Gas Well Deliquification Using Surfactant, Sodium Lauryl Sulphate

by

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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

September 2014

CERTIFICATE OF ORIGINALITY

This certificate of originality is used to certify that I am fully responsible for the work submitted in this project, that the original work is mine except as specified in the references and acknowledgements, and that the original work contained herein have not been commenced or done by undetermined sources and persons.

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MUHAMAD AZFAR BIN MAT JUSOH

ABSTRACT

Nowadays, as natural gas is being treated as one of the major energy sources worldwide, the producers has came out with various methods in order to get optimum natural gas production from all the reservoirs. It is normal that in a gas well, there will be water or hydrocarbon condensate produced along together with the gas. It is noticeable that once the gas wells become matured, the formation pressures will decrease by time and as a result, the velocities or gas rate will decrease. This situation will then gradually causes the liquids to accumulate in the well as the gas do not have sufficient energy to push the liquids out. In other word, gas rate cannot overcome the gas critical (minimum) flow rate. When this continues to happen, a problem arises which is the gas well will be loaded by the liquids. Numbers of techniques done by the operators to overcome the problem and they are divided mainly into two types which are mechanical and chemical methods. However, the mechanical types of treatments usually need high expenditure. Majority of operators found out that the gas well deliquification by chemical mean is cheaper. For the chemical methods, one of it is by injecting the foamers or surfactant into the well. By decreasing the surface tensions and density of the fluids, the chemicals will lower the gas critical (minimum) flow rate and help the liquids to be produced out together with the gas. So, this project is carried out to find the best recipe of surfactant that can be used in deliquification of the gas wells. The ability of one of the anionic surfactant, named Sodium Lauryl Sulphate makes this chemical to be the main content of the surfactant recipe used in this project. The additives for the recipe include Sodium Chloride and Calcium Chloride. The modified ASTM D-892 test is used as the test in this project to find that suitable recipe of surfactant which can be the solution for the problem raised. At the end of the project, the best recipe of the surfactant is proposed which can effectively deliquify the water loaded in the gas wells.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1   Background of Study

Nowadays, liquid loading is one of the common problems faced by mature gas wells (Passucci, Imbo, & Pelucchi, 2011). It is defined as the inability of the producing gas to remove out the produced fluid from the wellbore (Campbell, Ramachandran, & Bartrip, 2001). In most of gas wells globally, water or/ and condensate usually is/ are produced together with the gas. It is stated by Zhi-jian, Chunming, Wenkui, and Jun (2013) that problem arises in a period of time when the wells become mature that the formation pressures depleted, liquid tends to load in the wellbore as the gas unable to lift it together to the surface. The loaded liquid then gradually creates backpressure to the reservoir which resulting to reduction in the gas production rate. As this happen, it becomes harder for the gas to bring up the liquid together to the surface. After some time, the well might eventually killed by that liquid accumulation and affect the ultimate gas recovery of the gas reservoirs (Hearn, 2010).

Keeping this problem unsolved will surely give very big losses to oil and gas industry. To overcome this, a lot of methods have been tried. Those artificial lift to remove the liquid column in the wells or deliquification methods are basically divided in two types which are mechanical and chemical (Hearn, 2010). For this paper, only the deliquification of the gas well by chemical approach alone which is using foamers is discussed.

Foamers are the surfactant chemistries designed to modify the structures or physical properties of liquids loaded in the gas well for example surface tension and density (Jelinek & Schramm, 2005). By reducing the surface tension and density of the liquid, the gas critical (minimum) flow rate can be reduced. As it is reduced, the gas will have enough energy or flow rate to be produced and at the same time unload the

accumulated fluid in the production string (Passucci et al., 2011). This technique is/was being used at most of the gas wells those loaded by liquid as for its cheapest way to overcome the issue as shown by the Appendix 1. According to (Hearn, 2010), this chemical solution can be applied alone or can be synergized with other technique such as with intermittent production for a better unloading result.

1.2   Problem Statement

In mature gas wells, the decreasing of formation pressure lowers the gas flow rate. After period of time, the small portions of liquids which include water that is brought together with the gas are unable to be produced. The problem arose as this will cause those liquids including water to accumulate in the wells and lead to the death of the gas wells (Hearn, 2010).

Combination of techniques can be used to unload these liquids including the use of intermitters, installation of velocity strings and adding additional compressors capacity. But the problem is that, all of these mechanical type of treatments will cause high capital expenditure to the operators of the wells as reported by Passucci et al. (2011), Orta et al. (2007), Jelinek and Schramm (2005) and Poulose and Al Hamadi (2013).

1.3   Objectives

The project is carried out to find a suitable foamer or surfactant recipe so that the water loaded gas wells can be treated chemically which is described earlier by Francis-Lacroix and Seetaram (2014) as a very cost effective treatment. In this project, as described by Zdziennicka, Jańczuk, and Wójcik (2005) about its ability to reduce the high surface tension of the water, a surfactant named as Sodium Lauryl Sulphate (SLS) is chosen to become the main chemical for the project. For the additives, Sodium Chloride and Calcium Chloride are chosen by referring to the published paper written by Willis, Horsup, and Nguyen (2008). In order to find the best surfactant recipe that

can be cheaper alternative treatment of the liquid loaded gas wells, tests had been carried out in this project with the objectives to:

- Prove the ability of Sodium Lauryl Sulphate to deliquify loaded water from the gas wells.
- Test the effect of the concentration of Sodium Lauryl Sulphate on the percentage of water unloaded.
- Test the effect of additives including Sodium Chloride and Calcium Chloride.
- Test the ability of the produced surfactant to deliquify the condensate loaded gas wells.

1.4   Scope of Study

This paper discusses on the investigation to come out with new recipe of foamer or surfactant to be used to unload the water accumulated gas wells. It includes studies about the surfactants, surface tension and gas critical (minimum) velocity. This study also includes some laboratory activities in order to test the potential chemical whether it is suitable or not to unload the water from the gas wells. Several recipes of the surfactant are tested in order to figure out the best mixture of the chemicals. Field applications of the foamers are not done in this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Gas Well Deliquification

2.1.1 Gas Well Liquid Loading

Gas well liquid loading is defined as the accumulation of the fluids in the tubing (Steven Oude Heuvel, 2013). It is stated by Pakulski (2009) that this phenomenon will happen once the gas flow rate is not high enough to overcome the gravity.

According to Jelinek and Schramm (2005), gas wells those are having high gas flow rate and smaller liquid content will have a continuous gas phase. Small liquid droplets are carried and lifted by the gas to the surface by entraining in the gas phase in form of mist. Because of that, there might be formation of thin film of condensated liquid coating at the wall of the pipe. The liquid condensed as water or/ and hydrocarbons or brine. However, below point where gas flow rate equals the gravitational forces, the flow does not supply enough energy to lift up the liquids up to the surface and the point is called as "critical velocity" (Passucci et al., 2011). At that point below the critical velocity, the liquid films will follow the gravity to move down hole and accumulate there. This occurring will eventually stop the production of that well once fluids build up until the hydrostatic head equal to reservoir pressure.

This means the critical gas rate determines the minimum flow rate under which the liquids droplets lifting by the gas is not possible. The most common and used formula to explain the occurrence are Turner's and Coleman's equation (Li, Yang, & Zhang, 2007). These are the equation used to know the terminal velocity of the gas which is the maximum velocity that freely falling

liquid droplets can be together with the gas flow under the influence of the gravitational force.

$$V_t = 1.912 \frac{\sigma^{1/4}(\rho_L - \rho_G)^{1/4}}{\rho_G^{1/2}}$$ Equation 1: Turner terminal gas velocity

$$V_t = 1.593 \frac{\sigma^{1/4}(\rho_L - \rho_G)^{1/4}}{\rho_G^{1/2}}$$ Equation 2: Coleman terminal gas velocity

Where V_t is terminal velocity free falling drop (ft/s), σ is interfacial tension (dynes/cm), ρ_L is liquid phase density (lb/ft³) and ρ_G is gas phase density (lb/ft³).

Both these equations consider all drop shape, size and density, density and viscosity of production medium fluid (liquid plus gas phases), drag coefficient and surface tension between phases. According to Passucci et al. (2011), in 1969, Turner et al came out with Turner terminal gas velocity equation that takes account 20% adjustment to consider the liquid removal of all the droplets. Two years after that, Coleman et al. has removed that assumption so that the constant in the equations changed from 1.912 to 1.593. Both equations have their own usage. Turner's point of view usually used in the wells with wellhead pressure more than 500psi while Coleman's terminal gas velocity equation is used to the wells with less than 500psi wellhead pressure.

The gas velocity is can be consider as critical when it is just sufficient to hold the drops in suspension, in other words, drag force is equal to the gravitational force. This situation is equal to the free fall terminal velocity of the drop. To move the liquid upwards, the gas velocity should exceed this point and if failed, the liquids will start to accumulate in the well.

Then, there were complications which proved that liquid phase composition can significantly change the terminal velocity value. As a sample,

with variation of pressure, temperature and percentage of components, water and condensate are not changing in the same way. By that, Turner et al. again modify the previous models by simplifying them and considering only one liquid is present. The equation modified to be:

$$V_c = D \frac{(\rho_L - 0.0031p)^{1/4}}{(0.0031p)^{1/2}}$$ Equation 3: Simplified critical gas velocity

Where, V_c is gas critical (minimum) velocity (ft/s), ρ_L is liquid phase density (lb/ft^3) and p is pressure (psi). For this modified equation, there are few assumptions listed as below:

- The mono-liquid is either condensate or water
- Gas gravity is 0.6
- Gas temperature is 120°F
- Gas compressibility factor 0.9
- Surface tension 60 dynes/cm (water), 20 dynes/cm (condensate)
- Specific density 67 lb/ft^3 (water), 45 lb/ft^3 (condensate)

The following table shows the 'D' parameter values:

Table 1: 'D' Parameter Values

Method	For Water	For Condensate
Turner et al.	5.62	4.02
Coleman et al.	4.43	3.37

By that, the authors finally defined the equation for the critical (minimum) gas flow rate:

$$Q_c = \frac{3056 * p * V_c * A}{(T + 460) * z}$$ Equation 4: Critical gas flow rate

Where, Q_c is critical gas flow rate (Mft^3/day, p is pressure (psi), V_c is critical (minimum) gas velocity (ft/s), A is cross sectional area of flow (ft^2), T is temperature (°F), and z is gas compressibility factor.

As the production of water is increased (in case of water loaded gas wells) for example by the aquifer, the flow regimes will change to slug annular transition followed by a slug flow (Steven Oude Heuvel, 2013). The flow might be changing until the bubbly flow regimes or may be leave the liquid alone in single phase.
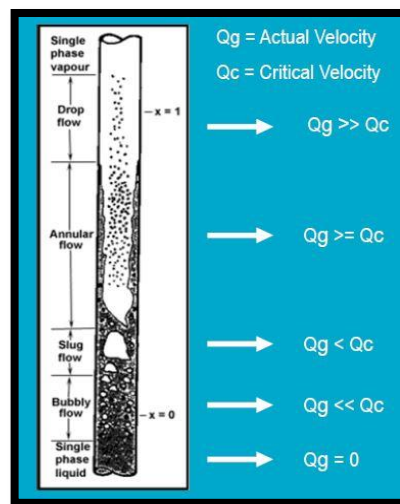
Figure 1: Flow Regimes

To compare, when the actual rate is greater than the critical rate, all fluids shall move out of the well along the annular film or in entrained droplets. At that time, the well is not considered to be "loading". On the other hand, when the actual rate is lesser than critical rate, most of the fluids are not pushed out of the well and the well is considered to be "loading". The liquids accumulation in the well bore will create back pressure that will further reduce the gas flow rate. As the flow rates reduced, the fluid will accumulate more and the situation will continue to cascade.
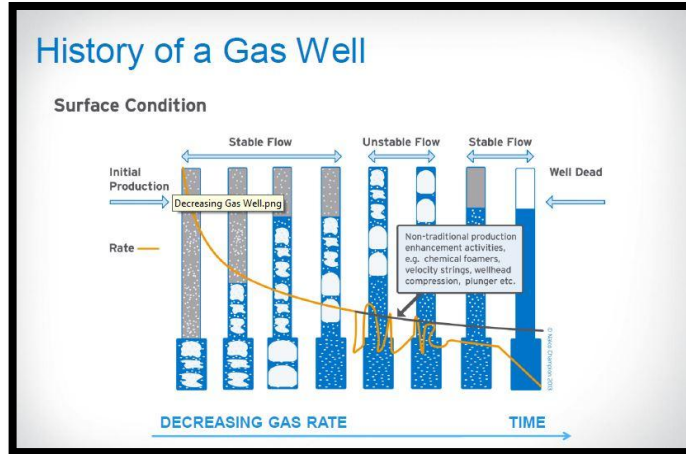
Figure 2: History of a gas well

Below are typical signs of liquid loading listed byHearn (2010):

- Tubing and casing pressure differential – In open ended completion wells, if liquid loading is happening, we will see decrease in tubing pressure and increase in casing pressure. The increase in casing pressure is caused by the increased in flowing bottom hole pressure (FBHP) as there is liquid accumulated in the tubing.
- Orifice pressure spikes- The increases and decreases in differential pressure across gas measurement device, orifice tells the unstable flow.
- Liquid slugging- Production of liquid reach to surface in form of slugs of fluid or heading instead of in steady continuous flow.
- Liquids production stops at all.
- Fluctuating gas production- With no changes to flow line pressure, daily gas production is dramatically different.
- Variation in Decline curve- Deviation from the decline curve will not follow an exponential type curve; it will be lower than predicted production rate.
- Pressure survey finds out heavier gradient in tubing pressure.

2.1.2 Definition of Gas Well Deliquification

Deliquification means the process of removal of liquids inside the production string (Passucci et al., 2011).So, term "gas well deliquification" is term of technologies used to expel or remove water or condensates accumulated in the producing gas well (Lea, Nickens, & Wells, 2011). The term can also be referred as gas well dewatering as commonly it is considered only for water accumulation.

2.1.3 Gas Well Deliquification Techniques

For the time being, there are two main gas well deliquification techniques which are mechanical and chemical techniques. In mechanical method, Simpson said that several artificial lift options can be used including rod pumps, submersible pumps, hydraulic pumps, plungers, velocity string and also compressors. Alternatively, the gas well deliquification also can be done chemically by using foamer or foaming agents. Those available technologies have different capabilities in the job of deliquification. These techniques listed also can be used in combination in order to have a better result. But, there also differences in term of cost and time of installation as well. All constraints should be considered in choosing right method so that expected production budget can be achieved.

2.2   Gas Well Deliquification using Foamer

Based on KAWALE, van NIMWEGEN, PORTELA, and Henkes (2012), injection of foamers to solve the liquid loading problem is the most popular and easiest method. Foamers used to create foam which able to remove the liquid at a lower gas velocity. The foamer is chosen based on experience. In other words, different well will

use different foamer to unload the liquid. There is no single theory that can predict whether the foam will work in a given well. In short, for every single model, it is essential that the foam is characterized.

2.2.1 Surface Tension

Surface tension is a function of diffusion rate of surfactant(Campbell et al., 2001). Defay, Bellemans, and Prigogine (1966) described that, surface tension is a phenomenon where the surface of liquid that in contact with the gas, acts like a thin elastic sheet. Interface tension is the surface between two liquids for example water and oil. This surface tension is measured usually in the units of dyne/cm. Numbers of intermolecular forces including Van der Waals forces cause this surface tension to exist. These forces draw the liquid particles together and along the surface of the liquids, the forces cause the liquid particles to be pulled towards the rest of the fluid. The higher the surface tension the higher forces needed by other particles to meet with the respective liquids.

2.2.2 Surface Active Agents (Surfactant)

The responsible part of a foamer (soap) for foaming is known as surfactant (Merianos, 2001). It is a molecule that contains two groups which are hydrophobic 'tail' and hydrophilic 'head'. Water soluble head group consist of functional groups which are readily dissolve in water for example amines (NH_2^+) and hydroxyl (OH). In contrast, tail group cannot dissolve in water. For example hydrocarbon or fluoro hydrocarbon chains of either aliphatic or aromatic series.
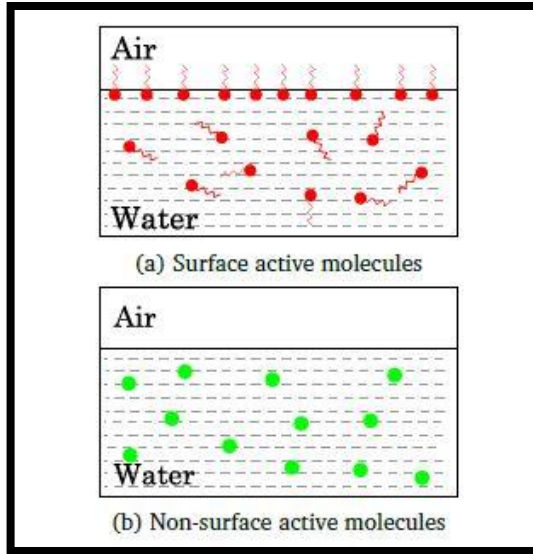
Figure 3: Partition of surface active molecules at water-air interface

From the Figure 3 above, we can see that the presence of hydrophobic and hydrophilic group in (a) causes the surfactant to preferentially adsorb at water-gas interface. The tails of surfactant are having lower surface tension σ (mN/m), than water and as a result of that, surface tension of water- gas is lowered. The reduction of the surface tension is depending on the type and number of molecules adsorbed at the interface. This means, the reduction is a function of surfactant bulk concentration.
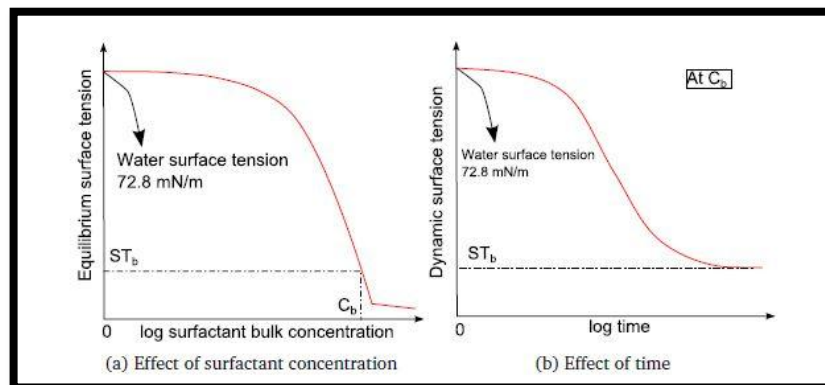
Figure 4: Equilibrium and dynamics surface tension of aqueous surfactant solutions

In Figure 4 (a), it shows that the surface tension of aqueous surfactant is affected by the bulk concentration of surfactants. Reduction in surface tension is a dynamic process (KAWALE et al., 2012). Like in Figure 4 (b), when fresh interface in created at t = 0, the interface consist only of water molecules and σ = $\sigma_{pure\ solvent}$. The surface tension is reducing in time surfactant molecules get adsorbed on the surface. Different surfactant may take different time to reach equilibrium and it varies from milliseconds to even days.

2.2.3 Classification of Surfactants

There are four main classes of surfactants which are nonionic, anionic, cationic and amphoteric. These four classes of surfactant are same in term of their hydrophobic part which consists of uncharged carbohydrate group that can be straight, cyclic, branch or aromatic. They only differed by the charge of their hydrophilic type. Below are brief explanations of each of the surfactant classes which are explained in term of gas well deliquification (Andalu, 2013):

a. Nonionic surfactants: Non- charged hydrophilic part. These types of surfactants do not ionize in aqueous solution. This is due to their hydrophilic group is of a non- dissociable type such as alcohol, ester, ether phenol or amide (Salager, 2002).The properties in terms of deliquification are:
- Low to medium foaming performance
- At higher temperatures (cloud point), solubility is reduced
- At higher salt content, solubility is reduced
- May act as emulsifier which reduces water quality
- Often applied in foam sticks
- Applied as co- surfactant in formulations
- Generally, it is environmentally acceptable

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b. Anionic Surfactants: Negatively charged hydrophilic part. Described as excellent water foamers byWillis et al. (2008), these types of surfactants are usually generated from nonionic type products those undergone a sulfation process. The properties in terms of deliquification are:

- High foaming performance
- At high salt contents, the foaming performances reduced
- Generally not stable at high temperature except sulfonates
- May act as emulsifier which reduces water quality
- Most of the time applied in high water cut and low temperature wells
- Generally toxic to fish especially the long hydrophobic chain versions

c. Cationic Surfactants: Positively charged hydrophilic part(Lu, 1988). Example of these types of surfactants is quaternary amines. The properties of these types of surfactants in relation to the deliquification are:

- Moderate foaming performance
- Stable in high temperature
- Can be used as corrosion inhibitor
- Perform better in brine than in fresh water
- These low molecular weight chemicals are good to foam mixtures of oil and brine. Higher molecular chemicals of these types are better for the use with high oil weight percentage wellbore fluids.
- High molecular weight quats can be ineffective to be applied to brines.
- Toxic to organisms.

d. Amphoteric Surfactants: Most versatile type of foamers as they are having dual charge which make them exhibit cationic in acidic condition, anionic in basic condition and nonionic in neutral condition. In other words, their hydrophilic part is controlled by the pH value of the solution (Lomax,

1996). In term of deliquification, the properties of these surfactant are as follows:

- High foaming performance
- Good foaming performance at high salt content
- Good foaming at medium condensate content
- Excellent stability in any temperature
- Usually corrosive because of the chloride as by- product

2.2.4 Foams

Foam is used extensively in our daily life as fire fighting foam, shampoo lather and also washing up liquids. In oil and gas industry, foam is normally unwanted as existence of foam in separators can lead to inefficiency(Heuvel, Ubbels, & Dijk, 2010). However, there are some exceptions as foam can be used in gas well deliquification and also in foam drilling.
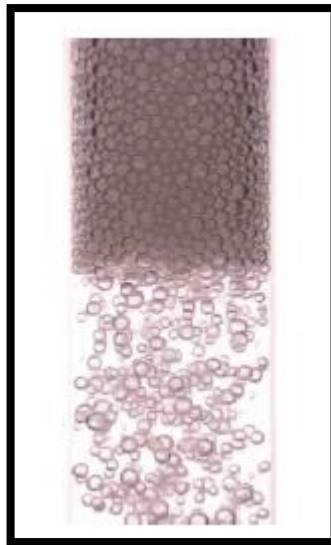
Figure 5: Foam produced by bubbling N2 through needles

Let's take a look at Figure 5 above. It is raising bubble of soap solution that produced foam. Once the bubbles reach at the surface, they stay with their form. Column of bubbles will form when more bubbles reaching the surface of

the solution. The structure of bubbles those stacked together is called foam. KAWALE et al. (2012) believed that a unit volume of this structure weighs about the same if compared to the amount of water it contains. With that, we can say that foam density, ρ_{foam} (g/cm^3), can be defined to quantify the water content of the foam. The higher the ρ_{foam} the larger the water content.

2.2.5 Foam Formation
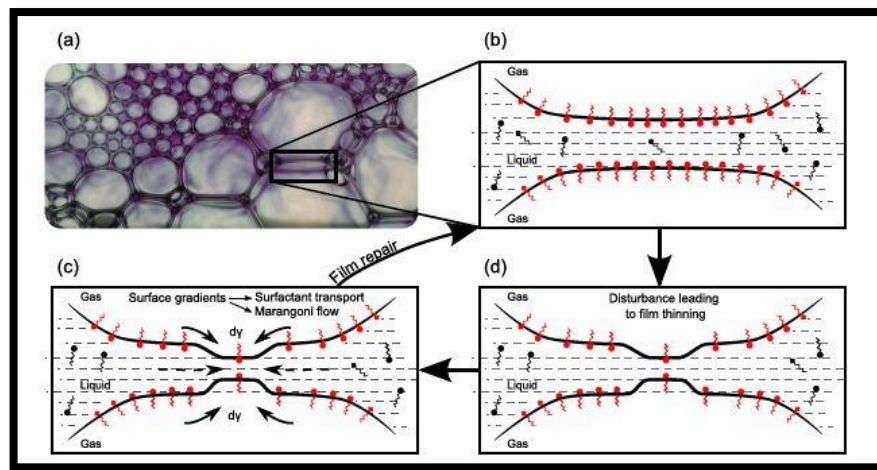
Figure 6: Foam structure and internal molecular film repair mechanism by Marangoni flows

Foam structure is not the same like the bubbles in pure water. Figure 6 (a) shows that, the foam bubbles do not coalesce or merge which is differs compared to bubbles in pure water. The foam bubbles form a 3D structure which having a certain mechanical strength. R. J. Pugh Pugh (1996) once said in his book of "Advances in Colloid and Interface Science" that all foams, in term of thermodynamics, are unstable because of the high interfacial free energy. However, the surfactants existence can stabilizes the foam film to make them metastable.

More than that, the time dependant adsorption of surfactants gives such effects to the foaming. The surface tension will increase as the interface is expanded and vice versa. This happens as the surfactant surface coverage changes and this phenomenon is known as Gibbs effect. When foam is disturbed, the foam film will suffer thinning just like from Figure 6 (b) to Figure 6 (d) as shown by the arrow in the diagram. This thinning will increase the local surface area and due to the Gibbs effect, the surface tension of thinned area will become higher. These surface tension gradients over the thinned region will lead to the flows from the low surface tension to higher surface tension. The flow is called as Marangoni flow (KAWALE et al., 2012). That flow will transport liquid mass to the thinned film and fix or stabilize it. Altogether, this occurrence is known as Gibbs- Marangoni effect and it is very important in assisting the repairing of thinned film.

Next is relaxation period. This is the period that following up after the Gibbs effect occurred. This is the event of transporting the surfactant due to the concentration gradient and it is done by the Marangoni flows. Adsorption of new surfactants from the bulk to the place where the surface tension is increased should be slow enough to ensure that Marangoni flow can repair the film. Surface tension gradients creation will be failed with high adsorption of the surfactant. Successful film repair need enough liquid mass transported to the affected region before the surface tension gradients disappear.

2.2.6 How Foamers can Deliquify a Gas Well?

There are many foams exist in the world and used in variety of daily activities. In oil and gas, the foamers are used in many purposes and one of it is to deliquify the loaded gas well. Most of the oil and gas operators' use the wet foams are used to remove the water accumulated in the gas well. But how does is it work? Basically, foamers are the chemical substances which contain surfactants. These surfactants act to reduce the relative density of the fluids due

to generation of foam and also the surface tension of the fluids in the wells (Stebe & Lin, 2001). These activities then consequently reduce gas critical (minimum) velocity needed in order to push up or produce the gas together with the loaded liquids. Let takes a look on the simplified critical gas velocity equation or equation 3 below:

$$V_c = D \frac{(\rho_L - 0.0031p)^{1/4}}{(0.0031p)^{1/2}}$$ Equation 3: Simplified critical gas velocity

Based on the above equation, gas critical velocity acts proportionally with the density of liquids. So by lowering density of liquids, the minimum velocity for the gas to be produced can be decreased. In other words, by applying the foamers, gas can be produced at lower velocity or rate together with the loaded liquids.

2.3   Sodium Lauryl Sulphate

Based on Karimi, Varaminian, Izadpanah, and Mohammadi (2014), this chemical of Sodium Lauryl Sulphate has the International Union of Pure and Applied Chemistry (IUPAC) name of Sodium Dodecyl Sulphate. It is categorized as an anionic class of surfactant. Sodium Lauryl Sulphate is stated to have the formula of $CH_3(CH_2)_{11}OSO_3Na$. The ability of this chemical to remove the oil stains and residues make it popular as a very highly effective surfactant and widely used in many cleaning and hygiene products such as engine degreasers, car wash soaps and floor cleaners.

Sodium Lauryl Sulphate is categorized as one of the most popular ingredient in the detergent or shampoo (Salager, 2002). In contact to oil and gas industry, Sodium Lauryl Sulphate has already been used for several purposes for example, it is used in purpose to increase the ethane hydrate formation rate (Karimi et al., 2014). It is hard to find the test where the Sodium Lauryl Sulphate is used as a surfactant in Enhanced Oil

Recovery (EOR). The commonly used surfactant includes betaines, alkyl ether sulphate and olefin sulfonate as stated by (Willis et al., 2008).

However, as the Sodium Lauryl Sulphate is categorized as an anionic surfactants, this mean that it has the ability to produce foam and of course can reduce the surface tension of the solution especially water (Salager, 2002). Andalu (2013) in her paper also stated that anionic type of surfactant is having an excellent foaming performance.

CHAPTER 3

METHODOLOGY

In this chapter, the planning of the flow of this project is generally explained in order to achieve the objective of the study.

3.1   Research Methodology and Project Activities

Define Problem Statement and Objectives

↓

Perform Literature Study and Preliminary Research

↓

Experimental Design

↓

Data Analysis

↓

Discussion and Recommendation

↓

Reporting and Documentation
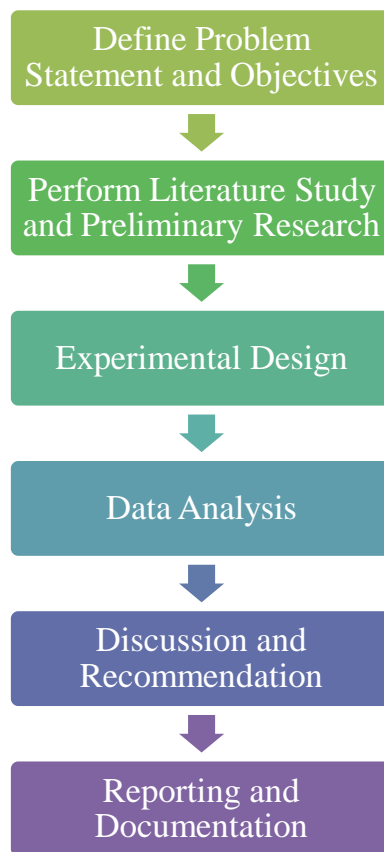
Figure 7: Research methodology and project activities flowchart

3.1.1 Perform Literature Study and Preliminary Research

In this part of the project, the purpose is to get more knowledge and stronger fundamental related to the Gas Well Deliquification using Foamer. Several theories need to be understood clearly in order to ensure that the project can be done smoothly and achieving the target. The studies include reviewing previous foamers used in the industry, identifying problems of previous foamers and also choosing potential foamers to be used in project. Numbers of sources including internet, books, past thesis are very useful in the way to find out the solution of the problems.

3.1.2 Experimental Design

The main experiment carried out in this project is the test of the performance of the foamers as the potential treatment to deliquify or unload the water accumulated in the gas wells. Among numbers of tests, ASTM D-892 (Dynamic Test) is chosen. This test can determine the rate of foam growth and collapse time (Nadkarni, 2007). This test uses the gas source to generate the foam and temperature can be varied in attempt to reproduce field conditions.
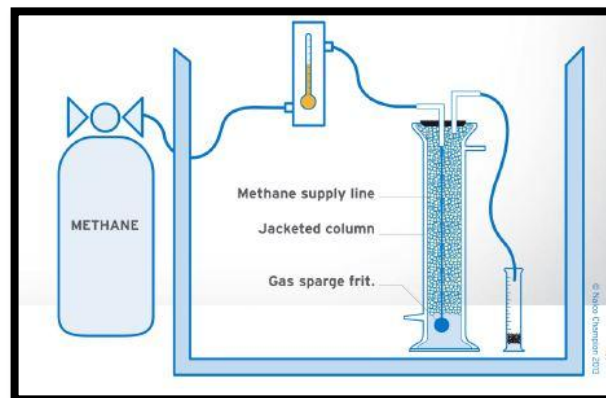
Figure 8: Apparatus set-up for ASTM D-892

However, this setup of the test is not available in Universiti Teknologi Petronas. So, the test setup is modified a little bit without changing the function of the experiment. As the gas flow meter is not available, the gas input is replaced with the small electric air pump with constant flow rate of 3L/min. The temperature of the setup is controlled by putting the water bath with constant temperature of 40°C. Originally, unloading efficiency can be determined by following equation:

$$\%Unloading = \frac{Unloaded\ Weight}{Initial\ Weight} * 100$$ Equation 5: Unloading efficiency

In order to suite with the test which is already modified, the following equation is used:

$$\%Unloading = \frac{Final\ volume\ of\ liquid\ sample}{Initial\ volume\ of\ liquid\ sample} * 100$$ Equation 6: Unloading efficiency (modified)

For this project, the test is done examine a total of 21 recipes of the surfactant. By keeping the gas rate and temperature parameter at constant values same as the test by that paper, performance of Sodium Lauryl Sulphate with 21 different recipes to deliquify water from the gas wells are observed. At the end of the tests, the best recipe is used to try whether it is suitable or not to deliquify the condensate loaded gas wells. So, there are three activities in this paper. First is to prepare the main solution of Sodium Lauryl Sulphate and then 21 recipes of surfactant (Anderson, 2012). Finally the performances of each recipe are tested. The procedures of the activities are as follows:

a. Preparing main solution of Sodium Lauryl Sulphate (200ppm, 400ppm and 600ppm):
    i.   0.2g of Sodium Lauryl Sulphate powder is weighted.
    ii. The weighted Sodium Lauryl Sulphate powder is added into 1000ml of distilled water.

iii. The mixture is stirred using the hot plate for 5 mins.

iv. Steps i to iii are repeated with 0.4g and 0.6 g weighted Sodium Lauryl Sulphate to produce 400ppm and 600ppm of Sodium Lauryl Sulphate solutions.

b. Prepairing 21 different recipes of surfactants (50ml for each recipe):

i. The recipes are prepared by mixing the respective ingredients with the specific amount for each recipe as shown below. The recipes are separated in three different tables according to tests which are test of the effect of concentration of Sodium Lauryl Sulphate, test of the effect of concentration of Sodium Sulphate and test of the effect of presence of Calcium Chloride respectively.

Table 2: Recipes of Surfactants (for test of the effect of concentration of Sodium Lauryl Sulphate)

No	Recipes	Ingredients
1	200ppm Sodium Lauryl Sulphate	50 ml of 200ppm Sodium Lauryl Sulphate alone
2	400ppm Sodium Lauryl Sulphate	50 ml of 400ppm Sodium Lauryl Sulphate alone
3	600ppm Sodium Lauryl Sulphate	50 ml of 600ppm Sodium Lauryl Sulphate alone

Table 3: Recipes of Surfactants (for test of the effect of concentration of Sodium Chloride)

No	Recipes	Ingredients
1	200ppm Sodium Lauryl Sulphate + 10% NaCl	45ml of 200ppm Sodium Lauryl Sulphate + 5g NaCl
2	200ppm Sodium Lauryl Sulphate + 20% NaCl	40ml of 200ppm Sodium Lauryl Sulphate + 10g NaCl
3	200ppm Sodium Lauryl Sulphate + 30% NaCl	35ml of 200ppm Sodium Lauryl Sulphate + 15g NaCl

4	400ppm Sodium Lauryl Sulphate + 10% NaCl	45ml of 400ppm Sodium Lauryl Sulphate + 5g NaCl
5	400ppm Sodium Lauryl Sulphate + 20% NaCl	40ml of 400ppm Sodium Lauryl Sulphate + 10g NaCl
6	400ppm Sodium Lauryl Sulphate + 30% NaCl	35ml of 400ppm Sodium Lauryl Sulphate + 15g NaCl
7	600ppm Sodium Lauryl Sulphate + 10% NaCl	45ml of 600ppm Sodium Lauryl Sulphate + 5g NaCl
8	600ppm Sodium Lauryl Sulphate + 20% NaCl	40ml of 600ppm Sodium Lauryl Sulphate + 10g NaCl
9	600ppm Sodium Lauryl Sulphate + 30% NaCl	35ml of 600ppm Sodium Lauryl Sulphate + 15g NaCl

Table 4: Recipes of Surfactants (for test of the effect of presence of Calcium Chloride)

No	Recipes	Ingredients
1	200ppm Sodium Lauryl Sulphate + 10% NaCl + 3% $CaCl_2$	43.5ml of 200ppm Sodium Lauryl Sulphate + 5g NaCl + 1.5g $CaCl_2$
2	200ppm Sodium Lauryl Sulphate + 20% NaCl + 3% $CaCl_2$	38.5ml of 200ppm Sodium Lauryl Sulphate + 10g NaCl + 1.5g $CaCl_2$
3	200ppm Sodium Lauryl Sulphate + 30% NaCl + 3% $CaCl_2$	33.5ml of 200ppm Sodium Lauryl Sulphate + 15g NaCl + 1.5g $CaCl_2$
4	400ppm Sodium Lauryl Sulphate + 10% NaCl + 3% $CaCl_2$	43.5ml of 400ppm Sodium Lauryl Sulphate + 5g NaCl + 1.5g $CaCl_2$
5	400ppm Sodium Lauryl Sulphate + 20% NaCl + 3% $CaCl_2$	38.5ml of 400ppm Sodium Lauryl Sulphate + 10g NaCl + 1.5g $CaCl_2$

6	400ppm Sodium Lauryl Sulphate + 30% NaCl + 3% CaCl$_2$	33.5ml of 400ppm Sodium Lauryl Sulphate + 15g NaCl + 1.5g CaCl$_2$
7	600ppm Sodium Lauryl Sulphate + 10% NaCl + 3% CaCl$_2$	43.5ml of 600ppm Sodium Lauryl Sulphate + 5g NaCl + 1.5g CaCl$_2$
8	600ppm Sodium Lauryl Sulphate + 20% NaCl + 3% CaCl$_2$	38.5ml of 600ppm Sodium Lauryl Sulphate + 10g NaCl + 1.5g CaCl$_2$
9	600ppm Sodium Lauryl Sulphate + 30% NaCl + 3% CaCl$_2$	33.5ml of 600ppm Sodium Lauryl Sulphate + 15g NaCl + 1.5g CaCl$_2$

ii. For all the recipes, distilled water is added so that the total volume is 50 ml. All recipes are heated and stirred using the hot plate until they are perfectly mixed.

c. ASTM D-892 test (modified)

i. The apparatus are set up as the figure below:
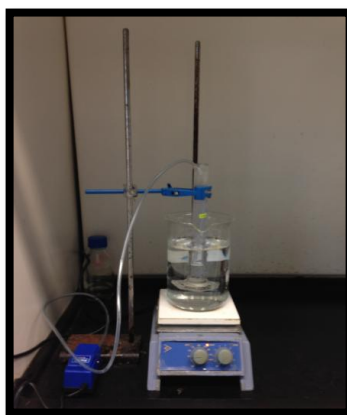
Figure 9: Set-up for modified ASTM-D892 test

ii. The water bath is heated using the hot plate and once the temperature reaches 40^oC, 20ml (initial volume of sample) of tap water (sample liquid) is poured into the 100ml measuring cylinder.

iii. Then, 20ml of a surfactant recipe is added into the same measuring cylinder.

iv. Next, the sample is sparged with 3L/min constant rate of gas using the electric air pump.

v. The setup is left for 5 minutes and observation is made. Data and observation are collected and recorded.

vi. The percentage of liquid unloaded is calculated using the Equation 6.

vii. Steps i to vi are repeated using the other 20 recipes of surfactant those are prepared earlier.

viii. Finally, the best recipes which having the highest unloading percentage is tested by replacing tap water with condensate as the sample of loaded liquid.

ix. All observations and data are collected and analyzed in the next chapter of Results and Discussions.

3.2 Project Key Milestones

3.2.1 Project Key Milestones (FYP 1)

3.2.2 Project Key Milestones (FYP 2)

| Completion of Data Preparationand Lab Experiments | Submission of Progress Report | Completion of Data Analysis and Ongoing Project Documentation | Pre- SEDEX | Submission of Project Dissertation | Viva and Hardbound Submission |
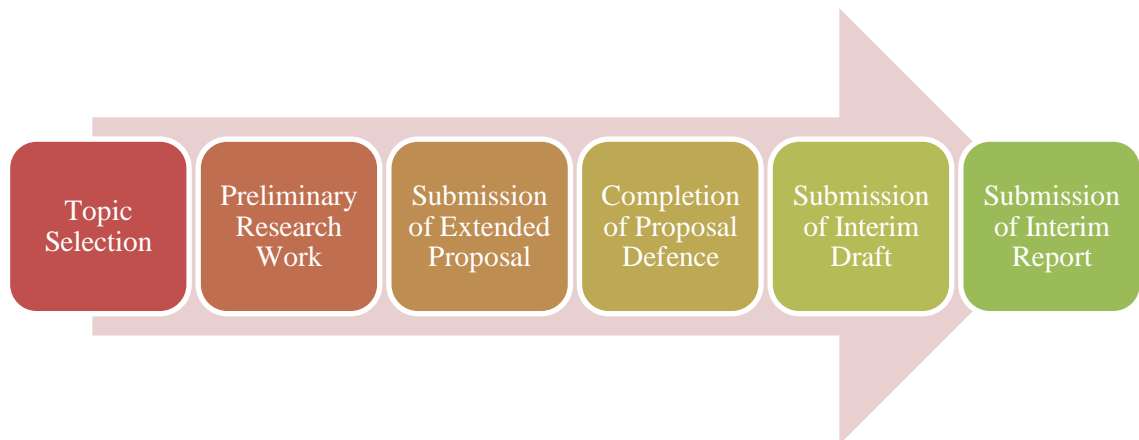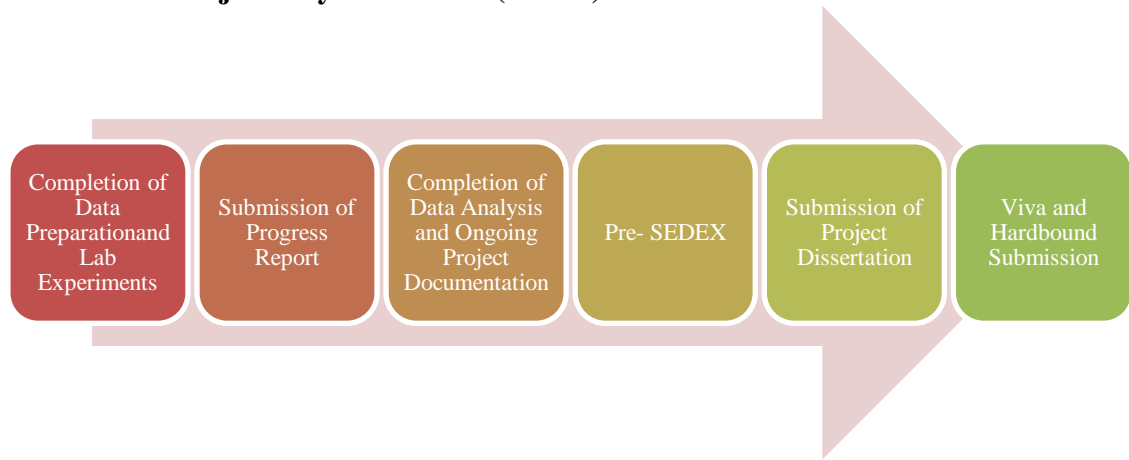
3.3 Project Gantt Chart

No.	Detail/Week	May-14														Break	Sep-14													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Break	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Project Technical																													
1	Topic Selection	■	■																											
2	Preliminary research and literature review			■	■	■	■	■																						
3	Proposal preparation				■	■	■	■	■																					
4	Submission of extended proposal and proposal defence								■																					
5	Improvement of the project proposal									■	■	■	■	■																
6	Submission of interim report													■	■															
7	Completion of data preparation																	■	■											
8	Laboratory experiments																			■	■	■	■							

No.	Task																												
9	Submission of progress report																							▓					
10	Data analysis and project documentation																						▓	▓	▓	▓			
11	Pre- SEDEX																									▓			
12	Submission of project dissertion																												▓

CHAPTER 4

RESULTS AND DISCUSSIONS

All the observations, data and findings of the project are gathered and discussed in this chapter of the report.

4.1   Results

All the data gained from this project are tabulated, graphed and reported below.

4.1.1 Table and Graph of Concentration of Sodium Lauryl Sulphate against Percentage of Water Unloaded

Table 5: Concentration of Sodium Lauryl Sulphate against percentage of water unloaded

Concentration of Sodium Lauryl Sulphate (ppm)	%Unloaded
200	20
400	30
600	75
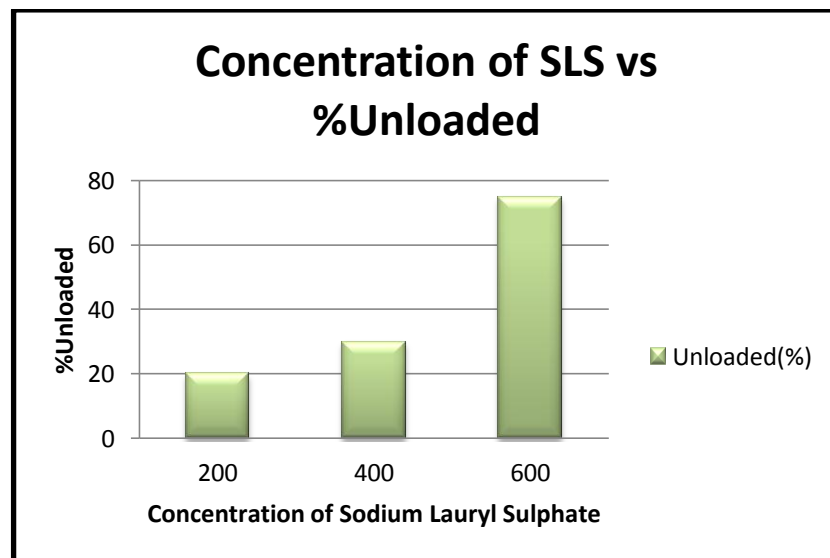
Figure 10: Concentration of Sodium Lauryl Sulphate against percentage of water unloaded

4.1.2 Table and Graph of Concentration of Sodium Chloride (NaCl) against Percentage of Water Unloaded

Table 6: Concentration of Sodium Chloride (NaCl) against percentage of water unloaded

Concentration of Sodium Chloride (%)	%Unloaded
10% + 200ppm SLS	40
20% + 200ppm SLS	15
30% + 200ppm SLS	0
10% + 400ppm SLS	50
20% + 400ppm SLS	15
30% + 400ppm SLS	0
10% + 600ppm SLS	80
20% + 600ppm SLS	70
30% + 600ppm SLS	15
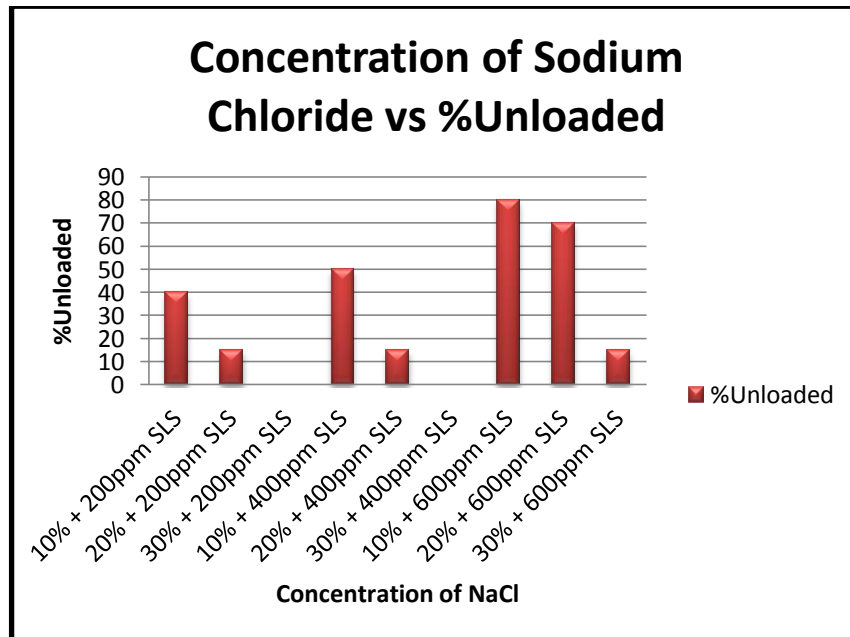
Figure 11: Concentration of Sodium Chloride (NaCl) against percentage of water unloaded

4.1.3 Effect of the Presence of the Calcium Chloride (CaCl₂)

Table 7: Table of the effect of the presence of Calcium Chloride

Recipes of Surfactant	%Unloaded (Without CaCl2)	%Unloaded (With 3% CaCl2)
200ppm SLS + 10% NaCl	35	40
200ppm SLS + 20% NaCl	15	20
200ppm SLS + 30% NaCl	0	0
400ppm SLS + 10% NaCl	50	55
400ppm SLS + 20% NaCl	15	50
400ppm SLS + 30% NaCl	0	0
600ppm SLS + 10% NaCl	80	85
600ppm SLS + 20% NaCl	70	70
600ppm SLS + 30% NaCl	15	15
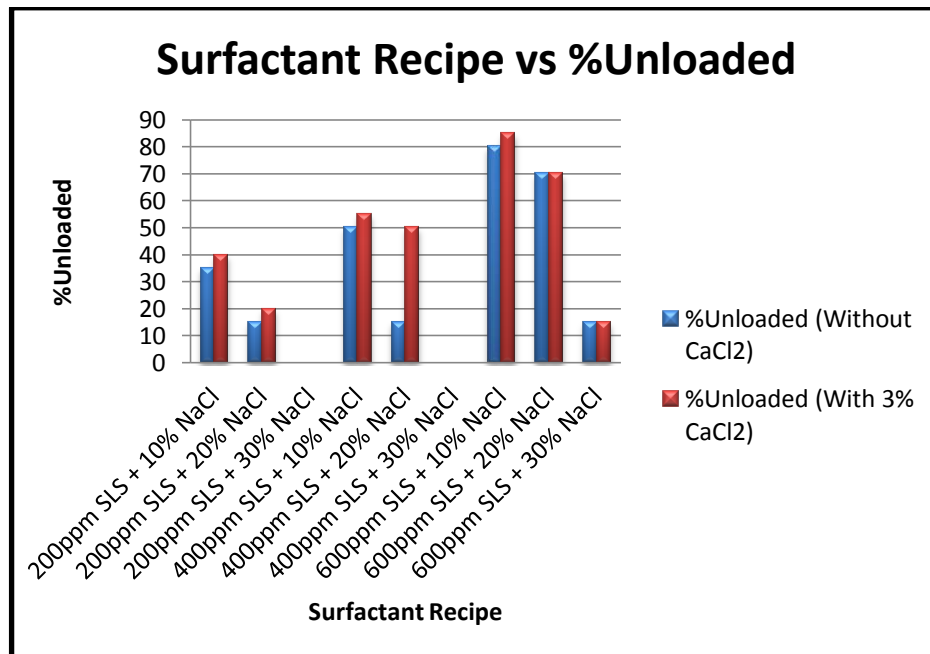
Figure 12: Graph of the effect of the presence of Calcium Chloride

4.1.4 Table and Graph of Overall Results

Table 8: Table of overall results

| Recipes of Surfactant	%Unloaded
200ppm SLS	20
200ppm SLS + 10% NaCl	35
200ppm SLS + 10% NaCl + 3% CaCl2	40
200ppm SLS + 20% NaCl	15
200ppm SLS + 20% NaCl + 3% CaCl2	20
200ppm SLS + 30% NaCl	0
200ppm SLS + 30% NaCl + 3% CaCl2	0
400ppm SLS	30
400ppm SLS + 10% NaCl	50
400ppm SLS + 10% NaCl + 3% CaCl2	55
400ppm SLS + 20% NaCl	15
400ppm SLS + 20% NaCl + 3% CaCl2	50
400ppm SLS + 30% NaCl	0
400ppm SLS + 30% NaCl + 3% CaCl2	0
600ppm SLS	75
600ppm SLS + 10% NaCl	80
600ppm SLS + 10% NaCl + 3% CaCl2	85
600ppm SLS + 20% NaCl	70
600ppm SLS + 20% NaCl + 3% CaCl2	70
600ppm SLS + 30% NaCl	15
600ppm SLS + 30% NaCl + 3% CaCl2	15
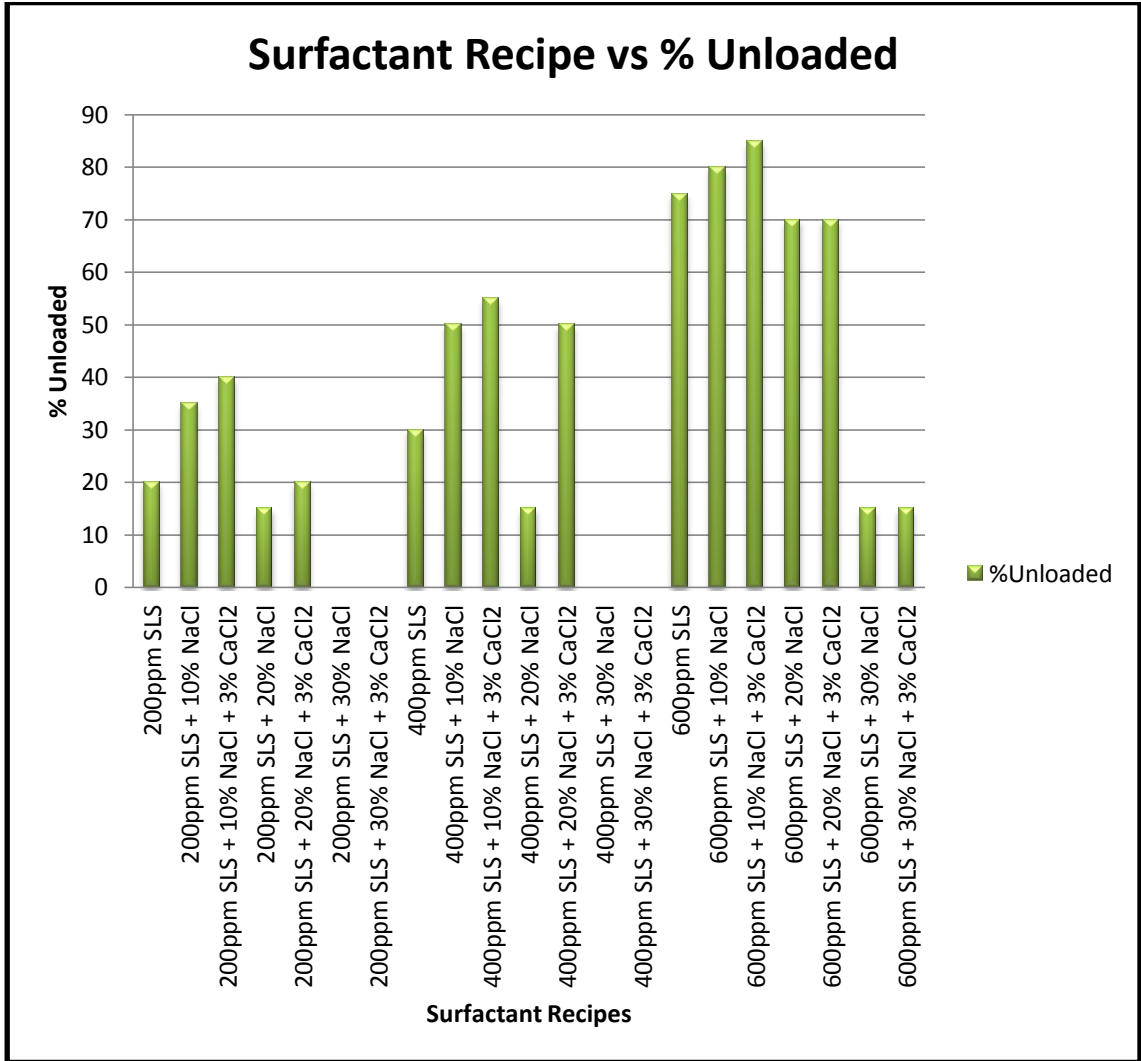
Figure 13: Graph of overall results

4.1.5 Table of the Type of Sample Liquids against Percentage of Liquid Unloaded

Table 9: Table of the type of sample liquids against percentage of liquid unloaded

Type of Sample Liquid	%Unloaded
Water	85
Condensate	0

4.2   Discussions

Based on the results gained, several analysis and discussions are done.

4.2.1 Effect of Concentration of Sodium Lauryl Sulphate on the Unloading Performance of the Surfactant

As shown in Table 3 and Figure 10 above, the increasing of the concentration of the Sodium Lauryl Sulphate in the surfactant recipe can increase the performance of the recipe. With 200ppm of the Sodium Lauryl Sulphate, an amount of 20% of sample water is unloaded. Increased to 400ppm and 600ppm of Sodium Lauryl Sulphate, the percentage of water that can be expelled out is increased to 30% and 75% respectively. Hence, based on the result, it is proven that the performance of the surfactant recipe is proportional to the concentration of the Sodium Lauryl Sulphate.

It is stated before by (Li et al. (2007)) that when the concentration in the surfactant (in this project is Sodium Lauryl Sulphate) is increased, the surface tension is decreased until the Critical Micelle Concentration is reached where increment of surfactant concentration will give no more reduction to the surface tension. Let's refer back to the Equation 3.

$$V_c = D\,\frac{(\rho_L - 0.0031p)^{1/4}}{(0.0031p)^{1/2}}\qquad \text{Equation 3: Simplified critical gas velocity}$$

In this equation, the minimum or critical gas velocity, which is the minimum gas velocity needed to push up the liquid droplet is directly proportional to the density of the liquid. So, by having higher concentration of surfactant, the surface tension or interfacial tension is decreased and density of liquid is also decreased. As a result, the minimum or critical gas velocity is lowered. So, this can help the liquid to be unloaded by low gas velocity or rate.

4.2.2 Effect of Concentration of Sodium Chloride (NaCl) on the Unloading Performance of the Surfactant

For this part, it can be referred to the Table 4 and Figure 11. It is shown that, the presence Sodium Chloride in the recipe gives the effect to the performance of the surfactant recipe. It is shown that, adding 10% of Sodium Chloride into the 400ppm Sodium Lauryls Sulphate manages to boost the performance of the surfactant recipe to unload water up to 40%, higher percentage of water unloaded compared to without adding the Sodium Chloride which is only 20%. However, adding 20% or more Sodium Chloride in the surfactant recipe can decrease its performance. For example in 400ppm Sodium Lauryls Sulphate, if 20% of Sodium Chloride is added, the percentage of water unloaded down to only 15% and when 30% of Sodium Chloride is added, there is no more water can be deliquified.

According to Sammalkorpi, Karttunen, and Haataja (2009), it was proven that the addition of any excess salt including the Sodium Chloride can lead to larger micellar aggregates that in absence. However, the amount of the salt addition into the surfactant recipe must be controlled as there is a critical amount in which, after that point, the addition of the salt will give no more improvement or unfortunately can reduce the surfactant performance.
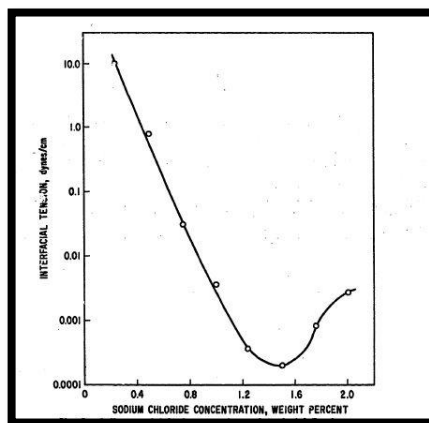

Figure 14: Plot of interfacial tension vs Sodium Chloride concentration

The plot by Wilson, Murphy, and Foster (1976) above shows that, the Sodium Chloride can be used in lowering the interfacial tension of fluids, and it is varied by its concentration. From the plot, it is exposed that increasing the Sodium Chloride concentration can lower the interfacial tension of fluid until 1.5%, in which after that point the effect is alternate. This can be the evidence on why the performance of the surfactant recipe depleted when more than 10% of Sodium Chloride is added in this project. It is explained by Romanowski (2011) that adding salt into the surfactant can turn it thicker which means better soap quality. However, adding too much of it can cause the soap becomes thinner. The salt works differently in different type of surfactants, concentration of surfactants, ratio of surfactants, temperature and also charge density. In order to determine the optimum value of the salt need to be added into the recipe, a salt curve can be created which is used to show the optimum value of salt needed. It is done by testing the performance of the surfactant in the presence of various percentages of salt added. Based on the results recorded from this project, it can be said that the optimum value of the Sodium Chloride needed is 10%. Adding the Sodium Chloride above this value can lower the performance of the surfactant.

4.2.3 Effect of the Presence of the Calcium Chloride ($CaCl_2$) in the Surfactant

This part can be referred to the results shown in Table 5 and Figure 12. In this project, the concentration of the Calcium Chloride added is kept constant which is 3%. With that concentration, it can be seen that the presence of the 3% of Calcium Chloride helps to increase the performance of the surfactant recipe. For example, without 3% Calcium Chloride, the mixture of 400ppm of Sodium lauryls Sulphate and 10% of Sodium Chloride can only unload 35% of water. With the addition of 3% of Calcium Chloride, the percentage of water unloaded is increased to 40%. However, this addition of the Calcium Chloride seemed useless to the mixture of the Sodium Lauryl Sulphate and Sodium Chloride that cannot deliquify the water at all.

It is known that the Calcium Chloride is also categorized as the salt, more specifically is inorganic salt. So, the addition of this salt also can be explained same as the discussions in 4.2.2. However, there is slightly difference existed between these two salts. It is their ionic valence. For Sodium Chloride, the Sodium ion is a monovalent ion while for Calcium Chloride, it is divalent ion. According to Sammalkorpi et al. (2009), these ionic valence gives effects on the formation of the micellar aggregates. In their projects, they find that the presence of divalent Ca^{2+} ions dominate ion condensation around the micelles, leading to more compact aggregates or thicker soap compared to monovalent Na^+. This is why the result shows that the addition of only 3% of the Calcium Chloride gave better performance increment compared to the Sodium Chloride.

4.2.4 The Best Recipe of the Surfactant and Effectiveness of the Recipe in Different Type of Sample Liquids

Based on the overall results gained and shown in the tables and graphs in part 4.1, a recipe which possible to deliquify water the most is chosen to be the best recipe in this project. So, the best surfactant recipe is the mixture of 600ppm of Sodium Lauryl Sulphate, 10% of Sodium Chloride and 3% Calcium Chloride which can unload 85% of water.

This best surfactant recipe is then tested to deliquify different of sample liquid. In that test, the surfactant recipe is tried to unload the condensate and as shown in Table 6, the result is very contradict compared to the test where the water is used as sample liquid. 0% of the condensate is unloaded using the best surfactant recipe produced in this project. This occurrence is explained by Steven Oude Heuvel (2013) in which he said that the oil can be the natural defoamer or antifoaming agent. The lamella of the foam can be ruptured by the oil.
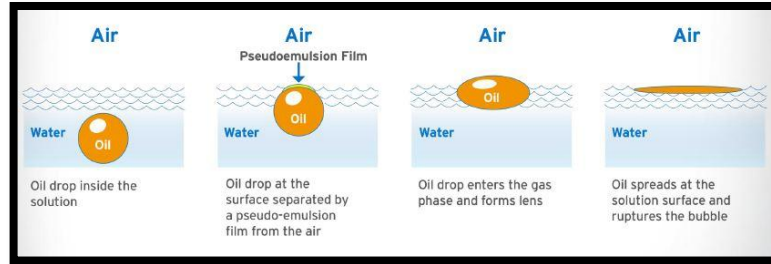
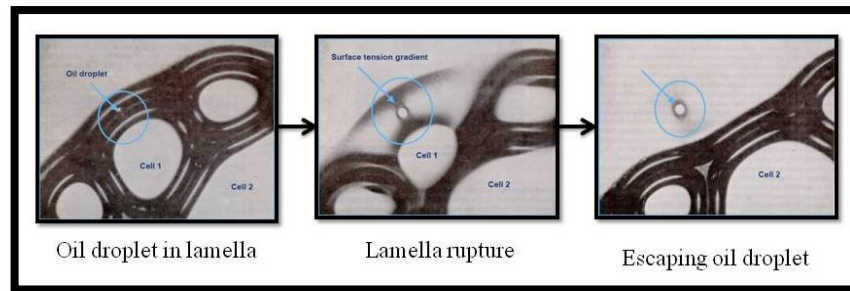Figure 15: Configuration of oil at air/liquid interface

Figure 16: Oil in foam

Without any special additives in the surfactant recipe, the presence of oil droplets or condensate can retard the function of the surfactants.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the results and discussions from the previous section of the project, all objectives are achieved successfully which are:

- The ability of Sodium Lauryl Sulphate to deliquify loaded water from the gas wells is proven.
- The effect of the concentration of Sodium Lauryl Sulphate on the percentage of water unloaded is verified.
- The effect of additives including Sodium Chloride and Calcium Chloride in the surfactant recipe is checked.
- The ability of the produced surfactant to deliquify the condensate loaded gas wells is established.

In conclusion, the recipe of the surfactant with higher concentration of Sodium Lauryl Sulphate, optimum concentration of Sodium Chloride and containing 3% of the Calcium Chloride is the best recipe to solve problem of deliquifying the water loaded gas wells by lowering the water interfacial tension. However, this recipe is not applicable to be used in the process of deliquification of the condensate loaded gas wells. By this finding, the accumulated water can still be unloaded using the cheaper chemical method instead of using the mechanical techniques of deliquification.

5.2 Recommendations

Every project will always need to be improved so that better results can be gained. For this project, there are some recommendations which are proposed in order to get a better results and findings in the future. The recommendations are listed as below:

- Consider the volume of the surfactant recipe used in the test to be the manipulated variable.
- Investigate the critical Sodium Lauryl Sulphate concentration that will result critical micelle concentration.
- Consider addition of other additives in the surfactant recipe to increase its effectiveness, for example alcohol.
- Figure out the recipe which can be used in the deliquification of condensate.

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APPENDICES

Appendix 1: Typical Cost of the Gas Well Deliquification Treatments

Economic and Environmental Benefits

Method for Reducing Natural Gas Losses	Volume of Natural Gas Savings and Incremental Production[1] (Mcf/well/year)	Value of Natural Gas Savings and Additional Production (Mcf/well/year)			Implementation Cost[1] (2010 $/Well)	Project Payback (years)		
		$3 per Mcf	$5 per Mcf	$7 per Mcf		$3 per Mcf	$5 per Mcf	$7 per Mcf
Use Foaming Agents	500 – 9,360	$1,500 - $28,080	$2,500 - $46,800	$3,500 - $65,520	$500 - $9,880	0 to 7	0 to 4	0 to 3
Install Velocity Tubing	9,285 – 27,610	$27,855 - $82,830	$46,425 - $138,050	$64,995 - $193,270	$7,000 - $64,000	0 to 3	0 to 2	0 to 1
"Smart" Well Automated Controls for Plunger Lift[2]	800 – 1,463[2]	$2,400 - $4,389	$4,000 - $7,315	$5,600 - $10,241	$5,700 - $18,000	1 to 8	1 to 5	1 to 4
Install Rod Pumps and Pumping Units[2]	973 – 2,040[2]	$2,919 - $6,120	$4,865 - $10,200	$6,811 - $14,280	$41,000 - $62,000	6 to 22	4 to 13	3 to 10

[1]Based on results reported by Natural Gas STAR Partners
[2]Does not include incremental gas production. Includes only potential gas savings from avoided well venting.