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Article

Kinetics of CO_2 Absorption from Motor Vehicle Exhaust Gas Using K_2CO_3 (Potassium Carbonate) Absorbent in a Bubble Column Reactor

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ABSTRACT

This study investigates the kinetics of CO_2 absorption from motor vehicle exhaust using potassium carbonate (K_2CO_3) as an absorbent in a jet bubble column reactor. The research aims to analyze the effect of process variables on reaction rate constants and CO_2 conversion efficiency. Employing an experimental method with factorial design, the study was conducted at the Chemical Engineering Laboratory, Sriwijaya State Polytechnic, from August 2023 to July 2024. The population comprised all absorption processes using K_2CO_3, with purposive sampling applied to select experimental conditions. Key instruments included a jet bubble column reactor, gas analyzer, and supporting equipment. Data analysis utilized descriptive statistics and quantitative comparison across variable treatments. Results revealed that optimal CO_2 absorption occurred at a gas flow rate of 0.3–0.4 L/min, liquid flow rate of 0.6–0.7 L/min, temperature of 40°C, and K_2CO_3 concentration of 0.04 M, yielding the highest reaction rate constant and CO_2 conversion. The study concludes that optimizing process variables is crucial for enhancing reactor performance, while further research is recommended to address scale-up and equipment limitations.

1. Introduction

Indonesia's population growth of 1.51% between 2022 and 2024 has driven an increase in the need for public mobility, which has implications for increased use of motorized vehicles and fossil fuel consumption. As a result, motor vehicle exhaust emissions, particularly carbon dioxide (CO_2), increasingly contribute to declining air quality and global warming. Data shows that CO_2 concentrations in Indonesia increased from 373 ppm to 383 ppm between 2004 and 2010, with West Java and Banten provinces as the largest contributors, namely 95 million tons of CO_2 in 2004 (Samiaji, 2011). In addition to CO_2, vehicle exhaust also contains NO_2 and CH_4, which have a higher global warming potential than CO_2, so that increasing levels of these gases increase the risk of climate change (Snip, 2010).

Motor vehicle exhaust emissions, especially from fossil fuel-powered vehicles, produce various pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), hydrocarbons (HC), particulates, and lead (Pb), which have negative impacts on health and the environment (Suryanto, 2012). The imperfect combustion process in vehicle engines, especially in the compression cycle, results in the formation of pollutant gases whose composition is influenced by combustion quality, air adequacy, and fuel mixing (Heywood, 2000; Sukidjo, 2011). Previous research has shown that CO_2 absorption using a strong base solution such as K_2CO_3 can be an effective solution to reduce CO_2 emissions from motor vehicle exhaust. Process variables such as absorbent concentration, gas flow rate, and contact time between the gas and the solution significantly affect the absorption efficiency and the rate of the CO_2 absorption reaction. However, studies on the optimization of CO_2 absorption kinetics using K_2CO_3 in a bubble jet reactor are still limited, so further research is needed to systematically understand the influence of process variables on the reaction rate constant and CO_2 conversion.

This study aims to identify the CO_2 absorption process from motor vehicle exhaust gas using K_2CO_3 absorbent in a bubble shower reactor, as well as to analyze the effect of independent variables on CO_2 kinetics and conversion. The urgency of this research lies in the effort to develop a more effective and efficient CO_2 gas absorption technology to support the reduction of environmental impacts due to motor vehicle emissions. The novelty of this research is the use of a bubble shower reactor with K_2CO_3 solution as an absorbent, which is relevant to the development of exhaust gas processing technology in industry and can be a reference for further research in the field of chemical engineering, especially in chemical reactor and chemical reaction engineering courses.

2. Literature Review

2.1 Motor Vehicle Exhaust Emissions

Motor vehicle exhaust emissions are a major source of air pollution in urban areas in Indonesia, contributing 60-70% of total air pollution. The significant increase in the number of motorized vehicles, imbalanced transportation infrastructure, and centralized traffic patterns in city centers are dominant factors worsening air quality. Furthermore, the number of motorized vehicles in Indonesia continued to increase in 2021-2022, with motorcycles being the largest contributor, reaching over 120 million units. This phenomenon emphasizes the importance of controlling emissions through relevant reaction and mass transfer mechanisms, such as the CO2 adsorption process with K2CO3 (Hardin, 1968; Sudrajad, 2006).

Motor vehicle exhaust emissions contain various hazardous pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SO2), hydrocarbons (HC), particulate matter (PM), and lead (Pb), which can cause serious health problems and increase the risk of respiratory diseases and cancer (Ulfah, 2018; Rosianasari, 2016). Emission standards implemented in Indonesia, such as Euro 4, aim to reduce these pollutant levels, but their implementation still faces technical and economic challenges (Marlis Kwan, 2020; Ismiyati, 2019). In addition, CO2 emissions from motor vehicles are a major contributor to greenhouse gases, which contribute to global warming and climate change (BPLH DKI Jakarta, 2013; Nafisah, 2024).

2.2 CO_2 absorption

CO_2 absorption is a method of separating CO_2 gas from exhaust gas streams using solvents or absorbents, which is widely used in the gas processing industry due to its effectiveness and efficiency (Treybal, 1981; Wang, 2003). An ideal absorbent should have high gas solubility, low vapor pressure, be non-corrosive, affordable, low viscosity, be non-toxic, non-flammable, and chemically stable. One of the widely used solvents is amine, but in this study, K_2CO_3 (potassium carbonate) was chosen because it has advantages such as low cost, low toxicity, can operate at high temperatures, and does not experience degradation or corrosion (Shen et al., 2013; Saidi et al., 2014). However, the reaction rate of K_2CO_3 with CO_2 is lower than other absorbents such as MEA, DEA, and KOH (Nuclea, 2017).

Factors influencing the CO_2 absorption process include contact surface area, fluid flow rate, gas concentration, operating pressure, temperature, and absorption time (Fatimura, 2021; Huttenhuis et al., 2022). The main reaction that occurs in the absorption of CO_2 with K_2CO_3 is the formation of $KHCO_3$, which can be described by the equation: $CO_2 + K_2CO_3 \rightarrow 2KHCO_3$. Optimizing these variables is crucial to improving the efficiency of CO_2 absorption in industrial and environmental applications.

2.3 Jet Bubble Column Reactor

The jet bubble reactor is a device widely used in the chemical and petrochemical industries for mass transfer processes between gas and liquid phases. Its working principle is to create intensive contact between gas and liquid through the formation of small bubbles, which increases the contact surface area and mass transfer coefficient (Nugroho et al., 2014; Ide et al., 2001). The main advantages of this reactor are its simple design, easy operation, small reactor volume, and no need for a stirrer because mixing occurs naturally due to fluid collisions.

Factors affecting the performance of a jet bubble reactor include bubble penetration depth, nozzle diameter and height, nozzle length-to-diameter ratio, and fluid physical properties (Harby et al., 2014; Baawain et al., 2012). Research on the influence of these variables is crucial for optimizing the CO_2 absorption process and increasing reactor efficiency in vehicle exhaust gas processing applications.

3. Research Methodology

3.1 Types and Methods of Research

This study used a purely experimental approach to test the kinetics and efficiency of CO_2 absorption from motor vehicle exhaust using K_2CO_3 absorbent in a bubble jet reactor. The experimental method was chosen because it allows researchers to strictly control the research variables and directly observe the effect of changes in independent variables on CO_2 absorption results (Sugiyono, 2022; Cresswell & Creswell, 2022). This experimental research was also supported by a systematic laboratory design, so that the results obtained could be tested for validity and reliability (Emzir, 2021; Sudaryono, 2023).

3.2 Data Analysis Instruments and Techniques

The main instruments used in this study include a bubble jet reactor, water bath, gas bag, gas analyzer, and supporting devices such as pumps and motors. The gas analyzer was used to measure CO_2 concentration before and after the absorption process, allowing for quantitative calculations of CO_2 conversion and absorption efficiency (Fatimura, 2021; Huttenhuis et al., 2022). Data analysis was conducted using descriptive quantitative techniques by comparing measurement results across various independent variables and using statistical analysis to test the significance of the influence of these variables (Sugiyono, 2022; Cresswell & Creswell, 2022).

3.3 Experimental Design

The population in this study is the entire CO_2 absorption process from motor vehicle exhaust gases that can be carried out using a bubble jet reactor with K_2CO_3 absorbent. The research sample consists of experiments conducted at the Chemical Engineering Laboratory of the Sriwijaya State Polytechnic of Palembang during August–July 2024, with variations in liquid flow rate, gas flow rate, temperature, and K_2CO_3 concentration as independent variables (Sirait et al., 2025; Susianto, 2022). The sample determination was carried out by purposive sampling, namely selecting operating conditions that represent the range of variables to be tested systematically (Sugiyono, 2022; Emzir, 2021).

3.4 Research Procedures

The research procedure began with the preparation of tools and materials, namely preparing a K_2CO_3 solution, a CO_2 gas source from motor vehicles, and distilled water as a solvent. Next, the absorbent solution was introduced into the bubble jet reactor, and the system was run by adjusting the independent variables according to the experimental design. Vehicle exhaust gas was flowed into the reactor, and the absorbed gas was collected in a gas bag for analysis using a gas analyzer. After the process was complete, the solution in the reactor was discarded and the reactor was cleaned before the next experiment was carried out (Setiadi et al., 2020; Fatimura, 2021). The measurement data were analyzed to determine CO_2 conversion and absorption efficiency for each treatment variation, and the results were interpreted to identify the effect of process variables on reactor performance (Sugiyono, 2022; Cresswell & Creswell, 2022).

4. Results and Discussion

4.1 CO2 Gas Analysis Data

In this study, initial CO2 and process CO2 measurements were conducted on motor vehicle exhaust emissions. The engines used in this study are expected to have incomplete combustion, resulting in relatively high CO2 emissions. These CO2 measurements were conducted at the Chemical Engineering Laboratory of Sriwijaya State Polytechnic.

This study aims to determine the process of CO2 gas absorption from motor vehicle exhaust emissions and to determine the effect of K2CO3 absorbent on CO2 gas absorption in motor vehicle exhaust. The process variables in this study consist of Concentration, Gas Water Rate, Liquid Flow Rate and Temperature. For each process variable, the best one will be taken and then varied with other process variables. The results and measurement analysis data can be seen in tables 1 and 2.

Table 1. Analysis Results

Parameter	Mark	Unit
CO2	3212	ppm

Table 2. Results of CO2 Gas Analysis of the Process

No	Gas Flow Rate (L/min)	Concentration (M)	Liquid Flow Rate (L/min)	Temperature (C)	Before CO2 (ppm)	After CO2 (ppm)
1.	0.2	0.03	0.6	30		785
2.	0.3	0.03	0.6	30		435
3.	0.4	0.03	0.6	30		416
4.	0.5	0.03	0.6	30		588
5.	0.3	0.03	0.6	40		511
6.	0.4	0.03	0.6	40	3212	520
7.	0.3	0.03	0.6	50		726
8.	0.4	0.03	0.6	50		1187
9.	0.4	0.03	0.7	40		670
10.	0.4	0.03	0.8	40		819
11.	0.4	0.04	0.7	40		411
12.	0.4	0.05	0.7	40		468

CO_2 absorption is the process of separating CO_2 gas using a solvent or absorbent to capture the CO_2 gas. This method is frequently encountered and preferred in the gas processing industry over other technologies due to its high efficiency and high product quality. To absorb CO_2, contact must be established between the absorbent (solvent) and the sour gas (Treybal, 1981).

The CO_2 gas used in this study is CO_2 gas found in motor vehicle exhaust emissions. The exhaust emissions will be contacted with a potassium carbonate absorbent solution at varying concentrations. The instrument used in this study is a jet bubble column reactor. The jet bubble column is a device used to contact the gas and liquid phases. This process involves mass transfer from the gas phase to the liquid phase (Setiadi et al., 2018).

This study aims to determine the effect of variations in gas flow rates, and will continue to take the best data and variations using K2CO3 absorbent on carbon dioxide (CO2) absorption and determine the Ph results in each solution that has been tested. This absorption process uses the concept of solubility product, using a K2CO3 solution that absorbs CO2. In the absorption process, one reactor tube is used in the Bubble Jet Reactor tool which is expected to absorb CO2 and better CO2 conversion. In this case, the reaction that occurs between K2CO3 and CO2 gas.

4.2 The Effect of Gas Flow Rate on Reaction Rate Constant and CO2 Conversion.

It can be seen in Figure 1 that, at gas flow rates of 0.3 and 0.4, higher reaction pressures result in an increase in the reaction rate due to collisions between molecules that enter simultaneously into the bubble jet reactor. The effect of time on the reaction rate constant on the Gas Flow Rate.

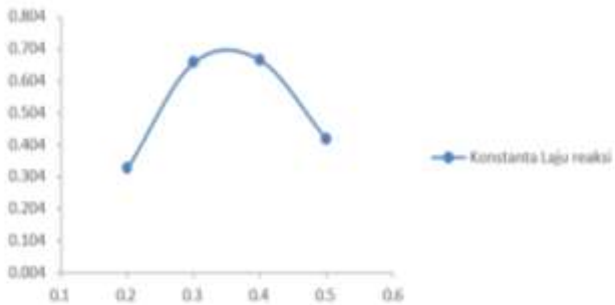

Figure 1. Graph of Gas Flow Rate Against Reaction Rate Constant

In Figure 2, it can be seen that, at a gas flow rate of 0.2 liters/minute, the conversion rate is getting smaller because the gas from motor vehicles entering the reactor is increasingly hampered, therefore the CO2 entering is getting smaller, so the CO2 absorption process is not perfect. On the other hand, at a flow rate of 0.3 and 0.4 liters/minute, it shows a very significant increase in CO2 conversion, from this we can see that the gas flow rate opening has a very big influence on CO2 conversion. Meanwhile, at a flow rate of 0.5 liters/minute, the conversion rate decreases due to the contact between CO2 gas from motor vehicles and the liquid flow rate for a short time because at a flow rate of 0.5, the time needed for a full gas bag is 6.36 minutes or 0.1060 hours.

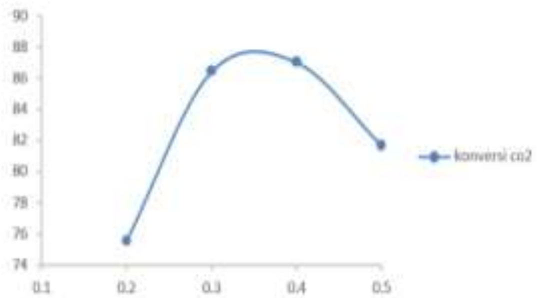

Figure 2. Graph of Gas Flow Rate Against CO2 Conversion

It can be seen in tables 1 and 2, that the independent variables used are gas flow rates of 0.2, 0.3, 0.4, and 0.5 liters/minute and the fixed variables used are temperature 30oC, water flow rate 0.6 and absorbent concentration 0.03M. At gas flow rates of 0.3 and 0.4, the highest reaction rate constant and CO2 conversion were obtained and became fixed variables for subsequent research.

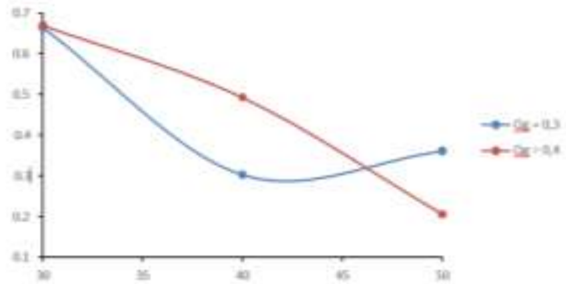

Figure 3. Graph of Temperature Against Reaction Rate Constant

4.3 Effect of Temperature on Reaction Rate Constant and CO2 Conversion

In Figure 3, it is known that the temperature of 30oC is the most ideal temperature, but for further research, the temperature of 40oC will be varied because we want to see the effect of temperature on the reaction rate constant. The highest reaction rate constant is obtained at a temperature of 30°C, because the reaction rate will decrease if absorbent evaporation occurs in the reactor column.

Figure 4 shows that CO2 conversion decreases due to an increase in the solution flow rate which increases turbulence, solvent concentration and gas solubility which affect the absorption rate so that CO2 gas removal increases. Conversely, higher solvent temperatures result in lower CO2 removal, this is because the gas solubility factor affects the absorption process (Erlinda Ningsih, 2012).

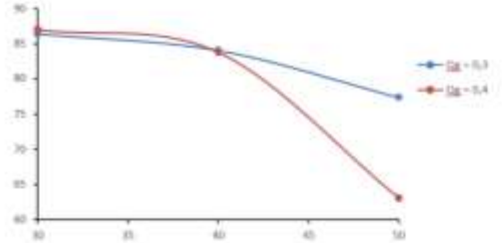

Figure 4. Temperature Graph Against CO2 Conversion

It can be seen in tables 3 and 4, that the independent variables used are gas flow rates of 0.3 and 0.4 liters/minute and temperatures of 40oC and 50oC, while the fixed variables are water flow rates of 0.6 and absorbent concentrations of 0.03M. In this study, the independent variables are gas flow rate and temperature, which aims to determine the appropriate gas flow rate and temperature for subsequent research. The graph shows the best gas flow rate at 0.4 liters/minute and the best temperature at 40oC. In subsequent research, a gas flow rate of 0.4 liters/minute and a temperature of 40oC will be used and will be varied with the liquid flow rate.

4.4 The Effect of Liquid Water Rate on Reaction Rate Constants and CO2 Conversion.

In Figure 5, it can be seen that at a flow rate of 0.6 the reaction rate constant is the highest because the contact relationship between the absorbent and the gas is longer, resulting in more absorption processes occurring in the reactor. In the test, the absorption process contained in the gas bag at a flow rate of 0.6 was for 10 minutes or 0.1667 hours. Then the contact time at a flow rate of 0.7 was for 0.1167 hours and 0.8 for 0.0717 hours, which means that the contact time at the flow rate greatly affects the reaction rate constant.

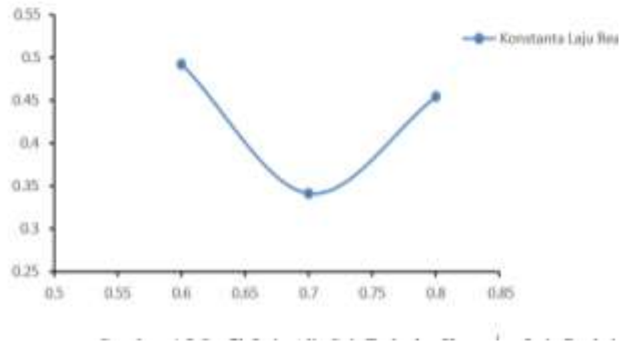

Figure 5. Graph of Liquid Flow Rate Against Reaction Rate Constant

In Figure 6, the highest CO2 conversion at a flow rate of 0.6 was 83.81%. It can be seen that the contact time at a flow rate of 0.6 for 10 minutes affects the CO2 conversion, meaning that the longer the contact time in the reactor, the greater the conversion that occurs in the bubble jet reactor (Muhrinsyah Fatimura, October 2021). According to (Ali Altway, April 2008), increasing the absorbent flow rate will also reduce the CO2 concentration in the liquid body and consequently will increase the driving force for mass transfer.

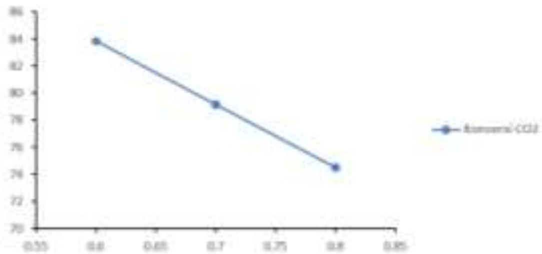

Figure 6. Graph of Liquid Flow Rate against CO2 Conversion

It can be seen in Figures 5 and 6 that the independent variables used are liquid flow rates of 0.7 and 0.8 liters/minute and the fixed variables used are gas flow rate of 0.4, temperature of 40oC and concentration of 0.03. In the next study, a liquid flow rate of 0.7 liters/minute will be used.

4.5 The Effect of Concentration on Reaction Rate Constants and CO2 Conversion.

Figure 7 shows that the effect of K_2CO_3 concentration on the reaction rate constant is due to the reaction rate being a function of the absorbent concentration (Hendriyana, May 2021). The reaction rate constant increased by almost 50% with an increase in K_2CO_3 concentration from 0.03 M to 0.04 M.

Then at a concentration of 0.05 there should be an increase, however, this graph shows a decrease in the reaction rate constant, this occurs due to a decrease in the performance of the tool due to a leak in the tool and the length of time to fill the gas bag at a concentration of 0.04 for 5.32 minutes, while at a concentration of 0.05 for 5.05 minutes, the length of time the liquid contacts in the reactor also affects the reaction rate constant.

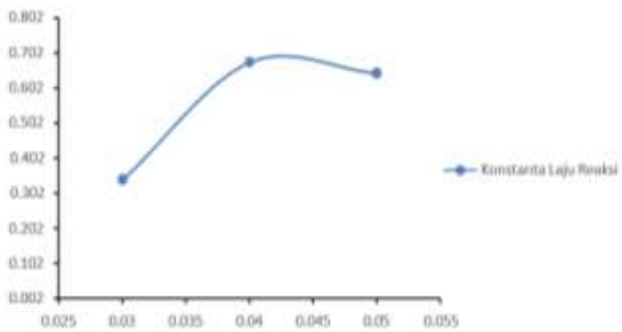

Figure 7. Graph of Concentration Against Reaction Rate Constant

Based on Figure 8, it is known that the data on the use of 0.04 M K2Co3 as an absorbent is different from the use of a smaller concentration of K2CO3, this can be caused by the greater number of K2CO3 molecules so that it can absorb more CO2 gas, also influenced by the conditions of the absorbent flow rate and CO2 gas carried out in the absorption process (Faisal Huda, 2022).

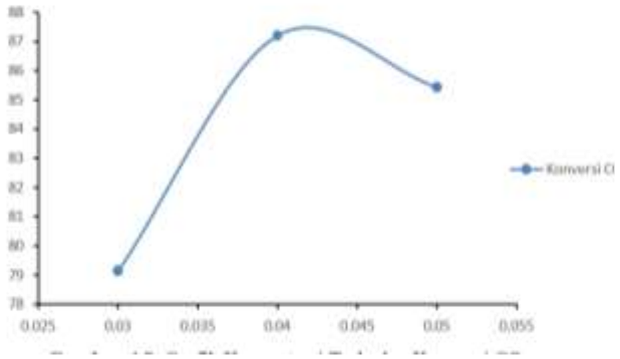

Figure 8. Graph of Concentration Against CO2 Conversion

In Figures 7 and 8, it can be seen that the independent variables used are absorbent concentrations of 0.04 M and 0.05 M, which aim to show the effect of absorbent concentration on the reaction rate constant and CO2 absorption, and the fixed variables used are the gas flow rate of 0.4 liters/minute, the liquid flow rate of 0.7 liters/minute and the temperature of 40oC.

Discussion

The results of the study indicate that the CO_2 absorption process from motor vehicle exhaust gases using K_2CO_3 solution in a bubble jet reactor is strongly influenced by process variables such as gas flow rate, liquid flow rate, temperature, and absorbent concentration. At gas flow rates of 0.3 and 0.4 L/min, the highest reaction rate constants and CO_2 conversions were obtained, indicating that increasing the gas flow rate to the optimum point can increase CO_2 absorption efficiency due to the greater frequency of molecular collisions in the reactor. However, too high a gas flow rate actually decreases efficiency because the contact time between the gas and the solution becomes shorter, so the absorption process does not take place optimally (Fatimura, 2021; Huttenhuis et al., 2022).

The effect of temperature is also significant on the reaction rate constant and CO_2 conversion. A temperature of 30°C gives the highest reaction rate constant, but for practical applications, a temperature of 40°C is chosen to further observe the effect. At higher temperatures, the absorption efficiency decreases because the solubility of CO_2 gas in K_2CO_3 solution decreases due to increased absorbent evaporation, in accordance with previous findings that gas solubility decreases at high temperatures (Erlinda Ningsih, 2012).

Liquid flow rate also plays a crucial role in the absorption process. A liquid flow rate of 0.6 L/min produces the highest reaction rate constant and CO_2 conversion, due to the longer contact time between the absorbent and gas, increasing the potential for mass transfer. However, increasing the liquid flow rate above the optimum value reduces the contact time and decreases absorption efficiency, in line with the principle of mass transfer in gas-liquid systems (Ali Altway, 2008; Muhrinsyah Fatimura, 2021).

The concentration of K_2CO_3 absorbent affects the reaction rate and CO_2 conversion. Increasing the concentration from 0.03 M to 0.04 M increases the reaction rate constant by almost 50%. This indicates the optimal potential absorbent concentration to achieve maximum absorption efficiency (Hendriyana, 2021; Faisal Huda, 2022).

Overall, the results of this study confirm that process variable optimization is crucial for improving the performance of the bubble jet reactor in absorbing CO_2 from motor vehicle exhaust. This finding aligns with the literature stating that contact surface area, flow rate, temperature, and absorbent concentration are key factors in the CO_2 absorption process (Fatimura, 2021; Huttenhuis et al., 2022; Sirait et al., 2025; Susianto, 2022). Furthermore, the use of a bubble jet reactor with K_2CO_3 solution has proven effective and can be an alternative environmentally friendly and efficient exhaust gas treatment technology for industrial and transportation applications.

5. Conclusion

This study successfully identified that the CO_2 absorption process from motor vehicle exhaust gas using K_2CO_3 solution in a jet bubble reactor is strongly influenced by process variables such as gas flow rate, liquid flow rate, temperature, and absorbent concentration. The main findings indicate that a gas flow rate of 0.3–0.4 L/min, a liquid flow rate of 0.6–0.7 L/min, a temperature of 40°C, and a K_2CO_3 concentration of 0.04 M are the optimum conditions to obtain the highest reaction rate constant and CO_2 conversion. The CO_2 absorption efficiency increases with optimization of these variables, but decreased equipment performance and too short contact time can reduce the absorption results. This study also confirms that the jet bubble reactor with K_2CO_3 solution is an effective and environmentally friendly technology for motor vehicle exhaust gas processing, and is relevant for industrial development and chemical engineering education.

The limitations of this study lie in the laboratory scale, potential equipment leaks, and variations in contact time that have not been fully controlled, so the results obtained cannot be directly generalized to the industrial scale. Suggestions for further research are to conduct testing on a pilot or industrial scale, improve the equipment design to minimize leaks, and add variations in process variables such as the type of absorbent and reaction promoter. The practical implications of this study are to encourage the application of bubble jet reactor technology with K_2CO_3 solution as a solution to reduce CO_2 emissions in the transportation sector, as well as serve as a reference for curriculum development and further research in the fields of chemical reaction engineering and gas waste treatment.

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