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Performance of Polytetrafluoroethylene Membrane and Specific Energy Consumption in VMD

Priya Pal[1], Sushant Upadhyaya[2] and S.P. Chaurasia[3*]

Department of Chemical Engineering, MNIT Jaipur (India)
E-mail: chch1962@gmail.com

Abstract—*Membrane technology has a great potential as it can provide solutions for many environmental problems by recovering valuable products as well as treating effluents and minimizing their harm to the atmosphere. Vacuum membrane distillation (VMD) is a thermally driven process, in which only vapour molecules are transported through porous membranes. Removal of water from glycerol/water mixture was performed through VMD. Polytetrafluoroethylene (PTFE) membrane of 0.45micron pore size, thickness 175mm and 85% porosity has been used. Permeate was found to contain pure water due to the low vapour pressure and larger molecular size of glycerol which cannot be penetrate through PTFE membrane. The percentage rejection of PTFE is 88.5% and reasonable water flux in the range 80-120kg/m^2/h at a vacuum of 720 mmHg at constant glycerol concentration of 10 wt.%.*

Keywords: *Membrane technology, Vacuum membrane distillation, hydrophobic polytetrafluoroethylene membrane, Glycerol.*

1. INTRODUCTION

The economy of biodiesel has been increased by purification of glycerol and make it suitable for other valuable products. Glycerol is produced as a by-product from saponification and hydrolysis reactions in oleo-chemical plants as well as transesterification reaction in biodiesel plants. Very limited management choice and proper disposal of glycerol further adds to the problem thereby making environmental concern[7]. Over the years, the shift in focus on developing suitable technologies for conversion of raw glycerol in a valuable product for improving the economic viability of biodiesel production has feverishly led to its purification and further processing [4,7]. The crude glycerol contains various undesirable components such as alcohol, spent catalyst, ash, water, and fatty acid that barely differs from glycerol in their physical properties [7], which reduces its overall quality and inhibits its utilization in making valuable products[2]. Therefore, it is necessary to purify the glycerol for its subsequent utilization in pharmaceutical, cosmetic, food industries, textile industry, paper industry, printing ink and surface coating industry[8,9].

Glycerol also known as Glycerine or propane-1-2-3-triol, 1,2,3-propanetriol, 1,2,3-tri hydroxyl-propane, glyceritol, and glycyl alcohol, is a chemical that consists of three-carbon chain with a hydroxyl group attach to each carbon. It is derived from Natural or petrochemical feedstock. It is a clear, colourless, odourless, viscous liquid, hygroscopic in nature and highly soluble in water[5].

Membrane technology, is a new separation technology, specially in the field of waste water treatment, water desalination &daily life etc. it mainly consist of microfiltration, ultrafiltration, nano filtration, dialysis and reverse osmosis. Now a days membrane technology has been emerged with other technology such as membrane gas absorption, membrane crystallization, membrane extraction, membrane contactor and membrane distillation. Above these process membrane act as a barrier, which does not allow the liquid to pass through the membrane and form the liquid-vapour interface at the surface of the membrane[7]. Membrane distillation considered as a most famous technology for water purification. It is a non-isothermal separation process and diving force is vapour pressure difference across the membrane. There are four configuration developed to perform MD process i,e direct contact membrane distillation (DCMD), air gap membrane distillation (AGMD), sweeping gas membrane distillation (SGMD), and vacuum membrane distillation [10].

In vacuum membrane distillation (VMD), the feed solution directly contacts with the membrane surface and is kept at pressure lower than the minimum entry pressure (LEP); at the other side of the membrane, the permeate pressure is often mentioned below the equilibrium vapour pressure by a vacuum pump. The mass flux of VMD is generally larger than that of other MD configurations. Another advantage of VMD comes from the negligible heat conduction through membrane. It is environmentally good, less energy consumption and gives a more purity of glycerol compared to conventional process. This advantage makes VMD highly thermal efficient [10,11].The appropriate membrane for vacuum membrane distillation should be highly porous and highly hydrophobic (excellent mechanical stability) in nature. Therefore, excellent hydrophobicity, appropriate pore size and narrow pore size distribution of microporous membranes are necessary to ensure the high permeate flux and rejection coefficient in the MD process[8]. The most common and commercially available flat sheet microporous hydrophobic membranes are Polytetrafluorethylene (PTFE), polypropylene (PP) or polyvinylidene fluoride (PVDF). Their pore size ranges from 0.01 micron to 1 micron.

The objective of this paper to study on PTFE flat sheet hydrophobic membrane for VMD. The effect of feed flow rate and feed temperature on permeate flux and percentage rejection. Effect of temperature on specific energy consumption in VMD.

2. EXPERIMENTAL WORK

2.1. Materials

Glycerol was purchased from Thermo Fisher Scientific India Pvt. Ltd., Mumbai, India. Hydrophobic Polytetra fluoro ethylene membrane PTFE procured from Merck Millipore Mumbai. The specification membrane are shown in Table 2. Concentration of glycerol water mixture were measured by refractometer (model RX-7000i, ATAGO, Russia). The physical and chemical properties of glycerol are shown in Table 1. .

Table 1: Physical and Chemical Properties of Glycerol

Chemical Formula	**C3H8O3**
Molecular Weight	92.09 g mol-1
Appearance	Colorless liquid, hygrosopic
Odour	Odorless
Density (g/cc at 500C)	1.261 g cm-3
Melting Point (0C)	17.8
Boiling Point (0C)	290
Refractive Index (ηD)	1.4746
Viscosity	1.412 pa.s

Table 2: Specification of membrane

Parameter	Specification
Product name	Fluoropore membrane filter
Material	PTFE, hydrophobic
Membrane type	Flat sheet membrane
Max Operating temperature °C	130
Pore size (µm)	0.45
Thickness (µm)	175
Diameter (mm)	90
Area (m2)	0.00212

2.2 VMD performance

In VMD, Feed sample containing a mixture glycerol and water with 10 vol % glycerol was fed to the tank and was heated using the heating coils which are at the bottom of the tank. The temperature of the feed was varied from 50- 70 °C. Feed was sent to the membrane module using a centrifugal pump (Crompton KFPM 26045). Feed Flow Rate was varied in the range of 1 to 5 LPM using the rotameter, a flow measuring device. The temperature was measured using thermocouples via digital thermometer which are at 4 positions, in feed tank, above membrane surface, permeate temperature and cooling water tank. Vacuum Pump (IVC Oil Seal Rotary High Vacuum Pump, IVO-100-1/0.25 H.P.) was connected to the permeate side of the membrane module to draw the water vapours being generated in feed side. A condensing unit was used at the permeate side to condense the vapours passing through the membrane. A pressure gauge was used for the measurement and maintaining of the vacuum created by vacuum pump. Various meters were also housed in the assembly to measure the power consumption of Feed Pump, Heating element, Vacuum Pump and Cooling pump. A schematic representation of VMD setup is shown in Fig. 1.Permeate flux N, percentage rejection and specific energy consumption was calculated by using the following equation:

The permeate volume was measured during the separation process which was divided by the product of effective membrane area and run time.

Permeate flux

$$N=\frac{V}{A*t}$$

Where V = volume of the permeate,

A = effective area of the membrane, m^2

t = Run time, hr

The percentage rejection is calculated by the separation performance of the membrane. The performance of the membrane is denoted by Rejection.

Percentage rejection

$$R= (C_F- C_P)/C_F \quad * 100$$

Cf = concentration at feed side

Cp = concentration at permeate side

R = Rejection

Specific heat consumption

= (energy consume)/(flux*hour)

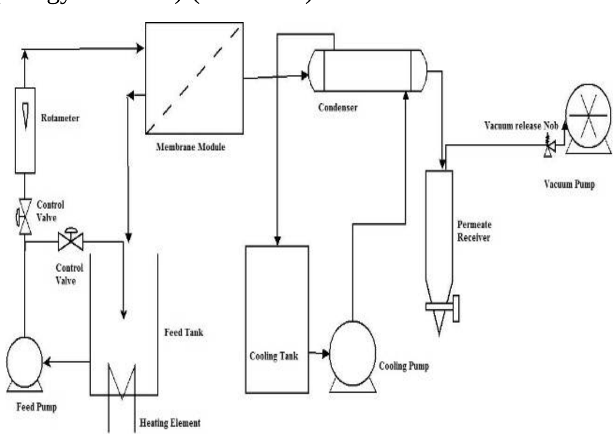

Fig. 1: Schematic representation of VMD setup

3. RESULTS AND DISCUSSION:

3.1 Effect of feed flow rate

The experiments are conducted on VMD at constant feed concentration and at constant feed temperature 70 °C, feed flow rate from (1-5 lpm) and vacuum pressure (720 mmHg).The effect of feed flow rate on permeate flux and %rejection were investigated. On increasing the feed flow rate, the permeate flux increases linearly while the other operating parameters remain constant. It was observed in Fig. 2 (a) that on increasing feed circulation velocity, the effect of concentration and temperature polarization decrease due to minimization of heat transfer resistances results in a reduction in boundary layer thickness on the feed side of the membrane due to which flux increase and maximum flux 77kg/m2/h attain at 4lpm and after that increase in feed flow rate that may distorted the membrane performance and may puncture and due to which glycerol will pass through the membrane. The effect of percentage rejection is more effective in feed flow rate as shown in Fig. 2(b). On increasing feed flow rate the percentage rejection will increase but after some time it will decrease due to puncture of membrane. The maximum percentage rejection attain at 4lpm is 88.4%.

3.2 Effect of feed temperature

An exponential increase of the flux with the increase of the feed temperature as shown in Fig. 3(a). This is due to the exponential increase of the vapour pressure of the feed solution with increase in temperature, which increases the transmembrane vapour pressure (i.e. the driving force) as all the other involved MD parameters are maintained invariables. Feed bulk temperature significantly affects the permeate flux and the energy requirement; thus, it is considered as a very sensitive parameter. At feed temperature 70°C, maximum flux observed 120 $kg/m^2/h$ keeping other parameter constant at feed flow 4lpm because it give a higher flux at this condition similarly for vacuum pressure 720mmHg. In Fig. 3(b) percentage rejection minutely increase with increase in temperature because there is no physical and chemical change in membrane on increasing temperature because membrane can bear a temperature up to 130°C and pressure should be lower than liquid entry pressure. If the external pressure increases above the LEP, membrane get puncture and mixture will pass through membrane and flux will increases at permeate side. So, percentage rejection decreases. The maximum percentage rejection is 88.75% at optimum condition.

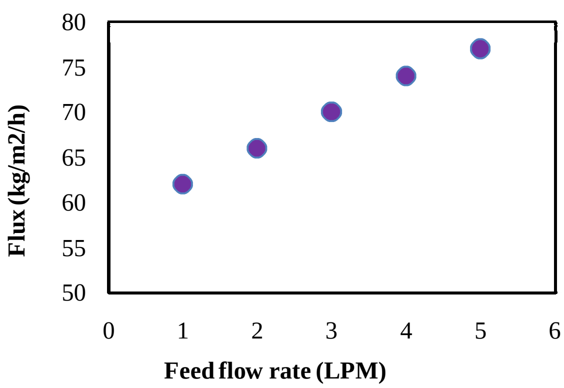

Fig. 2: (a) Effect of feed flow rate on flux ($kg/m^2/h$)

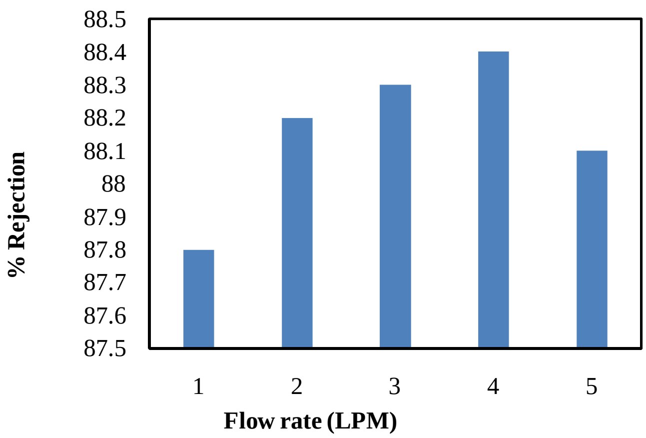

Fig. 2(b) Effect of feed flow rate on % rejection.

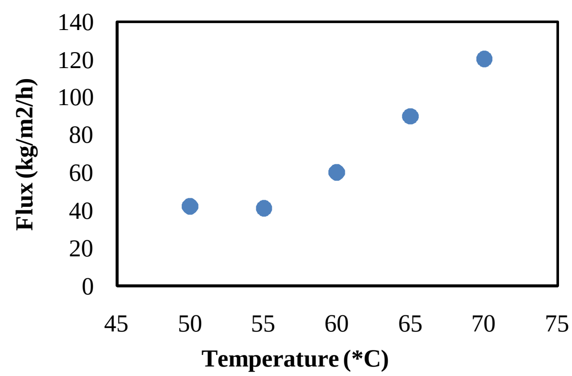

Fig. 3 (a) Effect of temperature on flux (kg/m2/h)

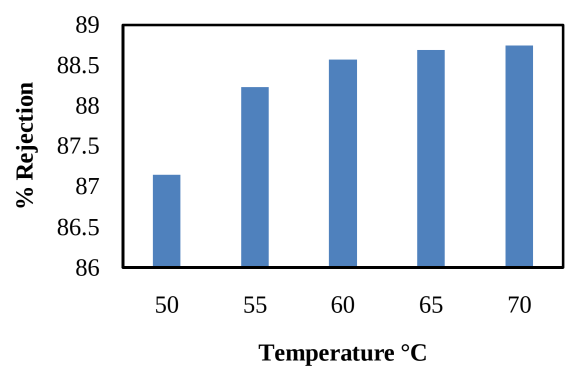

Fig. 3(b) Effect of feed temperature on % rejection.

3.3 Effect of feed concentration

The effect of the feed concentration between 10 to 50 vol% glycerol mixture in water. In these experiments, the feed temperature was kept at 70 °C, the vacuum pressure at 720mmHg & the feed flow rate at 5 LPM. From the fig. 4(a) increasing the feed concentration resulted in a steep decrease in both the permeation flux and the salt rejection. At higher feed concentrations, there was a gradual decline in permeation flux and salt rejection shown in Fig. 4(b). According to these results, an increase in the glycerol concentration at the membrane surface resulted in fairly less water diffusing from the bulk feed solution to the membrane surface. Hence, the polarization effect limited the driving force for water permeation and the permeate flux declined.

3. 4 Effect of Vacuum Degree

The effects of the applied vacuum degree on the performances (permeate flux and salt rejection) of the membranes was investigated. The vacuum degree were set at 680, 690, 700, 710 and 720 mmHg while keeping all other parameters constant (feed temperature 70 °C, feed flow rate 5LPM and 10vol% glycerol concentration).As shown in Fig. 5(a), the permeation flux increased as the downstream pressure decreased (i.e., higher vacuum level), and at 720 mmHg had the highest flux (120 kg/(m2.h)). A similar trend is observed for the salt rejection percentage as shown in Fig. 5(b) but the highest salt rejection (99.7%) at 720mmHg was obtained.

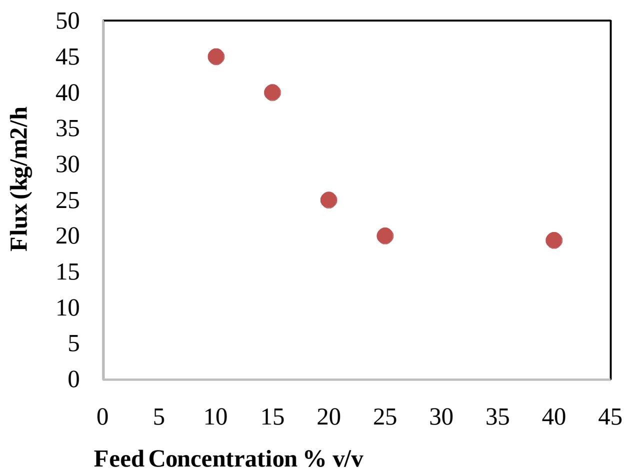

Fig. 4 (a) Effect of Concentration on flux (kg/m2/h)

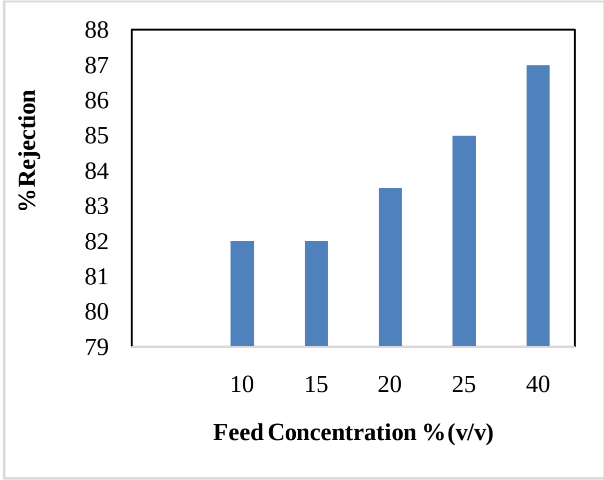

Fig. 4 (b) Effect of concentration on %Rejection.

These results indicates that the MD driving force is the vapor pressure difference between the sides of the membrane. This can be achieved with either a temperature difference or a vacuum on the permeate side of membrane module. For all MD configurations, the permeate flux generally increases linearly with the transmembrane vapour pressure difference [2]. In VMD both the permeate flux and the transmembrane hydrostatic pressure increase with a decrease in the vacuum pressure applied to the permeate side (downstream), which can lead to good % rejection.

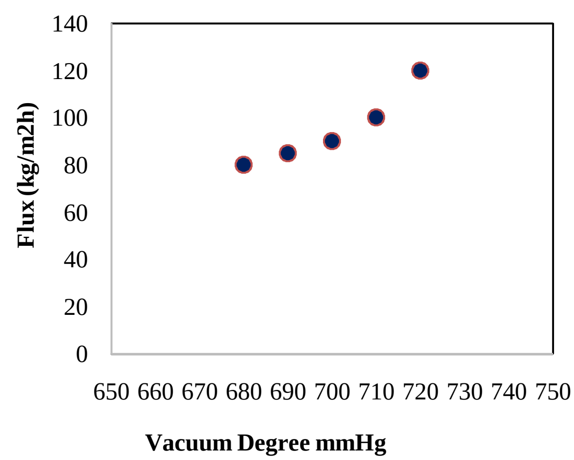

Fig. 5 (a) Effect of Vacuum Degree on flux (kg/m2/h)

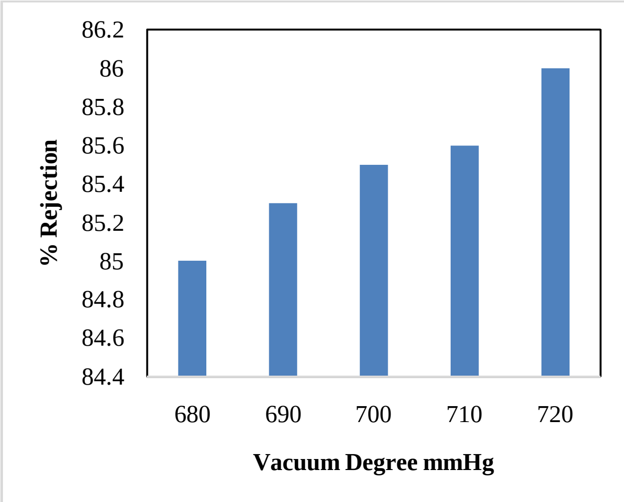

Fig. 5 (b) Effect of Vacuum Degree on %Rejection.

3.5 Effect of temperature on specific energy consumption

The effect of feed temperature on specific energy consumption is shown in Fig. 6. From the fig4, it is clear that on increasing feed temperature from 50-70°C linear decrement was observed in specific energy consumption this is the fact due to inverse relationship between energy consumption and permeate flux.

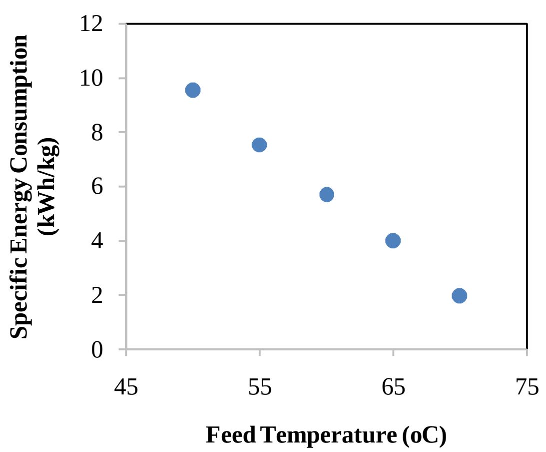

Fig. 6: Effect of feed temperature on specific energy consumption

4. CONCLUSIONS

The effect of various operating parameter has been investigated. The Permeate flux increases with the increase in feed temperature and feed flow rate. Results indicated that maximum % rejection i.e.88.4% was achieved at feed flow rate of 5lpm at 70°C temperature, 10% glycerol concentration & 720mmHg vacuum pressure. Similarly when 70°C feed temperature was used obtain maximum % rejection of 88.75% at 10 % (v/v) feed concentration, 5 LPM feed flow rate & 720mmHg vacuum pressure and obtained flux of 120kg/m^2.h. Hence Vacuum Membrane Distillation is a promising technology for glycerol water separation.

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