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Assessment of CO_2 Purity and Recovery in Absorption from Natural Gas Wells

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Abstract. One potential technology to mitigate emissions is Carbon Capture and Storage (CCS) technology. Carbon capture and purification technology is one of the key requirements in the CCSU system, which necessitates a high level of CO2 purity as a raw material for production. In utilizing CO2, different CO2 capture technologies are required to achieve the required purity according to utility standards. Absorption technology is one of the most common and effective methods. In this study, absorption technology was used to capture carbon from gas wells with different concentrations of 10%, 20%, 30%, and 40%. Researchers analyzed the effectiveness of solvents in the CO2 gas absorption process from various CO2 concentrations simulated using Aspen Hysys V.15.0. The simulation results showed the highest purity obtained in the CO2 variation in the 40% feed at 86.58%. In comparison, the highest recovery was found in the CO2 variation of 30% at 99.85%. Although the recovery obtained was high, this study still requires review because the purity achieved was still below the CCUS requirement standard.

1 Introduction

The increase in CO_2 concentration in the atmosphere is a serious threat to national and global climate stability, especially considering that Indonesia is a country that is vulnerable to the impacts of climate change, such as rising sea levels, extreme weather, and ecosystem damage [1,2]. These emissions mainly come from the energy sector, such as coal burning in power plants, transportation, and industrial activities, as well as from the forestry sector due to deforestation and forest fires [3,4]. Indonesia is one of the countries with relatively high levels of carbon dioxide (CO_2) emissions in Southeast Asia. As a form of commitment to reducing greenhouse gas emissions, Indonesia has set a Nationally Determined Contribution (NDC) target to reduce emissions by 31.89% with its efforts, and up to 43.20% with international support by 2030 [5]. One potential technology to mitigate emissions is Carbon Capture and Storage (CCS) technology.

CCS technology can contribute up to 19% to reducing emissions by 2050, resulting in around 9 Gt/y of CO2 reduction from 48 Gt/y [6]. The main obstacle in the development of CCS in several countries is the relatively high cost [7,8]. In addition to CCS technology,

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researchers have begun to develop the integration of CCS and CCU systems as a carbon capture, storage and utilization (CCSU) system which produces a positive impact because carbon emissions are not only captured and stored in storage but are used as raw materials so that revenue is obtained from product sales [3,9]. Carbon capture and purification technology is one of the main requirements in the CCSU system, which requires a high CO2 purity as the raw material to be produced.

In CO2 capture, there are several technologies frequently used by researchers, ranging from chemical absorption, adsorption, membrane, distillation, and CFZ technologies, both with emission sources from industry and from natural gas wells [10–12]. Absorption technology has been widely applied in industry, due to its higher efficiency and lower pre-treatment requirements compared to other CO2 separation processes [13–15]. Technology screening was carried out to identify viable CCUS technologies. Consequently, several technologies were selected as candidates for further development under capture, transportation, storage, and utilization [9,16,17]. The first option, utilizing CO2 as a raw material for methanol production, does not require permanent storage. Therefore, the utilization of CO2 in this way is considered a form of resource conservation strategy [18]. As for the second option, CO2 can also be used for enhanced oil recovery (EOR) applications that require high levels of purity [19–21].

Utilizing CO2 requires different CO2 capture technologies to achieve purity that meets utility standards. Absorption technology is one of the most common and effective methods in gas capture and industrial emission control [22]. This process works by capturing specific gas components into a liquid phase using chemical or physical solvents. In the context of carbon capture, chemical absorption using solvents such as monoethanolamine (MEA) has been widely used to absorb carbon dioxide (CO_2) from exhaust gases. The reaction between CO_2 and MEA is reversible, allowing solvent regeneration and reuse of the separated CO_2 [23]. The effectiveness of this technology is the main reason for its use in carbon capture and storage (CCS) systems in the fossil fuel power generation industry.

Despite its efficiency, absorption technology has several challenges, such as high energy consumption for solvent regeneration, chemical degradation of solvents, and high corrosivity in piping systems [10,15]. Therefore, various studies are now focused on the development of alternative solvents that are more thermally and chemically stable, such as piperazine-based solvents, mixed amines, physical solvents such as sulfolane and selexol, and even phosphonium and organic liquids [24,25]. Additionally, the integration of absorption technology with other industrial processes, such as heat generation or cooling, is being studied to enhance overall energy efficiency. With these developments, absorption technology continues to evolve into a potential solution for reducing greenhouse gas emissions, particularly in sectors that are challenging to decarbonize. In this study, absorption technology is used to capture carbon from gas wells with different concentrations. Researchers analyzed the effectiveness of solvents in the CO2 gas absorption process of various CO2 concentrations simulated using Aspen Hysys V.15.0.

2 Methods

The absorption process using chemical solvents is the most widely used technology for post-combustion carbon capture. In this study, carbon from emissions and gas wells with varying CO2 content was captured using absorption technology, simulated using Aspen Hysys V.15.0. Table 1 shows the carbon sources and CO2 variations present in the feed stream.

Table 1. CO2 variations in the feed stream

Component	Natural gas	Variation of CO2 in Feed (%)			
	Mole (%)	10	20	30	40
C_1	60.14	85.23	75.23	65.23	55.23
C_2	2.29	2.29	2.29	2.29	2.29
C_3	0.68	0.68	0.68	0.68	0.68
I-C_4	0.21	0.21	0.21	0.21	0.21
N-C_4	0.19	0.19	0.19	0.19	0.19
I-C_5	0.08	0.08	0.08	0.08	0.08
N-C_5	0.06	0.06	0.06	0.06	0.06
N-C_6	0.09	0.09	0.09	0.09	0.09
N-C_7	0.06	0.06	0.06	0.06	0.06
N-C_8	0.05	0.05	0.05	0.05	0.05
N_2	0.34	0.34	0.34	0.34	0.34
H_2S	0.72	0.72	0.72	0.72	0.72
CO_2	35.09	10.00	20.00	30.00	40.00
Total	100	100	100	100	100
Flowrate (kmol/jam)	1484	1484	1484	1484	1484
Pressure (bar)	42	42	42	42	42
Temperature (°C)	100	100	100	100	100
Reference	[12]				

Table 1 shows the natural gas composition and variations in CO_2 content in the simulation for the carbon capture process analysis. The main component of natural gas is methane (CH_4), with a mole fraction of 0.6014 at the initial conditions. When the CO_2 content is varied from 10% to 40%, the methane mole fraction gradually decreases to 0.5523 at 40% CO_2, while other components, such as ethane, propane, and butane, remain constant. Increasing the CO_2 content in the feed gas directly affects its concentration in the mixture, from 10% to 40%, partially replacing methane as the dominant component.

Other components, such as H_2S, also remain constant at 0.0072, while nitrogen, hydrocarbons, and other gases remain unchanged, while the mass flow rate, pressure, and temperature of the gas remain steady at 1484 kmol/h, 42 bar, and 100°C. The purpose of this variation is to observe the effect of CO_2 levels on carbon capture system performance, solvent efficiency, and process energy requirements at each composition condition. This data is crucial in determining the optimal operating limits for a technically and economically efficient CO_2 capture system.

The feed stream is fed into an absorption column and separated using a chemical solvent, such as MDEA (Methyl Di Ethanol Amine), at a concentration of 90% and a flow rate of 30,000 kmol/h. MDEA reacts with the CO2 and H2S contained in the feed stream, dissolving them and leaving them in the MDEA-rich stream. The CO2 content is then separated from the MDEA in a stripper column. Figure 1 shows a schematic of the CO2 separation process using an absorption-stripper.

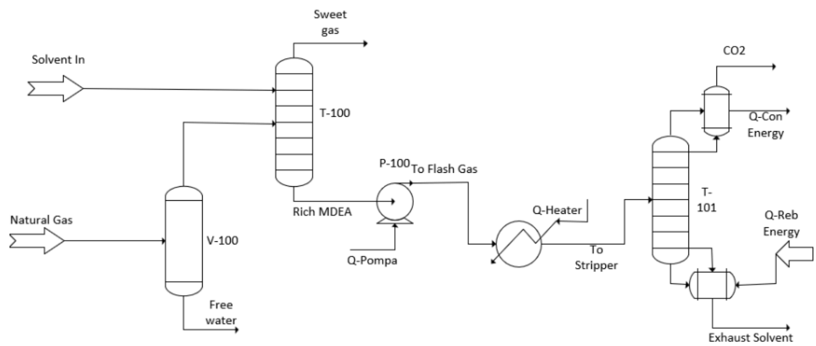

Fig. 1. Scheme of CO2 separation with Absorption-Stripper

In this study, CO2 capture, as shown in Table 1, was simulated using Aspen Hysys V.15.0, as illustrated in Figure 1. Simulation of carbon capture using the chemical solvent MDEA, as part of the fluid package Chemical Solvent: Acid Gas. This fluid package is chosen because it is suitable for MDEA (methyl diethanol amine), which is a solvent for capturing acid gas from natural gas [26,27]. Some of the data used in this study will follow the default from the Aspen Hysys database. Other variables, such as operating condition data, are shown in Table 2.

Table 2. Operating Condition.

Types of equipment	Temp. (^{0}C)	P (bar)	Add. Parameter
Absorber (T-100)	T1: 40; Tn: 45	P1: 40; Pn: 55	25 stage
Stripper (T-101)	Tc: -100; Tr: 350	Pc: 33; Pr: 34	10 stage
Pump (P-100)	-	Delta P = 5	Adiabatic Eff. = 75%
Heater (E-101)	Delta P = 240	Delta P = 25	

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The simulated CO2 capture using Aspen Hysys V.15.0 will be analyzed based on purity and % recovery. The purity of CO2 will affect the delivery for utilization and storage in the CCUS system [16,17]. In general, the CO2 purity and recovery required in CCUS technology reach 95% to avoid equipment corrosion during delivery and contamination of raw materials that will be used for the following process [11,12].

3 Results and Discussion

Carbon capture from industrial gas emissions and gas wells using absorption technology simulated with Aspen Hysys V.15.0 at various CO2 content levels in the feed stream. The process begins by mixing the incoming feed gas according to the conditions in Table 1 with MDEA solvent at 42°C and 55 bar. The feed gas then enters the absorber unit (T-100) after passing through the initial separation vessel (V-100) to remove free water. In the absorber, CO_2 is captured by the MDEA solvent, producing sweet gas that exits at a temperature of 51.58°C and a pressure of 40 bar with a molar flow rate of 863.6 kg/h. Meanwhile, the CO_2-rich solvent is passed to the regeneration section.

The regeneration process occurs by heating the rich solvent in a heat exchanger (E-101) before entering the stripper (T-101). In the stripper column, the solvent is heated to a temperature of 284.7°C at a pressure of 35 bar, with a heat supply of 2.141×10^8 kcal/hour, so that CO_2 is released and exits as a product at a very low temperature of -100.5°C and a pressure of 33 bar with a molar flow rate of 608.5 kgmole/hour. The exhaust solvent will be recycled at a temperature of 357.8°C and a pressure of 34 bar, indicating that this system works in a closed cycle. The energy efficiency of the system is also considered through the utilization of heat exchangers and condensers that reject heat of -5.323×10^6 kcal/hour. This diagram illustrates the overall working principle of the amine scrubbing system for separating CO_2 from high-pressure natural gas streams. Figure 2 shows a simulation of the carbon dioxide (CO_2) capture process that is varied from the gas feed using MDEA-based solvents with Aspen Hysys V.15.0.

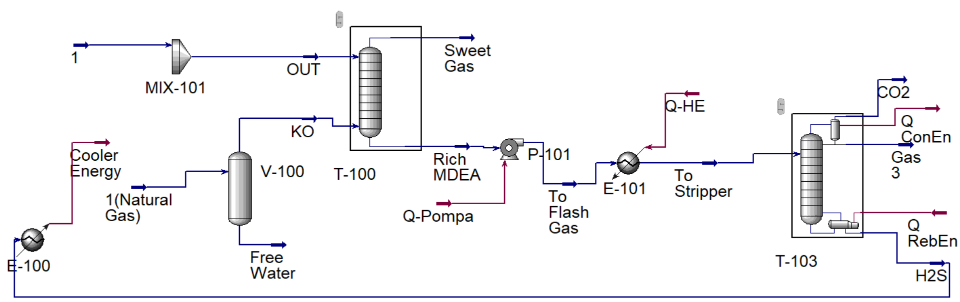

Fig. 2. CO2 separation simulation with Aspen Hysys V.15.0

This study begins with a simulation of CO2 capture from a gas well and continues with variations in CO2 content based on the composition and operating conditions of the gas well. Table 3 shows the simulation results for the CO2 product stream from the capture process, with variations in CO_2 content in the feed ranging from 10% to 40%. The CO_2 mole fraction in the product stream, as determined by the simulation results, ranges from 0.6371 to 0.8658, indicating the process's success in separating CO_2 from hydrocarbons in the feed stream, which is natural gas. Increasing variations in CO_2 content in the feed result in a corresponding increase in the CO_2 fraction in the product stream. This indicates that the higher the CO_2 content in the feed, the greater the amount of CO_2 that can be successfully separated in the product stream.

Table 3. CO2 Capture Results from CO2 Variations in Feed Gas

Komponen	Natural gas	Variation of CO2 in Feed Gas			
		10%	20%	30%	40%
Methane	10.40	26.69	16.62	11.97	9.14
Ethane	1.87	3.38	2.38	1.98	1.81
Propane	0.79	1.41	0.99	0.83	0.77
i-Butane	0.00	0.00	0.00	0.00	0.00
n-Butane	0.02	0.01	0.01	0.02	0.02
i-Pentane	0.00	0.00	0.00	0.00	0.00
n-Pentane	0.00	0.00	0.00	0.00	0.00
n-Hexane	0.01	0.01	0.01	0.01	0.01
n-Heptane	0.00	0.00	0.00	0.00	0.00
n-Octane	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.01	0.02	0.01	0.01	0.01
H2S	1.75	4.66	2.80	2.00	1.56
CO2	85.05	63.71	77.07	83.08	86.58
H2O	0.10	0.10	0.10	0.10	0.10
MDEAmine	0.00	0.01	0.00	0.00	0.00
Total	100	100	100	100	100
Flowrate (kmole/h)	608,5	229.87	380.27	535.07	654,87
Temperature (^{0}C)	-100.5	-98.21	-99.55	-100.29	-100.76
Pressure (bar)	33	33	33	33	33

The remaining components other than CO_2 included in this stream are relatively small, with mole fraction values below 0.1, such as hydrocarbon compounds and H_2S. The mole fraction of methane compounds decreased from 0.2669 to 0.0914, while H_2S also decreased from 0.0466 to 0.0156. This indicates that some light gases are still separated with CO_2, although in limited quantities. The temperature of the CO_2 product ranges from -100.5°C to 100.8°C, depending on the composition and condensation process conditions. This study shows good separation efficiency and a significant increase in the quantity of CO_2 product as the CO_2 concentration in the feed gas increases.

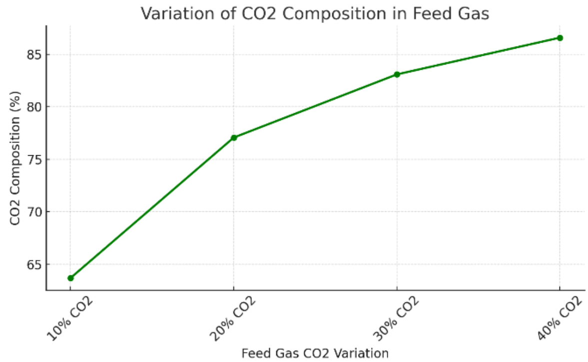

Fig. 3. CO2 Purity based on variations in CO2 composition in feed gas.

The CO_2 composition in the gas mixture increases with the increasing percentage of CO_2 in the feed gas. The increase is non-linear but shows a consistent positive trend from 63.71% to 86.58%. However, CO2 capture using MDEA with absorption stripper technology based on gas well data still needs to be reviewed. The purity obtained in this study is still below the CO2 purity standard required for CO2 delivery or utilization for CCUS systems. This is in contrast to the CO2 purity obtained from CO2 separation using Cryogenic Distillation and CFZ technology, which is 99% [11,12].

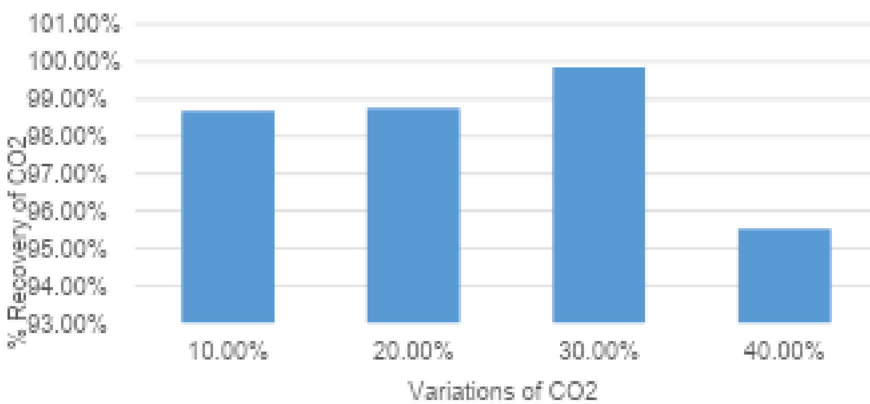

Fig. 4. CO2 recovery based on variations in CO2 composition in feed gas.

Figure 4 shows that the 30% CO2 concentration variation has the highest recovery percentage compared to other CO2 variations. However, at the 40% CO2 concentration variation, the recovery percentage decreases to 93%, indicating process instability at high concentrations. High recovery is due to the balance between the CO_2 partial pressure and optimal adsorption or separation reaction kinetics, while the decrease in recovery percentage can be caused by oversaturation, flow disturbances, or regeneration effects that hinder the separation process. Further studies are needed to investigate system performance at high concentrations and identify factors that reduce the recovery percentage. In addition, optimization of process parameters, such as pressure, temperature, and solvent selection, also needs to be considered for CO2 capture simulations [28].

4 Conclusion

In this study, the CO2 product flow from the capture process increased based on variations in CO_2 content in the feed by 10% to 40%. The CO_2 mole fraction in the product stream, as determined by the simulation results, ranged from 63.71% to 86.58%, indicating the process's success in separating CO_2 from hydrocarbons in the feed stream, which is natural gas. Although some hydrocarbon compounds were still separated with CO_2 in limited amounts, this study successfully achieved 99.85% CO_2 purity at a 30% concentration variation in the feed. CO2 capture using MDEA with absorb stripper technology based on gas well data still needs to be reviewed because the purity obtained is still below the standard requirements of the CCUS system.

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