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Email : editorijhess@gmail.com

Optimization Of Antifoaming Agent Usage On Co2 Removal Unit Performance To Increase Product Co2 Purity

Amos Rante Salu
Chemical Engineering Study Program, Bontang Industrial Technology College

*Corresponding Author
Email : tekkimramozsalu@gmail.com

Abstract

CO2 Removal units in the chemical fertilizer industry often experience foaming in the MDEA absorption-desorption process which reduces CO2 absorption efficiency. This study aims to optimize the concentration of PDMS-based antifoaming to minimize CO2 slip and maximize product CO2 purity through SCAFC identification. The experimental method was carried out on an industrial CO2 Removal unit with a population of four main equipment (Absorber, Stripper, HPFD, LPFD) and samples of varying antifoaming concentrations of 100-200 mL per 100 L of solvent. Measurement instruments include Collapse Time (CT) tester, CO2 analyzer, and laboratory tests, analyzed with a comparative multi-location injection approach. The results show the optimal SCAFC at 150 mL with the fastest CT of 12 seconds (Stripper/Absorber), minimum CO2 slip of 0.001%, and product CO2 purity of 99.45-99.50%. The conclusion of the study recommends 150 mL injection on low-pressure-high-temperature equipment for optimal operation of the fertilizer industry.

Keywords: Antifoam, CO2 Purity, Foaming Control, MDEA Solvent, SCAFC.

INTRODUCTION

CO2 Removal Units play a crucial role in process gas purification, particularly in the chemical fertilizer industry, which relies on natural gas as its primary raw material. These units not only purify synthesis gas for ammonia production but also produce high-quality CO2 as a raw material for other fertilizers (Chafid, 2017; Thaim, 2015). Various CO2 separation methods are applied, including chemical, physical, or hybrid absorption, adsorption, and membrane separation, where the adsorbent specifically interacts with CO2 to efficiently capture it (Wang et al., 2011; Nisa et al., 2019).

Adsorption-desorption methods with alkanolamines such as Methyl Diethanolamine (MDEA) dominate due to their ability to handle extreme operating conditions, with the advantages of high reactivity to CO2, large adsorption capacity, thermal stability, and optimal selectivity (Shanchez-Bautista et al., 2021; Alsheinat et al., 2015). This process allows solvent regeneration through stripping, making it economical for industrial scale (Wang et al., 2011).

Despite its effectiveness, MDEA is prone to foaming, which disrupts the CO2 absorption and desorption processes. Foaming reduces absorption capacity, limits gas-solvent contact, and risks solvent carryover to the outlet gas, thus reducing the overall efficiency of the unit (Haziq, 2014; Shanchez-Bautista et al., 2021). Factors triggering foaming include organic contaminants, hydrocarbons, or solvent degradation, which can impair the performance of equipment such as absorbers and strippers (Nugraha et al., 2002).

The addition of Polydimethylsiloxane (PDMS)-based antifoaming agents is often used to overcome moderate to high levels of foaming by preventing new bubble formation. However, excessive injection actually increases foaming and carryover, while low concentrations fail to break up the foam quickly (Nugraha et al., 2002; Haziq, 2014). The main challenge lies in determining the critical concentration and optimal injection location in an integrated system (absorber, stripper, HPFD, LPFD), because changes in one point affect the others (Chafid, 2017).

This study aims to optimize the use of PDMS antifoaming in CO2 Removal units to minimize CO2 slip, shorten foaming collapse time, and maximize product CO2 purity, with a focus on identifying Surfactant Critical Antifoaming Concentration (SCAFC). The urgency of this research arises from the need of the chemical fertilizer industry in Indonesia to improve operational efficiency and reduce downtime due to foaming, which impacts production costs (Wang et al., 2011; Shanchez-Bautista et al., 2021). The novelty lies in the mapping of a specific SCAFC (150 mL) via multi-location injection testing under low-pressure-high-temperature conditions, which has not been empirically explored in the context of silicone-based MDEA, providing practical guidance for sustainable operations (Haziq, 2014).

RESEARCH METHODS

The CO2 Removal unit system is a unified system of interconnected equipment to regenerate the solution. There are 4 main tools, the first is the Absorber that operates at high pressure and low temperature with a high solvent inlet rate, Second is the Stripper that operates at high temperature and low pressure with a low solvent inlet rate, Third is the HPFD that operates at high pressure and a fairly high temperature with a high flow rate. And fourth is the LPFD that operates at low pressure, high temperature and a large flow rate. All of these tools have the potential to form foaming so that antifoaming injection facilities are available on each equipment. Some companies producing antifoaming agents with a PDMS base recommend injecting antifoaming with a concentration of 100 mL. However, in some cases, antifoaming is often added up to 200 mL.

Preparation of Antifoaming Injection Solution

Before the Antifoaming is injected into the system, a solution preparation is necessary, namely by mixing the antifoaming with 100 L of solvent solution in a stirred tank until the solvent and antifoaming solution become homogeneous. In some cases, the antifoaming is directly injected into the system without being dissolved first, but this has the potential to cause the injection pump strainer to become dirty easily. In this study, the antifoaming mixture was mixed with various concentrations, namely 100 mL, 125 mL, 150 mL, 175 mL and 200 mL.

Equipment Injection Line

As an interconnected system, antifoaming injection into one piece of equipment will reduce foaming in other pieces of equipment. Proper injection technique will effectively reduce foaming, as demonstrated by the foaming collapse time (CT) of the solution, and efficiency, using only one fixed injection line for each piece of equipment, can provide optimal performance across all pieces of equipment.

RESULTS AND DISCUSSION

The success of antifoaming use can be determined by testing solvent samples in the laboratory and also by analyzing indicators on equipment that will show the Collapse Time value, the amount of CO2 leak and the purity of the CO2 product.

Collapse Time (CT)

The time required for foam to collapse after antifoaming is added to the system is called the Collapse Time (CT). The CT calculation is used to assess the antifoaming's performance in overcoming foaming. A faster CT time means the antifoaming is working effectively. Table 1 and Figure 1 show a graph of the CT comparison results obtained by each injection technique.

Table 1. CT value obtained for each injection technique

Amerel Concentration (mL)	Collapse Time Value (seconds) in Injection Technique -			
	Stripper	Absorber	LPFD	HPFD
100	23	15	25	21
125	15	15	15	15
150	12	12	15	15
175	14	16	16	18
200	12	14	16	16

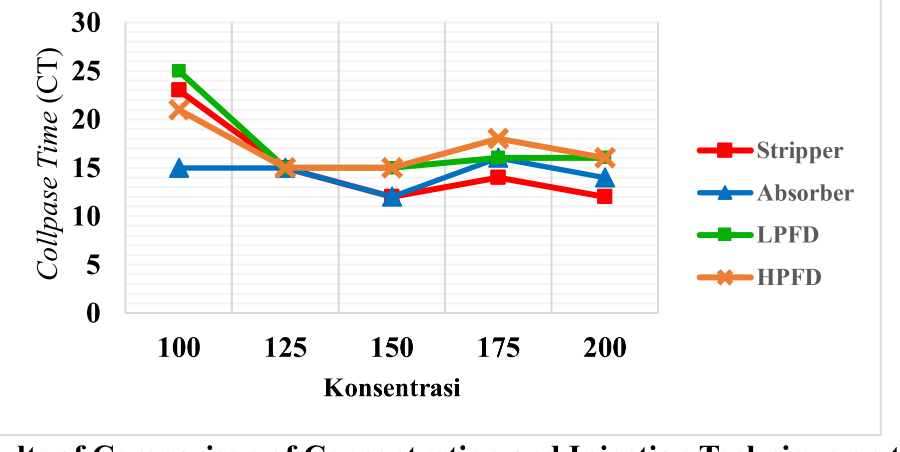

Figure 1. Results of Comparison of Concentration and Injection Technique on the Collapse Time Produced

Based on Figure 1, it is known that the best CT value is shown by the injection technique at a concentration of 150 mL to the Stripper and Absorber and injection at a concentration of 200 mL to the Stripper with a CT value of 12 seconds. While the injection technique with a concentration of 100 mL provides the slowest CT value with an average of above 20 seconds. This is possible because the antifoaming concentration is too low, it takes longer to break the foam, but this does not mean that the higher the concentration, the faster the CT value is obtained. This is proven because the injection with a concentration of 175 mL slowed down the CT value to 14 and 16 seconds in the Stripper and Absorber, then accelerated again when the concentration was increased to 200 mL.

CO2 leak content

As a gas purification unit, one of the performance parameters of the CO2 Removal Unit is the CO2 Leak content or CO2 that escapes that is still present in the process gas that exits the CO2 Removal unit. The CO2 Slip content is limited to a maximum of 500 ppm or 0.05%. The CO2 Slip content can be determined through the Analyzer Indicator and process gas laboratory results. In this study, data was collected based on the Analyzer Indicator value that records data every 2 hours because it is considered more accurate than laboratory analysis carried out only once a day. The results of the analysis are shown in the following table:

Table 2. CO2 Slip values based on injection technique

Amerel Concentration (mL)	CO2 Leak Value (% Volume) at Injection technique to -			
	Stripper	Absorber	LPFD	HPFD
100	0.003	0.003	0.003	0.006
125	0.002	0.002	0.001	0.002
150	0.001	0.001	0.001	0.001
175	0.002	0.002	0.009	0.002
200	0.011	0.007	0.019	0.003

Based on table 2, the results of the frequency distribution of history of exposure to breast self-examination information show that the highest category is never, with 67 respondents (77.0%) and the lowest category is ever, with 20 respondents (23.0%).

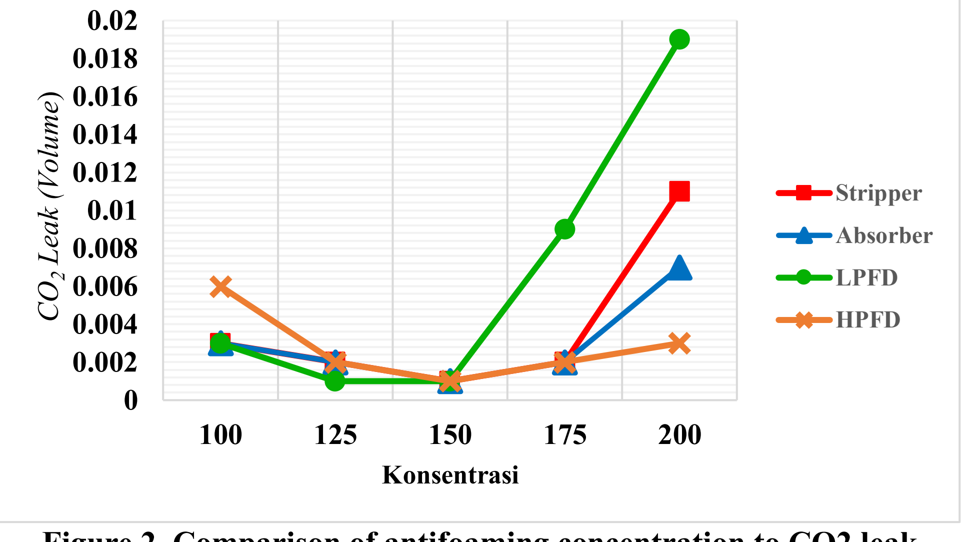

Figure 2. Comparison of antifoaming concentration to CO2 leak

Based on the data in Table 2, it is known that the optimum concentration so that the amount of %CO2 Leak coming out of the CO2 Removal unit is minimal, namely a concentration of 150 mL with a %CO2 Leak of 0.001% while the highest %CO2 Leak value is shown by injection with a concentration of 200 mL. Based on Figure 4.7, it is known that the addition of antifoaming concentration from 100 mL to 150 mL will linearly reduce the %CO2 leak from 0.003% to 0.001%. When the concentration is increased beyond 150 mL, there is a tendency for an increase in the %CO2 leak as occurred at concentrations of 175 mL and 200 mL with the injection technique into the LPFD which shows a very significant increase, namely from 0.001% to 0.009% and increased drastically to 0.019%.

The review based on CO2 leak also supports previous reviews which showed that antifoaming injection at a concentration of 150 mL was the most optimum concentration, while the injection technique into the LPFD was a technique that showed quite high sensitivity to changes in concentration so that it could be used to monitor changes in CO2 leak.

Based on observations of Collapse Time (CT) and CO2 Slip, it is known that the addition of silicone-based antifoaming indicates a critical concentration point called SCAFC (Surfactant Critical

Antifoaming Concentration) at a concentration of 150 mL. When antifoaming is added to the media, the bubbles formed will collapse more quickly because the liquid film between the bubbles is disrupted. The addition of antifoaming concentrations exceeding SCAFC also does not show a linear effect (Rosenberg & Kunjappu, 2002).

***Purity*CO2 Products**

*Purity CO2 Product*is an important indicator of the success of the CO2 Removal unit's performance, meeting the desired standard of 99% by volume. The CO2 Product purity value is obtained based on laboratory test results on the CO2 Product gas outflow from the LPFD. The following data shows the CO2 Product purity based on the injection technique used.

Table 3 CO2 Purity Value of Products based on injection technique

Amerel Concentration (mL)	Product CO2 Purity (% Volume) at Injection technique to -			
	Stripper	Absorber	LPFD	HPFD
100	99,251	99,160	99,340	99,106
125	99,432	99,490	99,477	99,101
150	99,442	99,495	99,466	99,467
175	99,519	99,416	99,582	99,496
200	99,581	99,527	99,646	99,541

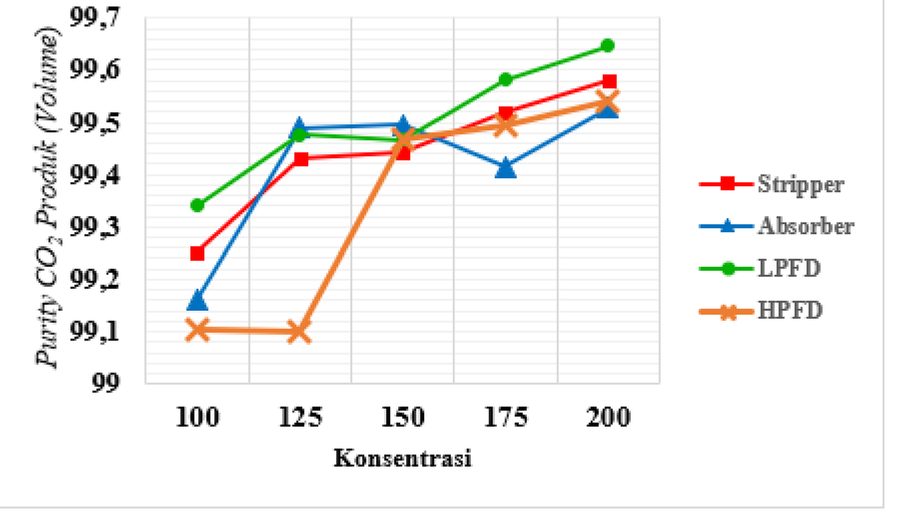

Figure 3. Graph of the Effect of Concentration on Product CO2 Purity

Based on Table 3, it is known that injection with a concentration of 200 mL into LPFD provides the best CO2 product purity with a value of 99.646% by volume. Meanwhile, the lowest CO2 product purity value is 99.101% by volume obtained from injection with a concentration of 125 mL into HPFD. Both values are still within the expected CO2 product purity target of 99% by volume. Figure 3 shows a graph of the relationship between concentration and CO2 Product purity. Based on the figure, it can be seen that the increase in concentration shows a linear trend towards increasing CO2 product purity.

The direct impact of antifoaming on product CO_2 purity is not directly measurable, but reducing foaming in the system will contribute to preventing carryover or the inclusion of solvent liquid, thereby increasing the purity of the resulting gas (Lau et al., 2023). This occurs because the upper part of the LPFD where the CO_2 product exits contains a washing column that functions to purify CO_2 gas through the diffusion of absorbent solution that is still included in the product (Nisa et al., 2019).

CONCLUSION

This study successfully identified Surfactant Critical Antifoaming Concentration (SCAFC) at a concentration of 150 mL of PDMS-based antifoaming injected into low-pressure and high-temperature equipment, In Stripper and LPFD equipment, resulting in the fastest Collapse Time (CT) of 12 seconds, minimum CO2 slip of 0.001%, and product CO2 purity of up to 99.45%. These findings prove that the optimal concentration maximizes the performance of the CO2 Removal unit by effectively reducing foaming, minimizing CO2 leakage, and increasing absorption-desorption efficiency using MDEA solvent, thus supporting sustainable operations in the chemical fertilizer industry.

However, limitations of the study include the lack of long-term testing of antifoaming degradation and interactions with specific contaminants in local natural gas, as well as seasonal variations in operating conditions that may impact SCAFCs. Suggestions for future research include integrating dynamic simulation models such as Aspen Plus to predict multi-phase foaming behavior and testing non-silicone hybrid antifoamings to mitigate the risk of excessive carryover. Practically, these results provide precise antifoaming injection guidance for CO2 Removal unit operators in Indonesia, potentially reducing downtime, saving solvent costs by 10-15%, and improving the quality of CO2 products for urea fertilizer.

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