Liquid Foaming Agent for Liquid Loading Reduction in Gas Producing Wells

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ABSTRACT

The main objective of this research was to develop a liquid foaming agent for optimizing gas production in wells belonging to the Santa Rosa field in Área Mayor de Anaco, Venezuela. In this research, three liquid foaming agent formulations were developed with an anionic and amphoteric surfactants mixture, performing tests to evaluate foaming and lifetime on samples with different produced water/hydrocarbon condensate ratios. A liquid drag test was also carried out, explaining the liquid recovery performance after applying the developed formulations at different dosages and finally evaluated products results were compared with a commercial one. Formulation 1 obtained a higher liquid recovery compared to the other formulations, in addition, recovered liquid amount in dynamic drag tests decreased as the condensates composition increased in four samples evaluated. Formulation 1 and commercial product used as a reference did not have statistically significant differences.

Keywords: Surfactants; Liquid foaming agents; Condensates; Liquid loading; Liquid production.

INTRODUCTION

One of the biggest problems in the oil and gas industry occurs during the gas extraction process and is generated when water and/or condensate particles that move with the gas, have a lower velocity than the gas critical velocity (Guo et al., 2005), causing liquid particles not to be able to be transported from inside the well to the surface, forming a liquid accumulation at well bottom (water and hydrocarbon condensate) (Lea & Nickens, 2004; Joseph et al., 2013; Ajani et al., 2016; Joseph & Hicks, 2018); this multiphase phenomenon is also known as liquid loading and is defined as produced gas inability to remove the liquid at well bottom (Park et al., 2009; Alzhanov et al., 2018), which results in a decrease in gas production due to the formation of a fluid hydrostatic column, generating a back pressure that can be great enough for the gas to stop flowing from the reservoir (Lea & Nickens, 2004; Zhou et al., 2016; Pagou et al., 2020).

There are different methods to solve liquid loading problem, commonly known as deliquification techniques and generally associated with the use of plunger lift, critical velocity reduction systems and use of foaming agents (surfactants) (Veeken & Belfroid, 2011; Campbell et al., 2001; Stephenson et al., 2000). As for foaming agents, whose main component are surfactants, they provide a method that allows liquid density to be reduced so that it is easier to lift it with the gas flow, thus discharging accumulated liquid in gas wells (Ajani et al., 2016; Wu et al., 2020). In previous research by Alzhanov et al. (2018), Ren et al. (2018), Wylde et al. (2017), Liu et al. (2009) y Liu et al. (2020) the efficiency of this method has been demonstrated to remove accumulated liquids at the bottom of gas condensate producing wells in conventional and unconventional reservoirs, through experimental procedures that allowed simulating this phenomenon in laboratory. In addition, satisfactory results have been obtained using solid surfactants when applied in pilot tests, in order to reduce liquid loads in gas wells in a mature field (Irazuzta et al., 2020).

In Venezuela, specifically in gas-producing wells of a field in the east of the country, this liquid accumulation problem occurs affecting 115 of 120 wells drilled in producing reservoir (Petróleos de Venezuela, S.A. [PDVSA], 2019); which are inactive due to their low productive potential. For this reason, the purpose of this research was to develop a liquid foaming agent at an experimental level, establishing the optimal dose to be applied, as well as the effect water - condensate percentage would have on the accumulated liquids recovery for fluids samples from the gas condensate field evaluated. For this, three surfactants formulations were made and different dosages were established, in order to determine efficiencies of each one through the drag test specified in ASTM D 892 standard and finally, the effect that had factors such as formulations used and their doses on the performance of the developed foaming agent, through a multifactorial ANOVA.

MATERIALS AND METHODS

2.1. Foaming agents formulation for liquids produced removal (water and hydrocarbon condensate)

Liquid surfactant products were supplied by Stepan Company Inc., and condensate and produced water samples from a gas field in eastern Venezuela were provided by the national oil company Petróleos de Venezuela, S.A. A series of liquid foaming agent formulations were made by mixing anionic and amphoteric surfactants that have the ability to generate and stabilize foams with solvents compatible with them. Surfactant compounds selection was carried out based on those that had good solubility in water and excellent capacity to generate foams, choosing sodium lauryl sulfate at a 30% concentration as basis for the three formulations developed, using it at 95% of the formulations composition. Sodium lauryl sulfate, also called sodium dodecyl sulfate is an alkyl sulfate belonging to the anionic surfactants family. It has a good ability to generate foam, which is why it is generally used as a base in foaming agents formulations in the oil industry (Arslan et al., 2018; Bondi et al., 2015; Wołowicz & Staszak, 2020).

Sodium dodecylbenzenesulfonate anionic surfactant was also selected, which is a sodium salt of linear alkylbenzenesulfonic acid, its properties of generating high foam, rapid wetting and emulsion make it a compound widely used in foaming agent formulations (Salager & Fernández, 2004). Similarly, chemical compounds cocamidopropylbetaine and cocamidopropylhydroxysultaine were used; these compounds are amphoteric surfactants that are used as stimulants in foams formation. In this research sodium lauryl sulfate was combined, in case of formulation 1 with a betaines mixture and formulations 2 and 3 with a long-chain anionic surfactant at different concentrations of active matter. Table 1 shows the three liquid foaming formulations generated summary, highlighting the critical micelles concentration (CMC) for each formulation.

Table 1. Liquid foaming agents formulations generated in this research

Formulation 1		**CMC (%m/m)**
Components	Composition (%)	
Sodium Lauryl Sulfate at 30% active matter	95	10
Cocamidopropyl Betaine at 30% active matter	04	
Cocamidopropyl Hydroxysultaine at 43% active matter	01	
Formulation 1		
Components	Composition (%)	
Sodium Lauryl Sulfate at 30% active matter	95	7
Sodium dodecylbenzenesulfonate at 38% active matter	05	
Formulation 1		
Componentes	Composition (%)	
Sodium Lauryl Sulfate at 30% active matter	95	5
Sodium dodecylbenzenesulfonate at 55% active matter	05	

For comparative purposes, a commercial surfactant also from Stepan Company was used as a reference standard, this product is a betaines mixture used for injection into wells that present liquid accumulation problems

at bottom. It has good thermal stability and can be used in wells with a high solids content and hydrocarbon condensate due to the good tolerance it presents in both cases (Stepan Company, 2020). Table 2 shows its main physicochemical properties.

The proposed formulations were subjected to laboratory tests essential in chemical products development phase, such as stability tests, because they provide all data that indicates the relative stability degree of a product in different conditions at which may be subject from its manufacture to its use. In addition, and within the same evaluation protocol, centrifugation test was carried out, subjecting formulation to be evaluated to 3000 revolutions per minute (rpm) for 30 minutes, using a Koehler brand centrifuge, model K60005. Formulations that give satisfactory results in this test can be subjected to preliminary stability tests.

Table 2. Commercial product physical and chemical properties at 50% active material

Physical and chemical properties	
Physical state	Liquid
pH (@10% water)	4.0 – 7.0
Freezing point (°C)	-37
Flash point (°C)	>93.9
Viscosity (centiPoise @ 25 °C)	<100
Densidad(Lbs/gal @ 25 °C)	8.74

Taken from: Stepan Company (2020)

Subsequently, formulation(s) that gave satisfactory results to the primary stability tests were verified for their potential to generate foam and their stability or useful life through ASTM D 3519-88 standard or blender test. The samples used had a composition (produced water - hydrocarbon condensate) of 70/30, 80/20, 90/10% V/V and a 100% water sample, respectively, with foaming agent formulation at a dose of 1000, 5000, 10000, 20000 and 30000 ppm. This last test allowed us to observe the formulations performance, using the foam column height and its stability over time, as evaluation criteria.

2.2. Liquid foaming agents efficiency in accumulated liquids recovery, through the laboratory tests application

The efficiency of the liquid foaming agents developed was determined, applying a drag dynamic test and liquids overflow through ASTM D 892 "Column/Cylinder Test Method" standard and using a prototype similar to the one used by Ren et al. (2018) in their research. To carry out the test, 100 milliliters of four produced liquids samples prepared in laboratory were introduced at the produced water - hydrocarbon condensate proportions already indicated in a Pyrex® brand graduated cylinder, injecting air through the column bottom at a constant velocity of 0.5 m/s using a UTGE model 3705 air compressor. Three (3) repetitions were made for each formulation with doses of 1000, 2000, 3000, 4000, 5000, 10000, 20000 and 30000 ppm. Foaming agent efficiencies were determined by the amount of liquids was displaced from the cylinder bottom to the collection container, for each of the developed formulations and they were compared with the commercial liquid foaming agent efficiencies.

2.3. Statistical Analysis

Subsequently, using results obtained from drag test application, an analysis of variance (ANOVA) was performed for factorial experimental designs, relating the effect of the research independent variable (formulations application of liquid foaming agents and the different applied doses) on the performance of each liquid foaming agent. Finally, a post hoc test of multiple comparisons was carried out on the factors that presented statistical differences, using Fisher's least significant differences (MSD) to determine which sample means were the cause of these differences and thus be able to establish appropriate conclusions. This analysis was performed using the Statgraphics Centurion XVI program.

RESULTS AND DISCUSSION

3.1. Formulated foaming agents preliminary evaluation

Figure 1 shows the three formulations developed did not show any instability signs or separation of any of the chemical compounds contained in them. Subsequently, ASTM D 3915-88 standard was applied to verify foam formation and its stability or useful life, at water ratios produced – hydrocarbon condensate (W/C) and using the doses for each formulation, already specified.

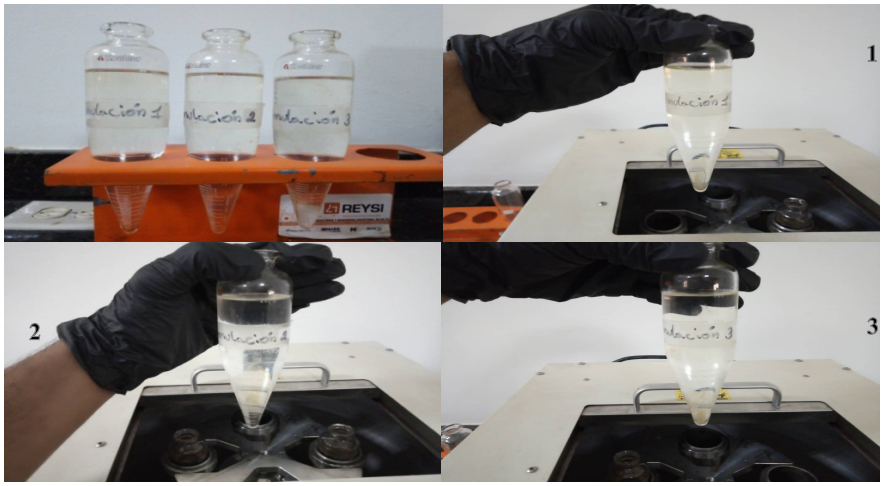

Figure 1. Centrifugation test result for the three formulations.

It is important to note that in most of the studies carried out by different researchers including: Alzhanov et al. (2018), Wylde et al. (2017) y Omrani et al. (2016), they only perform the liquid drag test (ASTM D 892) and few authors perform the liquefied or mixed test (ASTM 3915-88), among them Ren et al. (2018), who perform it but showing the results qualitatively, that is, they only show whether or not foam was formed with the chemical formulations they tested. However, this research analyzed not only from qualitative point of view, but also from quantitative point of view the generated foam amount with the measurement in centimeters of foam column created for each developed formulation, as well such as its useful life and stability over time.

In order to understand studied phenomenon behavior, the samples treated results at 30,000 ppm are shown, taking into account the other doses analyzed were also measured. Formulation 1 at a dose of 30,000 ppm generated foam in the four samples analyzed, as shown in Figure 2.

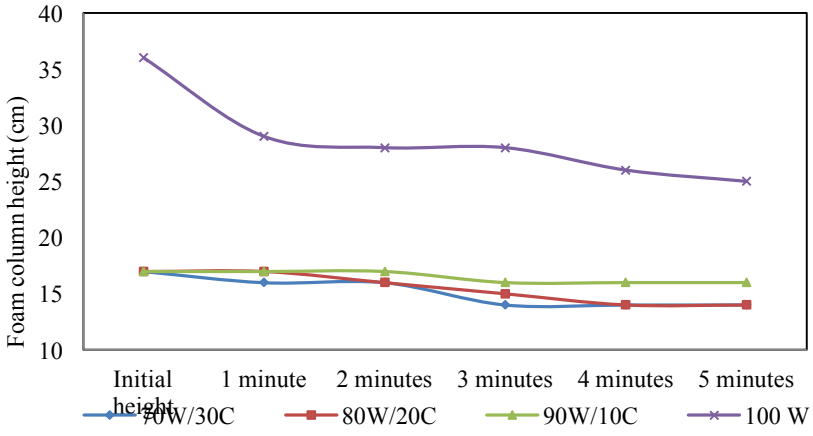

Figure 2. Foam formation and stability with formulation 1 application at a 30,000 ppm dose.

In figure 2, it is observed that in the 70/30% W/C sample, foams begin to form, appreciating in this research foam amount increases as the chemical formulation dose. All tested samples show an almost constant stability with few variations, because the condensate, when completely emulsified with produced water, due to the high foaming agent doses used, do not cause a direct effect on foam breaking (Omrani et al., 2016).

Figure 3 shows a decrease in the amount of foam formed in the 100%W and 70/30%W/C samples analyzed compared to formulation 1. However, in the 80/20 and 90/ 10% A/C the amount of foam formed initially was higher than formulation 1, because the foam formed with the application of formulation 2 is denser (see Figure 4).

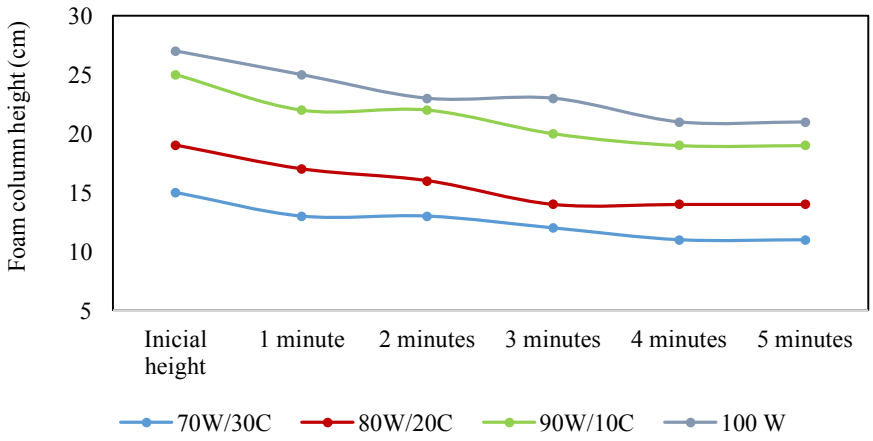

Figure 3. Formation and stability of the foam with the formulation 2 application at a 30,000 ppm dose.

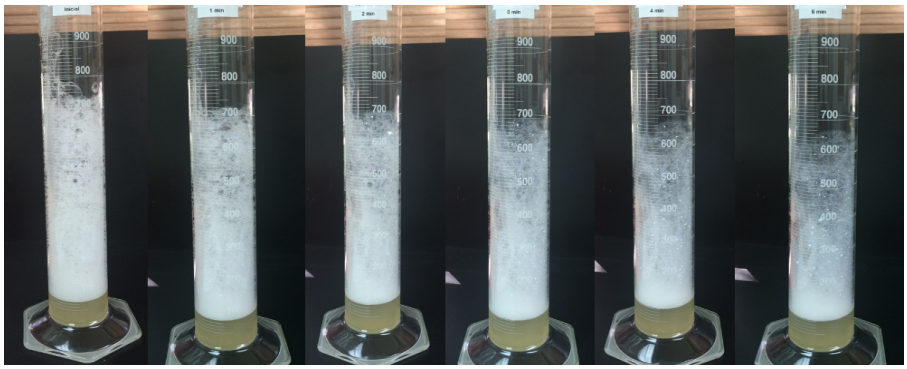

Figure 4. Formed foam with formulation 2 at a 30,000 ppm dose in a produced water / condensate 90/10% sample.

The bubble molecules are more compacted by the chemical properties effect of the bubble enhancing agent. This compaction effect, as concluded by Wu et al. (2020) greatly improves the foam stability as shown in Figure 3, with the attenuation that solid particles absorbed in gas-liquid interface can weaken the foam drainage velocity.

Next, formulation 3 was analyzed, showing in figure 5 it had a higher foam formation in all samples analyzed compared to the previous formulations at the same dose, this occurred because active matter concentration of the foam enhancer sodium dodecylbenzenesulfonate is 55%, this concentration being greater than the other foam-enhancing agents used in formulations 1 and 2. Likewise, a greater stability over time is observed in terms of the foam formed, this as a high density consequence of the gas bubbles structure in the foam column.

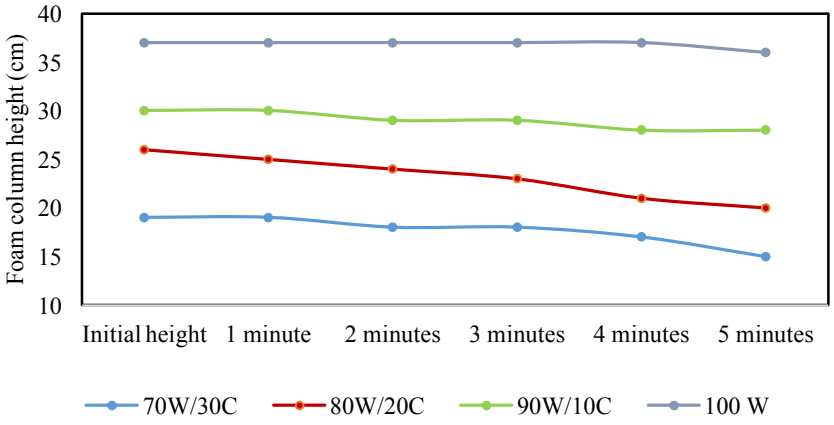

Figure 5. Formation and stability of foam with the formulation 3 application at a 30,000 ppm dose.

Therefore, after the three formulations were analyzed, it was determined formulation 1 is the one with the most instability over time compared to formulations 2 and 3, because the formed foam liquid film by the surfactant agent is dynamically unstable. Therefore, it is not possible to avoid gas diffusion, which results in the foam breaking easily, as indicated by Wu et al (2020) in their study.

3.2. Liquid foaming products efficiency for water and condensate recovery, through laboratory tests – Statistical Analysis

Figure 6 shows that formulation 1 in the produced water 100% sample compared to the other developed formulas and the commercial one, had a greater recovered liquid amount in the liquid drag test, an amount that remained constant at 20,000 and 30,000 ppm doses. This result is consistent with obtained in the foam formation test of previous stage, where it was shown that despite the overflow that occurred in the liquefied test, it is formulation 1 that generated the greatest foam amount for this sample.

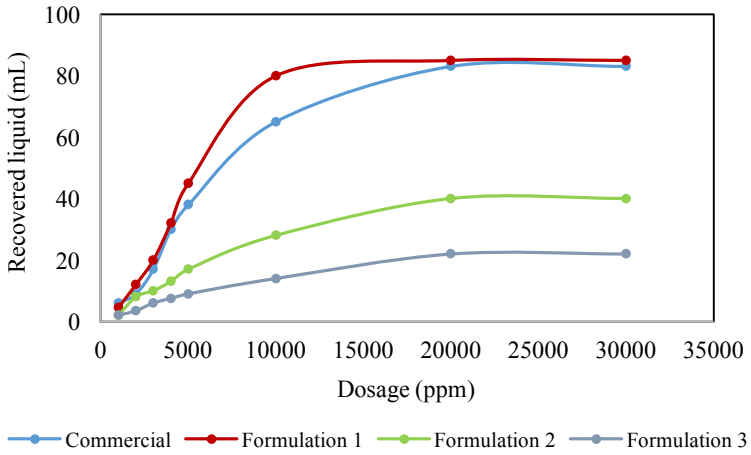

Figure 6. Liquids recovery with application of the developed foaming agents and the commercial product for a produced water 100% sample.

The behavior and result obtained in this sample confirm what was stated by Alzhanov et al. (2018), who mention that the best results in the liquids recovery from the gas wells bottom that present liquid load are obtained in samples biphasic (water - air) with dosages equal to or greater than 1,000 ppm of the surfactant agent.

Immediately, a multifactorial analysis of variance was performed with the results of recovered liquid, at each of the doses described on the produced water 100% sample, studying effect of each formulation and the chemical formulations doses, on the recovered liquid. The results obtained in Table 3 show that the P statistic value is equal to zero (0) for both formulations and dosages with a confidence degree of 95% and being less than 0.005 indicates these factors have a statistically significant effect on recovered liquid.

Table 3. Multifactorial analysis of variance (ANOVA) of liquid recovery with the application of the developed surfactants and the commercial product for a produced water 100%sample.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Main effects					
A:Formulations	6,732.21	3	2,244.07	13.22	0.0000
B:Treatment	13,358.5	7	1,908.36	11.24	0.0000
Residues	3,564.6	21	169.743		
Total (corrected)	23,655.3	31			

After verifying there are significant effects of the factors on the studied variable, a multiple comparison was made to determine which means are significantly different from others. Table 4 shows the results of the multiple comparisons for a produced water 100% sample.

Table 4. Multi-range test of the developed liquid foaming agents and the commercial product applied on a produced water 100% sample.

Contrast	Sig.	Difference	+/- Limits
Commercial - Formulation 1		-4.0625	13.5472
Commercial - Formulation 2	*	21.625	13.5472
Commercial - Formulation 3	*	30.625	13.5472
Formulation 1 - Formulation 2	*	25.6875	13.5472
Formulation 1 - Formulation 3	*	34.6875	13.5472
Formulation 2 - Formulation 3		9.0	13.5472

* Indicates a significant difference

The results confirm formulation 1 obtained a higher performance in liquid recovery compared to the other two formulations in the water 100% sample, as there were statistically significant differences between it and the others. Likewise, the behaviors of formulation 1 and the commercial product are not statistically different, as well as formulations 2 and 3 (between them), presenting similar behaviors in liquid recovery, as shown in Figure 6. Figure 7 shows the results of the liquid drag test for samples 90/10, 80/20 and 70/30% produced water – hydrocarbon condensate.

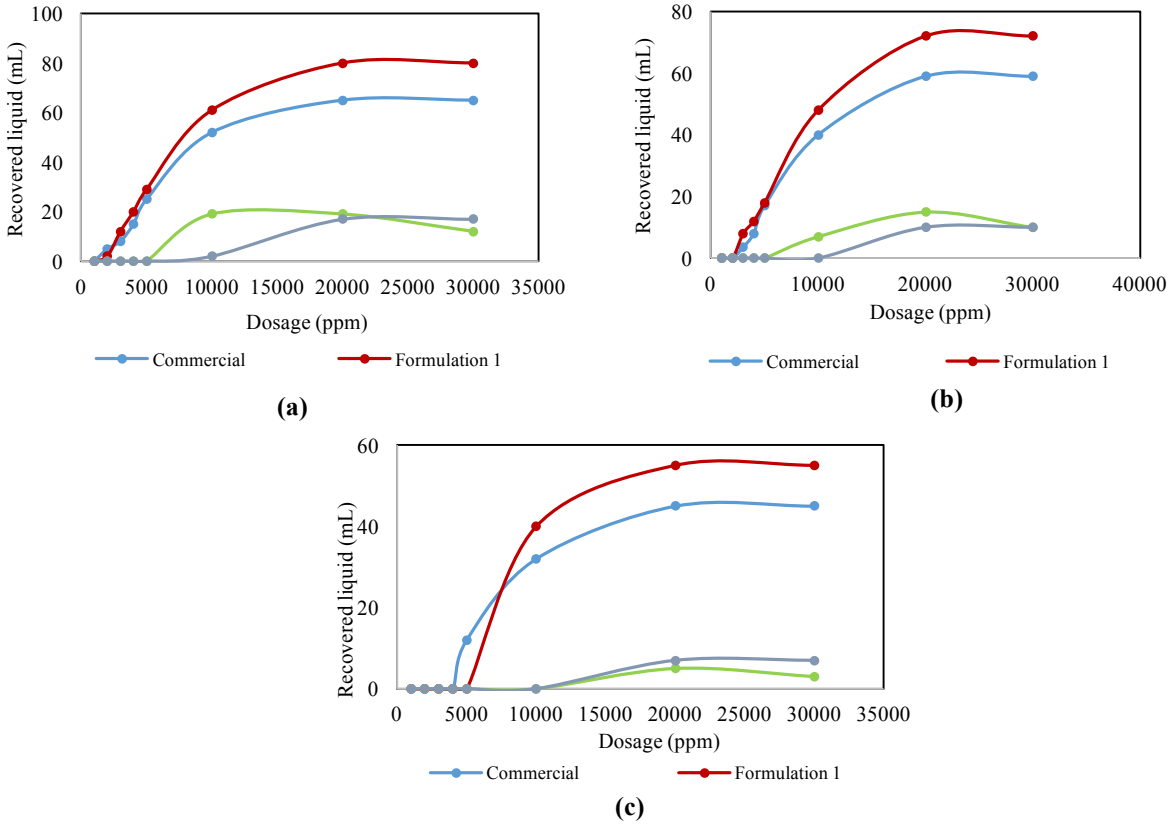

Figure 7. Liquids recovery with the application of the developed foaming agents and the commercial product for samples **(a)** 90/10, **(b)** 80/20 and **(c)** 70/30% produced water – hydrocarbon condensate.

Figure 7 shows that formulation 1 in sample 90/10% produced water - hydrocarbon condensate (a) presented a greater amount of recovered liquid in the drag test, compared to the other developed formulas and the commercial product; this liquids amount remained constant in the doses of 20,000 and 30,000 ppm with 80 mL recovered. The formed foam in formulations 2 and 3 was denser, so the recovered liquids amount is less, since these liquids are trapped in a film that forms between bubbles. In (b), it can be seen how the recovered liquid amount has decreased by 13 mL compared to the produced water 100 % sample, which recovered 83 mL with formulation 1. Similarly, it occurs with formulations 2 and 3 respectively; with this it is inferred while hydrocarbon condensate amount in the sample composition increases, the liquid dragging capacity decreases, because in the samples as the concentration increases, the foam column structure becomes denser, especially in the treatments carried out with formulation 3, where the liquid dragging capacity decreases.

In (c), the decrease in recovered liquid was maintained in all formulations at the different dosages used, proving even more that the higher condensate amount in sample, the lower liquid dragging capacity. This supports what was mentioned by Alzhanov et al. (2018) who subscribe that in triphasic flows (air - water - oil) the surfactants effect decreases if sample has a water percentage equal to or less than 70%. Formulation 1 was the one that obtained the best performance in this sample; however, the commercial product began to drag liquid at a dose of 5,000 ppm, compared to formulation 1, which did so at a dose of 10,000 ppm, and formulations 2 and 3 at 20,000 ppm. Formulation 3 maintained the behavior of dragging more liquid than formulation 2 in this sample, as well as in the 80/20% produced water/hydrocarbon condensate sample, due to the higher emulsion degree generated by the anionic surfactants mixture between condensate and produced water from the dosage of 20,000 ppm.

In summary, formulation 1 obtained an efficiency of 55% for a sample with 70% water percentage, 59% for samples with 80% water cut, 80% for the sample with 90% water percentage and 85% for samples of 100% water produced at the maximum dose evaluated (30,000 ppm). The excellent performance of formulation 1 is because it is a mixture of an anionic surfactant (alkyl sulfate) with two betaines as enhancing agents in foam formation in the four samples evaluated in this investigation; demonstrating as stated by Ren et al. (2018) that the betaines combination allows to obtain a better result in the liquids recovery, due to the tolerance they present to generate foams in media with high contents of total dissolved solids and condensate percentages up to 20%.

CONCLUSION

Formulation 3, in the preliminary evaluation, generated a greater amount of foam compared to formulations 1 and 2 in four samples that were evaluated in this research, also having a greater stability over time, so its useful life was greater, but formulation 1 was the one that recovered the greatest liquid amount compared to the other formulations, obtaining efficiencies ranging from 55% for a sample with 70% water up to 85% for samples with 100% produced water at the evaluated maximum dose (30,000 ppm). It was also shown that recovered liquid amount decreases as the condensate composition increases in the analyzed samples and according to the statistical analysis, the formulations and dosages used have a significant effect on the recovered liquid, with no statistical differences between formulation 1 and the commercial product used as reference in this research.

REFERENCES

Guo, B., Ghalambor, A., & Xu, C. 2005. A Systematic Approach to Predicting Liquid Loading in Gas Wells. SPE Production & Operations 21(1): 81-88. DOI: 10.2118/94081-PA.

Lea, J. F., & Nickens, H. V. 2004. Solving Gas-Well Liquid-Loading Problems. Journal of Petroleum Technology 56(4): 30-36. DOI: 10.2118/72092-JPT.

Joseph, A., Sand, C. M., & Ajienka, J. A. 2013. Classification and Management of Liquid Loading in Gas Wells. Nigeria Annual International Conference and Exhibition. Lagos, Nigeria: Society of Petroleum Engineer. DOI: 10.2118/167603-MS.

Ajani, A., Kelkar, M., Sarica, C., & Pereyra, E. 2016. Effect of surfactants on liquid loading in vertical wells. International Journal of Multiphase Flow 83: 183-201. DOI: 10.1016/j.ijmultiphaseflow.2016.03.019.

Joseph, A., & Hicks, P. D. 2018. Modelling mist flow for investigating liquid loading in gas wells. Journal of Petroleum Science and Engineering 170: 476-484. DOI: 10.1016/j.petrol.2018.06.023.

Park, H.-Y., Falcone, G., & Teodoriu, C. 2009. Decision matrix for liquid loading in gas wells for cost/benefit analyses of lifting options. Journal of Natural Gas Science and Engineering 1: 72-83. DOI: 10.1016/j.jngse.2009.03.009.

Alzhanov, Y., Karami, H., Pereyra, E., & Gamboa, J. 2018. Efficacy of Surfactants in Rich Gas Shale Wells. SPE Artificial Lift Conference and Exhibition - Americas. The Woodlands, Texas, U.S.A.: Society of Petroleum Engineers. DOI: 10.2118/190941-MS.

Zhou, C., Wu, X., Li, H., Lin , H., Liu, X., & Cao, M. 2016. Optimization of methods for liquid loading predictionin deep condensate gas wells. Journal of Petroleum Science and Engineering 146: 71-80. DOI: 10.1016/j.petrol.2016.04.016.

Pagou, A. L., Han, G., Peng, L., Dehdah, O., Kamdem, V. G., Abimbola, F., . . . Kanturina, Z. 2020. Liquid loading prediction and identification model for vertical and inclined gas wells. Journal of Natural Gas Science and Engineering 84: 1-12. DOI: 10.1016/j.jngse.2020.103641.

Veeken, C. A., & Belfroid, S. P. 2011. New perspective on gas-well liquid loading and unloading. SPE Annual Technical Conference and Exhibition. Florence, Italy: Society of Petroleum Engineer. DOI: 10.2118/134483-PA.

Campbell, S., Ramachandran, S., & Bartrip, K. 2001. Corrosion Inhibition/Foamer Combination Treatment to Enhance Gas Production. SPE Production and Operations Symposium. Oklahoma City, Oklahoma, U.S.A.: Society of Petroleum Engineer. DOI: 10.2118/67325-MS.

Stephenson, G. B., Rouen, R. P., & Rosenzweig, M. H. 2000. Gas-Well Dewatering: A Coordinated Approach. SPE International Petroleum Conference and Exhibition. Villahermosa, México: Society of Petroleum Engineer. DOI: 10.2118/58984-MS.

Wu, J., Jia, W., & Xian, C. (2020). Foaming Agent Developed for Gas Wells with Liquid Loading Problem Using New Surfactant and Nanotechnology. SPE Journal 25(6): 3138–3144. DOI: 10.2118/201249-PA.

Ren, G., Sanders, A., Friesen, D., & Seymour, B. 2018. Understanding the Impact of Condensate Composition on Performance of Gas Well Deliquification Surfactants. SPE Asia Pacific Oil and Gas Conference and Exhibition. Brisbane, Australia: Society of Petroleum Engineers. DOI: 10.2118/192142-MS.

Wylde, J. J., Turner, N., Austill, M., Okocha, C., & Obeyesekere, N. 2017. Development, Testing and Field Application of a Novel Combination Foamer-Iron Sulfide Scale Inhibitor-Corrosion Inhibitor in East Texas. SPE International Conference on Oilfield Chemistry. Montgomery, Texas, U.S.A.: Society of Petroleum Engineers. DOI: 10.2118/184584-MS.

Liu, Y.-P., Zhang, H., Wang, S.-H., & Wang, J. 2009. Effect of binary mixtures of surfactants on horizontal gas–liquid flow with low liquid loading. Journal of Petroleum Science and Engineering 68: 235–244. DOI:10.1016/j.petrol.2009.07.002.

Liu , Y., Luo, C., Zhang, L., Wu, P., Zhao, Y., & Wang, L. 2020. Experimental investigation of the surfactant effect on liquid removal in vertical pipes. Journal of Petroleum Science and Engineering 185. DOI: 10.1016/j.petrol.2019.106660.

Irazuzta, V. L., Schenkel, M. L., Candia, G. A., Aguero, S. D., Jouli, M. J., Perez, W., . . . Reinoso, O. 2020. New Technology Based on Solid Surfactant to Deal with Liquid Loading in Gas Wells of a Mature Field in an Urban Area. SPE Latin American and Caribbean Petroleum Engineering Conference. Virtual Event: Society of Petroleum Engineers. DOI: 10.2118/199093-MS.

Petróleos de Venezuela, S.A. [PDVSA]. 2019. Reporte de pruebas de producción del Campo Santa Rosa PDVSA Gas Anaco. Anaco, estado Anzoátegui, Venezuela: Petróleos de Venezuela, S.A. (PDVSA).

ASTM International. 2018. ASTM D892-18: Standard Test Method for Foaming Characteristics of Lubricating Oils. West Conshohocken, Pennsylvania, U.S.A.: ASTM International. DOI: 10.1520/D0892-18.

Arslan, A., Topkaya, E., Bingöl, D., & Veli, S. 2018. Removal of anionic surfactant sodium dodecyl sulfate from aqueous solutions by O3/UV/H2O2 advanced oxidation process: Process optimization with response surface methodology approach. Sustainable Environment Research 28(2): 65-71. DOI: 10.1016/j.serj.2017.11.002.

Bondi, C. A., Marks, J. L., Wroblewski, L. B., Raatikainen, H. S., Lenox, S. R., & Gebhardt, K. E. 2015. Human and Environmental Toxicity of Sodium Lauryl Sulfate (SLS): Evidence for Safe Use in Household Cleaning Products. Environmental Health Insights 9: 27-32. DOI: 10.4137/EHI.S31765.

Wołowicz, A., & Staszak, K. 2020. Study of surface properties of aqueous solutions of sodium dodecyl sulfate in the presence of hydrochloric acid and heavy metal ions. Journal of Molecular Liquids 299: 1-16. DOI: 10.1016/j.molliq.2019.112170.

Salager, J.-L., & Fernández, Á. 2004. Cuaderno FIRP S302-PP. Surfactantes: III Surfactantes Aniónicos. Retrieved on May 20, 2021, from: http://www.firp.ula.ve/archivos/cuadernos/S302.pdf.

Stepan Company. 2020. Productos y Mercados. Retrieved on May 22, 2021, from: https://es.stepan.com/content/stepan-dot-com/es/products-markets.html.

ASTM International. 2007. ASTM D3519-88: Standard Test Method for Foam in Aqueous Media (Blender Test). West Conshohocken, Pennsylvania, U.S.A.: ASTM International. DOI: 10.1520/D3519-88R07.

Omrani, P. S., Shukla, R. K., Vercauteren, F., & Nennie, E. 2016. Improving the Foamer Selection Procedure for Gas Well Deliquification Application. SPE Annual Technical Conference and Exhibition. Dubai, U.A.E.: Society of Petroleum Engineers. DOI: 10.2118/181592-MS.