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ANNULUS TESTING FOR CONDITION ASSESSMENT AND MONITORING OF FLEXIBLE PIPES

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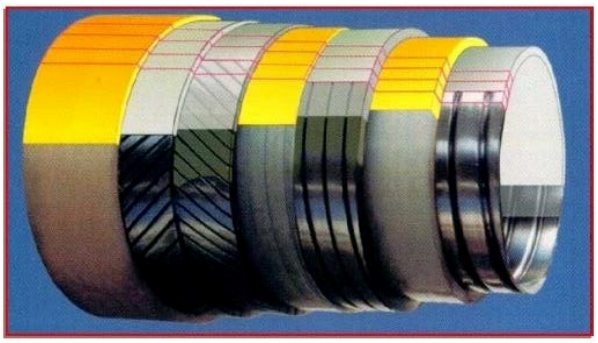
ABSTRACT

The Norwegian operator Norsk Hydro has more than 80 flexible dynamic risers and service lines in operation at different platforms. Riser integrity monitoring programs have been established for the flexible risers in order to ensure safe and reliable operation. SeaFlex has performed annulus testing on a large number of these risers as a part of the programs.



Picture 1. Flexible pipe body structure

The free annulus volume of a flexible pipe is defined as the volume between the extruded internal pressure barrier layer and the extruded external sheath subtracted the volume occupied by pressure- and tension armor, tape and eventual other layers. Two methods are presently used by the industry for annulus free volume testing of flexible pipes, namely nitrogen pressure testing and vacuum testing. Both methods identify trends of volume reduction with time and to detect annulus flooding. Annulus testing has proven to be an efficient and reliable tool for detecting annulus flooding, blocked vent ports and outer sheet damages.

This paper address the challenges related to annulus testing of flexible pipes, advantages, experiences and how such tests and the results are used for condition assessment and monitoring of the risers.

INTRODUCTION

Norsk Hydro and other Operators have applied annulus testing on flexible risers on the platforms they are operating in the Norwegian sector of the North Sea. Annulus free volume testing (annulus testing for short) has either been performed by nitrogen pressure tests or vacuum tests. Selection of method depends on the testing contractor. The testing has been performed on risers in service and in connection with different types of riser related marine operations since 1999. Later, annulus tests have been specified as an additional factory test

prior to delivery in order to establish reference volumes for later in service testing.

The tests have verified empty annuli, filled annuli, annuli that are slowly filling over time, blocked and partially blocked end-fitting annulus vent ports.

Results from annulus tests provide valuable information in the process of evaluating riser integrity, including:

- Prevent burst of outer sheath by implementing corrective actions in due time.
- Explain background for bursts in outer sheaths.
- Give important information for reassessment of pipe fatigue service life.
- Detect outer sheath damage.
- Verify successful riser installation operations.

BACKROUND

Norsk Hydro decided to perform annulus tests on all their flexible risers in operation after ROV inspections revealed some risers with bursted outer sheaths. The need to inspect the risers' annuli was further strengthen after detection that some risers were installed with leaking or missing subsea end-fitting plugs. Later, experience with several outer sheath installation damages was the background to also use annulus tests as an additional test to verify successful installation.

The testing revealed several risers with filled or partially filled annuli and several blocked or restricted topside end-fitting annulus vent ports. In service inspection programs were consequently revised to include annulus and vent port testing at regular intervals.

Later testing identified that annulus filling over time can occur, and that vent port status may change from open to restricted or blocked.

Results from the annulus tests have been used to implement corrective actions in order to avoid future damages and as input to reassessment of pipe fatigue service life.

In order to document sufficient fatigue life and avoid unnecessary riser shut downs, the following actions were taken:

- Implement more accurate fatigue life analysis methodology.
- Develop steel armor wire SN-curves representative for in service annuli environments.

ANNULUS FREE VOLUME TEST METHODS

If the riser annulus is connected to a pressurized flare system, the riser is isolated from this system and allowed to vent to the atmosphere prior to testing.

Nitrogen pressure testing is performed by pressurizing the flexible riser annulus through the end fitting annulus vent port(s). The annulus is pressurized according to an established procedure. The test pressure is at all times kept below the riser supplier specified pressure capacity for the outer sheath. Unless specific issues are related to the riser, a pressure of typical 3 barg is applied. A typical 10" riser with a length of 800 m will have a filling rate of approximately 0.3-1.0 bar/h if the vent ports allow free flow of nitrogen. When the final annulus pressure is reached, the riser must be given some time for pressure stabilization. If the pressure stabilizes, the annulus free volume is calculated based on the difference in initial and final annulus pressure and the volume of nitrogen used for pressurization. A pressure decrease during stabilization indicate leak in the outer sheath.

Vacuum testing is performed by extracting annulus gas from the end fitting annulus vent port(s) according to an established procedure to a predetermined under pressure. Unless specific issues are related to the riser, a pressure of typical 0.2 to 0.4 bara is applied. When the final annulus pressure is reached, the riser must be given some time for pressure stabilization. If the pressure stabilizes, the annulus free volume is calculated based on the difference in initial and final annulus pressure and the volume of annulus gas extracted. The volume extracted is verified by measuring the volume of air that is entering into the annulus after stabilization reestablishing annulus pressure equilibrium with the atmospheric pressure. If the vacuum tests reveal anomalies, nitrogen pressure tests are applied as back up to obtain more information.

For risers in service, temperature correction of the calculated annulus free volume according to the ideal gas law is performed. The temperatures (^{o}K) are the calculated temperature in the annulus and the ambient temperature of the nitrogen or atmosphere.

$$pV = nRT \quad (1)$$

ANNULUS TEST EQUIPMENT

For nitrogen pressure testing is it convenient to use standard 50 liters nitrogen bottles. The nitrogen pressure regulator is modified not to provide outlet pressure above maximum acceptable for the annulus testing. Safety pressure relief valve with setting to maximum acceptable annulus test pressure is mounted between the nitrogen source and the riser to be tested. The regulator modification combined with the use of pressure relief valves minimizes the risk of over-pressurizing the riser annulus. Accurate pressure gauges for the nitrogen bottle and for the nitrogen feed in/annulus pressure are used. Good experience with digital ex-proof pressure gauges has been obtained. In addition, isolation valves, hoses and fittings as needed to make up the system and connect to the riser are used.

For vacuum testing electrical driven vacuum pump is applied. Safety pressure relief valves are not required since the method is working below atmospheric pressure. Accurate volume flow meters and pressure gauges are required.

For both methods leak test chemicals, liquid tread sealant agent and, from experience gained, a wide range of fittings are required.

MOBILISATION OF EQUIPMENT

The nitrogen pressure testing equipment is relatively small and packed in a toolbox. One toolbox with two test kits weights between 15 – 19kg and may be carried as cargo on helicopter flights. Nitrogen pressurized to maximum 200bar in 50 liter bottles are usually shipped by supply vessels and provided by the Field Operator at site to the testing personnel.

The vacuum testing equipment is bigger and heavier, but the toolboxes can be hand carried, and usually shipped by supply vessels. Careful interfacing of voltage, ex requirements, allowable type and length of cables and type of sockets related to the electrical vacuum pump and the site requirements are required.

As long as equipment rate is less than personnel rate, is it recommended to mobilize two sets of testing equipment in order to reduce the time needed at site. One testing technician may operate at least two sets simultaneously. Two sets will in addition provide additional equipment contingency.

Ex certificates of electrical equipment, if applied, and chemical agents health and safety data sheets must be brought to the test site.

TEST DURATION

The test durations are highly dependent upon both riser volume and especially the vent port status. Nitrogen pressure testing of riser without anomalies will typically be tested within a 12 hours working shift. The test technician can normally operate two test kits in parallel, i.e. at least testing of two risers per 12 hours shift can be scheduled if two test kits are mobilized. If anomalies are revealed, the test duration may decrease or increase depending on the nature of the anomalies. Repetition of tests may be required to verify test results in case of anomalies.

RESULTS

SeaFlex tested 49 risers at different sites in 2003 for different field Operators. Several of the risers were tested multiple times, typically prior to and after replacement of neighboring risers, hence the total number of tests performed were close to 70. Some of the risers were installed in 2003, some in 2002 and the others between 1997 and 2001. The results from the tests can be summarized as follows:

- 3 risers, 1 installed in 2003 and 2 installed in 2002, with restricted vent flow were identified. Corrective work was recommended, needed for one riser and beneficial in order to increase the safety margin for one other riser. The recommendations were given onboard. Planning, mobilization and execution of corrective work were performed within less than 3 weeks.
- 23 risers, 1 installed in 2002 and the remaining in 2001 or earlier, with partially flooded annulus. Some of the risers showed reduced free volumes compared to test results from previous years.
- 26 risers with no anomalies.
- No flexible pipe outher sheath installation damages, end-fitting plugs or sealing leaks causing rapid filling of the annulus were discovered.

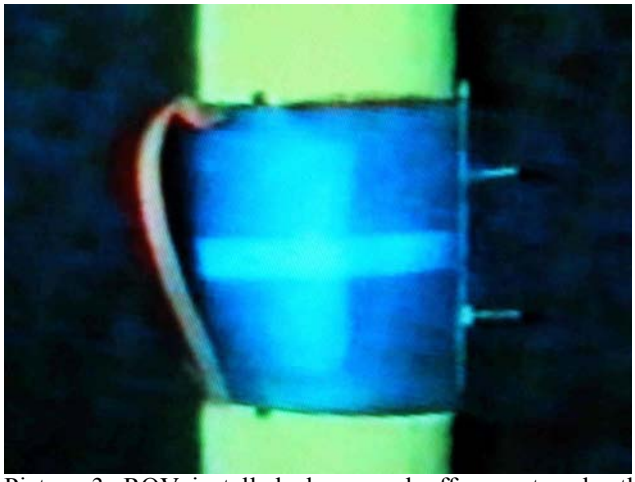
Previous tests results and corrective actions:

- Blocked annulus vent ports for 3 risers in service. ROV inspections following the annulus tests revealed burst in the outher sheath for 2 of the 3. The 2 risers were later replaced due to corrosion effects giving insufficient remaining service life. The 3rd riser had an alternative vent path established and retests were scheduled.
- Blocked annulus vent ports on 1 riser that was installed, but not yet in service. ROV inspections following the annulus tests revealed no anomalies in the outher sheath. Alternative vent path was established and retests were scheduled.
- Several risers with partially filled annuli. Corrosion fatigue analyses performed with actual operating pressures documented sufficient fatigue service lives provided that the liquid in the annuli does not enter the bend stiffener or bellmouth regions.
- Several risers with filled annuli. Corrosion fatigue analyses performed with actual operating pressures documented sufficient fatigue service lives for all risers except one. This riser was replaced prior to production start up.
- One umbilical with water in the core. The core had to be dewatered or a minimum hose pressure applied in order to prevent collapse of the hoses. Dewatering process was implemented with successful results.
- Several umbilicals with integrated methanol line had liquid filled methanol line annuli. The liquid chemical analysis identified water and methanol. Corrosion fatigue analyses performed with actual operating pressures documented sufficient fatigue service lives.

Picture 2. Outher sheath burst due to blocked annulus vent

Other activities that has been taken based on annulus tests revealing anomalies are:

- Development of SN-curves representative for flexible pipe steel armoring exposed to recorded annulus environments such as water combined with different partial pressure of diffused CO_2 and/or H_2S.
- Development of flexible pipe armor steel corrosion rates in applicable annuli environment for engineering assessment.
- Development of procedures to empty liquid filled annuli.
- Development of procedures to establish alternative annulus vent paths on risers in service with potential hydrocarbon gas in the annuli.
- Development of procedures and equipment to seal off flexible pipe outer sheath through thickness damages.



Picture 3. ROV installed clamp seal off an outer sheath through thickness damage.

EVALUATION OF RESULTS

If results from previous testing, from factory tests and/or at site tests are available, the obtained results will be compared to these results and calculated theoretical annulus free volumes. If no previous results are present, the calculated figures will be the basis for evaluation of the obtained test results. The accuracy of the test methods is believed to be within 10% of the real volumes.

The accuracy is reduced for risers in or recently been in service due to diffusion of gases from bore to the annulus. The same inaccuracy is applicable for risers that recently have been in service due to release of absorbed gases in the pressure barrier material. The reduction in accuracy is greater for PVDF materials than Nylon 11 (Rilsan). Although the accuracy is reduced valid results for evaluation will be obtained when testing risers in this status.

Each end fitting has normally 3 vent ports, one or two connected to topside vent system and the remaining plugged. If the flow rate is low compared to experience with similar risers or from previous test results, the flow rate has to be determined. When the flowrate is established, it will be evaluated versus calculated annulus vent flow rate for the actual riser in service. If blocked or significantly restricted annulus vent is discovered, corrective actions in order to prevent burst of the outher sheath have to be evaluated. In case of annuls vent restrictions, all end-fitting vent ports should be tested in order to assess the total vent port status for the riser in question. Blocking or different degrees of restrictions may be related to several different sources:

- Collapse of vent path through the end fitting.
- Corrosion products in the vent paths.
- Epoxy from end fitting in the vent path.
- Low viscosity oil in the vent path.

Picture 4. Annulus vent path blocked with corrosion product.

In case of results giving partially filled annulus volumes, the evaluations have to take into account that the test methods are only measuring the free volume between the flexible pipe end-fitting and a liquid surface in the annulus. The possible liquids in a flexible pipe annulus are oil from manufacturing of the pipe, seawater due to outher sheath damages, condensed water due to diffused H_2O from the pipe bore and, in some cases, unexpected liquids from the topside vent annulus system. However, small outer sheath damages or end-fitting seal leaks

cannot be ruled out. It has been experienced riser with small measured free annulus volume that actually just had a small "plug" of liquid and additional free volume underneath the "plug". This situation has been verified by a retrieved, retrieved due to other reasons than annulus test results, riser that went through an onshore annulus emptying process followed by removal of the outher sheath and subsequent scrapping. Recommendations will in most cases be based on the assumption that there is liquid from the measured surface level to the other end of the riser, and that there may be changes in annulus free volume over time.

In case of results showing that the riser annulus is filled to the seawater level or liquid is escaping through the annulus vent ports, the riser annuli should be assumed full of liquid. The possible liquids in this situation are either seawater due to outher sheath damages, condensed water due to diffused H_2O from the pipe bore or unexpected liquids from the topside vent annulus system. It has to be noted that annuli liquid has been observed evacuating from end-fitting annulus vent ports for risers hanged off more than 20m above the sea surface level. Recommendations will in most cases be based on the assumption that there is a driving force from diffused gases from the pipe bore that may "lift" the liquid up to the end-fitting vent ports and even further up into the topside riser annulus vent system.

Picture 5. Annulus liquid out of the vent port

CORRECTIVE ACTIONS

In case of blocked riser annulus vent, an alternative vent path has to be established to prevent burst of the outer sheath. Experience shows that vent path anomalies normally occur within a short distance from the end fitting, or in the end fitting itself. Alternative vent path can be established by:

- Check all 3 vent ports. If one of the other vent ports is acceptable, apply this for annulus vent.
- Drill new vent ports and, if required and feasible, channels. This corrective action has been successfully applied on several risers and work if there is communication in the crevice around the end-fitting armor anchoring epoxy and the flexible pipe annulus.
- Drill new vent port directly through the outer sheath below the end fitting.
- Cut off the end fitting and re-terminate the riser.

In case of restricted riser annulus vent flow rate, the following corrective actions are identified:

- Check all 3 vent ports. If one of the other vent ports is acceptable, apply this for annulus vent.
- Check the vent port flow rate versus the required rate, if acceptable, no corrective actions are needed. If not acceptable, alternative vent path as for blocked annulus vent has to be established.

In case of partly filled annulus, the following corrective actions are identified:

- Perform ROV survey in order to inspect the riser outher sheath.
- Perform corrosion fatigue analysis based on the assumed applicable annulus environment for the flooded section of the riser. The analysis may use historically experienced operating conditions up to the anomaly detection date and predicted conditions for the future years. General corrosion has to be addressed in case CO_2, H_2S or O_2 is present. In most cases, refined analysis will be sufficient to document required fatigue service life. If the required service life cannot be met, planning for replacement should be initiated.

In case of annulus full of liquid, the following corrective actions are identified:

- Same actions as for partly filled annulus.
- If the riser annulus is connected to a topside vent system it should be disconnected from the system in order to avoid flooding of the liquid into the topside system. If the riser will remain in service, an alternative topside vent route has to be established.

In case outher sheath burst or other through thickness damages are revealed, the following corrective actions are identified:

- Perform general corrosion and corrosion fatigue analysis, as for partly filled annuli, assuming water filled annulus. The water has to be assumed saturated with oxygen in the close vicinity of the damage. Often refined analysis will be sufficient to document required fatigue service life if the damage was revealed shortly after it occurred. If the required service life cannot be met, planning for replacement should be initiated.
- Install clamps over the damage area in order to isolate the annulus from the sea. This will give stagnant water conditions in the annulus after short time. Stagnant conditions will give longer fatigue service life.

- Evaluate possible H_2S formation in stagnant seawater in the annulus.

RECOMMENDATIONS

Based on the good experience with annulus tests it is recommended that:

- Flexible risers should be annulus free volume tested as part of the factory acceptance testing prior to delivery.

- Annulus free volume testing should be performed at regular intervals as part of a dedicated flexible riser integrity monitoring program.

- Annulus free volume testing should be applied to verify status after dewatering of annuli that have been water filled.

CONCLUSIONS

Based on the experience from annulus tests performed it can be concluded:

- Annulus testing is a simple, well establish and proven test method.

- Annulus testing is a reliable method in order to determine annulus free volume above a liquid surface in the annulus.

- Annulus testing is a reliable method in order to determine annulus vent restrictions or blocked vent path.

- Corrective actions implemented based on annulus test results have prevented flexible riser failures.

ACKNOWLEDGMENTS

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REFERENCES

None.