Automated Coiled Tubing Integrity Monitoring (ACIM)

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ABSTRACT

Coiled Tubing (CT) integrity decreases during its service lifetime with several different types of damage mechanisms. Failure of Coiled tubing during a well intervention can cause stoppage of well operations for extended periods, therefore detecting, monitoring and assessing the extent of damage is the main reason for inspecting Coiled Tubing. However the integrity decline during Coiled Tubing's service life is not solely limited to corrosion/erosion processes and can be caused by numerous factors such as fatigue. This paper describes the utilization of Automated Coiled Tubing Integrity Monitoring (ACIM) to detect various integrity problems associated with Coiled Tubing Operations.

HISTORY OF COILED TUBING

Coiled tubing originated because of the logistical need to supply the Allied troops in France after the D-Day landings in 1944. Project, code name PLUTO (Pipeline Under The Ocean) was established in 1942 to develop a suitable method of supplying petrol across the English channel. Pipelines were considered necessary to relieve dependence on oil tankers, which could be slowed by bad weather, were susceptible to enemy submarines, and were also needed in the Pacific War. Three methods were researched:

- Short buoyed lengths of pipe linking ships moored off-shore (abandoned as unfeasible).
- HAIS - Flexible lead pipeline similar to an underwater power cable (the origins of flexible piping, risers, etc).
- HAMEL - Rigid steel 3″ pipe spooled of drums, codenamed ConunDrum and laid under the channel (the origins of Coiled Tubing and coiled pipe lay 'Reeling').

The first HAIS line to France was laid on August 12, 1944, over the 130 km (70 nautical miles) from Shanklin Chine on the Isle of Wight through the English Channel to Cherbourg. A further 18 other lines (11 HAIS and 7 HAMEL) with Operation Pluto considered one of history's greatest feats of military engineering.

Coil Tubing (CT) as seen today was developed in the early 1960's with the first CT unit being butt welded 1 $^3/_8$″ CT of about 15000ft in length. In the beginning there were many failures due to bad steel properties and the numerous butt welds. Continuous improvements of utilizing better steel properties, having fewer butt welds and the use of bias welds have resulted in better reliability.

USES OF COILED TUBING

Coiled Tubing is utilized in the onshore and offshore maintenance of wells with many applications such as:

- Nitrogen Kick Off

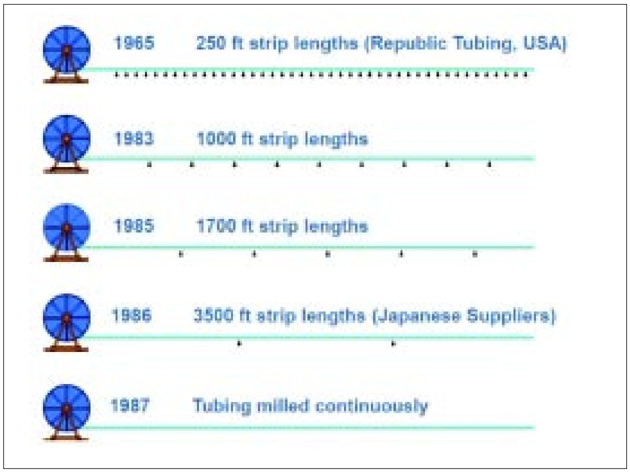

Fig 1: Coiled Tubing milestones

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- Wellbore Clean Outs
- High Pressure Jetting
- Cementing
- Acidizing
- CoilFRAC (a process to fracture a rock formation)
- Fishing
- Bridge Plugs and Packers
- Coiled Tubing Logging
- Perforating
- Drilling

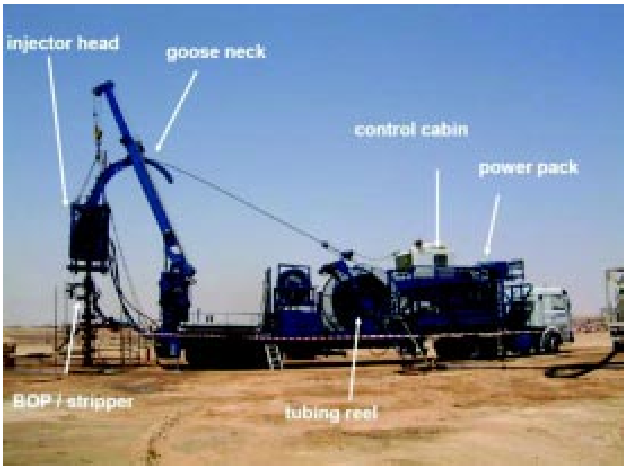

Fig 2: Coiled Tubing typical equipment (onshore)

COILED TUBING DAMAGE MECHANISMS

Coiled Tubing is subjected to different environments, loadings and pressures so several damage mechanisms can occur. A survey of coiled-tubing failures in various field applications shows that pitting and tensile overloads induce the greatest number of coiled-tubing failures.

Fatigue and weld area failures are the most common type followed by H_2S and brine-water corrosion. The following is a breakdown of some of the common damage mechanisms.

Corrosion Mechanisms

Internal Pitting – Occurs when residual fluids from manufacturing, transportation or from Coil Tubing operation (e.g. strong acids, HCI, KCI) are left in the coil. Also can be caused by insufficient washing or using sea water and long periods of time in storage (may also occur even when back-filled with nitrogen). Appearance is relatively small, at regular intervals along the 6 o'clock position, elliptical shape and may crack under tensile stress.

External Pitting – Caused by same residual fluids as internal pitting which collect in the crevices between the wraps. Typically relatively small and more severe towards the inner wrap.

General Erosion – Caused by abrasive materials in the fluids such as sand and drill cuttings (pumping operations).

Localized Erosion – Can occur when the Coiled Tubing rubs against the side of the well (OD), at regular intervals (buckling in the well) and at bends in the coil while pumping (ID).

General Corrosion – Occurs when the Coiled Tubing is left in a corrosive environment (acid operations). Normally uniform around the pipe wall, localized to certain areas and may be accelerated along the seam weld (not common in operations < 30hours).

Atmospheric and Filiform Corrosion – Is caused by remnant fluid (water) in the ID, splashed fluid (OD) and in areas of high humidity and warm climate. This appears as streaks of long, narrow pits that can grow deep within a short time during storage or transit (pinhole).

Pitting and Crevice Corrosion – one of the most common forms of Coiled Tubing corrosion damage. Primarily occurs in hot acidic environments (low pH), > temperature and high flow rates (velocity strings, Coiled Tubing T completions).

Marine Corrosion – Results from contact with marine salts, mainly sodium chloride (NaCl). Accelerated corrosion growth rate dependent upon exposure e.g. 12 times faster when located 25m from the coast line than when it is located 250m. Salt tends to increase time-of-wetness by absorbing water at lower humidity.

Environmental Cracking - Hydrogen sulfide is non-corrosive in the absence of moisture, low risk of corrosion or cracking in dry H2S gas wells. The presence of moisture and either CO^2 or O^2 result in highly corrosive environments.

Blistering – Typically occurs in lower strength Coil Tubing grades (e.g. CT70) in sour wells.

Hydrogen-Induced Cracking (HIC) – Occurs subsurface, principally responsible for axial (longitudinal) failures. Common (but not exclusively) in moderate to high strength Coil Tubing grades and is also associated with pre-existing mechanical damage or severe cold work.

Sulfide Stress Corrosion Cracking (SSC) – Is a most severe form of hydrogen-related cracking which results in brittle failure due to stress and severe hydrogen absorption. It is common with high strength Coil Tubing grades (CT-90, CT-100). Typically occurs within the first few cycles if the steel is susceptible.

Surface Micro fissure Cracks – these occur longitudinally and are initiated as SSC by wet H2S corrosion. Influenced by the residual, operating stresses and surface cold work and can occur on both the ID and OD or may also occur selectively along welds.

Mechanical Damage (Surface Handling Equipment)

Gripper Block Damage – Result in small marks over 360 deg of the OD circumference and may locally increase the hardness and cause indentations.

Injector Ring Damage_– The tight sealing rings may indent the tubing.

Gouges – Are removed metal from the OD and can appear as shallow elongated longitudinal scratch-like marks to deep regions of wall loss caused by hanging up against hard objects.

Spooling Damages - Section of Coiled Tubing is moved against the adjacent wrap or sides of the reel during uneven spooling or when there is a high "fleet angle" between the Coiled Tubing going on to, or coming off the reel, and the wraps on the reel.

Ultra Low Bend Cycle Fatigue – As Coiled Tubing is spooled and unspooled plastic deformation occurs during bending and straightening which results in cumulative and regressive changes in the material. Fatigue can result in fatigue cracking, shape/diameter changes, loss of yield strength, and loss of elongation and accumulated lengthening.

Fatigue Cracking – typically occurs as micro cracking and propagate through the Coil Tubing until it breaches. In high pressure applications the cracks propagate rapidly around circumference or may also be initiated by transverse orientated damages (e.g. gouges, pits). This will affect the electrical conductivity and magnetic permeability.

Shape and Diameter Changes - Cyclic bending leads to changes in shape and diameter. Diameter can increase during bending (cycle) or with internal pressure and ovality can occur.

Loss of yield strength - Commonly occurs during the first few cycles with a tendency lower rapidly and then to stabilize but no rules have been presented for an accurate assessment. Combinations of ovality and loss of yield strength may lead to severe lowering of the collapse pressure and accumulated lengthening.

Splitting - Occurs when the wall has thinned with cycled pressure, vibration or some form of embrittlement (e.g. hydrogen).

Manufacturing Imperfections

The following imperfections have been noted as resulting in poor performance of used coiled tubing:

Pinholes – Result in a pathway through the tube and can be 0.025mm long still could pass the mill hydrotest but enlarge under cycling, pressure and acid.

Partially Open Seam – Initiates from incomplete fusion of the seam weld which could survive the mill hydrotest but enlarges under cycling, pressure and acid.

Low Physical Properties – are caused by poor manufacturing processes that can result in low yield strength, low tensile strength, high hardness, porosity, large grains, weld cracking and elongation of tube-to-tube weld imperfections.

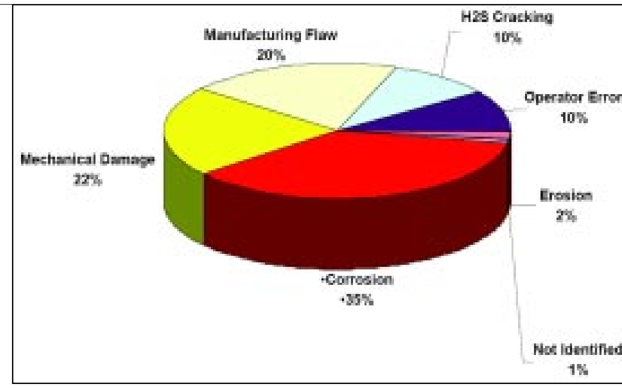

Figure 3: Failure Statistics 1995 –mid 2004

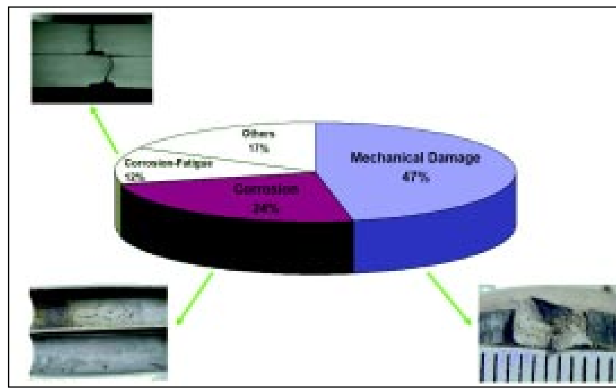

Figure 4: Failure Statistics Mid 2004 -2006

Material Imperfections – are caused by poor quality material that is sub sequentially processed and can result in surface pits, inclusions, segregations and laminations, lower the cycling ability. Can also provide sites of hydrogen ingress and crack initiation.

DEVELOPMENT OF ACIM

Rosen was approached to develop a tool to inspect Coiled Tubing after several failures, one such failure resulted in a loss of well production in excess of 3 weeks. Rosen engineers employed their experience with magnetic flux leakage (MFL) technology gathered from the inspection of thousands of kilometres of pipelines. ACIM was developed as a real time inspection device performing online detection of general corrosion, pitting and it also conducts online determination of the tube geometry. The ACIM tool is now used on new spools at the coil suppliers' facilities and during onshore and offshore operations.

EQUIPMENT

The ACIM testing system consists of an Mfl unit, Geo unit, Odo unit, MFL sensor cable, Geo-Odo sensor cable, DAC unit and a 'ruggerdised' laptop computer (Figure 5, 6 and 7).

Mfl Unit – (**Magnetic Flux Leakage**). Detects metal loss, fractures and wall thickness measurements. There are always three MFL sensor arrays per ACIM tool and the number of sensors depends on tool size. The determination of the Coil Tubing wall thickness is based on the readings

Figure 5: Mfl unit, Geo unit, Odo unit, MFL sensor cable and Geo-Odo sensor cable

Figure 6: DAC Unit

of the MFL Unit taking the physical relation between wall thickness and magnetization of ferromagnetic material into account. The detection of metal loss represents an essential part of a Coiled Tubing integrity monitoring program.

Geo Unit – (**Geometry**). Measures ovality and diameter. Always four sensors per array on every tool size with three Geo arrays on every tool.

Odo Unit – (**Odometer**). Distance and speed measurement with three odometers on each tool, space 120° apart.

DAC Unit – (**D**igital **A**nalog **C**onverter). Supplies power to the sensor array's, connects the sensor array's with the laptop and separates the Ex proof part of the ACIM system from the non Ex proof part.

Features of the ACIM system

- 45 / 54 MFL sensors.
- 12 linear OD sensors.
- 1 _ to 2 _ inch OD
- Clamp system
- Measuring wall thickness, diameter, speed and depth.
- Detecting metal loss, butt welds.
- Zone II.

Figure 7: ruggerdised, laptop

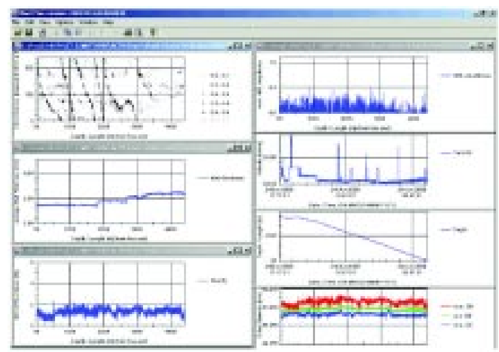

Figure 8: Rosoft® reporting and analysis software.

CONCLUSION

The ACIM tool is being successfully utilised conducting inspection of Coiled Tubing on new spools, or at onshore and offshore well interventions. Inspection by ACIM reduces the risk of Coiled Tubing failure during operations thus reducing the likelihood of lost production and revenue loss.

REFERENCES

1. *API-5C8 Recommended Practice for Care, Maintenance and Inspection of Coiled Tubular Product,* American Petroleum Institute, 9th Draft, Revision 0, March 2008.
2. *Pitting, tensile overloading produce most coiled-tubing failures,* The Oil and Gas Journal, by Maldonado, Julio G.; Cayard, Michael S.; Kane, Russell D., 26 June 2000.
3. *Automatic Coiled Tubing Integrity Monitoring System,* Petromin, by Patrick H Rosen, October 2001 PP

PetroMin PipeLiner would like to show appreciation to Mr. Michael Trinidad and Mr. Muhammad Rudaini Ahmad Zaki, Rosen Asia Pacific, Malaysia for this special report which was presented at our NACE East Asian & Pacific Regional Conference & Exposition, held at Prince Hotel, Kuala Lumpur, Malaysia on 23rd to 25th November 2009.