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Use of Pressure-Activated Sealant To Cure Leaks in Subsea Wells - A Case Study in Campos Basin

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Abstract

Offshore oil and gas production systems are complex systems comprised of wells, flow lines, a variety of subsea and dry subsystems, production platforms and export lines. Hydraulic systems are extensively used in offshore production systems, particularly for valves control and operation. Failures in hydraulics systems may cause loss of redundancy, loss of control and well shut-in with economic losses and risks to system integrity and environment. Leaks, mostly internal, represent one of the most common failures in the hydraulic systems. The conventional approach to repair these leaks makes use of rig and/or support vessels, being time and money consuming, not mentioning the risks imposed to the system under intervention. The difficulty, risks and costs increase with water depth. In the Campos Basin, offshore Brazil, with around 500 subsea wells, in water depths range from shallow to ultra deep, leaks in hydraulic systems have a significant impact on maintenance costs. Sensitive components are down-hole safety valves, wet christmas trees valves, annulus subsurface safety valves and subsea manifolds subsystems. These aspects made the search for reliable remote or light workover solutions an important issue. A promising solution was introduced in Campos Basin in the year 2000, which makes use of a pressure-activated sealant fluid. This paper presents a case study comprised of tens of pressure-activated sealant applications, both in fixed and floating systems, carried out in Campos Basin in the last four years. The paper summarizes the operational programs, the field reports, the post-job analyses and the results achieved. The study revealed that pressure-activated sealants are a safe and economic method to repair leaks in offshore hydraulic systems. As the number of offshore oil and gas production systems, mainly the floating ones, tends to increase considerably in the near future, the knowledge acquired in Campos Basin may be useful worldwide. The main differential of this paper is a thorough and critical review, from the operator point of view, of 71 applications from 01/21/2000 to 05/16/2005.

Introduction

Campos Basin is located in southeastern Brazil, mostly offshore of the states of Rio de Janeiro and Espírito Santo, occupying an area of 115,000 km². The following approximated numbers illustrates the size and complexity of Campos Basin: 13 fixed platforms and 24 floating systems distributed among 42 oil fields; 700 wells drilled in WD up to 1,500 meters and 150 wells drilled in WD deeper than 1,500 m; 500 WCT; 20 submarine manifolds; 2,700 km of flexible lines; 2,000 km of umbilical[1]. Campos Basin is the most mature deep water oil and gas offshore basin in the world. Amongst the many issues that can compromise flow assurance in a mature offshore basin this paper addresses leaks in hydraulic systems.

The leaks in oil and gas production systems can be classified in dynamic seals, static seals and connections. Connection leaks are seen in hydraulic lines, umbilical lines, control systems, flow hubs, tubing, casing and associated components. Dynamic seal leaks are found in SCSSVs, actuators; valves control systems and related components. Static seal leaks are found in wellheads, hangers and analogous components. Downhole leaks sources include tubing, casing, packers, sleeves and other components.

This paper will cover the conventional repair methods, pressure-activated sealant chemistry, hydraulic leaks that can be cured with pressure-activated sealants, study methodology, sealant delivery methods, program guidelines and operation procedure, two phase history of pressure-activated sealant applications in Campos Basin, two case histories and results and conclusions.

Conventional Mechanical Repair Methods

The conventional approach to cure leaks in the hydraulic systems is the mechanical repair. It can be accomplished by rerouting leaking circuits, or with ROV operation or with rig operation. Rerouting leaking circuits, that should be the first option, depend on available redundant circuits and may require an ROV intervention. ROV operation uses remote vehicle with special manipulator arms in an attempt to reach into the location of the leaking component and repair or replace it. Although the cost of ROV operation is lower than the rig option, there is risk of failing to repair the component or damaging other equipment. Rig operation, the last, but many times only conventional option, is complex, time-consuming and costly. Many times rig operation requires shutting the well and sometimes demands pulling the production string out of hole. In these cases the costs and risks to production, safety and environment increase dramatically. In 2000 a new solution was introduced in Campos Basin, which makes use of a pressure activated sealant. This paper reviews the application of this technology in Campos Basin.

Chemistry of the Pressure-activated Sealants

The sealants consist of a super-saturated mixture of short-chain polymers, monomers and polymerizing chemicals in a carrier fluid. The sealant formula is adjusted with additional components based on temperature, pressure, system fluids and leak rate. This adjustment aims to create the proper pressure differential at the leak site to seal the leak without plugging vital equipment. The uniqueness of this solution is that the sealant remains fluid until it flows through a leak site. The differential pressure at this point starts the sealant reaction. There is a cross-linking reaction analogous to blood coagulating at a cut. As the reaction proceeds, the polymerized sealant plates out on the edges of the leak site and, simultaneously links across the leak site to seal the leak. The resulting seal is an elastic bond across the leak. The rest of the sealant will remain fluid not clogging the hydraulic system or well[2].

According to Petrobras laboratory tests and field applications the sealants have never plugged a control line or damaged any component of a hydraulic system. The sealants do not react with or damage electronics or metal seals. Specific tests were carried out in umbilical lines and the SCSSV mechanisms. Replicated leaks were created in the fittings, connections and hoses of umbilical systems. Seals in SCSSVs were damaged or removed to create severe leaks. Using the sealant process, all leaks were cured except where the line was actually cut deeply through the control line. The flexible seals created were able to hold at the rated equipment pressure of 5000 psi. **Figure 1** shows a flow hub testing.

In Campos Basin field applications, the flexible seals have been stablished at pressures as high as 5000 psi.

Hydraulic Leaks That Can Be Cured With Pressure-activated Sealants

Applications of pressure-activated sealant were reported to seal leaks in offshore hydraulic systems[2] and in annular gas leak through cement channels, casing leaks, tubing leaks and wellhead hanger[3].

Not all leaks can be cured with pressure-activated sealant. There are limitations regarding leak identification, leak rate, injection point access, and logistical issues. As the sealant structure builds out from the edges until the leak seals, the higher the surface area to leak area ratio, the more likely that the leak seals. Again, the blood circulation analogy may be useful: a long thin cut might leak a lot of blood, but will stop bleeding and heal more quickly than a round puncture wound. So, both the rate of leak and the area where it occurs should be considered.

The injection point access is also an issue. The delivery method adopted will depend on the type of access and the available resources – logistics.

Pressure-activated Sealant Delivery Methods

The methods of delivering the sealant are very flexible. The sealant will not harden during delivery regardless of the time, the temperature of the well (below 500°F) or the ambient pressures [4]. The delivery method depends on the nature and location of the leak. The treatment can be pumped from an intervention rig, from a dry completion well head, from a remote production platform, or from subsea equipments.

From an intervention rig the delivery methods comprise use of wireline dump bailer, use of coiled tubing straddle packer or bullhead down the tubing or the annulus.

From a production platform the treatment can be pumped atomized sealant into the gas lift system, through the flowlines or through umbilical lines.

Subsea delivery options include pumping through subsea umbilical, temporary umbilical plugged into a hot stab using an ROV and or divers, and ROV *belly tank* into a hot stab near the leak site.

Program Guidelines and Operation Procedures

The key features to the success of a pressure-activated sealants application are:

i) Correct diagnostics;
ii) Simple and complete operational procedure;
iii) Correct execution of the procedure;
iv) Application of proper post-operational procedures.

The main goal of diagnostics is to verify that the sealant can be delivered to the leak site generating a pressure differential that will activate the sealing process.

The operating procedure must specify the diagnostic step, the sealants chemical composition, the sealing delivery method, and parameters such as volume, rate and pressure along the operation as well as the post-operational procedures.

It is presented below an operation program sequence for a delivery option from a remote production platform.

- Rig up equipment on production unit (pump, blender, circulation tank);
- Align WCT valves;
- Establish circulation and fill lines with diesel;
- Establish the leak severity visually (ROV) and by measuring pressure loss vs. time and leak volume vs. time @ expected injection pressure; * The injection pressure must provide the differential pressure at the leak point that starts the sealant reaction;
- Define composition and volume of the sealant pill;
- Pump the sealant pill and displace it to WCT with diesel (add dye to the sealant to assist in ROV observation.)
- Close valves at WCT
- Increase pressure in steps observing sealant flow (external leak) with ROV; if necessary open WCT valves and displace the sealant in additional volumes steps; close WCT valves;
- Squeeze sealant into the leaking area at the injection pressure
- Allow sealant to cure
- Open valves at the WCT

- Circulate remaining sealant pill from system; be prepared to capture the sealant pill in a separate tank once it returns to the platform; continue circulating until clean returns are obtained.
- Rig down all pump equipment;
- Return well to service applying proper post-operational procedures;
- Watch the system carefully; if necessary, repeat the treatment.

An example of detailed program is presented in the second case history.

Study Methodology

This work is a multi case study as it analyses applications of the pressure-activated sealant in two business units, 12 assets, 21 oil production units and 43 wells of Campos Basin, from 01/21/2000 to 05/16/2005. The secondary data were obtained from operation reports (special vessel reports and production unit's records), from a data table organized by the operator sub sea equipments service unit, and from a literature review. The primary data were obtained by surveys carried out in all the production units. The first survey was an open questionnaire, sent to each production unit asking a few questions on pressure-activated sealant in the unit. Then the data table was updated with the obtained feed-back and sent to each production unit for comments. After processing the comments the final data table was achieved. This critically analyzed data table was the basis for the results and conclusions. This study phase brought up interesting observations:

i) there were discrepancies among different data source;
ii) clients and service providers had some different views, regarding results and objectives;
iii) in some cases the clients were not very aware of the treatments carried out in their units.

The study of the reports and the literature provided information on the pressure-activated chemistry, properties, limitations, advantages and disadvantages, program guidelines and operation procedures. Two case histories were selected to enrich the paper.

Two Phase History of Pressure-activated Sealant Applications in Campos Basin

From the data table a two phase history is clear. A three years learning period occurred from 2000 to 2002. A total of 23 applications with 8 success, 8 failures and 7 non-conclusive operations comprised this phase. These results revealed the necessity of better diagnostics and detailed operation procedures comprising all the process, since equipments rig up until the proper post-operational procedures. After the implementation of improvements a phase of mature technology application occurred from 2003 to 2005. In this period (till May 2005) 48 applications were done: leaking repair in 22 WCT, 8 SCSSV, 4 ASSV, 1 oil flowline flange, 1 flowline connector and 1 submarine manifold and 11 service operations (diagnostic and lines plugging repair).

Two Case Histories

The first case history is very illustrative of the learning period. A sub sea well in 300 m water depth was shut for three years due to a leak in the ASSV. A malfunction of the WCT would demand its replacement in case of rig intervention, making this approach cost prohibitive. A special diving operation was then carried out to repair the leak. After a detailed analyses a two steps treatment was carried out in June 2002. A skid holding the pressure-activated sealant injectors was placed with a ROV at 6 m from the WCT. Then divers connected a hot line into the skid and a skid line into the ASSV. See **Figure 2.** In the first treatment step a solvent was pumped into the ASSV to remove a compound previously used, periodically, to seal the leak and no more effective. In the second step a specific tailored pressure-activated sealant was pumped through the ASSV leak, sealing it. The well was put on stream with a sustained rate of 150 m³/d of oil. A design mistake let a trapped pressure in the system, making it impossible to close the ASSV if wished.

The second case history is about a leak in a Wet Christmas Tree – Flow Line Mandrel interface at 479 m water depth [4]. During normal production, with 30 kgf/cm² flowing pressure at the production platform, there was no leak. During shut-downs a leak was observed. A video taken via ROV indicated continuous gas and oil bubbles from the 4 in WCT-FLM interface whenever the internal flowline pressure was greater than 35 kg/cm² (500 psi). As an alternative to the mechanical repair options, pressure-activated sealant was selected to cure the leak. **Figure 3a** shows the schematics to carry on the treatment from the production platform The operational procedure, which was concluded in 08/17/2004, was as follows:

1. Rig up the triplex pump and blending tanks to the 4 in flowline and 2in gas lift line on the production unit. **Figure 3b.**
2. Test all equipment and discharge lines to 200 psi low and 2500 psi high.
3. Set the subsea wellhead valves to allow circulation via production flowline- Cross-Over -gas lift flowline.
4. Using diesel, establish circulation down the flowline, through the tree and back up the 2 in gas lift line to the platform. Keep circulating until full returns of clean diesel.
5. Close the Wing 1 and Cross-Over WCT Valves.
6. Carry on diagnostic pumping diesel. Obtained: 1 liter per minute at 140 kg/cm² (2000 psi) surface injection pressure. As the leak started at 35 kg/cm², the differential pressure through it was about 105 kg/cm² (1500 psi).
7. Blend the necessary three-phase sealant treatment
8. Open the Wing 1 and Cross-Over WCT valves.
9. Inject the sealant pill into the 4 in flowline. Add dye to the sealant pill to assist in ROV observation.
10. Displace the sealant treatment to the WCT with diesel.
11. Close the Wing 1 and Cross-Over WCT Valves.
12. Increase the flowline pressure to 1000 psi. Monitor the flowline hub to determine if the sealant front has reached the location.
13. If no sealant is seen after 5 minutes of observation, open the Wing 1 and Cross-Over valve and displace the sealant treatment with another 30 gallons of diesel. Repeat the above step to determine sealant progress. Continue displacing sealant in 30 gallon steps until sealant is observed and then go to the next step.

14. Continue squeezing sealant into the leak area until a seal is obtained at 1000 psi. Allow the seal to cure for 1 hour.
15. Increase the flowline pressure to 1500 psi. Allow the seal to cure for 1 hour.
16. Increase the flowline pressure to 2000 psi. Allow the seal to cure for 4 hours.
17. Cycle the flowline pressure from 300 psi to 2000 psi a minimum of 6 times.
18. Apply 2000 psi squeeze pressure and allow the seal to cure for an additional 6 hours. Monitor with the ROV to ensure no leaks.
19. Open the Wing 1, Cross-Over and Wing 2 WCT valves.
20. Circulate the remaining sealant pill up the gas lift line and back to the platform. Capture the sealant pill in a separate tank once it returns to the platform. Continue circulating until clean returns are obtained.
21. Rig down all pump equipment from the production flowline and gas lift flowline entry points.
22. Purge diesel from the gas lift line. Return all safety systems to normal service.
23. Return the well to production slowly according to operator procedure.

Results and Conclusions:

There were two phases in the pressure-activated sealant history in Campos Basin: a learning phase (2000 – 2002) and a mature technology application phase (2003 – 2005). Two case histories were presented illustrating the two phases.

The results and conclusions hereafter presented refer to the mature phase. This phase comprises 11 service operations and 37 sealant applications. Focusing on the sealant applications the analyses showed 34 success, 2 failures and 1 non-conclusive operation.

A significant improvement in the diagnostic phase improved the operation procedures and avoided improper treatments.

Most of the applications (30) were in WCT (22) and SCSSV (8). The sealant application success index is about 94.4%.

The economic results are very favorable to the sealant treatment. This has an average cost around one hundred thousand dollar, while a conventional mechanical repair costs above one million dollar.

The sealant treatments are more friendly to health, safety and environmental.

There were a few instances where the flexible seals failed after a period of time. Most of the failures were attributable to attempts to seal leaks that were beyond the reasonable capabilities of the sealant technology. It is still too early to establish treatment longevity. The longevity of the seals as correlated to the severity of the leaks cured may be the subject of a later study.

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Acronyms and Abbreviations

ASSV: Annulus safety subsurface valve
°F: Fahrenheit degree
kg/cm²: Kilogram per square centimeter
km²: Square kilometer
m: Meter
m³/d: Cubic meters per day
MD: Measured depth
Psi: Pounds per square inch
ROV: Remote Operated Vehicle
SCSSV: Surface controlled subsurface safety valve
WCT: Wet Christmas tree
WD: Water depth

Metric Conversions

psi x 6.894 757	E+00 = kPa
in x 2.54*	E-02 = m
ft x 3.048*	E-01 = m
mi x 1.609344	E+00 = km

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Figure 1. Sealant efficiency test on a flowline hub

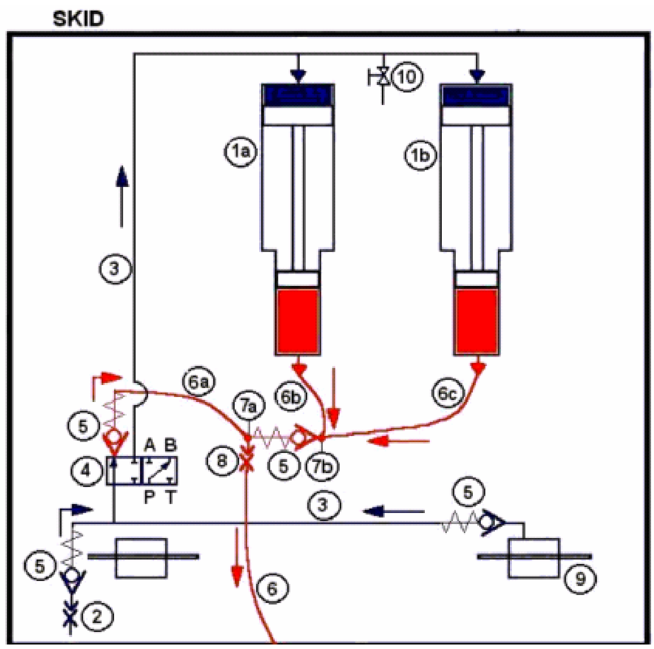

Figure 2. Delivery scheme used in the first case history

1. Sealant injector.
2. Connection to the production unit – JIC – 5.000 psi.
3. Steel tubing – 5.000 psi.
4. Válvula seletora 3/8 in selector valve – 3 ways 2 positions – 5.000 psi – actuated by ROV.
5. 3/8 in check valve – 10.000 psi.
6. 3/8 in hose – 10.000 psi.
7. 3/8 Te JIC 6 – 10.000 psi.
8. JIC 6 – 10.000 psi.
9. Hot stab.
10. System relief valve

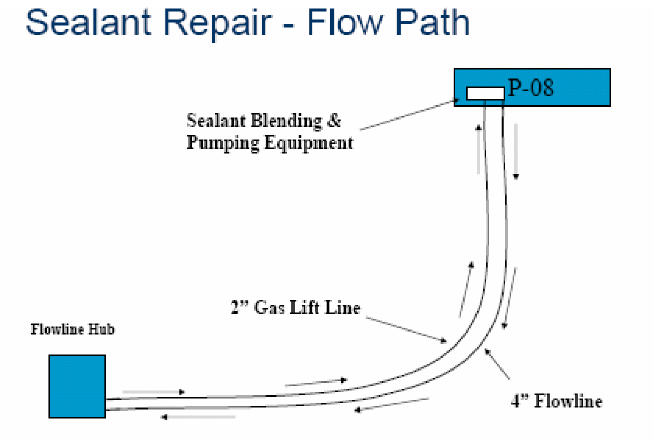

Figure 3a. Sealant pumping scheme in the second case history

Figure 3b. Triplex pump and blend tank in the second case history