9th International Seminar of Research Month 2024
Volume 2025
http://dx.doi.org/10.11594/nstp.2025.4747

Conference Paper

Desorption of CO2 Gas in KOH Solution by Using Gas Absorption Column

Okik Hendriyanto Cahyonugroho*, Iqbal Syah Putra

Faculty of Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Surabaya 60294, Indonesia

*Corresponding author:
E-mail:
okikhc@upnjatim.ac.id

ABSTRACT

Technological developments in industry will lead to increased energy consumption. Human dependence on fossil resources will trigger serious problems with air pollution due to high CO2 gas emissions while nature's ability to accept pollutant loads is very limited. To solve this problem, CO2 gas capture is carried out from the source. CO2 gas capture is done using Carbon Capture and Storage (CCS) technology. This technology converts CO2 gas emissions into hydrocarbons through a hydrogenation process. One form of this technology in the form of Gas Absorption Column is a type of reactor in a closed column that uses absorbents in the form of KOH as a promoter. The purpose of this research is to determine the optimum solution and gas flow rates with variations of 2, 4, and 6 L/min on the KOH solution, and 10, 20 and 30 L/min on the gas flow rate, while the fixed variable is air injection of 10 L/min. The methods used are sampling and alkalimetric methods. This method is used when the absorption process runs for 20 minutes with a sampling time of every 5 minutes which each sample will be analyzed in the form of pH, temperature, and EC and dissolved CO2. The analysis showed an effective flow rate of 2 L/min on solution and 30 L/min on CO2 gas. The concentration captured was 114 mg/L by removing 52% of the absorbed concentration. In addition, from the results of pH analysis, there was a decrease due to mass transfer that occurred and inversely proportional to temperature and EC which increased. It can be concluded that the flow rate of the solution will affect the contact time of the adopted CO2 gas. Meanwhile, the higher the CO2 gas flow rate, the greater the CO2 absorbed in the absorpben.

Keywords: Absorption, KOH absorbent, solution flow rate, CO2 Gas Flow Rate

Introduction

Technological developments in the industrial area will cause the amount of energy emissions consumed to increase. The energy emissions produced come from fossil fuels in the form of petroleum, coal, and natural gas (Okonkwo et al., 2023). The fossil fuels used produce emissions in the form of CO_x, NO_x, and CH_4. One of the CO_2 emissions accounts for 80% of emissions that can cause global warming through greenhouse gases (Shu et al., 2023). Carbon dioxide gas or CO_2 is a chemical compound that contains oxygen covalently bound to carbon produced in the incomplete combustion process (Roussanaly et al., 2021). Carbon dioxide gas has the property of absorbing sunlight in the form of infrared so that it can cause the temperature on Earth to increase (Zahro et al., 2023). The increase in temperature on earth will result in damage to the ecosystem and climate, to ensure that the sustainability of the earth is maintained, various ways are carried out to minimize the emissions produced (Kurnia & Sudarti, 2021). One of them is Carbon Capture and Storage (CCS). The technology is a form of carbon dioxide or CO_2 gas capture tool that is used on a large or small scale, and then will be used in industrial activities as an alternative energy source (Hong, 2022). One form of application of Carbon Capture and Storage (CCS) technology is the Gas

How to cite:
Cahyonugroho, O. H., & Putra, I. S. (2025). Desorption of CO2 Gas in KOH solution by using gas absorption column. *9th International Seminar of Research Month 2024*. NST Proceedings. pages 598-607. doi: 10.11594/ nstp.2025.4787

Absorption Column, a reactor that can capture CO_2 gas in a column equipped with packing that is operated continuously (Dziejarski et al., 2023).

An absorption column is a process of absorption and collection of a substance passing through a closed column or tube that has a different phase with the opposite flow direction (Nasir & Go, 2024). The opposite flow will cause a chemical substance to be transferred from the gas phase to the liquid phase (Hanifa et al., 2023). The absorption column has three parts including the spray where the gas diffuses with the liquid. In the packed tower section as a place to contact the touched surface, the wider the contact area, the longer the residence time will be so that the absorption process will increase. At the bottom, there is an influx of injected carbon dioxide gas (Zhou et al., 2024). The dissolved gas from the outlet of the reactor will be fed to the final reservoir for further analysis. The functional mass transfer that occurs in the absorption column is directly proportional to the contact time in the column. Contact time can cause particles or substances in the absorption column to diffuse (Huda et al., 2023). The absorbent used will be injected into the top of the column. The absorption process that enters the column that meets between liquid and gas has irreversible properties, while in diffusion distillation it will experience equimolar counter diffusion. Counter-current flow is a contact flow direction that produces friction or friction between substances to be large (Martin-Roberts et al., 2021). In addition, in the absorption column, the type of packing will affect the diffusion time of the gas to the solvent. The type of packing that is generally used is random packing which has a large surface type and a small cost. With an irregular packing position, it will trap the residence time of the solution longer so that the concentration of dissolved gas is higher (Mao et al., 2023).

In the absorption process, absoben is needed for solvent regeneration which is interpreted as a stripping or desorption process (Arning et al., 2024). The desorption process is CO_2 gas captured by a solvent in the form of KOH which is a strong base with the results of the process being rich in CO_2 which is absorbed in the final reservoir (Isya et al., 2021). To determine the CO_2 gas dissolved effectively, a variable is carried out between the solution flow rate and the gas flow rate. These variables are used to determine the optimum conditions in the desorption process by analyzing the influence of pH, temperature, EC, and dissolved and remaining CO_2. Based on the research conducted, the basic flow rate will be obtained to absorb CO_2 gas.

Material and Methods

In the research conducted on the absorption of CO_2 gas, it is necessary to prepare the tools and materials used in the form of a Gas Absorption Column reactor, KOH absorbent, and analysis of pH, temperature, EC and dissolved and remaining CO_2. The reactor used is self-designed with the following reactor specifications:

1. CO2 gas cylinder with a capacity of 2 m3 a diameter of 0.14 m and a height of 1.2 m.
2. The initial and final reservoirs can accommodate 150 L or 0.15 m3 of water with a length of 0.73 m; width of 0.6 m; and 0.46 m high.
3. The absorption column is made of acrylic with a length of 1.4 m and a diameter of 2.5 inches in which there is *a riching solvent* with a size of 10 mm x 10 mm.
4. Centrifugal type pump with a capacity of 12 L/min and compressor with a capacity of 25 L/min.
5. The size of the reactor is 1.84 m long: 2.17 m high and 0.9 m wide.

The circuit of the CO_2 gas absorption device is in Figure 1.

Research Variables

According to scientific articles from Robiah et al. (2021) and Oktarina et al. (2023) the variables used in the study as the basis for determining bound variables and independent variables with the following details:

a. Bound Variables
   The bound variable used is in the form of a relationship between the parameter and the correlation obtained. The parameters used consist of pH, temperature, Electrical Conductivity (EC), and dissolved CO_2 gas. In addition, the effect of the airflow rate used is 10 L/min. From the absorption process carried out, the type of absorbent used during the analysis was in the form of KOH in the form of a solution with a concentration of 0.01 M.
b. Independent Variable
   The free variables used are the flow rate of the solution and the flow rate of the gas with different speeds. The flow rate of the solution used consists of 2, 4, and 6 L/min. As for the CO_2 gas flow rate used, it consists of 10, 20, and 30 L/min. From each flow rate of the solution and the gas injected into the reactor, an analysis will be carried out for 20 minutes with every 5 minutes sampling will be carried out to determine the concentration of CO_2 gas captured during the process.

Research Methods

CO_2 gas absorption with KOH solution absorbent uses two types of methods including the sampling method and the alkalimetric method. The method is used after going through the gas absorption process in the reactor. The results of the absorption process in the reservoir will be analyzed using these two types of methods. The first method uses the sampling method by taking a 200 ml solution in the initial and final reservoirs to analyze pH, temperature, and Electrical Conductivity (EC). Sampling was carried out at times 0, 5, 10, 15, and 20 minutes. The process was carried out for 20 minutes every time one process on each of the specified variables. Furthermore, the second method was carried out using the alkalimetric method which is a wet acid titration analysis used to determine the concentration of dissolved CO_2 gas. Wet acid titration is carried out in two stages. The first stage is carried out an initial titration by determining the starting point of the solution using a sample in the form of a KOH solution with a concentration of 0.01 M in an initial reservoir of 50 ml and an indicator is added in the form of phenolphthalein (PP) which works in a wet route. After obtaining the value of the titration results, then titrated the outlet tub by taking 50 samples and adding an indicator in the form of metal orange (MO) which works in the acidic route. From each sample that is taken and has been added, the indicator will then be titrated using an HCl solution until the color changes from pink to clear and orange to reddish-orange. In the second stage of the titration, $BaCl_2$ is added to the catch basin outlet sample as much as > 10% of the T_2 (final titration) - T_1 (initial titration) value. Add methyl orange indicator (MO) into the solution until it turns orange to reddish-orange and titrate using HCl solution with a concentration of 0.1 M. Record the titration results obtained and record the results. Record the titration results obtained and process in the form of a graph.

Results and Discussion

The observation shows that in the absorption process in KOH solution the greater the concentration, the higher the coefficient of mass transfer. The analysis shows the reaction formed between the KOH solution and CO_2 as follows:

$$2\ KOH + CO_2 \rightarrow K_2CO_3 + H_2O$$

The results of research conducted for the initial concentration of each parameter were obtained as a starting point in determining the final concentration in each sample (Chai et al., 2022). The concentration results obtained are derived from the effect of variations in solution flow rate and gas flow rate obtained as follows:

Table 1. Initial concentration on the KOH solution of each parameter

Solution Flow Rate	CO_2 Gas Flow Rate	Sample Analysis Test		
		pH	Temperature	EC
2 L/Min	10 L/Min	9.5	27.5	0.200
	20 L/Min	9.5	28.5	0.211
	30 L/Min	9.5	28	0.213
4 L/Min	10 L/Min	9.5	28.5	0.214
	20 L/Min	9.5	27.6	0.214
	30 L/Min	9.5	28.4	0.213
6 L/Min	10 L/Min	9.5	29.1	0.202
	20 L/Min	9.5	29.5	0.202
	30 L/Min	9.5	29.5	0.202

Effect of KOH flow rate and CO_2 gas flow rate on dissolved CO_2

The initial titration results, it is continued with further titration to determine the concentration of CO_2 gas dissolved in the KOH absorbent. Then the reaction formed from the absorption results is the K_2CO_3 solution. The K_2CO_3 solution used will be titrated with HCl solution, the reaction that occurs is as follows:

$$KOH + HCl \rightarrow KCl + H_2O$$

In the second stage, the analysis of the remaining KOH that does not form a new solution is carried out by adding $BaCl_2$ solution as much as > 10% of the value of T_2 (final titration) - T_1 (initial titration). From the titration, the following reaction occurs:

$$K_2CO_3 + BaCl_2 \rightarrow 2\ KCl + BaCO_3$$

Titration is carried out using HCl, from this titration the volume of HCl is obtained which shows the concentration of residual solution that does not react to form a new solution. From these results, the efficiency of CO_2 gas absorbed by absorbents will be determined (Robiah et al., 2021). The following are the results of CO_2 gas efficiency on the solution flow rate and gas flow rate.

Table 2. Effectiveness of dissipated CO_2 Gas in K_2CO_3 Solution

KOH flow rate (Liters/min)	CO_2 Gas Flow Rate (Liters/min)	% CO_2 Absorbent
2	10	40%
	20	44%
	30	48%
4	10	36%
	20	40%
	30	44%
6	10	36%
	20	40%
	30	43%

From table 2 above, it will be interpreted in the form of a graph that explains the relationship between the flow rate of laruan and the flow rate of CO_2 gas to the concentration removed in the solution.

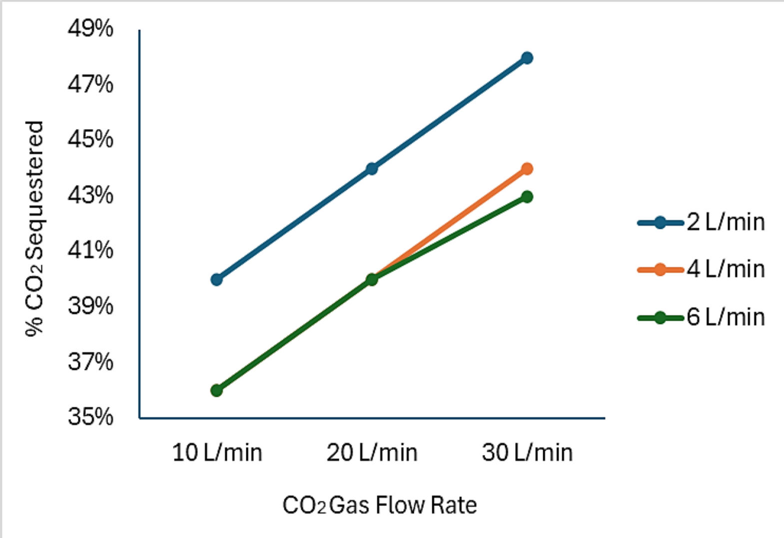

Figure 1. Relationship Between Solution Flow Rate and CO_2 Gas Flow Rate to Removed Concentration

The graph above shows that if the flow rate of the absorbent solution is higher, it will result in flooding. Flooding occurs due to the collection of liquid in the column area because the space initially traveled by CO_2 gas and air becomes full due to the accumulation of excess liquid. Flooding will cause liquid to hold up or liquid trapped in the column (Nugroho et al., 2023). From this event, the concentration of CO_2 gas captured will be small. For this reason, the effective solution flow rate is shown at 2 liters/minute with the smaller the speed, the longer the gas absorption to contact time (Putro et al., 2023). Meanwhile, the flow rate of gas mixed with air through the bottom area of the column with the opposite flow direction will cause friction between fluids. The friction occurs in gas-to-liquid phase mass transfer, so that the gas that is absorbed is higher. Absorbents that capture CO_2 gas with solution flow rates and gas flow rates that are at the optimum point will show the maximum percentage of saturation points so that absorption runs effectively (Chotimah et al., 2022). From the results of the study, the greater the gas flow rate, the higher the concentration of CO_2 gas absorbed. Looking at the research data shows a large flow rate at 30 liters/minute as the concentration of CO_2 gas injected.

Looking at the results of the relationship between the flow rate of solution and gas to the percentage of CO_2 captured, the highest concentration was obtained reaching 48% with a solution flow rate of 2 liters/minute and a CO_2 gas flow rate of 30 liters/minute which has been mixed with air with a flow rate of 10 liters/minute.

Effect of pH on K_2C0_3 Solution

The influence of pH during the absorption process has an impact on the sample results in the *outlet* tub which shows a decrease from a strongly alkaline solution to a weak acid. This is shown in Table 3 as follows.

Table 3. pH Concentration with solution flow rate and CO_2 gas flow rate

Solution Type	Solution Flow Rate (L/min)	CO_2 Gas Flow Rate (L/min)	Sample Analysis Test
			pH
KOH Solution	2	10	6.9
		20	6.4
		30	6.2
	4	10	6.9
		20	6.4
		30	6.3

To be continued…

	10	7
6	20	6.5
	30	6.3

Table 3 above, will be interpreted in the form of a graph that explains the relationship between the flow rate of laruan and the flow rate of CO_2 gas to the pH parameter.

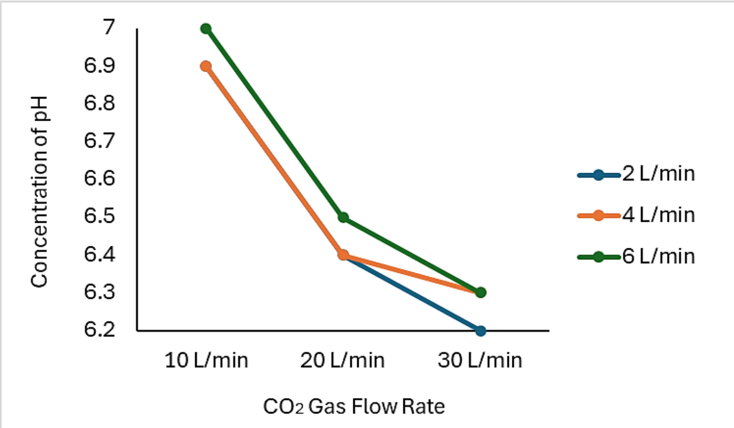

Figure 2. Relationship of pH with solution flow rate and CO_2 gas flow rate

The graph above shows that the effect of pH will have an impact on the absorption of CO_2 gas. Changes in pH that decrease are influenced by the flow rate of the solution and the CO_2 gas injected. This effect shows that the higher the injected gas, the more acidic the pH in the solution, on the other hand, the lower the injected gas, the more neutral the pH in the solution (Dewi et al., 2024). This is best compared with the solution flow rate, the solution flow rate follows the injected gas but with the residence time in the column with a small solution flow rate, the absorption process will be more effective (Huda et al., 2022). This will make the concentration of dissolved gas higher. The results of the analysis prove that the effect of pH is related to the concentration of CO_2 gas captured because CO_2 gas has high acidic properties (Yuliani et al., 2023).

From the optimum condition and maximum saturation point in a state of captured CO_2 levels, an effective solution flow rate of 2 liters/minute and a gas flow rate of 30 liters/minute with the help of air injection of 10 liters/minute were obtained. From the results of the effective flow rate and gas, the pH obtained is 6.2 which is a weak acid.

Effect of temperature on K_2C0_3 Solution

The influence of temperature during the absorption process has an impact on the sample results in the *outlet* tub which shows an increase from the solution at low temperature to high temperature. This is shown in Table 4 as follows.

Table 4. Temperature concentration with solution flow rate and CO_2 gas flow rate

Solution Type	Solution Flow Rate (L/min)	CO_2 Gas Flow Rate (L/min)	Sample Analysis Test Temperature
KOH Solution	2	10	27.9
		20	28.4
		30	28
	4	10	28.7
		20	27.8
		30	28.5
	6	10	28.9
To be continued…		20	29.5

		30	29.6

Table 4 above, will be interpreted in the form of a graph that explains the relationship between the flow rate of laruan and the flow rate of CO_2 gas to temperature parameters.

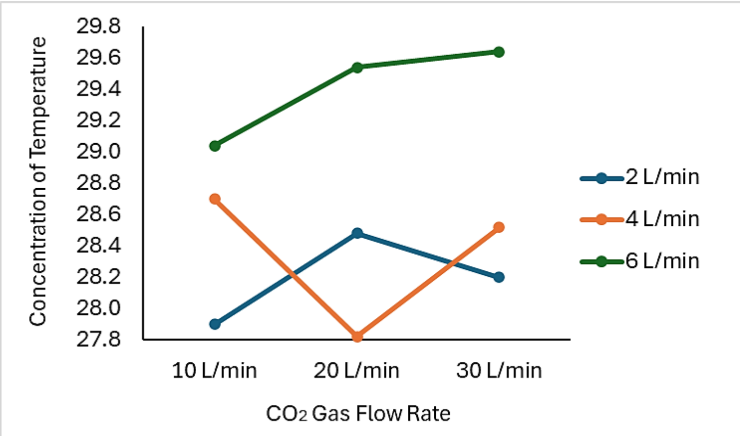

Figure 3. Relationship of temperature with solution flow rate and CO_2 gas flow rate

The graph above shows that the absorption process is influenced by the temperature in the rich solvent. This is directly proportional to the solubility of CO_2 gas that is injected so that when there is an increase in temperature, the concentration of CO_2 gas will be higher (Parningotan & Dewi, 2021). When the CO_2 gas is high, it will cause the concentration of CO_2 gas in the liquid to increase because of the reaction between the absorbent solution and the absorbate so that the heat temperature increases. The results of the study conducted state that increasing temperature can increase the value of the reaction rate constant so that the reaction rate increases. In addition, an increase in solution temperature also affects gas diffusivity (Ihsanpuro et al., 2023). This is evidenced by the effect of increasing temperature will be able to increase the diffusivity of gas at its concentration value. The increase occurs when the temperature exceeds the initial concentration so that the mass transfer of substances is characterized by hot conditions (Zavira et al., 2022).

Effect of EC on K_2C0_3 solution

The influence of EC during the absorption process has an impact on the sample results in the *outlet* tub which shows an increase from a solution with low electrical conductivity to a high electrical conductivity. This is shown in Table 5 as follows.

Table 5. EC Concentration with solution flow rate and CO_2 Gas flow rate

Solution Type	Solution Flow Rate (L/min)	CO_2 Gas Flow Rate (L/min)	Sample Analysis Test
			EC
KOH Solution	2	10	0.214
		20	0.227
		30	0.230
	4	10	0.225
		20	0.227
		30	0.228
	6	10	0.213
		20	0.214
		30	0.216

Table 5 above, will be interpreted in the form of a graph explaining the relationship between the laruan flow rate and the CO_2 gas flow rate to EC parameters.

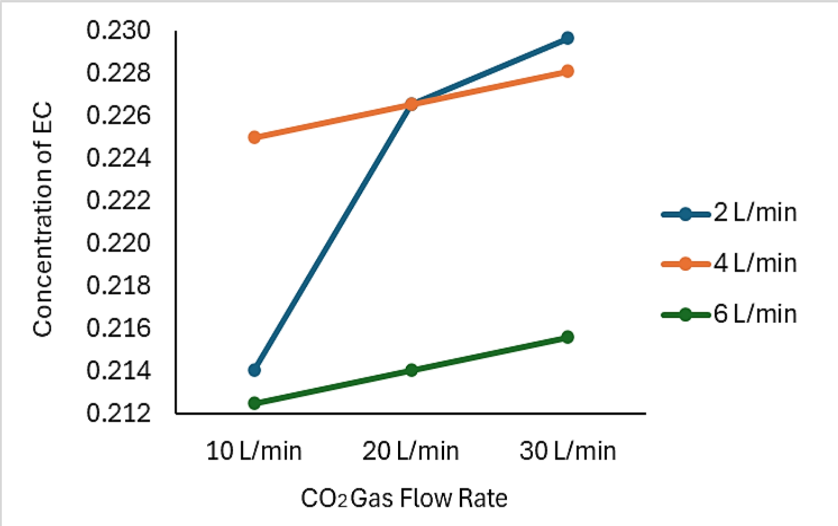

Figure 4. Relationship of EC to solution flow rate and CO_2 gas flow rate

The graph above shows that the absorption process is influenced by the electrical conductivity that occurs in rich solvents. This is in line with the flow rate of CO_2 gas that is input with high pressure. When CO_2 gas is injected with a high concentration, this will result in the concentration of dissolved CO_2 gas increasing due to the reaction between the absorbent and the absorbent so that the electrical conductivity increases (Nannuba et al., 2022). The increase in the concentration of electrical conductivity during the absorption process is influenced by the presence of ions that move freely. The presence of these ions allows the solution to conduct electricity (Arisukma et al., 2021). A solution that conducts high electrical power is because its molecules can be perfectly ionized. Therefore, the CO_2 gas absorption process in the EC parameter increases the presence of ions that are completely free and can move freely in a solution that can conduct electricity (Ramadhanti, 2023).

The concentration of electrical conductivity that shows a significant increase in the results of the study was obtained at 0.230 μmhos/cm with the optimum solution flow rate at a speed of 2 liters/minute with a gas flow rate at a speed of 30 liters/minute which has been mixed with air at a speed of 10 liters/minute.

Conclusion

Based on the discussion above, it can be concluded that carbon dioxide or CO_2 gas emissions using the absorption method can effectively capture 48% of the CO_2 gas concentration into the absorbent. This is due to the flow rate of the KOH solution, which is getting smaller, the higher the chance of contact time between the solution and CO_2 gas in the absorption column, while at the CO_2 gas flow rate the higher the concentration, the greater the CO_2 gas absorbed by the absorbent. In addition, it has been strengthened by testing the results of the pH influence parameter which has decreased significantly to an acidic solution, for temperature and EC parameters which show an increasing concentration due to mass transfer during the process.

Acknowledgment

The author would like to thank the research and community service institution at the Universitas Pembangunan Nasional "Veteran" Jawa Timur IX Edition Year 2024 which has provided grant funds in the form of funding money to support research to run smoothly and can

realize the form of Carbon Capture and Storage (CCS) technology to support the achievement of SDGs targets.

References

Arisukma, P., Purnomo, N. A., Udyani, D. K., Adhi, I. T., & Surabaya, T. (2021). Studi Desain Absorber untuk Penyerapan CO_2. *Seminar Nasional Sains Dan Teknologi Terapan IX*, 327–337.

Arning, K., Linzenich, A., Ziefle, M., Meuleneers, L., Rezo, D., & Aßen, N. Von Der. (2024). Eliciting laypeople's mental models and risk perceptions of direct air carbon capture and storage: Implications for effective risk communication. *Energy Reports*, *12*(July), 1068–1079. https://doi.org/10.1016/j.egyr.2024.06.070

Chai, S. Y. W., Ngu, L. H., & How, B. S. (2022). Review of carbon capture absorbents for CO_2 utilization. *Greenhouse Gases: Science and Technology*, *12*(3), 394–427. https://doi.org/10.1002/ghg.2151

Chotimah, C., Syafitri, N. N., & Udyani, K. (2022). Absorber design simulation for co_2 using k_2co_3 absorbent with aspen Hysys V.10 Software. *Konversi*, *11*(2), 119–124. https://doi.org/10.20527/k.v11i2.14134

Dewi, L. T. P., Rosita, W., & Petrus, H. T. B. M. (2024). Pengaruh konsentrasi larutan natrium silikat hasil pengolahan limbah coal fly ash dan laju alir gas CO_2 untuk proses carbon capture. *Senastitan*, *2*(Senastitan Iv), 1–6.

Dziejarski, B., Krzyżyńska, R., & Andersson, K. (2023). Current status of carbon capture, utilization, and storage technologies in the global economy: A survey of technical assessment. *Fuel*, *342*(October 2022), 127776. https://doi.org/10.1016/j.fuel.2023.127776

Hanifa, M., Agarwal, R., Sharma, U., Thapliyal, P. C., & Singh, L. P. (2023). A review on CO_2 capture and sequestration in the construction industry: Emerging approaches and commercialised technologies. *Journal of CO_2 Utilization*, *67*(October 2022), 102292. https://doi.org/10.1016/j.jcou.2022.102292

Hong, W. Y. (2022). A techno-economic review on carbon capture, utilisation and storage systems for achieving a net-zero CO_2 emissions future. *Carbon Capture Science and Technology*, *3*(December 2021), 100044. https://doi.org/10.1016/j.ccst.2022.100044

Huda, F., Qomariyah, N., & Udyani, K. (2022). Design of packed tower absorber for carbon dioxide absorption by potassium hydroxide absorbent. *Konversi*, *11*(2), 112–118. https://doi.org/10.20527/k.v11i2.14158

Huda, H., Aditya, R., Worotikan, R. B. J., & Nurdin, N. (2023). The effect of pressure on the concentration of methane and carbon dioxide absorption in biogas. *Konversi*, *12*(1), 9–11. https://doi.org/10.20527/k.v12i1.14680

Ihsanpuro, S. I., Ramadhan, K. A., Gabriel, A. A., & Halim, A. (2023). Simulasi pemurnian biogas secara absorpsi menggunakan software DWSIM. *Jurnal Vokasi Teknologi Industri (Jvti)*, *5*(1), 23–31. https://doi.org/10.36870/jvti.v5i1.303

Isya, A. A., Arman, K. R., & Wintoko, J. (2021). Mini-review teknologi Carbon Capture and Utilization (CCU) Berbasis Kombinasi Proses Kimia dan Bioproses. *Equilibrium Journal of Chemical Engineering*, *4*(2), 71. https://doi.org/10.20961/equilibrium.v4i2.47908

Kurnia, A., & Sudarti. (2021). Efek rumah kaca oleh kendaraan bermotor. *GRAVITASI: Jurnal Pendidikan Fisika Dan Sains*, *4*(2), 1–9.

Mao, X., Chen, H., Wang, Y., Zhu, X., & Yang, G. (2023). Study on Benzylamine (BZA) and Aminoethylpiperazine (AEP) mixed absorbent on ship-based carbon capture. *Molecules*, *28*(6), 2661. https://doi.org/10.3390/molecules28062661

Martin-Roberts, E., Scott, V., Flude, S., Johnson, G., Haszeldine, R. S., & Gilfillan, S. (2021). Carbon capture and storage at the end of a lost decade. *One Earth*, *4*(11), 1569–1584. https://doi.org/10.1016/j.oneear.2021.10.002

Nannuba, H., Prajogo, S., & K, A. S. (2022). Perancangan wet scrubber kapasitas 0,72 m 3 / jam pada proses pemurnian biogas dari kotoran sapi. *Prosiding The 13th Industrial Research Workshop and National Seminar*, 851–858.

Nasir, E., & Go, Y. I. (2024). Carbon capture and storage at Malaysia power plants: Evaluation of its feasibility and requisite enablers. *Journal of Cleaner Production*, *469*(July), 143173. https://doi.org/10.1016/j.jclepro.2024.143173

Nugroho, A., Bekti Susanto, Y., Lidzati Kamilah, V., & Prameswari, R. (2023). Carbon dioxide (CO_2) absorption process using sodium hydroxide (NaOH). *IPTEK The Journal of Engineering*, *9*(1), 30. https://doi.org/10.12962/j23378557.v9i1.a15192

Okonkwo, E. C., AlNouss, A., Shahbaz, M., & Al-Ansari, T. (2023). Developing integrated direct air capture and bioenergy with carbon capture and storage systems: progress towards 2°C and 1.5°C climate goals. *Energy Conversion and Management*, *296*(April), 117687. https://doi.org/10.1016/j.enconman.2023.117687

Oktarina, N., Ayu, D. P., Effendy, S., & Zurohaina, Z. (2023). Pemurnian biogas dengan proses absorpsi menggunakan absorben K_2CO_3 dan Fe_2 (SO_4) 3. *Jurnal Pendidikan Tambusai*, *7*(3), 21551–21554.

Parningotan, D., & Dewi, M. N. (2021). Pengaruh Laju Alir Metildiethanolamina (MDEA) pada Proses Penyerapan Hidrogen Sulfida. *Seminar Nasional TREnD,* 19–25.

Putro, F. A., Waluyo, J., Al Haq, B. F., Hidayat, W. N., & Pranolo, S. H. (2023). Absorption of tar content in producer gas using used cooking oil in a packed-bed column. *Equilibrium Journal of Chemical Engineering*, *7*(1), 27. https://doi.org/10.20961/equilibrium.v7i1.70383

Ramadhanti, Y. (2023). Peran katalis dalam reaksi kimia: mekanisme dan aplikasi. *Hexatech: Jurnal Ilmiah Teknik*, *2*(2), 74–78. https://doi.org/10.55904/hexatech.v2i2.915

Robiah, R., Renaldi, U., Melani, A., Jend Ahmad Yani, J., Seberang Ulu, U. I., Plaju, K., Palembang, K., & Selatan, S. (2021). Kajian pengaruh laju alir NaOH dan waktu kontak terhadap absorpsi gas CO_2 menggunakan alat absorber tipe sieve tray. *Jurnal Distilasi*, *6*(2), 27–35.

Roussanaly, S., Berghout, N., Fout, T., Garcia, M., Gardarsdottir, S., Nazir, S. M., Ramirez, A., & Rubin, E. S. (2021). Towards improved cost evaluation of Carbon Capture and Storage from industry. *International Journal of Greenhouse Gas Control*, *106*(October 2020), 103263. https://doi.org/10.1016/j.ijggc.2021.103263

Shu, D. Y., Deutz, S., Winter, B. A., Baumgärtner, N., Leenders, L., & Bardow, A. (2023). The role of carbon capture and storage to achieve net-zero energy systems: Trade-offs between economics and the environment. *Renewable and Sustainable Energy Reviews*, *178*(July 2022), 113246. https://doi.org/10.1016/j.rser.2023.113246

Yuliani, T. D., Junaidi, R., & Meidinariasty, A. (2023). Making methane gas from CO_2 using Ni/Al_2O_3 Catalyst in a fixed bed reactor. *Konversi*, *12*(2), 66–69. https://doi.org/10.20527/k.v12i2.17111

Zahro, F., Budiyanto, M., & Ilhami, F. B. (2023). Potensi biomassa gasifikasi: Alternatif berkelanjutan dalam menghasilkan energi listrik untuk masa depan. *TESLA: Jurnal Teknik Elektro*, *25*(2), 103–115. https://doi.org/10.24912/tesla.v25i2.23804

Zavira, L. F., Narariyadi, D. B., & Musadi, M. R. (2022). Simulasi penangkapan gas CO_2 dengan pelarut monoethanolamine menggunakan simulator aspen Hysys V.11. *Diseminasi FTI-6*, *1*, 1–6.

Zhou, J., Zhang, J., Jiang, G., & Xie, K. (2024). Study on shipboard carbon capture technology with the MEA-AMP-Mixed absorbent based on ship applicability perspective. *ACS Omega*. https://doi.org/10.1021/acsomega.4c05145