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Recovery of baker's yeast wastewater with membrane processes for agricultural irrigation purpose: Fouling characterization

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HIGHLIGHTS

- Agricultural irrigation is the largest usage of fresh water.
- Baker's yeast wastewater was treated by two-step NF process.
- Desal 5DL was determined as appropriate membrane for membrane selection.
- The lowest flux decline was obtained at pH 7, 12 bar, 25 °C.
- Agricultural irrigation water quality was achieved by two-step NF process.

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ABSTRACT

Increasing water demands for both industrial and public uses as well as more restrictive laws make the industrial wastewater recovery necessary. In this study, it was aimed to propose membrane treatment process for recovery of biologically treated baker's yeast wastewater to the degree of agricultural irrigation water quality. In addition to water recovery, membrane fouling mechanism was investigated. Membrane selection was carried out using FM UP020, FM UP005, NF 270, NF 90 and Desal 5DL membranes. Desal 5DL membrane was selected as appropriate membrane for baker's yeast wastewater treatment according to relatively higher rejection performance, lower flux declines and lower increase in contact angle. The effects of pH, temperature, and transmembrane pressure (TMP) were investigated on Desal 5DL membrane fouling. In addition, atomic force microscopy (AFM) and Fourier transform infrared (FTIR) spectroscopy measurements were used for fouling characterization. NF 90 membrane was determined as suitable membrane to increase the quality of composite permeates obtained from Desal 5DL membrane. As a conclusion, the treated baker's yeast wastewater by two-step nanofiltration (NF) process was classified as class B in terms of pH, biological oxygen demand (BOD_5), suspended solids (SS) and fecal coliform parameters. II. Class irrigation water was achieved for degree of restriction on irrigation use.

1. Introduction

In recent years, fresh water scarcity has been the growing problem for many arid and semi-arid countries in the world and fresh water resources have becoming insufficient to satisfy increasing demand. Agricultural irrigation is the largest usage of fresh water. More than 70% of the water that is withdrawn all over the world is used for agricultural irrigation [1,2]. Therefore, there is a big potential for the application of treated wastewater in irrigation. Application of treated wastewater for irrigation has some following benefits for environmental and economic impacts: water shortage could be prevented; high quality resources could be used for potable utilization; economic benefits could be provided due to the nutrient content of the wastewater [3]. The main water quality factors for determining the suitability of the recycled water for irrigation are pathogen content, salinity, sodicity (levels of sodium), specific ion toxicity, trace elements, and nutrients [4]. The quality and the safety of produced food and the health concerns of agricultural workers are the most important concerns for agricultural use of treated wastewaters. Advanced wastewater treatment technologies which are able to produce effluent for agricultural irrigation offer solutions for these concerns [5].

Increasing water demands for both industrial and public uses as well as more restrictive laws referred to water consumption make the industrial wastewater recovery necessary. The baker's yeast industry produces significant quantities of wastewater with high organic matter concentration and dark brown color. Today, most

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Nomenclature

AFM	atomic force microscopy
ATR	attenuated total reflectance spectra
BOD_5	biological oxygen demand ($mg\,L^{-1}$)
CMF	concentration mode of filtration
COD	chemical oxygen demand ($mg\,L^{-1}$)
C_p	concentration of a particular component in the permeate ($mg\,L^{-1}$)
C_f	concentration of a particular component in the permeate ($mg\,L^{-1}$)
DFZ	DurchsichtsFarbZahl = Indexes of Transparency (m^{-1})
FTIR	Fourier transform infrared
IEP	isoelectric point
ICPMS	inductively coupled plasma mass spectrometry
J	permeate flux ($L\,m^{-2}\,h^{-1}$)
J_0	pure water flux of clean membrane ($L\,m^{-2}\,h^{-1}$)
J_f	pure water flux of fouled membrane ($L\,m^{-2}\,h^{-1}$)
J_s	wastewater flux ($L\,m^{-2}\,h^{-1}$)
MF	microfiltration
MWCO	molecular weight cut-off (Dalton)
NF	nanofiltration
Q	cross-flow rate ($L\,min^{-1}$)
R	rejection of feed components (%)
R_a	the mean roughness on membrane surface (nm)
R_{rms}	root mean square of average height of membrane surface peaks (nm)
R_z	mean difference between five highest peaks and lowest valleys (nm)
RO	reverse osmosis
SAR	sodium adsorption ratio
SAR_{adj}	adjusted sodium adsorption ratio
SS	suspended solids ($mg\,L^{-1}$)
TKN	total kjeldahl nitrogen ($mg\,L^{-1}$)
TMP	transmembrane pressure (bar)
TP	total phosphorous
UF	ultrafiltration
V_c	final volume of the concentrate (L)
V_f	initial volume of feed (L)
V_p	total volume of permeate (L)
VRF	volume reduction factor
θ	contact angle (°)

of the baker's yeast wastewaters are treated by biological treatment systems consisting anaerobic and aerobic steps. Conventional biological processes are effective in the removal of chemical oxygen demand (COD). However, the brown color remains in the biologically treated effluent due to the repolymerization of pigments [6]. The main colored compounds presented in the molasses fermentation wastewater are known as melanoidins which are responsible for the brown color, residual COD, and nitrogen in baker's yeast effluent that limits the recovery of wastewater [7]. Hence, biological treatment should be used in combination with other treatment technologies such as advanced oxidation processes, membrane processes, electrochemical processes, coagulation/flocculation, and adsorption. Among the advanced treatment processes, membrane technology offers an attractive alternative for reclamation of wastewater due to its clean, easy, high efficiency and flexibility of operation. In literature, limited study has been found dealing with membrane treatment process for biologically treated baker's yeast wastewater [8–11]. Based on a literature review, there is no reported publication about recovery of biologically treated baker's yeast wastewater with membrane processes for irrigation reuse.

The main objective of this study is to propose membrane treatment process for recovery of baker's yeast wastewater to the degree of agricultural irrigation water quality. In addition, the influence of operating conditions on membrane fouling was investigated and optimum operating conditions which provide minimum flux decline were determined. Experimental studies comprised of membrane selection considering rejection performance and flux decline, determining the effects of operating conditions on membrane fouling, enhancement of permeate quality with additional membrane stage for attaining agricultural irrigation water. Membrane fouling mechanism was evaluated using contact angle, AFM and FTIR spectroscopy measurements for the verification of membrane surface hydrophobicity, roughness and chemical changes, respectively.

2. Materials and methods

2.1. Characterization of baker's yeast wastewater

Wastewater used in this study was obtained from two-step (anaerobic–aerobic) biological wastewater treatment plant discharge effluent of a baker's yeast manufacturing company. The characteristics of the biological wastewater treatment plant effluent are given in Table 1.

2.2. Membranes and experimental set-up

Totally six polymeric flat-sheet membranes; FM UP020, FM UP005 (Microdyn-Nadir GmbH), NF 270, NF 90, BW 30 (Dow-FilmTech) and Desal 5DL (GE-Osmonics) were tested in the present work. The properties of these membranes are shown in Table 2.

The experiments were carried out by a lab-scale plant (Osmo, Germany) in cross-flow operation. The membrane module, which was made from stainless steel material with the membrane channel dimensions of 200 mm in length, 40 mm in width and 13 mm in depth. Cross-flow rate (Q) was kept at 2.0 $L\,min^{-1}$ throughout all the experiments. The experiments were conducted in concentration mode of filtration (CMF). In the CMF tests, volume reduction factor (VRF) was calculated using the following Eq. (1):

$$VRF = V_f / V_c \quad (1)$$

where V_f and V_c are the initial volume of feed and the final volume of the concentrate, respectively.

Table 1
Characteristics of biologically treated baker's yeast wastewater.

Parameter	Value
pH	7
COD ($mg\,L^{-1}$)	440
BOD_5 ($mg\,L^{-1}$)	132
TKN ($mg\,L^{-1}$)	26
TP ($mg\,L^{-1}$)	4
SS ($mg\,L^{-1}$)	79
Total hardness (mg $CaCO_3$ L^{-1})	800
Chloride ($mg\,L^{-1}$)	1600
Sulfate ($mg\,L^{-1}$)	467
Color as DFZ	
(436 nm) (m^{-1})	65.9
(525 nm) (m^{-1})	24.5
(620 nm) (m^{-1})	9.7
Conductivity ($\mu S\,cm^{-1}$)	7580
Total alkalinity (mg $CaCO_3$ L^{-1})	880
Fecal coliform (MPN 100 mL^{-1})	1300