The Application Of Process HAZOP Techniques To Well Intervention Systems ("Why Would We Want To Do A Wells HAZOP?")

Jim McDougall & Mark Taylor, ERM, UK
E-mail:james.mcdougall@erm.com

HAZOPs have been used widely in the process, oil and gas industries for over 40 years. However, well and well intervention systems have not traditionally undergone a formal HAZOP review. Rather the design of well and well intervention systems has used risk assessment processes such as HAZID, design review, what-if analysis and Test Well On Paper (TWOP). This paper looks at how process HAZOP techniques have been applied to wells systems and the benefits that accrue through their use.

Well intervention systems are usually temporary in nature and are largely manually operated. They often consist of an assembly of pre-existing sub systems, each with separate design parameters, operation conditions and limits. The systems may be supplied and operated by different services companies. The operating histories of the equipment may be uncertain or unknown. The design process for well intervention systems usually only allows for a single HAZOP (compared to the usual 3 or 4 for process plants). As such, a modified HAZOP process must be employed which addresses the challenges of complex interfaces and separate systems, and is effective, succinct and reliable. The HAZOP process therefore has to be extended to be more flexible, taking causes (initiating events) from the part of system under scrutiny (the node) and identifying the consequences within the node, within the intervention system as a whole, and external to the temporary system such as downstream production systems.

By having operators and supervisors meet and discuss their systems prior to commencing work, the HAZOP process educates all parties about the failure modes and consequences of not only their own systems but also the potential impact on other systems, and how others may impact upon them. The HAZOP methodology requires the prior production of good documentation, such as written procedures and complete P&IDs, which are often not produced for temporary well intervention packages. The result is that good documentation is available to manage change, and to carry over lessons learnt to future designs. This expanded methodology incorporates a thorough assessment of the sufficiency of human controls for both prevention and mitigation of unplanned events.

The HAZOP process requires an experienced facilitator and, perhaps more importantly, a very good HAZOP scribe to capture the information being shared by the HAZOP team and to write clear, concise and self-contained recommendations. This paper illustrates the benefits of well intervention HAZOPs, drawing on the experience of applying these methods to a variety of operations.

Keywords: Risk; Wells; HAZOP;

Introduction

A Hazard and Operability study is based on the idea that accident events are caused by deviations from design or operating intentions. HAZOPs were initially developed by ICI in the United Kingdom, but the wider use of the technique to within the chemical and process industries only started after the Flixborough disaster in the UK in 1974, where a chemical plant explosion killed twenty eight people, many of whom were ordinary householders living nearby. The oil and gas industry, which has a similar potential for major disasters also adopted this system. In the USA HAZOP is one of the recognized techniques of Process Hazard Analysis under the OSHA Process Safety Management (PSM) standard (OSHA 1994). There are a number of recognized standards such as BS IEC 61882:2001 with guidance described in documents such as the IChemE's HAZOP: Guide to Best Practice, (Crawley and Tyler, 2015). In addition most of the large oil and gas companies, oil service companies and EPCs have their own standards.

In the wider process industry, HAZOP is a well proven technique for critically and dispassionately reviewing the design of a permanent process system. It affords the opportunities for people to use their imagination and identify all the possible (Kletz 1989) ways in which hazards or operating problems may arise. It is carried out in a systematic way to reduce the chance that something is missed.

In the upstream oil and gas industry the HAZOP approach is also being applied to well intervention and well test systems. These are generally temporary systems built for operations that may last anything from a day to a several weeks.

Well intervention is a term that encompasses many different types of operations including:

- Coil tubing - pumping of fluids;
- Concentric Coil tubing - pumping of fluids;
- Well perforation;
- Gravel packing;
- Well Testing
- Snubbing;
- Well stimulation; and
- Frac' ing.

These operations involve pumping fluids into a well or flowing from the well at a variety of stages of the wells life. For example, fluids may be pumped down production tubing or temporary tubing from a temporary surface system or alternatively well fluids may flow into temporary surface systems or permanent production systems.

These well operations have some of the characteristics of continuous production and batch process systems. However some of the key distinguishing features include:

1. Planning of the intervention activity may take many months, but the length of operation is short and may last for a day to a week or so. In that sense the process system can be regarded as temporary.
2. Systems are designed and operated by well intervention and testing personnel who often have no formal training in process engineering.
3. The fluids passing through the system may be complex and ill defined, consisting of sand, hydrocarbons, acids, alkali, nitrogen, brine and muds.
4. The unit operations, pumps, vessels, storage tanks, compressors and boilers are not bespoke for the job and are not designed with a particular process operation in mind.
5. Equipment design specifications are pre-determined, i.e. the surface and subsurface system are assembled for a "set" of "available" parts and not always driven by the needs of the process.
6. The equipment will rarely be new. The equipment may have been used for similar jobs many times before and been arranged in a variety of configurations.
7. The level of automation is generally low, with most operations being controlled manually.
8. The level of instrumentation may be low, unsophisticated and often not integrated.
9. Different parts of the whole system may be owned and operated by different companies and different company personnel.
10. The knowledge of the design of the system by the operators may be low. Often they know what to do but not why they are doing it.
11. Well intervention operations can requires diversity and flexibility in the system, and often the Intervention Team demands equipment that has the ability to perform planned but unscheduled tasks.

System Design

HAZOP developed for process systems are more often than not designed from the ground up i.e. they go through a series of design stages to end up with a finalized process system. Process Systems are generally largely automated systems designed to minimize the need for operators in the field, designed to operate continuously and to a limited range of performance criteria. Well intervention and well test systems on the other hand are usually temporary systems, assembled from pre-existing modules, operating in a wide range of conditions on fluids with often poorly defined characteristics and are largely manually operated. The modules are supplied and operated by separate service companies who have to work together to provide an integrated package that may or may not be connected to a permanent process system.

The design process for well intervention systems usually only allows for a single HAZOP (compared to the usual 3 or 4 for process plants). As such, a flexible HAZOP approach must be employed which addresses the challenges of complex interfaces and separate systems, and is effective, succinct and reliable. For some operations, for example a drill stem test, there will be both surface and subsurface systems which may require analysis and understanding from a range of technical personnel who may not be familiar with process engineering or the HAZOP process.

To illustrate the above, Figure 1 and Figure 2 show some typical process modules used for intervention activities. Figure 1 shows a coil tubing spread where much of the equipment comes on a truck, is used for a few days and then dismantled. Figure 2 shows standard modules used in well intervention work.

Figure 1: Coil Tubing Rig Up

Figure 2: Modular Well Intervention Equipment

The safety and reliability of this equipment essentially relies upon the application of various codes of practice, design codes and standards that have been used in its design and are used in its operations. These codes represent the accumulation of knowledge and experience of both individual experts and the industry as a whole, but are in many respects backward looking. They can be considered to be derived from what has gone wrong in the past rather than looking forward to the operation they will be used for.

The design, commissioning and operation of the well intervention system is more often than not carried out by sets of engineers working for different organizations (service companies) who are contracted through the client oil company and have to work together. That is the client oil company coordinates the work and has to ensure that all the pieces of the jigsaw fit together. In this sense the client oil company takes on many of the responsibilities of the engineering contractor as well as the end user of the system.

In this environment it is generally accepted that, these systems will be designed to approved codes of practice. However, it is important to supplement these codes with an imaginative anticipation of what could go wrong to ensure that the designs are fit for purpose, i.e. can do a particular job on an individual well.

The contractual relationship and the nature of work both introduce some interesting challenges, particularly with regards to the information available at the HAZOP and the level of knowledge of participants at the workshops. These issues are briefly described below in the following sections.

HAZOP Information

Understanding the process under review is essential to the HAZOP procedure, and that necessitates having well defined design and operating limits, with good documentation and drawings. This enables the systematic challenge of the design and operation to proceed. Process plants generally have well defined Engineering Line Diagrams, ELDS, Piping and Instrument Diagrams, P&IDs, or Process Engineering Flow Sheet, PEFS, however this is often not the case for well interventions systems. In general the P&IDs of intervention systems rarely meet a standard such as PIC 001 (PIP 2008). Sometimes the documentation may resemble and include many elements of a P&ID as illustrated in Figure 3. However exceptions in the documentation may include the lack of line specification information, absence of details of the routing of the relief lines and a general lack of information on the control and shutdown systems. More commonly an intervention P&ID would take the form of a cartoon illustration, part process flow diagram and part P&ID. Some would argue that because the P&ID is not "up to scratch" the system cannot be subject to HAZOP, however the authors disagree with this thinking. It is possible to apply HAZOP process to such systems without lowering standards. Indeed it is the process of going through the HAZOP which leads to the raising of standards and understanding.

To complicate matters further downhole systems are generally represented in a diagram (the string diagram) that does not remotely resemble a traditional P&ID see Figure 4.

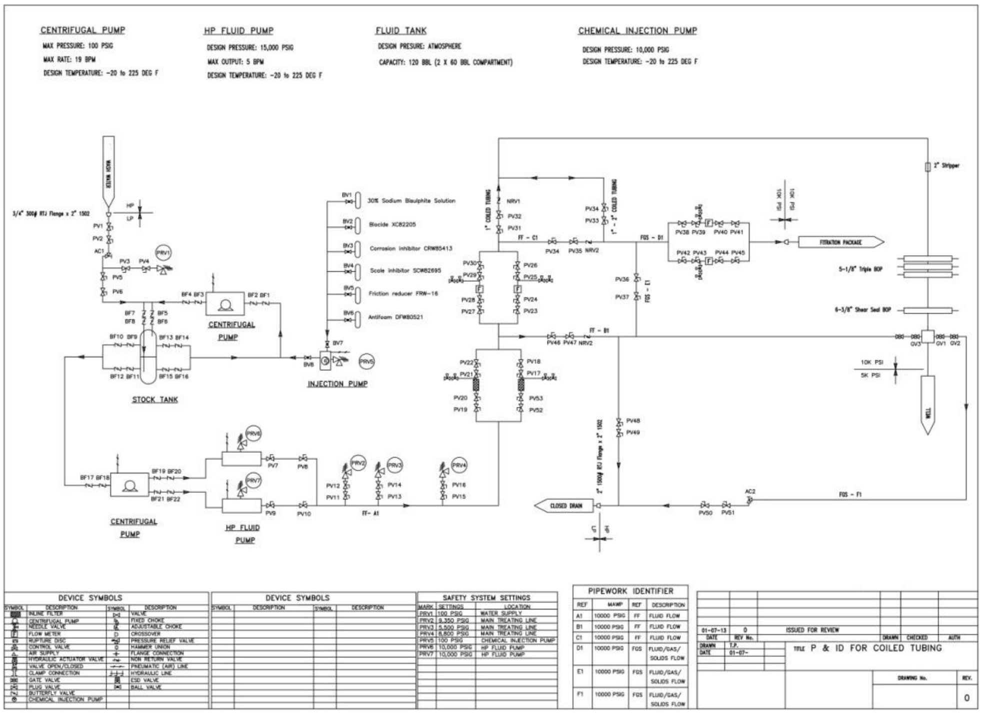

Figure 3: Well intervention P&ID example

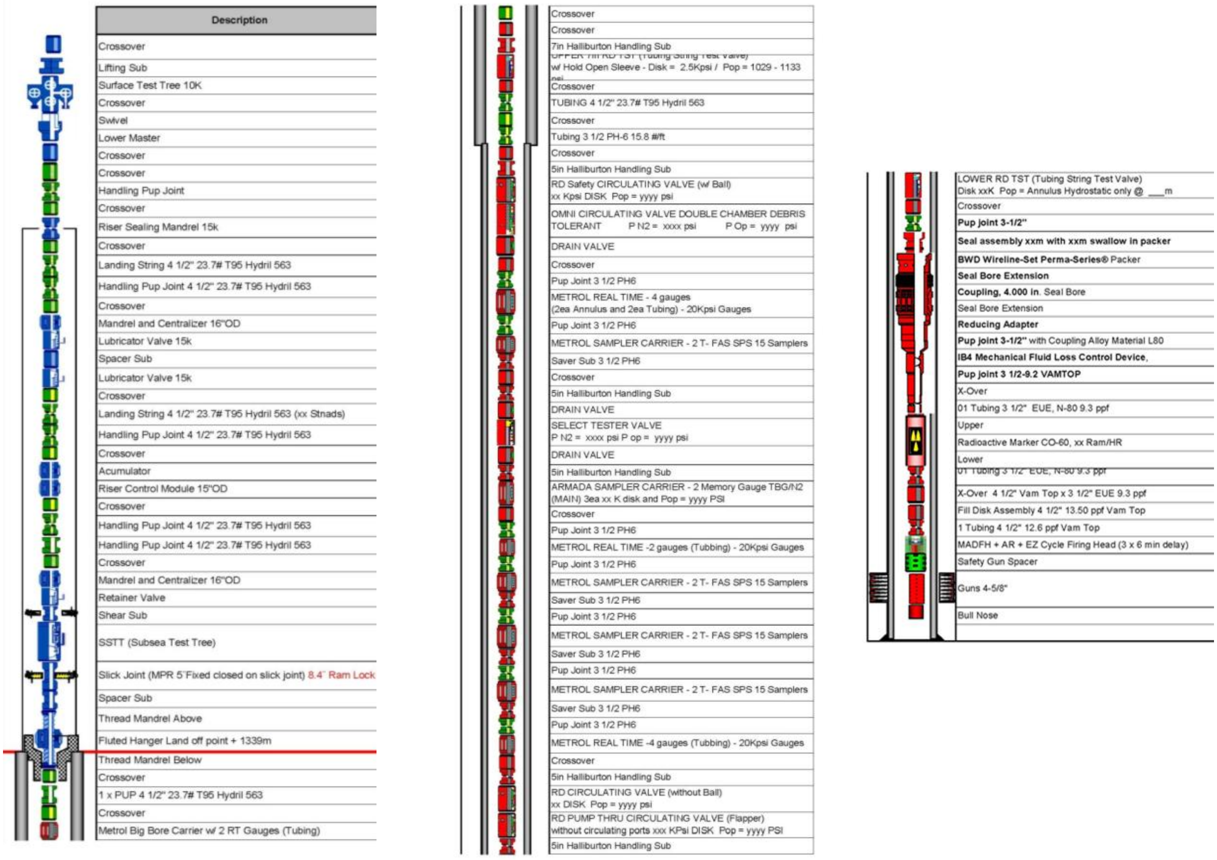

Figure 4: Drill Stem Test String

HAZOP workshop

Many participants at a well intervention HAZOP are not process engineers or instrument engineers and often have not been to HAZOPs. For the design engineers the whole process can be extremely challenging, especially when the HAZOP is being conducted in English which is often not their primary language. It can be difficult for engineers who are not used to the formal challenge of HAZOP to accept the review process. In some circumstances it can be seen as a challenge to their integrity or competence. This can lead to significant tension building up during a workshop, which inhibits the ability of the HAZOP team to understand the system and make recommendations.

For the operators it can be even harder. As explained earlier the level of general instrumentation and the sophistication of the instrumented protection system of well intervention systems tend to be low. This inevitably means that many of the initiating events identified in the HAZOP are due to "human error" in one form or another. Where operators are unfamiliar with the process, this emphasis on "human error" can become very frustrating and even annoying.

It is therefore extremely important that while the study is carried out by a knowledgeable team consisting of the service company engineers, the client company engineers and operators, and that all the members of the team understand fully that it is the design and operation that is being challenged, not the team members themselves. Human barriers are at the heart of the HAZOP, rather than instrumented protective systems. It should be remembered that during intervention operations for much of the time the operators are operating in skill based mode (Crawley and Tyler, 2015), carrying out familiar tasks and not having to consciously think about them. They occasionally move to rule-based mode for less familiar tasks or knowledge based mode to seek out explanations that will allow a suitable response. The HAZOP team must address all these modes of operation and assure themselves that the operators have sufficient sources of information to carry out their tasks.

Well intervention HAZOP teams tend to be fairly large, with it being common to have 10 to 15 engineers present. These can come from the oil company and service companies, and for of offshore operations will often include representatives of the drill rig, intervention vessel and/or platform.

The size of the teams has often given well intervention HAZOPs the unfortunate reputation of being time consuming and not cost effective. However, the authors of this paper believe that entirely the opposite is true. Real value in the workshop comes from interaction between the team members and the discussion over the design, the planned operation (the intervention programme), the procedures, and the cross-company interfaces. The sharing of knowledge about the operation prior to mobilisation often highlights otherwise unnoticed hazards, and reduces risks associated with these types of operations.

Well Intervention System Design issues

The HAZOP for the surface system is conducted much like any other process system HAZOP, using nodes, keywords and deviations.

- A node is a selected part of the system that is a beginning or an end point. The end point of one node being the beginning of the next until all of the scope is covered.
- Primary Keyword – Conditions used to define a process, including flow, pressure, temperature and level.
- Secondary keyword is a word chosen to help the HAZOP team consider potential hazards associated with the section of the system between nodes. Words, such as "”high", "low", and "no", that are applied to parameters to create a potential deviation from the design intention.
- Deviation is a combination of the keywords to examine departures from the design intent.

Added to standard words above might be relevant operational words such as: isolate, drain, vent, purge, inspect, maintain, start-up, shutdown, compensator, tubing stress and differential pressure.

The objectives of the HAZOP process are to identify the following:

- The potential failures applicable to the system within the Nodes;
- The safeguards or means of prevention in place; and
- Where the safeguards or means of prevention in place are not deemed sufficient for the potential consequence by the HAZOP team, to recommend actions assigned to named individuals.

Mitigation may be considered but this is often not discussed in any great depth. The focus of the HAZOP is to keep the hydrocarbon fluids contained rather than managing a loss of containment incident. Nonetheless it is wise to consider bunding, fire and gas detection and the host facilities ESD system during the HAZOP as these systems can materially affect the ability to carry out that well intervention programme and the design of the well intervention system.

A typical well intervention / well test system is sketched in Figure 5. The well head systems will generally be rated for either 5 kpsi or 10 kpsi (15 kpsi is also possible). The well head may be connected by fixed piping (onshore) or flexible piping (offshore) to a choke manifold. The choke manifold is used to regulate the flow from the well and reduce the pressure for the well head into the downstream process system. The control is performed manually. The choke manifold will often include a fixed or positive choke that is adjusted by changing the size of the orifice plate or "bean" and a variable choke which is adjusted by changing the position of the valve stem. For well testing and some other operations the flow may pass to a well test separator, typically designed for 1440 psig. From there the gas may go to vent, flare or a process system, and the liquids sent to low pressure (150 psig rated) "gauge tanks". There are therefore a number of HP / LP interfaces that must be managed and the management of these must be addressed during the HAZOP.

Consider the system illustrated in Figure 5. The only source of pressure is the well and this is regulated by manually controlled chokes, one choke is fixed and the other is variable. It is clear that there is significant potential for error in this system. An example that is often discussed during a HAZOP is the case of the choke washing out through erosion of sand or damaged by cavitation. A typical response to this being raised in the HAZOP would be "this will not happen because…..". On discussion it often turns out that this concern has been considered but in terms of engineering there is no satisfactory solution that will stop the choke damage. Alternatively the loss of choke control could be caused by poor operation of the variable choke or by not putting a "bean" in the fixed choke or by putting in the wrong bean in the choke. If any of these scenarios are considered credible the HAZOP team has to consider whether the system downstream of the choke is adequately protected for the case of choke damage, washing out or incorrect operation. Again the typical response in a HAZOP is this will not happen. However the scenario just discussed is credible and there no instrumented protection systems that will prevent it from happening.

In well intervention management of pressure and the prevention of overpressurisation of parts of the system is the most important aspect of the design to be examined. For this reason it advisable to start the HAZOP with pressure as the first keyword to focus the attention of the team.

Some proponents of the HAZOP methodology state that there is no need for the HAZOP chair to have any knowledge of the plant being reviewed, the chairs function being only to ensure that the meeting progresses smoothly. However for well intervention the authors do not believe this is a good approach. It is important that the HAZOP chair does have a good understanding of the well intervention process, so that they can understand the issues under discussion, ensure there are contributions from all members of the HAZOP team and can challenge "it won't happen" with authority. Particularly in this case, a broad knowledge of past incidents is key to support discussion around failure modes, and to inform and reasoned judgement of their associated risk.

Other well intervention operations involve fluids being pumped into a well where the systems may be operated in a number of different modes. For example it may be necessary to pump fluid, such as brine or mud, down the production tubing or a test string. It may then be necessary to reverse the direction of flow down the annulus and up the production tubing to displace one fluid such as mud with a second fluid such as brine or in some cases nitrogen. In this sense the surface system has to be treated as a batch system, with the operating mode of each node being treated separately. In these types of operations it is often the sequence of operations that need to be divided into manageable parts.

Potential for human error is increased by the varying uses of specific equipment items and increases the challenges when identifying hazards. It cannot be taken for granted that what was safe for the previous stage of the operation may no longer be appropriate. The keywords may well focus on the sequential operations such as next step, missed step, wrong routing, incorrect density, wrong additive and insufficient quantity. This methodology is required because an individual plant item is very likely to be put into differing states and serve different purposes at various stages of the sequence.

When this type of HAZOP process is being followed it is often tempting to save time by referring back to earlier modes of operation. However more often than not this means that reviewing and understanding the HAZOP at a later date becomes significantly harder. There is a trade-off to be had between the time required to record information at the HAZOP and the ability to use and audit the HAZOP at a later date.

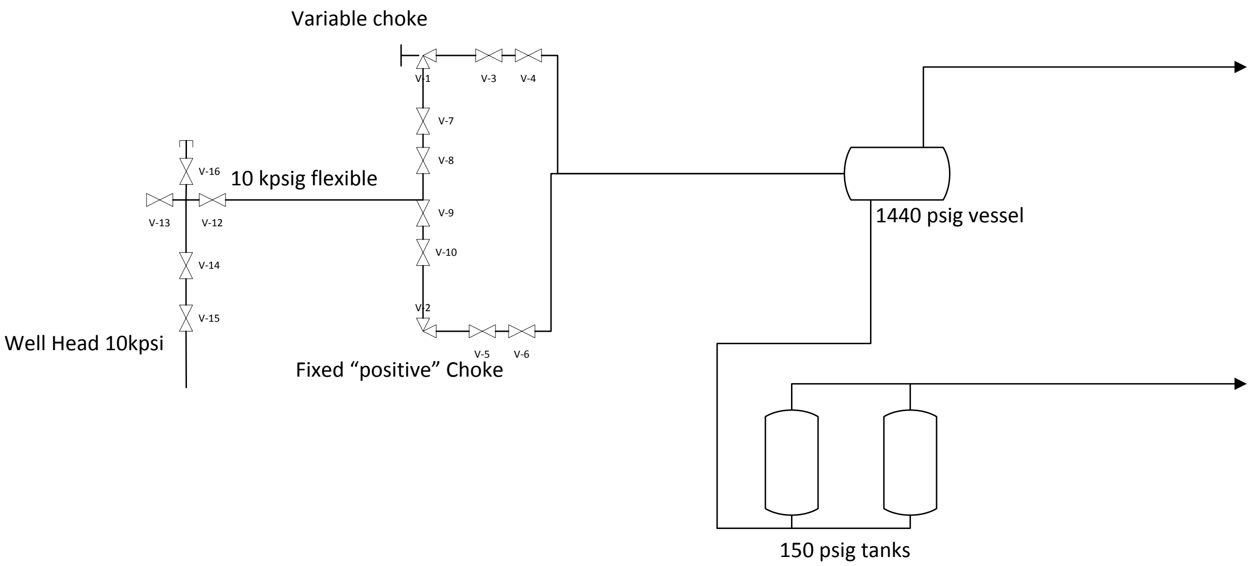

Figure 5: Well Test System Schematic

Another typical issue that is discussed during well intervention HAZOPs is for the potential for high pressure gas blowby to occur. Referring to Figure 5, for example, the liquid level in the 1440 psig vessel may not be controlled and enables gas to flow directly to the 150 psig tanks. As with all the equipment in the system these tanks will come with their own relief valves but these may not be sized correctly for the fault scenario. In addition the valves at the boundary of the skid may only be rated for 150 psig, but if closed could be subjected to significantly higher pressures as they are connected to a 1440 psig system.

Managing the levels in tanks (Such as in Figure 2) is an area with high incident potential. The levels in tanks are monitored by personnel using gauges mounted on the side of the tanks. Not only can these gauges be blocked by wax or oil, but it may be difficult for personnel to see the gauges while they are being filled or emptied by pumps. These tank systems will not usually have automatic level control and the alarm system is rudimentary such as an air driven high level horn. Therefore engagement of the operators during the HAZOP is vital if the adequacies of the safeguards designed into the system are to be discussed in a constructive manner. Maintaining a blame free and inclusive atmosphere is important in achieving this goal.

Downhole systems can be difficult for process engineers to understand, not because of the design of the systems but the way they are represented as shown in Figure 4. However it is not difficult to convert a string diagram to a form recognisable to a process engineer as presented in Figure 6. Once the conversion is made the system can be subjected to HAZOP in the standard manner. The control of downhole valves is not always the same as surface systems. For example some downhole valves may be actuated hydraulically but they may be actuated by change in the pressure on the annular side of the well. Annular pressure changes are generated by pumping in calculated volumes of liquid into the annulus and then bleeding the liquid back to the surface after the valve position change has been initiated.

To carry out the downhole HAZOP new keywords such as hydraulic head or fluid density may be introduced. Alternatively words such as stress and strain can be used to look at the effects of temperature and depth on the strength of the string, while level can be used at the potential of putting pills of fluids at the wrong depths during the operations.

It is industry general practice to “Test the well on paper”, TWOP, or “intervene on paper” IWOP and the HAZOP does not supplement or replace these techniques. These exercises usually test that the procedures will work as intended. Indeed it is the expectation that the procedure will work as it has been done before. The HAZOP process on the other hand has no such expectation and can be used to challenge the system design and planned operation. The advantage of subjecting the downhole system to HAZOP in the same manner as the surface system is that it enables everyone to understand how the two systems will need to interact and to examine what could go wrong in a systematic manner that can be documented. The disadvantage is that the P&ID format is not that familiar to some of the service organisations and there is a reluctance to subject the system to this form of scrutiny.

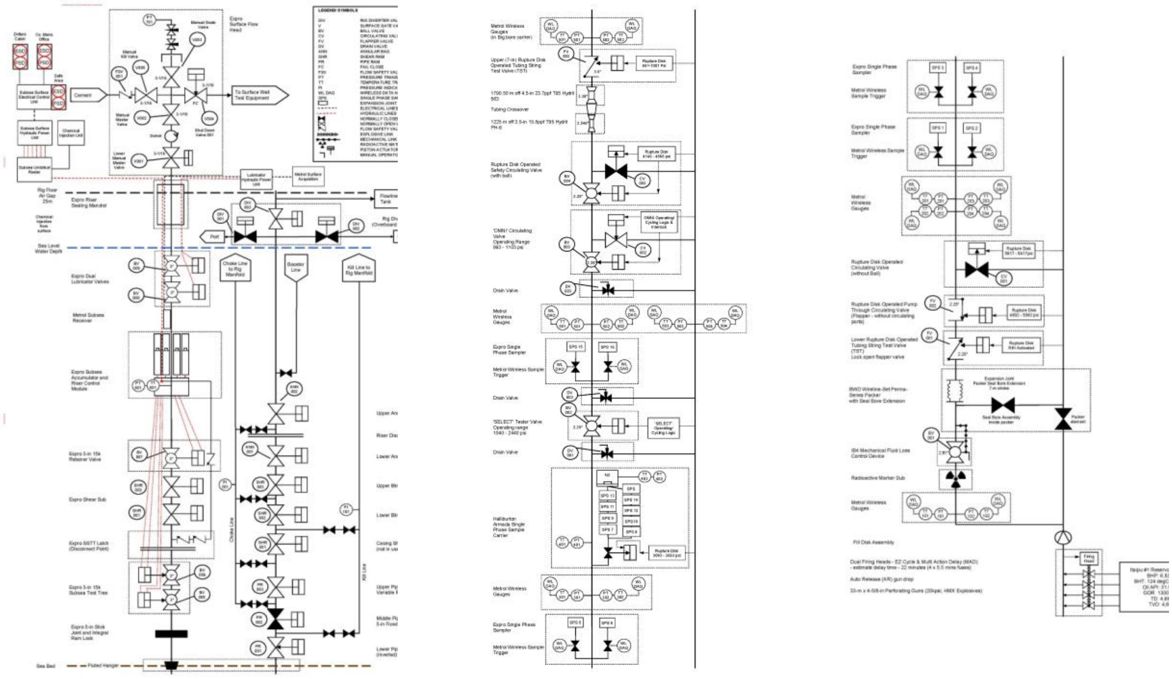

Figure 6: DST String "P&ID"

HAZOP actions

When formulating actions during intervention HAZOPs it is important to bear in mind the manual nature of the operation. The systems will have pressure protection provided by a mechanical relief system but there may not be much else. It is important to confirm that the relief is sized correctly. Often there are no instrumented protective systems in place to protect against some of the initiating events that can be identified in an intervention HAZOP. The only safeguards identified will be procedural control, supervision and perhaps an alarm. Therefore the test of sufficiency or adequacy is reliant on the expertise in the HAZOP workshop. It is important that the HAZOP chair draws on this expertise and does not automatically push for an engineered solution, adding additional instrumentation, alarms, trips, etc. It is important that due regard is taken of the temporary nature of the operation and the inherent problems with regards to maintenance, reliability, calibration and the understanding of new systems proposed during a HAZOP. Furthermore it should be remembered that there is nothing to be gained by recommending sophisticated systems if the operators do not and will not understand how they function. Indeed the resulting over-engineered solution may be less safe than the original "manual" system due to the lack of familiarity and difficulty of testing and maintenance.

Generally it is best that intervention HAZOPs do not recommend a solution, but instead recommend that the intervention engineer or service company review the issue and propose solutions that may be incorporated into the design to address the issue raised.

Conclusion

HAZOPs are widely used in the process and upstream oil and gas industry. For well intervention operations the use of HAZOP can and should be the norm. The HAZOP process ensures that the design is formally documented prior to implementation, and that this design can be scrutinised in a systematic and authoritative manner. Using this formal method means that safe implementation of the design can be assessed prior to operations commencing, and further that all personnel are familiar with the design, intent and operation of the system. All these factors reduce risks associated with the operations. Great benefit has been seen by the result of information shared in the HAZOP session, and the actions raised in response to previously unrecognised hazards.

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