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Treatment of Sudan III Dye from wastewater using Vacuum Membrane Distillation

Rakesh Baghel[1], Sarita Kalla[2], Sushant Upadhyaya[3*], S.P. Chaurasia[4] and Jitendra Kumar Singh[5]

[1,2,3,4]Department of Chemical Engineering, MNIT Jaipur (India)
[5]Department of Chemical Engineering, JK Lakshmipat University Jaipur (India)
*E-mail: *supadhyay.chem@mnit.ac.in*

Abstract—*In the present work, Vacuum Membrane Distillation (VMD) process has been applied for removal of Sudan III dye from wastewater. The Poly Tetra Fluoro Ethylene (PTFE) membrane of 0.22 µm pore size was used for carrying out experiments at different concentrations. The effect of the various operating parameters such as feed inlet concentration, feed circulation rate, feed bulk inlet temperature and permeate pressure was investigated on permeate flux and simultaneously on the percentage removal of Sudan III dye. The results shows that the permeate flux significantly increased from 5.17 kg/m^2.h to 45.152 kg/m^2.h with increase in feed bulk inlet temperature from 40 to 80 ^{o}C. The linear increments were observed on increasing feed circulation rate and permeate pressure. In continuous operation of 24 hrs, reduction in permeate flux was observed from 42.91 to 39.30 kg/m^2.h due to deposition of dye on the membrane surface. The study of surface morphology was carried out using Scanning Electron Microscopy (SEM) analysis and the deposition of dye was confirmed by comparing the SEM images of before and after use.*

Keywords: *Vacuum Membrane Distillation, PTFE membrane, Sudan III dye, SEM*

1. INTRODUCTION

In the present scenario of continuous population growth, the textile industries have developed vigorously. Textile industries consumes large amount of water and discharge effluent of high dye concentration. The dissolved substances in the discharged effluents show various harmful effects on environment as well as human being. So, the treatment of this residual dye contaminated water is very essential to reduce environmental problems and also helpful in reducing water crisis by re-using discharged wastewater. [1] – [3].

Vacuum membrane distillation is considered as prominent technology for treatment of textile effluent. VMD is thermally driven membrane based separation process. The driving force for VMD is trans-membrane vapor pressure difference across the pores of the hydrophobic membrane. In VMD, vacuum is applied on the permeate side of the membrane so that the heat and mass transfer resistances are reduced. The equilibrium vapor pressure of the feed side should be higher than the applied permeate pressure [2], [4] – [6].

In this paper, the effects of various operating parameters on permeate flux, specific energy consumption and percentage removal has been studied for treatment of Sudan III dye. The effect of operating time was also determined and the deposition of dye on membrane surface was identified using scanning electron microscopy.

2. MATERIAL AND METHODS

The permeate flux of VMD is calculated by using given equation (1):

$$N = \frac{V_p * \rho}{A_e * t} \tag{1}$$

Where V_p is volume of permeate in litre, ρ is the density of permeate material, A_e is the effective area of the membrane and t is the experimental running time of VMD. The specific energy consumption is calculated using the equation (2) given below:

$$Specific\ Energy\ Consumption = \frac{EnergyConsumed(kWh)}{V_p * \rho} \tag{2}$$

The percentage removal of dye is calculated using equation (3) given below. Where C_1 is the initial feed dye concentration and C_2 is the final dye concentration in permeate. All dye concentrations is determined using UV-Vis spectrophotometer.

$$\%RE = \frac{C_1 - C_2}{C_1} * 100 \tag{3}$$

3. EXPERIMENTAL

The feed solution was prepared at different initial dye concentrations and heated in feed tank. The preheated feed dye solution from a feed tank was fed continuously using centrifugal pump to the flat sheet membrane module in which porous hydrophobic membrane was placed as shown in Fig. 1. The properties of the feed dye and membrane are given in Table 1 & Table 2 respectively. The vapors of the volatile material was passed through the pores of the membrane on the permeate side. The vacuum is applied at different levels on the permeate side of the membrane to remove the vapors from the pores of the membrane using the vacuum pump. The vapors were condensed in the external condenser. The temperature of the condenser was maintained lower by circulating cold feed into the condenser using centrifugal pump. The condensed permeate was collected into the receiver.

Table 1: Chemical structure and characteristics of Sudan III Dye

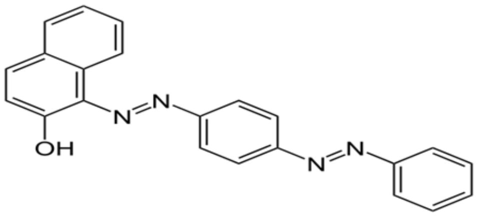
Chemical Structure	
Molecular weight	352.40 g/mol
λ_{max}	508-512nm
IUPAC Name	1-(4-(phenyldiazenyl)phenyl)azonaphthalen-2-ol

Table 2: Membrane Characteristics

Properties	Specifications
Membrane Material	PolyTetraFluoroEthylene
Surface Property	Hydrophobic
Used membrane diameter, mm	52 mm
Pore Size	0.22µm
Membrane Thickness	150µm
Membrane Porosity	85%
Membrane Area	0.00212 m^2
Maximum Operating Temperature	130 °C
Liquid Entry Pressure	2.80 bar
Supplier	Millipore

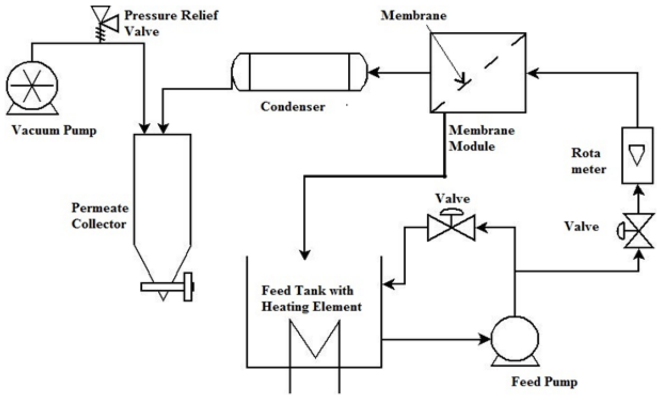


Fig. 1: Schematic line diagram of VMD experimental setup

4. RESULTS AND DISCUSSIONS

4.1 Effect of Feed Bulk Inlet Temperature

The exponential increment in permeate flux is observed on increasing feed bulk inlet temperature from 40 to 80 °C as shown in Fig. 2(a) for PTFE membrane of 0.22 µm pore size. The reason is that because at feed side the vapor pressure on membrane surface is increased exponentially by Antoine relation which enhanced the driving force of mass transfer. However, the specific energy consumption is decreased on increasing feed bulk inlet temperature because energy consumption is inversely proportional to permeate flux. The same trend was also observed by various researchers [5], [7].

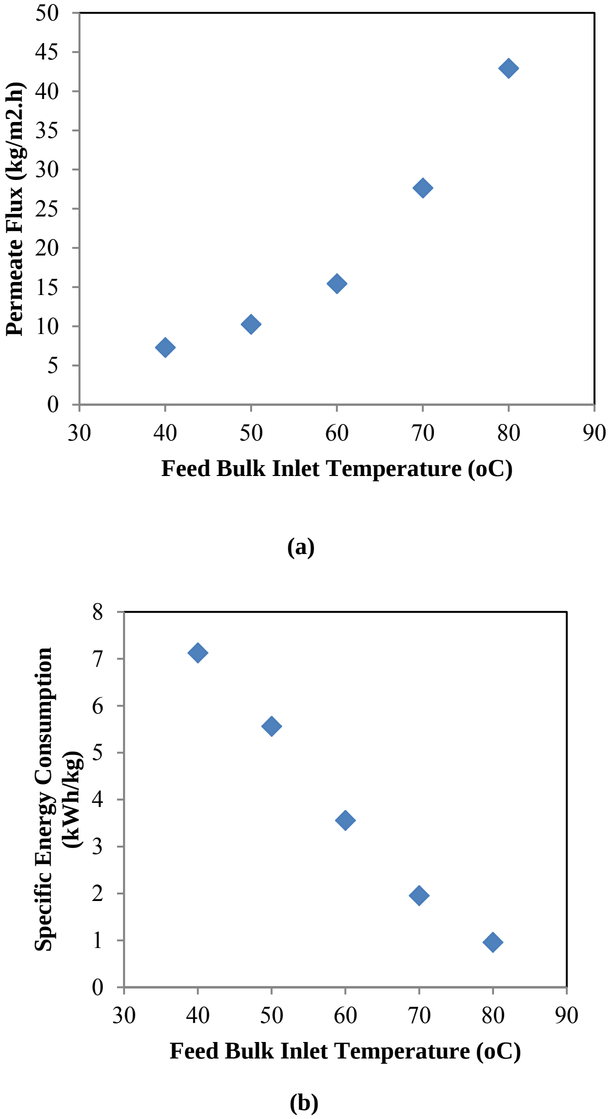
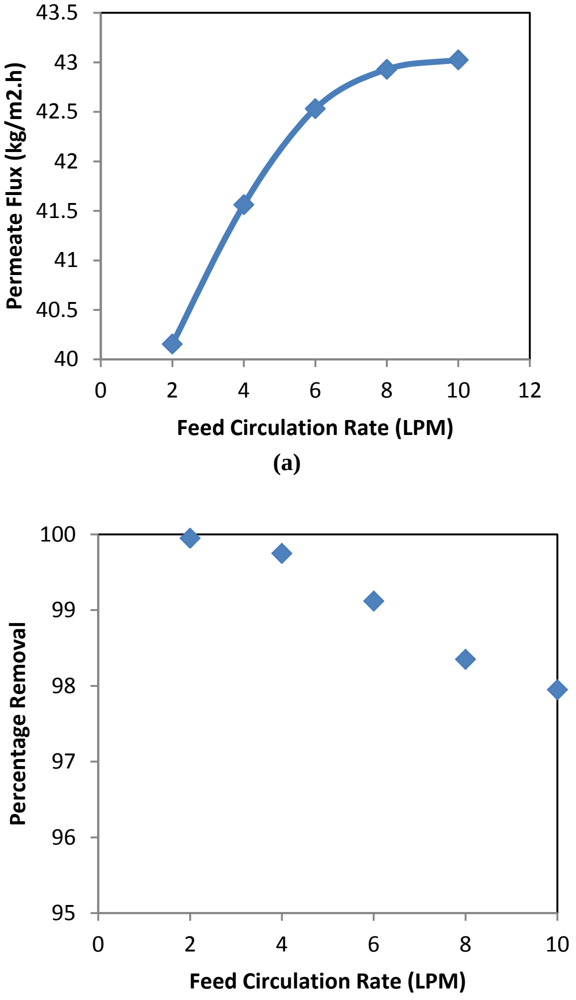


Fig. 2: Effect of Feed bulk inlet temperature on permeate flux and specific energy consumption [Feed Circulation Rate = 8 lpm, Permeate Pressure = 760 mmHg, Feed dye concentration = 60ppm]

4.2 Effect of Feed Circulation Rate

The effect of feed circulation rate on permeate flux and percentage removal is shown in Fig. 3 at constant feed bulk inlet temperature of 80 °C, permeate pressure of 760 mmHg and initial dye concentration of 60 ppm. From Fig. 3, it can be observed that permeate flux increased linearly on increasing feed circulation rate from 2 to 10 lpm due to reduction in temperature and concentration boundary layer thickness at the membrane surface. This decrement in boundary layer reduced the mass transfer resistances of vapor to pass through the pores of the membrane which influence the permeate flux. However, the percentage removal of dye concentration was decreased on increasing feed circulation rate due to increase in hydrodynamic pressure at membrane surface as shown in Fig. 3(b). The same behaviour was also observed by many authors [8] – [11].



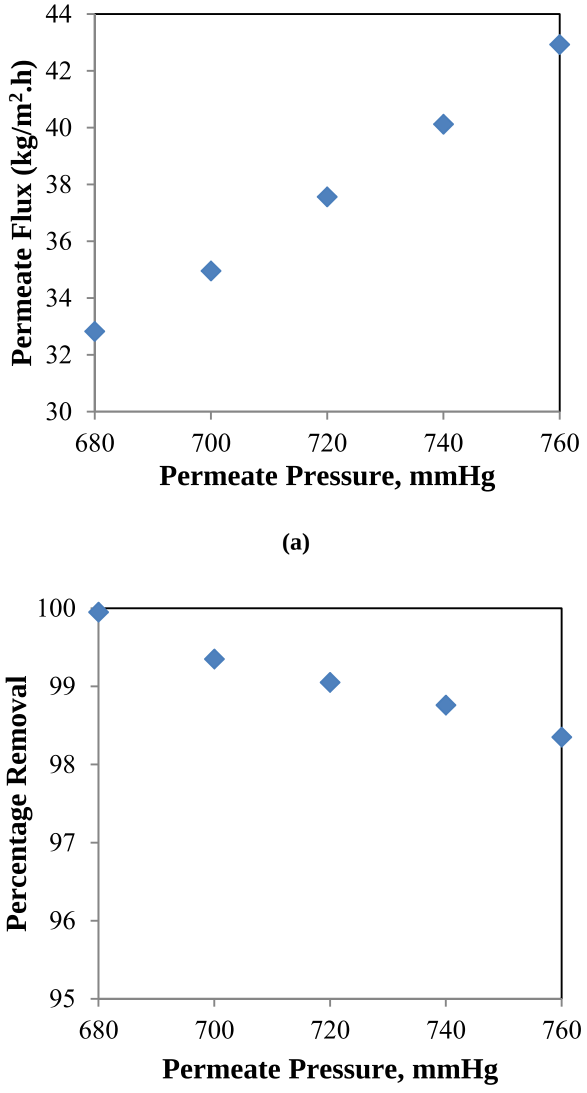
(a)

(b)

Fig. 3: Effect of feed circulation rate on permeate flux and percentage removal
[Feed bulk inlet temperature = 80 °C, Permeate pressure = 760 mmHg, feed dye concentration = 60 ppm]

4.3 Effect of Permeate Pressure

The linear increment in permeate flux is observed on increasing the permeate pressure from 680 to 760 mmHg as shown in Fig. 4(a). The reason for this increment is that the transmembrane pressure difference across the pores of the membrane is increased which reduces the mass transfer resistances and the increased the permeate flux. However, on increasing permeate pressure, the reduction was observed in percentage removal of dye as shown in Fig. 4(b). This happened due to increased pressure on the pores of the membrane which cross the liquid entry pressure limit and allow penetrating dye into the pores of the membrane.



(a)

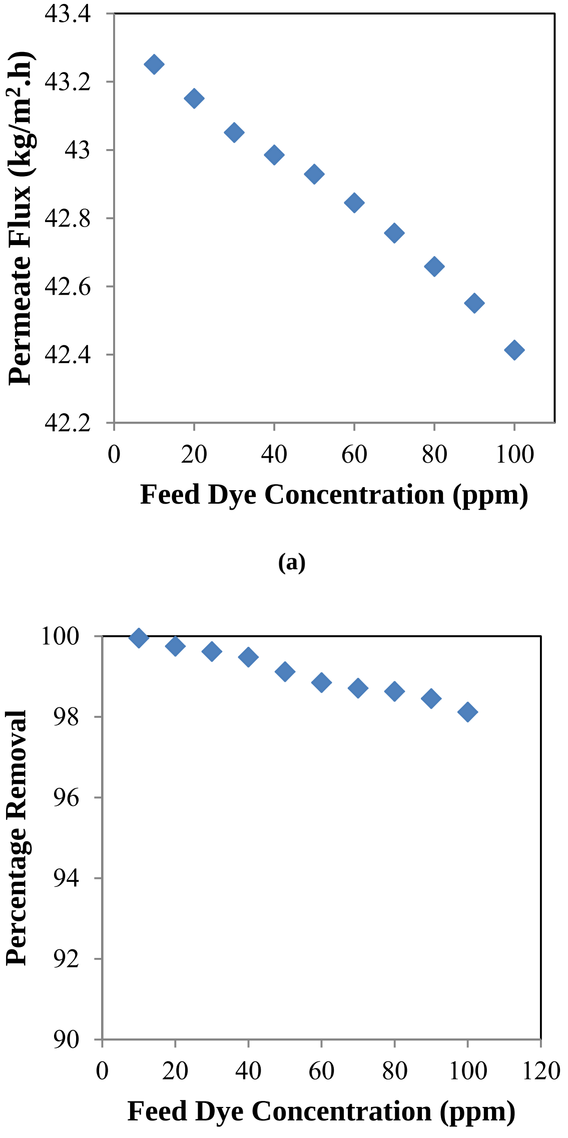
(b)

Fig. 4: Effect of permeate pressure on permeate flux and percentage removal

[Feed bulk inlet temperature = 80 °C, Feed circulation rate = 8 lpm, feed dye concentration = 60ppm]

4.4 Effect of Feed Dye Concentration

The effects of feed dye concentration on permeate flux and percentage removal is shown in Fig. 4. From this Fig. 4, it is clear that on increasing feed dye concentration from 20 to 100 ppm, the permeate flux and percentage removal reduced linearly. This happened due deposition of dye on the membrane surface which block the pores of the membrane and ultimately increased the mass transfer resistances which results in reduction of permeate flux.



(a)

(b)

Fig. 4: Effect of feed dye concentration on permeate flux

[Feed bulk inlet temperature = 80°C, Feed circulation rate = 8 lpm, permeate pressure = 760mmHg]

4.5 Effect of Operating Time

In continuous operation, the feed dye solution of 60 ppm was fed to VMD setup and the flux was collected for 24 hrs. In 24 hrs of run time the permeate flux reduced from 42.91 to 39.30 $kg/m^2.h$ as shown in Fig. 5. This reduction in flux is due to deposition of dye on membrane surface. The surface morphology of membrane was analyzed using scanning electron microscopy before and after use as shown in Fig. 6. The deposition of dye on membrane surface was confirmed by SEM images as shown in Fig. 6(b).

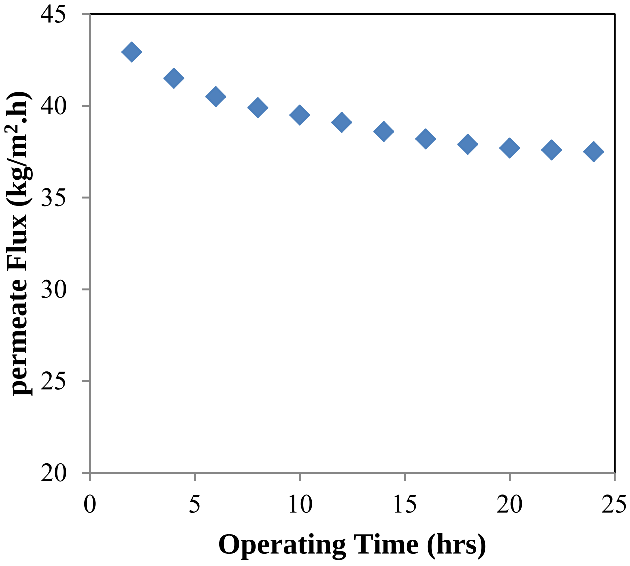
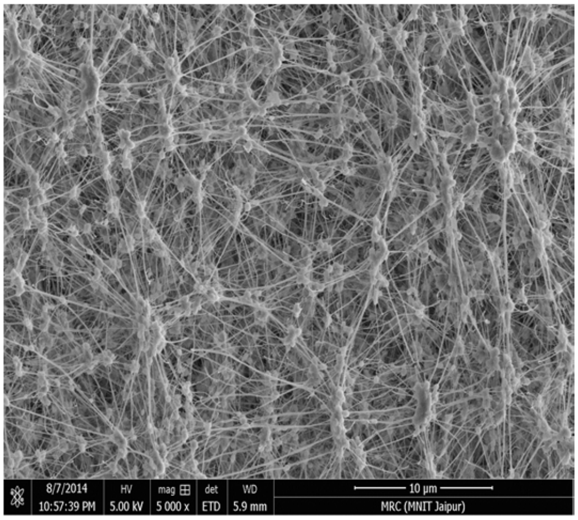
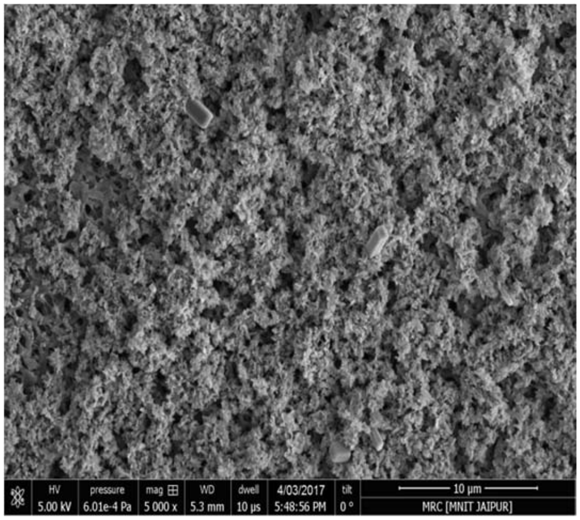


Fig. 5: Effect of operating time on permeate flux

[Feed bulk inlet temperature = 80°C, Feed circulation rate =8 lpm, Permeate pressure = 760mmHg, Feed dye concentration =60ppm]



(a)



(b)

Fig. 6: SEM images (a) before, (b) after use, of membranes at 5000x magnification

5. CONCLUSIONS

In the present work, the effect of various operating parameters were studied on permeate flux, specific energy consumption and percentage removal. The exponential increment was observed in permeate flux from 5.17 kg/m^2.h to 45.152 kg/m^2.h on increasing feed bulk inlet temperature while specific energy consumption was decreased. The linear increments were observed on increasing feed circulation rate and permeate pressure from 2 to 10 lpm and 680 to 760 mmHg respectively. However, the percentage removal of Sudan III dye was decreased on increasing feed circulation rate, permeate pressure and feed dye concentration. The fouling on the membrane surface was determined using scanning electron microscopy.

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