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EFFECTS OF FEED PRESSURE AND RETENTATE FLOW RATE ON THE PERFORMANCE OF LOCALLY DEVELOPED POLYSULFONE MEMBRANE OXYGEN ENRICHMENT SYSTEM

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Abstract. Oxygen enrichment from surrounding air by using membrane is gaining wide acceptance through out the world today as an alternative to the conventional methods such as pressure swing adsorption and cryogenic system. Air separation using membrane is a more flexible process that requires lower capital investment and simple operation. Studies and testing had been performed on a locally new developed polysulfone hollow fiber membrane system, where effects of feed pressure and retentate flow rate on the oxygen enrichment were observed. At constant retentate flow rate, permeate enrichment increased and then decreased with pressure due to the effect of pressure difference across the membrane, which affects the permeability of the skin layer. While at constant pressure, the highest permeate enrichment value was obtained at highest retentate flow rate due to the increase of permeation resistance. The highest oxygen purity obtained in this experiment was 27.2% and the O_2 permeate enrichment was 1.295.

Key words: Air separation, hollow fiber membrane, oxygen enrichment, permeability, polysulfone

Abstrak. Pengkayaan oksigen daripada udara persekitaran dengan menggunakan teknologi membran diterima secara meluas di seluruh dunia sebagai teknologi alternatif kepada kaedah konvensional seperti penjerapan ayunan tekanan dan sistem kriogenik. Pemisahan udara menggunakan membran adalah proses yang lebih anjal di mana ia memerlukan pelaburan modal yang rendah, kaedah operasi yang mudah dan murah jika dibandingkan dengan kaedah konvensional. Kajian dan pengujian telah dijalankan ke atas sistem membran gentian geronggang polisulfona, di mana kesan tekanan suapan dan kadar alir baki dikaji. Pada kadar alir malar, pengkayaan telapan meningkat dan kemudian menurun dengan peningkatan tekanan disebabkan oleh kesan perbezaan tekanan merentasi membran mempengaruhi kebolehtelapan lapisan kulit. Manakala pada tekanan suapan malar, nilai pengkayaan telapan mksimum dicapai pada kadar alir maksimum disebabkan oleh peningkatan rintangan penelapan. Nilai maksimum ketulenan telapan oksigen yang diperolehi dalam uji kaji ini ialah 27.2%.

Kata kunci: Pemisahan udara, membran gentian geronggang, pengkayaan oksigen, kebolehtelapan, polisulfona

1.0 INTRODUCTION

Gas separation is a major industrial process, which involves enrichment of product stream, recovery of reactants, removal of impurities and dehumidification of the process streams. During the past two decades, separation processes using mem-

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branes have gained considerable potential in industrial applications. The simplicity and low capital investment of membrane systems have led to several advantages over conventional separation processes, which include cryogenic, pressure swing adsorption and others, whereas membrane systems primarily consist only a compressor and a membrane assembly.

Membrane can be defined essentially as a barrier, which separates two phases and restricts transport of various chemicals in a selective manner [1–3]. The membrane phase interposed between two bulk phases controls the exchange of mass between the two phases in a membrane process. In the membrane separation process, the bulk phases are mixtures. Permeate is defined as the fluid that passed through the semi-permeable membrane while retentate or reject is the constituents that have been rejected by the membrane [2–4].

Separation is achieved because of differences in the relative transport rates of the feed components. Components that diffuse more rapidly become enriched in the low-pressure permeate stream, while the slower components are concentrated in the retentate stream. The degree to which components are separated is governed by the ability of the membrane to discriminate between those components, as well as by the relative driving force of each component [1–3]. The objective of current paper is to present the effects of feed pressure and retentate flow rate on oxygen enrichment process on a locally developed polysulfone hollow fiber membranes system.

2.0 MEMBRANE OXYGEN ENRICHMENT

The availability of hollow fiber membranes and membrane modules has brought forth the development of simple processes for the production of oxygen and nitrogen from surrounding air. Membrane O_2 enrichment process is an air separation process where air from atmospheric is separated into one phase of O_2 enriched-air in permeate stream and one phase of N_2 enriched-air in retentate stream. Membrane O_2 enrichment system are based on the concept of continuous process. Hence, separation is achieved only if the system is maintained away from equilibrium state, where a continuous driving force must be applied. This is directly proportional to the pressure difference in the feed and permeate stream [2]. In this oxygen enrichment system, a compressor and regulator are used to pressurize the feed. While the permeate exits the module at atmospheric pressure and the retentate is available at essentially the same pressure as the compressed feed air.

In general, hollow fiber technology provides the module of choice for membrane oxygen enrichment. Hollow fibers can generally pack 3 to 30 times more working membrane area into a module of comparable volume. In addition, hollow fibers are self-supporting and resistant to collapse in high pressure and environmental difficult conditions [3]. For low purity applications, such as fermentation and combustion, single stage configuration is adequate based on investment cost effectiveness. This is because no additional costs are needed for further stages of separation.

According to the experimental work done by Ettouney and Majeed [5], studies show that membrane systems performance depend not only on the type of membrane used but also on the operating parameters such as pressure, flow rate, temperature, membrane effective area, flow patterns and feed composition. It is therefore very important that operation is carried out at an optimum condition to ensure higher efficiency of enrichment and lower cost performance.

3.0 EXPERIMENTAL

Figure 1 shows a schematic diagram for the experimental system. The system consists of a compressor for the feed gas, regulator, pre-treatment section that contains an air filter, a CO_2 trap and moisture trap, flowmeters and pressure gauges for measuring the flow rates and pressures of various streams, O_2 analyzer, valves and connection lines. Figure 2 shows the basis elements of the separation cell, which includes the feed and permeate compartments, the membrane and the feed, permeate and retentate streams. As shown, the feed compartment operates at a pressure of p_f, which is higher than permeate, p_p.

The membrane used in the experiment is locally produced polysulfone hollow fibers. The membrane module has a total separation area of 282.78 cm^2, where the

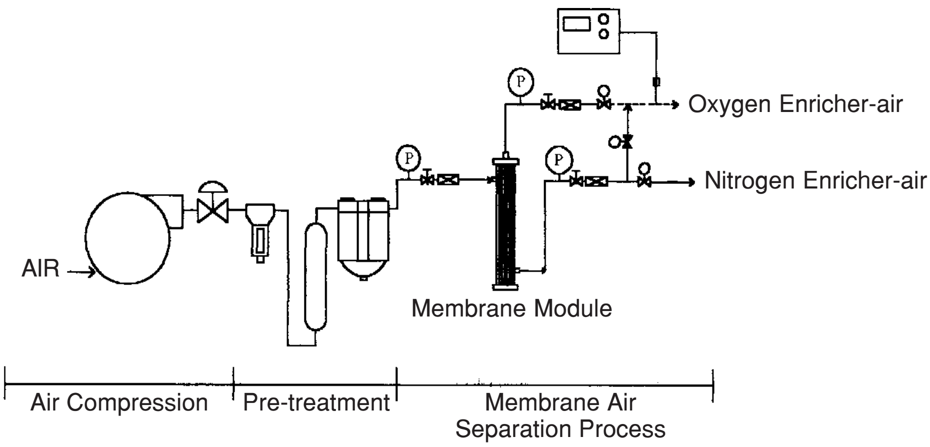

Figure 1 Schematic system flow diagram

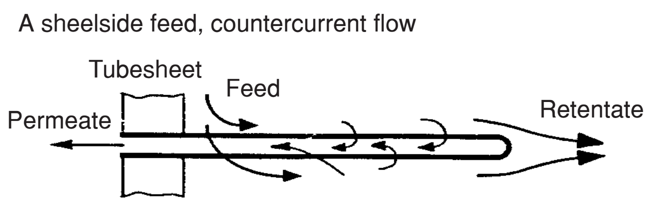

Figure 2 Shell side feed, countercurrent flow membrane module

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individual fiber has an average inner diameter of 0.3 mm and an outer diameter of 0.5 mm. The separation module has a total length of 30.00 cm and a diameter of 2.22 cm. The module was operated in a counter-current flow mode. The feed gas was introduced on shell side and the permeating stream was collected at the bore side of hollow fibers.

The measurement performed in the experiments include pressures and flow rates of feed and retentate stream, and also the purity variation of the permeate stream. The gas composition was determined by using oxygen analyzer, with accuracy (0.5% of the full measuring scale. The operating variables used to obtain the experimental data are the feed pressures and retentate flow rates. For each measurement, the instruments were allowed to adjust over a period of 15 minutes. All measurements were repeated 3 times to insure reproducibility of the results and consistency of membrane separation properties.

4.0 RESULTS AND DISCUSSION

The experimental results are tabulated in Table 3 and Table 4 as a function of the feed pressure and retentate flow rate. From the results, graph of O_2 permeate enrichment versus feed pressure and retentate flow rate were plotted in Figure 3 and

Table 3 Effect of feed pressure on permeate purity at constant retentate flow rate

Retentate flow rate at 25 LPM				
Feed Pressure, p_f (psig)	**Feed O_2 concentration, x_f (%)**	**Feed flow rate, V_f (LPM)**	**Permeate O_2 concentration, y (%)**	**O_2 permeate enrichment, P_e**
10.00	21.00	25.00	26.20	1.25
20.00	21.00	25.00	26.70	1.27
30.00	21.00	25.00	27.00	1.29
40.00	21.00	25.00	26.50	1.26
50.00	21.00	25.00	26.00	1.24
Retentate flow rate at 20 LPM				
Feed Pressure, p_f (psig)	**Feed O_2 concentration, x_f (%)**	**Feed flow rate, V_f (LPM)**	**Permeate O_2 concentration, y (%)**	**O_2 permeate enrichment, P_e**
10.00	21.00	20.00	26.00	1.24
20.00	21.00	20.00	26.60	1.27
30.00	21.00	20.00	26.90	1.28
40.00	21.00	20.00	26.50	1.26
50.00	21.00	20.00	25.90	1.23

(*cont.*)

Table 3 (*cont.*)

Retentate flow rate at 10 LPM				
Feed Pressure, p_f (psig)	**Feed O_2 concentration, x_f (%)**	**Feed flow rate, V_f (LPM)**	**Permeate O_2 concentration, y (%)**	**O_2 permeate enrichment, P_e**
10.00	21.00	10.00	25.90	1.23
20.00	21.00	10.00	26.30	1.25
30.00	21.00	10.00	26.60	1.27
40.00	21.00	10.00	26.30	1.25
50.00	21.00	10.00	25.60	1.22

Table 4 Effect of retentate flow rate on the permeate purity at constant feed pressure

Feed pressure at 50 psig				
Retentate flow rate, V_R(LPM)	**Feed flow rate, V_f (LPM)**	**Feed O_2 concentration, x_f (%)**	**Permeate O_2 concentration, y (%)**	**Permeate O_2 Enrichment, P_e**
10.00	10.00	21.00	25.60	1.22
20.00	20.00	21.00	25.90	1.23
30.00	30.00	21.00	26.00	1.24
40.00	40.00	21.00	26.10	1.24
Feed pressure at 40 psig				
Retentate flow rate, V_R(LPM)	**Feed flow rate, V_f (LPM)**	**Feed O_2 concentration, x_f (%)**	**Permeate O_2 concentration, y (%)**	**Permeate O_2 Enrichment, P_e**
10.00	10.00	21.00	26.30	1.25
20.00	20.00	21.00	26.50	1.26
30.00	30.00	21.00	26.60	1.27
40.00	40.00	21.00	26.70	1.27
Feed pressure at 30 psig				
Retentate flow rate, V_R(LPM)	**Feed flow rate, V_f (LPM)**	**Feed O_2 concentration, x_f (%)**	**Permeate O_2 concentration, y (%)**	**Permeate O_2 Enrichment, P_e**
10.00	10.00	21.00	26.60	1.27
20.00	20.00	21.00	26.90	1.28
30.00	30.00	21.00	27.10	1.29
40.00	40.00	21.00	27.20	1.30

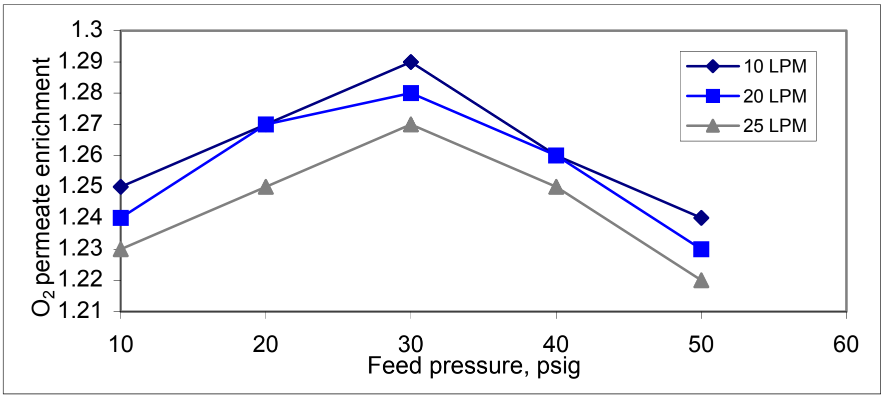

Figure 3 O_2 permeate enrichment versus feed pressure

Figure 4. According to Figure 3, O_2 permeate enrichment at every constant retentate flow rate, increases from 0 to 30 psig and then decreases with increasing pressure from 30 to 50 psig. The figure 3 indicates that the optimal operating pressure obtained from this experiment is at 30 psig. According to Figure 4, O_2 permeate enrichment slightly increases with increasing retentate flow rate. In this experiment, the purity of oxygen in permeate stream achieved the increment up to 30%.

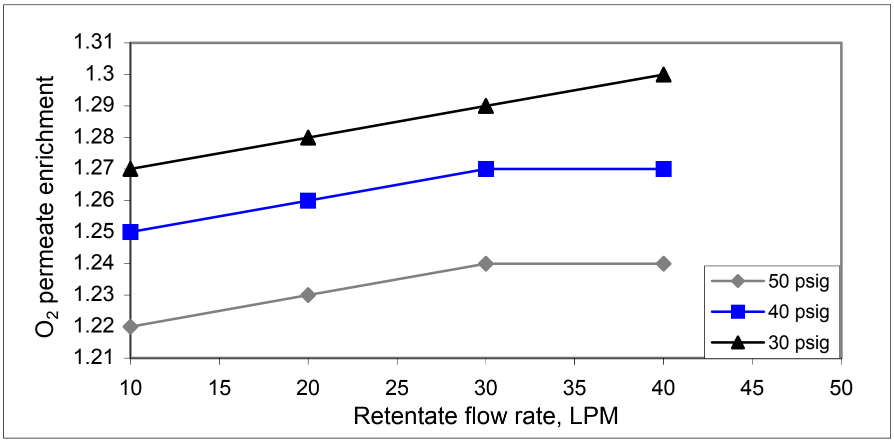

Figure 4 O_2 permeate enrichment versus retentate flow rate

4.1 Effects of Pressure on O_2 Permeate Enrichment

O_2 permeate enrichment is defined as the permeate O_2 concentration over feed O_2 concentration. As shown in Figure 3, increasing the feed pressure from 10 to 30 psig resulted in the increase of the pressure difference across the membrane as well as the driving force for the separation process. In addition, the increase in species permeability as a function of pressure is caused by the increase in species solubility and diffusivity, with higher values for O_2 of the faster permeating species. Hence, more O_2 diffused through the membrane and as a result, the permeate purity increases. However, at this condition the available driving force is insufficient for the permeation of low solubility N_2 into the membrane [5].

Further increases of feed pressure from 30 to 50 psig, the O_2 permeate enrichment decreases monotonically. This phenomenon was also reported by previous researchers [5, 9]. The separation factor decreases faster when increasing the feed pressure. In this condition, the less permeable gas will permeate through the membrane more significantly. The fiber diameter changes due to the applied pressure difference on the membrane causing compression on fiber. Since the membrane resistance increases as previously porous regions of the membrane are compressed and densified, this will increase the thickness of the effective skin. Consequently, permeability of O_2 will decrease. As a result, the O_2 permeate enrichment decrease at high pressure accordingly.

4.2 Effects of Retentate Flow Rate on O_2 Permeate Enrichment

As shown in Figure 4, the effect of the retentate flow rate on the species permeance is detectable when comparing values at the highest and lowest flow rates. This difference is caused by the higher gas transport resistance and stage cut reduction within the membrane, which is caused by reduction in gas residence time at higher flow rates [5]. As a result the O_2, which have higher permeability than N_2 will permeate at higher rate than N_2 through the membrane. Also at higher flow rates it is possible that the feed gas may bypass some portion of the hollow fiber area especially N_2, a low solubility molecules.

Theoretically, concentration polarization exists in all membrane separation processes because of the selective permeability of membrane. It has serious adverse effects in membrane separation processes. It leads to a decrease in the driving force for the more permeable species, O_2 across the membrane and an increase for the less permeable species, N_2 [3, 10]. This reduces the overall efficiency of separation and raises the costs of capital and operation. Increasing retentate flow rates will provides a smooth flow on the membrane surface and reduce converge molecules on the membrane area, which do affect the permeability of O_2 into the permeate stream. As a result, O_2 permeate enrichment increases with increases the retentate flow rate.

5.0 CONCLUSION

Experiment has been executed to analyze the performance of oxygen enrichment in the locally developed polysulfone membrane system based on feed pressure and retentate flow rate. The results showed that the oxygen purity in the permeate stream increased with increasing feed pressure from 10 psig to 30 psig. However, the increment was only up to a certain feed pressure level. After that pressure range, the oxygen purity was found to decrease with increasing feed pressure from 30 psig to 50 psig due to the passage of larger amount of feed gas through the membrane. In the effect of retentate flow rate, at constant feed pressure, the O_2 purity slightly increases with increasing retentate flow rate. At these conditions, the permeation resistance is high and the O_2, which has higher permeability will permeate through the membrane at higher rate than N_2.

From this study the purity of oxygen-enriched air is not high, however the system developed clearly proved that the membrane fabricated locally has good potential to be developed for oxygen enrichment. The maximum O_2 permeate enrichment achieved was about 1.295 or 27.2%. This value is acceptable when compared with the current commercially available membrane material. Higher value of enrichment can be achieved if larger membrane area is employed.

The current research successfully proves that the locally produced hollow fibers membranes and the system developed have a good potential in producing O_2 enriched-air system for industrial application.

NOTATIONS

PP	partial pressure	psig
TP	total pressure	psig
p_f	feed pressure	psig
y	permeate O_2 concentration	% by volume
x_f	feed O_2 concentration	% by volume
Vf	feed flow rate	Liter per minute (LPM)
V_r	Reject flow rate	Liter per minute (LPM)
P_e	O_2 permeate enrichment	% O_2 in permeate/% O_2 in feed

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