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EFFECT OF VARIOUS OPERATING CONDITION TO THE PERMEATION RATE OF CARBON DIOXIDE

By

Tg. Mohd Hazwan B. Tg. Zainal Alam Shah

Petroleum Engineering

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Dissertation submitted in partial fulfillment
of the requirements for the
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(Petroleum Engineering)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Geosciences and Petroleum Engineering Department
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons.)
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Approved by,

(AP. Aung Kyaw)

Aung Kyaw
Associate Professor
Geosciences & Petroleum Engineering Department
Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750 Tronoh
Perak Darul Ridzuan, Malaysia.

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
August 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work that submitted in this project, that the original work is my own except as specified in references and acknowledgment, and the original work contained herein have not been undertaken or done by unspecified sources of persons.

(TG MOHD HAZWAN B. TG. ZAINAL ALAM SHAH)

ABSTRACT

The repot focus on acid gas removal technology that is membrane technology that currently being used widely in industry to remove acid gas such as carbon dioxide. Membrane is one of the technologies that currently ongoing rapid research & development to cater the problem of carbon dioxide that recently keep on increasing in gas field.

The performance of membrane is depending on two factors that are membrane material and processing condition. To achieve better flux, correct membrane material as well as correct processing condition is needed. Therefore, the effect of various operating condition to the performance of membrane is investigated. The performance of membrane is evaluated based on observing the effect of various operating condition such as feed temperature, feed pressure and permeate pressure to the permeation rate of carbon dioxide.

The scope of study revolves around adjusting differences operating condition such as feed temperature, feed pressure as well as permeate pressure and see the effect to the permeation rate of carbon dioxide. The study is carried out by using simulation software available called HYSYS simulator and incorporated with visual basic for calculation part. The process flow diagram that consists of flow stream, compressor, heater and membrane is built. Then, simulation start with allowing carbon dioxide to flow through these components until they reach membrane where from there, carbon dioxide is permeated through permeate channel. After running the simulation, the result that obtained is analyzed and discussed.

It was found that the effect of various operating condition such as feed temperature, feed pressure and permeate pressure give significantly impact to the performance of membrane in terms of permeation rate of carbon dioxide. Therefore, we need to take a consideration regarding operating condition when come to design or optimize the performance of membrane.

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Tg. Mohd Hazwan B. Tg. Zainal Alam Shah,

Petroleum Engineering
University Technology Petronas

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CHAPTER 1: INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, gas field that produce gas contain an elevated contents of carbon dioxide which above the specific limit of 8 % in gas sales. It is commonly found in natural gas streams as high as 80%. Carbon dioxide, which falls under category of acid gases need to be removed from the natural gas streams. In combination with water, it is highly corrosive and rapidly destroys pipelines and equipment unless expensive construction material is used. Carbon dioxide also reduces the heating value of a natural gas streams and waste pipeline capacity. In LNG plant, carbon dioxide must be removed to prevent freezing in the low-temperature chillers [5].

Currently, there are a lots of acid gas removal technologies available at the market such as adsorption process, absorption process such as the Benfield process(hot potassium carbonate solution) and Amine Guard-FS process, physical separation like cryogenic as well as hybrid solution and the latest one is development of membrane system technology[4]. Decision in selecting a carbon dioxide removal process can be simplified based on gas composition and operating condition. Every acid gas removal system has its own operating condition in order to enhance its capability to operate more efficient. For this project, membrane system has been chosen to study its operating condition in order to operate the membrane system well to achieve target sales quality as low as 8%.

Membranes are thin semi permeable barrier that selectively separate some compounds from others and membrane materials used for carbon dioxide removal are polymer based like cellulose acetate. Membrane operates based on the principle of solution-diffusion through nonporous membrane. It allows selective removal of fast gases from slow gases. Because carbon dioxide under category of fast gas, it permeate quickly than hydrocarbon gases.

The performance of membrane is depending on its material and operating condition. In order to design and optimize the performance of membrane, we need to take consideration these both things. For this project, the author had decided to focus more on operating condition. The effect of various operating condition such as feed temperature, feed pressure and permeate pressure are expected to give significant impact to the performance of membrane. Therefore, through this project, the effect of various operating condition to the permeation rate of carbon dioxide is investigated.

1.2 PROBLEM STATEMENT

Recently, carbon dioxide is rapidly increasing as level as 80% in the gas field. To cater this problem, acid gas removal is needed. One of the acid gas removals is membrane system. The important thing that we should concern is to know the performance of membrane itself. One also should know whether various operating condition give significant effect to the membrane or not. If it is yes, this must be taken care when designing the membrane system as well as optimizing the performance of membrane.

1.3 OBJECTIVE OF STUDY

The Objective of the research project is to study the effect of various operating condition such as feed temperature, feed pressure and permeate pressure to the permeation rate of carbon dioxide.

1.4 SCOPE OF STUDY

The scope of study for this research project revolves around adjusting the various operating condition such as feed temperature, feed pressure and permeate pressure of membrane. This will be done through running simulation software called HYSYS simulator as well as visual basic for design and calculation. The result gained will be investigated to see the effect of wide range of operating condition on the permeation rate of carbon dioxide.

1.5 THE RELEVANCY OF PROJECT

Removal of carbon dioxide from natural gas is currently become a global issue as it commonly found in natural gas at level as high as 80%. In the future, this amount of gas is expected to increase in Peninsular Malaysia gas field as high as 40%. The acid gas removal technology is needed in order to reduce this amount of carbon dioxide to meet the certain specific limit in gas sales. Recently, one of the acid gas removal that rapidly ongoing research & development is membrane system. The performance of membrane is studied in term of membrane material as well as its operating condition.

Therefore, through this research project, study need to be made to see the effect of various operating condition to the performance of membrane. The performance is evaluated based on permeation rate of carbon dioxide through membrane. Hence, the outcome of this project is deemed crucial to make membrane even more natural choice in the future especially for application requiring higher level of carbon dioxide removal.

1.6 FEASIBILITY OF PROJECT WITHIN THE SCOPE AND TIME FRAME

The objective stated earlier is achievable and feasible within the project scope and time frame. The data that will be used is available in the research journal. to the Within the period of this final year project, result gained from running the simulation software called HYSYS simulator that already available at UTP will be managed to analyzed and discussed to provide the solution for problem statement.

CHAPTER 2: LITERATURE REVIEW & THEORY

2.1 LITERATURE REVIEW

Many process parameters can be adjusted to optimize performance depending on the customer and application needs. Optimization is most critical for larger systems where small improvements can bring large rewards. Some typical requirements are low cost, high reliability high on-stream time, easy operation, high hydrocarbon recovery, Low maintenance, low energy consumption, low weight and space requirement. Many of these requirements work against one another: for example, a high-recovery system usually requires a compressor, which increases maintenance costs. The design engineer must therefore balance the requirements against one another to achieve an overall optimum system [5]. Below are membrane configuration types as well as process flow of membrane system.

2.1.2 Configuration Type of Membrane Element

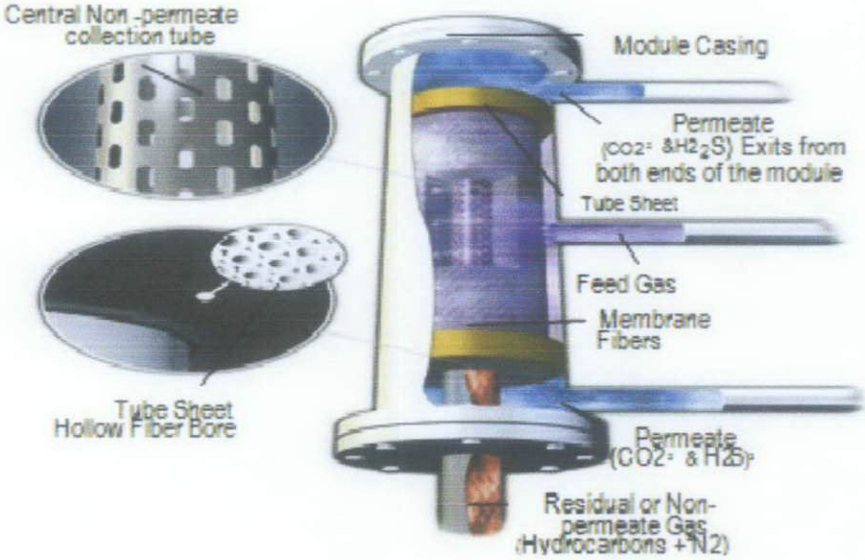


Figure 1:Hollow Fiber

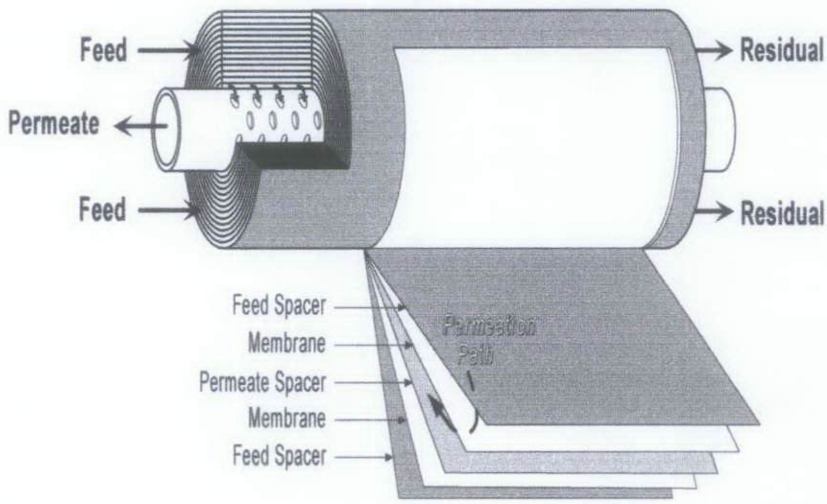


Figure 2: Spiral Wound

2.1.3 Process Flow For Membrane

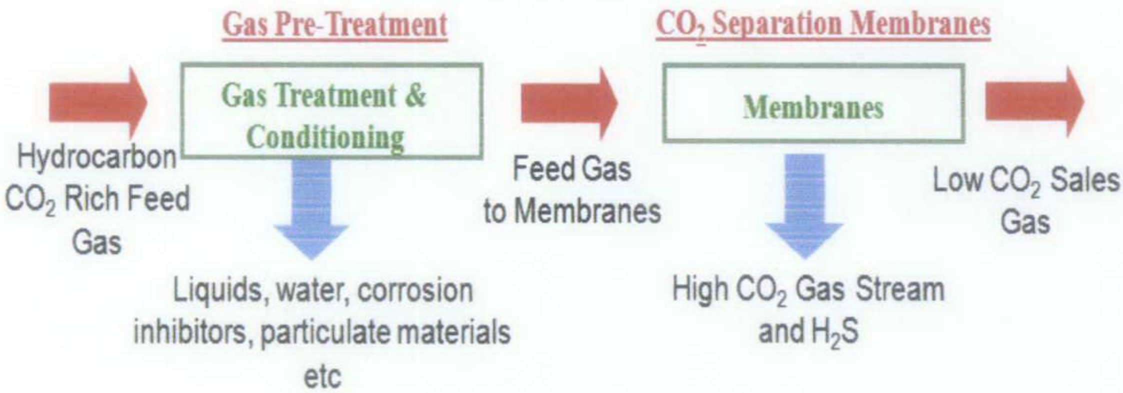
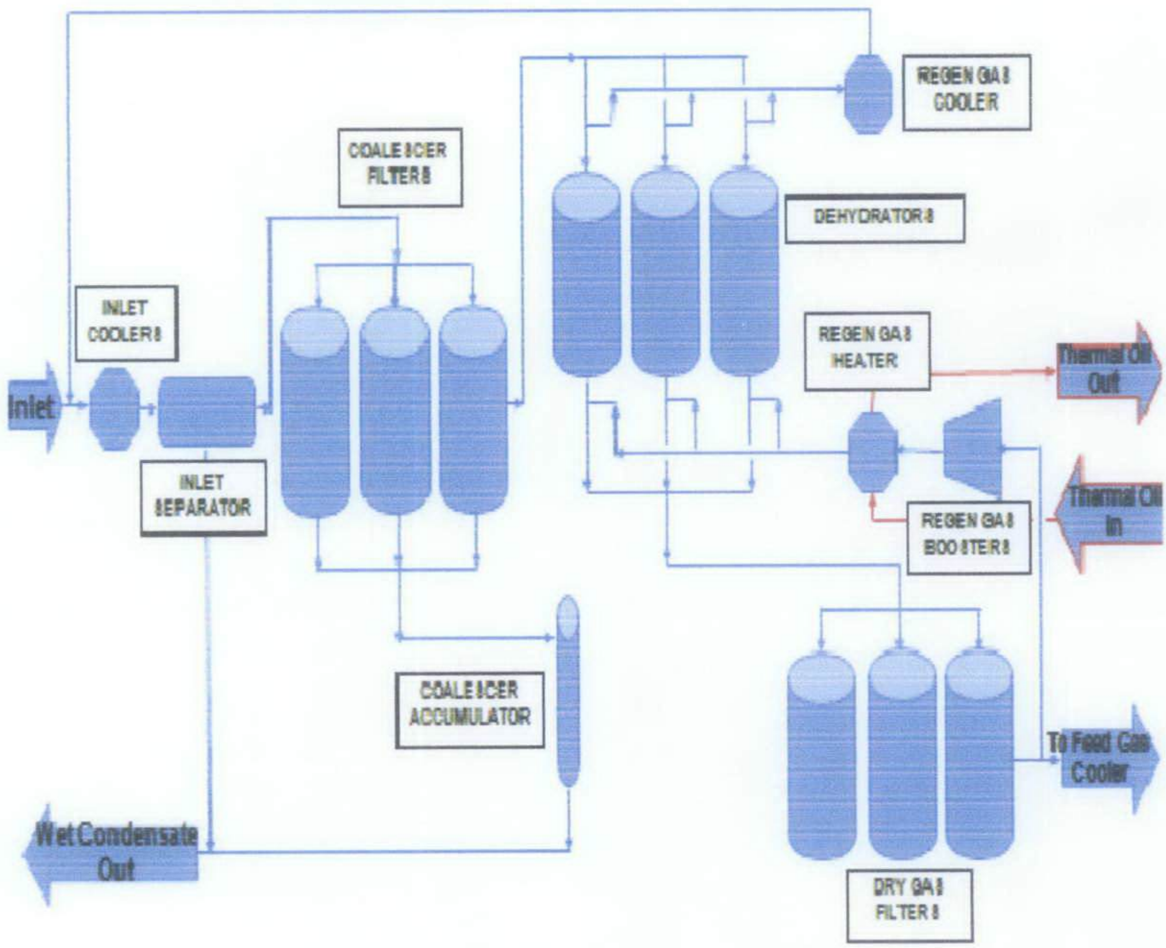
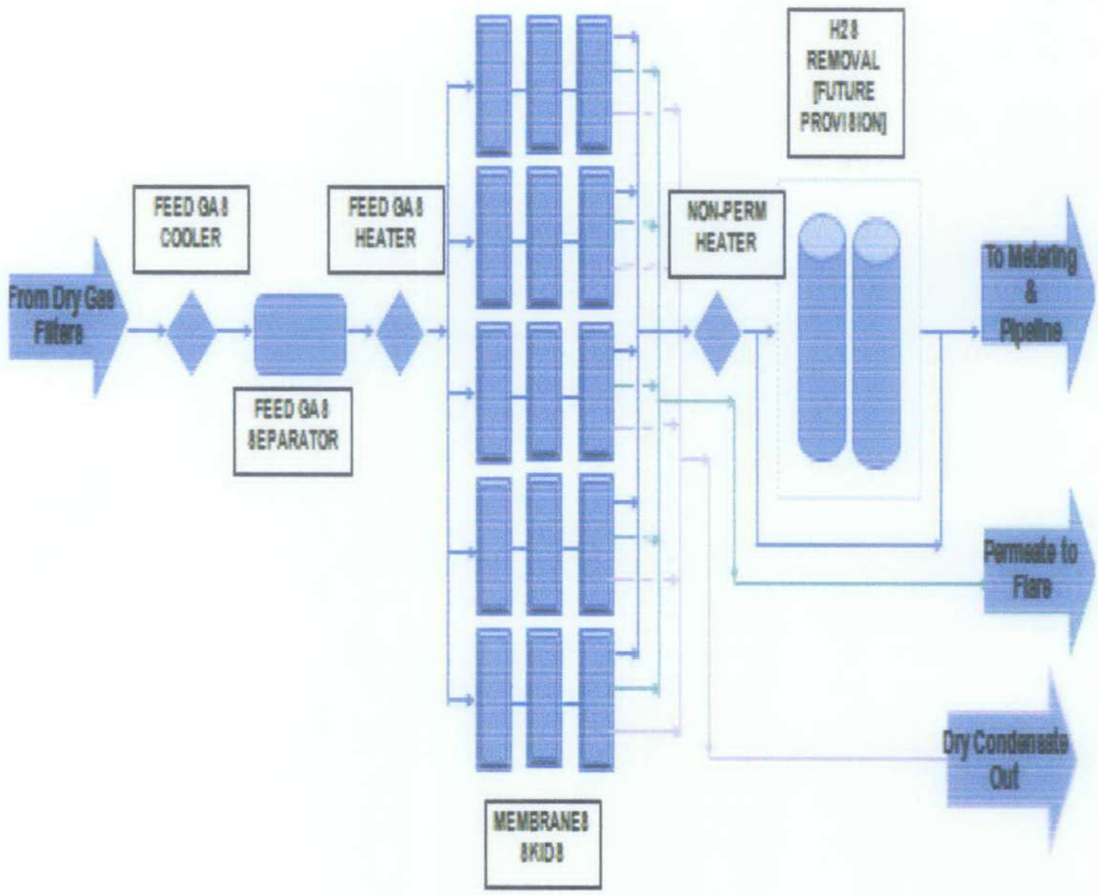


Figure 3: Process Flow of Membrane System

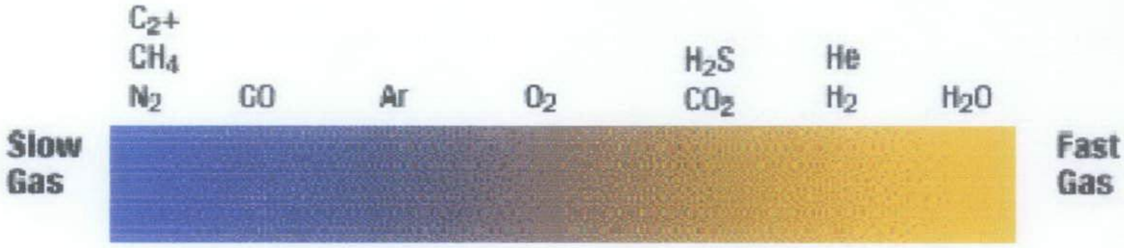

REGEN GAS COOLER
COALESCER FILTERS
DEHYDRATORS
INLET COOLERS
REGEN GAS HEATER
Thermal Oil Out
Inlet
INLET SEPARATOR
Thermal Oil In
REGEN GAS BOOSTERS
COALESCER ACCUMULATOR
To Feed Gas Cooler
Wet Condensate Out
DRY GAS FILTERS



From Dry Gas Filters
FEED GAS COOLER
FEED GAS SEPARATOR
FEED GAS HEATER
H2S REMOVAL [FUTURE PROVISION]
NON-PERM HEATER
To Metering & Pipeline
Permeate to Flare
Dry Condensate Out
MEMBRANES SKIDS

2.2 THEORY

Membrane system operates based on principle of solution-diffusion through nonporous membrane and not operates as filters, where small molecules are separated from larger ones through a medium with porous. This means that it separates based on how well different compounds dissolve into the membrane and diffuse through it. There are two categories of gases that are fast gas and slow gas. The gas from fast category will be permeated at faster rate than the slow one. Carbon dioxide, hydrogen sulfide, water vapor and helium are under category of fast gas, so they permeate faster than other hydrocarbon.



To describe more detail regarding this principle, equation of Fick's law will be explained .

Fick's Law Equation[5]:

$$J = \frac{k \times D \times \Delta\rho}{\ell}$$

J : Membrane flux of CO2, the molar flow of CO2 through the membrane per unit

K : solubility of CO2 in the membrane

D : diffusion coefficient of CO2 through the membrane

deltaP: partial pressure difference of CO2 between the feed pressure and permeate pressure

L : membrane thickness

To simplify matters further, the solubility and diffusion coefficients are usually combined into a new variable called *permeability* (P). Fick's law can therefore be split into two portions: a membrane-dependent portion (P/ L) and a process-dependent portion (Dp). To achieve a high flux, the correct membrane material and the correct processing conditions are needed. P/ is not a constant; it is sensitive to a variety of operating conditions such as temperature and pressure **[5]**.

Arrhenius Equation:

The Arrhenius equation is formula for the temperature dependence of the reaction rate constant, and therefore, rate of a chemical reaction. The equation was first proposed by the Dutch chemist J. H. van't Hoff in 1884; five years later in 1889, the Swedish chemist Svante Arrhenius provided a physical justification and interpretation for it. Currently, it is best seen as an empirical relationship. It can be used to model the temperature-variance of diffusion coefficients, population of crystal vacancies, creep rates, and many other thermally-induced processes, reactions **[2]**.

Based on this equation, there is relationship between temperature and permeation flux.

$$J_t = A \exp(-Ea/RT)$$

J_t= Permeation Flux

A= Reaction Constant

Ea= Activation Energy

R=Gas Constant

T= Feed Temperature

CHAPTER 3: METHODOLOGY

3.1 RESEARCH METHODOLOGY

3.1.1. First Step is to select the appropriate fluid package and thermodynamic model. For this project, Ping Robinson is selected.

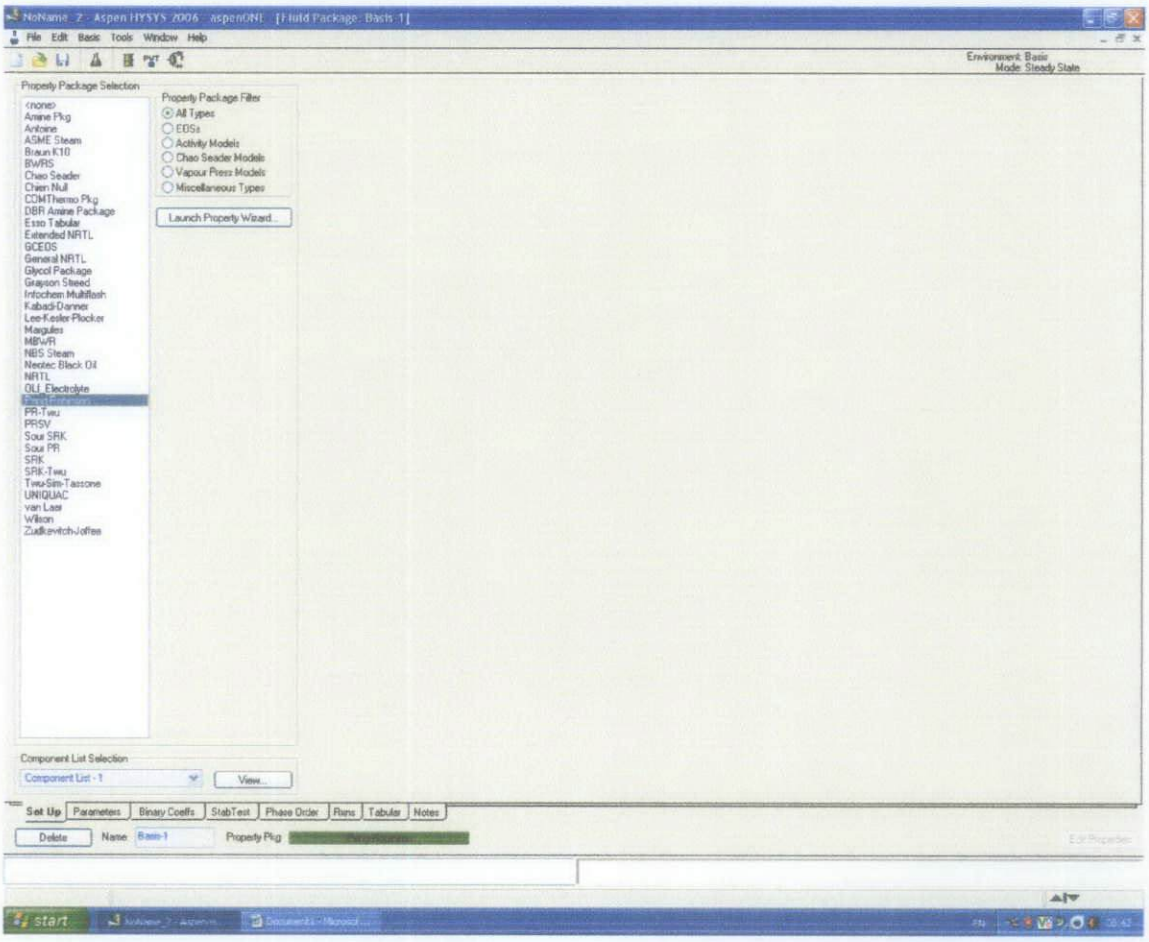


Figure 4: Fluid Package Basis

3.1.2. The component selection window is opened by selecting view in the component list. For this case, carbon dioxide is chosen as component.

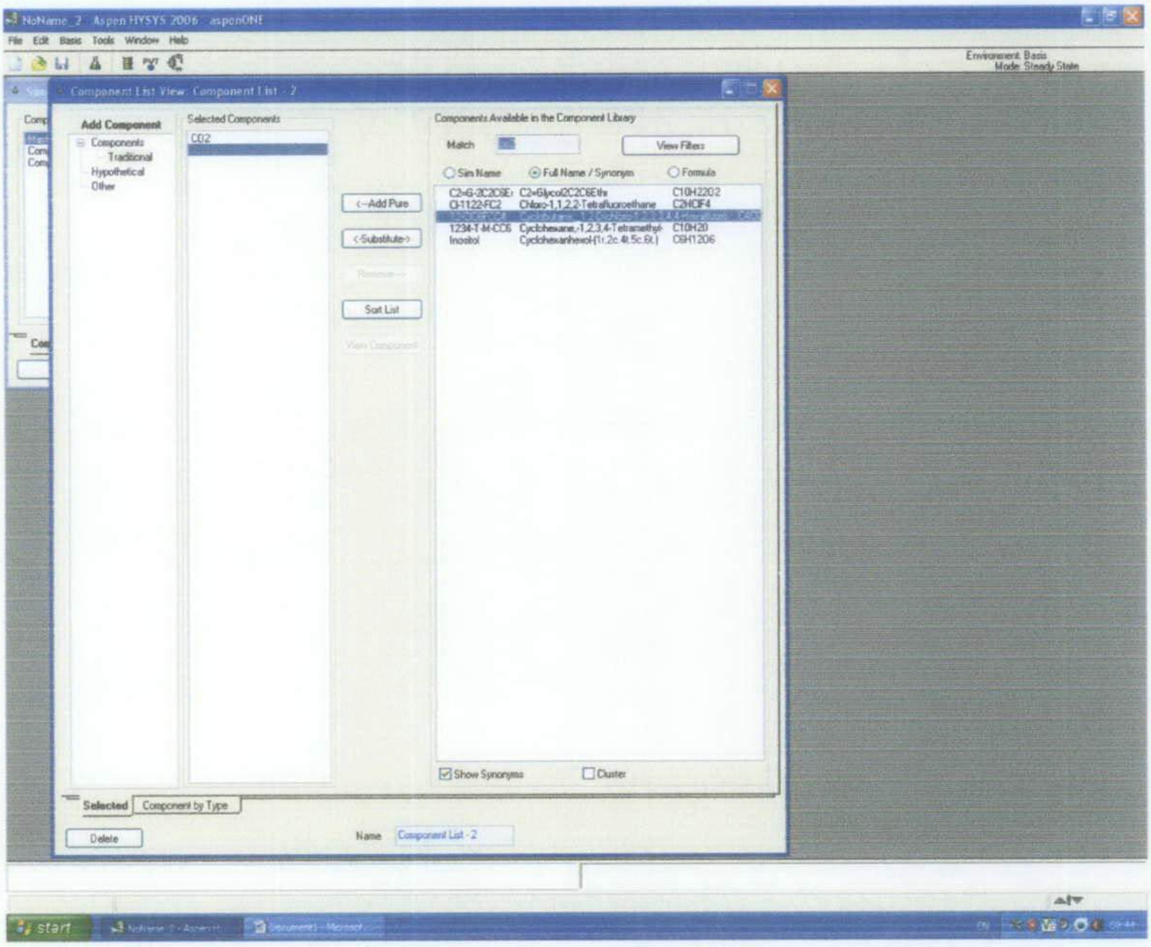


Figure 5: Component selection windows.

3.1.3 After selecting component of fluid, one can now enter the simulation environment where the process flow diagram (PFD) is built for membrane system. The process starts with adding unit operation in this diagram. The unit operation includes flow stream, compressor, heater and finally membrane itself.

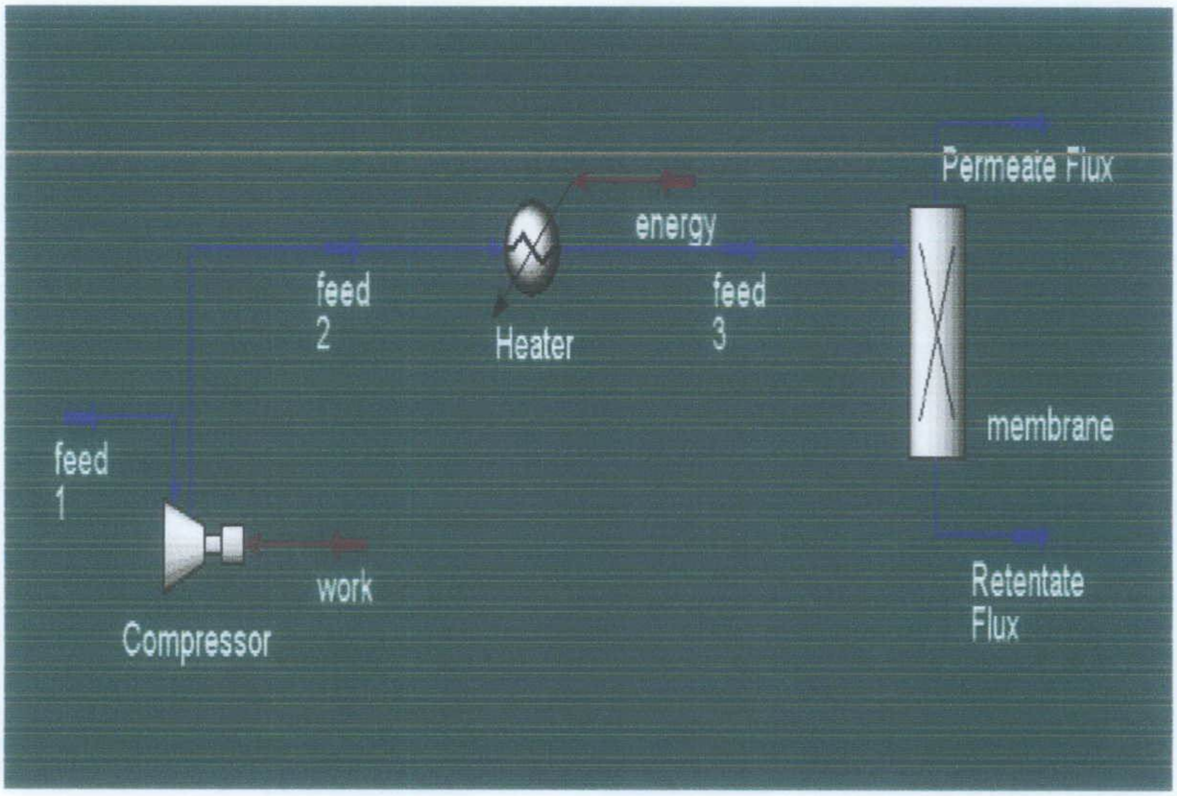


Figure 6: Simulated Membrane system Process Flow Diagrams

3.1.4 The simulation of process begin with simulation of feed sour gas stream by specifying the gas feed temperature, feed pressure, permeate pressure and flow rate with percent of carbon dioxide to be treated.

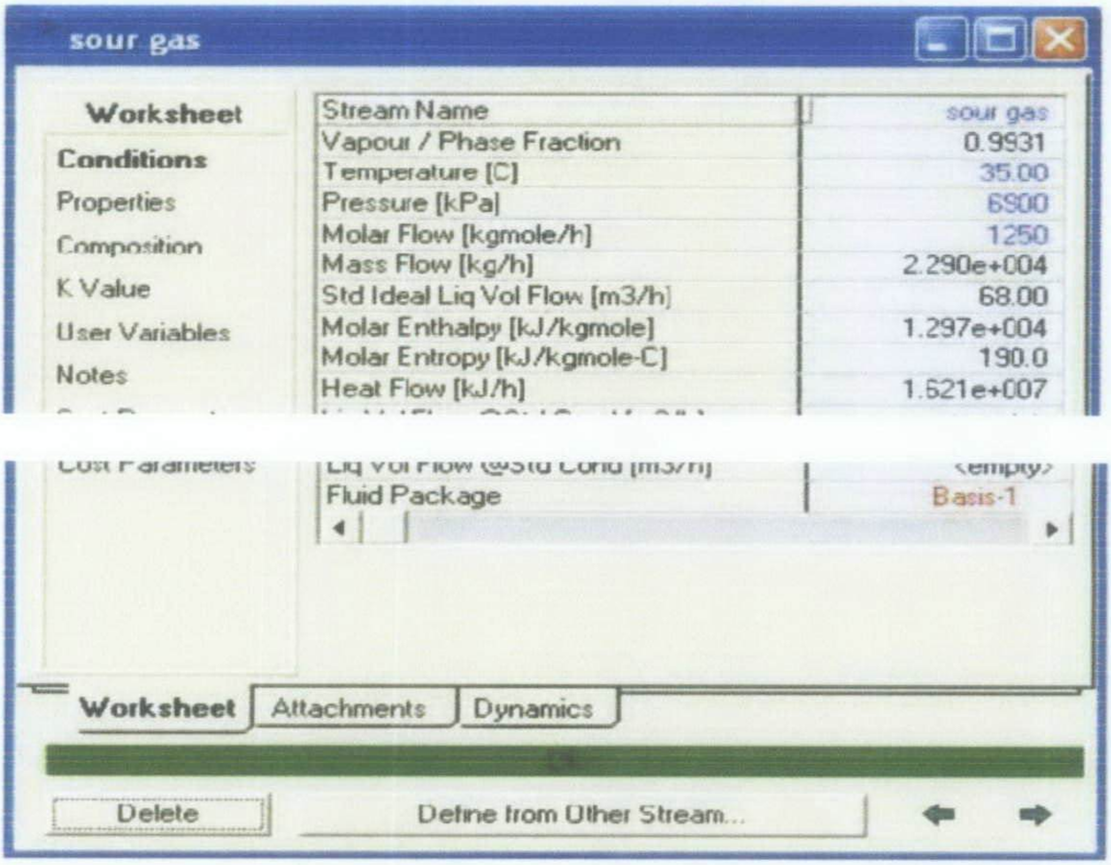


Figure 7: Sour Gas specification windows

3.1.5 Finally, the result obtained is present in the form of table and graph. The result is analyzed by looking at the trend of the graph for various operating condition versus permeation rate of carbon dioxide.

3.1.6 Before that, in order to see of operating condition to the permeation rate, the mathematical model is that relate of the various operating condition with permeation rate is developed and calculated using visual basic.

```
Public Class Form1
    Dim A As Double = 19.63
    Dim exp As Double = 2.7182818
    Dim Ep As Double = 22
    Dim R As Double = 44.01
    Dim T As Double = 350
    Dim temp As Double
    Dim tValue As Double
    Dim result As Double

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button1.Click
        TextBox1.Text = tValue
        result = A * (exp ^ (-Ep / R * tValue))
        Label1.Text = result
    End Sub

    Private Sub Label1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Label1.Click

    End Sub
End Class
```

3.2 PROJECT ACTIVITY.

Within the period of final year project, some of the activities had been planned to make sure this research project carried out successfully without facing any constraint. Following are the activities that will be carried out to complete the research project.

3.2.1 Study the research project.

This will be done by reading from SPE journal, reference book as well as internet. From this reading activities, hopefully all the theoretical as well as concept applicable for this project is deeply understand regarding the main principle involved in carbon dioxide removal by membrane.

3.2.2 Acquire Data from Different Operating Condition.

After understanding the concept of membrane system, the author will find at least three journals that already done testing the membrane through experiment. This three mother papers will be used to compare their result with simulation.

3.2.3 Learn and Perform Calculation Using Visual Basic

Time will be spent to learn and understand visual basic well. Then, visual basic will be used to perform some calculation as input to the variable of operating condition as well as permeation rate.

3.2.3 Learn HYSYS Software and Run Simulation Software to See the Result.

After understand the journal paper, HYSYS simulator will be used to run the simulation with different operating condition (feed temperature, feed pressure, permeate pressure) to see the result. Before that, time also will be spent in order to learn and understand HYSYS.

3.2.4 All the result and discussion will be compiled in report writing.

3.3 GANTT CHART FOR FYP 1

No	**Detail/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Mid –Semester Break**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Selection of Project Topic	■	■													
2	Preliminary literature view of membrane system.		■	■	■	■										
3	Submission of Extended Proposal Defense						■									
4	Proposal Defense									■	■					
5	Continue doing research through reading from journal, reference books and internet.											■	■	■		
6	Submission of Interim Draft Report														■	
7	Submission of Interim Report															■

GANTT CHART FOR FYP 2

No	Detail/Week	1	2	3	4	5	6	7	Mid –Semester Break	8	9	10	11	12	13	14
8	Run simulation software to see the result from different operating condition and discuss the result.	■	■	■	■	■	■	■								
9	Submission of Progress Report									■						
10	Compile all the result and discussion into report writing									■	■	■	■	■		
11	Pre-EDX												■			
12	Submission of Draft Report													■		
13	Submission of Dissertation (soft bound)														■	
14	Submission of Technical Paper														■	
15	Oral Presentation															■
16	Submission of Project Dissertation (Hard Bound)															■

3.4 TOOL/EQUIPMENT REQUIRED

To conduct the experiment, the only tool required is HYSYS™ software. Hypro Tech HYSYS is powerful software for steady and dynamic state simulation processes. HYSYS is an interactive and flexible process modeling software which allows engineer to design, monitoring, troubleshooting, perform process operational improvement. For this project, HYSYS is used to predict carbon dioxide removal process operating conditions.**[10]**. Visual basic software also will be used to perform calculation based on available equation for various variables that relate with operating condition and permeation rate.

CHAPTER 4: RESULT & DISCUSSION

[illegible]	Removal Rate [illegible]	Feed Temperature [illegible]	Permeation Rate [illegible]	[illegible]	[illegible]
15	63.07	300	15.20	100	17.35
30	55.79	350	17.92	150	19.87
45	51.78	400	20.61	200	22.38
60	49.04	450	23.68	250	24.88
75	46.97	500	25.93	300	27.37
90	45.31	550	28.57	350	29.66
105	43.94	600	31.20	400	32.35
120	42.77	650	33.83	450	34.83

Figure 8: Result of various operating condition vs permeation rate

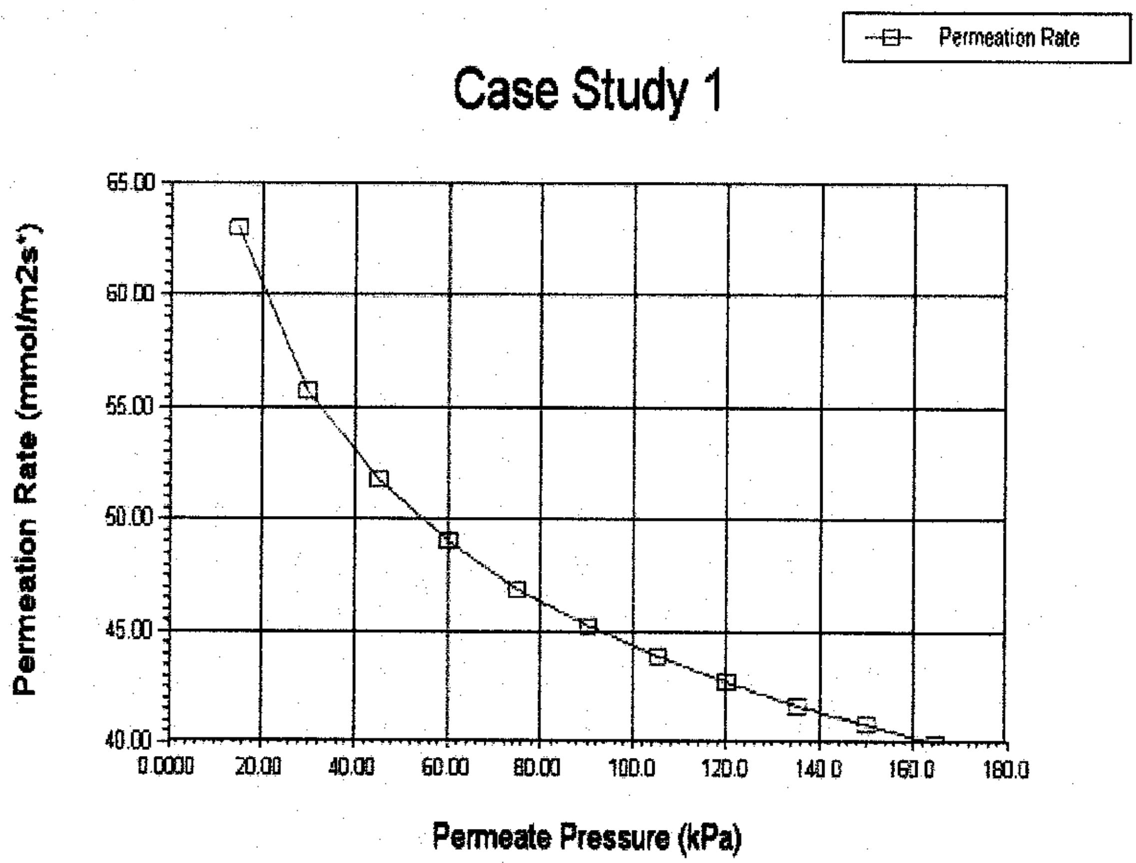


Figure 9: Graph of Permeate Pressure Versus Permeation Rate

For case study 1, when permeate pressure keep on increasing, the permeation rate of carbon dioxide is declined. The theory behind it is related with driving force. Driving force is used to supply energy for carbon dioxide to dissolve through membrane and diffuse through it. This driving force is created by supplying pressure to the flow stream. The carbon dioxide also permeates through membrane based on concentration in term of pressure. When the permeate pressure is keep on increase, the concentration will be low. That is why when permeate pressure is increasing, the permeation rate will decrease

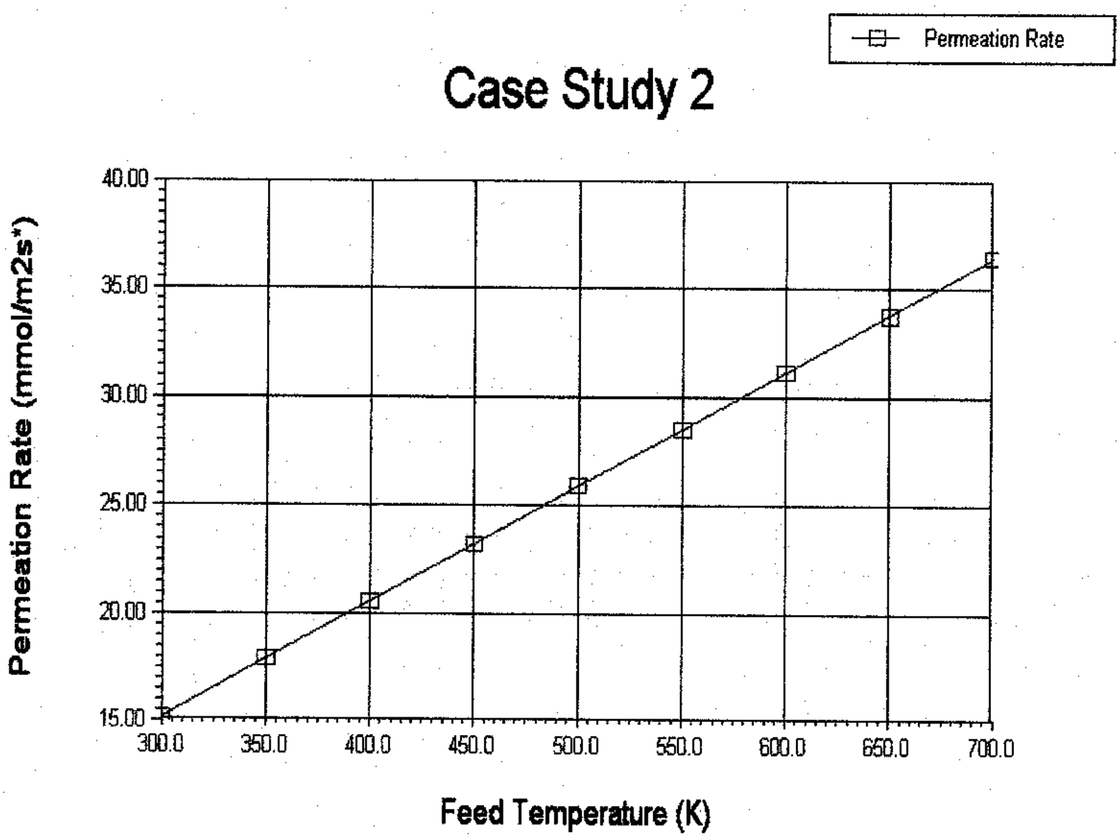


Figure 10: Graph of feed temperature versus permeation rate

For case study 2, we can see that when feed temperature is increase, the permeation rate of carbon dioxide also increase linearly. The temperature is related with activation energy. The value of apparent activation energy for permeation depends on both the activation energy for diffusion and the heat of solution. When temperature increases, it will supply higher activation energy for carbon dioxide. So, when activation energy is higher, it will make carbon dioxide more diffuse through membrane. Therefore, it will permeate through membrane more rapidly.

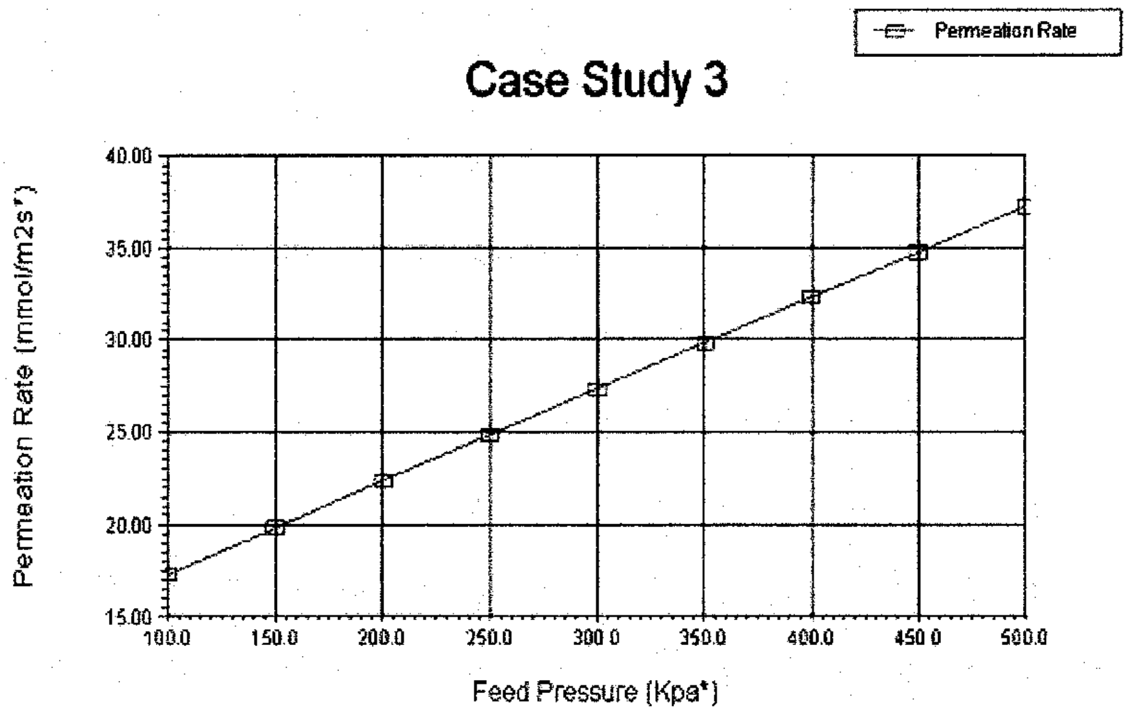


Figure 11: Graph of feed pressure versus permeation rate

For case study 3, the effect of feed pressure to the permeation rate of carbon dioxide is opposite of the effect of permeate pressure. We can see clearly from the graph, when feed pressure is increase, the permeation rate of carbon dioxide is increase too. When feed pressure increase, it will supply greater driving force to the carbon dioxide to dissolve across membrane. So, the permeation rate of carbon dioxide through membrane will increase.

CHAPTER 5 : CONCLUSION & RECOMMENDATION

It was found that the effect of various operating condition such as feed pressure, feed temperature and permeate pressure give significant impact to the performance of membrane in term of permeation rate of carbon dioxide across membrane. Therefore, before designing the membrane system, one needs to take account regarding operating condition in order to design the membrane system so that performance of membrane can be fully optimized and increase efficiency of carbon dioxide removal from natural gas.

For the future work, study can be expanded to include more various operating condition such as effect of composition. The scope of research also can be widening to study effect of various operating condition to the separation of carbon dioxide and natural gas in term of permeability and selectivity. Second thing, the research need also focus on aspect of membrane material itself that also can give significant effect to the performance membrane. Therefore, all the research will be significant to the development of membrane system as important acid gas removal system in the future.

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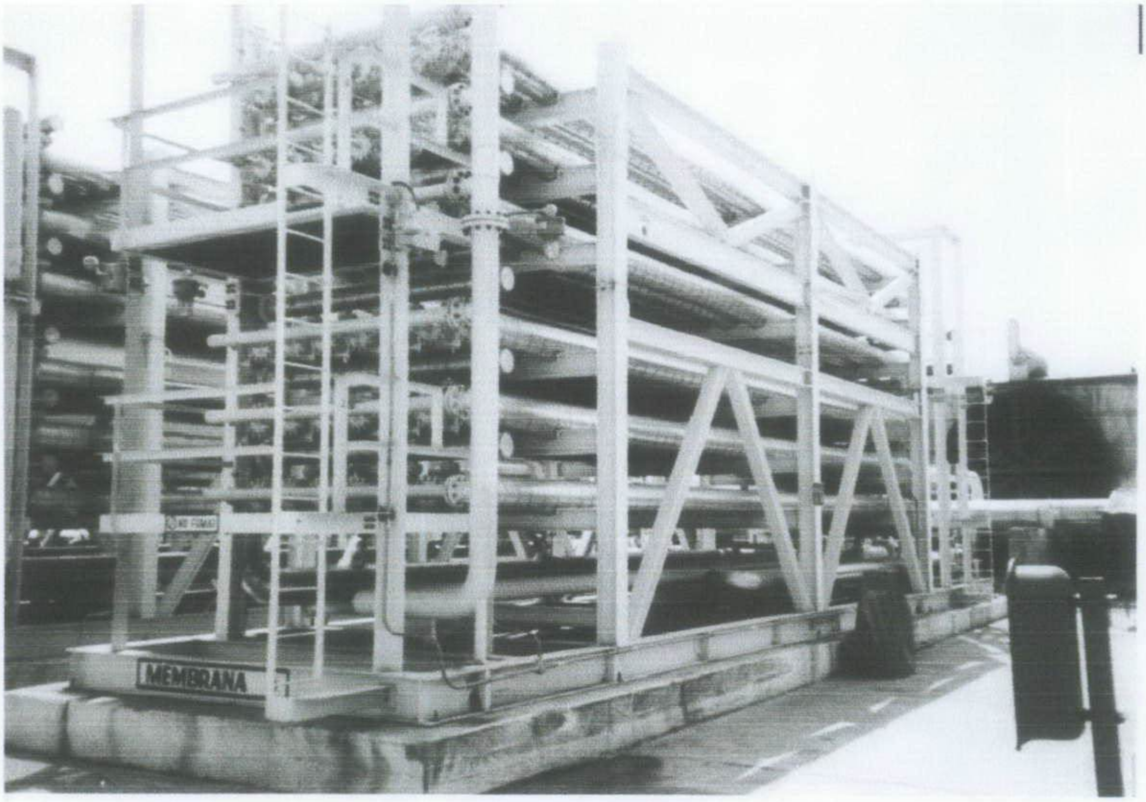
APPENDIX



Membrane skid.