Carbon Dioxide (CO_2) Absorption Process Using Sodium Hydroxide (NaOH)

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***Abstract*— An absorption process can be carried out to reduce carbon dioxide gas emissions in the surrounding environment. Absorption is a contact process between a mixture of gas and liquid that aims to remove one of the gas components by dissolving it in a suitable liquid. In this study, the CO_2 absorption process was carried out to determine the effect of CO_2 flow rate on the amount of CO_2 absorbed with NaOH absorbent. The results showed that the correlation between CO_2 flow rate and absorption factor was inverse because an increase in CO_2 flow rate caused the contact between CO_2 gas and NaOH to decrease. As a result, the absorption factor decreased because the ratio of CO_2 was greater than the absorbent. While the relation between L/V and the absorption factor is directly proportional if the flow rate of the liquid increases, the retained liquid tends to saturate and can accelerate the diffusion of CO_2 in the water, so the absorption factor also increases. In addition, after the absorption of CO_2 gas, sodium carbonate is produced, which is the result of the reaction of CO_2 with NaOH.**

***Keywords*— Absorption, Carbon Dioxide, Sodium Hydroxide**

I. INTRODUCTION

The rapid development of industries in Indonesia, such as the cement and petrochemical industries, impacts environmental pollution, especially that caused by carbon dioxide (CO_2) exhaust gases. The concentration of CO_2 in the atmosphere has increased significantly every year. Based on data from the Ministry of Energy and Mineral Resources in 2015, CO_2 emissions from the industrial sector alone have risen from 83 million metric tons in 2013 to 162 million metric tons of CO_2 in 2035, with an average increase of 5.2% per year. CO_2 gas is one of the greenhouse gases with the smallest global warming index. Still, it has the second- highest concentration after water vapor, making it the dominant contributor to temperature changes [1].

The magnitude of the impact caused by CO_2 gas on global warming prompted the Indonesian Ministry of National Development Planning to commit to reducing CO_2 gas emissions by 26%. Therefore, to achieve this commitment, it is necessary to make efforts to control all activities that have the potential to produce CO_2 exhaust gas, for example, industrial activities that act as the largest source of CO_2 emissions, namely the cement, iron, paper, and petrochemical industries. Mitigation efforts to manage industrial activities in order to reduce CO_2 gas emission products may be beneficial in reducing the risk of CO_2 gas emission growth [2].

Gas-liquid absorption is a separation process that can be used to separate certain gases, such as carbon dioxide, from flue gases using certain solvents. The absorption process aims to reduce or eliminate toxic gases to comply with quality standards and reduce impurities, thereby increasing the efficiency of the production process [3]. The method commonly used for CO_2 gas reduction is absorption with amine-based solvents such as monoethanolamine, followed by a desorption process because this process can reduce CO_2 emissions by up to 85% [4]. One application of the absorption process in industry is CO_2 capture in the petrochemical industry, methane gas separation, and the capture of carbon emissions from the coal combustion process in the energy industry [3].

Absorption of carbon dioxide using NaOH absorbents offers higher stability, lower costs, and is safe for the environment [5]. Because NaOH has faster reaction kinetics with CO_2 than Monoethanolamine (MEA) and its derivatives amines, it outperforms organic adsorbents in CO_2 capture. In addition, alkaline solutions have a higher absorption efficiency (92-99%) than amine solutions (61-90%) or ammonia solutions (78-98%) [6]. Using membrane technology, the CO_2 gas absorption process obtained carbonate by-products by reaction with NaOH, which then returned as $Na_2CO_3.10H_2O$ crystals in a membrane crystallizer [7]. NaOH absorbent is used in a spray dryer system to absorb carbon dioxide. Increasing the absorbent concentration and operating temperature increases reaction speed and CO_2 removal efficiency [8]. Therefore, this study aims to determine the absorption factor of CO_2 gas to NaOH and the ratio of CO_2 flow rate and NaOH flow rate to absorption.

A. *Absorption*

Absorption is the process of separating substances by contacting a flue gas (gas mixture) with a certain absorbent. The absorption process aims to reduce or eliminate toxic gases to comply with quality standards and reduce impurities, thereby increasing the efficiency of the production process [3]. There are two types of absorption, physical absorption and chemical absorption. Chemical absorption occurs when a chemical reaction does not follow the gas dissolved in the absorbent because the absorption process occurs when there is physical interaction, such as gas diffusion into the liquid. The absorption of H_2S gas with carbonate solvents is an example of physical absorption. Then, chemical absorption occurs when the absorption of gas is followed by a chemical reaction, for example, when absorbing CO_2 gas using sodium hydroxide (NaOH) as a solvent.

The main principle of the gas absorption process is that there is contact between the gas and the liquid, and the gas will diffuse into the fluid because of its

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solubility. This is influenced by the flow rate, gas pressure, and the area between the gas and liquid phases [9]. The basic principle of chemical absorption is based on the neutralization reaction. Thus, according to [10], the solvent used must have the following specifications:

1. High reactivity due to gas absorption.
2. Low regeneration costs
3. High absorption capacity
4. High thermal stability and reduced solvent degradation
5. Low environmental impact
6. Low solvent costs

Factors affecting how effectively the absorption process will be carried out are fluid flow rate, pressure, temperature, contact surface area, type of packing, type of substance absorbed, type of solvent, and solvent concentration [11]. Several factors that can affect the rate of absorption are as follows [12]:

1. Fluid flow rate, if the rate of fluid flow is smaller, the contact time required between gas and solvent will be longer, so that it will increase the amount of gas that diffuses.
2. The concentration of the gas, driving force can be caused by the difference in concentration between several gases from the diffusion process that occurs in the two fluids.
3. The contact surface area, the rate of the absorption process will be greater if the contact surface area between the gas and the solvent is greater.
4. Operating pressure: The separation process's efficiency increases with increasing operating pressure.
5. Temperature, the temperature in the absorption process has little effect on the absorption rate.
6. The humidity of the gas, if it is too high, will limit the amount of gas that can take in the latent heat, so the process of dehumidification of the gas before it is injected into the absorber column is very necessary.

Absorption is one of the most widely used processes in the gas, petroleum, and petrochemical industries, especially in separating unwanted gases. In the gas industry, natural gas is cleaned of impurities such as water vapor, CO_2, and H_2S. Water vapor can be absorbed using glycol, while CO_2 and H_2S are absorbed using MEA, DEA, and TEA [9]. Furthermore, in the petrochemical industry, making sulfuric acid and soda ash is carried out using the principle of absorption, where H_2SO_4 production is carried out by absorbing SO_2 gas with H_2O, which becomes the product H_2SO_4 [13].

B. Carbon Dioxide (CO_2)

Carbon dioxide (CO_2) is a gas consisting of two oxygen atoms covalently bonded to one carbon atom. This carbon dioxide is a gas in sectoral conditions and atmospheric pressure. Carbon dioxide content in fresh air varies between 0.03% (300 ppm) depending on the location [14]. Carbon dioxide is a gas that is naturally formed from burning fossil fuels and biomass and results from changes in land use and other sectoral processes. CO_2 gas is the main anthropogenic gas that is considered to affect the radiation balance on earth [15]. The concentration of CO_2 in the atmosphere has continued to increase since the industrial revolution due to developments in human activities.Scientific evidence shows that the increasing concentration of CO_2 in the atmosphere is the main cause of global change and climate change. An increase in CO_2 will cause an increase in temperature on Earth between 2 and 4.5°C [16].

C. Sodium Hydroxide

Sodium Hydroxide is superior to organic adsorbents, such as Monoethanolamine (MEA) and its derivative amines, in capturing CO_2 because NaOH has faster reaction kinetics with CO_2 than Monoethanolamine. In addition, alkaline solutions have a higher absorption efficiency (92-99%) than amine solutions (61-90%) or ammonia solutions (78-98%) [6]. Based on research Ye et al.[7], using membrane technology, the CO_2 gas absorption process obtained carbonate by-products by reaction with NaOH, which then returned as $Na_2CO_3.10H_2O$ crystals in a membrane crystallizer. NaOH absorbent is used in a spray dryer system to absorb carbon dioxide. Increasing the absorbent concentration and operating temperature increases reaction speed and CO_2 removal efficiency [8]. Therefore, this study aims to determine the absorption factor of CO_2 gas to NaOH and the ratio of CO_2 flow rateand NaOH flow rate to absorption.

a. Absorber

The absorption column or absorber is a tube or column where the absorption of a substance that will be passed through the column or tube occurs. This process is carried out by providing substances that have been contaminated by other components. An absorber column design considers several parameters, including pressure, flow rate, absorbent concentration, and absorbent viscosity [17]. The choice of absorbent type needs to pay attention to several parameters, including operationalcosts, efficiency, and the rate of degradation of the absorbent used. In the use of amine systems, problems usually occur, including volatility, degradation, oxidative, and toxicity problems which are striking this causes the use of amines as absorbents to be considered less suitable for direct air capture of CO_2 systems. In this case, hydroxide compounds have a higher efficiency thanamines [6].

b. Absorption Factor (A)

Absorption factor (A) is one of the parametersused to determine how much gas content is absorbed from theabsorption process that has been carried out. Several factors, such as temperature andpressure, influence the absorption factor. The greater the value of the absorption factor A, the greater the flow rate of the liquid absorber and the fewer steps used in the absorption column. The absorption operation can be carried out at a high temperature and low pressure to reduce the absorbent required [18]. The equation used to determine the absorption factor is as follows:

$$A = \frac{L}{KV}$$

A = Absorption factor (unitless)
L = Total liquid flow rate (mol/time)
K = Equilibrium constant (mole fraction in gas)/(mole fraction in liquid)
V = Total gas flow rate (mol/time)

Based on the potential of a suitable sodium hydroxide absorbent to adsorb carbon dioxide gas, this study aimed to investigate the effect of sodium hydroxide and carbon dioxide flow rates on absorption factor of CO_2 gas. This research using NaOH, because to reduce production costs and prevent potential harm to the environment due to the use of toxic absorbents due to absorbent amines.

II. METHOD

The tools used in the CO_2 gas absorption experiment using absorbent NaOH were beaker glass, burette, funnel, erlenmeyer, watch glass, measuring cup, flask, pipette, absorption column, spatula, stand, and clamps. The materials used were distilled water, pure CO_2 gas, 0.1 N HCl, methyl orange indicator, and 0.1 N; 0.12 N NaOH. Then, the variables used in the absorption experiment were 0.1 N; 0.12 N NaOH solution; HCl 32% 0.1N; and CO_2 flow rate 1; 3; 5; 6; 7; 8 L/min (0.1N NaOH) and 2; 3; 5; 7; 8; 9 L/min (0.12N NaOH).

The CO_2 gas was absorbed by preparing a 0.12 N NaOH solution by weighning the NaOH solid. Then dissolve it in distilled water and make a 0,1 N HCl solution. Following that, 0.12 N NaOH was drawn from the reservoir in 20 ml for the standardization step. Then, one drop of methyl orange indicator was added and titrated with 0.1 N HCl until the color changed to violet-red.

The tank filled with 38 liters of 0.1 N and 0.12 N NaOH solution. Then, CO_2 gas flowed to the absorption column at 1; 3; 5; 6; 7; 8 L/min (0.1N NaOH) and 2; 3; 5; 7; 8; 9 L/min (0.12N NaOH). The pump is turned on to flow NaOH into the absorption column. After that, samples were taken at the bottom product after being in steady state. For each variable, CO_2 gas absorption with NaOH solution was carried out for 5 minutes. Then, the analysis phase was carried out by dropping one drop of methyl orange on the samples taken for each time variable.

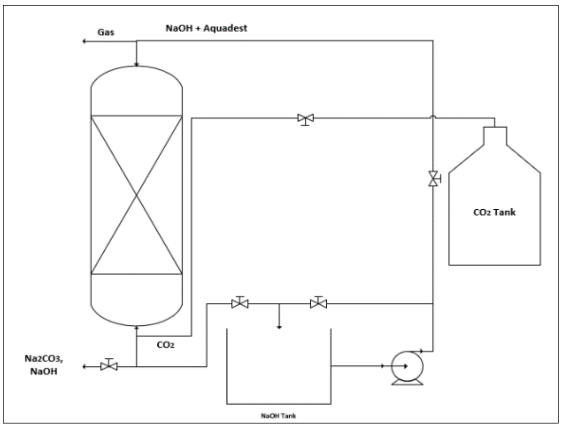

Figure 1. Schematic of Carbon Dioxide Gas Absorption Process with NaOH

III. RESULTS AND DISCUSSION

A. Carbon Dioxide (V) and Absorption Factor

Based on the experimental results of the absorption process of carbon dioxide gas with sodium hydroxide absorbent, the following data are obtained:

TABLE 1.
THE AMOUNT OF CO_2 ABSORBED AT EACH FLOW RATE OF CO_2 AND 0.1 N NaOH

CO_2 Flow Rate (L/min)	NaOH Flow Rate (mL/s)	CO_2 Absorbed (mol)
1	42	0.000203
3	56.67	0.000205
5	56.67	0.000055
6	56.67	0.000180
7	43.34	0.000185
8	8.8	0.00016

TABLE 2.
L/V VALUE AND ABSORPTION FACTOR (0.1 N NaOH)

CO_2 Flow Rate (L/min)	L/V	Absorption Factor
1	1.3175	1.1659
3	0.5856	0.5182
5	0.3514	0.3109
6	0.2928	0.2591
7	0.1919	0.1698
8	0.0341	0.0302

TABLE 3.
THE AMOUNT OF CO_2 ABSORBED AT EACH FLOW RATE OF CO_2 AND 0.12 N NaOH

CO_2 Flow Rate (L/min)	NaOH Flow Rate (mL/s)	CO_2 Absorbed (mol)
2	54	0.000597
3	52	0.000596
5	48	0.000595
7	39	0.000595
8	24	0.000597
9	14	0.000595

TABLE 4.
L/V VALUE AND ABSORPTION FACTOR (0.12 N NAOH)

CO_2 Flow Rate (L/min)	L/V	Absorption Factor
2	0.8370	0.7407
3	0.5373	0.4755
5	0.2976	0.2634
7	0.1727	0.1529
8	0.0930	0.082
9	0.0482	0.0427

Based on the results of absorption studies with variable CO_2 flow rates (V) 1; 3; 5; 6; 7; 8 L/minute (0.1N NaOH) and 2; 3; 5; 7; 8; 9 L/min (0.12N NaOH), there is a relationship between CO_2 flow rate and absorption factor (A) shown in Figure 2.

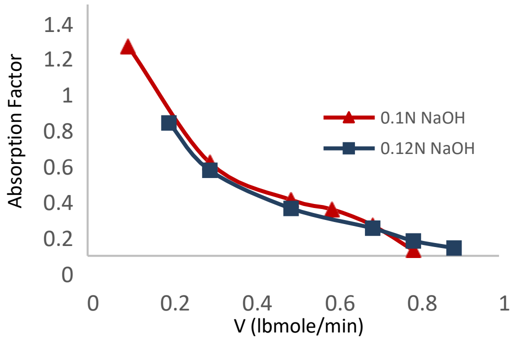

Figure 2. CO_2 Flow Rate vs Absorption Factor

The absorption factor can be seen from the fluid flowrate and gas concentration used. The fluidflow rate indicates the contact time between the gasand the solvent, which affects the amount of gas thatdiffuses. Meanwhile, the gas concentration indicates the driving force of the diffusion process between the two fluids [18]. It can be seen in Figure 2.

The relationship between CO_2 gas flow rate and absorption factor is inversely proportional. The higher the CO_2 flow rate, the lower the absorption factor. The flow rate of NaOH is inverselyproportional to the absorption of CO_2. The greater the flow rate of NaOH, the less CO_2 is absorbed, andvice versa. These results follow the results of research Ardhiany et al. [19], which at variations in the NaOH flow rate of 1 L/min; 2 L/min; and 3 L/min and a carbondioxide flow rate of 2 litres/minute, the percentage of absorption of carbon dioxide is 30.098%, 29.836%, and 28.685%. Then, based on the results of Sylvia et al.[20], using water absorbents in the absorption process of carbondioxide gas, the highest absorption percentage occurred at a CO_2 flow rate of 117.75 L/min and a flow rate of H_2O of 235.5 L/min, which was 45.89%. Furthermore, the lowest per cent absorption occurred at a CO_2 flow rate of 188.4 L/min and an H_2O flow rate of 376.8 L/min, which was 28.32%. This is because the slower the flow rate mass transfer of CO_2 gas to NaOH, the greater the CO_2 absorbed. Conversely, an increase in the flow rate of NaOH will reduce the possibility of contact between CO_2 and NaOH gases so that less CO_2 is absorbed, and the absorption factor also decreases [12]. At a large CO_2 flow rate, an increase in gas flowrate causes the amount of CO_2 enteringto increase so that the impact on CO_2 absorption decreases andthe absorption factor decreases because the ratio ofCO_2 and absorbent is higher [11].

B. L/V and Absorption Factor

Based on the results of an absorption study with the ratio of the flow rate of CO_2 (V) and the flow rate of NaOH (L), there was a relationship between the L/V ratio and the absorption factor (A), as shown in Figure 3.

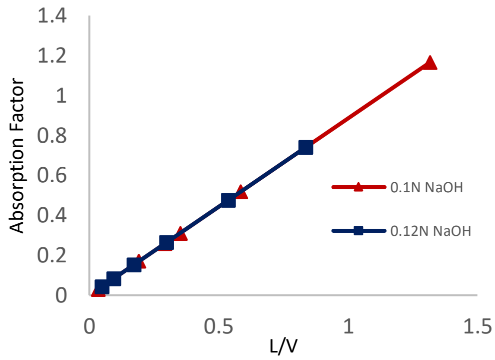

Figure 3. L/V vs Absorption Factor

Figure 3 shows the comparative relationship between CO_2 and NaOH flow rates with absorption factors has increased. The higher the concentration of NaOH, the closer distance between NaOH molecules so that the chances of collisions between NaOH and CO_2 molecules are greater and the phase contact between gas and liquid. As a result, the amount of gas that can move from the gas phase to the liquid phase is increasing [11]. In addition, thehigher the concentration of NaOH given, the higher the power produced. This is caused by a decrease in the levels of carbon dioxide in the gas, the reduction of CO_2 levels isdue to its reaction with NaOH solution, NaOH will bind CO_2 through the absorption process. Factors that can affectthe absorption rate are the flow rate of NaOH and CO_2. The flow rate of NaOH is inversely proportional to the absorption of CO_2. The greater the flow rate of NaOH, theless CO_2 is absorbed, but the flow rate of carbon dioxide is directly proportional to the CO_2 absorbed. The greater the flow rate of CO_2, the greater amount of CO_2 absorbed because the slower the flow rate of NaOH, the greater the chance of contact between CO_2 and NaOH gas, and the greater the mass transfer of CO_2 gas to the solvent (NaOH), so that the CO_2 absorbed is greater. On the other hand, an increase in the flow rate of NaOH will reduce the chances of contact between CO_2 and NaOH gases, so that less CO_2 will be absorbed [12].

IV. CONCLUSION

Based on the research that has been done, several conclusions are that the relationship between CO_2 flow rate (V) and absorption factor (A) is inversely proportional; the greater the CO_2 flow rate, the smaller the absorption factor because the greater the flow rate of NaOH, the smaller the amount of CO_2 absorbed because in the absorption operation with a large flow rate, the contact time between NaOH and CO_2 for the same number of molecules will be smaller. This short contact time causes less mass transfer, and the amount of CO_2 absorbed is also less. Then, the effect of the comparison between CO_2 and NaOH flowrates with the absorption factor is that the higher the L/V value, the higher the absorption factor (A) value because the higher the concentration of NaOH, the greater the chance of collisions between NaOH and CO_2 molecules and the phase contact between gas with liquid the better.

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