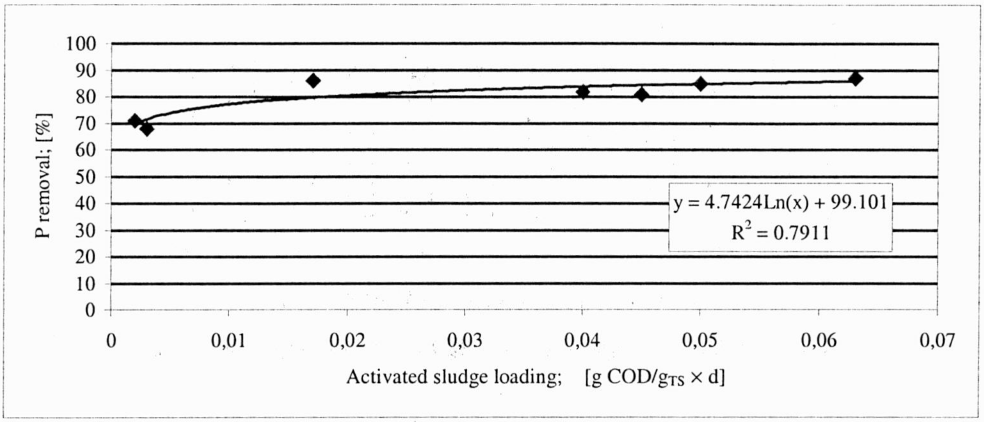


Fig. 7. Correlation between phosphorus removal and activated sludge loading

It is clearly seen that the determined activated sludge loading allowed the wastewater to be sufficiently purified so that it could be discharged into receiving water.

In figure 8, a comparison is made of the membrane and activated sludge in respect of an impact they exerted on a decrease in COD of the purified wastewater for various activated sludge loadings.

Table 5

Reduction in contamination indices for purified wastewater at activated sludge loading of 0.017 g $COD/g_{TS}\times d$

Contamination indices	Units	Raw wastewater	Reduction in contamination indices [%]	Purified wastewater
COD	$g\ O_2/m^3$	3880	96.9	115
BOD_5	$g\ O_2/m^3$	1600	99.1	14
Total nitrogen	$g\ N_{tot.}/m^3$	162	82.1	29
Ammonia nitrogen	$g\ N\text{–}NH_4/m^3$	48	98.8	0.6
Total phosphorus	$g\ P_{tot.}/m^3$	29	86.5	3.9

It was found that the activated sludge played a key role in removing contaminants from wastewater. However, a single process of biological treatment was not sufficient. COD of the wastewater was too high to discharge it directly into receiving water. Only its combination with microfiltration fulfilled our requirements.

As to figure 9, it clearly points to a linear dependence of the increase in activated sludge in the aeration chamber on its loading.

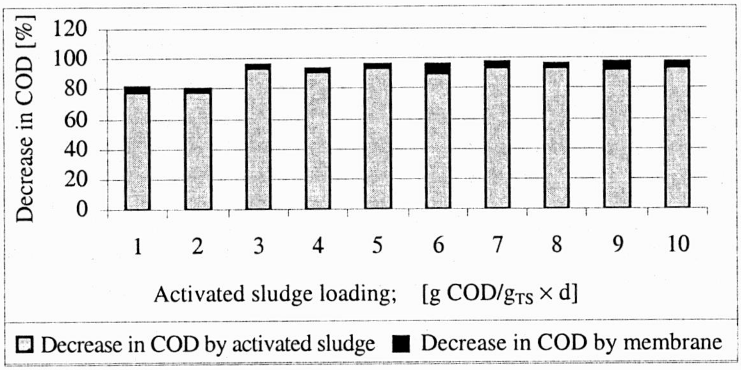


Fig. 8. Comparison of the impact of membrane and activated sludge on COD reduction for different activated sludge loadings

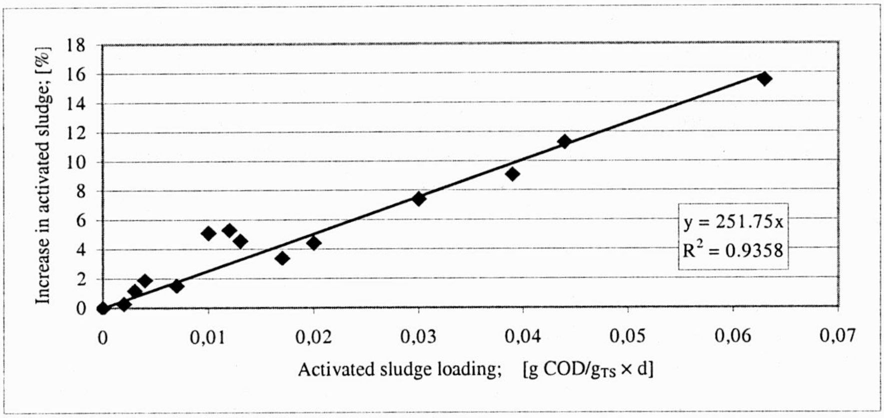


Fig. 9. Correlation between the increase in excess activated sludge and activated sludge loading

The lowest gain in weight of excess sludge of 0.3% was found for the activated sludge loading of 0.002 g COD/g_{TS}×d, while for the loading of 0.063 d COD/g_{TS}×d it was over 50 times higher.

4. CONCLUSIONS

The wastewater from the meat industry is difficult to treat due to considerable concentrations of organic matter and biogenic compounds. Furthermore, the treatment is hindered by its irregular discharge and therefore necessitates the use of an averaging tank.

The results presented confirm the possibility of treating the wastewater from the Meat Processing Plant Uni-Lang, Wrzosowa, in an oxygen membrane bioreactor equipped with a microfiltration capillary module. The low contamination indices for the purified wastewater allow it to be directly discharged into receiving water.

The most favourable substrate loading of activated sludge was found to be 0.017 g COD/g_{TS}×d. The wastewater treated under these conditions met the permissible standards and had the following values: COD – 115 g COD/m^3, BOD_5 – 14 g BOD_5/m^3, P_{tot} – 3.9 g P_{tot}/m^3, N_{tot} – 29.0 g N_{tot}/m^3, N–NH_4 – 0.6 g N–NH_4/m^3.

It has been found that activated sludge played a key role in removing contaminants from wastewater. However, a single biological treatment did not ensure the desired effects. COD of the treated wastewater was too high to discharge it directly into receiving water. Only a combination of activated sludge and microfiltration fulfilled the requirements. The increase in excess sludge against activated sludge loading was a linear function.

REFERENCES

[1] COTE P., BUISSON H., PRADERIE M., *The treatment of municipal wastewater with activated sludge and filtration on immersed membranes*, Materials for III International Forum on Waste Management "Technical and social aspects of waste management", Poznań, May 9–12, 1999.

[2] POTRZEBKA A., WAWRZYŃCZYK J., *The application of microfiltration Zee Weed® to the treatment of contaminated surface waters for drinking water production*, Scientific materials of the Silesian University of Technology, 2002, 46, 137–146.

[3] BODZEK M., KORUS I., *The application of gel permeation chromatography to the description of polymer membranes*, Polymers, 1995, 40 (3), 167–172.

[4] Handbook, Photometer SQ 118, MERCK.

[5] Handbook, BOD determination by manometric method, Oxi Top, WTW company.

[6] HERMANOWICZ W. (ed.), *Physical and chemical examination of water and wastewater*, Arkady, Warsaw, 1998.

TLENOWY BIOREAKTOR MEMBRANOWY W OCZYSZCZANIU ŚCIEKÓW Z PRZEMYSŁU MIĘSNEGO

Ścieki powstające w zakładach przetwórstwa mięsnego z uwagi na znaczne biologiczne i chemiczne zapotrzebowanie tlenu, dużą zawartość tłuszczu, znaczną ilość zawiesin oraz skażenie mikrobiologiczne wymagają oczyszczenia przed odprowadzeniem do odbiornika lub kanalizacji. Badania podjęto, aby ocenić efektywność tego procesu w tlenowym bioreaktorze membranowym. Wyznaczono najkorzystniejszą wartość obciążenia substratowego osadu czynnego, określono ilość powstającego osadu nadmiernego w zależności od obciążenia osadu czynnego oraz udział osadu czynnego i membran kapilarnych w oczyszczaniu badanych wód odpadowych.