Egyptian Journal of Petroleum (2016) 25, 79–90

HOSTED BY

Egyptian Petroleum Research Institute

Egyptian Journal of Petroleum

www.elsevier.com/locate/egyjp
www.sciencedirect.com

FULL LENGTH ARTICLE

Process engineering optimization of nanofiltration unit for the treatment of textile plant effluent in view of solution diffusion model

Ahmed Mohamed Farid Shaaban [a,*], **Azza Ibrahim Hafez** [a], **Mona Amin Abdel-Fatah** [a], **Nabil Mahmoud Abdel-Monem** [b], **Mohamed Hanafy Mahmoud** [b]

[a] *National Research Center, Chemical Engineering and Pilot Plant Department, Dokki, Cairo, Egypt*
[b] *Cairo University, Faculty of Engineering, Chemical Engineering Department, Egypt*

Received 11 December 2014; revised 25 February 2015; accepted 9 March 2015
Available online 9 January 2016

KEYWORDS

Nanofiltration;
Spiral-wound membrane;
Dye-house wastewater;
Color and COD removal;
Solution diffusion model

Abstract A nanofiltration (NF) based separation process is used to treat the effluent from a textile plant to allow for water reuse and fulfill environmental standards. The wastewater effluent contains reactive black (RB5)- and disperse (DR60) dyes. A NF-unit model E2 series with HL 2521 TF spiral wound module was used to carry out experiments. 90 & 93% color removal and COD reduction for RB5 and 98 & 95% for DR60 were achieved. A parametric study of the separation process is undertaken to characterize the effects of the operating variables, e.g., trans-membrane pressure, dye/salt concentration in the feed, temperature, and cross flow velocity. The solution diffusion model was used to develop power correlations to calculate the permeate side solute mass transfer coefficient as a function of effective cross-flow Reynolds number. In contrast to the commonly assumed constant hydraulic solvent permeability, a non-linear relationship was developed over the applied trans-membrane net driving pressure. The latter correlates exponentially with salt permeability for both dyes. The effects of feed salt-content on solute mass transfer coefficient, water and salt permeability, concentration polarization, dye hydrophobicity and ionic strength were studied. Results were used to assess engineering specifications of a commercial size NF-plant (500 m^3/d capacity).

1. Introduction

Weaving, textile and dying industry represent one of the most important economic sectors in Egypt whose production exceeds $5 billion in 2012. The latter constitutes 25% of the Egyptian gross domestic production. The textile fabrics – particularly

* Corresponding author.
E-mail addresses: drahmedshaaban@yahoo.com (A.M.F. Shaaban), hafez.a@hotmail.com (A.I. Hafez), monamamin7@yahoo.com (M.A. Abdel-Fatah), nabil_abdelmonem@yahoo.com (N.M. Abdel-Monem), mhanafy1967@yahoo.co (M.H. Mahmoud).
Peer review under responsibility of Egyptian Petroleum Research Institute.

http://dx.doi.org/10.1016/j.ejpe.2015.03.018

Nomenclature

A	membrane area (m^2)
A_{eff}	effective area (m^2)
b	leaf width (m)
c_{if}	concentration of component i in the feedstock (mg/L)
c_{ip}	concentration of component i in the permeate (mg/L)
c_{sp}	concentration of adsorbate on the membrane at equilibrium (mol/kg)
c_{dsp}	total dissolved adsorbate concentration remaining in the solution at equilibrium (mg/m^3)
$\overline{C}$	average salinity on the feed side (mg/L)
C_f	dye/salt feed concentration (mg/L)
C_c	concentrate concentration (mg/L)
C_p	permeate concentration (mg/L)
d_h	hydraulic diameter (m^2)
D	solute diffusion coefficient in water (m^2/s)
DR	dye rejection (%)
h	channel height (m^2)
h_{sp}	spacer thickness (m^2)
J_p	permeate flux (L/m^2 h)
J_s	salt flux (kg/m^2ṡh)
k	mass transfer coefficient (m/s)
k_p	permeate – side mass transfer coefficient (m/s)
K_{sp}	membrane sorption coefficient (m^3/kg)
K_s	salt permeability coefficient (m/s)
K_w	water permeability coefficient (m^3/m^2 s bar)
l	membrane thickness (m)
L	channel length (m)
M_s	rate of solid flow through the membrane (kg/s)
NDP	net driving pressure (bar)
P	operating pressure (bar)
ΔP	net hydraulic pressure differential across the membrane (bar)
$\overline{P}$	average hydraulic pressure side (bar) on the feed
P_f	hydraulic pressure on the feed side (bar)
P_p	hydraulic pressure on the permeate side (bar)
P_c	hydraulic pressure on the concentrate side (bar)
$(P_f - P_p)$	pressure difference across the membrane (bar)
Q_f	feed flow rate (L/h)
Q_c	concentrate flow rate (L/h)
Q_p	permeate flow rate (L/h)
R	universal gas constant (bar m^3/mol °C)
Re_{eff}	effective cross flow Reynolds number on permeate side (–)
Re_c	effective cross flow Reynolds number on concentrate side (–)
R_m	membrane hydraulic resistance (m^{-1})
$R_{non\text{-}rec}$	any non-recoverable resistance developed during filtration (m^{-1})
S_{fc}	wetted surface of the flat channel (m^2)
S_{sp}	wetted surface of the spacer (m^2)
Sc	Schmidt number (–)
Sh	Sherwood number (–)
SR	salt rejection (%)
T	operating temperature (°C)
U	fluid linear velocity (m/s)
u_{eff}	effective cross flow fluid velocity (m/s)
V_{fc}	volume of the flat channel (m^3)
V_{Tot}	total volume (m^3)
V_{sp}	volume of the spacer (m^3)

Greek symbols

ρ	fluid density (kg/m^3)
μ	dynamic viscosity of the solution (kg m^{-1} s^{-1})
σ	osmotic reflection coefficient (–)
ϑ_i	molar volume of component i (m^3/mol)
$\Delta\pi$	net osmotic pressure differential across the membrane (bar)
$\overline{\pi}$	average osmotic pressure on the feed side (bar)
π_f	osmotic pressure on the feed side (bar)
π_p	osmotic pressure on the permeate side (bar)
π_c	osmotic pressure on the concentrate side (bar)
ε	porosity (–)
τ	payback period (year)

dye houses – are frequently considered as one of the most hazardous water-polluting sources in Egypt.

Their wastewater usually contains residuals of dyestuffs, detergents, sulfide compounds, solvents, heavy metals and inorganic salts whose concentrations are beyond environmental allowances. Compliance with Egyptian environmental laws oblige such fabrics to practice treatment units to verify environmental standards [1,2].

The waste effluent contaminants are based on the type of the process being used [3,4] and cannot be directly discharged to receiving water bodies due to their dramatic harmful impact on the environment [5–10]. Dyestuff-effluents as the major toxic polluting source are usually subjected to conventional biological treatment by activated sludge. The latter does not meet great success as most of dyes resist aerobic biological treatment and chemical oxidation [3].

An advanced treatment technology is therefore necessary, especially if reuse of treated wastewater and de-colorization are objectives [11]. Membrane filtration can be considered as an optimal solution to remove color, COD and salinity [12,13]. Nanofiltration (NF) has proved high reliability in many waste water purification purposes [14–17]. NF-process is an efficient color removing technology, reducing the volume of generated wastewater, recovering and recycling valuable constituents. It functions by both pore size flow and the solution diffusion mechanism [18,19].

The present work is concerned with the study of the performance of low pressure NF-membrane unit for treating dyehouse effluents from El-Alamia Company for Textile and Dying (10th of Ramadan Industrial City) aiming to: (i) recycle water permeate for reuse, (ii) recovery of residual dyestuffs in concentrate stream, and (iii) reduction of pollution impacts to conform with environmental standards.

Wastewater effluents of dyed-cotton and polyester were thoroughly analyzed for pH, COD, TSS, and TDS according to standard analytical procedures, with HACH spectrophotometer