

Management of Well Integrity during Production Operations

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Introduction

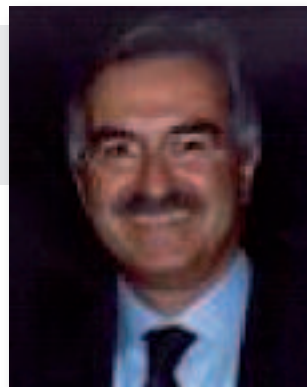
The most common definitions of "Well Integrity" are based on the concept of retaining two intact barriers between the well and the external environment, as normally dictated by the original design, throughout the entire life cycle of the well. Norsok Standard D-010 "Well Integrity in Drilling and Well Operations" defines Well Integrity Management as the application of technical, operational and organizational solutions to reduce the risk of uncontrolled release of formation fluids throughout the entire life cycle of the well.

Management of well integrity starts from well design, continues during its construction and is constantly implemented during the production phase. In particular, this article deals with well integrity during the production life of a well, after the well has been successfully constructed and handed-over from Well Operations Dept. to Production Dept.

During Well Commissioning, Well Operations prepare a Well Commissioning Final Report which includes:

- a description of well criticalities, identified during well planning and execution, which could have an impact on the following Production Operations;
- a list of well monitoring and reporting requirements throughout the productive life of the well;

- the maximum allowable values of annular and inter-casing pressures (MAP);
- a list of ordinary well maintenance requirements and plans.



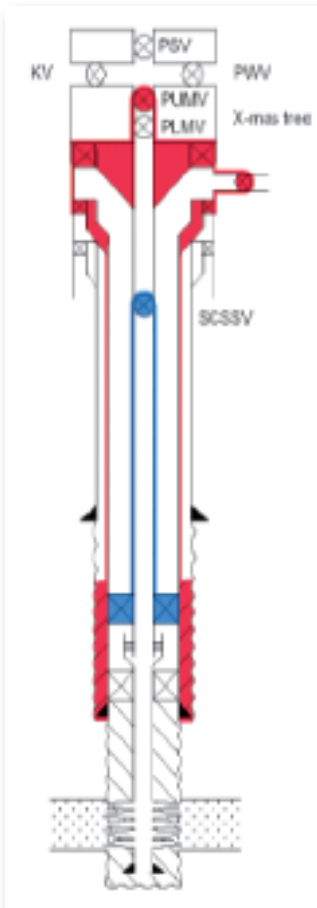
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Definition of Well Barriers given by the above NORSOK Standard is: "envelope of one or several dependent barrier elements preventing fluids or gases from flowing unintentionally from the formation, into another formation or to surface".

Figure 1 shows an example of Well Barrier Schematics given by NORSOK Standard for a typical production well in shut in condition.

Well Integrity Assessment

The loss of a Well Barrier causes a fluid flow which, in its turn, generates a pressure accumulation in well annuli at surface, also called Sustained Casing Pressure (SCP). Therefore, assessment of Well Integrity is generally carried out by measuring possible annular and inter-casing pressures and comparing them with the relevant values of the MAP. Such a comparison provides a quite precise indication about how much the well is close to loose its safety conditions.



Typical well capable of flowing - Shut-in

that corresponds to the situation in which its weakest delimiting element works in safety limit conditions. It is calculated on the basis of the following parameters:

- fracturing gradient of formations;
- drilling and completion fluids characteristics;
- well as-built characteristics and

operations which exhibit SCP will be analysed to identify possible causes of occurrence and to plan suitable pressure monitoring and/or remedial actions. The MAP of an annulus is the maximum allowable pressure, measured at the wellhead,

- collapse and burst resistances of tubing and casings
- maximum historical values of pressure measured in each annulus.

What is Sustained Casing Pressure (SCP)?

The American Minerals Management Service (MMS) defines SCP as “a pressure measurable at the casing head of a casing annulus that rebuilds after being bled down”. Thermal expansion of the tubing and casing and the fluids in them may cause annular pressure buildup when the wells are placed on production. But this pressure, once bled off, does not re-appear in the annulus if the well is in a normal production mode and, therefore, can not be considered to be a SCP. The same concept is valid in case the annulus pressure is deliberately applied, such as in gas lifting applications.

Well barrier elements	See Table	Comments
Primary well barrier		
1. Production packer	7	
2. Completion string	25	Tubing between SCSSV and production packer.
3. SCSSV	8	
Secondary well barrier		
1. Casing cement	22	
2. Casing	2	
3. Wellhead	5	Casing hanger, tubing head with connectors.
4. Tubing hanger	10	
5. Annulus access line and valve	12	
6. Production tree	33	Body and master valve.

Figure 1: well barrier schematic for a typical production well (shut in)

Risks Associated with SCP

Industry experience with SCP has shown that the most serious problems have resulted from tubing leaks; when the resulting pressure on the production casing causes its failure, the outcome can be catastrophic. The outer casing strings could also fail, resulting in an underground blowout.

Flow rates through the tubing leak can quickly escalate if sand is present in the flow stream. Thus, a blowout of sufficient flow rate to jeopardize the production platform is possible.

The magnitude of the leak rate is as important as the magnitude of the pressure when determining the potential hazard posed by SCP.

To have an idea about the frequency of SCP occurrence, reference can be made to an in-depth study conducted by the University of Louisiana on more than 8.000 wells in the Gulf of Mexico. Main conclusions from this study are:

- about 50 % of wells with SCP have pressure in the production casing
- about 10 % of the casing exhibiting SCP are intermediate casing strings
- about 30 % of the casing exhibiting SCP are surface casing strings
- about 10 % of the casing exhibiting SCP are conductor casing strings.
- about 90 % of SCP observed are less than 1,000 psi in magnitude.
- more than 90% of all SCP observed are less than 30 % of the minimum internal yield.



Figure 2: Photograph of a offshore blowout

Origins of SCP

The most common cause of SCP in the annulus between tubing and production casing is the leakage of the tubing which can result from a poor thread connection, corrosion, thermal-stress cracking or mechanical rupture of the string.

The most common cause of SCP (see Figure 3) in the outer annuli, outside of the production casing, is a poor cement bond, either deriving from a poor cement job or from its damage during the production life of the well.

During the cement job, the bond can be compromised in several ways, the most common being the invasion of gas into the cement during the setting process.

Cement can be also damaged by operations occurring after the cement has set:

- Mechanical impacts occurring during tripping drill collars, stabilizers and other tubulars.

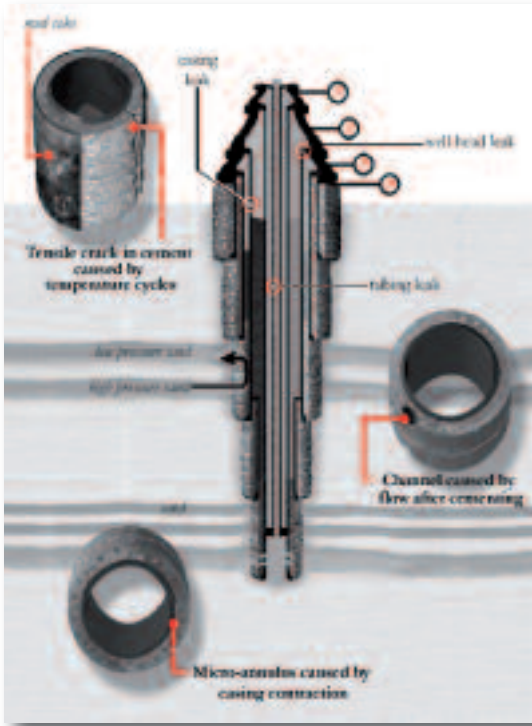


Figure 3 - Origin of SCP

Regulations and Standards

Not many regulations are currently available.

As already mentioned, NORSOK issued a standard for Well Integrity which focuses on the minimum functional and performance requirements of well barriers.

The American Mineral Management System (MMS) issued the regulation 30 CFR 250.517, which states that the lessee shall immediately notify the MMS in case of SCP occurrence, and establishes operability levels of the well on the basis of SCP value and build-up rate after bleed off.

API has just issued a standard for Well Integrity (API 90). In its first edition, it does not provide specific standards, but more general guidelines to manage SCP in Offshore Wells.

Well Integrity Assurance

In consideration of the above mentioned causes of SCP, the best prevention methods consist of ensuring barriers functionality over the entire life-cycle of the well. These methods include:

- Expansion and contraction of casing and cement sheath due to changes in pressure and temperature: this can result in the separation of the casing from the cement.
- Execution of casing pressure tests, conducted to confirm the competency of each string and also performed prior to perforating, fracturing and after setting packers or bridge plugs.
- High pressures occurring during acidizing, fracturing, cementing and Frac-Pack operations.

- selection of adequate tubular materials and connections;
- new cementing formulations;
- improved primary cementing practices;
- maintenance of a reasonable margin between pore pressure gradient and fracture pressure gradient in the open borehole being cemented;
- use of annular casing packer.

Furthermore, Well Integrity can be assured through the proper execution of ordinary

monitoring and maintenance activities, such as:

- check of possible tubing thickness reduction caused by corrosion/erosion;
- functionality test of the downhole safety valve and the surface control system
- functionality test of wellhead and mastree valves.

Monitoring

Regular monitoring of possible SCP development and the prediction analysis of its trends are essential for the integrity control of all wells and for safe management of wells with SCP.

Pressure will be recorded inside the tubing, in the annulus tubing/production casing and in the outer annuli according to a specific monitoring programme, for example on a monthly basis.

If any casing annulus exhibits an SCP, frequency is increased and diagnostic tests are initiated.

Diagnostic Methods

Diagnostic methods are used to determine the severity of the leak through the barrier and the source of the occurring SCP. They may include the following:

- pressure bleed-off performance. The process of bleeding-off pressure from an annulus presents one of the best opportunities to obtain information about the severity of the leak;
- pressure build-up performance. The rate of pressure build-up provides additional information about the size and, possibly, the location of the leak; the pressure

- build-up test is especially important when the SCP cannot be bled to zero;
- flow sampling. The density and composition of the fluid that flows from the well during pressure bleed-off operations provides valuable information about the annular fluid and the source of the influx;
- well log analysis. Several cased hole logging tools are available that can provide information about gas or water flow behind casing: noise and temperature logs to get information regarding the fluid entry and exit points, Cement Evaluation Tool (CET) to evaluate the quality of the cement bond, Thermal Decay Time (TDT) log to detect gas accumulations in the annular space outside of the casing;
- monitoring fluid levels. Monitoring fluid levels in the production casing, performed with a conventional acoustic test, can indicate the presence and sometimes location of tubing leaks;
- wellhead and tubular pressure testing. Wellhead, tubing and production casing leaks can often be identified by pressure testing, generally performed after SCP has been bled down.

Remediation efforts

The primary remediation method for SCP is a well workover designed to block the leak path causing the problem. Although technically straightforward, such workover can be expensive and may not be economically justified. Remediation of flow through channels outside of the production

casing are often technically difficult to achieve, even when an expensive well workover is performed. It is generally necessary to perforate or cut the production casing in order to attempt to squeeze cement into leak paths that are outside the production casing.

Remediation methods that can be accomplished without a workover rig include:

- periodic bleeding of excessive pressure (not always accepted since it could worsen the leak);
- partial bleeding followed by lubricating in a higher density fluid;
- insertion of a small diameter tubing into the annulus exhibiting SCP to allow shallow annular circulation.

Conclusions

The management of Well Integrity is extremely important, since it affects operations on both the safety and economical points of view.

Such management is not just about ensuring that the well operates safely today, but also about being confident that it will properly work during the entire life

cycle. This implies that:

- in the design phase, loads that the well and its elements are expected to experience during the construction and production phases shall be identified and determined. Then, suitable well components shall be selected in order to maintain an acceptable level of safety;
- operations must be carried out to ensure that the bases of design are preserved during well construction; this shall be accomplished by following proper handling and installation procedures;
- during the productive life of the well, the Production Dept. must regularly carry out monitoring activities and manage the well as per established maintenance and well integrity procedures;
- well monitoring and maintenance operations must be carried out in close cooperation between the Production and Well Operations Depts. In particular, in case of loss of well integrity, the Production Dept. shall involve the Well Operations Dept. for analysis and possible remedial actions.