Inline Separator For CO_2 Separation: Parametric Studies And Performance Comparison With Absorption Column

by

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13594

Dissertation submitted in partial fulfillment of

the requirements for the Bachelor of Engineering (Hons)

(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr. Lau Kok Keong)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I 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.

(MOHD SAIFULIZMIN BIN MUSTAPA)

ABSTRACT

The inline separation technology has attracted the attention of oil and gas field operators due to the considerable weight, space and cost savings that can be achieved compared to the existing conventional separators. In addition, the inline separation technology can play a major role in debottlenecking and upgrading the existing production facilities. It is also an environmental friendly technology as its operation requires minimal, or no chemical consumption.

Besides, the production of natural gas in Malaysia gas wells is becoming more challenging due to the increase of high CO_2 gas field in the region. The Inline Separator for absorption process is a new breath of inline separation technology that built especially to handle the separation of carbon dioxide gaseous from natural gas by employing the concept of ejector and physical absorption implemented in the design. This paper will basically study the performance of inline separator prototype by focusing on the effect of feed flow rates of mixed gases (natural gas and carbon dioxide) towards the carbon dioxide absorption. The efficiency of the Inline Separator are compared to the packed column by using the simulation in the ASPEN HYSYS software.

From the results obtained, the absorption performance of inline separator is not as good as the packed column. The performance of the packed column is almost double of inline separator at the lowest flowrate of mixed gases. This inline separator can be optimized further especially to the nozzle and geometry to increase the performance of CO_2 absorption.

ACKNOWLEDGEMENTS

In the preface of this report, I would like to take the opportunity to acknowledge all the parties that assisted me either directly or indirectly particularly to UTP for providing laboratory equipment, facilities and manpower for me during my final year project and make this as a successful and memorable project.

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Last but not least, thanks to my colleagues, friends and those who involved directly and indirectly towards accomplishing my final year project objectives. In short, I feel blessed to have successfully completed my final year project and for all help that the aforementioned parties have given me. My final year project only becomes a success with their help.

Thank you.

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CHAPTER 1 : INTRODUCTION

This chapter consists of (1) project background, (2) problem statement, (3) objectives, (4) scope of study and (5) significance of this project.

1.1 Project Background

1.1.1 Natural Gas

Natural gas is one of the cleanest, safest, and most useful forms of energy in our day-to-day lives. This is one of the energy source often used for heating, cooking, and electricity generation. It is also used as fuel for vehicles and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals.

Due to the expanding industries that use natural gas as their energy source, the demands for this energy become higher from year to year. Demand for natural gas will rise by 65% in 2040 and this natural gas will account for 25% of global energy needs by 2040, and it will become more important in the global energy mix as abundant resources are unlocked by “continuing technology advances (Exxon Mobil Corp., 2013). The Exxon Mobil Corporation expected the overall global energy demand will rise by 35% through 2040 and developing countries such as China and India will lead that growth.

Methane is the major component (75%-90%) of natural gas but it may also contain significant amounts of ethane, propane, butane and traces of higher hydrocarbons depending upon the source (Baker & Lockhandwala, 2008). Most of the natural gas contain impurities and contaminants such as hydrogen sulphide, carbon dioxide and carbon monoxide which can cause environmental hazards and problems in natural gas processing. The upgrading of low quality crude natural gas is attracting interest due to the high demand for pipeline-grade gas in recent years.

Component	Molecular Formula	Range (mol%)
Methane	CH_4	70~90
Ethane	C_2H_6	0.20
Propane	C_3H_8	
Butane	C_4H_{10}	
Pentane	C_5H_{12}	0.05~2
Carbon Dioxide	CO_2	0~8
Oxygen	O_2	0~0.2
Nitrogen	N_2	0~5
Hydrogen Sulphide	H_2S	0~5
Rare Gases	Ar, He, Ne, Xe	trace
Metals	Nickel and Mercury	trace

Table 1.1: General composition of crude natural gas (Jusoh, 2013)

Table 1 shows the general composition of the crude natural gas where methane and carbon dioxide with the highest composition compare to other gases. Nowadays, development of high Carbon Dioxide (CO_2) gas fields offshore will indisputably give significant new challenges for all Exploration and Production companies worldwide. These challenges has indeed realized especially by PETRONAS as Malaysia is proven to be one of the countries with high CO_2 gas fields in the world (Md Isa & Azhar, 2009). High CO_2 content gas reservoirs make most of the gas field development uneconomical and it has remained undeveloped. As a developing country, Malaysia's resources have to be developed timely to sustain supply to meet the increasing gas demand. In addition, the development of these high CO_2 gas fields requires prudent management of CO_2 capture, transportation and storage and utilization to enable commercialization of these gas fields.

Natural gas in commercial operations includes variable amounts of CO_2 ranging from CO_2-free natural gas in Siberia to as high as 90% CO_2 content in the Platong and Erawan fields in Thailand (Tan, Lau, Bustam, & Shariff, 2012). The Natuna field in the Greater Sarawak Basin in Indonesia is the largest gas field in south Asia, with estimated 46 trillion cubic feet recoverable reserves. Unfortunately, it remains unexplored due to high CO_2 content of 71% (OECD/IEA, 2008). In Malaysia, CO_2 content in natural gas fields varies from 28%−87%. High CO_2 gas fields in Malaysia represent an excellent opportunity for significant CO2 capture and storage (CCS).

Carbon dioxide (CO_2) removal is an essential step in natural gas (NG) processing to provide high quality gas stream products and minimize operational difficulties. CO_2 must be removed in order to serve the following purposes; increase the heating value of the gas, prevent corrosion of pipeline and process equipments and crystallization during liquefaction process (Hao, Rice, & Stern, 1993). CO_2 removal also can avoid the wasting of pipeline capacity. The maximum level of CO_2 permitted in natural gas transmitted to customers by pipeline is typically less than 3% (Hubbard, 2010) although local contracts may stipulate quality specifications different to these values.

1.1.2 Technologies for Natural Gas Separation

The removal of acid gases (CO_2, H_2S and other sulfur components) from natural gas is often referred to as gas sweetening process. The separation of carbon dioxide can be accomplished in a numbers of ways. Varieties of processes and (improvement of each) have been developed over the years to treat certain types of gas with the aim of optimizing capital cost and operating cost, meet gas specifications and for environmental purpose (Tennyson & Schaaf, 1977). The focus for this project is to investigate the potential efficiency and performance of inline separator for the energy-efficient and effective separation of CO_2 and CH_4. The current techniques and technologies used in separating CO_2 from the natural gas are using chemical or physical absorption, membrane separation, adsorption and cryogenic distillation. The most frequently used method is amine absorption process.

Table 1.2 shows the technologies used for separation of natural gas and the critical issues exist for large scale application. Most of the existing separation technologies have some issues that need to be improved to ensure they can provide high separation with optimum cost.

Technology	**Industrial Applications**	**Critical issues for large scale application**	**Future needs/Emerging trends**
Absorption	- Removal of CO_2 from flue gas. - Purification of natural gas	- Energy requirement for regeneration. - Pretreatment of other acid gases.	- Improved process design. - Solvents with high CO_2 capacity and low regeneration energy. - Rotating absorber. - Novel and improved contacting equipment.
Membranes	- CO_2 separation in H_2 production. - Purification natural gas.	- CO_2 selectivity. - Degradation/fouling issue.	- Ceramic facilitated transport. - Cross-linking the mixed matrix membranes to attain enhanced permeability and selectivity.
Cryogenic distillation	- CO_2 liquefaction from gas wells.	- Refrigeration $< 0^oC$. - Pretreatment for impurities that freeze above operating temperature (e.g. H_2S).	- Hybrid process. - Integration with sequestration processes. - Efficient refrigeration cycles.
Adsorption	- CO_2 separation in H_2 production. - Purification of natural gas.	- Adsorbents tend to have low capacity/selectivity. - Energy penalty for regeneration. - Long cycle times.	- New adsorbents that adsorb CO_2 in presence of water vapor. - Carbon-based adsorbents.

Table 1.2: CO_2 capture technologies and its future directions (Tan, Shariff, Lau, & Bustam, 2012)

1.2 Problem Statement

The increasing importance of natural gas as a source of energy poses difficult gas separation design challenges, as the streams recovered from gas fields are at high pressures (typically about 10 MPa) and can contain a high proportion of CO_2 (up to 70%). CO_2 removal is an essential step in natural gas processing to provide high quality gas stream products and minimize operational difficulties. Physical absorption using packed column is the most suitable technology for CO_2 separation with the presence of high feed pressure from the gas fields and offshore conditions. This separation techniques are usually restricted and not viable under the offshore conditions due to the requirement of larger installation space and higher installation cost.

The new technology is needed to overcome this problems and one of the solution is by using the compact inline separator to separate CO_2 from the natural gas. One of the advantages by using the compact inline separator is the compact design which is much smaller compare to conventional absorption column. Conventional separation equipment consists of large vessels and contributes heavily to the size and weight of the overall processing system. The common problem is there are limited opportunities to modify the existing processing plants as the separator vessels have defined volume. It is normally not feasible to add processing capacity by installing new separator vessels on an existing offshore platform. However, inline separation technology can offer new degree of freedom to modify the processing plants. The inline separation equipment can be put in series and in parallel to already installed separators to improve capacity and performance.

Currently, there are very limited studies and works regarding the CO_2 absorption using inline separators and most of the published works are related with CO_2 absorption by using the conventional packed column. Therefore, parametric studies and performance comparison of inline separator and packed column is crucial to explore the potential of applying this new technology in physical absorption of CO_2 under offshore conditions.

1.3 Objectives

The objectives of this project are:

a) To evaluate and determine the performance of carbon dioxide removal by using inline separator experimentation.

b) To compare the performance of the compact inline separator with packed column using simulation in ASPEN HYSYS software.

1.4 Scope of Study

This project is limited to the use of carbon dioxide separation only. The commissioning and experimentation are conducted to ensure the effectiveness and performance of the prototype which using the inline separator. The simulation for packed column using HYSYS is done to evaluate and compare the separation performances of both separators.

This study will be divided into two parts:

1. **Experimental work** - To conduct the experiment by using the inline separator prototype.

2. **Simulation work -** To compare the performance of the compact inline separator with packed column by using ASPEN HYSYS software.

1.5 Significance of Study

The compact inline separator is a prototype to capture and separate the CO_2 from the natural gas. The inline separation technology has attracted the attention of oil and gas field operators due to the considerable weight, space and cost savings that can be achieved. The conventional separators is not viable to be installed at the offshore platform due to bigger size and higher cost for the installations and operations.

Therefore, the new effective separators that promise to be lighter and smaller than the current separation equipment need to be developed, and they must be suitable for gas-liquid and liquid-liquid separation. To reduce the cost and maximize the effectiveness of separation equipment, the compact inline separation technology may be an attractive alternative to conventional separation methods for certain oil and gas applications. This inline separation technology also have the potential to reduce the investment for modifying the existing facilities by eliminating the need for bulky and costly conventional separators.

CHAPTER 2: LITERATURE REVIEW

The literature review consists of (1) conventional carbon dioxide absorption process, (2) inline separation technologies and (3) concept of inline separation.

2.1 Conventional Carbon Dioxide Absorption Process

The selective physical or chemical absorption of CO_2 by a solvent is the most well-established method of CO_2 capture in power plants and from natural gas sources (Khoo & Tan, 2006). By using these method, the company can obtain high product yields and purities.

Absorption processes with chemical solvents are currently the most used technology for carbon dioxide separation from natural gas (Tan, Lau, Bustam, & Shariff, 2012). Chemical absorption usually using amine based processes that efficiently removed acid gas impurities such as CO_2 and H_2S from the process gas streams. Widely-used absorbents in the industrial application are family of alkanolamines and usually utilized as aqueous solution in the CO_2 absorption process. (Hyung-Taek & Seok, 2004). Alkanolamines are divided into three classes which are primary, secondary and tertiary amines according to their functional group. The classification is based on the substitute of the hydrogen on the nitrogen atom. Usually, the alkanolamines used are monoethanolamine (MEA), diethanolamine (DEA). diisopropanolamine (DIPA), methyl diethanolamine (MDEA) and 2-amino-2 methyl-1-propanol (AMP) (Kuntz & Aroonwilas, 2008).

The operation of physical absorption is based on Henry's Law. CO_2 is absorbed under a high pressure and a low temperature, and desorbed at reduced pressure and increased temperature. This technology is widely applied to many industrial processes including nature gas, synthesis gas and hydrogen production with high CO_2 contents (Olajire, 2010). According to (Hamoud, Boudi, & Al-Qahtani, 2008), absorption process is where the two liquids or liquid and gas is achieved by allowing the fluids to have a few minutes retention time. In oil and gas industries, packed columns usually use absorption as a process to separate and remove the CO2 from the natural gas.

The separation process is the heart of the offshore production system. Conventional technology requires massive equipment to allow for required separation of oil, gas, water and sand (Fantoft, Akdim, Mikkelsen, Abdalla, Westra, & de Haas, 2010). Most separation equipment is based on gravity separation principles that require larger retention times and low fluid velocities. These separators have over several years been subject to further development by introduction of new separation principles.

2.2 Inline Separator Technologies

Inline Separator Technologies are seen as an important technology for the oil and gas industry because they have many advantages compared to the conventional bulk separators. This technologies was initially developed for de-bottlenecking of processing plants where it was difficult to solve specific operating challenges by conventional technologies. Compact separation solutions have received substantial attention for offshore process system over many years (Fantoft, Akdim, Mikkelsen, Abdalla, Westra, & de Haas, 2010). The capacity, size and robustness of separation equipment are key parameters when it comes to the value of an offshore production system.

For example, the implementation of inline separator called 'Flow Induced Inline Separation' (FIIS) are conducted by Statoil Company at the Gullfaks Field. FIIS consists of the De-sander (separating sand from oil), De-liquidizer (separating liquid from gas), Phase-Splitter (separating gas from liquid) and De-watering Unit (separating water from oil). For all these four FIIS units, the separation process is initiated by using a swirl element of similar to force the multiphase flow into a tangential flow (spin), thus utilizing centripetal force to separate two phases of different density (Bjørkhaug, Johannesen, & Eidsmo, 2011).

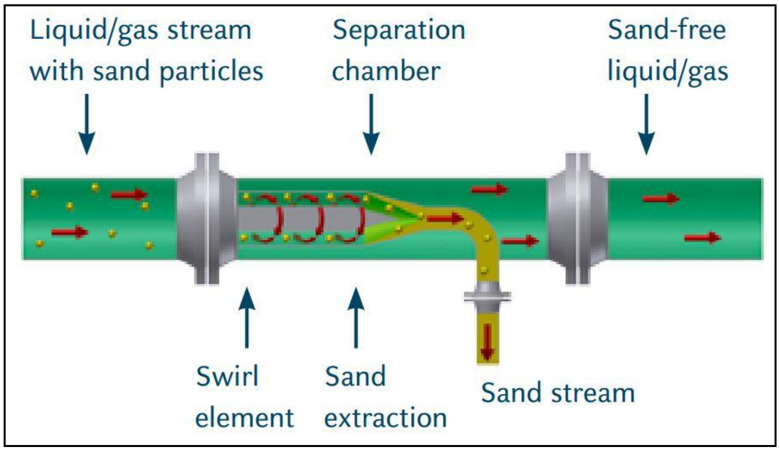

Figure 2.1: Inline Desander

The InLine DeSander in Figure 2.1 is used to remove sand from single and multiphase fluids and can be customized to suit any application. It is a compact cyclonic unit without any reject streams that can handle a wide range of flow rates and achieve efficiencies up to 99 %. Particle sizes down to 1 micron can be removed depending on the size of the unit (FMC Technologies, 2011).

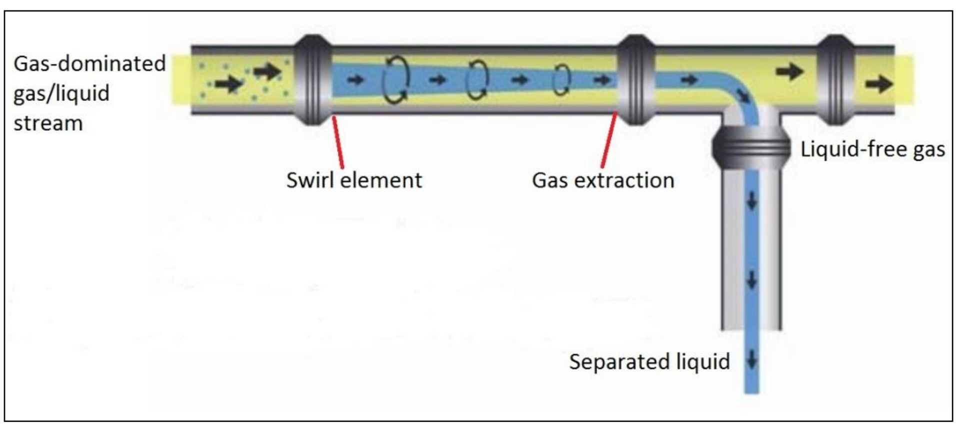

Figure 2.2: Inline DeLiquidizer

An Inline DeLiquidizer in Figure 2.2 was developed and first applied at the Statoil Sleipner field to remove liquid from a gas upstream an existing scrubber to improve the overall gas scrubbing efficiency. The liquid stream containing gas enters the swirl element which causes a liquid film to form on the wall of the InLine DeLiquidiser.

The liquid-free gas is discharged through the smaller diameter pipe in the centre of the InLine DeLiquidiser, while the liquid film is discharged to the vessel boot (FMC Technologies, 2011).

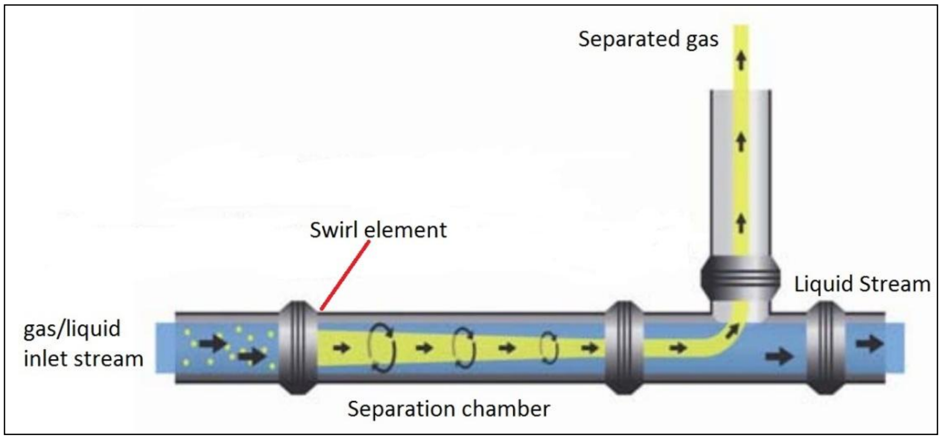

Figure 2.3: Inline PhaseSplitter

Figure 2.3 shows the Inline PhaseSplitter which is used to split a multiphase stream into two single phases – a gas and a liquid phase. The InLine PhaseSplitter was designed to cover the gap between the InLine DeGasser and InLine DeLiquidiser. The principle of operation is the same as that of the InLine DeGasser and the InLine DeLiquidiser, while the InLine DeLiquidiser and InLine DeGasser can be considered to be polishing units, the PhaseSplitter is in general for bulk separation. It has one separation stage and is normally considered for applications with inlet gas volume fraction (GVF) ranging from 10% to 90%.

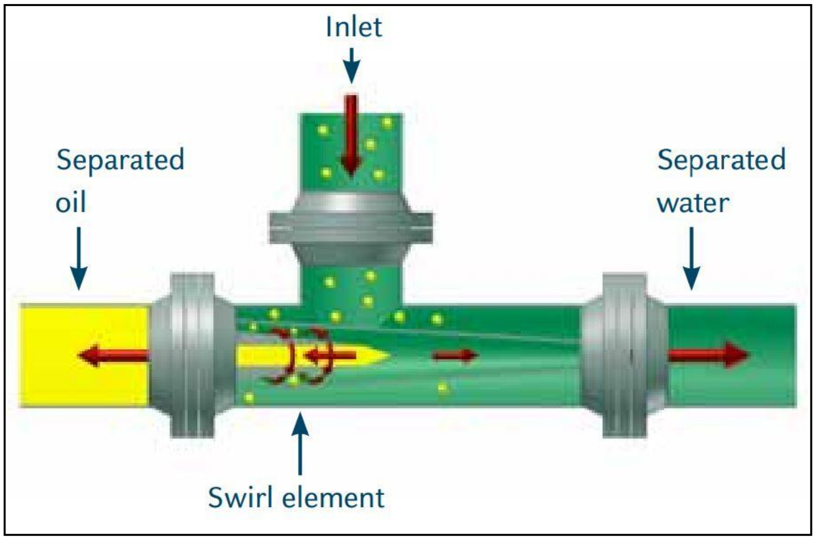

Figure 2.4: Inline Dewaterer

The InLine DeWaterer in Figure 2.4 is a compact cyclonic unit designed for efficient separation of bulk oil from water which combines high efficiency with low pressure-drop in a compact design. It is an axial flow cyclone that uses a fixed swirl element. The technology has been developed and qualified with Statoil and, during testing, efficiencies exceeding 99 % have been achieved (FMC Technologies, 2011).

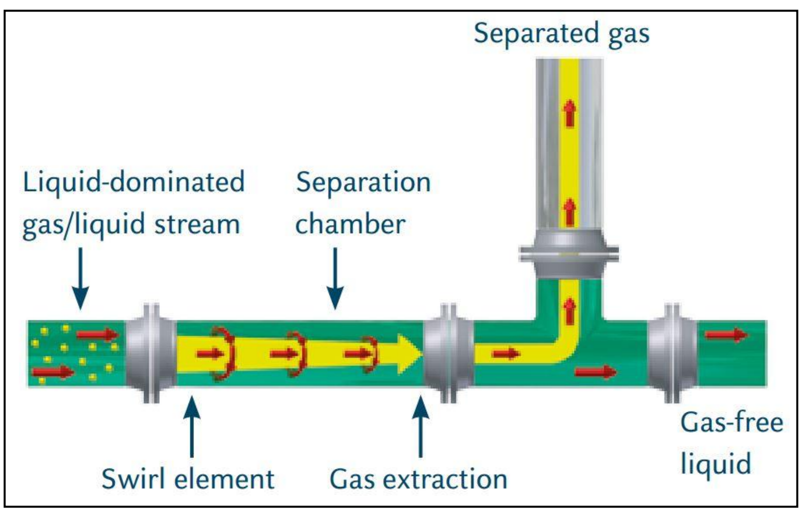

Figure 2.5: Inline Degasser

The purpose of the InLine DeGasser in Figure 2.5 is to separate gas from a liquid stream. The liquid stream containing gas enters the swirl element which causes a gas core to form in the centre of the InLine DeGasser. The gas core then enters the smaller diameter pipe in the centre of the InLine DeGasser and is discharged to the scrubber section, while the gas-free liquid reaches the outlet. The technology was developed and qualified with Statoil. The first unit, which was installed on Statfjord B in the Norwegian sector of the North Sea, has been in operation since 2003 (FMC Technologies, 2011).

	GasUnie™	**Degasser**	**Deliquidiser**	**Phase Splitter**	**Demister Spiraflow**
Separation Efficiency	90-99 % removal of incoming gas	90-99 % removal of incoming gas	90-99 % removal of incoming liquid	About 98 %*	99.99 % removal of incoming liquid
Continuous Phase	Gas or Liquid	Liquid	Gas	Gas or Liquid	Gas
Dispersed Phase	GVF** < 10 %	GVF < 60 %	LVF*** < 10 %	20 % < GVF < 95 %	LVF < 5%
Second Stage Separation	NA	Scrubber	Liquid boot	NA	MashPad
Control System required	Yes	Yes	Yes	No****	No
Control Strategy	Liquid level in GasUnie	Liquid level in scrubber	Liquid level in boot	Application dependent	—
Turndown Ratio	50 %	50 %	50 %	50 %	50 %
Pressure drop	0.2 to 1 bar depending on operating pressure	0.45 to 2.5 bar depending on operating pressure	0.4 to 0.7 bar depending on operating pressure	0.4 to 0.7 bar depending on operating pressure	0.2 to 0.7 bar depending on operating pressure
Slug handling capability	High	Moderate	Moderate	Low	High
Fouling Tolerance	High	Low	Low	Low	High

Table 2.1: Main Characteristics of Inline Gas/Liquid separation equipment (Fantoft, Akdim, Mikkelsen, Abdalla, Westra, & de Haas, 2010)

Table 2.1 shows that somehow, inline separators are effective since the separation efficiency is more than 90 percent. Shell Company also implementing the FMC Technologies inline equipment in PDO Al-Huwaisah, Oman where the floating production, storage and offloading (FPSO) cause operational problems such as spurious alarms and shutdown. As to solve the problem, inline equipment is installed since it does not affected by the movement and best to apply to the FPSO.

The concept used for inline separation by Statoil and Shell Company is a little bit different with this project. FIIS used the desorption method of separation while this project will use the ejector type inline separator. In this project, CO_2 will be captured using absorption method where the conventional approach is remained but only the structure of the separator is compact and operates in high efficiency. There, this new technology of separation will become great potential to upgrade the conventional and existing separator in the industry.

As the inline technology matures, total production systems can be developed based on use of inline separation technology. This will allow for substantially more compact and cost efficient field developments. It will also enable new applications, such as heavy oil and deepwater subsea applications, which are not feasible to develop with conventional technology (Fantoft, Akdim, Mikkelsen, Abdalla, Westra, & de Haas, 2010).

2.3 Concept of Typical Inline Separation

The typical inline separators perform the same function as the conventional separators, but in a smaller shell. The separation is achieved by the use of centrifugal force, which is thousands of times greater than the force of gravity, resulting in flow patterns to separate fluid phases of different densities (Hamoud, Boudi, & Al-Qahtani, 2008). Apart from that, the inline separator also tends to be sensitive to flow variation, therefore high continuous flow is needed for the separation to occur efficiently.

The conventional separation of two liquids or liquid and gas is achieved by allowing the fluids to have a few minutes of retention time under the influence of gravity alone. With inline separators, the speed of separation is significantly increased, therefore the need for long retention times within the vessel is eliminated, and the size of the separation vessel can be greatly reduced. Inline separation techniques utilizing centrifugal force may not produce outlet streams with as good quality as conventional separation, but they are sufficient for many practical applications (Hamoud, Boudi, & Al-Qahtani, 2008).

2.4 Concept of Ejector Type Inline Separation

Ejectors, jet-nozzles and similar devices are used for dispersion of gas in liquid. Ejectors are co-current flow systems, where simultaneous aspiration and dispersion of the entrained fluid takes place. This causes continuous formation of fresh interface and generation of large interfacial area because of the entrained fluid between the phases. The ejector essentially consists of an assembly comprising of nozzle, converging section, mixing tube/throat and diffuser (Balamurugan, Lad, Gaikar, & Patwardhan, 2007).

According to the Bernoulli's principle, when a motive fluid is pumped through the nozzle of a gas–liquid ejector at a high velocity, a low pressure region is created just outside the nozzle. A second fluid gets entrained into the ejector through this low pressure region. The dispersion of the entrained fluid in the throat of the ejector with the motive fluid jet emerging from the nozzle leads to intimate mixing of the two phases (Balamurugan, Lad, Gaikar, & Patwardhan, 2007).

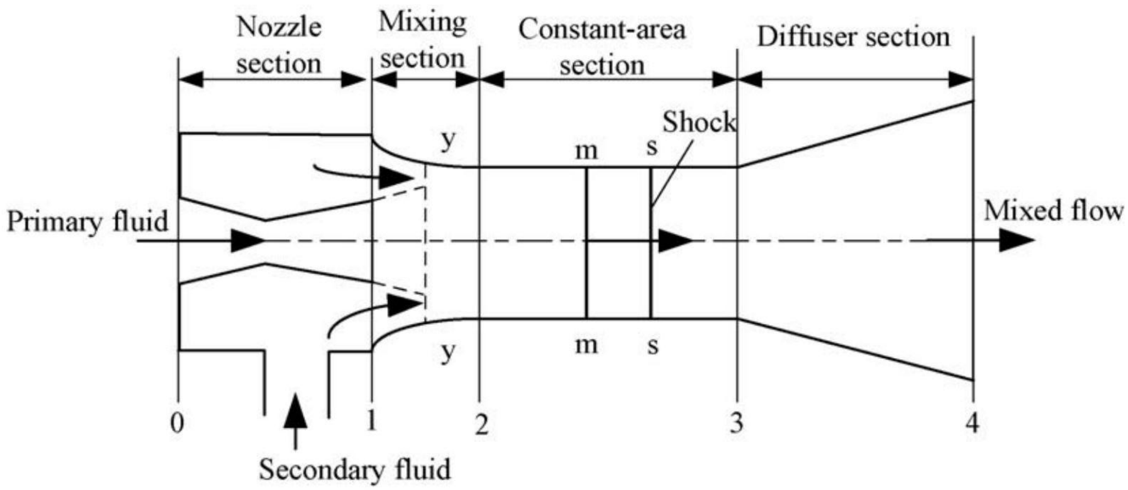

Figure 2.6: Principle structure of ejector (He, Li, & Wang, 2009)

From Figure 2.6, a primary fluid is accelerated to supersonic speed by the convergent-divergent primary nozzle, which forms low pressure region at the nozzle exit plane. From Figure 2.7 below, the theory is proved where experimentation done by S. Balamurugan (2006) shows that the pressure is low inside the nozzle and this satisfied the Bernoulli's principle. The same principles also applied in the ejector to produce the entrainment effect of the liquid to entrain the secondary fluid (He, Li, & Wang, 2009).

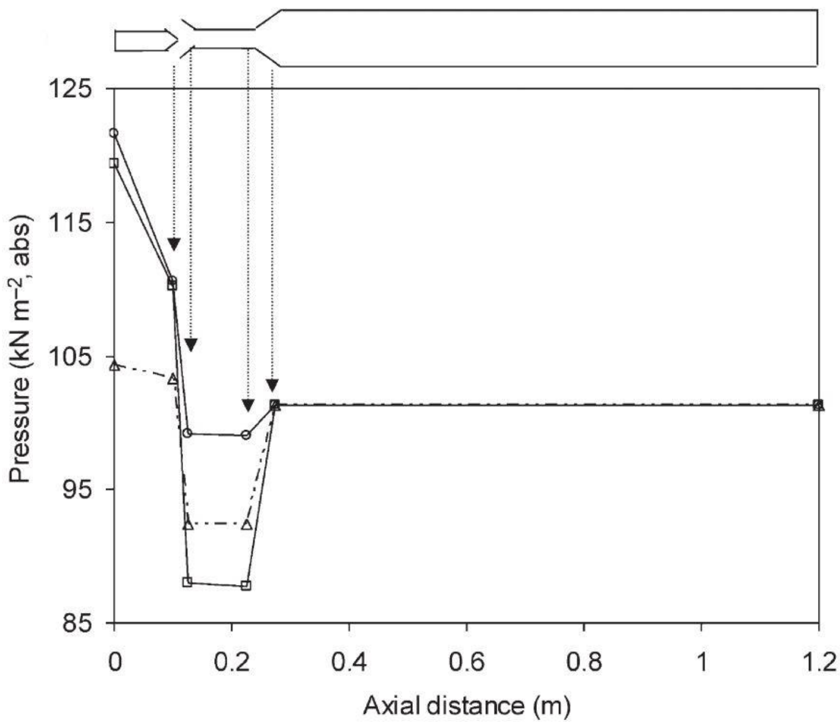

Figure 2.7: Effect of nozzle velocity on pressure profile (Balamurugan, Gaikar, & Patwardhan, Hydrodynamic Characteristics of Gas-Liquid Ejectors, 2006)

In the mixing section, a sudden reaction in the mixture velocity and a rise pressure takes place and makes the fluid mixture easily undergoes phase (He, Li, & Wang, 2009). On the diffuser section, the mixture of primary and secondary flows passes through the diffuser, and converts kinetic energy into pressure energy. According to He et al., (2009), at the diffuser exit, the velocity is reduced to zero and the pressure is lifted high enough to cause discharge.

Ejectors produce higher mass transfer rates by generating very small bubbles or droplets of the dispersed phase where it resulted in improving the contact between phases (Balamurugan, Gaikar, & Patwardhan, Hydrodynamic Characteristics of Gas-Liquid Ejectors, 2006).

2.5 Research Gap

Based on the literature review, the research gap has been identified and there have been a number of studies that highlighted the use of inline separator in the oil and gas stream. The separation is achieved by the use of centrifugal force. However, none of these studies using the absorption as the process in it and also the concept of ejector which the liquid is injected in a sprayed droplet size.

Compact inline separator design is equipped with three main concepts which are using the compact design of separator, absorption process and also the concept of the ejector in spraying the liquid in droplet size. It is believed that inline separator using absorption process can be used to separate the CO_2 from natural gas.

CHAPTER 3: METHODOLOGY

3.1 Project Flowchart

This project proposed a new technology for separation process called compact inline separator. A simulation using ASPEN HYSYS will be conducted to compare the performance between inline separator and conventional packed column. Below is the overview of the workflow of the project.

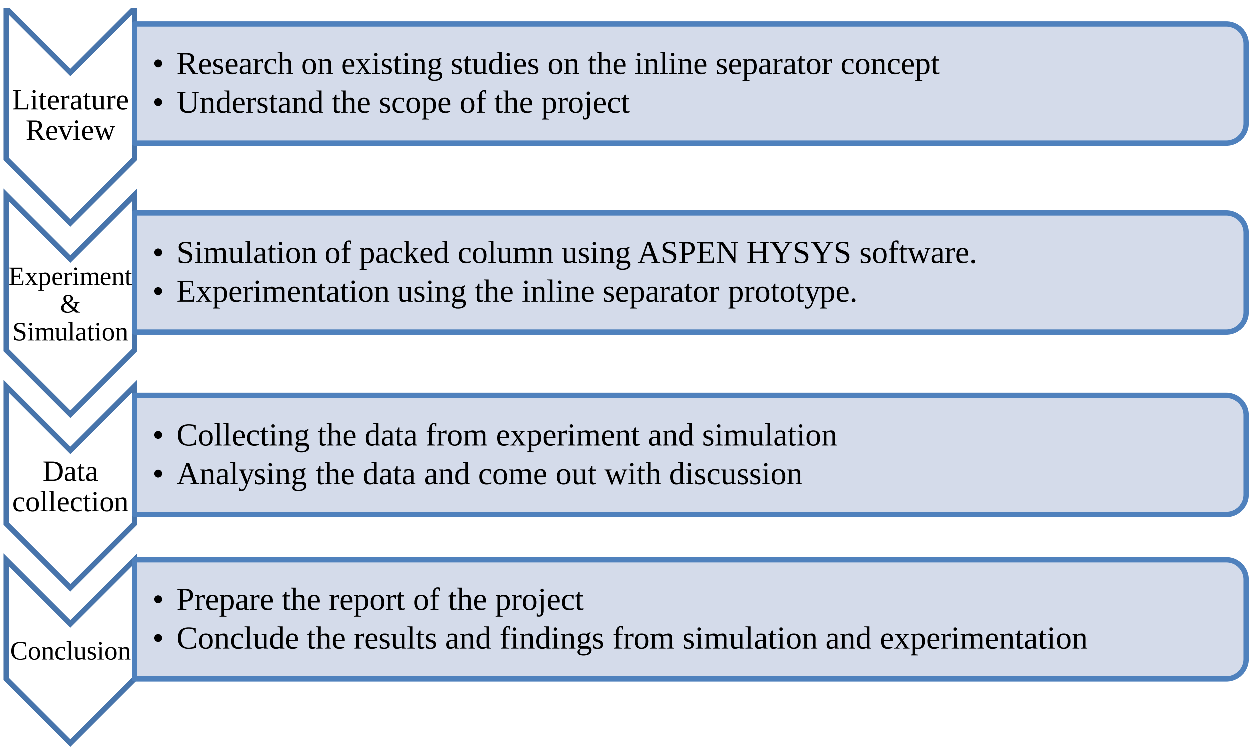

Figure 3.1: Project Flowchart

3.2 Project Gantt chart & Key Milestones

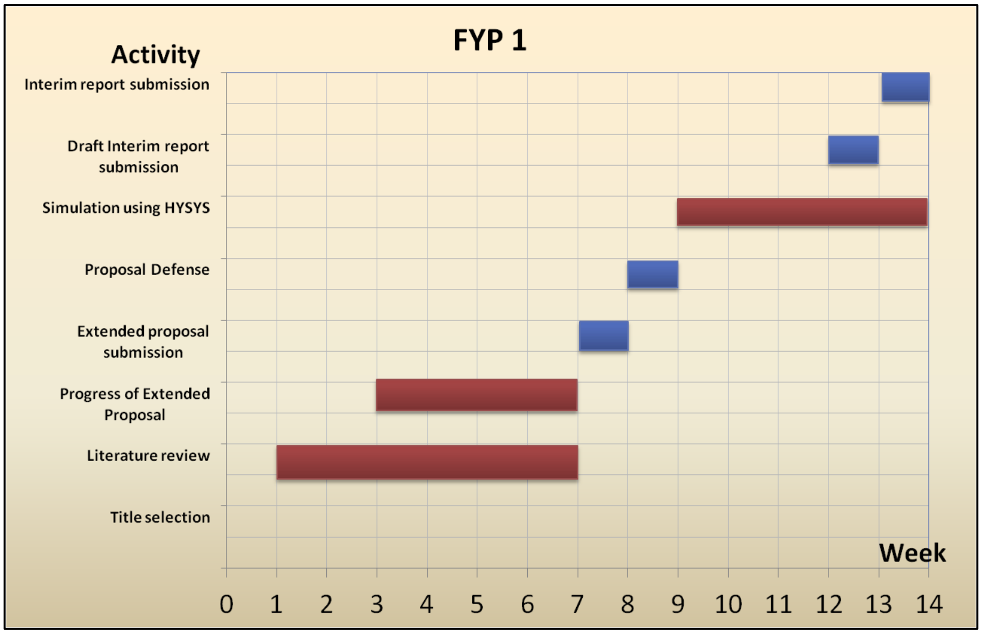

Figure 3.2: FYP 1 Gantt Chart and Key Milestones

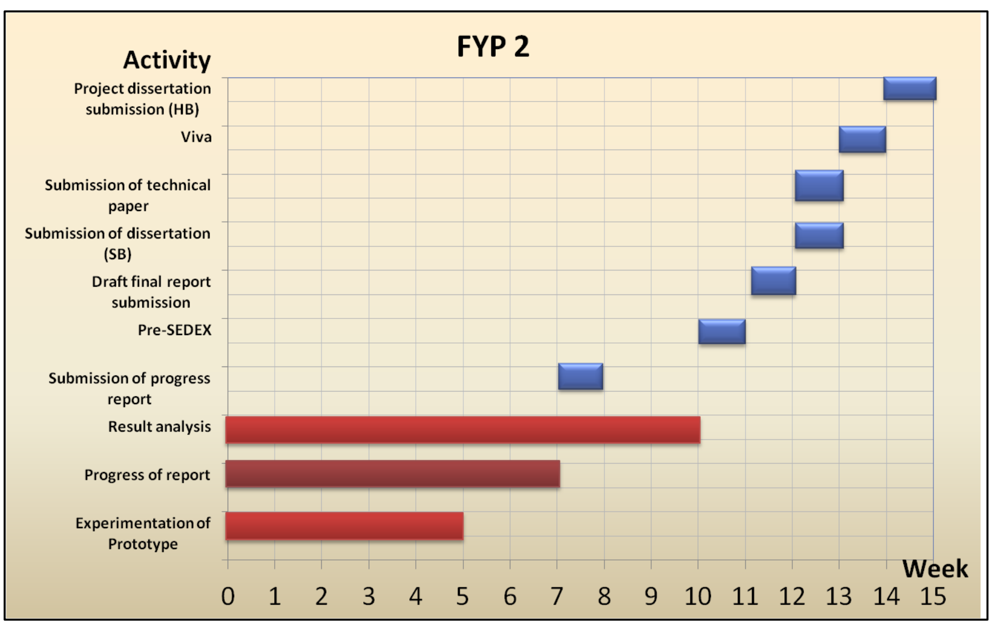

Figure 3.3: FYP 2 Gantt Chart and Key Milestones

3.3 HYSYS Simulation Methodology

This methodology is used to model a continuous CO_2 absorption process in a packed column by using ASPEN HYSYS software. In the absorption process, natural gas and CO_2 are mixed before they enter the packed column where the CO_2 is removed from the natural gas by water. Table 3.1 shows the parameter used in the simulation which is the same with the experimentation.

Specified parameter [dimension]	**Value**
Inlet CO2 mole fraction [mol]	1
Inlet Natural Gas mole fraction [mol]	0.97 CH4, 0.03 CO2
Inlet CO2 gas temperature [^oC]	30
Inlet CO2 gas pressure [bar]	70
Inlet Natural Gas temperature [^oC]	30
Inlet Natural Gas pressure [bar]	70
Solvent temperature [^oC]	30
Solvent pressure [bar]	70
Solvent flowrate [L/min]	0.3
Packed column pressure [bar]	70
Column packing type	Raschig Rings (Ceramic) 1/4 inch
Packed column diameter [m]	0.04
Packed column height [m]	0.45

Table 3.1: Specification for packed column simulation in ASPEN HYSYS

The details procedure for the simulation are as below:

START A NEW CASE

- HYSYS icon is double-clicked to start the program.
- Go to File>New>Case.

SELECTING THE COMPONENTS

- After open the new case, '*Simulation Basis Manager*' window will appeared.
- In this simulation, Methane (CH_4), Carbon Dioxide (CO_2) and water (H_2O) will be used. To add a component, click on '*Add*' and in the '*Match*' box, type the name of the component. Click on '<…*Add Pure'* and the component will be selected.

SELECTING A 'FLUID PACKAGE'

- Click on '*Fluid PKgs*' tab and click on the '*Add*' button. '*Fluid Package: Basics-1*' window will opened.
- In the '*Property Package Selection*' window, scroll down and select '*Sour PR*'. (The ideal gas law [i.e PV = nRT] would be the simplest case).

ENTERING AND SETTING-UP THE SIMULATION ENVIRONMENT

- Click on the '*Enter Simulation Environment*' button on the '*Simulation Basic Manager'* window. HYSYS will open up a '*PFD*' window.
- Click and select the icon that says "*Absorber*". Click on the PFD window to insert the absorption column into the simulation environment. The name for the absorber is 'T-100'.
- The conditions are set up : pressure (70 bar) and temperature (30^{o}C).

DEFINING STREAM COMPONENT SPECIFICATIONS

- On the PFD, double-click on the blue line that says "Solvent in" (stream). A "Solvent In" window will pop up. Enter the values for the Temperature (30 °C), the Pressure (70 bar) and the Volume Flow (0.5 L/min).
- Click on "*Composition*" and the window will transform into one that is requesting the mole fraction of the specified components in the "*Solvent In*" stream. Since this stream consists only of water, input '1' next to 'H2O' and press "Enter" on the keyboard. Set the other mole fractions to zero.
- For the "Gases In" stream, enter the composition as methane – 0.5, CO_2– 0.5 & water – 0. Specify Volume Flow as 1.5 L/min.

CHANGING TRAYS TO PACKING

- Go to the 'Tools' menu and select 'Utilities'. Scroll down and select 'Tray Sizing'. Click on the 'Add Utilities' button. A tray-sizing window should pop up. Name the utility as "Packing". Click on the 'Select TS…' button.
- Click on the button that says 'Auto Section'. For the tray internal, select 'Packed'. When 'Packed' is selected, a drop down menu box will appear in the window. Scroll the drop down menu box for the desired packing type. For this case, 'Raschig Rings (Ceramic) ¼_inch' is chosen.

RUNNING THE SIMULATION

- On the PFD, double click on "*T-100*". When the column window pops up, click on the "*Run*" button located near the bottom of the window. The red "*Unconverged*" box should turn to green "*Converged*" if all the above procedure was followed.

ANALYSING THE EFFICIENCY

- The CO2 absorption efficiency is calculated and tabulated in the table.
- The graph is plotted using Microsoft Excel.
- The data will be compared with the data of inline separator experimentation.

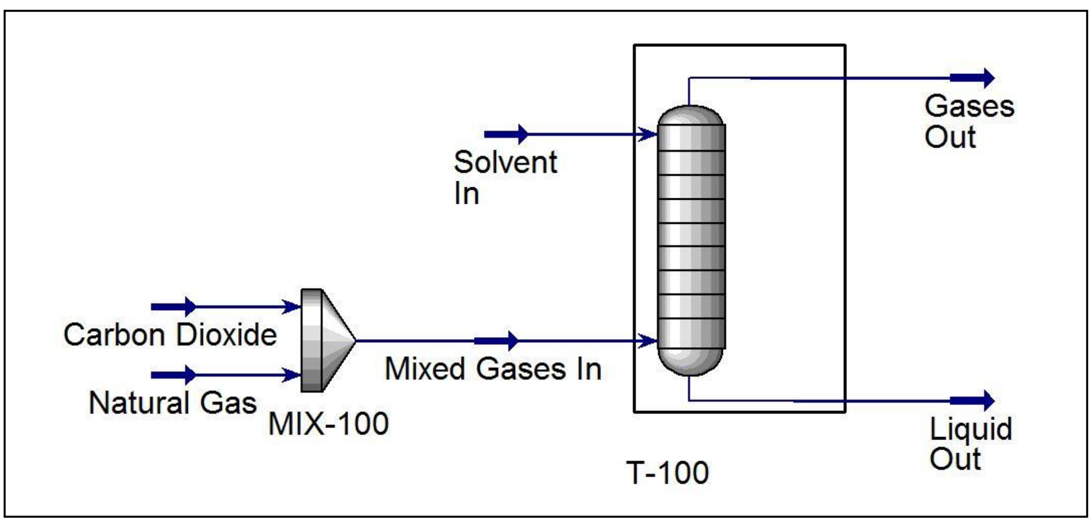

Figure 3.4: Simulation of packed column using ASPEN HYSYS

Figure 3.4 shows the configuration of the equipments used in the simulation of packed column. The simulation used counter current flow which are mixed gases will enter column from the bottom and the solvent will enter from the top.

3.4 Experimentation Methodology

3.4.1 Inline Separator Prototype

Inline separator using absorption process will be test using the test rig provided in Universiti Teknologi PETRONAS. The absorbent used is distilled water and will be injected through the liquid inlet while natural gas and carbon dioxide is injected through the gas inlet.

Then, the process continues to the compressor which the flow rate of the mixed gases will be varied. Lastly, the mixed gas will be sent to the inline separator where inside it, the absorption process will take place. The inline separator can operates pressure from 50 up to 100 bar. It is equipped with series of pressure indicators to study the pressure distribution. The pressure needs to be higher in order to have a good absorption.

Figure 3.5: Inline Separator Prototype

3.4.2 Detailed Methodology for MISEC setup

TEST CONDITION

- Pressure set : 70 bar
- Heater temperature : 30^{o}C

STARTING THE SYSTEM

- Main power supply is turned on.
- NI lab view is activated and the software is allowed to complete loading.
- The analyzer switch is turned on.

Figure 3.6: Starting system for MISEC

HEATING-UP HOT WATER SYSTEM

- The main power is powered up.
- The heater is set to 80^{o}C.
- The water pump is run to circulate the hot water inside the heat exchanger.

FEED GASES SET-UP

- The natural gas and CO_2 gas are chosen to be used.
- Valves are opened at the cylinder gas.

FEED GASES SET-UP AT FEED PANEL

- Inlet and Outlet valve are opened for CO_2 and natural gas.
- Feed regulator is set at 7 bar.
- The flow rate is set for both types of gases at Mass Flow Controller (MFC) at NI interface.

Figure 3.7: Flow rate setting for CO_2 and Natural Gas

COLLECTING DATA

- The toggle is tapped ON.
- All valves which suitable to experiment are opened
  - Through saturation vessel or bypass.
  - Permeate line or retente line
  - Manual BPR or Auto BPR

STARTING THE COMPRESSOR

- The compressor switch is turned on at control panel.
- The "START" button is pressed at compressor.
- Inlet COMP1 valve is immediately opened.
- Inlet pressure is set up to 0.4 bar.

MONITORING THE READING

- Monitor via National Instrument Interface.
- Monitor via instrument indicator at test rig.

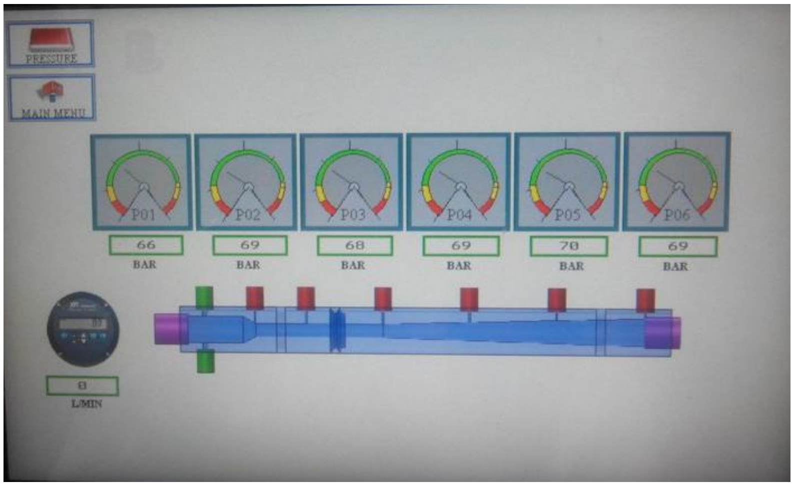

Figure 3.8: Monitoring pressure reading at NI Interface

Figure 3.9: Monitoring pressure reading at the equipment

ANALYZING SAMPLE

- The needle valve is slowly opened.
- The "START" button at compressor is pressed.
- Inlet COMP1 valve is immediately pressed.
- Inlet pressure is set up to 0.4 bar.

Figure 3.10: IR analyzer for gas sampling

SHUT DOWN COMPRESSOR

- To shut down, the inlet ball valve to compressor 1 is closed.
- The "STOP" button at compressor is immediately pressed.
- "COMP1 switch" is stopped to stop compressor 1.

3.5 Tool and Equipment

The only equipment used in this project is the inline separator which already being fabricated. The test rig is used in order to support the inline separator. The CO_2 is purchased from Air Product Malaysia with 99.9% of purity while natural gas with 97% CH4, 2% CO2 and heavier hydrocarbons is supplied by Petronas Dagangan Berhad.

CHAPTER 4: RESULTS AND DISCUSSION

The results and discussion part consist of effect of flow rates of mixed gases on CO_2 absorption by (1) using the simulation of packed column in ASPEN HYSYS software and (2) experiment setup of inline separator prototype.

4.1 Effect of Flowrate of Mixed Gases towards CO_2 Absorption (HYSYS Simulation)

Figure 4.1 illustrates the effect of flowrate of mixed gases on CO_2 absorption of packed column using HYSYS simulation. In this simulation, CO_2 and natural gas feed flow rates represent the concentration of CO_2 and CH_4 and the total flowrate is varied from 3 SLPM to 7 SLPM. The inlet pressure and flow rates of solvent (water) was set at 70 bar and 0.3 L/min in this simulation.

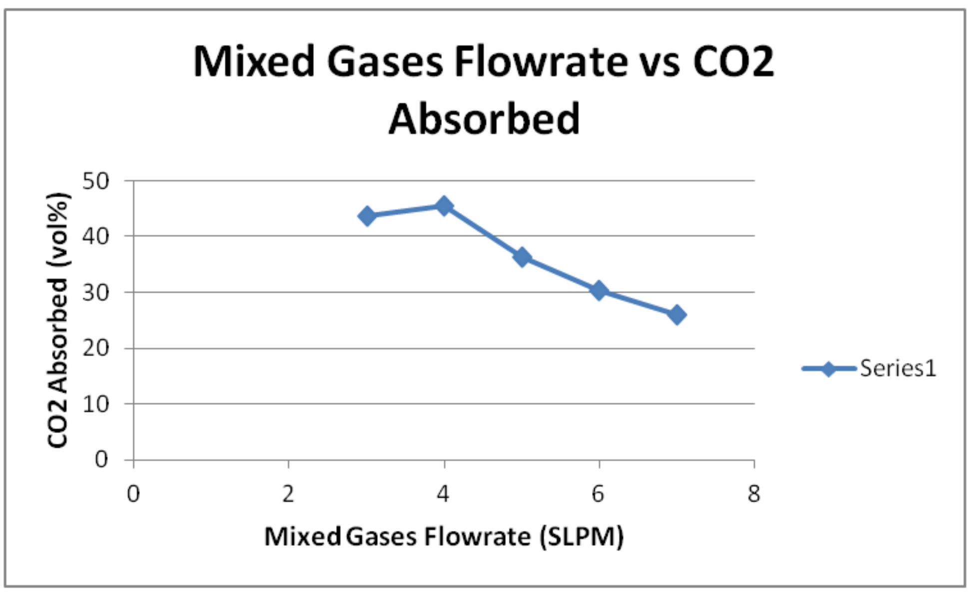

Figure 4.1: Effect of flowrate of mixed gases on CO_2 absorption of packed column using HYSYS simulation

Based on Figure 4.1, the lowest gas flow rate at 3 SLPM shows 43.7 vol% CO2 absorption and the highest gas flowrate shows 26.05 vol% of CO_2 absorption. The increase of the total mixed gases flow rates which is from 3 SLPM to 7 SLPM cause the decreasing of CO_2 absorption performance. The CO_2 absorption reduce after reaching the optimal absorption residence time which is approximately at 4 L/min. This is because the inlet solvent was insufficient to further absorbed the CO_2 gas. The solvent used (water) much more soluble to CO_2 and it explains the increased of the CO_2 absorption to the optimal value (Herzog, Meldon, & Hatton, 2009). This result can be associated with the experiment conducted by (Park, Min, Lee, Nam, Han, & Hyun, 2004) in Figure 4.2 below.

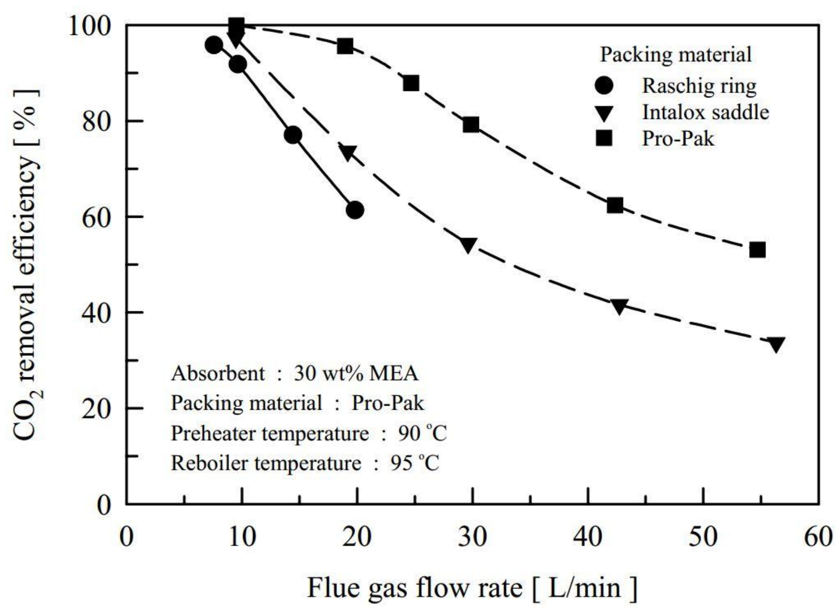

Figure 4.2: CO_2 removal efficiencies under different flue gas flow rates and packing material (Park, Min, Lee, Nam, Han, & Hyun, 2004)

In Figure 4.2, the experiment was conducted using three different packing materials which are Raschig ring, Intalox saddle and Pro-Pak at constant absorbent concentration which is 30wt% MEA. To compare with the inline separator experiment, it shows that higher flue gas flow rate under constant absorbent flow rate means shorter gas-liquid contact time and lower the CO_2 absorption.

4.2 Effect of Flowrate of Mixed Gases towards CO_2 Absorption (Experimentation)

Figure 4.2 shows the effect of different feed flow rates of mixed gases (natural gas and CO_2) of CO_2 absorption performance of inline separator in the experiment. The pressure and flow rate of solvent (water) was kept at 70 bar and 0.3 L/min. The flow rates of CO_2 and natural gas are set from 3 SLPM to 7 SLPM. In this experiment, the flow rates of natural gas and CO_2 are increased but maintained at 50% of CO_2 and 50% of natural gas.

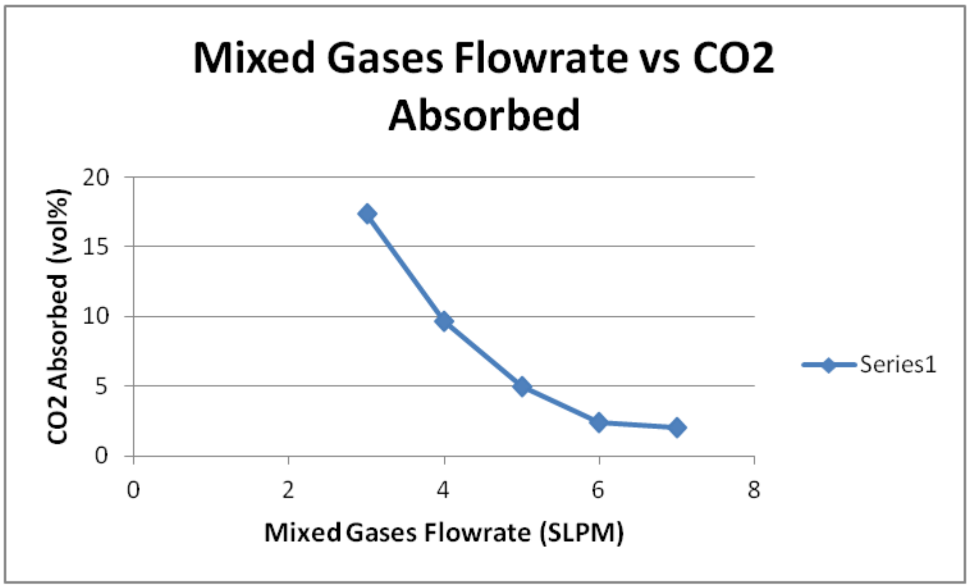

Figure 4.3: Effect of flowrate of mixed gases on CO_2 absorption of inline separator

Based on Figure 4.2, the highest absorption of CO_2 is at lowest flowrate (3 SLPM) which is 17.4 vol%. As the total mixed gases flowrate increased, the absorption of CO_2 reduced and have only 2 vol% of CO_2 absorption at 7 SLPM. The results can be associated with the HYSYS simulation of the packed column where the CO_2 absorption decreases with higher flowrate of the mixed gases. The CO_2 absorption reached a level where the solvent was limited to absorb the increase of the flow rates of natural gas and CO_2. The higher flow rate of the mixed gases under constant absorbent flow rate means shorter gas liquid contact time.

Figure 4.4 shows the CO2 absorption using the straight pipe with the same diameter and length with the inline separator.

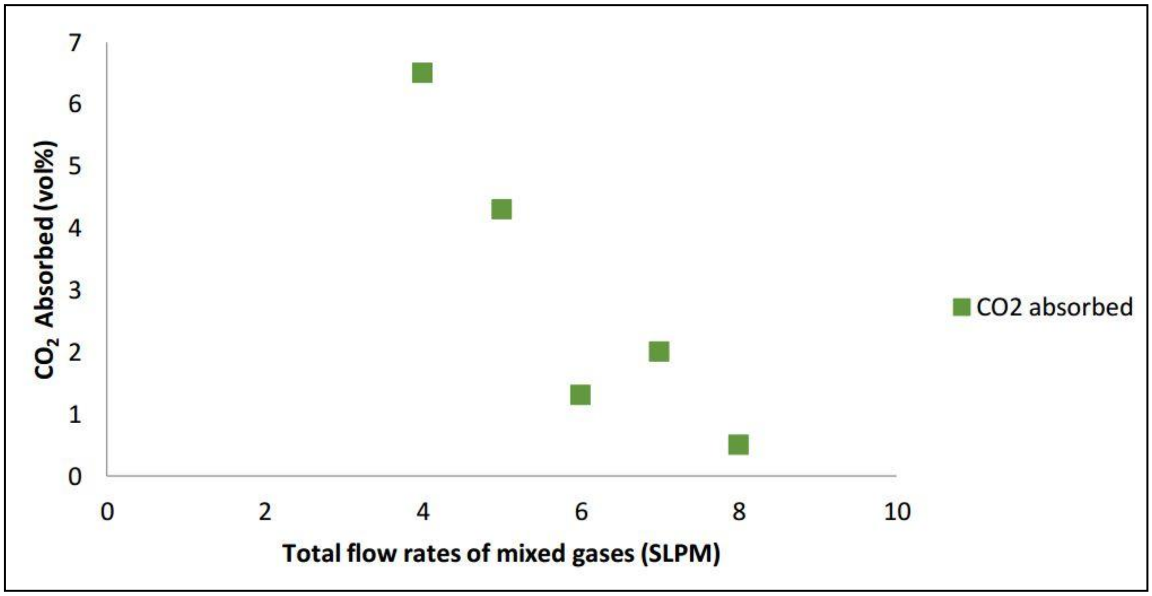

Figure 4.4: Effect of flowrate of mixed gases on CO_2 absorption of straight pipe

Based on Figure 4.4 , the pattern of the CO_2 absorbed is the same as the effect of feed flow rates of mixed gases (natural gas and CO_2) on CO_2 absorption on inline separator. When the feed flow rates of mixed gases increased, it is found that the CO_2 absorbed is decreases. The highest CO_2 absorbed can be achieved by using straight pipe is only 6.5 vol% and the lowest is 0.5 vol% which are much lower than the CO_2 absorbed using inline separator.

4.3 Performance Comparison of Inline Separator with Packed Column

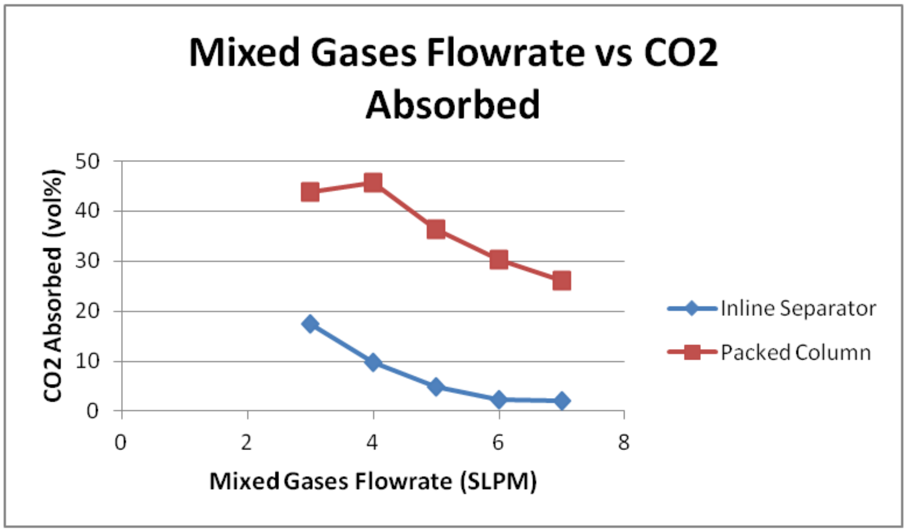

Figure 4.5: Comparison of inline separaror with packed column on CO_2 absorption

Based on Figure 4.5, inline separator shows good CO_2 absorption but not as good as the packed column. At the same conditions and parameters, the highest CO_2 absorption of inline separator is 17.4 vol% at 3 SLPM and the packed column has 43.7 vol% at the same flowrate. The absorption performance of packed column is almost double of the inline separator. This is because this inline separator is still under development and many optimization can be done especially to the nozzle and geometry itself. The nozzle need to produce very small water droplets to ensure it has bigger contact area with the gas and provide higher absorption of the CO_2 gas.

Based on the parametric study, the existing packed bed absorber in the industry is large and need a larger space while inline separator is compact and easily to be installed. Besides, the process of absorption in the packed column need to undergo retention time and also the experiment has to be conducted in steady state condition. The inline separator does not involve any steady state conditions where it still can absorb CO_2 from the natural gas.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of this project to study and evaluate the performance of inline separator with packed column in the HYSYS has been successfully achieved. The physical absorption that has been implemented in inline separator shows that it has good absorption of CO_2 from the natural gas even though only use water as the absorbent. In the experiment, the pressure and flow rate of the absorbent were kept constant at 70 bar and 0.3 SLPM.

From the results obtained in the experiment, the performance of inline separator for CO_2 separation are good enough but not as good as packed column. The absorption performance of packed column is almost double of the inline separator. This is because this inline separator prototype still under development and can be optimized further especially to the nozzle and geometry itself. This shows that the inline separator technology has potential to replace the conventional packed column in the oil and gas industry for separation of CO_2 from the natural gas.

As a conclusion, the performance of the inline separator is not optimized yet for the separation of CO_2 from natural gas. It is believed that the absorption performance of this inline separator can be higher than the current results if it is fully optimized. This inline separator technology has a lot of advantages to the oil and gas industries which can overcome the problems at the offshore platform such as higher installation and maintenance cost as well as provide higher total production to the company.

5.2 Recommendation

In order to fully evaluate the performance of inline separator, further study on the specification modeling of the inline separator is mandatory to improve the efficiency and absorption of CO2. Simulation of the modeling can be done in order to get more accurate results of the absorption since inline separator is new equipment and there is a need to further study on it.

Besides, instead of an Infra-red (IR) Gas Analyzer, a Gas Chromatography(GC) analyzer should be equipped in the MISEC system since GC analyzer is more accurate and precise compare to IR Gas analyzer.

In addition, some other parameters such as pressure, temperature, types of solvent, flow rates can be added to the experiment to fully evaluate the performance of inline separator to absorb CO_2 from natural gas.

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APPENDICES

Appendix A: Physical Properties of Carbon Dioxide

Gas	Carbon Dioxide
Formula	CO_2
Molecular Weight(g/mol)	28.01
Density (kg/m3)	1.977
Freezing Temperature (K)	194.7
Boiling Temperature (K)	216.6
Critical Temperature (K)	304
Dynamic Viscocity (µP)	147

Appendix B: Data from Simulation and Experimentation

1) Effect of Flowrate of Mixed Gases towards Carbon Dioxide absorption of packed column using HYSYS simulation.

Total Mixed Gas Inlet Flowrate (SLPM)	Total Mixed Gas Inlet Flowrate (L/min)	Mixed Gases Inlet Stream		Overhead Outlet Stream		Carbon Dioxide Absorbed (%)
		Mole Fraction of Carbon Dioxide (mol)	Molar Flow (kgmole/hr)	Mole Fraction of Carbon Dioxide (mol)	Molar Flow (kgmole/hr)	
3	0.0390	0.5000	0.0304	0.2782	0.0304	**43.70**
4	0.0526	0.5000	0.0590	0.3523	0.0456	**45.56**
5	0.0658	0.5000	0.0739	0.3884	0.0604	**36.43**
6	0.0790	0.5000	0.0887	0.4103	0.0753	**30.34**
7	0.0921	0.5000	0.1034	0.4249	0.0900	**26.05**

2) Effect of Flowrate of Mixed Gases towards Carbon Dioxide absorption of inline separator experimentation

Total Mixed Gases Inlet Flowrate (SLPM)	Mixed Gases Inlet Stream		Outlet Stream		Mole fraction of CO2 absorbed (vol%)
	Mole Fraction of Carbon Dioxide (vol%)	Mole Fraction of Methane (vol%)	Mole Fraction of Carbon Dioxide (vol%)	Mole Fraction of Methane (vol%)	
3	47.7	54.9	30.3	73.1	**17.4**
4	49.2	52.3	39.5	58.6	**9.7**
5	47.8	53.6	42.8	55.7	**5.0**
6	47.5	52.9	45.1	52.2	**2.4**
7	50	48.2	48.0	48	**2.0**

Appendix C: Inline Separator Configuration