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Comparative Experimental Investigation of Surfactant Performance for Improved oil recovery by unloading the Wells

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Abstract

This research paper analyses the potential for surfactants to lessen this frequent industry difficulty by delving into the complicated world of liquid-filled gas wells. The major goal is to clarify the intricacies of liquid buildup from gas wells by making use of sodium dodecyl sulfate's (SDS) effectiveness as a potent surfactant. SDS emerged as a suitable choice after thorough testing and analysis, demonstrating impressive effectiveness in lowering surface tension and aiding the separation of trapped liquid from the well surface. Research also explores the topic of carrier fluids, looking into how they can improve the efficacy of surfactants. In a significant development, studies have shown that the condensate looks to be a highly efficient carrier fluid due to its compatibility with SDS and its innate capacity to suppress foaming. This special mixture guarantees the surfactant's ideal dispersion and interaction with the collected liquid, which enhances the unloading procedure.

The study then broadened its reach by outlining and meticulously analyzing various injection techniques. These include the coil injection and annular approaches. Utilizing this multifaceted approach, the study thoroughly evaluated the inherent advantages and disadvantages of each methodology. These evaluations offer very significant information that enables a thorough comprehension of their individual advantages and difficulties. The combined findings of this research make a substantial contribution to our comprehension of the intricate interactions between surfactant, carrier fluid, and various injection strategies.

This thorough understanding, which was developed by combining theoretical knowledge with empirical analysis, should pave the way for the creation of sophisticated solutions to address one of the complex problems—the problem of fluid loading into gas wells.

Keywords

Surfactants, Liquid Loading, Water Loading, Carrier Fluid, Sodium Dodecyl Sulfate (SDS)

1. Introduction

Globally, mature gas fields with liquid loading provide a substantial operating issue. This problem becomes apparent as a reservoir's back pressure increases over time because of the buildup of a rising liquid column within the well. This condition first causes a decrease in deliverability, which makes it more difficult to extract gas effectively. If this process is not stopped, eventually the well's ability to produce gas comes to an extensive end. According to theoretical considerations, nearly every gas well will invariably experience this devastating occurrence in the final stages of its useful life. [1]. Fig. describes the condition of a well which is loaded with liquid.

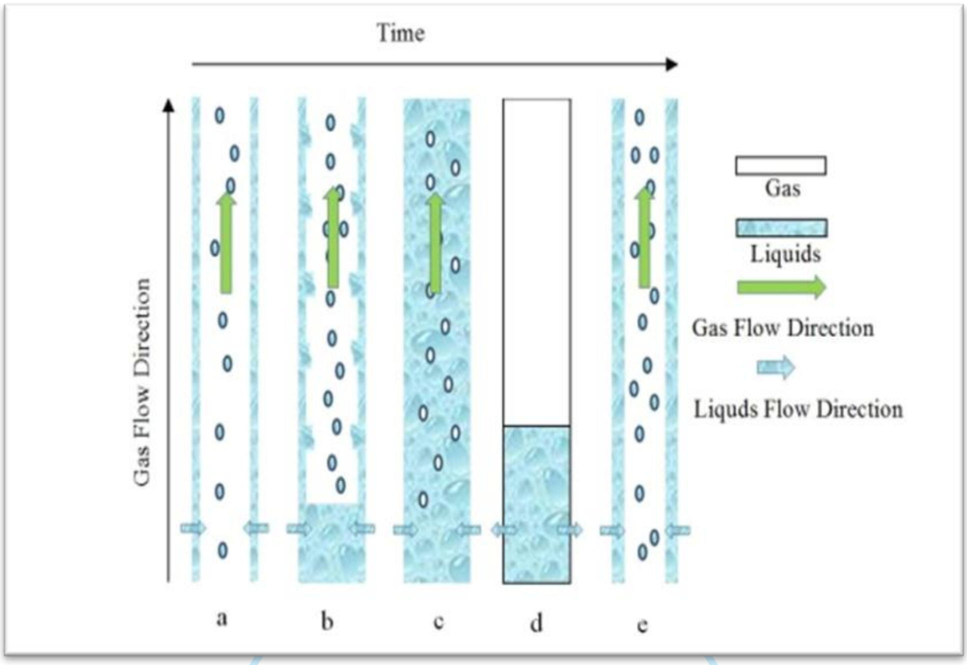

Fig. 1 Typical Liquid Loading Process [1]

Velocity string, plunger lift, gas lift, submersible pumps, sucker rods, swabbing, foaming, and jetting are some of the major techniques used in unloading a well. By far the most cost-effective methods are those that make use of reservoir energy (such as plungers, velocity string, and foaming) [2].

For gas-well dewatering, foaming is a low-cost initial option, but it can get pricey if a lot of surfactants are needed. It has been successfully employed in a variety of applications. This simplest and most affordable liquid lifting technique can be used in different ways. The "soap stick" form is the most common way that foam lift is used. Another potential application involves the intermittent or continual injection of surfactant solution from the wellhead via the annulus [3]**.**

1.1 Background

For efficient gas production, fluid loading into gas wells presents a considerable problem. Water, condensate, or other liquids build up in the well and obstruct the upward movement of gas. This phenomenon, which causes a drop in gas velocity and a fall in production rates, is especially noticeable in low-pressure wells or as wells mature. A buildup of fluid can cause the wellhead pressure to decline, production to become unstable, and even the well's possible closure. Therefore, maintaining optimal gas flow rates and extending the well's production life depend on efficient technologies for eliminating fluids from gas wells.

A potential solution to this issue is foaming, a procedure for removing the liquid head in gas wells. Gas or air is injected into a liquid to produce foam, which has high gas content. Foam can be pumped into the well during gas well operations to displace and discharge collected fluid. The foam's special qualities make it more effective than just gas at bringing liquids to the top.

Injecting a gas-liquid mixture into the well causes foam to form, which lifts the liquid along with it as it rises. The foam's lift is improved by its increased viscosity and gas content, which enables it to go around the restrictions of just gas velocity. This technique successfully lowers the liquid column's hydrostatic head, improving airflow and preventing or lowering fluid loading [4]. Viscosity enhancement and momentum transfer are just two of the ways that foam is used to work. The foam's higher viscosity than the gas's aids in rolling and transporting the liquid upward. Additionally, the air bubbles within the foam give the liquid momentum to move against gravity [5]. Foam has the benefit of being effective in wells with low gas velocities, which makes it particularly appropriate for gas wells sensitive to the liquid head. Foam can also efficiently reduce fluid loading issues while reducing the requirement for pricey shutdowns or interventions. This is a flexible method that can be used for a range of wells and circumstances, including vertical wells. [6]. The project will investigate the mechanism of foaming, as well as its applications to gas well operations, through in-depth analysis, simulation, and maybe field testing. The study will dive into the elements, such as well geometry, foam quality, and gas-to-liquid ratio that influence foam performance. This thesis makes a significant contribution to the optimization of gas well performance by offering in-depth understanding of foam-based liquid material removal. This thesis does this by offering a long-lasting solution to a crucial operational difficulty.

1.2 History

Since the beginning of oil and gas production, fluid filling in the setting of gas wells has gradually developed into a complex problem demanding creative solutions. Here we start our historical exploration, learning about the turning points and changes that have influenced our knowledge of and approach to managing fluid filling in gas wells. Gas wells were largely regarded as a valuable source of hydrocarbons before oil and gas extraction began in the 19th century. Although not well understood at the time, liquid loading occasionally produced operational issues because gas production was strongly tied to the amount of liquid in the tank. Manufacturing procedures are archaic and lack the sophisticated knowledge and technology necessary to successfully handle fluid complexity [3].

As oil and gas production advanced, the sector became aware of the need for techniques to raise productivity. By providing mechanical or pneumatic assistance to lift liquids to the surface, artificial lifting techniques like beam pumping and gas lifting strive to optimize production. Even though these techniques were mainly created for oil wells, their application to gas wells created the framework for resolving fluid loading issues. Liquid charge, as a distinct phenomenon, is still not fully understood currently. The study of multiphase flow dynamics and reservoir engineering both made considerable strides in the middle of the 20th century. To better understand the mechanisms that control how gases and liquids behave in reservoirs, scientists and engineers have started to unravel the complexity of fluid behavior in porous media and wells. With this information, fluid loading as a phenomenon resulting from decreased gas velocity and fluid loss might be evaluated more thoroughly [3].

The awareness of fluid loading as a significant difficulty in gas wells changed dramatically in the latter half of the 20th century. The industry has seen instances where fluid buildup in gas wells has lowered their efficiency as gas fields mature and production rates fall. To comprehend the causes of fluid loads and create practical mitigation solutions, research activities have been stepped up. The creation and improvement of artificial lifting techniques, such as piston lifting and gas lifting, have become important approaches for resisting fluid loads in the twenty-first century. Gas lifting uses injected gas to reduce fluid buildup, whereas piston lift involves periodically pushing stored fluid to the surface. These methods have become more popular because of their effectiveness in maintaining gas flow rates and optimizing production.

Recent developments in modelling, simulation, and data analysis have made it possible to anticipate the occurrence of fluid loads with greater accuracy. Real-time data, multiphase flow models, and reservoir simulations have all been integrated to help with proactive management of fluid load issues. Additionally, continuous research and development keeps looking for novel approaches and technologies to enhance gas well productivity under fluid loading circumstances [4]. The fluid loading tale demonstrates the dynamic character of the oil and gas sector, where problems spur inventiveness and comprehension. The industry's ongoing effort to reduce fluid loads promises to push gas well performance and optimization to new heights as the sector develops [7].

2. Literature Review

As gas reservoirs mature and production rates decrease, liquid filling initiation becomes a critical issue, preventing optimal hydrocarbon recovery. In search of new strategies, researchers and engineers have delved into the field of surfactant-based interventions. This review sums up the current state of knowledge, providing insight into the potential mechanisms, challenges, and benefits of using surfactants to combat fluid loading in gas wells. Liquid loading in a gas well is an important issue affecting gas production rates and operational efficiency. Recent publications have focused on suggesting new models and approaches for predicting the onset of fluid loads and developing effective mitigation strategies.

Fadairo et al. (2022) presents Liquid loading has been characterized as liquid accumulation in the well bore that causes a decrease in output of gas or a full stoppage of production. This occurrence, particularly in wet and or retrograde gas development wells, frequently results in sub-optimal recoveries or expensive corrective measures. This study proposes an improved model that describes a systematic way for calculating liquid loading in a gas well using the numerical integration method while considering the accumulation term, kinetic term, and time. When liquid loading occurs, it is important to identify the issue as soon as possible and choose the best preventive measure [8].

The unique software method proposed by Ghadami et al. (2022) makes use of statistics and machine learning to forecast the beginning of fluid loading and critical gas velocities. With this technique, data from gas wells are gathered on gas flow, liquid retention, well geometry, wellhead pressure, tube and shell size, gas type, and temperature. This strategy has been shown successful in predicting fluid loads in a variety of gas wells, and it offers useful information for identifying wells at risk of fluid loading and implementing effective mitigation measures [9].

In order to forecast liquid loading, this research offers a model based on a liquid film reversal. It goes beyond the limitations of earlier models by using the momentum balance equation for each phase as a basis. The hypothesis, on which the suggested model is based, contends that the loading phenomena begins when an annular flow (a liquid film encircling the gas core) changes into a slug or churn flow. The created model also considers the effects of the deviation angle, tube diameter, and void fraction [10].

Pagou et al. (2020) in this research offers a model based on a liquid film reversal. The effectiveness of the proposed model is assessed by contrasting it with a few well-known current models using newly acquired datasets, laboratory datasets from published publications, and published datasets from vertical, inclined, and near-horizontal gas fields. The proposed model consequently offers the best prediction accuracy as well as the fewest average mistakes. Further findings indicate that the critical gas flow velocity/rate is mostly influenced by the tube diameter and the inclination angle. As a result, the proposed model is the best model for recognizing and forecasting the liquid loading in vertical, inclined, and near-horizontal gas wells since it performs better than the prior reported models [11].

Lee and associates. (2022) examined sodium dodecyl sulfate (SDS) using different carrier fluids. Water, mixture ethanol and isopropanol were used as carriers for solubilization of SDS. Research concludes that water is the most efficient medium in most cases, due to its low viscosity and surface tension. The dissolution rate of SDS is affected by the viscosity, density, and surface tension of the carrier liquid so it needs to be studied A surfactant, when present in small amounts, lowers a liquid's surface tension or raises colloidal stability by preventing bubble coalescence. The study provides valuable insights into the use of carrier fluids to improve SDS dissolution efficiency [12].

Sun and associates (2020) investigate how liquids affect SDS's dissolving behavior. The study demonstrated that the solubility of SDS is influenced by the viscosity, density, and surface tension of the carrier fluid. Slower dissolution rates are caused by higher viscosity and density, but better SDS molecule dispersion is made possible by lower surface tension. The authors' conclusion which offers recommendations for maximizing the usage of the carrier fluid in real-world applications—is that the properties of the carrier fluid are crucial to the dissolution of SDS [13].

Liu and associates. (2020) discuss the application of carrier liquid in the preparation of SDS nanoparticles. The authors emphasize the importance of carrier fluid by providing thorough study for stabilizing the SDS nanoparticles and improving their dispersibility. Various carrier fluids are tested for best results which also include including water [14].

2.1 Theory and Concept

Liquid loading is a phenomenon that occurs in natural gas wells where liquid accumulates in the wellbore, reducing gas production efficiency. This can happen when the production rate of gas drops below a critical value, causing liquids to accumulate in the wellbore rather than being carried to the surface with the gas. Several theories and concepts are associated with liquid loading in gas wells. Understanding these theories and concepts is crucial for designing effective strategies to prevent or alleviate liquid loading in gas wells. Engineers and operators often use models and simulations to optimize well designs and operational parameters to minimize the impact of liquid loading on gas production.

2.2.1 Overview of Liquid Loading

The term "liquid load" describes a phenomenon in which the rate of production in natural gas or oil wells reduces because of the buildup of liquid (often water) in and around the well bore. This fluid accumulation limits the flow of gas or oil, reducing production rates and perhaps posing operational issues for the well [15].

A certain amount of liquid from the reservoir is also transported by a well when it generates gas or oil. This liquid may take the form of condensate or water. The gas velocity is adequate to carry this liquid to the surface at higher production rates. However, as the rate of production declines, so does the gas velocity, which may prevent the gas from transporting the liquid to the surface. The effective flow area of the gas or oil is therefore reduced when this fluid starts to build up in the well and close to the perforations [16]. In Fig. **1**, different stages of liquid loading are mentioned through which the process of liquid loading goes on. It takes time and with decrease in reservoir pressure, the accumulation occurs within the wellbore and at one stage, the well become loaded.

Lower production rates, greater back pressure on the formation, and probable equipment damage are all effects of liquid head stock. There are several ways to tackle this issue [17].

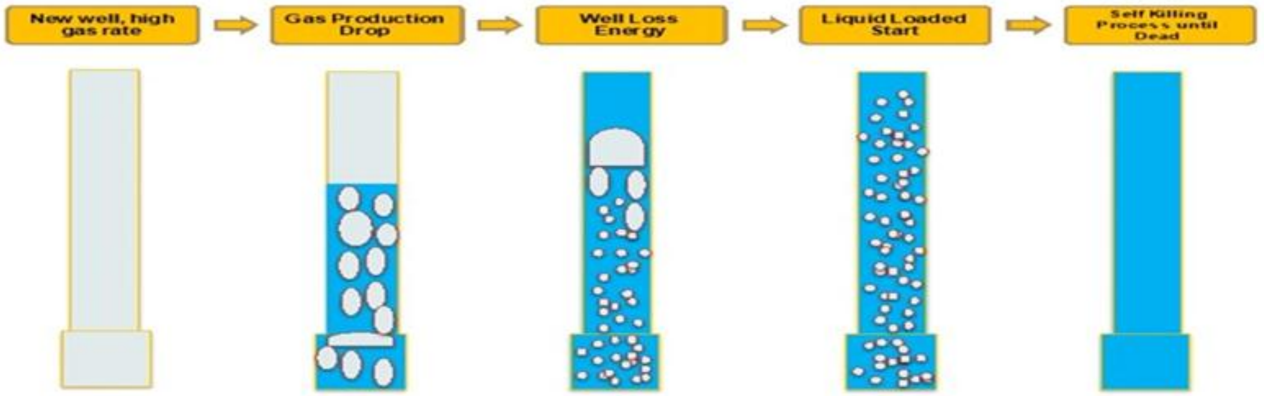

Fig. 1 Stages of Liquid Loading in Gas Wells [17]

2.1.2 Effect of Principle of Liquid Loading On Improved Oil Recovery (IOR)

Fluid filling into gas wells works based on several principles related to fluid dynamics, flow regimes, and interactions between gas and liquid phases. Here are some key principles that contribute to liquid charging:

2.1.2.1 Velocity and Momentum

At higher production rates, the gas flow velocity is sufficient to carry the liquid droplets. This is because the momentum of the gas can overcome the force of gravity acting on the liquid. However, as the production rate decreases, the gas rate decreases, leading to a point where the gas can no longer efficiently transport the liquid, causing it to build up in the well [17].

2.1.2.2 Slug Flow and Slippage

Recoil and Slip Under low-velocity flow conditions, the gaseous and liquid phases may separate, resulting in a phenomenon known as “recoil”. The gas forming the bubble is separated by the liquid slug. In this case, the gas can slip through the liquid slug due to the difference in flow behavior, and this slip may contribute to fluid accumulation near the bottom of the well [18].

2.1.2.3 Impact of Capillary Force and Wetting Ability on Improved Oil Recovery

The interaction between the liquid and the well surface also plays a role. Capillary forces and the wetting properties of rocks and reservoir shells can affect a gas's ability to carry liquids. Several conditions may be favorable for fluid retention near perforations [12].

2.1.2.4 Well Geometry

The geometry of the well, including its diameter and length, can affect flow dynamics. Narrower wells can have higher velocities with lower production rates, which can delay or prevent fluid loading. In contrast, larger boreholes can load fluids more easily [19].

2.1.2.5 Effect of Surfactants on Reservoir and Fluid Properties for Improved Oil Recovery

Reservoir and product fluid characteristics, such as gas density, liquid density, and viscosity, can affect the initiation of the filling process liquid. As soon as the fluid density or higher viscosity becomes higher, it can make the problem worse [20].

2.1.3 Drawbacks of Liquid Loading In Gas Well

Fluid filling into gas wells has a host of disadvantages that can negatively affect production efficiency, equipment integrity, and operating costs. A significant drawback is the reduced production rate, as fluid buildup restricts gas flow, ultimately reducing output. This reduction in gas flow is further exacerbated by an increase in back pressure to the formation due to liquid accumulation, resulting in a further decrease in the production rate. Additionally, liquids can erode and corrode well equipment, including casing and conduits, which could harm or even destroy the machinery. Because of this, operators frequently must pay for makeshift lift systems or chemical fixes, which drives up operational costs. It is difficult to maximize results [17] [18].

2.1.4 Removal of Loaded Liquid Using Surfactant

Removing sludge from gas wells using surfactants involves the use of specialized chemicals to change the surface tension and wetting ability of the fluid in the well. Surfactants, also known as surfactants, are compounds that are somewhat hydrophilic (attracts water) and hydrophobic (impervious to water). They can be used to alleviate fluid loading problems in gas wells by reducing the adhesion of liquids to the well surface and promoting their movement to the surface [21].

Surfactants are added, and this alters the properties of the junction between the gaseous and liquid phases, enabling the gas to disperse and carry the liquid to the surface more effectively. The surfactants aid in the breakdown of the liquid slugs and enable their entrainment in the gas stream by lowering the liquid's surface tension. Surfactants can also change how moist the well surface is, which lessens the propensity for liquids to stick to the well walls.

The well fluid's specific characteristics, such as its composition, temperature, and pressure, must be taken into consideration while choosing the right surfactant. To be effective, a surfactant needs to be stable for the requisite working time as well as compatible with the well's circumstances.

The use of surfactants to remove liquids from gas wells is a complicated procedure that calls for close consideration of variables such surfactant concentration, injection rate, and capacity to interact with other liquids or chemicals in the well. The ideal surfactant formulation and application technique are frequently determined through laboratory studies and field trials [22].

2.1.4.1 Advantages of Using Surfactant

Surfactants have various benefits that can significantly increase production efficiency and operational efficiency when used to counterbalance fluid loads in gas wells. Surfactants promote fluid mobility in the gas stream by decreasing the surface tension between the well surface and the collecting liquid. Due to the increased mobility, liquids are separated and dispersed more effectively, allowing them to migrate to the surface more easily and reducing buildup. Additionally, the modified gas-liquid interference qualities encourage better gas-liquid interactions, minimizing the occurrence of fluid slide, particularly in circumstances with low flow rates.

In contrast to mechanical interventions like the installation of gas lifts or piston lifts, the use of surfactants offers a non-invasive solution to the problem of fluid loading. This method assists in maintaining optimal production rates while also assisting in lowering operating expenses by preventing the need for more expensive interventions. Additionally versatile and flexible, surfactant treatments can be tailored to specific well circumstances and fluid parameters. These advantages make surfactant-based liquid offloading a flexible and affordable method for enhancing gas well performance [23].

2.1.4.2 Disadvantages of Using Surfactant

Surfactants can be used to reduce liquid loading in gas wells, but there are also some significant drawbacks to this strategy. It can be challenging to select the right surfactant because it depends on a variety of factors, such as temperature, pressure, the makeup of the liquid, and compatibility. Due to this complexity, it may be challenging to produce the intended effects and results in all circumstances. In addition, adding surfactants to the reservoir may have unanticipated effects that shorten the reservoir's operational lifespan, such as changes in the moisture content of the reservoir or changes to the liquid characteristics. Chemicals have a tendency to cause environmental issues, particularly if they are not eco-friendly or if suitable injections and manufacturing management are lacking. Another drawback is that surfactant treatments may have a finite shelf life, necessitating repeated applications over time to preserve their benefits, which would raise complexity and operational expenses. When using surfactant-based solutions to reduce fluid loads in well reservoirs gas, these limits underscore the necessity for careful study, in-depth aquifer analysis, and adequate risk assessment [23].

2.1.5 Carrier Fluid

The carrier fluid acts as the medium into which the surfactant is injected into the well when surfactants are used to lessen the fluid load in a gas well. To effectively deliver the surfactant to the target locations where liquid loading takes place, the carrier fluid is chosen. Due to its availability and compatibility with a wide range of surfactants, water is a preferred carrier fluid. Oil wells can use hydrocarbon-based carrier fluids to mimic the properties of the reservoir fluid, such as diesel or light oil. In addition, the performance of surfactant treatment can be improved by using specialized carrier fluids made for certain well conditions or surfactant characteristics.

It's crucial to pick a carrier fluid that works well with the surfactant, won't harm reservoir or well components, and can deliver the surfactant to the troublesome locations. The solubility, stability, and interactions of the surfactant with the containing liquid are a few examples of the parameters that influence the choice of carrier fluid [24] [25].

2.1.6 Methods of Injection

Chemical injection in oil and gas wells is a common practice to enhance production, prevent corrosion, control scale, inhibit the formation of hydrates, and address other issues related to fluid properties and reservoir conditions. Various methods are employed for chemical injection into wells. There are different methods through which injection can be performed in the well which are:

2.1.6.1 Annular Injection

To create a distinct flow through which the surfactant can interact with the liquid stored in the well, annular injection requires injecting the surfactant into the annular space between the tubing and the well casing. If the entire well needs to be treated or if there is fluid buildup in the annular gap, this procedure is extremely helpful. By effectively distributing and interacting with the surfactant in the collected liquid, the annular spray method lowers surface tension and enhances fluid mobility in the gas stream [26] [27].

2.1.6.2 Through Coil Tubing

The oil and gas sector uses coiled tubing, a specialized technology, for several operations, including well intervention, stimulation, and production enhancement. It accomplishes different functions without requiring the removal of the tubing from the well by using a length of continuous metal tubing wound on a sizable spool and inserted into oil or gas wells. When loading fluids, the flexible conduit known as a spool offers several advantages. By inserting a long, continuous roll of casing into the well, controlled direct distribution of surfactants to certain well depths where buildup is an issue is made possible. The areas most impacted by liquid fillers will receive tailored treatment thanks to this exact placement.

The flow dynamics in the tube cause turbulence as surfactant-filled liquid travels through the spool, which encourages full mixing of the surfactant with the liquid buildup. This potent mixture significantly lowers surface tension by enhancing surfactant dispersion and increasing its interaction with liquid accumulation. As a result, the surfactant's capacity to alter the junction properties between the gas and liquid phases is maximized, making it easier for liquid in the well to rise to the surface.

The spool treatments also have the benefit of requiring less carrier and surfactant volume than conventional techniques. By using less fluid, this is not only economical but also suited for activities that respect the environment. Additionally, the spool's flexibility makes it possible for it to navigate through wells with complex geometries, making it appropriate for managing a wide range of well configurations, including those with production rates and flow patterns. Spool operation includes real-time monitoring and control as a fundamental component. Modern technology offers continuous process progress and downgrade condition monitoring, enabling operators to make any necessary adjustments in real time. This versatility makes it possible to tailor process parameters to the well conditions that arise during operation. Fig. **2** shows a simple installation mechanism of coiled tubing.

However, the success of spool treatment depends on careful planning, including a thorough assessment of well geometry and potential obstructions. The compatibility of the surfactant with the tubing material, as well as the overall operational expertise of the process team, are also important factors in achieving safe and effective surfactant injection efficiently through the spool [28].

Fig. 2 Surfactant Injection through Coil Tubing [28]

2.1.6.3 Dropping Solid Surfactant Sticks

The introduction of stick solid surfactants directly into the well bed as a solution to reduce the fluid load in gas wells is an attractive idea. However, its actual implementation comes with several challenges that need to be carefully addressed. The feasibility of this method lies in its ability to effectively place the rod in areas of fluid accumulation. It is important to ensure that the sticks dissolve or decompose rapidly enough to release the surfactant into the liquid and achieve a uniform distribution in all affected well portions. Good fluid compatibility, temperature, and pressure, as well as the potential for adverse reactions or blockages, should be carefully evaluated. Hydraulic conditions play a role in how the poles deploy and distribute. Monitoring and controlling the deployment and performance of solid sticks can be more complex than injecting liquid surfactants, potentially limiting real-time adjustments. Environmental considerations also arise, as incomplete dissolution of solid sticks can cause environmental concerns. Although specific literature on the implementation of solid sticks for fluid load reduction may be limited, broader discussions of solids handling materials in good interventions could yield significant results insight into potential methods [29] [30].

3. Design and Methodology

It explores various approaches crucial for the methodology of selecting and designing the suitable surfactant for the proposed well-unloading experiment using foaming. This chapter outlines the specific workflow and process employed for conducting the surfactant performance experiment and methodology.

3.1 Project Design

Designing a project involves the systematic planning and organization of various elements to achieve specific goals within defined constraints. Below is a generic experimental setup for describing a project design:

3.1.1 Experimental Samples

The project involves the examination of water samples and surfactants with the aim of formulating the optimal foaming solution, demonstrating favorable outcomes as a foaming agent. Additionally, alternative liquid samples were employed to develop carrier fluids for these surfactants.

3.1.1.1 Sample Water

The water sample collected directly from a well that is filled with liquid is used as the base fluid to study the foaming characteristics and properties of surfactants. Table 11 shows some specific properties of produced water which are being testing in the laboratory.

Table 1 Specific Properties of Field-Produced Water at Room Temperature

S#	PROPERTY	VALUE
1	Density (ppg)	8.3
2	Specific Gravity	1
3	TDS (ppm)	2270
4	pH	3.9

3.1.1.2 Surfactants

The term "surfactant" is an abbreviation for "surface-active agent." These chemical compounds possess characteristics that enable them to alter the behavior of fluids at the boundary between liquid and gas phases. They aid in the breakdown of emulsions formed between oil and water, reduce surface tension, modify wetting properties, and facilitate the creation of foam. These agents generate foam to decrease the density of the liquid phase making it easier to extract liquids from gas wells and prevent accumulation. This study investigates the efficacy of two surfactants; Sodium Dodecyl Benzene Sulphonate (SDBS) which is shows in **Fig. 3** and Sodium Dodecyl Sulfate (SDS) which is shown in **Fig. 4**. By comparing their performance our aim is to determine which surfactant exhibits properties in terms of efficiency. Through this analysis we seek to identify the option for practical applications.

Table **2** describes major properties of different surfactants used in this research for experimental investigation of liquid unloading.

Table 2 Description of different surfactants

S. No.	NAME OF SURFACTANT	FORMULA	NATURE OF SURFACTANT	PROPERTIES			
				FORM	COLOR	MELTING POINT	DENSITY
1.	Sodium Dodecyl Benzene Sulphonate (SDBS)	C_{18}-H_{29}-NaO_3-S	Anionic	Powder	Yellow	>300 °C	1.02 g/cm3
2.	Sodium Dodecyl Sulfate(SDS)	$CH_3(OH_2)_{11}$-OSO_3-Na	Anionic	Powder	White	206 °C (403 °F;479 K)	1.01 g/cm^3

Fig. 3 Sodium Dodecyl Benzene Sulphonate (SDBS)

Fig. 4 Sodium Dodecyl Sulfate (SDS)

3.1.1.3 Liquid Samples for Carrier Fluid

The carrier fluid is an essential medium to transport the surfactant to the designated well location. The surfactant is combined with the carrier fluid, and this solution is injected into the well to react with the loaded liquid and create foam. In this investigation, two carrier fluids are utilized: Hard water with a high concentration of minerals, and Gas Well Condensate, having a high degree of API.

3.1.1.3.1 Hard Water

It is a type of water that has a high content of minerals such as salts of calcium and magnesium, principally bicarbonates, chlorides, and sulfates. The nature of hard water can affect how well surfactants interact and disperse in it. Different properties of hard water and its calculated values are show in Table 3.

Table 3 Specific Properties of Hard Water at Room Temperature

S#	PROPERTY	VALUE
1	Density (ppg)	8.34
2	Specific Gravity	1.01
3	TDS (ppm)	4220
4	pH	8.4

Fig 5 Sample of Hard Water

3.1.1.3.2 Gas Well Condensate-High Api

This high American Petroleum Institute (API) gravity gas well condensate refers to the lighter and more volatile and flammable mixture of hydrocarbons, which could have an impact on how well surfactants disperse and perform as foaming agents.

Table 4 Specific Properties of High API Condensate at Room Temperature

S. No.	PROPERTY	VALUE
1	Density (ppg)	6.15
2	Specific Gravity	0.7328
3	API Gravity	62.84

Fig. 6 Sample of Gas Well Condensate-High API

3.1.2 Experimental Equipment

Various equipment configurations enable the exploration of the mechanisms underlying the interaction between surfactants, field-produced water, and carrier fluids in foam formation.

3.1.2.1 Digital pH Meter

A Total Dissolved Solids (TDS) meter is used to determine the amount of dissolved solids in a liquid. This TDS meter works by measuring conductivity. When there are dissolved solids like minerals and salts in a solution it increases the conductivity. The TDS meter utilizes this change in conductivity to estimate the concentration of dissolved solids.

The main purpose of using a TDS meter is to analyze the content of dissolved substances in the field-produced water, hard water samples, and solutions formed by mixing surfactants with them. It provides a measurement of the dissolved substances found in water sources. Helps observe how surfactants affect the levels of these substances known as TDS levels.

Fig. 7 Digital pH Meter

3.1.2.2 TDS Meter

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Fig. 8 Digital LCD TDS Tester for Measuring TDS

3.1.2.3 Mud Balance

The mud balance is a tool for measuring changes in density that occur due to interactions with surfactants. It provides data that helps us understand how various fluids react when surfactants are added and how these interactions play a role in the creation of foam. In general, foam tends to have a density compared to fluid.

Fig. 9 Mud Balance

3.1.2.4 Mud Mixer

A mud mixer is a machine that is designed to combine and blend fluids. It uses agitation to ensure that the surfactant and other fluids are thoroughly mixed, in a manner. This is important for studying and measuring how the surfactant impacts factors such as foam formation changes in density and other properties that are relevant to our understanding.

Fig. 10 Mud Mixer

3.1.2.5 Viscometer

An 8 Speed Rotational Viscometer is a device that is used to determine the thickness or stickiness of fluids. This instrument consists of a spinning spindle or rotor that is submerged in the fluid being analyzed. As the spindle rotates, it encounters resistance from the thickness of the fluid. By measuring the amount of force needed to overcome this resistance, we can calculate the viscosity of the fluid. Viscosity refers to how resistant a fluid is to flow and is an important characteristic for understanding how fluids behave, particularly when they are mixed with other substances, such as surfactants. The viscometer typically offers speeds allowing us to assess how viscosity changes under different levels of shear stress.

Fig. 11 8-Speed Rotational Viscometer

3.1.2.6 Magnetic Stirrer

It is a device that uses a rotating magnetic field for mixing liquids by placing a magnetic-coated stir bar within the liquid to generate rotatory fluid motion. It also helps to achieve the desired temperature of the solution. The magnetic stirrer would be used to blend the surfactant with different fluids, ensuring consistent and uniform distribution. It helps in isolating the impact of the surfactant to observe how it affects foam formation, density changes, and other properties consistently across fluid types.

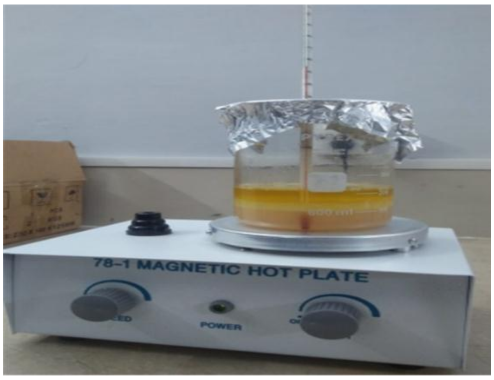

Figure 12 Magnetic Stirrer

3.1.2.7 Drying Oven

The drying oven shows up as an important tool. It makes it easier to carefully heat liquid samples and surfactant amalgamations. This method of controlled heating allows for a systematic investigation of the foaming properties over various temperature gradients. The exact temperature control of the oven forms the basis of this project because it makes it possible to carry out a thorough investigation.

Fig. 13 Drying Oven

3.2 Experimental Work

The core methodology of this project revolves around the experimental work conducted to achieve its objectives. The following section provides a comprehensive explanation of the experimental work undertaken in this study.

3.2.1 Analyzing Foaming Behavior of Surfactants in Field-Produced Water

After collecting samples of surfactants and field-produced water and assessing their respective specific properties at room temperature, each surfactant is separately blended with a water sample. Investigating foaming properties at various temperatures is the goal of this procedure. The following list of methodological steps is in order:

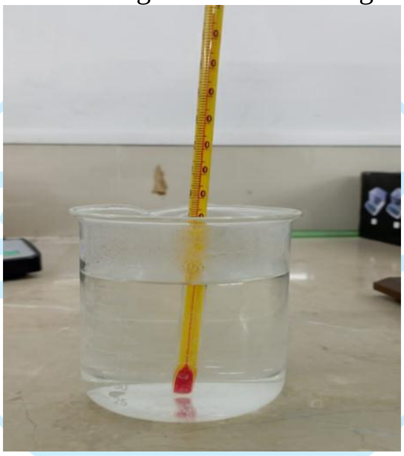

Fig. 14 Heated Sample

3.2.1.1 Mixing Surfactants

The chosen surfactants, SDBS and SDS, are carefully added to each field-produced water sample at known concentrations. Precise mixing for each surfactant is ensured by using a mud mixer. A magnetic stirrer can also be used, but it has a lower RPM and might not yield optimal foaming results.

Fig. 15 Mixing Surfactants using Mud Mixer

3.2.1.2 Foaming Assessment

- Observe and record the formation of the foam, its stability, and any visual differences for each mixture.

3.2.1.3 Temperature-Based Testing

The resulting foaming solutions of water and surfactants are carefully put through a series of evaluations at three different temperatures (e.g., 60°C, 70°C, and 80°C):

- Examine the total dissolved solids (TDS) and pH of the foaming solutions.
- Use a mud balance to measure density and specific gravity.
- Utilize a viscometer to gauge the viscosity of the foaming solution.

3.2.1.4 FOAM STABILITY

The final foam volume is carefully measured and recorded after foam stability has been established. This data point offers vital information about the duration and extent of foaming stability.

Fig. 16 Foam Stability

3.2.1.5 Comparative Analysis

Compare the outcomes of different surfactants and how effectively they create foam in the field-produced water.

3.2.3 Investigating Foaming Behavior of Surfactants in Different Carrier Fluids

After obtaining samples of surfactants and carrier fluids, specifically hard water and high API gas well condensate, and conducting measurements of their specific properties at room temperature, the next steps involve mixing each surfactant separately with the respective carrier fluid. This process intends to evaluate foaming behavior. The steps in the methodology are as follows:

3.2.3.1 Surfactant Mixing

Distinct concentrations of the surfactants (SDBS and SDS) are carefully introduced into the carrier fluids (hard water and gas well condensate) individually. A mud mixer is used in this combining procedure to ensure a thorough fusing of the components. A magnetic stirrer that runs at a lower RPM than the mud mixer can also be used to enable simultaneous heating and blending of the solution.

3.2.3.2 Stability Measuremen

The final foam and remaining liquid volume is measured after reaching stability, giving information about the foam's perseverance through time.

3.2.3.3 Comparative Analysis

The effectiveness of various liquids as carrier fluids is examined by identifying which liquids generate foam and which do not. The fluid that doesn't promote foam formation is the greatest option for a carrier fluid that is effective.

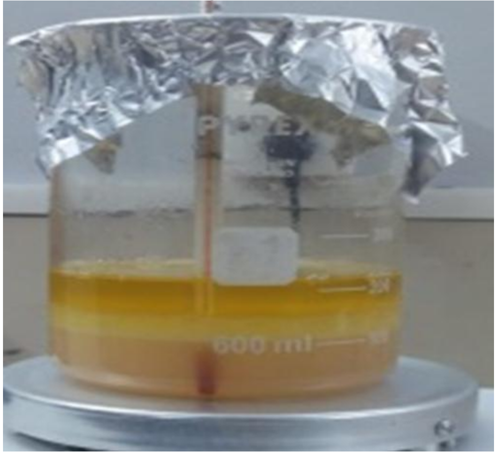

Fig. 17 Mixing of Surfactant and Carrier Fluid

4. Results and Discussion

The section will take a comparative look at how different surfactants function in the setting of liquid-loaded gas wells. To understand how surfactant applications' complex dynamics affect productivity and overall efficiency, the study investigates these dynamics. The collected data are then presented in detail, followed by a thorough analysis and explanation of the identified trends. With the help of this study, insightful comparisons between the surfactants' performances, highlighting each one's distinct advantages and disadvantages are made.

4.1 Results and Comparison

Experiments are performed to analyses the different aspects of surfactants and fluid. The behavior of surfactants and carrier fluid is investigated at different temperatures because both the chemical is bound to encounter high pressure and temperature while sending downward to unload well. The results calculated after the completion of this experimental work are:

4.1.1 Comparison of Surfactants

Table 5 Properties of Water Sample after mixing SDBS at various Temperatures

S. No.	Properties	Readings at Room temperature	Readings at 60 °C	Readings at 70 °C	Readings at 80 °C
1.	TDS (ppm)	6426	4632	5052	3758
2.	pH	8.6	8.7	8.7	8.7
3.	Specific Gravity	0.97	0.9	0.9	0.98
4.	Density (ppg)	8.1	8.3	8.3	8.25
5.	Viscosity	0.5	0.5	0.5	0.2

Table 6 Properties of Water Sample after mixing SDS at various Temperatures

S.No.	Properties	Readings at Room temperature	Readings at 60 °C	Readings at 70 °C	Readings at 80 °C
1.	TDS (ppm)	2954	2983	2940	2915
2.	pH	5	5	5.1	5.1
3.	Specific Gravity	0.99	1.01	1.0	0.98
4.	Density (ppg)	8.2	8.32	8.3	8.25
5.	Viscosity	0.5	0.3	0.3	0.1

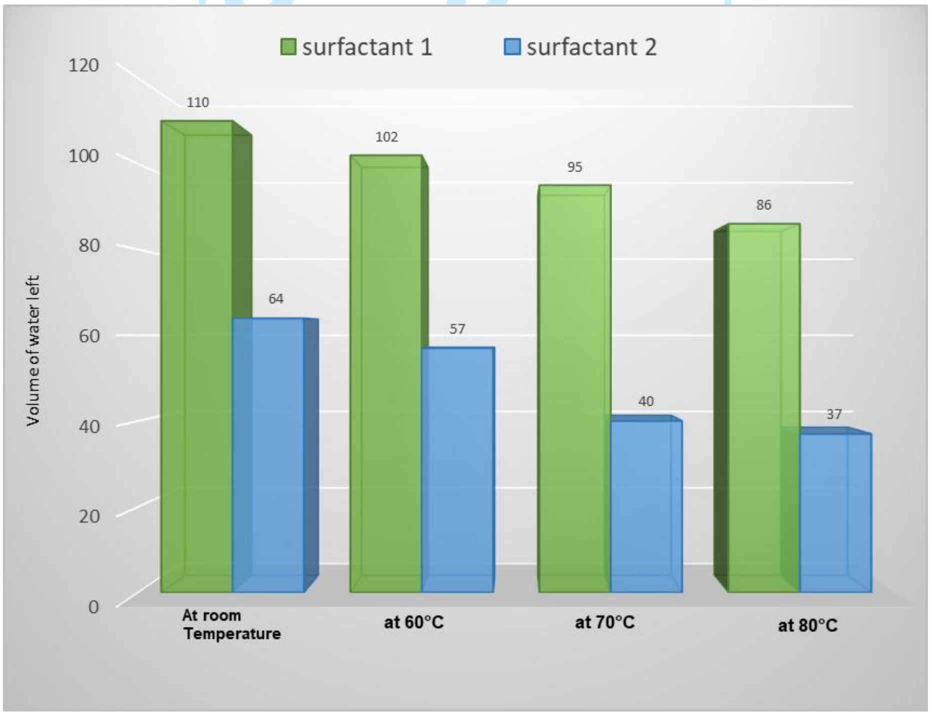

Fig. 18 Comparison of liquid left after foam formation using surfactants in an equal amount of water

4.1.1.1 Technical Discussions

4.1.1.1.1 Surfactant 1: Foam Generation

When Surfactant 1 was added to the field water sample, the liquid phase's conversion to foam was less effective. This result raises the possibility that Surfactant 1's interfacial qualities may not be as helpful in stabilizing the gas-liquid interfaces required for foam generation. Surfactant 1's molecular configuration might cause weaker contacts between gas bubbles and the liquid phase, which would reduce the stability of the foam.

4.1.1.1.2 Surfactant 2: Enhanced Foam Generation

Surfactant 2 on the other hand was more effective in turning field water into foam. Due to Surfactant 2's ability to lower interfacial tension, stable gas-liquid interfaces are more likely to form due to its enhanced propensity for foam production. Surfactant 2's molecular shape probably makes it easier for surfactant molecules to bind to the gas-liquid interface, increasing foam stability and producing more persistent foam forms.

4.1.1.1.3 Factors Influencing Foam Conversion

Due to their different surface-active qualities, molecular configurations, and adsorption kinetics, surfactant 1 and surfactant 2 were found to differ from one another. The degree to which surfactant molecules attach at the gas-liquid interface and stabilize the ensuing foam formation depends on these variables. The effectiveness of foam conversion depends heavily on the balance between hydrophilic and hydrophobic qualities.

4.1.2 Carrier Fluid Quantification

Table 7 Properties of carrier fluids

S. No	Carrier Fluid	Surfactant	Initial Volume of Liquid (ml)	Amount of Surfactant (gm)	Temperature (°C)	Mixing time (min)	Volume of liquid left after mixing (ml)
1.	Hard Water	SDS	100	0.5	29	10	65
2.	High API Condensate	SDS	100	0.5	29	10	100

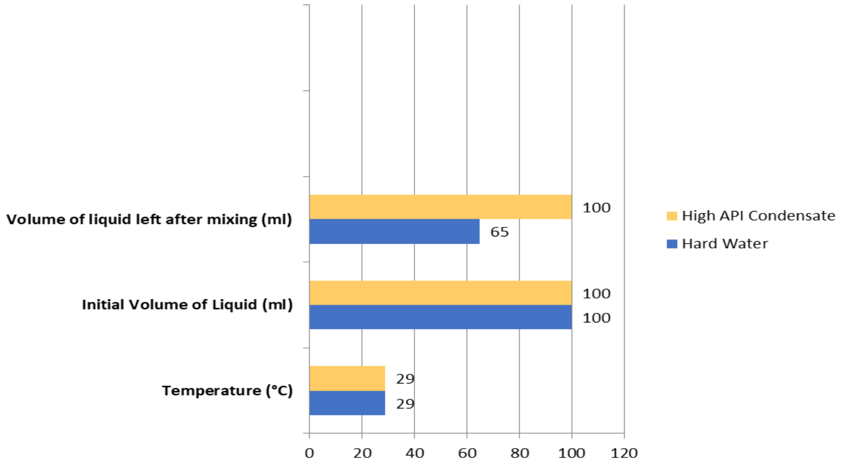

Fig. 19 Comparison of foaming behavior of Liquids after mixing Surfactant (SDS)

4.1.2.1 Technical Analysis of Carrier Fluid Properties and Behavior

Due to its propensity to easily turn into foam when surfactants are added, the hard water utilized as a sample is not a suitable choice for use as a carrier fluid in liquid-loaded gas wells. Due to the possibility of foam-related operational difficulties and decreased gas well efficiency, the hardness of this water and the specific molecular characteristics that cause it to foam make it unsuitable for use as a carrier fluid.

A significant option for liquid-loaded gas well operations is condensation with minor foam production characteristics when exposed to surfactants. Due to a distinct molecular structure that prevents foam stabilization even in the presence of surfactants, this condensate variety keeps its liquid state. This characteristic makes it an appropriate carrier fluid since it prevents foam-induced constraints, ensuring efficient gas movement. Its low foaming propensity is due to a surface-active behavior that interferes with the stabilization of the gas-liquid interface. The surface tension-lowering properties of the non-foaming condensate make it compatible with other well fluids and allow for easy incorporation into liquid-loaded gas well production plans.

5. Conclusion and Future Recommendations

5.1 Conclusion

In conclusion, the addition of surfactants to produced water exhibits minimal impact on its basic properties, including pH, conductivity, and salinity. This lack of interference is crucial as it ensures that downstream treatment processes for produced water remain unaffected. The comparison between Sodium Dodecyl Sulfate (SDS) and sodium dodecyl benzene sulphonate reveals that SDS generates more foam due to its lower critical micelle concentration (CMC), forming micelles more effectively and reducing water's surface tension. The resulting SDS foam maintains stability for a longer duration, attributed to the denser packing of micelles, enhancing resistance against foam collapse processes. Overall, SDS proves to be a favorable choice for generating stable foams in produced water due to its cost-effectiveness, ease of use, and low CMC. However, it's imperative to consider specific factors while employing SDS for foam generation in produced water.

The study's focus on comparing the interaction of Sodium Dodecyl Sulfate (SDS) with two fluids, hard water and condensate, yields significant insights. When introduced to hard water, SDS generates foam through interaction with the water's mineral content. Intriguingly, the absence of foam generation when SDS is introduced to an equal amount of condensate indicates condensate's potential as an efficient carrier fluid for SDS. This finding suggests the viability of using condensate in various applications requiring foam generation. Exploring condensate's role as a carrier fluid through tailored testing could lead to valuable advancements in industries where controlled foam generation is essential, thereby enhancing process efficiency and sustainability.

5.2 Future Recommendations

In the field of optimizing gas well operations, the exploration of alternative surfactants has promising potential to advance foaming and liquid removal techniques. For future research aiming to achieve precise or nearly accurate results in subsequent investigations of this experiment, the following recommendations can be considered:

- Studying the efficacy of different surfactants may provide insight into their potential to improve stability, durability, and carry the liquid of the foam in the gas wells. By evaluating the physicochemical properties and interfacial behavior of the novel surfactants, researchers were able to identify compounds with superior foaming ability, which can outperform other surfactants' usual choice.
- In addition, such investigations may shed light on the compatibility of these surfactants with different well conditions and broader environmental impacts. Ultimately, this line of investigation has the potential to revolutionize gas well operations, leading to more efficient and effective methods for minimizing fluid buildup, improving gas flow, and ensuring durable yields sustainable in the energy sector.
- Expanding on this experiment, a potential direction involves improving gas well performance through advanced simulation techniques for surfactant injection and liquid removal. By creating detailed reservoir and well models, this method aims to find efficient surfactant dispersion strategies and enhance airflow. These simulations also focus on optimizing liquid removal to reduce production downtime. By integrating real-time data and collaborating with experts, these models can be refined, leading to benefits like increased gas production, less downtime, and improved sustainability in well operations. This approach holds the potential to significantly enhance gas production processes.

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