BP's Deepwater Intervention Techniques for Maintaining Integrity in Subsea Wells

Author: Daniel Gutierrez, BP Subsea Maintenance Engineer

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The following technical document outlines subsea integrity management issues that BP experienced during U.S. operations in the Gulf of Mexico. The issues summarized are BP success stories that required the use of innovative subsea repair techniques. The topics were chosen based on their technical diversity and their ability to apply to a number of subsea integrity management issues. Although it is unlikely that the problems outlined below will precisely match others in industry, the information provided will hopefully aid in the development of new and pioneering solutions to a variety of subsea challenges.

BP Subsea Integrity Management
Seal-Tite Casing Pressure Communication Repair
U.S. Operations / Gulf of Mexico

<u>Failure History</u>

In late 2002, BP identified a pressure anomaly in one of its subsea tieback wells. Pressure data acquired from the subsea well indicated slight pressure communication between the production tubing string and the production annulus. Preliminary diagnostics focused on the subsea tree and several isolation gate valves as the potential source of the pressure integrity problem. Using specialized testing procedures; BP was able to confirm that the subsea tree valves were sealing and that the source of the pressure communication was in a down-hole component. BP was able to also determine that the source of communication was above the surface controlled subsurface safety valve (SCSSV). The preliminary testing operations were able to isolate the location the communication to approximately 2500 ft. (760 m) of production tubing. Figure 1.1 illustrates the pressure communication seen between the production tubing and the annulus.

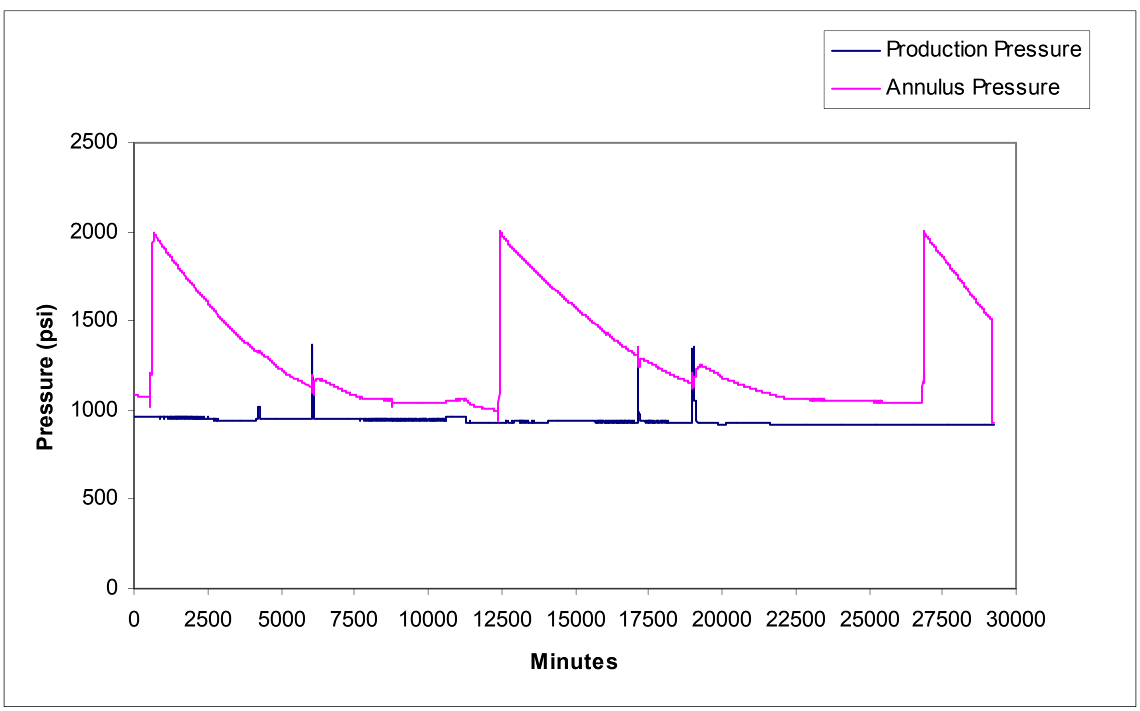

Figure 1.1 - Tubing Pressure Communication

As prescribed by the U.S Minerals Management Service (MMS), all subsea wells are required to meet pressure integrity requirements for the production annulus. The standard test procedures call for the operator to adjust annulus pressure from an equalized state by bleeding-off or adding pressure and monitoring the system for a 24-hour period. Test results confirmed that the subsea well in question did not meet regulatory requirements. It became apparent that the pressure communication in the subsea well would need to be repaired. Due to the high cost and risks associated with a subsea rig intervention, BP assembled a team to review repair alternatives for the tubing pressure communication. With few alternatives to work with, the team identified a sealant solution as a possible repair.

Diagnostic and Qualification Testing

Seal-Tite International was brought in to investigate the possibility of using a sealant to repair the production tubing pressure communication. The company recommended a proprietary sealant solution to possibly eliminate the communication between the production annulus and tubing string.

The sealant material is basically a pressure-activated fluid additive that polymerizes into a flexible solid upon contact with the leak site. This proprietary solution solidifies only at the high point of differential pressure. The release of pressure at the leak causes a chemical reaction within the sealant, so only the leak is sealed. Any excess sealant remains inert, in a liquid form, and will not plug adjacent equipment. The environmentally approved sealant can be left in the system indefinitely or flushed out.

Although the product specifications were promising, there were several technical hurdles to overcome before a repair operation could be initiated. BP and Seal-Tite International teamed up to systematically resolve the technical questions.

Question #1: How would the sealant material be delivered to the subsea well?

The subsea system would theoretically allow for injection of the sealant directly into the wellhead through a subsea mateable junction plate. An ROV equipped with a subsea reservoir and injection pump could be used to deliver the sealant material to the well. Several issues were quickly raised with this subsea intervention configuration. Although robust, the sealant material requires controlled injection rates/pressures along with specific procedures for setting and curing the sealant. Fine control of pressure and flow rate through an ROV deployed system into the well presented a significant concern. ROV vessel costs and injection control issues pointed the team toward the investigation of alternate delivery methods.

It became apparent that controlled delivery of the sealant material from the production platform presented the greatest chance for success at minimal intervention cost. Delivery from the platform would require that the material be injected through 7900 ft. (2400 m) of ½" ID umbilical tubing.

BP's hazard review process required a testing protocol to confirm that umbilical injection of the sealant material would not pose a threat to umbilical system. The testing would attempt to replicate actual subsea conditions and hardware to confirm no problems would be generated from the repair operation. Testing would cover chemical compatibility, low temperature behavior, and flow assurance of the sealant material. Figure 1.2 illustrates the testing mock-up to prove the sealant could be delivered to the subsea well without incident.

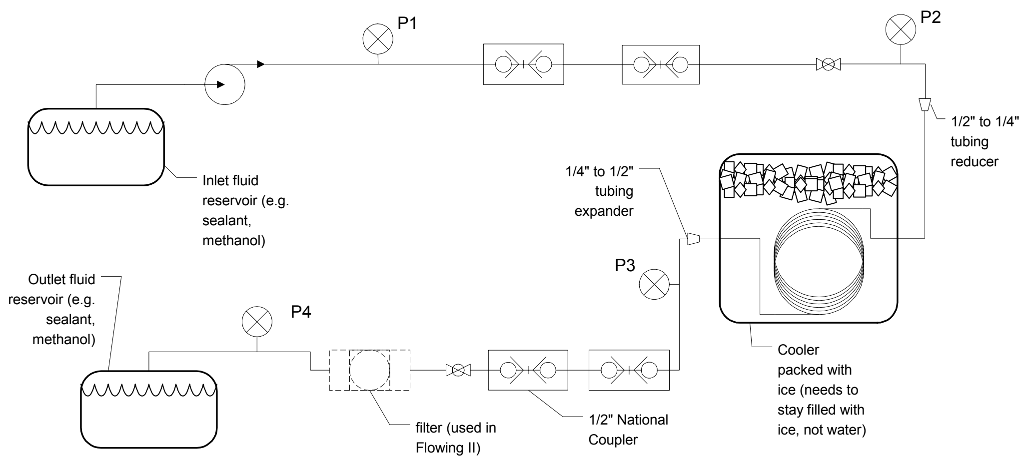

Figure 1.2 – Sealant Delivery Testing Operation

The testing operation was systematically arranged to mimic actual conditions that would be encountered during the repair operation. The tests proved to BP that the sealant material could effectively be delivered to the subsea well through the existing umbilical system without risk to the subsea system.

Question #2: How would the sealant material be delivered through the subsea tree?

Testing by Seal-Tite International assured BP that the sealant could be delivered to any location in the subsea system that was not highly restrictive. The next technical challenge required an investigation of the sealant being pumped through the subsea tree.

To effectively direct the sealant to the annulus, isolation gate valves in the subsea tree would need to be arranged to accommodate this requirement. BP was initially concerned that exposure of the sealant to subsea gate valves would result in accidental sealing of valves. Seal-Tite International confirmed that a seal would be generated at a valve leak location (if one existed), but that the seal would not restrict the gate valve operation. BP accepted Seal-Tite's standpoint on the issues surrounding the subsea gate valves.

As a general rule, it is recommended that the sealant be placed in the direction in which the pressure differential would be applied under normal operating conditions. With this recommendation in mind, procedures would be used to direct the sealant through the subsea tree to the production annulus of the well. The sealant would then be directed through the annulus master valve, through the tubing hanger assembly, and into the annulus. Using scale drawings of the hanger and tree assembly, confirmation was made that the sealant would not be introduced into a restrictive location that could introduce potential problems.

The investigation confirmed that the sealant material could effectively be delivered through the subsea tree and into the production annulus.

Question #3: How would the sealant material be delivered to the proper location in the tubing string.

The preliminary testing operations were able to definitively limit the location of the pressure communication to approximately 2500 ft. (760 m) of the production tubing. The annular volume associated with the area in question was approximately 88 BBLS. To minimize job costs, the team was required to develop an engineered solution for placing the sealant at the leak location using only 3-5 BBLs (less than 6% of the total volume in question). Accurate placement of the sealant at the leak site would be critical to the success of the operation.

Early diagnostic operations recognized a phenomenon occurring in the well's production annulus. As the well was flowing, the annulus would equalize to flowing pressure (due to the tubing string communication). When the well was shut-in and production pressure increased to shut-in pressure, the annulus would equalize to this elevated pressure. This would charge the annulus with production gas that would rise to the top of the casing string. When the well was brought back online and production pressure decreased to flowing pressure the gas charge in the annulus would force completion fluid in the annulus out of the leak site and into the production stream. As this process is repeated through the life of the well, the completion fluid level in the annulus moved downward toward the leak location. Over time, all of the original completion fluid above the leak was replaced with methanol (used for annulus service and pressure maintenance). This phenomenon would turn out to be critical for the success of the repair operation.

Knowing that there was very likely an interface of methanol (6.6 PPG) and calcium chloride (10.5 PPG) at or near the leak location, Seal-Tite proposed placement of the sealant utilizing a special weighted mixture of sealant. Once injected into the annular space, the weighted sealant (9.9 PPG) would sink through any methanol in the system and stop once it reaches the heavier calcium chloride interface. Theoretically, this would place the sealant at or near the leak location. BP and Seal-Tite International now had the critical answer to placing the sealant material at the source of the pressure communication.

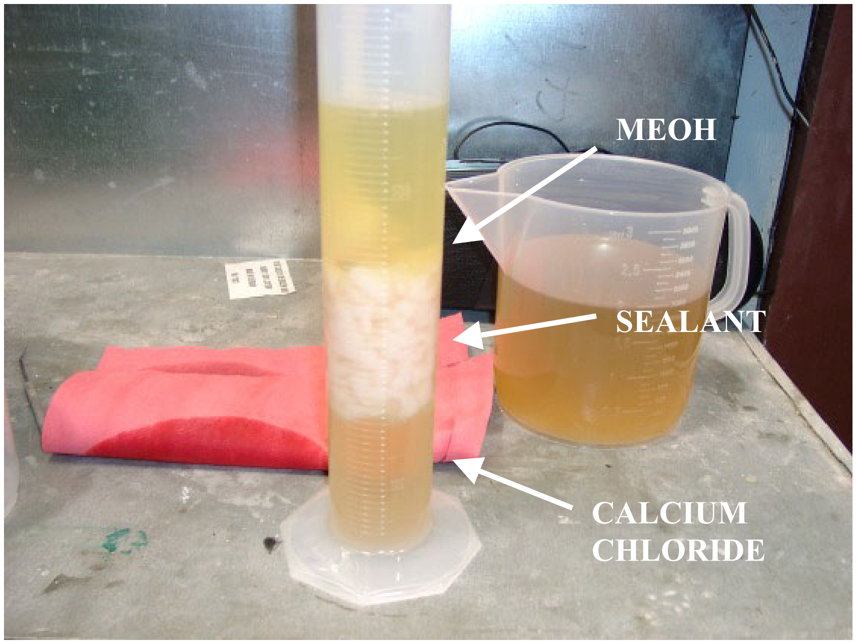

Figure 1.3 – Sealant Development

Job Summary

With several weeks of testing and diagnostics supporting the repair operation, BP decided to have Seal-Tite perform the repair operation. A pre-job meeting was held with BP and Seal-Tite personnel to finalize the repair procedure and prepare for offshore operations.

The following sealant and spacer volumes were agreed upon for the repair.

- 5 BBLS of 9.9 PPG water based sealant
- ½ BBL of spacer, 50/50 mixture of 6.6 PPG methanol and 10.5 PPG $CaCl_2$
- ½ BBL of 7.3 oil based sealant (contingency)

With procedures in place, BP obtained regulatory approval from the MMS to initiate the repair operation. The BP and Seal-Tite International team began offshore operations. The primary concern for the operation was flow rate and pressure control of the sealant material. Using surface pumps tied into the subsea umbilical system, there were no issues associated with rate or pressure control. The sealant material was successfully pumped into the annular space of the subsea well via the methanol supply umbilical circuit. Pressure control was maintained using both surface and subsea tree pressure gauges. Almost immediately, pressure trends in the annulus indicated a continuous decay in the tubing leak rate. The three-day operation resulted in the successful repair of the tubing pressure communication. The sealant was successfully flushed from the umbilical and the subsea tree with no residual effects.

As a result of the operation, BP was able to prove annulus integrity to the MMS and avoided a costly rig intervention.