SPE Brazil Flow Assurance Technology Congress
Rio de Janeiro, Brazil, November 06 – 08 2024

Development of Gas-Liquid Spacer for Hydrate Removal

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Abstract
This article describes the development of a gas-liquid spacer to facilitate the removal of hydrate blockage in offshore oil production flowlines. Hydrates are crystalline solids formed in the presence of water and gas at high pressures and low temperatures. During production shutdowns, the production fluids cool down and may form hydrate blockages. Conventional solutions for blockage removal typically involve the depressurization of the production flowline through the service flowline. But when liquid comes into the service flowline, it is needed to push the liquid into the well by pressurizing the service flowline with natural gas or nitrogen (N2). However, this method has limitations such as limited availability of N2 and the risk of hydrate formation during pressurization with natural gas. To overcome these challenges, a gas-liquid spacer was developed to act as an interface between gas and liquid, allowing the liquid to be pushed into the well by the gas reducing the risk of hydrate formation. The spacer was designed to seal in upward sections, to pass through restrictions, and to be soluble in oil at 80 °C. Many laboratory-scale tests were performed, and the results demonstrated the gas-liquid spacer's good performance. Although a field test was not conducted due to specific well conditions, it is expected that the technology will soon be qualified for commercial application.

Keywords
hydrate; remediation; gas-liquid spacer.

Introduction
The formation of hydrate blockage in oil production pipelines is a major flow assurance problem encountered in offshore production scenarios in deep and ultra-deep water. Natural gas hydrates are crystalline solids formed in the presence of water and gas under favorable thermodynamic conditions, typically at high pressures and low temperatures [1].

During production shutdowns, the production fluids cool down and enter the thermodynamic envelope for hydrate formation, requiring careful operational procedures to prevent hydrate blockage. When hydrate prevention measures are not sufficient, hydrate blockage formation can occur, preventing production from the well. The cost and time required for hydrate blockage removal can vary greatly depending on the operational conditions. The initial attempts to remove the blockage are usually made by depressurizing the production flowline. In this process, the service flowline is depressurized and connected to the production flowline through the Xmas Tree (XT) crossover valve [2]. The side effect of this procedure is the entry of liquid from the production flowline into the service flowline. The fluids settle until they reach equilibrium. If there are downward sections in the service flowline, it is highly likely that a siphon will form. A siphon occurs when a section of the flowline holds a pocket of pressurized gas, trapping a liquid piston in the riser. This phenomenon occurs because the flowline's bathymetry traps pressurized gas pockets that cannot change position with liquid pistons due to gravitational segregation. As a result, the siphon creates a hydrostatic column that prevents the depressurization of the production line and, consequently, the dissociation of hydrates. To overcome this problem, it is necessary to remove the liquid from the service line, either into the well or to the processing plant on the platform.

The usual procedures involve pressurizing the service line with gas to push the liquid into the well. In this situation, there is a risk of hydrate blockage formation due to the pressurization of fluids (water, oil, and gas) in a low-temperature environment (4°C). One way to mitigate this risk is to use nitrogen (N2) for pressurization. However, there are some inconveniences, namely: 1) N2 units are a critical resource and are not always available, requiring waiting for many days or even months to obtain the resource; 2) N2 units, both the generating units and the cryogenic units, have a certain flow limitation, which limits the gas velocity in the line and makes it difficult to carry the liquid in ascending sections until reaching the XT; 3) N2 depressurization to the process plant can extinguish the flare or create an obstacle for compressors, requiring additional care during depressurization maneuvers. As a result, the time required to dissociate a hydrate blockage can become quite long. The operations can become complex, requiring several cycles of N2 pressurization and depressurization.

To avoid these problems, a solution was devised using a gas-liquid spacer to serve as an interface between the natural gas and the liquid, in such a way that the liquid could be pushed into the well, ensuring that the natural gas injected behind the spacer does not encounter the liquid in front of the spacer, thus mitigating the risk of hydrate blockage formation in this operation.

Application Scenario

As explained above, the development of the gas-liquid spacer was done to facilitate the removal of liquid from the service line to allow depressurization of the production line and consequently dissociation of hydrate from the production line.

Figure 1 illustrates a typical offshore well production scenario in deep waters at Petrobras. The well has a production line and a service line, commonly used for gas lift and to allow circulation of diesel for hydrate prevention.

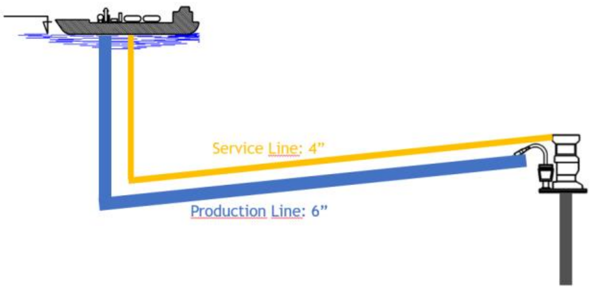

Figure 1: Typical offshore production well in Petrobras.

Figure 2 illustrates a scenario where the bathymetry is descending, meaning that the XT is shallower than the base of the riser. In this type of scenario, the fluids flow downward until they reach the base of the riser. In this scenario, siphoning occurs in the service line when pressure is communicated between both lines.

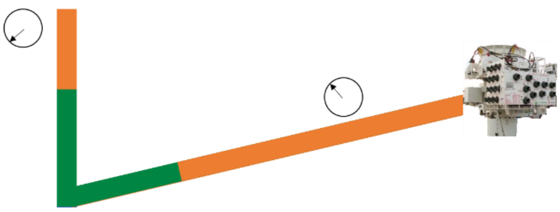

Figure 2: Downward well bathymetry.

It can be observed that the gas pocket (orange) near the XT can sustain a liquid column (green) in the vertical section of the riser after gravitational segregation of the fluids. When this situation occurs, the pressure at the XT can exceed the hydrate dissociation pressure, preventing the dissociation of hydrates from the production line.

Methodology

The devised solution considered that the spacer, in addition to ensuring sealing between the injected gas and the liquid, should also satisfy other requirements. The operation involves displacing the spacer through the service line, pushed by the gas. The spacer moves until it reaches the XT when its function is fully fulfilled. All the liquid in front of it would have been displaced into the well, thus ensuring that the depressurization of the service line does not generate a new siphon, allowing the pressure reduction of the production line.

Although the spacer no longer serves a purpose when it reaches the XT, a destination requirement had to be defined for it. The alternative found was to continue pushing the spacer into the production column. To do this, a dissolution requirement of the spacer in oil at the reservoir temperature was inserted to mitigate any risk of entrapment or blockage of the spacer at the bottom of the well.

In summary, the following requirements were defined:

1 - The spacer must be capable of sealing in upward sections of flexible (corrugated) 4" lines (typical diameter of service lines).

2 - The spacer must be able to pass through a 2" section within the XT circuit (AWV -> XO -> PMV -> tubing).

3 - The spacer must be liquid or soluble in oil at a temperature of 80 °C (typical temperature of post-salt reservoirs).

Before proceeding with the development of the actual product, some commercially available spacers were surveyed and evaluated, such as different types of gel pigs and low-density foam pig. However, no market solutions were found that satisfied all the requirements. Most spacers fail to completely seal the gas passage in flexible lines and/or are not soluble in oil at 80 °C.

Gas-Liquid Spacer Development

Given the lack of knowledge of a commercial product that could meet the application requirements, the development of a new innovative product was initiated.

For this purpose, a methodology was established, which involved hypothesis generation, definition of chemical formulas to be tested, preparation of chemical solutions, and performance evaluation on a laboratory scale.

Several formulations with different chemical components and formats were tested until two formulations that best met the requirements were identified.

Experimental Bench Apparatus
Once the formulation to be tested was defined, the spacer was manufactured using molds that represented the pipes of the laboratory bench apparatus.

The spacer was inserted into an inclined glass pipeline. Water with colorant was added for visualization, and compressed air was injected behind the spacer. The objective of this test was to evaluate the spacer's ability to seal the gas at the back and the water at the front.

Figure 3 shows one of the tested spacers. In this test, a small turbulence ahead of the spacer was observed, generated by the passage of air through the spacer. This specific spacer was rejected, and other formulations were developed.

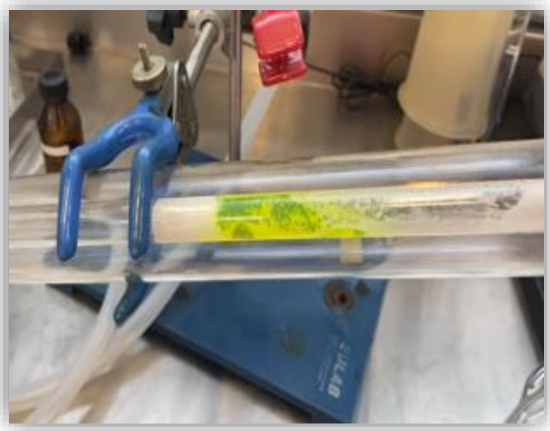

Figure 3: Mini-scale lab apparatus.

Figure 4 shows the experimental mid-scale apparatus. The approved spacers in this test showed no bubbles ahead or liquid behind the spacer.

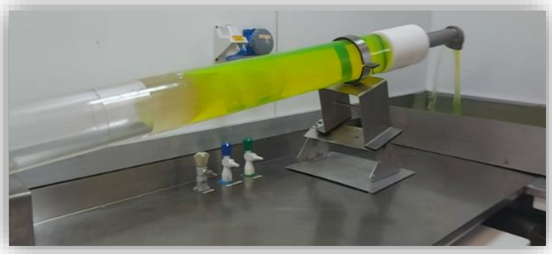

Figure 4: Mid-scale lab apparatus.

Solubility Tests
Solubility tests were conducted to verify if the developed formulation could meet the solubility criterion (to dissolve in oil at 80°C).

Figure 5 shows an example of one of the tests after subjecting a sample of the spacer to spindle oil at 80°C. It can be observed that the contents of the flask are completely in the liquid phase.

Figure 5: Solubility test example

Two different formulations showed good results in bench-scale laboratory tests and were pre-qualified to be tested on a larger scale apparatus, closer to the field scenario.

Figure 6: Pre-qualified gas-liquid spacers at laboratory scale: TINA on the left and CRIS on the right.

Large-Scale Laboratory Tests
To evaluate the performance of the spacers in terms of their sealing ability in flexible lines, a flow loop test was prepared at UTFPR using sections of 4" and 6" diameter flexible pipelines and visualization sections with acrylic pipes, 12 meters total, with a 10° inclination. See Figure 7.

Figure 7: Large-scale lab apparatus.

The spacer was inserted into the pipeline, water with colorant was placed ahead of the spacer, and the spacer was propelled with compressed air. At the end of the line, the water and spacer fell into an appropriate container.

In addition to the sealing test, an apparatus with a reduction of 4"x2" and 6"x4" was also prepared to test the spacer's passage through a smaller diameter section, simulating the passage of the spacer through the internal circuit of the Xmas Tree. In this test, the differential pressure required to pass through the reductions was measured. Figure 8 shows the schematic of the 4"x2" reduction apparatus.

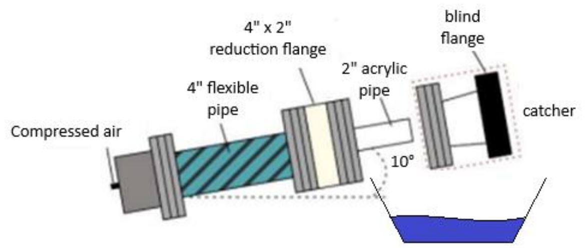

Figure 8:Schematic of the 4”x2” reduction apparatus.

Results and Discussion

In the laboratory tests, several formulations were tested, but only two of them were able to meet the minimum requirements in the mini-scale and mid-scale test benches.

After the first tests, one major lesson was learned. It was occurring a water fallback although no bubble was seen in front portion of the spacer. The calculations showed that the liquid volume collected after the run was equivalent to the volume of the interlocked carcass of the flexible pipe.

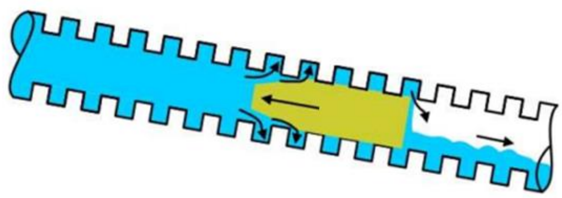

Figure 9: Water fallback in flexible line.

One of the spacers (TINA) (see Figure 6 on the left) was fully approved for meeting the desired criteria (good sealing capacity and passage through restrictions), which gives the developed technology a TRL-6 level, on a scale of 1 to 9. The other spacer (CRIS) (see Figure 6 on the right) was rejected for not being able to support the weight of the liquid ahead, showing material loss, and allowing compressed air to pass ahead.

Field Trial

A field test was planned for a scenario with a hydrate blockage in a descending production line. For this purpose, five spacers were manufactured and sent to the platform, an operational procedure was elaborated, and a risk analysis of the operation was conducted. However, the application of the spacer could not be performed. The hydrate removal operation showed that the hydrate was very close to the XT. In this case no siphon formation occurred in the service line after connecting it to the production line. The pressure at the XT was low enough to allow the dissociation of the hydrate from the production line. Therefore, the application of the gas-liquid spacer was not necessary in this scenario.

Currently, another field scenario is under evaluation to test the spacer's performance in terms of its ability to remove liquid from the service line and lower the pressure at the XT, even if there is no hydrate in the production line. The expectation is to approve and qualify the technology at TRL-7.

Conclusions

This work has shown one of the difficulties in hydrate removal when dealing with scenarios of wells with descending lines, where the use of the service line for depressurizing the production line can generate a liquid siphon that hinders the dissociation of hydrates from the production line.

To mitigate this situation, a technology was developed to allow the displacement of fluids from the service line into the well, mitigating the risk of hydrate blockage formation in the service line. The developed technology is a gas-liquid spacer that aims to prevent contact between the natural gas used to push the fluids and the water contained in the service line. Additionally, the spacer has physicochemical properties that allow its passage through the restrictions in the Xmas Trees and its dissolution when it reaches the deeper and hotter part of the well.

Although it was not possible to conduct a full-field test, the technology has already undergone several tests on scales compatible with the field scale. It is expected that soon the technology can be applied in a field scenario to validate the positive results obtained so far, allowing the technology to be made available with a relevant level of maturity for commercial application.

Acknowledgments

Authors would like to acknowledge Petrobras for all the support provided to develop the gas-liquid spacer technology, to register the patent application and to allow the publication of this paper. Authors would also like to acknowledge UTFPR and Professor Rigoberto Morales for the partnership and for all the technical support provided by his team to accomplish the large-scale test results.

Responsibility Notice

The authors are the only responsible for the paper content.

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