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# Effect of powdered activated carbon on integrated submerged membrane bioreactor–nanofiltration process for wastewater reclamation

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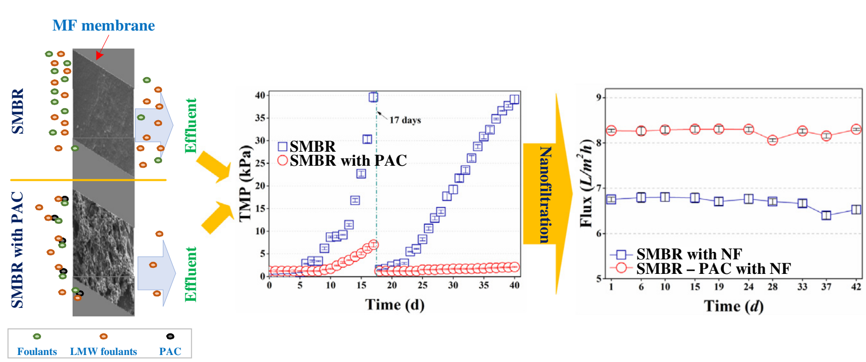
## HIGHLIGHTS

- Wastewater was treated by SMBR with PAC and NF integrated processes for reuse.
- PAC was able to prevent TMP increase in SMBR.
- The effluent of SMBR with PAC obtained better water qualities and performances.
- The integrated processes improved flux and water qualities for wastewater reuse.
- Mathematical model of SMBR with PAC and NF integrated processes is introduced.

## GRAPHICAL ABSTRACT

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## ABSTRACT

The aim of this study was to determine the effect of powdered activated carbon (PAC) on the overall performance of a submerged membrane bioreactor (SMBR) system integrated with nanofiltration (NF) for wastewater reclamation. It was found that the trans-membrane pressure of SMBR increased continuously while that of the SMBR with PAC was more stable, mainly because water could still pass through the PACs and membrane even though foulants adhered on the PAC surface. The presence of PAC was able to mitigate fouling in SMBR as well as in NF. SMBR–NF with PAC obtained a higher flux of 8.1 LMH compared to that without PAC (6.6 LMH). In addition, better permeate quality was obtained with SMBR–NF integrated process added with PAC. The present results suggest that the addition of PAC in integrated SMBR–NF process could possibly lead to satisfying water quality and can be operated for a long-term duration.


## 1. Introduction

The limited and uneven distribution of global water resources in conjunction with a growing population leads to an increasing water shortage in some regions of the world (Tijing et al., 2015; Woo et al., 2013). Recently, wastewater and effluent have been gradually treated and reused for increasing the water supply. Wastewater is considered as an alternative water resource, which can fulfill the demands for fresh water. Besides, the protection and sustainable use of high quality water resources are essential parts of an innovative resource management (Bunani et al., 2013;

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Haaken et al., 2014; Tang and Chen, 2002). Wastewater reclamation and reuse are effective approaches in sustainable industrial development programs. Increasingly stringent environmental legislation and generally enhanced intensity, efficiency, and diversity of treatment technologies have made the reuse of water more viable in many industrial processes.

Membrane bioreactor (MBR) technology comprises a conventional biological sludge process, which is a wastewater treatment process utilizing a suspended growth of biomass, and a microfiltration (MF) or ultrafiltration (UF) membrane system (Hoinkis et al., 2012). It is worth noting that MBR has been recognized as one of the famous biological wastewater treatments for simultaneous removal of total nitrogen (T-N), total phosphorous (T-P), and chemical oxygen demand (COD).

An important parameter in MBR systems is trans-membrane pressure (TMP). TMP control is strongly related to the efficiency of the systems (Kim et al., 2005). Fouling causes a significant increase in hydraulic resistance which leads to permeate flux decline or a rise in TMP. Frequent membrane cleaning is thus required. However, excess membrane cleaning may significantly increase the energy consumption leading to higher operating costs (Pradhan et al., 2012). For these reasons, it is essential to develop new systems to mitigate fouling issues and hence decrease cleaning periods. Various methods such as vortex generation on corrugated membrane surface, modification of feed flow pattern (Pradhan et al., 2012), development of new membrane materials (Wang et al., 2002), new design of membrane module (Bai and Leow, 2002, 2001) incorporation of in-situ or ex-situ cleaning regimes for membrane units (Parameshawaran et al., 2001) and the incorporation of organic or inorganic additives (Aun Ng et al., 2006; Lee et al., 2014) have been used to reduce membrane fouling and enhance filtration flux.

One of the most common strategies to reduce and control sludge/fouling in/on a submerged membrane bioreactor (SMBR) is to provide aeration (air scouring) close to the membrane surface. It is commonly accepted that air bubbling close to the membrane is one of the most efficient means for minimizing fouling and ensuring sustainable operation (Pradhan et al., 2012). However, eventually, foulants will still appear on the membranes.

Another possible method is to apply powdered activated carbon (PAC) as an adsorbent in the MBR process. Previous researches showed that the addition of PAC could provide better physical removal of natural organic matter (NOM) and synthetic organic compounds (SOCs), reduce the direct loading of dissolved organic pollutants onto the membrane, and prevent membrane fouling (Gai and Kim, 2008). MBR process incorporated with powdered activated carbon has been increasingly studied as an advanced treatment process due to the activated carbon's nature to remove soluble organic contaminants by adsorption (Guo et al., 2005).

To overcome the water quality problem in wastewater reclamation, new technologies such as reverse osmosis (RO) and nanofiltration (NF) have been applied as a post treatment. Several studies indicated that NF is an efficient system for the secondary or tertiary treatment of wastewater, producing water for industrial, agricultural and/or indirect drinking reuse (Andrade et al., 2014; Kummerer, 2009; Lee et al., 2014). In addition, some groups have reported on the application of electro-dialysis process with MBR or combining MBR with NF for drinking water production (Noronha et al., 2002; Wisniewski et al., 2001). MBR was used as a part of these hybrid processes to improve the water quality of effluent. The integrated membrane systems using low pressure (i.e., MF and UF) followed by membrane systems using high pressure (i.e., NF and RO), or MBRs coupled with NF and/or RO process, have been widely used to enhance the removal of micro-pollutants in the recycled water and mitigate fouling formation on the NF and RO membranes for municipal wastewater reclamation (Lee et al., 2014). A number of research groups have already studied the effect of PAC addition on the MBR fouling and performance, however, the effect of PAC addition not only to the SMBR but also to the nanofiltration as post-treatment for wastewater reclamation (i.e., the integrated SMBR–NF process) has yet to be reported.

The scope of this study was to evaluate the efficiency of PAC in the SMBR–NF hybrid process for wastewater reuse. In detail, the experiment was carried out under a continuous SMBR process. The indices for the treatment performance, the removal efficiency of the substances and the required time to reach a certain level of TMP were evaluated. NF was operated as a post-treatment for obtaining better water qualities and higher flux. In addition, the effluent was analyzed and several water qualities such as total phosphorous (T-P), total nitrogen (T-N), total dissolved solids (TDS), dissolved organic matters (DOC), chemical oxygen demand (COD), etc. were characterized. Further, membrane characterization was performed to confirm the effects of PAC on the foulants. Both experimental and modeling simulation tests were carried out to investigate the performance of the integrated process in this study.

## 2. Methods

### *2.1. Materials*

#### *2.1.1. Composition of synthetic wastewater*

The composition of the synthetic wastewater fed into the SMBR is given as follows: glucose, 500 mg/l as COD; $NH_4HCO_3$, 50 mg/l as T-N; $KH_2PO_4$, 22.5 mg/l as T-P; $NaHCO_3$, 300 mg/l; $MgSO_4{\cdot}7H_2O$, 50 mg/l; $CaCl_2{\cdot}2H_2O$, 10 mg/l; $MnSO_4{\cdot}H_2O$, 0.03 mg/L; $ZnSO_4{\cdot}7H_2O$, 0.04 mg/; $FeCl_2{\cdot}4H_2O$, 0.32 mg/l, and; yeast extract, 0.05 mg/l. Glucose and bicarbonate were added in the synthetic wastewater as organic and inorganic carbon sources, respectively.

#### *2.1.2. Powdered activated carbon (PAC)*

The adsorbent used with SMBR was PAC (Darco KB-B, Norit, US). The particle size ranges from 100 to 325 mesh, and the surface area was 500–1000 $m^2$/g. PAC was dried at 105 °C for 1 h and cooled down at 25 °C inside a desiccator before use. Then, the PAC was placed into the filtration tank as soon as the start of the experiment, and after that, there was no further addition of PAC into the system. SMBR1 refers to process without PAC in the reactor, while SMBR2 includes PAC in the reactor. In order to determine the PAC concentration for injection in the SBMR2, a jar-test was implemented with six beakers having a volume of 1 L each. PAC was added in each beaker at various dosages (0, 0.3, 0.5, 1.0, 2.0, 3.0 g/L) and stirred for 24 h. Samples were taken out and filtered using 0.45 μm PVDF syringe filter to separate the PAC from the sample. Then, these samples were measured by $UV_{254}$ and DOC. Three replicate measurements were carried out and the average with the standard deviation is reported here.

### *2.2. SMBR and NF processes*

Two methods were employed in the present study: SMBR without PAC (SMBR1) and SMBR with PAC (SMBR2). Two sheets of a PVDF flat-sheet membrane (pore size of 0.08 μm, Toray, Japan) with a surface area of 0.0288 $m^2$ were submerged in the bioreactor and continuously aerated. Table 1 shows the various operating conditions for the continuous SMBR process and the membrane specification. Level sensors were installed in both reactors, and the aeration rate was set at 2 L/min with an air blower through a diffuser located on the bottom of the reactor in order to fluidize PAC and to prevent the accumulation of PAC onto the membrane. In the present study, intermittent suction was done with 9 min filtration and 1 min relaxation. The permeate flux was fixed at