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EFFECT OF PAC ON MBR PERFORMANCE DURING THE TREATMENT OF SYNTHETIC WASTEWATER CONTAINING ORGANIC COMPOUNDS

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Abstract

The aim of this study was to determine the effect of powdered activated carbon on fouling intensity of capillary membranes working in the submerged membrane bioreactor during the treatment of synthetic municipal wastewater loaded with organic compounds. The research were carried out in a membrane bioreactor including a capillary ultrafiltration module made of polyethersulfone. The feed used in the presented study was synthetic municipal wastewater which was prepared in order to include high organic content. Moreover, the volumetric flux of the treated wastewater and the percentage of reversible and irreversible fouling were determined. It was found that activated carbon addition to a membrane bioreactor (MBR) treating wastewater reduced irreversible fouling. The volumetric flux of the treated wastewater for PAC-assisted MBRs was higher by approximately 40% as compared to the volumetric flux of the treated wastewater without any sorbents.

Streszczenie

Celem niniejszej pracy było określenie wpływu dodatku sproszkowanego węgla aktywnego na intensywność zjawiska foulingu membran kapilarnych zanurzonych w bioreaktorze membranowym podczas oczyszczania syntetycznych ścieków komunalnych obciążonych związkami organicznymi. Badania prowadzono w bioreaktorze membranowym z zanurzonym ultrafiltracyjnym modułem kapilarnym wykonanym z polieterosulfonu. Substratem badań były syntetyczne ścieki komunalne, preparowane tak aby charakteryzowały się wysoką zawartością związków organicznych. W trakcie prowadzenia badań wyznaczano objętościowy strumień ścieków oczyszczonych oraz procentowy udział foulingu całkowitego, który jest sumą foulingu odwracalnego i nieodwracalnego. Wykazano, że dodatek węgla aktywnego do bioreaktora membranowego zmniejszył intensywność nieodwracalnego zjawiska blokowania membran. Objętościowy strumień ścieków oczyszczonych w obecności PAC były wyższy w porównaniu do strumienia ścieków oczyszczonych bez dodatku sorbentu średnio 40%.

Keywords: **Membrane bioreactor; Fouling; Activated sludge; Wastewater treatment; Powdered activated carbon.**

1. INTRODUCTION

In recent years, pressure membrane techniques have become very popular because they allowed for the reduction of the number of unit processes in sequential technological systems used hitherto for wastewater treatment. They were considered to be an attractive alternative to conventional processes due to their inherent advantages, such as selective separation, purification without the need for additional chemicals, the ability to easily scale-up and a small volume [1]. One of the most interesting wastewater treatment technologies is a hybrid system combining the pressure-membrane method with the activated sludge method, that is known in literature as membrane bioreactor (MBR). According to the literature, the method is very successful for high-loaded municipal and industrial treatment [2]. It is particularly worth pointing out to the fact, that membrane bioreactors occupy less space than other biological wastewater treatments. It is important for manufacturers who are going to run a business associated with the wastewater treatment [2, 3]. Moreover, there is a possibility to eliminate a secondary settling tank from a conventional treatment system. As a result, it can decrease its area and give the possibility to use a high concentration of the activated sludge methods in order to increase the capacity of wastewater treatment plants [4].

A sequential combination of two or more unit operations results in a high efficiency of purification. However, the exploitation of membrane systems may be severely reduced by fouling which determines the amount of the volumetric flux of permeate, operating conditions and a membrane life. The phenomenon includes the sorption of the solution components, the deposition of pollutants in the form of a filter cake and the formation of the biological membrane on the membrane surface. Membrane coating is dependent on the following factors: the type of membrane, operating conditions of the bioreactor, the size of flocs, the intensity of mixing and aeration, sludge concentration and the amount of dissolved extracellular biopolymers. It can be assumed that Extracellular Polymeric Substance (EPS) is the main reason for blocking the membrane pores. A group of molecules such as proteins, polysaccharides, humic acids and other organic substances originated from feed water or microbial secretion are defined as EPS (Extracellular Polymeric Substances).They are produced by the majority of bacteria and affect flocculation and granulation of activated sludge and its morphology. Furthermore, they take part in the floc formation. EPS are initially combined with the bacterial cell, although some of them are separated from the cell and transform into a soluble form (SMP – Soluble Microbial Product). Furthermore, substances can form a gel layer including bacterial cells which may be nutrient medium for biological membranes. Thus it can lead to occur the fouling phenomena. During the process of membrane filtration, both forms of these substances are accumulated on the membrane surface [5-8]. The use of membrane technology is associated with preventing its pollution. The methods of membrane regeneration include: chemical and hydraulic cleaning (backwashing, the change of flow direction of filtered medium), aeration and proper selection of operating parameters of membrane processes. One of the ways is activated carbon dosing to aerobic tank, which due to their sorption properties, reduces the intensity of the deposition of contaminants on the surface and in the pores of the membrane. There are many studies reported in literature that aimed at determining the influence of activated carbon on the decrease amounts of soluble EPS, and thus reducing the intensity of the fouling phenomenon. As a result, the efficiency of the membrane system may be improved. Moreover, the addition of powdered activated carbon may reduce the costs associated with cleaning or replacing the membranes [9-11]. The main feature of activated carbon is an amorphous structure with a high carbon content and a hydrophobic surface. However, the irregular arrangement of the carbon atoms is broken up by numerous cracks and pores. The large number of pores gives activated carbon a larger inner surface (up to 1000 m^2/g), which is the basis of its remarkable adsorption properties. Nowadays, the following types of activated carbon are most available: Powdered Activated Carbon and Granular Activated Carbon [12, 13].

The aim of the study was to determine the influence of powdered activated carbon on the intensity of the fouling of capillary membranes, working in the submerged membrane bioreactor, during the treatment of synthetic municipal wastewater loaded with organic compounds.

2. MATERIALS AND METHODS

2.1. The substrate of the study

The feed used in the presented study was synthetic municipal wastewater. It was prepared in such a way so as to contain high organic content. Table 1 presents the characteristics of synthetic municipal waste-

Table 1.
Characteristics of synthetic municipal wastewater

Parameter	Unit	Value
COD,	mg/dm3	1525
BOD_5		760
NH_4^+ - N		5.5
NO_3^- - N		3.0
PO_4^{3-} - P		15.3
pH	-	6.86
Conductivity	mS/cm	1.4

water. However, Table 2 shows the content of the particular components.

2.2. Apparatus

The main element of an apparatus system was a membrane bioreactor. It was in the shape of a plexiglas cuboid. During these studies the treated wastewater was pumped from raw sewage tank to the reaction chamber with activated sludge, whose volume was at 20 dm^3.

Table 2.
Content of synthetic municipal wastewater

Component	Content, mg/dm^3
Broth	465
Casein peptone	678
NH_4Cl	200
NaCl	7
$CaCl_2 \cdot 6H_2O$	7.5
$MgSO_4 \cdot 7H_2O$	2
K_2HPO_4	40
KH_2PO_4	16

In the chamber the capillary ultrafiltration module was installed. The membranes were made of PES with a cut-off value of 80 kDa, and the filtration area was 0.4 m^2. Biologically treated wastewater, as a result of underpressure, passed through the capillary walls into the interior and was discharged to the tank of treated wastewater. Fig. 1 shows the membrane bioreactor.

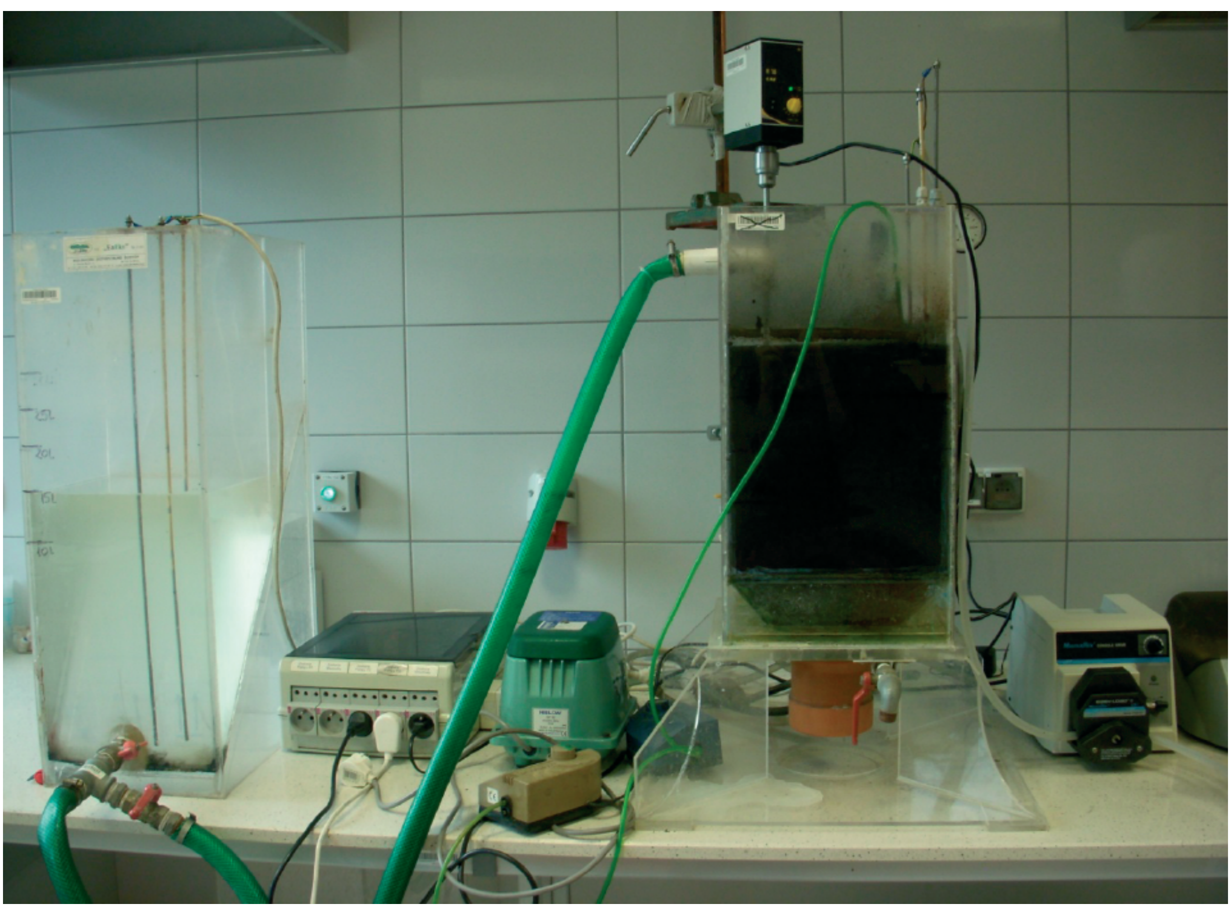

Figure 1.
The experimental setup

The experimental setup consisted of a pumping system with the cleaning pipe enabling backward flush (backwash) of the capillary membranes. In the reaction chamber as well as in the tank the level sensors and multifunction gauges were installed. As a result, the conditions of the process (such as pH, oxygen concentration and the temperature of waste water) could be monitored. Furthermore, the entire system was fully automated.

2.3. Methodology

The process of the biological wastewater treatment of the synthetic municipal wastewater was carried out with the use of activated sludge from the wastewater treatment plant located in Gliwice.

The operation cycle started with the adaptation of microorganisms and finished with the biodegradation of pollution present in the treated wastewater.

After four weeks, physico-chemical characteristics of the treated wastewater were comparable. The research were carried out under the stable temperature conditions. The temperature of wastewater was at 20°C on average keeping the load of the sludge with the contaminants at the level of 0.1 gCOD/gTSd. The oxygen concentration was at 2 mg/dm^3. The content of the chamber was mixed using a mechanical stirrer. The synthetic municipal wastewater from the retention tank was added twice a day. In the case of exceeding 4 g/dm^3, the excess sludge was being removed. Thus, the approximate age of the sludge was 20 days. During the biological wastewater treatment of the synthetic municipal wastewater, backwashing of membrane capillaries was carried out every other day. Moreover, the volumetric flux of treated wastewater was measured every single day.

Then the membranes before the filtration of wastewater were subjected to conditioning in order to stabilize the flux of deionized water (J_{wp}). In order to define the fouling phenomenon the following steps were taken: first of all, the volumetric flux of the treated wastewater was determined (J_v). Then, the capillary membranes were backwashed with 5 liters of permeate. After that, the volumetric the flux of deionized water was determined once more (J_w). These results allowed for the defining the volumetric flux of the permeate. In order to analyze the fouling process resistant ability of membranes, the total fouling ratio (R_t) was introduced which is determined as the sum of reversible (R_{rf}) and irreversible fouling (R_{if}) [14].

Then, after 32 days of carrying out the cleaning process of synthetic wastewater treatment in the membrane bioreactor, the chemical regeneration of capillary membranes was conducted. The research proceeded as follows:

- backwashing with the use of deionized water,
- cleaning with NaOH at a concentration of 0.5-1%,
- backwashing with deionized water,
- cleaning with HCL at a concentration of 1%,
- backwashing with deionized water.

The next stage of research was the addition of powdered activated carbon – Norit SX2 to the membrane bioreactor in order to improve its capability. Using the activated carbon caused the decrease of the amount of pollutants in membranes and the increase of the volumetric flux of the permeate. Moreover, the addition of powdered activated carbon may reduce the costs associated with cleaning or replacing the membranes. Based on the literature, a dose of the activated carbon was equal to 1 g/dm^3[10]. Powdered activated carbon was dosed into the membrane bioreactor once a day. The research was conducted using the same parameters as during the wastewater treatment without the occurance of PAC in the membrane bioreactor.

The backwash of capillary membranes was carried out every other day. The volumetric flux of the treated wastewater was measured every single day. As a result, specific types of fouling were determined. These results allowed for the defining the following parameters [4, 14]:

- volumetric flow of the permeate

$$J_v = \frac{V_v}{s * t}, \ m^3/m^2 \cdot s, \tag{1}$$

where:

J_v – volumetric flow of the permeate, $m^3/m^2 \cdot s$,
V_v – volume of permeate, m^3,
s – area of the membrane, m^2,
t – time, s.

The total fouling ratio (R_t) which is determined as the sum of reversible (R_{rf}) and irreversible fouling ratio (R_{if}) [14] .

$$R_t = R_{rf} + R_{if}, \ \% \tag{2}$$

$$R_{rf} = \left(\frac{J_{wp} - J_v}{J_w}\right) * 100\% \tag{3}$$

$$R_{if} = \left(\frac{J_w - J_{wp}}{J_w}\right) * 100\% \tag{4}$$

$$R_t = \left(1 - \frac{J_v}{J_w}\right) * 100\% \qquad (5)$$

where:

R_t – the total fouling ratio, %,

R_{rf} – reversible fouling ratio, %,

R_{if} – irreversible fouling ratio, %,

J_{wp} – volumetric flux of deionized water after wastewater filtration, $m^3/m^2 \cdot s$,

J_w – volumetric flux of deionized water prior to wastewater filtration, $m^3/m^2 \cdot s$,

J_v – volumetric flow of the permeate, $m^3/m^2 \cdot s$.

3. RESULTS AND DISCUSSION

3.1. Determining the influence of hydraulic and chemical regeneration of capillary membranes on the intensity of fouling phenomenon occurring in membrane bioreactors

The research have shown that during operation in the MBR the volumetric flow of the permeate decreased gradually. It was associated with the fouling of capillary membranes. Figure 2 shows the dependency of the volumetric flow of the permeate on time of the process. Moreover, the influence of membrane backwashing on efficiency was presented.

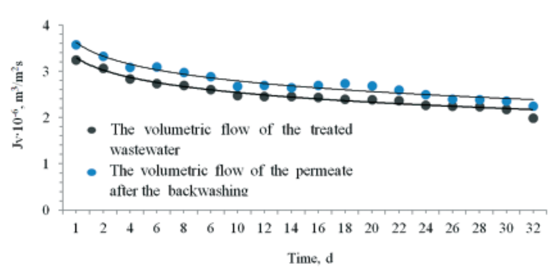

Figure 2.
The dependency of the volumetric flow of the permeate on time of the process (ΔP=0.03 MPa)

It was defined that the backwashing was recommended because it improved the efficiency of the membrane bioreactor. The volumetric flow of the treated wastewater was at $3.25 \cdot 10^{-6}$ m^3/m^2s. After the hydraulic regeneration of membranes it increased by 10% and was $3.58 \cdot 10^{-6}$ m^3/m^2s. After a 32-day operation on the membrane bioreactor its efficiency decreased by 38% and was $1.99 \cdot 10^{-6}$ m^3/m^2s. Then, in order to restore the initial properties of separation membranes the chemical regeneration was carried out. As a result, the volumetric flow of the treated wastewater increased by 57% and was $4.60 \cdot 10^{-6}$ m^3/m^2s. It was found that the chemical cleaning increasingly affects the improvement of effectiveness of the membrane bioreactor as compared to the backwashing.

The percentage share between reversible and irreversible fouling was determined based on equations from 2 to 5. Obtained results of the study are presented in Fig. 3.

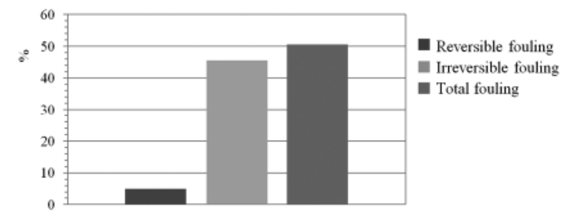

Figure 3.
The percentage share between reversible and irreversible fouling

Taking into account the hydraulic regeneration of capillary membranes it was determined that the total fouling was equal to 50%, and the share of irreversible fouling was much higher (45.5%). The share of reversible fouling was only at 4.9%. It shows that pore coating was persistent and it allowed for the decreasing initial transport properties of membranes. It was found that a hydrophobic nature affects the fouling of the membrane made of polyethersulfone.

3.2. The influence of Powdered Activated Carbon on the intensity of fouling phenomenon occuring in membrane bioreactors

Due to the fact that the fouling phenomenon increases costs connected with the exploitation of MBRs, the regeneration as well as other activites reducing the intensity of the phenomenon are required.

One of the methods is activated carbon addition to the activated sludge reactor. PAC assisted-MBR partially prevents the deposition of substances on the surface and in the pores of the membrane because it sorbs microbial cells and pollutants. Thus, it allows for the decreasing the amount of pollutants and gives the possibility to increase the volumetric flux of the permeate. It is defined that the activated carbon dosing addition to the MBR may reduce costs associated with cleaning or replacing membranes. It was concluded that activated carbon-assisted MBRs reduced the intensity of fouling. Moreover, the volumetric flux of the permeate for the PAC-assisted MBR increased by approximately 35%. Fig. 4. shows the dependency of the volumetric flow of the permeate on time of the filtration with and without PAC (ΔP=0.03 MPa)

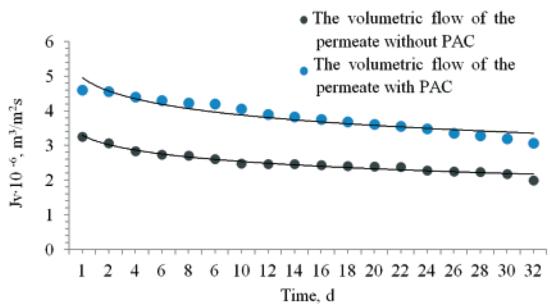

Figure 4.
The dependency of the volumetric flow of the permeate on time of the filtration with and without PAC (ΔP=0.03 MPa)

On the first day, the volumetric flux of the treated wastewater was at $3.25 \cdot 10^{-6}$ m^3/m^2s. In case of activated carbon addition the value was 30% higher and was equal to $4.6 \cdot 10^{-6}$ m^3/m^2s. However, it was observed that after 10 days PAC was characterized by the highest value of the volumetric flux. It increased by 40% as compared to the study in which the activated carbon was not used. On the last day, the volumetric flux of wastewater was at $1.99 \cdot 10^{-6}$ m^3/m^2s, and its value in the bioreactor including PAC increased by 35% and was $3.07 \cdot 10^{-6}$ m^3/m^2s. Based on the obtained results it can be concluded that the volumetric flux of the treated wastewater in the bioreactor with activated carbon addition was higher by 35–40% as compared to the volumetric flux without the activated carbon addition. Moreover, based on equations from 2 to 5 the percentage of reversible and irreversible fouling was determined (Fig. 5).

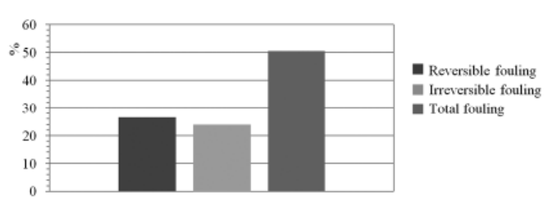

Figure 5.
Percentage share between reversible and irreversible fouling in activated carbon-assisted membrane bioreactors

The fouling for MBR-PAC (membrane bioreactor-powdered activated carbon) was at 50.5%. The share of irreversible fouling was at 24%, however reversible fouling was at 26.5%. Based on the obtained results it can be concluded that the activated carbon addition reduced the intensity of the membrane fouling.

4. CONCLUSIONS

The following conclusions can be drawn from the presented study:

1. It was found that the activated carbon addition to a membrane bioreactor (MBR) treating wastewater reduced the intensity of deposition of substances on the surface and in the pores of the membrane. The volumetric flux of the treated wastewater for PAC-assisted MBRs was higher by approximately 40% as compared to the volumetric flux of the treated wastewater without any sorbents.
2. It was determined that the total fouling for membranes without any sorbents was equal to 50%, and the share of irreversible fouling was much higher (45.5%). The share of reversible fouling was only at 4.9%. It shows that pore coating was persistent and it allowed for the decreasing initial transport properties of capillary membranes.
3. The fouling for MBR-PAC was at 50.5%. The share of irreversible fouling was at 24%, however, reversible fouling was at 26.5%. Based on the obtained results it can be concluded that the activated carbon addition reduced the intensity of the membrane fouling

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