AADE 01-NC-HO-07

Methodology for Optimum Deepwater Safety System Selection

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Abstract

This paper will acquaint readers with a methodology and guidelines for optimum selection of surface controlled subsurface safety systems for various deepwater completion scenarios. Operating pressure is of particular importance in deepwater safety system selection because of the adverse effect this pressure can have on the subsystems (i.e., control system, umbilical, and tree and wellhead ratings) that support the subsurface safety system. Generally, as the fail-safe setting depth for subsurface safety systems increases for deepwater applications, so does the operating pressure. For conventional tubing-pressure-sensitive safety system designs, this operating pressure may have significant cost implications, depending on whether a wet (subsea) or dry (surface piercing) tree is used to complete the well. This paper addresses both scenarios, including various methods of combating problems that may occur with each.

Various completion methodologies are reviewed that are currently being used in the deepwater Gulf of Mexico and other deepwater environments throughout the world. A discussion is presented of how completion design dictates safety system selection, with emphasis on the comparison and contrast of such aspects as ultra-deepset conventional valves; tubing-pressure-insensitive, dome-charged or balance line valves, and others.

Finally, based on these considerations, a detailed methodology is presented for selecting the most effective safety system for various given completion scenarios.

Introduction

Deepwater has been defined by the United States MMS as water depths in excess of 1000 ft. (305 meters). While deepwater discoveries are considered higher risk, with unique operational, environmental, health and safety concerns, it is recognized that the future of the oil and gas industry lies within the realm of deepwater. With the recent success stories, developments in water depths exceeding 7,000 ft are proving to be technically feasible and financially justified.

One of the most challenging attributes of a deepwater completion is the SCSSV system. There are several SCSSV designs available to meet today's design requirements for each particular deepwater completion. Particular importance should be placed on the required pressure to maintain the SCSSV in the open position to allow production of the hydrocarbons. All of the subsystems (i.e., control system, umbilical, tree and wellhead ratings) require pressure ratings that are compatible to the SCSSV operating pressure. Ultimately, the subsystems pressure ratings will be the primary factor driving the selection of a specific SCSSV design.

Setting Depth Issues

The depth at which the safety valve should be set will be specific to each well and should be at a depth where hydrates would not be expected to form. This depth is a function of the individual well characteristics such as pressure, temperature, water production rate, gas composition, etc. The formation of hydrates in an SCSSV can prove to be extremely detrimental to its performance and operation. Given the high costs associated with the workover of a deepwater well, every precaution must be taken to ensure optimum performance of the safety valve.

While placing the SCSSV deeper in the well may ease the concern of hydrate formation, it raises other technical and financial challenges. The deeper a conventional valve is placed, the stronger the power spring must be to overcome the higher hydrostatic pressures acting on top of the operating piston to be fail safe. Placing stronger power springs within the valve drives the opening pressure higher and possibly requires all of the subsystems to have higher pressure ratings.

Whether or not these higher pressure ratings have a substantial financial impact will largely depend on the type of completion. For a completion utilizing a dry tree, such as those used for a TLP or Spar, there may not be a significant increase in cost or technical difficulty associated with higher valve opening pressures. On the other hand, a completion utilizing a wet (subsea) tree may see a significant increase in system cost and technical feasibility. The primary concern for subsea completions is the umbilical rating. The umbilical is used to connect the host platform and the subsea pod to maintain communication with the necessary completion equipment. The length of the umbilical will vary from field to field. Offsets in excess of 20 miles are not uncommon in today's developments. Umbilical cost per foot can increase substantially as the working pressure increases so it is easy to derive the direct financial impact higher operating pressures can have on the subsystem.

Heavily Sprung Designs

Rod piston SCSSVs designed with strong power springs to overcome increasing hydrostatic pressures associated with deepwater applications are by far the most widely used and field proven designs available. This is in part due to the simplicity of the design but also due to significant engineering achievements with the standard shallow set safety valves.

Safety valve reliability has advanced to the point where many valve models are available with proven Mean-Time-Between-Failure (MTBF) data far exceeding the life expectancy of the well. One factor contributing to this increase in reliability is the elimination of elastomers within the safety valve. Most safety valves use a single non-elastomeric rod piston actuator for standard applications, with many piston designs incorporating redundant seals. The use of non-elastomeric seals on the rod piston actuator coupled with metal-to-metal premium housing threads allows the total elimination of all elastomeric components and their associated problems i.e. “extrusion”, “explosive decompression”, “embrittlement” and “chemical attack”. It has been proven by independent analysis in the North Sea that non-elastomeric safety valves are far more reliable than safety valves that have elastomeric components.

One can also see from reliability studies that many safety valve failures occur while running wireline tools through them. The most common failures associated with this action are damage to the closing mechanism and accidental shifting of internal sleeves within the safety valve accidentally. Internal sleeves were previously needed to lock the valve open and/or establish communication from the tubing bore to the control line for use of a wireline retrievable insert safety valve. These sleeves have been totally eliminated in some designs, greatly increasing reliability. Wireline resistant flappers also significantly reduce the risk of wireline damage. Previously, if wireline was run through a closed flapper of a safety valve you were almost assured of incurring damage to the flapper and/or seat. This damage would ultimately keep the valve from holding pressure in the closed position. Designs are currently available with protected sealing surfaces that greatly reduce the risk of this type of failure.

These significant design enhancements to the standard safety valve are important to note because they are carried over to the deepwater heavily sprung versions. The only major difference in design between the two versions is that the deepwater valve incorporates a stronger power spring to overcome the greater hydrostatic pressures. As a general rule of thumb, as you increase the setting depth by 1,000 feet, the opening pressure will also increase by 1,000 psi. The only other drawback to this design is the operating pressure dependency to tubing pressure. All sealing mechanisms and model features are identical. With this being said, this design would be the recommended choice for every application, dry or wet tree, where the operating pressure can be obtained without significant cost implications to the operating system.

Balanced Line Designs

The balanced line concept was the first attempt to provide a low operating pressure deepset safety valve. The design called for a second control line to be run, entering the valve below the operating piston. In theory, this created a hydrostatic balance on the piston. The power spring would no longer be required to overcome the hydrostatic pressure acting on top of the piston due to this hydrostatic balance. The piston configuration also allows the valve's opening pressure to be insensitive to tubing pressure.

Despite the simplicity of the design and the capability of low operating pressures, the balanced line concept contained many flaws. Most notable were the fail-open modes associated with this design. The last thing desired in a safety valve is a fail-open scenario.

Most of the problems associated with previous balanced line designs could be attributed to three things.

1. Wireline safety valve design. These designs impacted not only the safety valve reliability but also the effectiveness of the concept in general. It is well documented that tubing-retrievable safety valves are far more reliable than wireline retrievable safety valves. Therefore, the balanced line concepts implemented on wireline valves had inferior reliability compared to the tubing-retrievable, heavily sprung designs. Another problem associated with the wireline design was difficulty in regulating the fluid column in each control line. The control line ports of the nipple were exposed to the tubing until the safety valve was landed via wireline. Displacing the gas from the lines by continually flushing with hydraulic fluid would not completely solve the problem. Even though precautions when installing the safety valve were taken, gas would still migrate into the lines. The hydrostatic pressures in each line were then affected with the balance line possibly having a lower pressure. If this difference in pressure is greater than the closing pressure, the valve could remain in the open position with zero surface pressure applied.
2. **Elastomeric design.** As mentioned in the

previous heavily sprung design section, elimination of elastomers greatly increases the reliability of a safety valve. The original balanced line valves incorporated single elastomeric seals without redundancy thereby decreasing their reliability.

3. **Piston configuration and application.** Many of these valves were initially installed in low annulus pressure or gas lift applications. These applications presented potential problems. If a leak occurred from the balance line to the annulus, the balance line pressure below the piston would fall to the pressure in the annulus. This could create a difference in pressure between the control fluid hydrostatic pressure on top of the piston and the low annulus pressure below the piston. If this pressure differential were greater than the closing pressure, the valve would remain in the open position with zero surface pressure applied.

   Other potential fail-open scenarios in various applications have been detrimental to the reputation and applicability of the original balanced line safety valve.

There are designs available today that have eliminated all of the previous balanced line concerns. Tubing retrievable non-elastomeric rod piston designs and stronger power springs to overcome worst case pressure differentials across the operating piston have made the balanced line concept a viable solution. Incorporating these features with the original balanced line concept gives the industry a simple, low operating pressure safety valve that is fail-safe closed in all failure scenarios.

Dome Charged Designs

Dome charged safety valve technology was the next design that used a pressure balance across the operating piston to allow lower opening pressures for deepset valves. The dome charged designs were unique because they incorporated an integral pressure charged nitrogen chamber within the valve opposing the hydrostatic pressure acting on top of the piston. This nitrogen chamber was simply contained within coiled lines encompassed in the annular cavity of the valve. To aid in using lower operating pressures, the rod piston was designed so that operating pressures were insensitive to tubing pressures.

The standard configuration for this concept included independent and redundant operating systems. The valve would then remain fully operational even if the integrity of one operating system was jeopardized. Two independent control lines must be run attached to the safety valve in order to achieve this advantage. A barrier fluid isolated the nitrogen charge from the seals to add lubricity and absolute sealing capability.

While this design became accepted in the oil and gas industry, there was definite room for improvement. Designs are now available with no elastomers in contact with wellbore fluids. Dynamic pistons using one elastomeric seal per seal point have been replaced with pistons using non-elastomeric seals, with added redundancy at each seal point. The operating system has been simplified significantly to eliminate sensitive ball check seats, mechanical devices, and additional moving parts that could suffer from downhole exposure. The simplicity and elimination of elastomers are essential ingredients to increasing reliability.

Another major concern with dome charged valves has been eliminated with the new design. Previously, a major concern was the ability for the valve to be fail-safe closed if a loss in nitrogen chamber pressure occurred. Applications where the annulus pressure at the valve was lower than the pressure of the charged nitrogen chamber were subject to failing in the open position if the chamber pressure integrity were lost. Naturally, for a safety valve, this failure mode must be avoided. To maintain the fail-safe capability of the valve, steps had to be taken to ensure this fail-open scenario would never occur. Heavy-weight annulus fluids were successfully employed to combat this potential problem.

This requirement has been totally eliminated with the new dome charged designs by the addition of a fail-safe piston to each operating system. It is important to note that this fail-safe piston is static and does not increase the number of moving parts to the valve under normal operation. The only time the fail-safe piston will be called upon is in the unlikely event that the primary nitrogen chamber pressure is lost. If this occurs, the fail-safe piston will be shifted and the operating piston will become pressure balanced allowing the power spring to shift the operating piston up and thus closing the valve. These new designs are fail-safe closed if the primary nitrogen chamber pressure should ever be compromised even in gas lift applications.

Incorporating these features in a dome charged valve has given the industry another simple, low operating pressure safety valve that is fail-safe closed in all failure scenarios.

Self-Equalizing Designs

In addition to selecting the most suitable type safety valve design, the operator must decide if a self-equalizing system should be incorporated in the design. A self-equalizing safety valve contains an integral equalizing mechanism that allows shut-in pressure from below the safety valve to be vented to the tubing above the flapper. This will decrease (equalize) the differential pressure across the flapper and allow the valve to open. There is no need to fill the tubing above the flapper with fluid, and pressure down the tubing above the flapper to equalize the pressure across the flapper. The self-equalizing system will equalize the valve and have the well back on production quicker, safer and more efficiently.

The simplicity and advantages of being able to open a valve without having to mobilize pumps and fluids that are required to equalize a non self-equalizing valve have made a tremendous market for self-equalizing valves. While independent reliability studies have proven some self-equalizing designs to be less reliable than non-equalizing designs, it is important to note that some self-equalizing valves have proven to be just as reliable as their non-equalizing counterparts. The market has responded to this reliability of one self-equalizing design by utilizing this feature on over 70% of the SCSSV's ordered from this manufacturer.

Many operators have standardized on self-equalizing designs, especially for subsea completions where equalizing a non-equalizing valve has proven to be costly and somewhat time consuming. The economics generally provide that a self-equalizing system will pay for itself in a matter of a few months. In some applications the system pays for itself the first time that it is used.

While self-equalizing designs are suitable for most applications, some may require the use of a non-equalizing design. Equalizing volume, not just valve depth, is a primary factor when deciding whether a self-equalizing system should be employed. For example, a valve set at 6,000 feet in a dry tree application would have much more volume to equalize than a comparable subsea application. The dry tree self-equalizing system would need to equalize the full 6,000 feet of tubing while the system in a subsea application would be required to equalize only the tubing between the safety valve and subsea tree. This is accomplished by the use of choking devices installed in the production flow path which isolate the production tubing from the flowline. Once the tubing string is equalized and the SCSSV is opened, the pressurization of the flowline can take place. For comparison to the above mentioned dry tree application, most subsea applications require less than 3,000 feet of production tubing to be equalized.

Conclusions

Each project should be carefully scrutinized early in the process to ensure the best SCSSV solution is selected. The heavily sprung design should always be an integral part of the initial investigation. This design should be chosen as long as the opening pressure is attainable and does not have a significant cost impact on the system. If a low operating pressure safety valve is required, consideration should then be given to the balanced line or dome charged designs. Whatever the project requires, reliable safety valves have been developed to meet almost every foreseeable deepwater application.

Acknowledgements

The authors extend their thanks to Baker Oil Tools for allowing the publication of the material. The editorial contributions of Frank Radez, Baker Hughes Incorporated, are gratefully acknowledged.

Nomenclature

MMS = Minerals Management Service
SCSSV = Surface Controlled Subsurface Safety Valve
TLP = Tension Leg Platform

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