

Effect of Coating Method and Feed Pressure and Temperature on CO₂/CH₄ Gas Separation Performance of Pebax/PES Composite Membranes

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Received: Mar. 31, 2017 / Accepted: Apr. 20, 2017

Abstract

In this study, PES/Pebax composite membranes were prepared by coating the porous PES support layers by Pebax-1657. Film casting and pouring methods were used for coating Pebax layer. The effects of coating technique and conditions including coating solution concentration and curing temperature on CO₂ and CH₄ gas permeabilities of prepared composite membranes were investigated. SEM images were used to investigate the structure of the prepared membranes. Pure CH₄ and CO₂ gases were used to investigate the gas permeation properties of the prepared membranes at different trans-membrane pressures (1-11 bar) and feed temperatures (25-55°C). The obtained data showed that the prepared PES supports did not provide any CO₂/CH₄ selectivity. The results also showed the CO₂/CH₄ selectivity for the membrane prepared via pouring technique was higher than that of the film casting procedure due to the defect-free Pebax layer formation. CO₂ and CH₄ permeance increased as the feed temperature increased from 25 to 55°C. The results also showed that CO₂ permeance increased from 6.8 to 10.1 GPU with an increase in feed pressure from 2 to 12 barg, while CH₄ permeance remained almost constant and CO₂/CH₄ selectivity increased from 27 to 42.

Keywords: Pebax, Composite membrane, CO₂ separation, Coating method, Feed pressure, temperature.

1. INTRODUCTION

Membrane gas separation has been interested by many researchers due to the advantages of the membrane systems. Natural gas sweetening, including separation of carbon dioxide and hydrogen sulfide from the natural gas, is an example of membrane application in gas separation (Yampolskii and Freeman, 2010).

Inorganic membranes containing ceramic or metal membranes and organic membranes such as cellulose acetate, polysulfone (PSf), polyethersulfone (PES) and polyetherimide (PEI) have been investigated for gas separation applications (Ismail et al., 2015). Organic materials have been used and studied more than inorganic materials due to their low cost and simplicity in the membrane preparation.

Polymers used in the membrane preparation are divided into two groups of glassy and rubbery polymers. Glassy polymers are those polymers that their glass transition temperature is higher than the operating temperature; and in rubbery polymers, the glass transition temperature is lower than the operating temperature (Baker, 2004). The behavior of these two polymers in gas separation is different and for rubbery polymers the difference between gases' solubility in polymer is the key parameter of separation. The solubility of condensable gases such as carbon dioxide is often more than that of gases with low condensability, such as methane (Matsuura, 1993).

Selectivity and permeability are two important parameters in the membrane gas separation, and when they are high, it shows the high performance of the membrane. There is a limit to the polymeric membrane performance and it is the reverse behavior of selectivity and permeability. High permeability of the membranes leads to the low selectivity and vice versa. Robeson has examined this behavior and provided some diagrams for the used polymers and different gas separations which are known as the Robeson's upper bounds (Robeson, 2008) and new synthetic membranes are often compared with these plots.

Studies on the use of membranes for

gas separation applications usually include, synthesis of new polymers with higher selectivity and permeability (Wijenayake et al., 2014), addition of inorganic or organic additives into the membranes (mixed matrix membranes) to increase their performance [7-16], examining the effect of operating and preparation conditions on the membrane separation performance (Choi et al., 2010) and preparation of multi-layer composite membranes to improve the membrane performance (Ren et al., 2012, Li et al., 2013b, Ramon et al., 2012, Yong et al., 2013)

Composite membranes that have been used in many studies include coating of at least one polymer layer on the surface of another polymer. The upper layer is usually a rubbery polymer that is coated on the substrate (sublayer) which is a glassy polymer (Vankelecom et al., 1999). The upper layer is used for the two following purposes:

- Enhancing the selectivity with coating the pores and surface defects in the bottom layer
- Using the upper layer as a selective layer for gas separations.
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In the second case, the upper layer acts as a selective layer. The bottom layer which is a glassy polymer acts as an anchoring and guarantees the mechanical strength of the membrane. The upper layer which is a very thin layer also leads to the membrane selectivity. If the thickness of the upper layer decreases, then the permeance of the resulting membrane will increase. However, if the thickness of the selective layer decreases much, the probability of the defectless coating will decrease and in the case of defect in the upper layer, the selectivity will decrease. Some studies have been done on the effects of effective factors on the performance of the composite membranes such as preparation conditions (coating method) (Madaeni et al., 2013, Kargari et al., 2014, Choi et al., 2015), sublayer characteristics (Ramon et al., 2012, Zhu et al., 2015), upper layer thickness and using the middle layer (Li et al., 2013a).

There are several methods to prepare composite membranes (Ismail et al., 2015, Baker,

2004) such as casting, dip-coating and interfacial polymerization. For example, for hollow fiber membrane preparation, using the dip-coating method is more effective. Extrusion and press method are also used for making composite membranes (Bennett et al., 1997). Madaeni et al. (Madaeni et al., 2013) studied the effect of coating method (film casting and dip-coating methods) on gas separation performance of PDMS/PES composite membranes. In the film casting method, top layer materials are coated on the surface of substrate by film applicators or home-made blades. In dip-coating, the top layer is formed by immersing substrate in an appropriate polymer solution. They concluded that for similar concentration of coating solution in single coating, selectivity for the membrane prepared via film casting technique was higher compared to that of the dip-coating procedure due to the thicker coated layer in film casting method. However, its permeability was lower.

In recent years, a huge number of studies focused on development of PEO-based membranes for gas separation. These studies have eventuated in different grades of Pebax such as 1074, 1657, 2533, and 3533 (Li et al., 2013b, Reijerkerk et al., 2011, Car et al., 2008a, Car et al., 2008b, Murali et al., 2014, Murali et al., 2010, Liu et al., 2004, Nafisi and Hägg, 2014, Scofield et al., 2016, Mosleh et al., 2015). These copolymers have been used as pure or mixed with other ingredients for membrane gas separation applications (Cheng et al., 2015, Cheng et al., 2016, Lillepärq et al., 2016).

Pebax as a rubbery polymer has been used for CO_2/CH_4 separation in recent studies (Ren et al., 2012, Scofield et al., 2016). Pebax is a copolymer that is formed from the soft segments of polyethylene oxide and the hard segments of polyamide and according to the type and ratio of these two parts, there are commercially various types of them that have been investigated by researchers in gas separation applications (Li et al., 2013b, Reijerkerk et al., 2011, Murali et al., 2010, Car et al., 2008a, Murali et al., 2014, Nafisi and Hägg, 2014). This copolymer tends to absorb carbon dioxide, because it contains carboxyl groups and it is used to separate this gas from light gases such as methane. Usually,

it is used as a coating layer on a porous surface called a composite membrane. In this case, a thin layer of Pebax performs the separation as a selective layer.

In this study, PES was selected as support and commercial Poly (amide-6-b-ethylene oxide) (Pebax MH 1657) copolymer, composed of 60 wt% of PEO and 40 wt% of PA6 (nylon-6), was selected as selective layer to prepare flat sheet Pebax/PES composite membranes. The main purpose of this study was investigating the effect of coating method on performance of Pebax/PES composite membrane for CO_2/CH_4 gas separation. Film casting and pouring methods were used to coat the Pebax layer on PES supports. The effect of feed pressure and temperature on gas separation properties of prepared membrane was also investigated.

2. Experimental

A. Materials

Pebax-1657 which is a copolymer and is composed of polyamide and polyethylene oxide and PES were provided by Arkema Inc., France. Ethanol (EtOH) and dimethyleformamid (DMF) were purchased from Merck Co., Germany, and used as solvents in this study. The gas permeation experiments were conducted using pure CH_4 and CO_2 gases with purity of 99.99%.

B. Preparation of Pebax dense membrane

Pebax-1657 copolymer was dried in an oven at 60°C for 48 h to remove moisture content in the polymer. 4wt% Pebax-1657 solution was prepared by gradually adding Pebax pellets into the solvent mixture of ethanol/water (70/30 vol/vol). For the complete dissolution of polymer pellets, the solution was vigorously stirred and kept under reflux at 75°C for 4 h. Since the polymer does not dissolve in the ethanol/water mixture at low temperatures, the temperature control plays a key role in the solution preparation. After complete dissolution of polymer, the solution was gradually cooled

to the room temperature.

Solution casting and solvent evaporation techniques were used to prepare the dense films. Bubble free Pebax solution was cast on the uniform and clear glass plate and the solvent was evaporated to obtain a dense film. For complete removing the trace amount of solvent in the membrane, the obtained dense film was further dried at ambient temperature for 24 h and subsequently dried in the oven at 40°C for 24 h.

C. Preparation of composite membranes

Composite membranes were prepared by coating the selective thin layer of Pebax on the surface of PES porous supports. PES porous support membranes were also prepared by phase inversion technique. 18wt% PES solution was prepared by dissolving the polymer in DMF solvent under constant mechanical stirring speed of 200 rpm at ambient temperature. The completely dissolved polymer solution was sonicated for 6 h to remove the air bubbles. The homogeneous and bubble free solution was cast on the glass plate with the indigenously designed casting knife. The prepared films were immersed in distilled water bath for precipitation. Subsequently, membranes were immersed in fresh distilled water for 24 h for complete removal of solvent. The prepared membranes were dried for 24 h at ambient temperature. Dried and porous PES support layers were tested with pure gases.

The composite membranes were prepared by coating Pebax solution on the PES porous sublayers. Casting method and pouring were used in this study to coat the Pebax layer. In casting method, considering the porous nature of the substrate and the low thickness of the selective layer, it is difficult to obtain defect-free coated surface. In pouring method, PES membranes were attached to the glass plate and kept at an angle of 45°C. Using a dropper, specific amount of bubble-free Pebax solution was dropped on the PES surface. Membranes were dried at room temperature for 24 h. After that, membranes were kept in the oven at 40°C for 24 h.

D. Pure gases permeability

Gas permeation tests were performed using a constant pressure - variable volume system described elsewhere (Ismail and Lai, 2003). The membrane to be tested is placed into the membrane test cell with an effective permeation area of 13.5cm². The feed gas, CO₂ or CH₄, was passed on the upstream side of the membrane and the desired pressure was maintained. The downstream side pressure was ambient pressure. By measuring the volume changes with the time (*Q*), the gas permeability is calculated from the Eq. 1.

$$P = \left(\frac{QL}{A(p_1 - p_2)} \right) \left(\frac{273.15}{T} \right) \left(\frac{p_2}{76} \right) \quad (1)$$

Ideal selectivity (permselectivity) of membranes is calculated as the ratio of gas permeabilities:

$$\alpha_{CO_2/CH_4} = \frac{P_{CO_2}}{P_{CH_4}} \quad (2)$$

where *P* is the permeability coefficient, barrer (1 barrer = 10⁻¹⁰ cm³(STP).cm/cm².s.cmHg), *Q* is the permeation flow rate (cm³/s), *L* is thickness of the membrane (cm), *A* is the effective membrane area (cm²), *p*₁ and *p*₂ are the absolute pressure (cmHg) of two sides of the membrane, and *T* (K) is the absolute temperature of tested gas. If the thickness of the active layer of membrane is not measured accurately, the permeance (*P/L*) of the gases is calculated. The gas permeance unit is GPU (1GPU = 10⁻⁶ cm³(STP)/cm².s.cmHg).

Membranes were tested four times with each gas to determine the repeatability and consistency of results. In composite membranes, coating solution penetrates into the pores of the substrate, hence, it is not possible to determine the exact thickness of the effective selective layer. Therefore the permeance data was reported instead of the permeability in tables and charts.

E. Scanning electron microscopy (SEM)

The SEM images were used to see the structure of prepared membranes. Scanning electron microscopy (SEM) images were also used to measure the thickness of the Pebax layer in composite membranes. SEM images of PES supports and composite membranes were taken with a HITACHI Model TM3000 SEM machine. Membranes were fractured in liquid nitrogen to obtain clean cut for cross sectional view. The samples were then gold sputtered for producing electrical conductivity.

3. Results and discussion

A. SEM images of synthesized membranes

Figs. 1 and 2 present the SEM images of support layer without coating and composite membranes that were synthesized and used in this study. Surface images were shown in Fig. 1. Fig. 1a presents the PES support that was porous and the surface pores can be seen in the images. Different solvents used for the polymer solution behave differently during phase

inversion, which might also affect the porous structure of membrane. Fig. 1b presents the composite membrane surface. As can be seen, after coating, there is no pores on composite membrane surface and the surface is smooth.

SEM images of composite membrane surface demonstrated that the dense Pebax layer was coated uniformly on the surface of porous support membranes.

Fig. 2 presents the cross sectional images of composite and Pebax dense membranes. Based on the cross sectional images, no splits were found at the interface between the Pebax layer and the supports. Composite membranes were synthesized by varying the active layer thickness by coating with different thicknesses of Pebax solution on the sublayers. Figs. 2a, 2b and 2c present cross sectional SEM images that were made with two coating methods. The active layer thicknesses were different. Fig. 2a presents the cross sectional image of membrane that was prepared by pouring method and Figs. 2b and 2c present the cross sectional images of membranes that were prepared by film casting method. The top layer thicknesses in Figs. 2b and 2c were different.

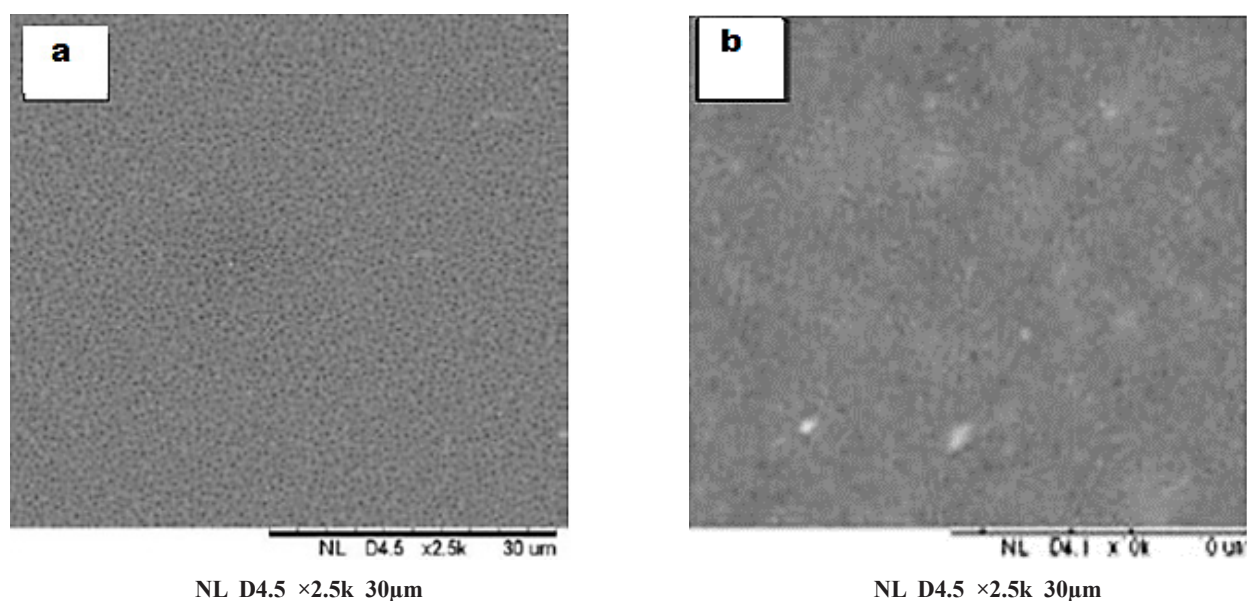


Figure 1. SEM images of (a) PES support surface and (b) composite membrane surface

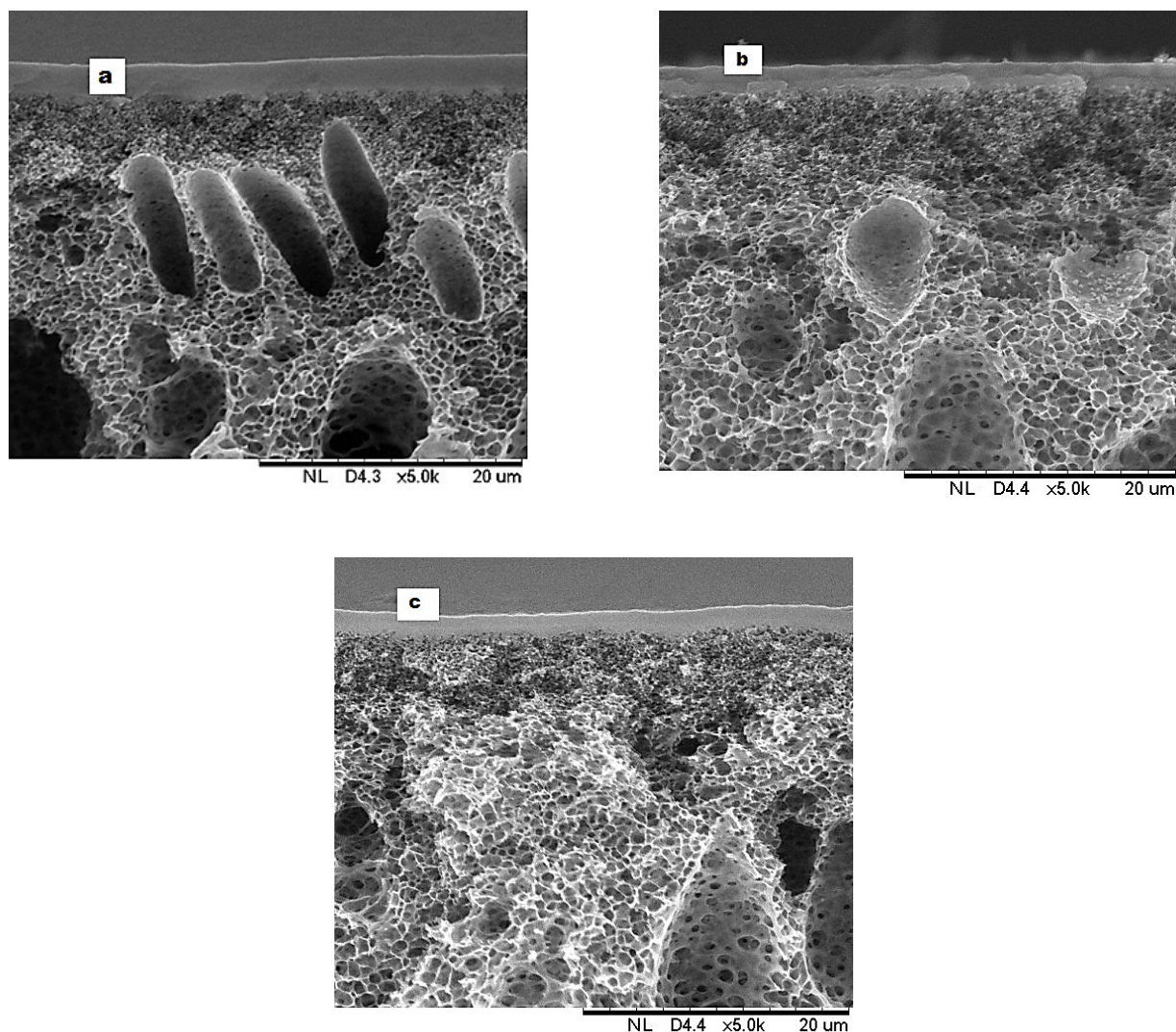


Figure 2. SEM cross sectional images of PES/Pebax composite membranes; (a) prepared by pouring method, (b, c) prepared by film casting method with different Pebax thicknesses

B. Pure gas permeation test

Pure CH_4 and CO_2 gases were used to determine the performance of the synthesized membranes. Initially, gas permeation properties were determined for the porous PES membrane

that was synthesized by phase inversion method. Permeances of both CH_4 and CO_2 gases for PES membrane at feed pressure and temperature of 1 barg (gauge pressure) and 25°C were shown in Table 1, which reveals that the support layer has less resistance for the gas permeation.

Table 1. CO_2 and CH_4 pure gas test results of supports and dense Pebax membranes

Membrane sample	CO_2 permeance (GPU)	CO_2/CH_4 selectivity
PES support	3700 ± 50	1.0
Dense Pebax	1.3 ± 0.05	26

The Pebax dense membrane that was prepared with thickness of 50 μm was also tested to measure the Pebax permeability at feed pressure and temperature of 4 barg and 25 °C and the obtained data was presented in Table 1. By considering the thickness of Pebax membrane (50 μm) that was determined by a digital micrometer, the permeability of carbon dioxide was 65 barrer. The CO₂ permeability for Pebax 1657 was reported as 55.8 and 72 barrer in other studies (Murali et al., 2014, Li et al., 2013b). As shown in Table 1, for support layer without coating, there was no selectivity because of its high porosity.

The properties of CO₂ and CH₄ gases have been listed in Table 2. It could be understood that the permeability of gases in rubbery membranes was mainly controlled by sorption and solubility. As mentioned previously, Pebax is a rubbery polymer and according to Table 2, due to the higher critical temperature of CO₂ than CH₄, that means the higher condensability of CO₂, the permeance of CO₂ should be much higher than CH₄ as it has been proved from Table 1. For Pebax dense membrane the CO₂/CH₄ selectivity

was 26 as shown in Table 1.

C. Effect of top layer coating method

One of the most important factors that affect permeation properties of composite membranes is coating technique. Film casting and pouring methods that are commonly used in composite membranes preparation, were compared in this study and the best method that has shown better separation properties has been introduced. Membranes were prepared by two methods of film casting and pouring and were tested by methane and carbon dioxide pure gases. In both methods, 4wt% Pebax solution in ethanol/water (70/30 vol/vol) is used for coating. In casting method the membranes was prepared by two different top layer thicknesses. For this purpose, different Pebax film thicknesses are considered for casting. After drying, the thickness of the upper layer has been identified by composite membranes cross sectional SEM images. The obtained results are presented in Table 3.

Table 2. Physical properties of CO₂ and CH₄ gases

Gas	Critical volume (cm ³ /mol)	Kinetic diameter (Å)	Critical temperature (K)
CO ₂	94.07	3.30	304.12
CH ₄	98.6	3.82	190.56

Table 3. Pure CO₂ and CH₄ permeances of Pebax/PES composite membranes at feed pressure and temperature of 4 barg and 25 °C

Membrane sample	Top layer coating method	Pebax layer thickness (μm)	CO ₂ permeance (GPU)	CH ₄ permeance (GPU)	CO ₂ /CH ₄ Selectivity
①	Pouring	2.6	8	0.28	28
②	Solution casting	1.7	8.6	0.53	18
③	Solution casting	2.4	7.2	0.42	19.5

As can be seen in Table 3, the prepared membranes by pouring method, as previously described, had higher CO_2/CH_4 selectivity and it is closer to the selectivity of dense Pebax membranes that was reported in Table 1. The high selectivity indicates better and defect-free coating. For samples No. 2 and 3 which were made by film casting method, from Table 3, the results show that the selectivity obtained for these samples is below the selectivity of dense Pebax membrane. The low selectivity in these samples is because of the defects were created during top layer formation. The existence of the pores causes methane and carbon dioxide to pass through these pores with the same rate. Therefore the membrane selectivity decreased. In sample No. 3, where the thickness of Pebax layer is higher, selectivity improved and permeability reduced. Increasing the thickness of upper layer leads to decrease in the probability of formation of large pores on the surface and the selectivity improves. By increasing the thickness of Pebax layer, the resistance of prepared membrane increased and in result the permeability decreased. In samples No. 1 and sample 3, the thickness of the selective layer is almost the same but CO_2/CH_4 selectivity in sample No. 1 is much more than that of sample No. 3 and this indicates that the coating method is important in identifying the gas separation properties of membranes. To achieve higher selectivity in coated membranes through film casting method, the thickness of upper layer should be increased and in turn the permeability will decrease. The difference in the permeability of membranes prepared with two methods depends on the overall resistance of composite membranes for gases.

D. Effect of feed pressure

The effect of feed pressure on permeability of gases in polymeric membranes depends on the polymer and gas structures. In rubbery membranes, the permeability of light gases is independent of pressure and by increasing the pressure, the permeability remains constant but the permeability of gases with high condensability the permeability increases by feed

pressure increment (Freeman et al., 2006). This increase in permeability is because of increasing gas absorption and solubility in membrane. Considering the fact that permeability of light gases (methane, hydrogen, ...) does not change with increasing the pressure, so the selectivity of rubbery membrane increases with increasing the pressure. Therefore, by increasing the feed pressure of the CO_2 pure gas, its permeability increases but for methane, the permeability is independent of pressure and because of this the CO_2/CH_4 selectivity increases by increasing the pressure. Figure 3 shows the CO_2 permeability and CO_2/CH_4 selectivity data and feed pressure for prepared composite membranes. Feed temperature is constant and was 25°C and feed pressure has been increased from 2 to 12 barg.

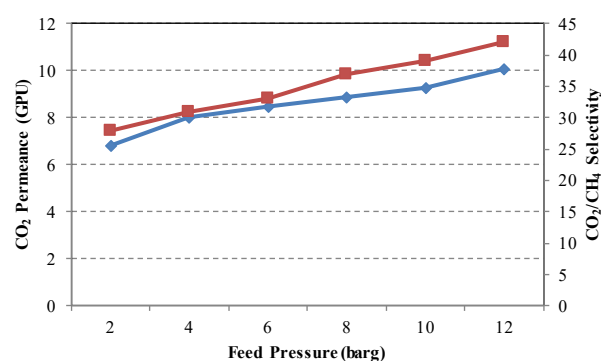


Figure 3. CO_2 permeance and CO_2/CH_4 selectivity versus feed pressure

In Fig. 3, it is observed that by increasing the feed pressure at constant temperature for pure gases, the carbon dioxide permeability and the CO_2/CH_4 selectivity have increased and as it was mentioned before, this behavior has been previously seen in rubbery membranes (Freeman et al., 2006).

E. Effect of feed temperature

Temperature plays an essential role in the separation properties of the membranes. Usually, the permeability of the components increases by increasing the temperature. The influence of temperature on permeability of pure gases of methane and carbon dioxide for Pebax/PES membrane has been investigated. The CO_2 and CH_4 permeability has been measured at three

temperatures of 25, 40, 55 °C and feed pressures of 2 and 4 barg. The obtained results are shown in Table 4. In this table, the relative selectivity that equals the selectivity of CO₂ /CH₂ at any temperature divided to selectivity at 298 K to show the selectivity reduction.

The temperature-dependence of the permeability is typically described by Arrhenius-like equations (Freeman et al., 2006):

$$P_A = P_{A0} \times \exp\left(-\frac{E_p}{RT}\right) \quad (3)$$

In the above equation, P_A is the permeability at temperature T , P_{A0} is the constant coefficient which is constant for each component and E_p is the activation energy of permeability. E_p with the equation (4) is related to E_D , activation energy of diffusion and enthalpy of sorption, ΔH_S .

$$E_p = E_D + \Delta H_S \quad (4)$$

The enthalpy of sorption can be thought of in terms of two contributions: where ΔH_{cond} is the enthalpy of condensation of the pure gaseous penetrant to the liquid phase and ΔH_{mix} is the partial molar enthalpy of mixing the condensed (or compressed) penetrant with the polymer segments. Therefore equation (4) can be written as follow:

$$E_p = E_D + \Delta H_{\text{cond}} + \Delta H_{\text{mix}} \quad (5)$$

The activation energy of diffusion is usually positive and it increases by increasing the size of the penetrating component. Condensation is energy producer and enthalpy change resulting from condensation of components

is negative. By increasing the condensability of components, the absolute value of the enthalpy of condensation will also increase. Enthalpy of mixing can be positive or negative, and it depends on the interactions between components and polymer. If there is a strong interaction between the component and the polymer chain, the enthalpy of mixing will be negative. Since the size of the methane molecule is larger than carbon dioxide, methane E_D is greater. Due to the high tendency of carbon dioxide to turn liquid and the strong interaction between the two polar bonds of CO₂ and ether groups in Pebax, the enthalpy of mixing and condensation of carbon dioxide is negative. Therefore, the E_p of methane is greater and at a similar temperature change, the permeability of methane increases more than carbon dioxide and in result the CO₂/CH₄ selectivity decreases by increasing the temperature. In Table 4, this reduction in selectivity by increasing temperature is observed. To better show the methane and carbon dioxide permeation change by temperature, the results were described in Figures 4 and 5. As can be seen, for both gases, permeance increased with increasing temperature. For both gases at 4 barg the permeance increased more than of increasing permeance at 2 barg for the same increasing in temperature. This behavior can be due to the fact that at higher pressures, the amount of existing gas in polymer is more and increasing the temperature leads to the more increase in both gasses diffusion, and the permeance increased more. But the CO₂/CH₄ selectivity reduction as reported in Table 4 is the same at both pressures.

Table 4. Pure CO₂ and CH₄ permeability for Pebax/PES composite membranes at different feed pressures and temperatures

Pressure (barg)	Temperature (K)	CO ₂ permeance (GPU)	CH ₄ permeance (GPU)	Relative selectivity
2	298	0.93	0.078	1
2	313	1.1	0.113	0.81
2	328	1.27	0.144	0.74
4	298	1.23	0.094	1
4	313	1.92	0.179	0.82
4	328	2.40	0.242	0.75

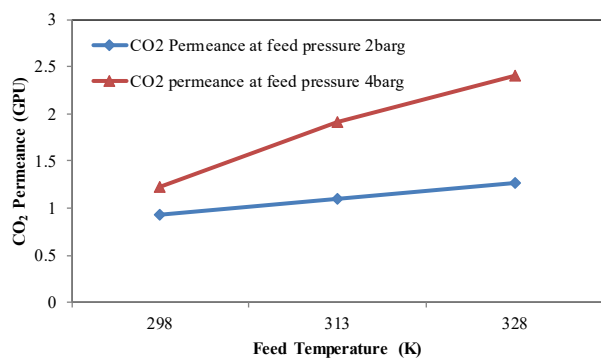


Figure 4. CO₂ permeance at different feed pressures versus feed temperature for Pebax/PES membrane

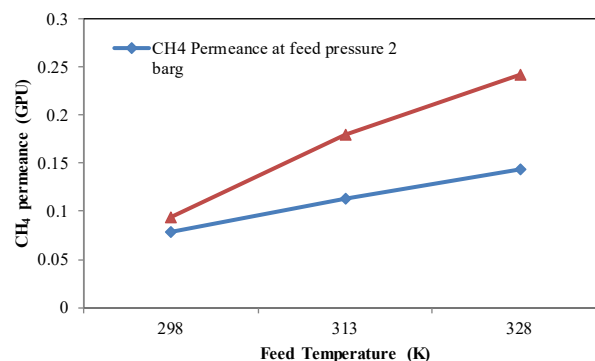


Figure 5. CH₄ permeance at different feed pressures versus feed temperature of Pebax/PES membrane

4. Conclusions

In this study, the effect of coating procedure (film casting and pouring) on the performance of prepared Pebax/PES composite membranes for separation of CO₂/CH₄ was investigated. The results showed that the CO₂/CH₄ selectivity for the membrane that was prepared via pouring technique was higher compared to the film casting procedure due to the defect-free Pebax layer formation. For film casting method, the CO₂/CH₄ selectivity was enhanced from 18 to 19.5 by increasing the top layer thickness from 1.7 to 2.4 μm. CO₂ and CH₄ permeance increased as the feed temperature increased from 25 to 55 °C. The effect of temperature on CH₄ permeance was dominated and in result the CO₂/CH₄ selectivity of Pebax/PES membranes decreased. The effect of feed pressure on performance of prepared Pebax/PES membranes was also studied. The results showed that CO₂ permeance increased from 6.8 to 10.1 GPU with an increase in feed pressure from 2 to 12 barg, while CH₄ permeance was remained constant and the CO₂/CH₄ selectivity increased from 27 to 42.

Acknowledgment

Authors would like to gratefully acknowledge Khorasan Razavi Gas Co. of Iran for their financial support.

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اثر روش پوشش و فشار و دمای خوراک بر عملکرد جداسازی دی اکسید کربن / متان غشاهای مرکب Pebax/PES

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چکیده

در این مطالعه غشای مرکب Pebax/PES با پوشش تک لایه Pebax-1657 بر روی لایه متخلخل PES ساخته شد. روش‌های ریخته‌گری و ریزش محلول برای پوشش لایه بالایی استفاده شدند. تأثیر روش پوشش و شرایطی مانند غلظت محلول Pebax و دما بر تراوش پذیری CO₂ و CH₄ غشاهای مرکب ساخته شده بررسی شد. تصاویر SEM برای بررسی ساختار غشاهای ساخته شده استفاده شد. گازهای خالص CO₂ و CH₄ برای بررسی خواص تراوش پذیری غشاهای ساخته شده در فشار و دمای خوراک به ترتیب ۱ تا ۱۲ barg و ۵۲ تا ۵۵ °C استفاده شدند. نتایج به دست آمده نشان داد که زیر لایه PES قبل از پوشش هیچ گزینش پذیری CO₂/CH₄ نداشته است. نتایج همچنین نشان داد که غشاهای ساخته شده با روش ریزش محلول گزینش پذیری CO₂/CH₄ بالاتری نسبت به غشاهای ساخته شده با روش ریخته‌گری داشته که این به دلیل شکل‌گیری لایه انتخابگر بدون نقص در حین پوشش با روش ریزش محلول است. تراوایی دی‌اکسید کربن و متان با افزایش دمای خوراک از ۲۵ تا ۵۵ °C افزایش یافت. نتایج همچنین نشان داد که با افزایش فشار خوراک از ۲ تا ۱۲ barg تراوایی CO₂ از ۶/۸ تا ۱/۱۰ GPU افزایش داشته، ضمن این که تراوایی متان تقریباً ثابت مانده و در نتیجه گزینش پذیری CO₂/CH₄ از ۲۷ به ۴۲ افزایش داشته است.

واژگان کلیدی: Pebax، غشای مرکب، جداسازی CO₂، روش پوشش، فشار خوراک، دما