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Taking the gas lift valves to a new level of reliability

Jørn Andre Carlsen/Statoil, Øyvind Stokka/PTC and Erling Kleppa/PTC

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Abstract

Gas lift valves are an integral part of the tubing in gas lifted wells. Many operators use tubing with premium threads for these wells. Additional safety equipment, including the packer and the downhole safety valve, has been subjected to a program intended to prove its capabilities as a safety device. This is not the case with standard gas lift valves, developed and delivered according to the governing standard, ISO 17078-2. On the contrary, this standard states that the valves are only intended to be a flow check and not a pressure safety device. This paper discusses the development of a new validation standard, where the intention is to prove the equipment's safety capacity, as well as new equipment developed to meet these challenges.

Introduction

Most operating companies design their wells according to external or internal regulations with respect to safety equipment and safety levels. Each component needs to meet material standards and specific equipment standards. The standards will also describe production requirements as well as acceptance testing procedures for the equipment in question. New equipment typically has to be qualified to a certain validation procedure described in a standard issued by an external standards organization and often to additional internal company requirements.

Barrier Philosophy

The safety philosophy of preventing uncontrolled release of hydro carbons is often referred to as barrier philosophy. The barrier philosophy for a given well typically depends on region, nationality and operating company. The Norsok D-10 is an example of a standard describing elements preventing hydrocarbon or pressure release to the atmosphere and it defines well barriers as; "Well barriers are envelopes of one or several dependent well barrier elements preventing fluids or gases from flowing unintentionally from the formation, into another formation or to surface. The well barrier(s) shall be defined prior to

commencement of an activity or operation by description of the required well barrier elements to be in place and specific acceptance criteria."

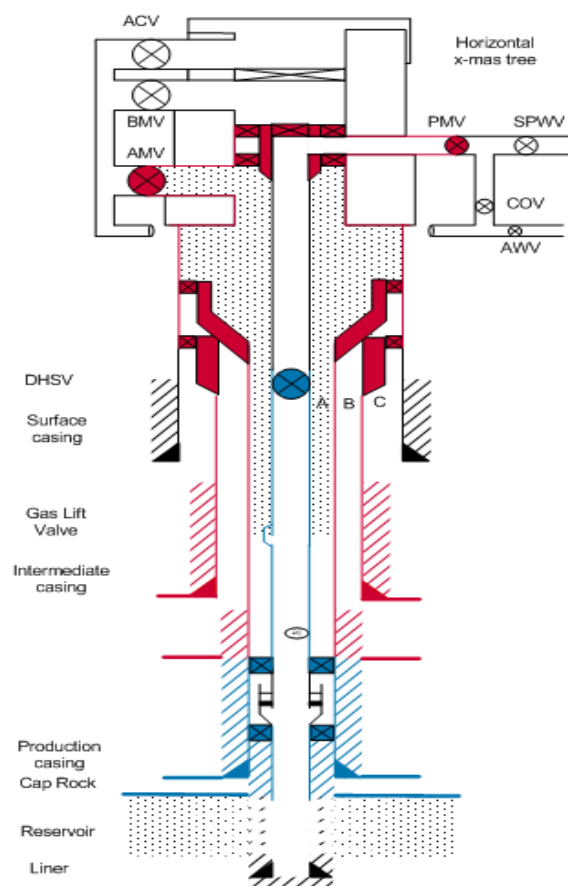


Fig. 1 The barrier schematic for a Statoil subsea well. The inner pressure containing envelope is managed by the blue items, i.e. the production packer, liner, tubing, gas lift valve and downhole safety valve. The outer barrier is managed by the production casing and the subsea horizontal tree system.

A key element in this philosophy is that the barrier elements are accepted on the basis of acceptance criteria. The acceptance criteria are often described in standards for known equipment. Examples of standards describing acceptance criteria are; “ISO 10423/API 6A Drilling and production equipment – Wellhead and Christmas tree equipment” or the “ISO 14310:2008 Petroleum and natural gas industries -- Downhole equipment -- Packers and bridge plugs”. The purposes of such standards are to define the process of qualification and production of the equipment. The qualification process will normally relate to the required safety level of the equipment based on its criticality and the expected lifetime of the equipment.

As an example the ISO 10423 describes a series of tests for one qualification level and also a leak criterion for this level, e.g. the PSL level 3G describes a leak criterion of zero visible bubbles for 15 minutes. In a similar manner the “ISO 13679 Procedures for testing casing and tubing connections”, has a leak criterion for gas of 9 cc/15 min.

In summary, these standards identify the equipment to be a part of the safety system for the well and describe processes and procedures in order for this equipment to be fit for its purpose.

The ISO 17078-2, Flow control devices for side-pocket mandrels

If one is not familiar with the ISO 17078-2 standard, one may be misled to believe that this standard is also referring to safety equipment in the same manner the above mentioned standards do. This is not the case and the standard itself points out that “*These devices are designed and intended to prevent reverse flow through a flow control device. They are not designed nor intended to be a part of the safety system*”.

In trying to design a system based on a standard of qualified barrier elements the content of ISO 17078-2 presents a problem. Other safety elements within the well construction, like the packer, tubing and wellhead, are establishing procedures to qualify safety equipment, while the ISO 17078-2 is stating that the equipment is not “*to provide a tight shut-off pressure safety seal*”.

A chain is no stronger than its weakest link, and in this case a weak link will be the gas lift valves qualified to ISO 17078-2. One will also be in breach with Norsok D-10 or similar standards, as the valves do not offer a “*tight shut-off pressure safety seal*”.

Development of a new qualification requirement for gas lift valves

By having the above facts in mind Statoil decided to establish a validation procedure that is in line with common practice for other safety devices. The current standard for gas lift valves, ISO 17078-2 was combined together with the ISO 14310 Packers and bridge plugs and ISO 10432 Subsurface safety valve equipment. In

particular, the focus was to investigate what elements were present in the standards that answered the requirement of the Norsok D10 standard of being a “*description of a specific acceptance criteria*”.

The main missing item in ISO 17078-2 (gas lift valves), is the lack of leak acceptance criteria comparable to other safety elements in the well. Additionally, a validation program that substantiates the probability for the valve to maintain its safety capability throughout the lifetime of the well was also missing.

Statoil stated that “The gas lift valve (s) shall together with the tubing be part of the primary barrier”. In light of this, the same leak acceptance criteria as used for downhole packers and bridge plugs was selected. The current criteria was the V1 criteria, describing the acceptable leak limit as 20 cc gas per 10 minute hold period, taken from the ISO 14310 standard.

The developed testing program can be divided into four phases. Three phases, including back check and water flow testing, were executed at the International Research Institute of Stavanger (IRIS). The gas flow test phase was done at K-Lab, a full scale laboratory owned by Statoil, located at the gas facility plant at Kårstø, Norway.

Phase 1. Open and close (back check) tests at ambient and elevated temperature, with and without spring installed.

Phase 2. Unloading tests (water), 600 bbl, 1.5 bbl/min. Back check leak tests at each 200 bbl with industrial water and gas.

Phase 3. Full scale gas flow test at 1885 psi. 100 open and close cycles with back check leak test after each 10th open and close cycle and a minimum of 140 hrs at maximum gas flow circulation 250,000 m³/d. The flow period was for future tests set to 24 hrs.

Phase 4. This final function test with water and gas is a repetition of the tests performed in phase 1.

Qualification of equipment for the new validation criteria

The qualification testing started in 2005 by testing eight current designs from various suppliers. It soon proved difficult to achieve a successful test result, even with some modifications to the valves. In 2007 Statoil evaluated the test program in order to see if the test program was too ambiguous. The conclusion from this evaluation was to continue the same test program with no modifications.

It was decided to invite new companies to present possible valve designs. These designs were evaluated and it was decided to go further with a design from Petroleum Technology Company (PTC).

The first step was to review what designs needed to be implemented for the gas lift valve to be a safety barrier for the intended lifetime. The lifetime of a gas lift valve had been set to 12 years, and several common failure modes were noted. The top ranked failure modes were:

- A. **Flow cutting in sealing seats due to unloading the well.** Flow cutting is mainly a problem when unloading the annulus of completion fluids. The valves will have an upper limit for tolerable fluid velocities that does not cut the metal. The API RP 11V5 describes a method of unloading a well. If this method is followed, the valves will most likely not be damaged. A case by case evaluation has to be done to compare the actual fluids and control measures against the procedure. It has not been possible to identify if the damaged valves have been subjected to unloading outside of this recommendation. However, the more resistance a valve has against fluid erosion, the lower probability it should have for damage, thereby having a potential to reduce the time for unloading the well. Based on this information, the design basis was a desire for increased unloading rates and more important, an increased resistance against erosion.

- B. **Spring fatigue failure.** The spring needs to be able to lift the dart in a vertical position. It should also have some strength in order to overcome potential smaller debris deposits that increase the required closing force. There was also a need to reduce the utilization level of the spring in order to minimize fatigue problems.

- C. **Damage during installation.** A number of valves were reported as being damaged during installation. The conclusion was that an improved external seal system was required.

- D. **Multi phase injection or wet gas erosion problems.** The gas was in some cases wet, and it seemed that a potential for micro particle movement was an issue in some wells, perhaps due to insufficient well cleaning. As a result, the design should allow for a level of multiphase flow and particles

- E. **Damage to valve seat due to chattering in low delta pressure applications.** Most spring closing valves will have a potential for valve chattering in a closing or opening mode. This chattering has a potential to damage the seals. A system to reduce the effect of valve chattering was implemented.

The design was divided into the following activities

Fluid calculations utilizing Computational Fluid Dynamics (CFD) analysis, including particle tracking analysis. The potential for flow cutting was investigated using a CFD program. It was found that the flow capacity for the valve could be increased both for gas and liquid rates. Later tests confirmed the increased capacity and that the valve allows for more gas flow than the Thornhill-Craver equation estimates. The test program has also verified that the model's prediction of seal surfaces remains intact after flowing of gas or liquids, even with liquids containing a certain amount of solids.



Fig. 2 The Gas Lift valve developed under this project can be retrofitted in all side pocket mandrels made according to ISO 17078-1

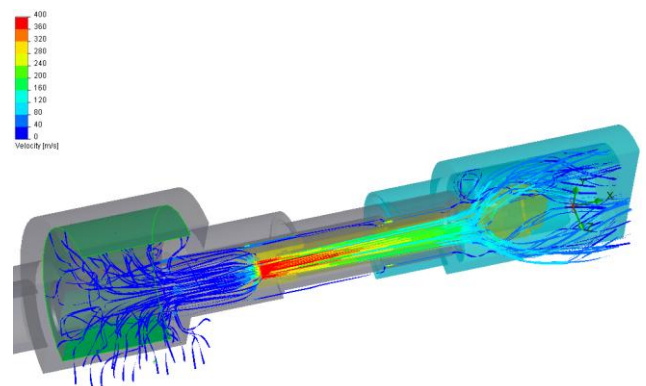


Fig. 3 Velocity calculations done by Computational Fluid Dynamics

Detailed risk analysis. The Failure Mode, Effect and Criticality Analysis (FMECA) were the preferred qualitative risk analyses for the detail design. The objective with FMECA is to identify potential component failures and reduce the risk to an acceptable level through risk reducing actions. This is achieved by identifying component functionality, component failure modes, causes, consequences, risks (criticality) and need for risk reducing actions.

Prototyping. Prototype valves were made to perform qualification testing and to optimize manufacturing. A set of quality control requirements is built into the development and delivery of the gas lift valves. Valves in various types of materials were made and were taken through initial testing. Ultimately, one gas lift valve type was selected for the main test.

1 ½" OD orifice valve (orifice range: 1/8" to ½")

- True metal-to-metal seals (no soft seals)
- Valve design is optimized for seal area protection (flow erosion)
- Spring activated valve with positive sealing
- Spring is protected from flow
- Vibrations are eliminated by design
- 25-180°C working temperature envelope (VO tested at +2 to +121C)
- Designed for 10 000 psi working pressure
- Spring can be pre-set to various opening differentials

FAT testing

The program has also developed a process for Factory Acceptance Testing to ensure that all valves delivered to the field are capable of delivering safety barrier features when leaving the factory. The FAT program is stricter as compared to the requirements in ISO 17078-2, and each valve has to pass a gas test criterion of 20 cc/10 min at a pressure of 100 psi and 10 000 psi.

Extended erosion testing. After completing the new validation program, the question of how well the valve would perform in an erosive liquid media remained. A separate erosion testing program was created. The erosive fluid was made by mixing water with Barite. The program was divided into two steps where the Barite concentration was increased for each step from 0.5 kg/m³ to 2 kg/m³. A total of 1,200 bbl were pumped at a rate of 1 bbl/min and polymers were added to keep the Barite particles in suspension. The program was intended to simulate a clean well before unloading where the cleanliness of the well was defined to be less than 150 Nephelometric Turbidity Units (NTU).

The valve being subjected to the erosion fluid performed at a zero bubble per 10 minutes gas test criterion throughout the test.

After completion of the Statoil program, PTC decided to pump an additional 600 bbl of water mixed with 4 kg/m³. The valve also passed this erosion test at a zero bubble per 10 minutes gas test criterion.

The valve developed under this program has also been subjected to additional testing initiated by other operating companies. One test focused on pumping water at and back check testing at a zero bubble criterion. The other test focused on pumping a completion fluid based on salt according to a recipe leaving salt particles in the brine. The valve was the first to pass the tests for both companies.

Results from the use of barrier qualified gas lift valves

The valves have been installed on a large number of wells with very good results. It is difficult to measure gas backflow in the field due to time requirements, temperature effects and volumes involved. However, it has been possible to measure a distinct improvement in wells and fields known for having considerable problems with leaking gas lift valves:

One company had wells in a field where a fluid was injected with the injection gas for production reasons. This fluid formed droplets that moved with very high velocity through the gas lift valves. This eroded the valves and the wells experienced a lifetime of only 3 months for the gas lift valves. When the valves developed under this program, the SafeLift valves, were installed, the leak problems stopped and the first valve stayed in the well for over 2.5 years before it was pulled due to orifice changes. The valve did not show any wear signs and it is also worth noting that this was the prototype validation valve that had been subjected to the testing at IRIS and Kårstø prior to the installation.

Another company also had problem wells involving injection of fluid in the gas and additional undetermined problems with the gas lift valve occurred. The lifetime of the valves in these wells was also about 3 to 4 months and by changing to SafeLift valves the lifetime was increased to more than 1.5 years.

Conclusions

The current "ISO 17078-2, Flow control devices for side-pocket mandrels" is not an appropriate standard for wells needing the gas lift valve to be a part of the barrier envelope and to be a pressure safety valve. The standard deviates in philosophy from standards validating comparable safety devices.

A new validation program for gas lift valves has been created. The test is more aligned with validation programs for comparable safety equipment.

Strong evidence from both the laboratory and the field suggest that the valve developed to the validation program

is considerably more robust and has an extended lifetime in harsh conditions. The increased robustness and lifetime will increase the safety level of the well and reduce intervention time and cost.

Acknowledgements

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References

ISO 10423/API 6A Drilling and production equipment – Wellhead and Christmas tree equipment.

ISO 13679 Procedures for testing casing and tubing connections

ISO 14310:2008 Petroleum and natural gas industries -- Downhole equipment -- Packers and bridge plugs

ISO 17078-2, Flow control devices for side-pocket mandrels

Norsok D-10 Well integrity in drilling and well operations