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Separation characteristics of acetone/water mixtures through sodium alginate/poly(vinyl pyrrolidone) membranes by vapor permeation and vapor permeation with temperature difference methods

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ABSTRACT

In this study the permeation and separation characteristics of acetone/water mixtures were investigated by vapor permeation (VP) and vapor permeation with temperature difference (TDVP) methods using sodium alginate/poly (vinyl pyrrolidone) (NaAlg/PVP) membranes crosslinked with calcium chloride. Membranes were prepared in different ratios (w/w) (100/0, 95/5, 90/10, 85/15, 80/20, 75/25) of NaAlg/PVP. The effects of blend ratio, feed composition, operating temperature and temperature of the membrane surroundings on the separation characteristics (separation factor, permeation rate) were studied for the acetone/water mixtures. The optimum NaAlg/PVP ratio, operating temperature and feed composition were determined as 75/25 (w/w), 40°C, and 20 wt% acetone, respectively. The separation factors decreased whereas permeation rates increased with the increase in permeation temperature for both VP and TDVP methods. In the TDVP method separation factors increased and the permeation rates decreased as the temperature of the membrane surroundings decreased. It was as observed that the permeation rate in TDVP method was lower than in VP; however the highest separation factor was obtained with TDVP method as 73.

Keywords: Membrane; Vapor permeation; Acetone; PVP; NaAlg

1. Introduction

In VP and TDVP methods, membrane is in contact with the vapor of the feed mixture. Furthermore a temperature difference between the membrane surrounding and the feed mixture was established in the vapor permeation with temperature difference method [1,2].

In VP (Fig. 1a), swelling or shrinking of the membranes due to the feed mixtures can be largely prevented and consequently improvement of membrane performance may be expected. In TDVP (Fig. 1b), the temperature of the membrane surrounding and the feed mixture are different from each other.

Acetone is a solvent used in pharmaceutical industry, production of chemicals and plastics. It does not form an azeotrope with water but a large reflux is required when attempting to distil a solution necessitating a large column and high-energy costs. NaAlg is a highly hydrophilic polymer, which is used as a membrane material [3,4]. When hydrophilic polymer is preferred as a membrane

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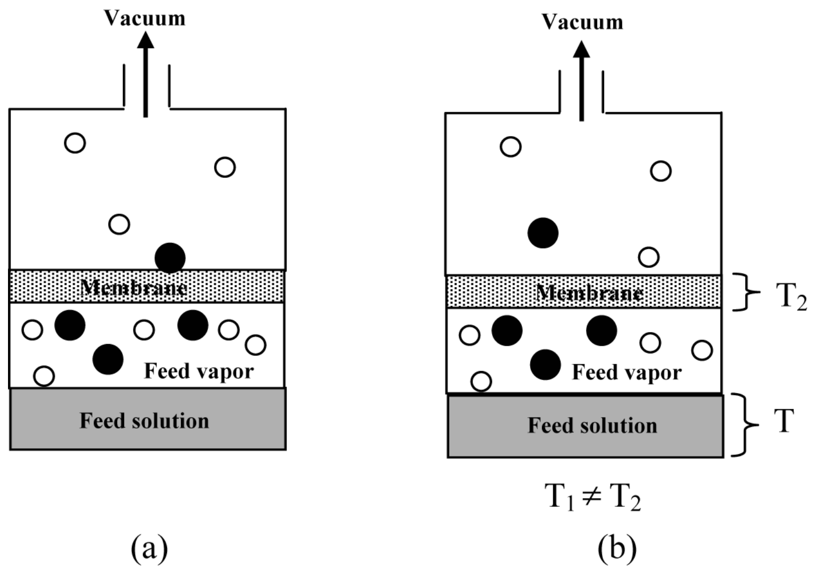

Fig. 1. Schematic diagram of (a) the VP method and (b) the TDVP method.

material it should be modified to have suitable combination of permeation rate and separation factor. For this purpose in this study PVP and NaAlg solutions were mixed to prepare NaAlg/PVP membranes.

There are many articles in the literature about the separation of acetone/water mixtures using pervaporation method [5–13]. Whereas there is no study concerning the separation of this mixture by vapour permeation and vapour permeation with temperature difference methods. In this mean this study is pioneer. We have previously studied the separation of acetone/water mixtures by using pervaporation method [14]. As a continuation of the studies on the separation of acetone/water mixture in this paper we have investigated separation characteristics through NaAlg/PVP membranes by VP and TDVP methods.

2. Experimental

2.1. Materials

Acetone, calcium chloride and PVP were obtained from Merck and used as supplied. NaAlg was provided from Sigma (medium viscosity).

2.2. Preparation of the NaAlg/PVP membrane

PVP (8 wt%) and NaAlg (2 wt%) were dissolved in water, mixed in 75/25 ratio (w/w), stirred and then casted onto rimmed round glass dishes. Solvent was evaporated at 60°C to form the membrane. The dried membrane was crosslinked with calcium chloride (0.1 M) for 24 h. The membrane thickness was determined as 70 (±10) µm according to our previous study [14].

2.3. Swelling study of the NaAlg/PVP membrane

Dried membrane was immersed in different concentrations of acetone/water mixtures at 40°C for 48 h and then wiped with cleansing tissue to remove the excess solvent mixture. These samples were dried at 60°C until a constant weight and water uptake was calculated as:

$$\text{Water uptake (\%)} = \frac{\left(M_S - M_D\right)}{M_D} \times 100 \quad (1)$$

where M_S is the mass of the swollen membrane in the feed solution and M_D is the mass of the dried membrane.

3. Methods

The mixture of acetone and water which was used as a feed solution placed into the lower part of the permeation cell, permeation side of the cell (upper part) was kept under vacuum. The feed mixture was circulated between the permeation cell and the feed tank at constant temperature and permeate was collected in liquid nitrogen traps (Fig. 2).

In TDVP method while the temperature of the feed solution was kept constant (40°C) temperature of the membrane surrounding (0–50°C) was controlled by a cold medium in a permeation cell of a jacket type. Upon reaching steady state conditions permeate vapour was collected in liquid nitrogen traps and weighed. The composition of permeate was found by means of refractive index values measured with an Atago DD-5 type digital refractometer. The membrane performance was expressed by separation factor (α) and permeation rate (*J*). The separation factor and permeation rate were defined as follows:

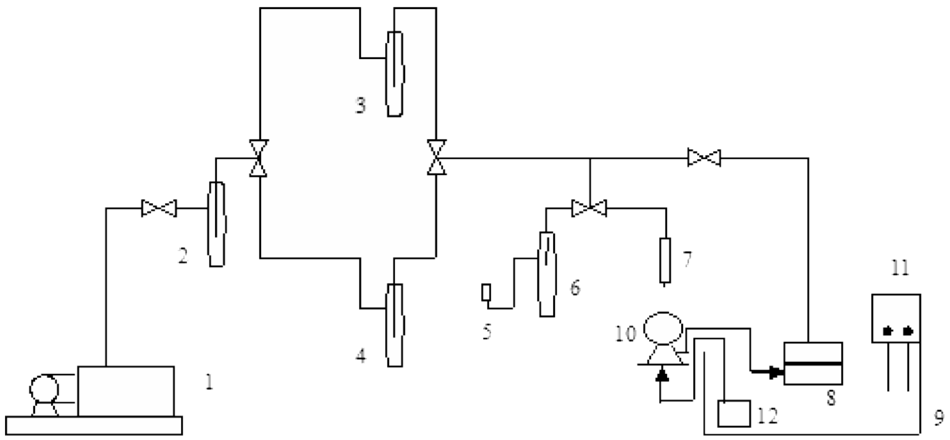

Fig. 2. Schematic diagram of the vapor permeation and vapor permeation with temperature difference apparatus used in this study: (1) vacuum pump, (2–4, 6) permeation traps; (5) McLeod manometer; (7) vent; (8) permeation cell; (9) constant temperature water bath; (10) peristaltic pump; (11) temperature indicator; (12) feed tank.

$$\alpha_{W/\text{acetone}} = \frac{P_W / P_{\text{acetone}}}{F_W / F_{\text{acetone}}} \tag{2}$$

where P_W and P_{acetone}, F_W and F_{acetone} are the mass fractions (wt%) of water and acetone components in the permeate and feed, respectively.

$$J = W / A \cdot t \tag{3}$$

where W is the mass of permeate (kg), A is membrane surface area (m^2), t is the experiment time (h).

4. Results and discussion

4.1. Effect of the different blend ratios

Effect of blend ratio was studied with 20 wt% acetone/water mixture in ratio of 100/0, 95/5, 90/10, 85/25, 80/20, 75/25 (NaAlg/PVP, w/w) at 40°C using the membranes with previously determined thickness of 70 μm (±10) [14]. Results are presented in Table 1. It is seen from the table, the permeation rate decreases, whereas the separation factor increases with the increase in the blend ratio. Similar results were found in the literature [15–17].

We have studied with 75/25 (NaAlg/PVP, w/w) ratio in the rest of the study due to acceptable flux and separation factor. The prepared membrane was characterized with Fourier transform infrared spectroscopy, scanning electron microscopy, differential scanning calorimetry. Characterization results have been presented in our previous study [14].

4.2. Effect of the feed composition in VP

The permeation performance of NaAlg/PVP membrane was investigated in VP at 40°C and the results are shown in Fig. 3. As the amount of acetone in the feed vapor decreases membrane material becomes more swollen (Fig. 4). Acetone molecules have larger molecular size (0.308 nm) than that of water molecules (0.193 nm) diffuse

Table 1
Effects of the separation factor and permeation rate for different ratios of NaAlg/PVP. [C_3H_6O]: 20 wt%, membrane thickness: 70 μm, pressure: 0.6 mbar, operating temperature: 40°C

NaAlg/PVP ratio (w/w)	Separation factor (α)	Permeation rate (J, kg/m^{2}h)
100/0	36.25	0.586
95/5	35.64	0.604
90/10	31.06	0.653
85/15	31.58	0.687
80/20	30.47	0.714
75/25	30.56	0.709

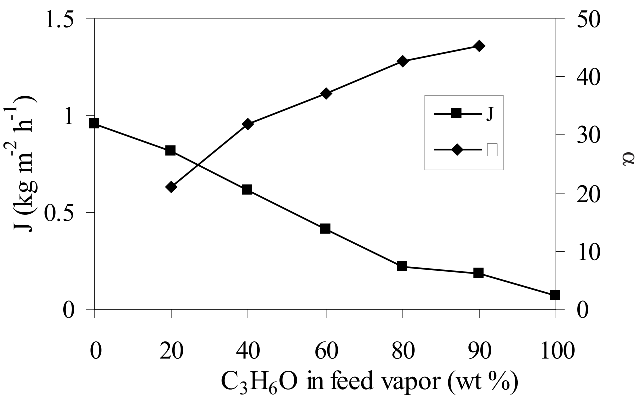

Fig. 3. Effect of the feed vapor composition in VP. The permeation conditions; membrane thickness: 70 μm, operating temperature: 40°C, pressure: 0.6 mbar.

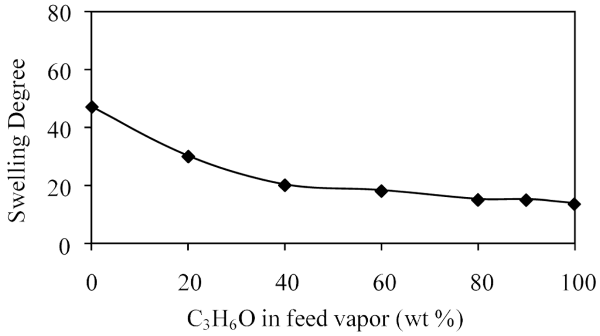

Fig. 4. Change in the swelling degree with the feed vapor composition.

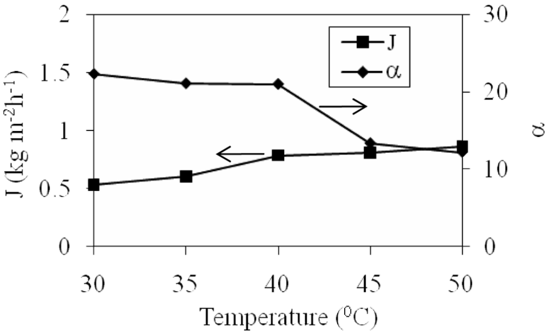

Fig. 5. Effect of operating temperature in VP. The permeation conditions; membrane thickness: 70 μm, [C_3H_6O]: 20 wt%, pressure: 0.6 mbar.

easily through the swollen membrane, permeation rate increases so the separation factor decreases.

4.3. Effect of the operating temperature in VP

The changes of the permeation rate and separation factor in VP for 20 wt% acetone were shown in Fig. 5. The permeation rate increased as the operating temperature increased whereas the separation factors decreased as in the studies in the literature. Similar results were reported in the literature [18–22].

4.4. Effect of membrane surrounding temperature in TDVP

Fig. 6 reflects the effect of temperature of the membrane surroundings on the permeation rate and the separation factor in TDVP. The permeation rate increases with the increase in temperature of the membrane surroundings but the separation factor decreases.

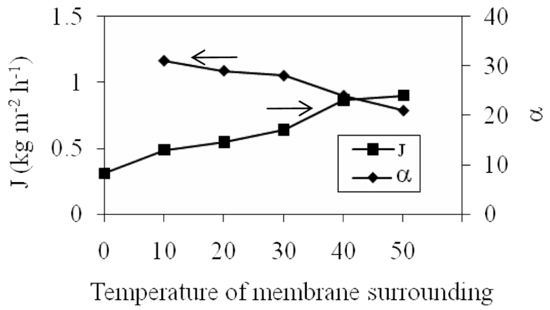

Fig. 6. Effect of the temperature of the membrane surroundings. The permeation conditions; membrane thickness: 70 μm, temperature of the feed solution: 40°C, pressure: 0.6 mbar.

5. Conclusions

The following conclusions can be drawn from the study on the separation of acetone/water mixtures using NaAlg/PVP membranes crosslinked with calcium chloride.

1. Increase in the operating temperature in VP and TDVP methods increased the permeation rate whereas decreased the separation factors.
2. Permeation rate decreased whereas separation factor increased as the acetone content of the feed increased.
3. In the separation of acetone/water mixtures using NaAlg/PVP membrane crosslinked with calcium chloride. The highest separation factor (73) was found in TDVP method whereas highest permeation rate (0.865 kg $m^{-2}h^{-1}$) was observed in VP method.

Acknowledgements

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