EFFECT OF FEED TEMPERATURE AND COMPOSITION OF PROPANE ON THE SEPARATION OF CARBON DIOXIDE – METHANE – PROPANE BY USING HOLLOW FIBER MEMBRANE

By

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12830

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

JAN 2013

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CERTIFICATION OF APPROVAL

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Approved by,

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(DR LAU KOK KEONG)

Date: 15^{th} September 2013

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JAN 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I, Rafiq Hakim Bin Razali (I/C No: 900622-01-6351), am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Carbon dioxide, CO_2 is known with its corrosive properties when react with water. Therefore, CO_2 is needed to be removed from the natural gas to avoid it from damaging the pipelines and equipment. Nowadays, there are a lot of method to separate CO_2 from natural gas such as physical absorption, chemical absorption, adsorption process and also membrane technology. A simple technology such as membrane technology is suggested to be applied to remove CO_2 from natural gas especially at remote and unattended situation like offshore area. This is because separation using membrane technology is known with its high efficiency and less cost. However, the research conducted on multi-component separation of CO_2 from natural gas using hollow fiber membrane is very limited nowadays. Most of them are more focusing on binary component separation. So, this project is conducted to study evaluate the permeability of multi-component separation of CO_2-Methane-Propane by changing the parameters which are feed temperature and composition of propane. First of all, the hollow fiber membrane is potted into the module shell before tested at the test rig. The experiment is conducted by using Carbon Dioxide Separation Membrane Unit (CO2SMU) facilities. The result obtained from this experiment will be used to analyze between the membrane permeability and the parameters. Based on result, the permeability is decrease as the feed temperature increase. Meanwhile, as the propane composition is increases, the permeability is also decrease.

ACKNOWLEDGEMENT

Thanks to God, whom with His willing giving me the opportunity to complete this Final Year Project. First and foremost, I would like to express my deepest gratitude to my helpful supervisor Dr. Lau Kok Keong, who has guided and support me during these two semester sessions to complete this project.

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Not to forget, to all my friends and work mates especially Tan Et Kuan and Ponmani Sivagnanam for their cooperation, encouragement, constructive suggestion and full of support for this project completion, from the beginning till the end. Thanks to everyone who has been contributing by supporting my work during the final year project progress till it is fully completed.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

As the year increase, the demand for natural gas increases rapidly. Natural gas consist of methane, ethane, propane, butane, higher molecular weight hydrocarbon and other impurities. Carbon dioxide, CO_2 is acid gas contains in natural gas. High CO_2 content in natural gas is one of the major problem that we are facing nowadays. CO_2 will become very corrosive when react with water and it can destroy pipelines and equipment.

Separation of carbon dioxide, CO_2 can be done in many of ways. Numerous of CO_2 separation processes have been developed and improved from time to time in order to optimize the capital cost and operating cost, to meet gas specifications, and for environmental purpose. Among the processes available for CO_2 separation are absorption processes (chemical and physical absorption), adsorption process (solid surface), hybrid solution (mixed physical and chemical solvent) and also physical separation (cryogenic separation and membrane).

However, to separate CO_2 at offshore situation need a more simple separation technology. In this case membrane technology is suitable to be applied. Gas separation using membrane technology is an essential unit operation in various industrial separations including petrochemical, gas processing and also biotechnology. Nowadays, hollow fiber membrane module is becoming widely used in the industrial separations because of its low capital cost, less space requirement, high efficiency, lower energy requirement, and chemical-free operation.

Membrane can be defined as a thin barrier placed between two mediums or phases which allow one or more constituents to selectively pass from one medium to another while retaining the rest. (Dutta, 2007).

1.2 PROBLEM STATEMENT

1.2.1 Problem identification

CO_2 need to be removed from natural gas before the gas is transported through the pipelines. It can destroy pipelines and equipment because the mixture of CO_2 and water is very corrosive. A simple process technology to remove CO_2 from natural gas is needed to be applied at remote, unattended, or offshore situations. In this scenario, hollow fiber membrane seems the best method to separated CO_2 from the natural gas. Many researches have been done to study the separation CO_2 from natural gas. However, most of them are focusing on binary component separation. So, this research is done to focus on multi component separation (CO_2-Methane-Propane) by using hollow fiber membrane.

1.2.2 Significant of the project

The aim of the project is to study the relationship between the changes in the in parameters (feed temperature and propane concentration) and the efficiency of the CO_2 removal using a multi-component hydrocarbon feed; CO_2, CH_3 and $C_3H_{8.}$ The experiment will be conducted using feed of different propane concentration and feed temperature to obtain data for the study. This can be used to evaluate and optimize the membrane system used to remove CO_2.

1.3 OBJECTIVE

1. To evaluate the permeability of CO_2-Methane-Propane separation at different feed temperature
2. To evaluate the permeability of CO_2-Methane-Propane separation at different Propane composition

1.4 SCOPE OF STUDY

The scope of this project is to conduct a literature review on removal of CO_2 from natural gas (methane and propane) stream using hollow membrane and the effect of feed temperature and propane composition. The next step is to proceed with conducting experiment on fabrication of hollow fibre membrane for different parameters that affect the separation process. Through this project student is exposed to explore research problems and build research objectives, applying appropriate methodology, analysing and interpreting data obtained from the experiment, troubleshooting any predicaments occur ad also reporting the findings.

1.5 THE RELEVANCY OF PROJECT

Availability of a simple process technology that can be applied in remote, unattended, or offshore situations is highly desirable. Membrane based system provide a simple, low-cost, compact solution to separate CO_2 from natural gas. This project is conducted so that the performance of hollow fiber membrane can be investigated based on the parameter which are the feed temperature and propane composition in the mixture of CO_2-Methane-Propane.

1.6 FEASIBILTY OF THE PROJECT

This project encompasses experimental work. The experimental work will be conducted by using Carbon Dioxide Separation Membrane Unit (CO2SMU) which is available at Block N in Universiti Teknologi Petronas. This project can be done within 8 months given that everything goes well. The objective can be achieved if the procedures are accurately followed.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

There were a lot of literatures found about the study on carbon dioxide separation from natural gas stream by using hollow fiber membrane technology. Therefore, these literatures would be very helpful reference and guideline to study on how the feed temperature and propane composition affect the CO_2 – methane – propane separation by using hollow fiber membrane.

2.1.1 Membrane Definition and Classifications

Membrane is defined as selective barrier between two phases that has ability to transport one component than the other (Mulder, 1996). Membrane applications attracting a broad range of applications such as for sea water desalination, waste-water treatment, and ultrapure water production for semiconductor industry and nitrogen enrichment from air. Each of these applications requires specific type of membrane morphology to ensure the effective separation (Iqbal, 2007).

Generally, membrane morphologies are classified into two categories, symmetric and asymmetric membrane (Mulder, 1996). Symmetric membrane is the membranes that have essentially same structure and transport properties throughout its thickness while asymmetric membrane is a membrane constituted of two or more structural planes of non-identical morphologies (Koros, 1996).

2.1.2 Hollow Fiber Membrane

Hollow fiber membrane can be defines as a capillary having an inside diameter of larger than 25 µm and outside diameter less than 1mm; and its wall functions as semipermeable membrane (Kirk-Othmer, 2004). Commonly, hollow fiber membranes are used as cylindrical membranes that permit selective exchange of materials across the walls. However they can also be used as reactors to chemically modify a permeate as it diffuses through a chemically activated hollow fiber wall.

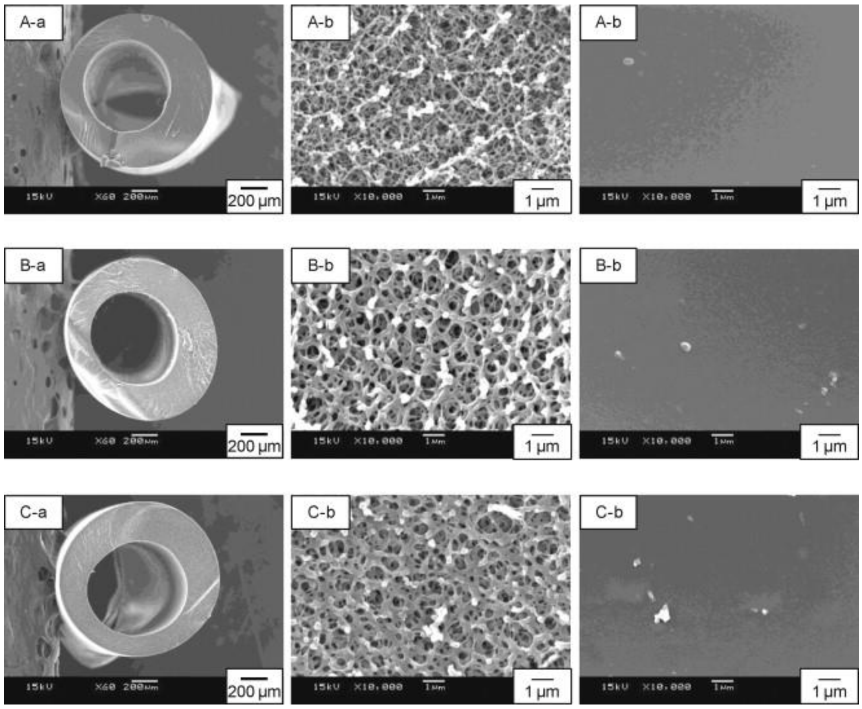

Figure 1: SEM image on hollow fiber membrane. a: cross-sectional; b: inner surface; couter surface. (Kirk-Othmer, 2004)

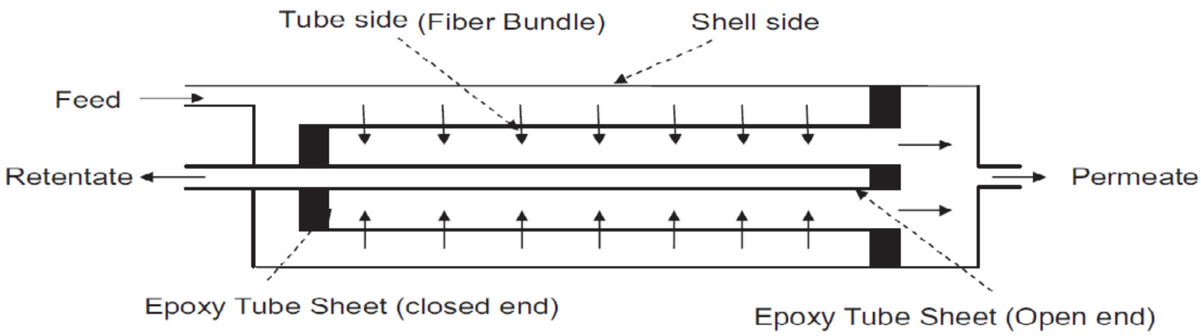

Figure 2: Schematic diagram of hollow fiber membrane separation (Kirk-Othmer, 2004)

Nowadays, the applications of hollow fiber membrane in industrial separation become wider due to its capabilities such as high efficiency, lower energy requirement, chemical-free operation, etc. (Katoh, 2011). Conventional hollow fiber membrane models in process simulators usually assume constant membrane permeance (independent temperature and pressure).

Recently, Faizan et al (2013) proposed a new simulation model to study the effect of temperature and pressure of the membrane permeates. Simulations are performed to study the effect of stage cut and temperature drop on membrane permeance of CO_2 and CH_4. As a result, it can be seen that permeance of both CO_2 and CH_4 decreases with the increase in stage cut. This is because of the increment of stage cut will increase the temperature drop which results in change of CO_2 and CH_4 permeance being dependent on temperature. Feed pressure also affects the membrane permeance. This is due to the mass transport of the membranes for the separation of CO_2 and CH_4 mixtures is determined by competitive sorption and plasticization.

2.1.3 Past researches done on CO_2 separation using membrane

No	Author	Year	Objectives	Findings
1	Qin et al.	2005	To investigate the effect of shear rate within the spinneret on CO_2/CH_4 separation performance.	1. The CO_2/CH_4 selectivity of the copolyimide dense film decreased significantly with an increase in temperature. 2. The performance of as-spun fibers was obviously influenced by the shear rate during spinning. For uncoated fibers, permeances of CH_4 and CO_2 decreased with increasing shear rate, while selectivity of CO_2/CH_4 sharply increased with shear rate until the shear rate reached 2169 s^{-1} and then

				the selectivity leveled off. 3. After silicone rubber coating, permeances of CH_4 and CO_2 decreased, the selectivity of CO_2/CH_4 was recovered to the inherent selectivity of its dense film. Both the permeances and selectivity with increasing shear rate followed their same trends as that before the coating. 4. There was an optimal shear rate at which a defect-free fiber with a selectivity of CO_2/CH_4 at 42.9 and permeance of CO_2 at 53.3 GPU could be obtained after the coating.
2	Chenar et al.	2006	To investigate the effect of water vapor on the performance of commercial polyphenylene oxide and Cardo-type polyimide hollow fiber membranes in CO_2/CH_4 separation applications	1. The presence of water vapor in the feed stream significantly reduced the permeation rates of both CO_2 and CH_4 through hydrophilic Cardo-type polyimide hollow fiber membrane. The separation factor and selectivity, however, remained the same because the permeation rates of both gases were declined to the same extent. 2. A small decline in the permeation rate of CO_2 was observed through PPO hallow fiber membrane, but CH_4 permeation rate was not affected significantly. As a

				result, a decline in the separation factor and selectivity of this membrane was observed.
3	Mohd Jefri b Yusof	2010	1. To study on carbon dioxide separation from natural gas using inorganic membrane. 2. To study on characteristics of the inorganic membrane when treated with natural gas on certain operating conditions. 3. To study on permeability and ideal selectivity of carbon dioxide on inorganic.	1. Higher feed flowrate and higher feed pressure gave higher permeability, but it gave almost same permeability. 2. Carbon dioxide has higher selectivity than methane, average value of 3.5 which mean that carbon dioxide permeate through membrane 3.5 faster than methane. 3. Selectivity of both gas reduced as the feed pressure increased. 4. Increase carbon dioxide concentration from 15% to 30%, based on analysis, has lower methane recovery in retentate stream
4	Atchariyawut et al.	2007	To investigate the effect of gas and liquid velocity, concentration of NaOH solution, absorbent temperature, and NaCl concentration on the CO_2 flux on separation of CO_2 from CH_4 using gas-liquid membrane contacting process.	1. CO_2 flux was enhanced by the increase of NaOH solution concentration, NaOH solution temperature and the CO_2 volume fraction in the feed stream 2. Increase of water temperature resulted in decreasing the CO_2 flux
5	Nurul Safiah Binti Mat Dagang	2010	1. To synthesize membrane with higher porosity	1. Porosity percentage increases when starch drop is increased.

			than 22.53 % (up to 25-30 %). 2. To synthesize membrane that provides high permeability and selectivity higher than 1.37 (up to 1.66 ideal separation factor). 3. To evaluate the performance of the synthesized membrane.	2. It shows that starch can be used as a binder to control the porosity of alumina support. 3. Flux is also increases when the inlet flow rate and inlet pressure are increased. However, flux decreases as the dip coating hours is increased. 4. The permeability decreases as the inlet pressure is increased due to concentration of gas molecules approaches saturation in the inlet side.
6	Shuji Himeno	2007	To study the synthesis and permeation properties of DDR-Type Zeolite Membrane for CO_2/CH_4 separation gaseous mixture.	1. In mixed-gas permeation experiments using the sweep method, the DDR-type zeolite membrane showed high selectivity for CO_2/CH_4 mixtures of 200 and high CO_2 permeance. 2. DDR zeolite membranes were compared to other zeolite membranes for evaluation of their CO_2/CH_4 selectivity and CO_2 permeance; the DDR-type zeolite membranes show better CO_2/CH_4 separation and CO_2 permeance.

7	Hedayat et al.	2011	To investigate the effect of temperature, pressure, gas and liquid flow rates, absorbent concentration and acid gas content of the feed.	1. The presence of CO_2 in feed gas decreased the $H2_S$ removal. However, increase of CO_2 concentration had a stronger negative influence on removal efficiency of itself compared with H_2S. 2. Pressure had a positive effect on the removal efficiency. 3. Temperature had no significant effect on H_2S removal, but decreased the CO_2 removal and thus enhanced H_2S selectivity.
8	Schrier	2012	To study carbon dioxide separation with a two-dimensional polymer	1. Developed a Langmuir-adsorption model to calculate the effect of surface adsorption of gases on membrane permeance 2. Simulated the CO2 separation from N_2 and CH_4 using hydrocarbon polymer, PG-ES 3. The CO_2 permeance is 3 × 10^5 gas permeation units (GPU) 4. The CO_2/N_2 selectivity is 60, and the CO_2/CH_4 selectivity exceeds 500
9	Jahn et al.	2013	To study CO_2 flux obtained from different membrane processes through experiments	1. Made a comparison of CO_2 flux obtained from different membrane processes through experiments using pure gas and also binary gas of CO_2-H_2 and CO_2-CH_4 2. CO_2 flux across selective membrane is higher for inorganic membrane and membrane contactors compared to

				polymer membrane 3. CO_2 flux is decreasing with increasing permeate side pressure whereas the CO_2 flux increases with increase in feed pressure
10	Yang et al.	2009	the effect cross flow model and co-current flow model	3.1 Difference between the cross-flow model and the other co-current model is insignificant 3.2 Increasing feed side pressure and decreasing permeate side pressure, decreases the membrane area required and increases CH_4 recovery 3.3 • Achieved CH_4 recovery of more than 98% and product purity of more than 98% by the single-stage system using membrane selectivity of 20%
11	Scholes et al.	2012	To study the current and future potential of polymeric membranes in acidic gas removal, heavy hydrocarbon recovery, water dehydration as well as nitrogen and helium separation	1. Polymeric membrane in natural gas separation have been successfully proven and efficient processes have been implemented 2. Membrane gas separation will grow in this market as the technology is increasing seen as commercially competitive and less high risk

2.1.4 Research Gap

From the literature review, it can be concluded that membrane system is one of the best methods to separate CO_2 from natural gas due to its advantages compared other technology in terms of operational cost and space requirement. Numerous of studies have been done on membrane separation technology.

The research are basically divided into simulation of development of mathemathical model, membrane performance, development of new membrane and optimization of existing membrane.

However, there are still lack of researches done on multi component separation. Most of them are focused on binary component separation. Therefore, there is still a large gap between the lab-scale and the real application in the industry. There is uncertainty over the effectiveness of these membranes under industrial conditions where the feed gas is made up of multi component. It can be clearly seen that there is a gap in understanding the effect of multi component feed on the membrane performances.

2.2 Theory

2.2.1 Flux and Permeability Concept

According to Munirah (2012), flux is one of the membrane transport where flux is expressed by the unit of [mol.m^{-2}.$s^{-1}$$Pa^{-1}$]. As opposed to flux which is normalized per unit pressure, permeation or permeability is normalized per unit thickness [mol.m.m^{-2}.$s^{-1}$$Pa^{-1}$].

2.2.2 Transport Mechanism

Basile (2011) stated that there are a few transport mechanisms for membrane such as surface diffusion, Poiseuille (Viscous) mechanism, Knudsen mechanism et cetera.

Surface Diffusion

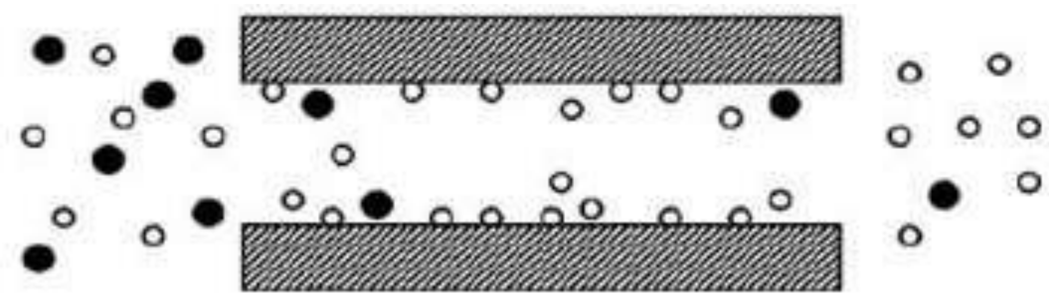

Figure 3: Surface Diffusion (Basile, 2011)

This mechanism is achieved when one of the permeating molecules is adsorbed on the pore wall. This type of mechanism can reduce the effective pore dimensions obstructing the transfer of different molecular species.

Capillary Condensation

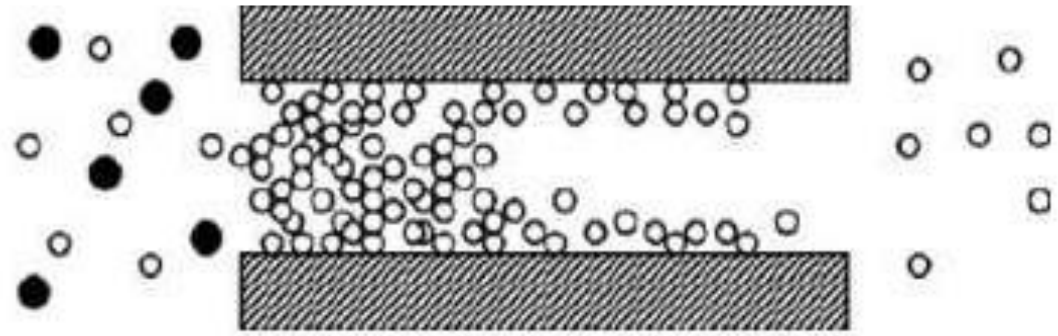

Figure 4: Capillary Condensation (Basile, 2011)

This type of mechanism takes place when one of the components condenses within the pores due to capillary forces. Generally, the capillary condensation favours the transfer of relatively large molecules.

Molecular Sieving

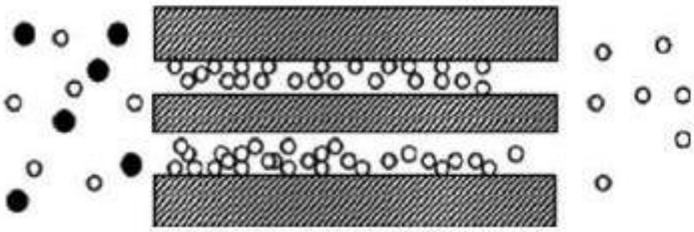

Figure 5: Molecular Sieving (Basile, 2011)

This takes place when pore diameters are very small, allowing the permeation of only the smaller molecules.

Multi-layer Diffusion

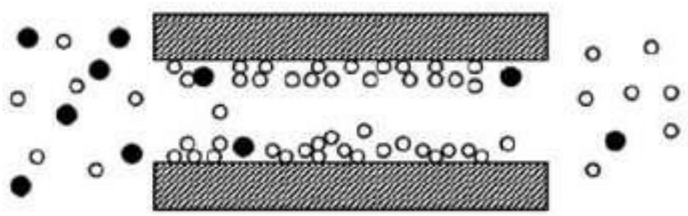

Figure 6: Multi-layer Diffusion (Basile, 2011)

When the molecule–surface interactions are strong multi-layer diffusion occurs. This mechanism is like to an intermediate flow regime between surface diffusion and capillary condensation.

Poiseuille (Viscous) Mechanism

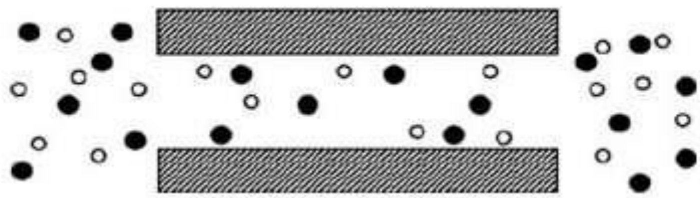

Figure 7: Poiseuille (Viscous) Mechanism (Basile, 2011)

This mechanism occurs when the average pore diameter is bigger than the average free path of fluid molecules. In this case, no separation takes place.

Knudsen Mechanism

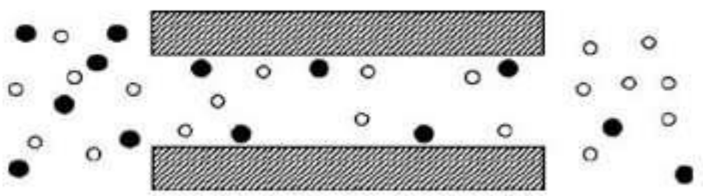

Figure 8: Knudsen Mechanism (Basile, 2011)

When the average pore diameter is similar to the average free path of fluid molecules, Knudsen mechanism takes place.

CHAPTER 3:

METHODOLOGY

3.1 Research Methodology and Project Activities

The methodology for conducting this research project is exploration and discovery. As this project is mainly an empirical research, the results obtained from this research can be used to compare with other literature results. The project activities in this research are mainly experimental work. After thorough literature review is done, experimental works can be conducted to investigate the effect of feed temperature and composition of propane toward the separation of CO_2 - Methane – Propane.

3.2 Experimental Procedures/Approach

The figure below shows the general experimental procedures that will be implemented in this research project.

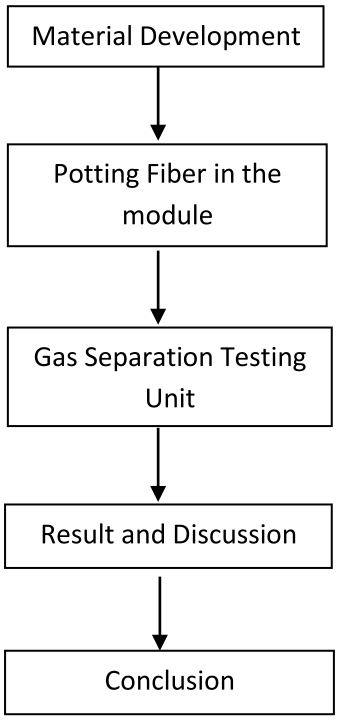

Figure 9 : The schematic diagram depicting the general approach in this project

3.2.1 Lab scale hollow fiber membrane module

The commercial modules diameters usually vary from 1 to 12 inches. For lab-scale module, the preferred diameter is around ½ in to ¾ in. One of the most important parameters to measure the effects of mass and heat transfer when module sizes change is the packing density. Packing density of a hollow fiber membrane module can be defined as the fraction of the cross-section of all fibers over the cross-section area of the module, where

$$\text{packing density } (\phi) = \text{no. of fibers } (n) \times \frac{\text{cross-section area of a fiber } (A_{\text{fiber}})}{\text{cross-section area of module } (A_{\text{module}})}$$

$$\phi = n \times \frac{(\text{o.d.}_{\text{fiber}})^2}{(\text{i.d.}_{\text{module}})^2}$$

Lab-scale hollow fiber membrane module with high packing density should meet these requirements:

a) The packing density should be near to the packing density of commercial one. (Usually above 45%)
b) The assembling and dismantling process should be as easy as possible; commercially available parts, apparatus and materials are preferred for the module construction.

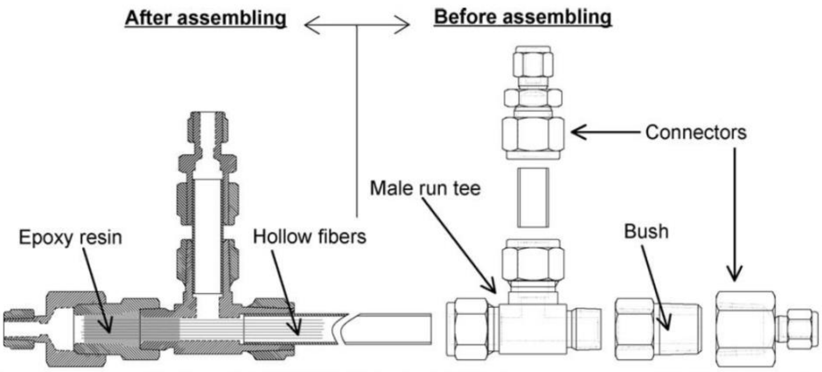

Figure 10: The hollow fiber membrane module structure

Figure 11: The lab-scale hollow fiber membrane module structure

3.2.2 Potting fibers in the module

- Fiber bundle preparation
  - (a) With assumption of 20% - 50% of packing density, the number of fiber and the length of fiber required are calculated based on the diameter and length of module.
  - (b) The fiber is cut into desired length. Then, placed the fibers in parallel order and placed the together as a fiber bundle.
  - (c) A piece of Parafilm M® is cut with a dimension of about 40 mm long and 10 mm wide. After removing the paper backing, the Parafilm is stretched to four or five times of its length. The end of the fiber bundle is wrapped with the stretched Parafilm. The ed of the fiber bundle will become denser because of the shrinkage of the film.
  - (d) The wrapped end is cut with a sharp razor to get a smooth end.
  - (e) A layer of Araldite® 5 Min is applied to the smooth end before the epoxy is applied.
  - (f) The smooth end is encircled with a thin string as show on Figure 6 (D).

- Module assembly
  - (a) The shell is placed vertically and leaves sufficient space under the module to accommodate the fiber bundle.
  - (b) The fiber bundle is pulled through the shell lumen and placed at designated position of the shell. The untied end of the fiber bundle is suspended freely, thus the fiber will become ordered and packed naturally when being pulled into the shell.

(c) Seal both ends of the shell with epoxy adhesive.

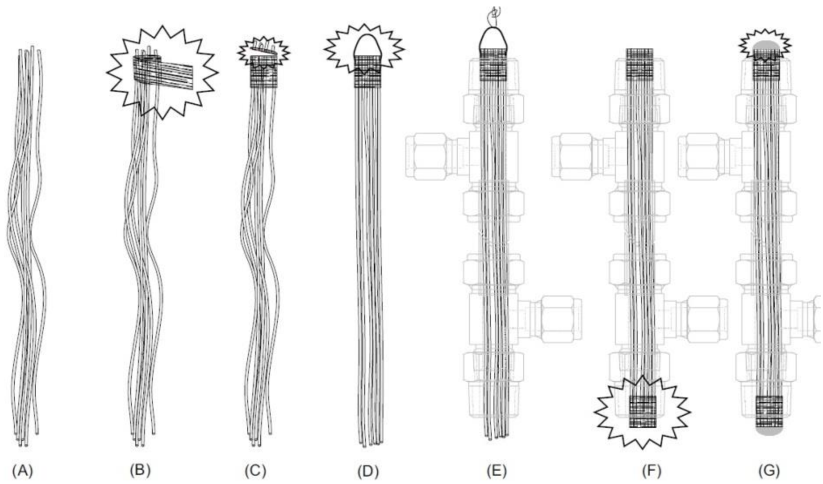

Figure 12: Budle preparation and module assembly

Figure 13: Epoxy adhesive

- Post treatment after casting

The solidified epoxy resin located outside the module tube sheets is removed with a hand drill and a clean cross-section is cut using a sharp operating blade (knife), clean-up residual epoxy resin on the thread area, and seal two tube sheets of the module by connectors and reducing unions.

Figure 14: Removing solidified epoxy resin using hand drill

3.2.3 Gas separation testing unit

Hollow fiber membrane module is installed in the experimental set up as shown in diagram below.

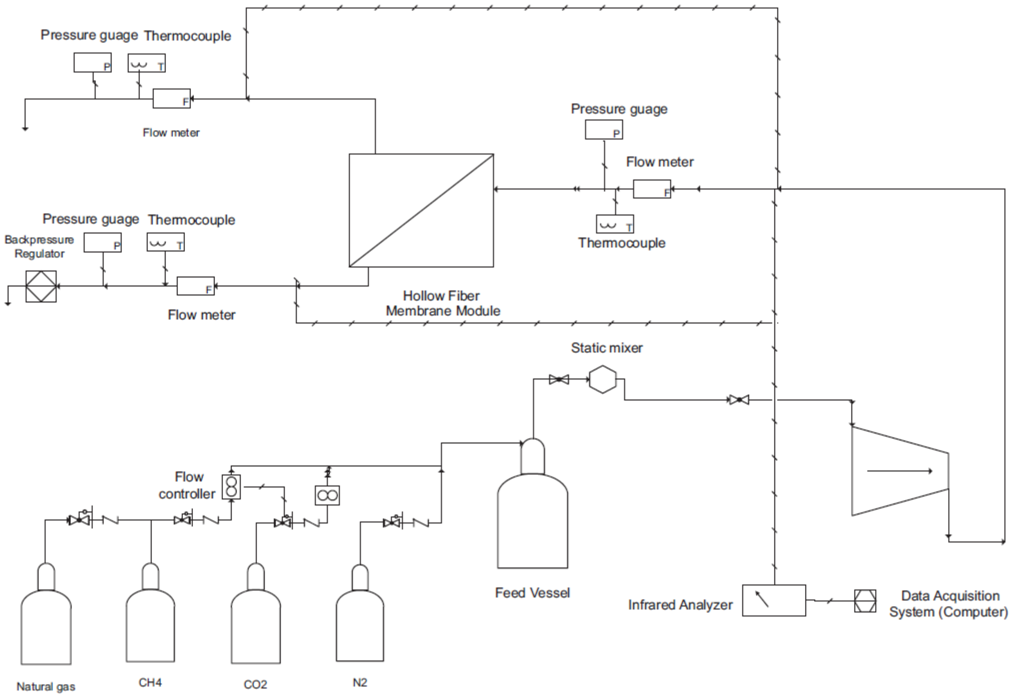

Figure 15: Flow sheet of gas separation testing unit for experimental validation.

The testing unit mainly consists of gas cylinders, mass flow controllers, compressor, and infrared analyser. Natural gas (with impurities) and pure methane can be used alternatively in the set up. In addition, nitrogen is used for purging the separation system. In the current study, pure methane, propane and CO_2 are used to evaluate the performance of separation system. Thermocouples and pressure gauges are installed before and after the permeation test cell to monitor the temperature and pressure drop across the membrane module. Furthermore, a back pressure regulator is fixed after the membrane module in order to generate trans-membrane pressure required for the separation of gases. The whole system except feed cylinders and compressor is placed in an oven to maintain the temperature of system and isolate from external effects. Coriolis flow meters are used to measure the mass flow rates of streams. Similarly, Infrared analyzer is used to measure the composition of feed, permeate and retentate streams. They are connected to data acquisition system in order to record the gas concentrations of streams at different times.

3.3 The effect of feed temperature

The first part of this project is conducted to study the effect of feed temperature to the separation of $CO_2 – CH_4 – C_3H_8$. Four sets of feed temperature values (40^{o}C, 50 ^{o}C, 60 ^{o}C and 70 ^{o}C) were used to investigate the parameter. Each set of experiment was conducted for 3 hours. The condition of the experiments in this part is as follow:

Feed Pressure	= 9 Bar
Back Pressure	= 8 Bar
CO_2 Flowrate	= 3 L/min
CH_4 Flowrate	= 2 L/min
C_3H_8 Flowrate	= 1 L/min
No of Fiber Used	= 10

3.4 The Effect of Propane composition

The second part is conducted to investigate the effect of feed temperature to the separation of CO_2 – CH_4 – C_3H_8. So, four sets of propane composition values (4%, 6%, 8% and 10%) are used to investigate the parameter. Time taken for each set to be conducted is 3 hours. These are the conditions of the experiment of this part:

Feed Temperature	= 70^oC
Feed Pressure	= 9 Bar
Back Pressure	= 8 Bar
No of Fiber Used	= 10

3.5 Gantt Chart

3.5.1 Final Year Project 1

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	First meeting with coordinator and supervisors															
2	Literature review compilation and analysis															
3	Start to write the Extended proposal															
4	Submission of Extended Proposal (First Draft)															
5	Submission of Extended proposal (Final Draft)															
6	Proposal Defense															
7	Cleaning the module and potting fiber															
8	Request for CO2SMU Lab Booking for FYP 2															
9	Purchase the gas required (Propane and Pentane)															
10	Submission of Interim Draft Report															
11	Submission of Interim Report															

	Completed Activities
	Uncompleted Activities

3.5.2 Final Year Project 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Potting the fiber into the module														
2	Experiment: Feed Temperature = $40^{o}C$														
3	Experiment: Feed Temperature = $50^{o}C$														
4	Experiment: Feed Temperature = $60^{o}C$														
5	Experiment: Feed Temperature = $70^{o}C$														
6	Experiment Propane Composition = 4 %														
7	Experiment Propane Composition = 6 %														
8	Experiment Propane Composition = 8 %														
9	Experiment Propane Composition = 10 %														
10	Start to write Progress Report														
11	Submission of Progress Report (Final Draft)														
12	Preparation for Pre-SEDEX (Poster, presentation, etc.)														
13	Pre-SEDEX														
14	Submission of Dissertation (soft bound) and Technical Paper														
15	Oral Presentation														
16	Submission of Project Dissertation (Hard Bound)														

CHAPTER 4:

RESULT AND DISCUSSION

4.1 Effect of Feed Temperature

The study of feed temperature effects on gas permeance is done by selecting feed temperature range of 40ºC to 70ºC and operating pressure of 9 bar.

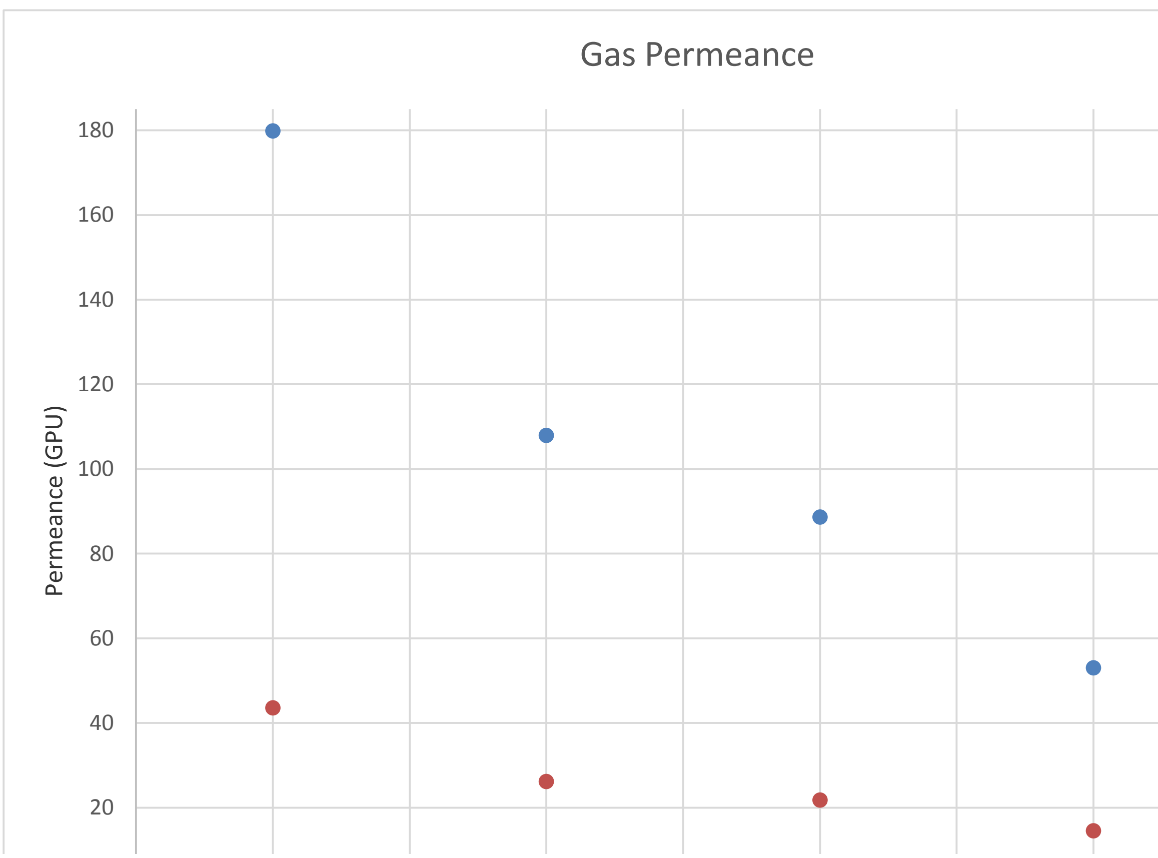

Figure 16: Graph of Permeance vs Feed Temperature

From the result, it is observed that the permeance of CO_2 is decreasing as the feed temperature increase. The same trend occurred to methane and propane. This situation can be explained by the relationship of temperature and permeability as shown in the surface diffusion equation:

$$P_{s,i} = \frac{2\varepsilon^2 t_m (1-\varepsilon) D_{s,i} \rho_m f_i}{z\tau^2 RPT r_{p,i}}$$

Where:

$P_{s,i}$ = is permeability of gas as a result of surface diffusion

ε = porosity

τ = tortuosity

t_m = membrane thickness

ρ_m = membrane density

f_i = loading factor

As the temperature increase, the permeability will decrease and that is why the permeance increase when the feed temperature increases. In the graph, it is observed that at feed temperature 40°C gives the highest permeance. Therefore, it is clear that permeance will decrease as temperature increases. This statement is also supported by Boributh (2009) where it is stated that when the temperature increase will caused decreasing in flux.

Most hydrocarbon streams also contain some portion of water that will cause the CO_2 to become soluble in water as temperature increases. The water could also vaporize and block at the membrane pores, thus, inhibiting other species to pass through (Boributh, 2009).

In addition, Safari (2009) told that the relationship between the cost and the operating temperature is proportional. So, when the temperature increase, the cost will increase and this situation makes higher temperature become less attractive.

4.3 Effect of Propane Composition

Based on the result obtained from this part, the graph of permeance vs gas composition is plotted.

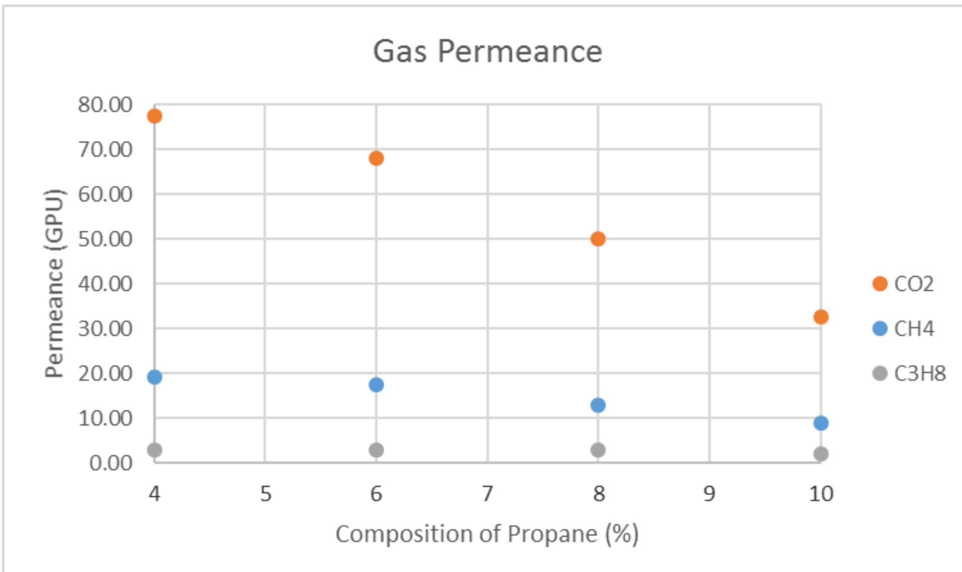

Figure 17: Graph of Gas Permeance vs Propane Composition

For this part, the study of different propane composition (4%, 6%, 8% and 10 %) is done at operating temperature and pressure of 40°C and 9 bar respectively. The feed CO_2 concentration is kept at 50% for all sets of experiment in this part as mentioned by Cakal (2012) that CH_4 permeation detected in the gas chromatograph is very limited in CO_2 rich mixture. From the result, it is observed that as the propane composition increases the permeance of CO_2, CH_4 and C_3H_8 is decreasing. This is due to CH_4 and C_3H_8 loss to permeate side.

In higher feed propane composition, the methane and propane loss is higher due to initial abundance presence of methane and propane molecules in the treated stream as compared to CO_2, which caused the tendency for methane and propane loss to the permeate site is higher. Therefore, the permeance of the gas is decreases.

CHAPTER 5:

CONCLUSION

This project aimed to study the effect of feed temperature and propane composition on the separation of CO_2 - CH_4 - C_3H_8. Basically this project is divided into two parts according to the parameter of study.

The first part of the study is focusing on effect of feed temperature on the gas permeability. From the result, the gas permeability increases as the feed temperature increase.

The second part focused on the other parameter which is propane composition. Holistically, the propane composition increment will caused the gas permeabily to decrease due to CH_4 and C_3H_8 loss to permeate side.

In conclusion, the main objective of this project which is to study the effect of feed temperature and the propane composition to the separation of CO_2 - CH_4 - C_3H_8 is achieved.

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APPENDIX

Data and result obtained from the experiment:

The first part of this project is conducted to study the effect of feed temperature to the separation of CO_2 – CH_4 – C_3H_8. So, four sets of feed temperature values (40^oC, 50 ^oC, 60 ^oC and 70 ^oC) are used to investigate the parameter. Each set of experiment is conducted for 3 hours. Table below show the data and composition (in vol %) of Carbon Dioxide, Methane and Propane for each sets of experiment.

Set 1:

Feed Temperature	= 40^oC
Feed Pressure	= 9 Bar
Back Pressure	= 8 Bar
CO2 Flowrate	= 3 L/min
CH4 Flowrate	= 2 L/min
C3H8 Flowrate	= 1 L/min
No of Fiber	= 10

	Manifold 1 (Feed)	**Manifold 2 (Feed)**	**Manifold 1 (Retentate)**	**Manifold 4 (Permeate)**
Pressure (Bar)	9	9	8	0.03
Temp (^oC)	40	39	40	39
Flow (kg/hr)	0.32	0.63	58.80	57.00
CO2 Composition (Vol %)	58.80	30.10	39.20	39.94
CH4 Composition (Vol %)	39.20	21.09	2.00	3.06
C3H8 Composition (Vol %)	2.00	48.81	58.80	57.00

Set 2:

Feed Temperature = 50^{o}C
Feed Pressure = 9 Bar
Back Pressure = 8 Bar
CO2 Flowrate = 3 L/min
CH4 Flowrate = 2 L/min
C3h8 Flowrate = 1 L/min
No of Fiber = 10

	Manifold 1 (Feed)	Manifold 2 (Feed)	Manifold 3 (Retentate)	Manifold 4 (Permeate)
Pressure (Bar)	9	9	8	0.03
Temp (ºC)	50	39	40	39
Flow (kg/hr)	0.37	0.63	0.62	0.02
CO2 Composition (Vol %)	58.80	52.60	52.50	90.80
CH4 Composition (Vol %)	39.20	36.86	37.70	8.00
C3H8 Composition (Vol %)	2.00	10.54	9.80	1.20

Set 3:

Feed Temperature = 60^{o}C
Feed Pressure = 9 Bar
Back Pressure = 8 Bar
CO2 Flowrate = 3 L/min
CH4 Flowrate = 2 L/min
C3h8 Flowrate = 1 L/min
No of Fiber = 10

	Manifold 1 (Feed)	Manifold 2 (Feed)	Manifold 3 (Retentate)	Manifold 4 (Permeate)
Pressure (Bar)	9	9	8	0.03
Temp (ºC)	60	39	40	39
Flow (kg/hr)	0.56	0.63	0.61	0.02
CO2 Composition (Vol %)	58.80	34.50	35.60	89.50
CH4 Composition (Vol %)	39.20	24.17	24.57	8.00
C3H8 Composition (Vol %)	2.00	41.33	39.83	2.50

Set 4:

Feed Temperature = 70ºC
Feed Pressure = 9 Bar
Back Pressure = 8 Bar
CO2 Flowrate = 3 L/min
CH4 Flowrate = 2 L/min
C3h8 Flowrate = 1 L/min
No of Fiber = 10

	Manifold 1 (Feed)	Manifold 2 (Feed)	Manifold 3 (Retentate)	Manifold 4 (Permeate)
Pressure (Bar)	9	9	8	0.03
Temp (ºC)	70	39	40	39
Flow (kg/hr)	0.61	0.63	0.60	0.03
CO2 Composition (Vol %)	58.80	30.10	31.90	80.30
CH4 Composition (Vol %)	39.20	21.09	21.30	8.00
C3H8 Composition (Vol %)	2.00	48.81	46.80	11.70

Feed Temperature (ºC)	Permeance (GPU)		
	CO_2	CH_4	C_3H_8
40	179.84	43.57	4.72
50	107.9	26.14	1.51
60	88.63	21.79	1.45
70	53.01	14.52	0.87

Table 1: Effect of Feed Temperature on Gas Permeance

The second part of this project is conducted to study the effect of propane composition to the separation of CO_2 – CH_4 – C_3H_8. So, four sets of feed temperature values (4%, 6%, 8% and 10 %) are used to investigate the parameter. Each set of experiment is conducted for 3 hours. Table below show the data and composition (in vol %) of Carbon Dioxide, Methane and Propane for each sets of experiment. Each set of experiment is conducted for 3 hours. The condition and result obtained from this part is as follow:

Set 1:

Feed Temperature = 40^oC
Feed Pressure = 9 Bar
Back Pressure = 8 Bar
CO2 Flowrate = 5 L/min
CH4 Flowrate = 4.6 L/min
C3H8 Flowrate = 0.4 L/min
No of Fiber = 10

	Manifold 1 (Feed)	Manifold 2 (Feed)	Manifold 3 (Retentate)	Manifold 4 (Permeate)
Pressure (Bar)	9	9	8	0.03
Temp (^oC)	40	39	40	39
Flow (kg/hr)	1.11	1.13	1.12	0.01
CO2 Composition (Vol %)	50.00	50.00	31.90	88.9
CH4 Composition (Vol %)	46.00	46.00	48.81	8.00
C3H8 Composition (Vol %)	4.00	4.00	19.29	3.10

Set 2:

Feed Temperature = 40^{o}C
Feed Pressure = 9 Bar
Back Pressure = 8 Bar
CO2 Flowrate = 5 L/min
CH4 Flowrate = 4.4 L/min
C3H8 Flowrate = 0.6 L/min
No of Fiber = 10

	Manifold 1 (Feed)	Manifold 2 (Feed)	Manifold 3 (Retentate)	Manifold 4 (Permeate)
Pressure (Bar)	9	9	8	0.03
Temp (^{o}C)	40	39	40	39
Flow (kg/hr)	1.11	1.13	1.12	0.01
CO2 Composition (Vol %)	50.00	50.00	35.60	86.00
CH4 Composition (Vol %)	44.00	44.00	48.13	8.00
C3H8 Composition (Vol %)	6.00	6.00	16.27	6.00

Set 3:

Feed Temperature = 40^{o}C
Feed Pressure = 9 Bar
Back Pressure = 8 Bar
CO2 Flowrate = 5 L/min
CH4 Flowrate = 4.2 L/min
C3H8 Flowrate = 0.8 L/min
No of Fiber = 10

	Manifold 1 (Feed)	Manifold 2 (Feed)	Manifold 3 (Retentate)	Manifold 4 (Permeate)
Pressure (Bar)	9	9	8	0.03
Temp (^{o}C)	40	39	40	39
Flow (kg/hr)	1.11	1.13	1.12	0.01
CO2 Composition (Vol %)	50.00	50.00	38.6	84.1
CH4 Composition (Vol %)	42.00	42.00	45.61	8.00
C3H8 Composition (Vol %)	8.00	8.00	15.79	7.90

Set 4:

Feed Temperature = 40°C
Feed Pressure = 9 Bar
Back Pressure = 8 Bar
CO2 Flowrate = 5 L/min
CH4 Flowrate = 4.0 L/min
C3H8 Flowrate = 1.0 L/min
No of Fiber = 10

	Manifold 1 (Feed)	Manifold 2 (Feed)	Manifold 3 (Retentate)	Manifold 4 (Permeate)
Pressure (Bar)	9	9	8	0.03
Temp (°C)	40	39	40	39
Flow (kg/hr)	1.19	1.25	1.24	0.01
CO2 Composition (Vol %)	50.00	50.00	52.50	82.50
CH4 Composition (Vol %)	40.00	40.00	44.68	8.30
C3H8 Composition (Vol %)	1.00	1.00	2.82	9.20

Composition (%)			Permeance (GPU)		
CO_2	CH_4	C_3H_8	CO_2	CH_4	C_3H_8
50	46	4	179.84	43.57	4.72
50	44	6	107.9	26.14	1.51
50	42	8	88.63	21.79	1.45
50	40	10	53.01	14.52	0.87

Table 2: Effect of Propane Composition on Gas Permeance