



## EMPIRICAL EVALUATION OF FOAM FORMATION CONTROL IN AMINE-RICH GAS TREATMENT SYSTEMS



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**Abstract:** Gas processing facilities often encounter the problem of foaming, which results in reduced absorption capacity and mass transfer efficiency of amine solutions. This, in turn, negatively impacts the gas-sweetening process. To address this challenge, defoamers play a crucial role in gas treatment operations, ensuring that the absorption of acid gases proceeds without interruption. However, determining the most effective antifoam and understanding the gas-sweetening process based on existing literature can be a daunting task. This study delves deeper into the underlying signs and causes of foaming in gas treatment facilities, including recent researches on the impact of defoamers on natural gas plant operations. The research provides valuable insights into various antifoaming agents used in the acid gas sweetening process, including their unique properties, advantages, disadvantages, and application methods. This study aims to provide a comprehensive review of the available literature, highlighting the latest advancements in this field. The findings of this study demonstrate that the use of one or more defoamers can effectively eliminate foam in gas treatment facilities, thereby improving the efficiency and effectiveness of the gas-sweetening process. The study concludes by suggesting that further research is necessary to develop more effective and efficient defoaming agents that can address the unique challenges faced by gas processing facilities.

**Keywords:** Amine, Defoamer, Foam, Gas, Surfactant, Treatment

### 1.0 Introduction

Foaming is a general issue that all gas processing facilities face at some point. It lowers amine solution mass transfer efficiency, absorption capacity, and carryover to downstream processes. It also hampers equipment handling and process control (Hajilary *et al.*, 2011). Consequently, interest is growing in foam prevention and control. Foaming is generally produced by organic pollutants such as organic acids, amine degradation products, and liquid hydrocarbons. These organic compounds may enter the amine units via the input streams or be produced within the unit due to amine breakdown (Pal *et al.*, 2015; Fredriksen & Jens, 2013; Alhseinat *et al.*, 2014). Foaming can occur in absorption columns where the solvent and gas are in close contact and in the desorption stages. Research indicates that foaming is more likely to occur in the desorption column and worsens at high temperatures and low pressures (Alhseinat *et al.*, 2017; Yanicki & Trebble, 2006; Giannaris *et al.*, 2021). In the worst-case scenario, the presence of unwanted foam results in the complete closure of the plant's operation (Chen *et al.*, 2007; Kister, 2003; Leuneret *et al.*, 2020; Senger & Wozny, 2011). When surface-active chemicals stabilise the phase interface during gas/liquid interaction, foaming conditions arise (Senger & Wozny, 2011; Thiele *et al.*, 2003). Evaporators in the chemical sector's bottom and feed areas of separation columns are thus particularly prone to foam formation.

Applying chemical compounds such as alcohol, silicone, or glycol-based anti-foaming agents is the most prevalent technique for chemical foam control in columns (Carpenter, 2014; Kar *et al.*, 2019). Antifoam compounds should only be used as a last resort in production processes because they usually only suppress foam momentarily, and overdose can enhance foaming (Gondule *et al.*, 2017; Kister, 2003). As a result, the most common way to prevent foam is to reduce the contact intensity between the gas and liquid phases. This involves increasing the column

diameter, increasing the residence time and lowering the gas velocity or gas load factor in the design case. If foam forms during operation, the problem can be solved by lowering the flow rate or throughput. The former, on the other hand, raise investment while the latter decreases capacity.

According to the conventional view, chemical additives and mechanical devices are the two most common strategies for preventing foaming (Garrett, 2015). Chemical defoaming additives have been the preferred method since the early twentieth century (Pal *et al.*, 2020). Amyl alcohol, caprylic alcohol, trimethyl cyclohexanol, rapeseed, castor, silicone, kerosene, and other well-known chemical additions are principal defoaming agents. In recent advancements, hydrophobic solid particles have also been introduced into the field of defoaming. During the defoaming process, the chemicals utilised are sometimes deactivated. When defoamers are used, pollutants are always introduced into the process. Spinning blades and neutron reflectivity are mechanical methods for reducing excess foam volumes. They have also effectively destabilised foams (Hill & Eastoe, 2017). The main downside of these technologies is their considerable energy consumption, which renders them costly and economically undesirable. Ultrasound as a mechanical way of defoaming has recently gained popularity. It is a safe way to eliminate foams that do not involve any liquid contact (Sun, 1951). Ultrasonic energy is applied to foam by irradiating it with high-intensity ultrasonic waves (Narsimhan & Wang, 2006; Khmelev *et al.*, 2007; GallegoJuarez *et al.*, 2015). The approach is non-invasive, produces no chemical pollution, and could be easily integrated into current processes. As a result, ultrasonic technology could be a viable industrial alternative to conventional mechanical and chemical methods (Chendke & Fogler, 1974). Surface waves are created on the foams by ultrasonic waves. The surface waves generated on one side of the film are transferred to

the opposite side. Foam drainage is aided by such squeezing waves (Sandor & Stein, 1993; Barigou, 2001). Nevertheless, the problem of foaming in the gas industry, especially in treating natural gas to meet market specifications, needs to be mitigated accordingly through robust research regarding the issue. However, there is rarely an extensive review in existing literature of the defoamers that can be used, viz possible solutions that can be procured. Consequently, the main intent of this study is to give an exposition of the problems associated with foaming in gas facilities, the possible causes and the methods that can be used to address the problem of foaming in gas facilities.

**2.0 Foaming in Gas Systems**

Foam is defined by Gondule *et al.* (2017) as a substance generated by trapping pockets of gas in a liquid or solid. Foams include a bath sponge and the head on a glass of beer (see Fig. 1). Foaming persists in amine plants due to a variety of factors. Foaming in systems causes significant annual capital losses. Such losses result from a temporary loss of sour-gas processing capability, resulting in lower sales and fuel-gas production and a failure to comply with environmental standards. The most prevalent method of foam suppression has been continuous antifoam injection. Even though antifoam injection is well-known and well-documented, it is only indicated as a last resort and then only temporarily.

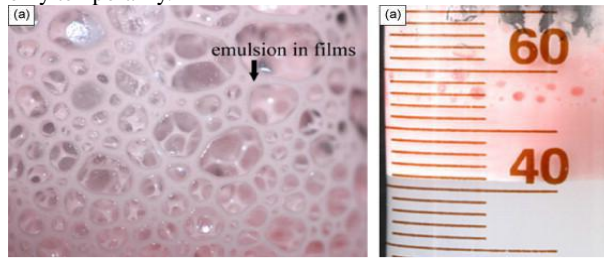


Fig. 1: Foam formation (Inger, 2013)

**2.1 Foam stability**

Drainage would be expected to remove all the water from the foam lamellas, allowing them to collapse independently. In practice, drainage stops when the surfactant concentration in the lamellas rises to the point where electrostatic repulsion forces between the surfactant molecules prohibit further retraction of the lamella walls. As a result, the drainage and amphiphilic molecular foam lamella reach a thermodynamically stable state of equilibrium (See Fig. 2).

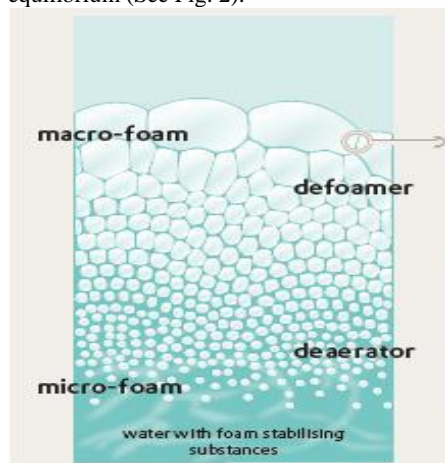


Fig. 2: Stabilization of the lamella by surfactants (Gondule *et al.*, 2017)

Depending on the foam's stability, foam ability can be determined using static or dynamic test methods. Static approaches are utilized for foams with great stability and are based on measuring the foam decay rate over a predetermined period after foam generation. The Bartsch, foam beating, and Ross-Miles methods all use this procedure (Miles & Ross, 1944). On the other hand, the dynamic approaches achieve an equilibrium between foam generation and decay, resulting in a steady-state foam volume. This foam volume describes the system's foaming ability (Rossand & Suzin, 1985). The determination of foamability is the most popular dynamic method. The substance system to be examined is gassed in a measuring cylinder through a perforated plate at a constant gas volume flow (Thiele *et al.*, 2004). A water bath maintains a steady temperature. The resulting stationary foam volume Vf is defined as the unit of foaminess or Bikerman Index in relation to the injected gas volume flow Vg:

$$\sum B = \frac{V_f}{V_g} (1)$$

The Bikerman Index measures the average time a foam bubble stays in the foam before decaying (Bikerman, 1973). In the past decade since Bikerman's original description, the approach has been improved and suited to the needs of various applications. Comparisons of the changed methods' results, on the other hand, reveal that the determined foamability is not an intrinsic property of the substance system but rather is dependent on the method used (Liet *et al.*, 2010; Ross & Suzin, 1985; Senger & Wozny, 2011). The dimensions of the measuring cylinder and the humidity of the gas phase above the foam surface greatly impact the measured foamability and limit the comparability of the different adopted methods (Ross & Suzin, 1985; Li *et al.*, 2010). A species' liquid stream was added to the top of the column in a test cell with an operating column to achieve comparable conditions (Senger & Wozny, 2011). As a result, an appropriate test technique must verify that the selected test conditions accurately reflect the intended application. Various studies have been conducted on the effect of ambient temperature on the foamability of a material system (Lesueur *et al.*, 2004; Oetjen *et al.*, 2014; Tyrode *et al.*, 2003). However, in these tests, foam is generated solely by pneumatic means. To characterize foam formation during the thermal processing of liquid mixes by evaporation, such as in distillation or desorption processes, partial evaporation of the mixtures must be generated. Foam generation is found in literature due to miscibility gaps (Ross-type foaming), surfactants, decomposition chemicals, or particles stabilizing the dispersed phase (AlYousef *et al.*, 2017; Bindal *et al.*, 2002; Keewan *et al.*, 2018). When a mixture is heated to boiling temperature, vapour bubbles form, which can be stabilized by accumulating surface-active components at the liquid-vapour interface (Wasan *et al.*, 2004; Strodtmann *et al.*, 2022).

**2.2 Amine gas treating**

Amine gas treating, also known as amine scrubbing, gas sweetening, and acid gas removal, is a systematic

procedure that removes hydrogen sulphide (H<sub>2</sub>S) and carbon dioxide (CO<sub>2</sub>) from gases using aqueous solutions of different alkyl amines. During the operation of an amine unit, the solvent degrades owing to reactions with impurities in the feed gas, such as oxygen, sulfur dioxide, and acids. Some of the tertiary amine oxidation products cause a variety of amine unit operational issues. Amine gas treatment may encounter solvent degradation issues for many reasons, including conditions that allow inlet contaminants. It is a common refinery unit process in petrochemical facilities, natural gas processing plants, and other industries. Because amine has a natural affinity for CO<sub>2</sub> and H<sub>2</sub>S, it can be used as a very efficient and effective acid gas removal process (Gondule *et al.*, 2017).

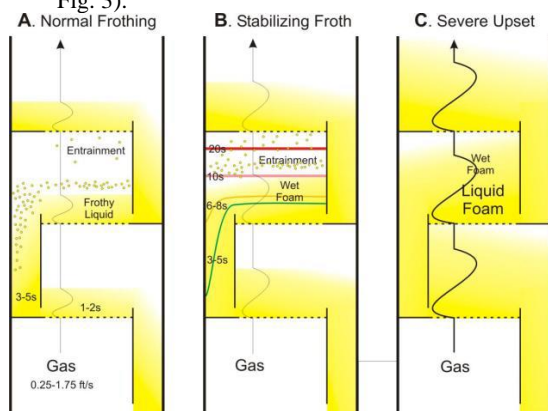
**2.2.1 Foaming in amine treatment facilities**

The most common issue in these liquefaction plants is foaming in alkanol amine solutions. It typically occurs in the absorber, but it can also occur in the stripper. Hydrocarbon liquid, organic acids, well chemicals, foam-reducing agents, and amine degradation products are all impurities in the feed gas that affect the amine's capacity to foam. Pure amine solutions do not produce stable foam. Other components must be present in the treatment solution for the stable foam to form. Contaminants are divided into two categories: those added to the solution and those that form within the solution. Each contaminant can affect foaming tendency and stability (Inger, 2013).

**2.2.2 Indicators of foaming in amine systems**

An amine system subjected to foaming exhibits the following behaviour, according to Gondule *et al.* (2017):

- 1) A sudden increase in the differential pressure in the column.
- 2) Foaming limits the vapour-liquid contact area, resulting in a smaller effective mass-transfer zone, allowing the amine to pick up less acid gas (a high H<sub>2</sub>S level suggests the possibility of foaming).
- 3) Carryover of amines to downstream devices.
- 4) A loss or drop in the rich-amine flow rate accompanies an abnormal level indication in the absorber column's bottom part.
- 5) The temperature profile of an abnormal absorber column can be another indicator; if foaming is produced by tainted sour gas, the bulge temperature generally shifts from the lower to the upper trays during foaming (See Fig. 3).



**Fig. 3:** Tower foaming, differential pressure and liquid level flux (Von, 2005)

**2.3 Prevention of foaming**

Foaming issues may normally be avoided by minimizing the amount of external contaminants entering the system, such as oil from compressors, well chemicals, and rust inhibitors. The best technique to keep external contaminants out of the system is to install a slug catcher, intake filter/separator, and a gas-liquid coalesce in series in the feed gas line. Aerosols of a diameter of 3 microns or smaller are difficult to remove using conventional separators. However, specialized high-efficiency gas-liquid coalesces can remove compressor-lubricating oil droplets as small as 0.001 microns. A differential pressure indication and alarm should also be included with amine contactors and regenerators to provide early warning of foaming problems (Gondule *et al.*, 2017).

**2.3.1 Defoamers**

The addition of chemical antifoaming agents is a common method of foam destruction. Antifoam is a chemical additive that stops foam from forming in industrial liquids. It is also called an antifoaming agent or defoamer. Insoluble oils, poly-dimethyl silanes and other silicones, and some alcohols, stearates, and glycols, are commonly used agents. The additive is used to prevent foam development or to break up a foam that has already developed. Commercially available defoamers come in various characteristics and foam destruction efficiency variations. The types of defoamers used for gas treating are listed as follows:

1. Oil based defoamers
2. Water based defoamers
3. Silicone-based defoamers
4. Alkyl poly acrylates

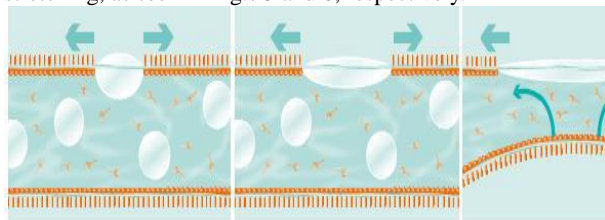
Furthermore, the general properties of defoamers are listed as follows:

1. Defoamers have surface-active properties and are insoluble in the foaming medium.
2. The antifoam product has a low viscosity and can spread quickly on foamy surfaces.
3. It has an affinity to air-liquid interfaces, destabilizing foam lamellas. This causes the air bubbles to rupture and the surface foam to break down.
4. Air bubbles entrained in the bulk liquid collect, and the larger bubbles rise to the surface of the bulk liquid faster.

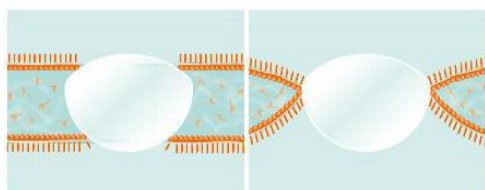
Regarding applications, defoamers function by penetrating and destroying the foam lamellas, as described by Gondule *et al.* (2017). The pseudo-emulsion film is the first barrier to overcome while penetrating. Between the growing antifoam droplet and the liquid surface is a thin liquid lamella. Antifoam droplets cannot penetrate the surface of the pseudo-emulsion film and are too stable; thus, defoaming is impossible. The force balance between the three phases is described once the antifoam droplet has overcome the pseudo-emulsion coating and penetrated the lamella (the liquid to be defoamed, antifoam and air). Upon penetrating the lamella, the antifoam droplet may spread. If the antifoam can spread over the surface, it produces an antifoam lens at the lamella surface, displacing the surfactants. As a result, the lamella's stability and flexibility are impaired and at risk of collapsing. In addition, the spreading mechanism causes the lamella liquid to flow in the spreading direction. The phenomenon, also known as Marangoni flow, induces a local lamella thinning around the spreading antifoam



droplet, leading to further destabilization. Fig. 4 depicts the penetration and spreading of an antifoam droplet. However, if the antifoam droplet penetrates both sides of the lamella, the lamella can rupture due to dewetting or stretching, as seen in Figs 5 and 6, respectively.



**Fig. 4:** Penetration and spreading of the active ingredient of the antifoam (Gondule *et al.*, 2017)



**Fig. 5:** Film bridging during defoaming (Gondule *et al.*, 2017)



**Fig. 6:** De-wetting under the defoaming process (Gondule *et al.*, 2017)

### 3.0 Findings from selected studies on defoamers application in gas treatment systems

In a work published in 2020 by Pal *et al.*, model foam makers for industrial lean methyl diethanolamine (MDEA) solutions were anionic surfactant sodium dodecyl benzene sulfonate (SDBS) and cationic surfactant hexadecyltrimethylammonium bromide (HTAB). Stirring produced foam while creating a lean MDEA solution with 300, 500, 1000, and 3000 mg/L surfactant concentrations. As the surfactant content and stirring speed increased, it was discovered that the final foam volume also increased. However, they noticed that at low surfactant concentrations (300 and 500 mg/L), SDBS demonstrated a larger foam volume (35 and 55 mL) than HTAB (20 and 25 mL). All investigated solutions could be effectively defoamed using ultrasonic waves. With rising temperatures, the defoaming rate accelerated. The exponential function was followed for foam production and defoaming at a constant temperature and stirring. Before and after sonication, there were negligible variations in the material's density, dynamic viscosity, and surface tension. Interestingly, the concentration of organic acids, or primary degradation products, stayed essentially constant. In short, their study showed that ultrasonic waves could be a good way to eliminate foam in amine solutions used in the natural gas industry.

Ng *et al.* (2021) presented a review that analyses the selection criteria of each type of defoamers for acid gas sweetening, particularly silicone, polyether glycol, alcohol, and blended-based defoamers. These selection criteria are crucial in defining the properties and

antifoaming performance in terms of solubility, dispersibility, surface tension, viscosity, defoaming rate, thermal stability, stability of defoaming performance, potential hazard, and chemical inertness. Their review provided valuable insight into the existing and potential antifoams that could be employed in the acid gas sweetening process, along with their distinctive antifoaming ability, benefits, and drawbacks.

Borhan *et al.* (2022) performed a series of experiments on foaming of two types of crude oil and four types of synthesized Gemini silicone-amine base defoamer in a simulated produced water system containing foam surfactant Foam Assisted-Water Alternating Gas (FAWAG) package and investigated their influence under a column temperature at 30 – 60 °C, and applied pressure of 1 – 4 bar, with a fixed fluid flowrate of 0.5 L/min. In their study, the high saturated composition in the crude oil at 45 – 75.8 % influences the foam stability of the fluids. This reflects that the waxy types of crude oils with higher density properties of 0.8768 – 0.858 Kg/L and increased concentration of foam surfactant from 30 % to 90 % in the produced water system influences the foaming stability. Furthermore, the microscopic observation showed that a bigger bubble size, about the average of 400 – 500 μm, would slow down the liquid drainage, resulting in foam stability behaviour.

In the context of amine gas treating, the lean amine temperature can affect several factors, including foaming caused by impurities in the rich amine solution (Abdul-Rahman & Zangana, 2020). The presence of contaminants, such as corrosion inhibitors, can also contribute to foaming in amine solutions (Keewan *et al.*, 2018). Therefore, controlling the temperature and monitoring the impurity content in the amine solution can help mitigate foam formation in amine-rich gas treatment systems.

### 4.0 Conclusion

Amine solutions form because air bubbles are stabilized into foam by the contaminating surfactants. The most common way to control foaming has been injecting antifoaming chemicals into the recirculating solution level, breaking the foam. The efficiency of antifoams can be reduced in various ways and they are likely to be unreliable when used alone as a long-term control solution. The only way to control amine foaming over the long term is to remove the foam-causing surfactants by blending two or more additives, including sourcing local defoaming agents with improved properties. Various solution impurities and operating conditions can cause air-trapping bubbles to stabilize into foam. Since foaming in amine plants causes upsets, mitigation actions are always recommended to avoid foam formation. The foam-reducing action is normally the addition of chemical antifoam. Defoamers are intended to facilitate gas and liquid disengagement by weakening the cell structure of the air bubbles. Defoamers have no positive impurity removal properties. The tracer of these chemicals into recirculating amine solutions is common and even regarded as necessary for normal plant operation.

Overall, controlling foam formation in amine-rich gas treatment systems requires a comprehensive understanding of the factors influencing foam behavior. Studies on the effects of process parameters, membrane characteristics, foam stabilizers, and impurities can

provide valuable insights for optimizing foam control strategies in these systems.

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