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CASING INTEGRITY SURVEILLANCE – A CASE STUDY OF SURVEILLANCE METHODS TO DETERMINE CASING CONDITION OF MATURE WELLS

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ABSTRACT

Two gas producer wells operated by a major international oil company in Sumatra Onshore needed to be recompleted to replace tubing and/or install bigger production tubing to maximize production. With a high H₂S and CO₂ content, effective barriers for containment of well fluids and pressures throughout the rest of well's lifecycle need to be maintained to ensure that the wells are safe for workers and communities, minimize risks of leaks and spills, protect groundwater and surface water, and have low probability of long-term failure.

A combined tubular inspection program consisting of a direct measurement Multi Finger Caliper and Electromagnetic measurement using Pulse Eddy Current was deployed. This allows quantitative corrosion evaluation/casing thicknesses of each multiple casing layer in the well and surface quality of inner most casing.

At the end of less than 2 days operation, information was obtained that allowed operator to determine the maximum allowable operating pressure of each casing annulus and best spot of inner most casing for packer setting placement. This significantly reduced the probability of long-term failure and potential for expensive future recompletions.

Keywords: annular integrity, corrosion, casing thickness

INTRODUCTION

A properly designed well is essential for the environmentally sound, safe production of oil and natural gas. Ensuring long term well integrity, the ability of a well to provide effective barriers for containment of well fluids and pressures throughout the well's lifecycle, is a vital part of well design and construction. Properly designed and constructed

wells safeguard workers and communities, minimize risks of leaks and spills, protect groundwater and surface water, are safe to operate and have low probability of long-term failure.

Wells are designed to maintain well integrity throughout their lifecycle. Design considerations begin with initial site selection and end with permanent well closure. Region specific geological, environmental and operational requirements are taken into consideration for each well. While there is some variability in how a well is constructed, every well is designed to maintain well integrity throughout its life.

Well casing, the steel pipe cemented into the ground at various stages during the throughout its life, provides the primary layer of protection between the oil and gas being produced and the rock formations transected by the well. A typical well includes multiple layers of casing and cement, each designed with a specific purpose:

1. To serve as a barrier to isolate and protect freshwater from fluids in the wellbore.
2. To provide a conduit for the production of well fluids such as oil and gas.
3. To contain the fluids and pressures required for subsequent completions activities.

Maintaining well integrity throughout the life cycle is a never-ending challenge. Various types of mechanical integrity tests are used to assess well integrity and seals over the productive life of the well. Operating pressure limits are established and casing strings are monitored to ensure that well integrity concerns are quickly detected and appropriately addressed. The ultimate goals are to maintain safe work practices to protect the environment, workers and the communities.

This paper outlines an analysis technique for

mechanical well integrity that integrates Multi Finger Caliper data and Magnetic Thickness Detector data to provide information on the condition of multiple casing strings. . This information can be used to determine Operating pressure limits on each annuli or in other word to ensure its ability to withstand the pressures to which it will be exposed.

The wells in this study are located in central Sumatra and were drilled in the 1990's. The main facilitating conditions for corrosion in this well are H₂S and CO₂ content. The drivers for the casing integrity surveillance are to maximize gas production while maintaining well integrity to protect the environment, workers and the communities.

Description of the Technology Deployed

Magnetic Thickness Detector (MTD) – a Pulsed Eddy Current Technology

The Pulse Eddy current technology was utilized to evaluate corrosion. The tool employs an electromagnetic transmitter and receiver coils to induce pulsed eddy currents in the cross section of the tubulars being evaluated and measure the decaying electromagnetic response generated from the induced signal with the receiver coils. The resulting signal is processed to extract individual metal thickness measurements from multiple concentric strings of tubing and casing (Riaz-ud-Din et al, 2011)³.

The working principle is based on Faraday's laws of electromagnetic induction. When a time varying power is supplied to the emitting coil in the tool, a transient electromagnetic flux is induced in the surrounding tubing and or casing which further induces eddy currents in the cross sections of the concentric tubular sections (Xingfu et al, 2007)⁵.

The A sensor is the main sensor of the tool as shown in Figure 1. This sensor has the deepest depth of investigation and is sensitive to corrosion and defects on an inner and outer tubular (often the completion tubing and the production casing). This axially mounted sensor is sensitive to vertically oriented thickness variation; The C sensor is a shorter axial sensor as shown in Figure 1. It is sensitive to smaller vertical defects within the innermost pipe string.

When a pulsed signal is supplied to the transmitter coil, the transient eddy current response produces a radial pattern around the tool with a radius that increases with time. The response of the receiver signal induced by the pulsed eddy currents from the

transmitter is manifested as a time decay signal with each increasing radius circular shell of metal corresponding to a "time window" in the decay. The ability of the tool to separate the signals coming from the concentric cylindrical shells of eddy currents in time domain provides the unique capability to differentially determine the thickness of the different strings of tubing and casings present in the well completion. (Rourke et al, 2013)⁷

When the thickness of the tubing or the casing changes, there is a corresponding, measurable change induced in the transient eddy current pattern, which can be detected in the change of the time domain decay spectrum. The measurement is precise enough to detect small changes of thickness in the concentric tubulars. Different sensors within the instrument have different depths of investigation. During interpretation, specific empirical relations between the decay responses and extensive data collected for varying combinations of well completion profiles, including eccentricity of tool and tubular layers are used to estimate the specific tubular thickness. (Rourke et al, 2013)⁷

As an estimated measurement, the tool provides an average thickness over a cross section of the tubular being evaluated at each depth. However, small localized flaws can only be detected by more detail sensor (i.e. imaging sensors) only if they are situated on the innermost pipe. The standoff between sensor and flaw is too large washing out the effects of the field perturbations by the defect. For un-centered casing, it can be the same case if the stand-off between two casings is too small.

Multi Finger Caliper (MFC)

Multi Finger Caliper is a mechanical downhole logging tool. The tool provides accurate and reliable measurements of internal tubing and casing diameters to detect deformation, bending, fracture, perforation and inner corrosion condition of casing or tubing with multi fingers directly contacting the casing wall. Each measuring finger connects to high measurement accuracy non-contacted displacement sensor.

Measuring fingers move radially along the inner casing or tubing wall, detecting any diameter change. This produces a high resolution record of the tubular geometry which can be viewed and presented as a conventional log, a cross section, or a 3-D color enhanced image. Auxiliary measurements include an integral wellbore temperature probe, along with deviation and relative bearing information. A range

of instrument diameters with different finger arrays (24, 40 and 56 arms) are available to provide optimized measurements in tubulars ranging from 2-3/8 in. to 13-3/8 in. diameter.

Area of Deployment

Two wells were selected for field deployment. The objectives of the campaign were to:

- Assess well conditions and provide information for recompletion plans
- Identify zone of significant corrosion and perform risk assessment, to determine updated MAWOP (Maximum Allowable Working Operating Pressure) of each annulus for future safe operation.

A brief description of the wells are provided below (Figure 2)

Well-A

The well was drilled and completed on August 2000 as active gas producer. Based on Annular Pressure Diagnostic on 2009, 2010, 2011 and 2013 the well was categorized as Significant Risk, a gas sample taken from the Tubing & A-annulus showed 5% CO₂. A leak detection log was carried out in April 2013 and suggested there are more than 10 leaks in tubing joints. A recompletion workover to replace the tubing was performed in July 2016. Prior to the recompletion work, GOWell 1-11/16" OD Magnetic Thickness Detector and 3-1/2" OD 56 arms Multi Finger Caliper tools were run to perform casing integrity diagnostic. A survey was undertaken from 2055 m to surface inside 9-5/8" production casing, and the result of short section at 553-578 m MD are shown in Figure 4.

Well-B

The well was drilled and completed on August 1998 as a gas producer on 5-1/2" completion string. The well was producing about 70 MMSCFD gas with 65 ppm H₂S and 36% CO₂. Upsizing tubing to 7" is expected to maximize well production to get a gain of 35 MMSCFD. A recompletion workover was carried out in November 2016. Prior to the recompletion work, GOWell 1-11/16" OD Magnetic Thickness Detector and 3-1/2" OD 56 arm Multi Finger Caliper tools were run to perform casing integrity diagnostic. A survey was undertaken from 1460 m to surface inside 9-5/8" production casing, and the result of the whole section are shown in Figure 3.

Results and Key Outcomes

The data acquired in the selected wells was repeatable and of good quality. All the MTD was run with a MFC, which provided a good benchmark to compare and qualify the measurement for the inner most tubular in the well. The MFC data processing includes centralization to eliminate the effects of eccentricity. Both wells logged in this evaluation had low to medium corrosion as shown in Table 1 and Table 2. This allowed the operator to continue to use the wells as gas producers on acceptable MAWOPS. The results are described in more details in the sections below.

The data from MTD is processed using empirical relationships established over extensive data collected for varying combinations of well completion profiles, normalized and presented as a thickness map along with a visual representation of the normalized decay curves. MTD results were combined with the MFC log, providing a comprehensive diagnostic service for multiple strings of casing

Effectiveness of Evaluation

By deploying this multi-barrier casing and tubing evaluation technology and combining it with the well history, available information and other measurements made in the well, a meaningful evaluation of the condition of the casings was obtained. The integrity of the production casing could be correlated with the cement evaluation results available. Metal loss tended to increase in zones of poorly cemented pipe and was minimal or absent in zones of good cement bond as shown in Figure 3. This trend was identified across different wells and in different zones within single wells. Additionally, in zones of significant corrosion, a corrosion rate of metal loss per year could be established and will serve as a reference for establishing future trends in certain zones in this field.

In addition to well integrity evaluation, Multi Finger Caliper data was also used to evaluate inner casing condition for the best placement of packer. As shown in Fig 5, the top section of the joint is an acceptable spot for packer placement. Knowing casing condition prior to setting the packer will minimize the potential of having leaks across the packer.

The results have enabled the prioritization of the workover program for these wells. The workovers

will also enable the further direct and detailed evaluation of the casing and physically verify the results of this campaign and forego some of the scheduled workovers. With a high cost of each workover, there is a potential to save significant remedial costs across the field.

Conclusion and Recommendation

A combination of Multi Finger Caliper, Magnetic Thickness Detector and Cement Bond Log, gives a clear picture of mechanical well integrity to determine safe operating envelope of the well.

A fair to good correlation was observed between the corrosion metal loss in the casing and the quality of cement bond behind casing as shown in Figure 3. External corrosion due to exposure to formation fluids spreads from the outside to the inner casings. Further evaluation of cement logs for the production and the outer casings is recommended, which may lead to possible remedial action to isolate the metal from the corrosive formation fluids

Future recommendation is to do time-lapse measurement of casing thickness, which can be a powerful method for evaluating the progression of corrosion in concentric tubulars, and update the MAWOPS as necessary to maintain safe operation of the wells. With a diameter of 1-11/16" (42 mm), the tool can be run through most of the commonly used tubing sizes and used to inspect casing conditions through the tubing by calculating both tubing and casing thicknesses and areas of corrosion. This allows for greatly reduced operating costs and time to evaluate the tubing and casing behind it without the need to pull-out the tubing string to evaluate the casing condition.

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TABLE 1**HIGHEST METAL LOSS FROM MTD LOG IN WELL B**

Top Body (m)	Bottom Body (m)	Body Length (m)	Nom Thk (in)	Min Thk (in)	Max Loss Depth (m)	Max Loss (%)	Grade
Highest Metal Loss in 9 5/8" casing from MTD Log							
1325.4	1337.7	12.3	0.472	0.422	1337.2	10.7	D
1429.6	1441.8	12.1	0.472	0.428	1430.2	9.4	C
Highest Metal Loss in 13-3/8" casing from MTD Log							
428.7	441.7	13.1	0.38	0.353	429.9	7.1	C
510.0	522.3	12.3	0.38	0.352	521.9	7.4	C

TABLE 2**HIGHEST PENETRATION RATES IN 9 5/8" CASING FROM MFC LOG IN WELL B**

Top Body (m)	Bottom Body (m)	Body Length (m)	Max Pen Depth (m)	Max Pen (in)	Max Pen (%)	Corrosion Grade
1403.19	1415.52	12.33	1406.15	9.1	40.7	C
1416.00	1428.85	12.85	1419.53	9.1	43.5	C

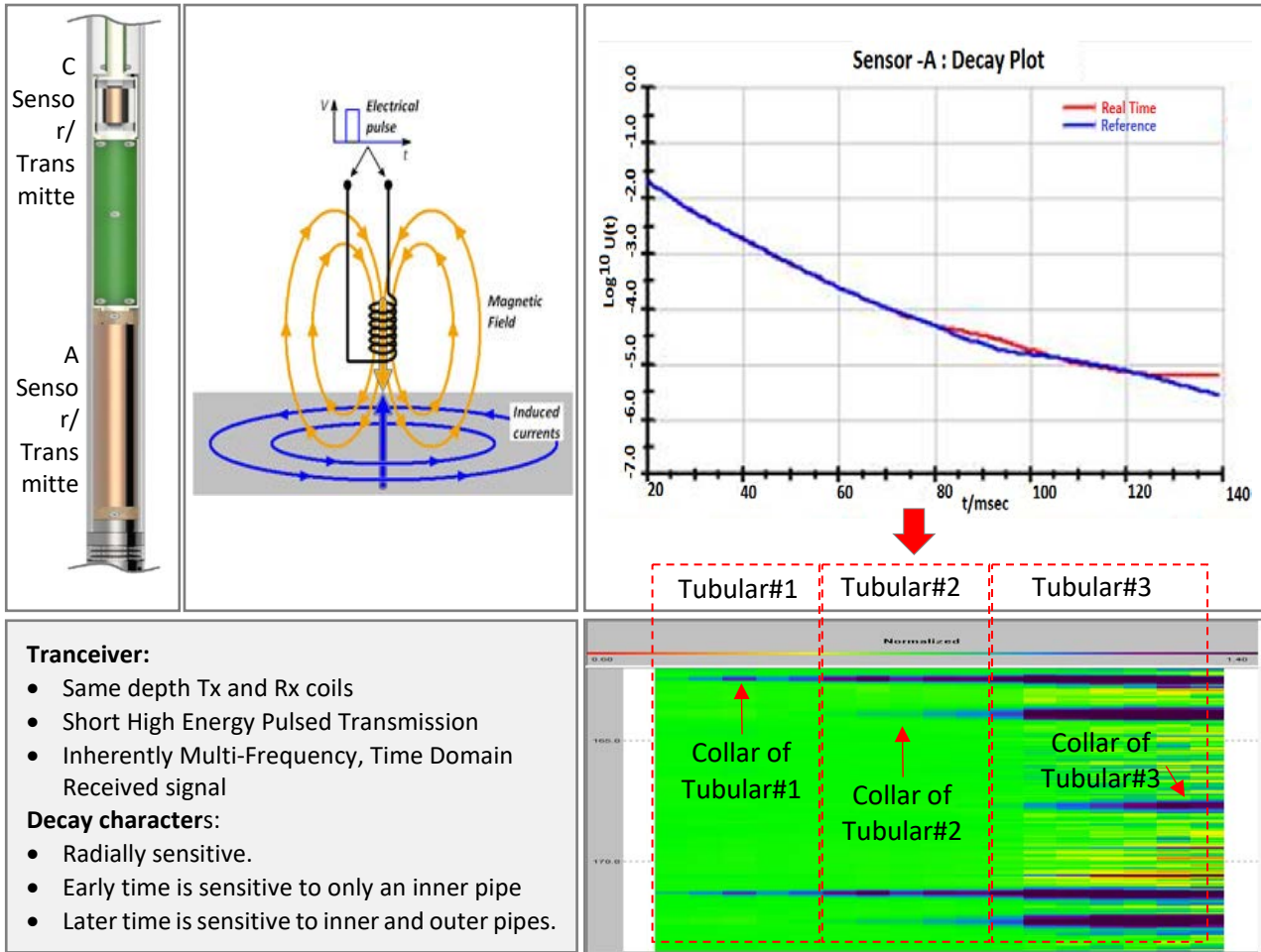


Figure 1 - Principle of Pulse Eddy Current thickness Detector

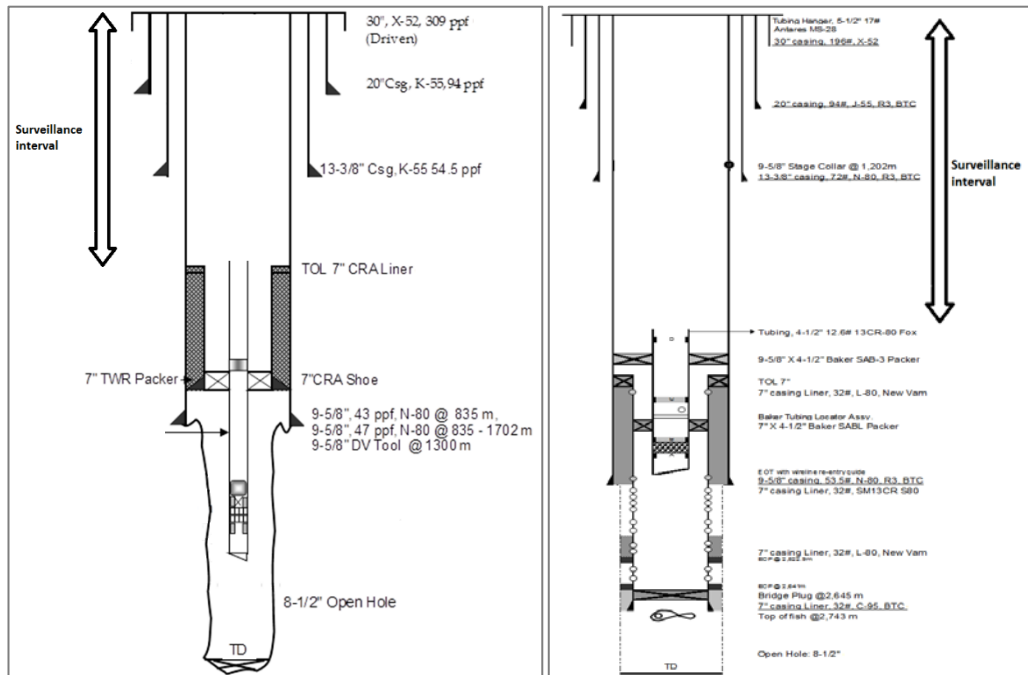


Figure 2 - Schematic of Well A (left) and Well B (right). Casing integrity surveillance were done over the production casing, from cutted tubing point to surface.

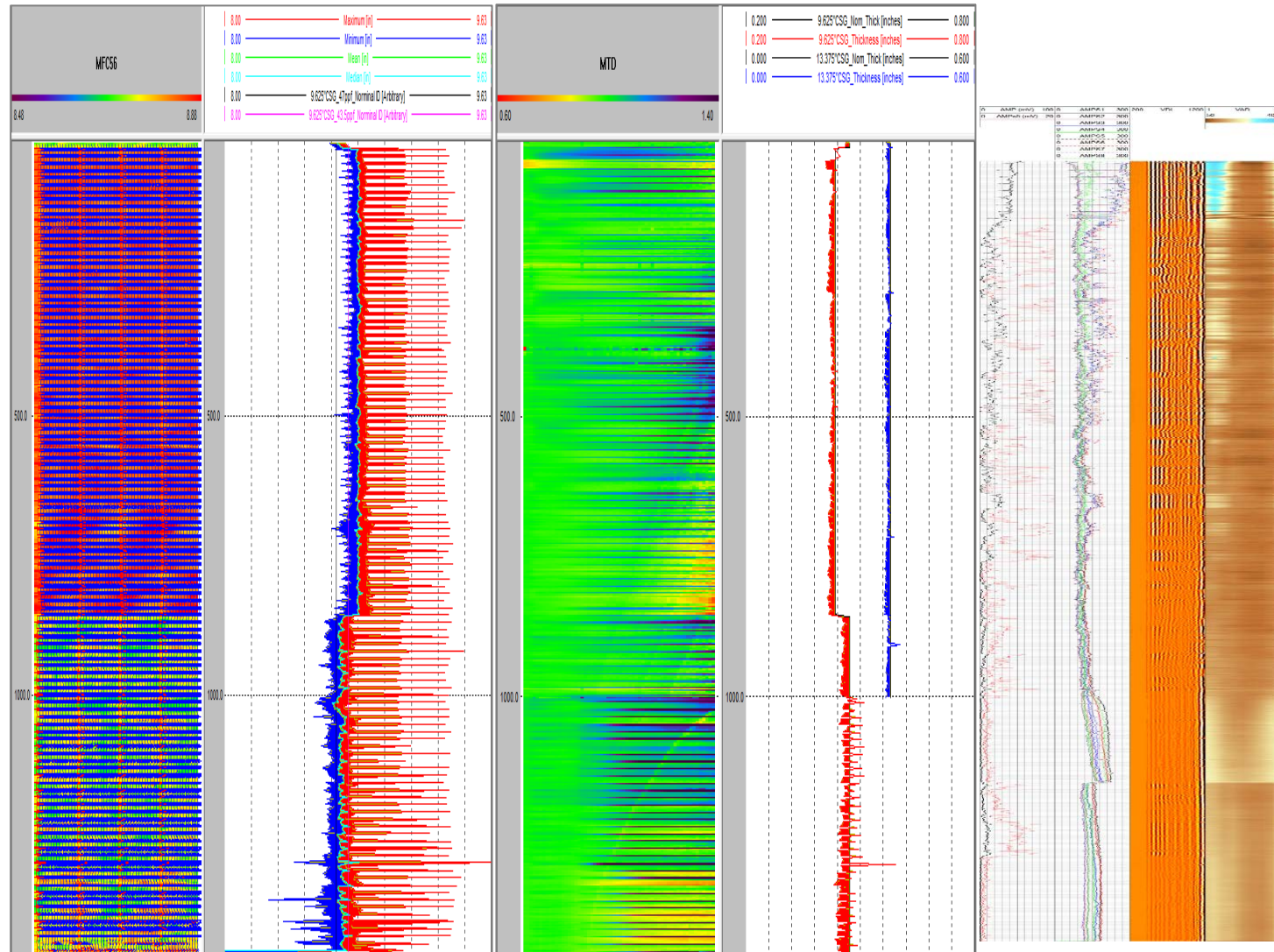


Figure 3 - MFC (left) and MTD (center) and CBL (right) log result of Well B. On Bottom section of the well at around 1200 – 1500 mMD, MFC showing erosion on inside of the 9-5/8” casing and MTD also showing metal losses. Confirming that the metal erosion/losses is happening inside the 9-5/8” casing. On top section of the well at around 0 – 300 mMD, mfc shows good quality of inside of 9-5/8” casing, but MTD shows some metal losses on it. There are correlation between the corrosion metal loss outside of the casing and the quality of cement bond behind the casing.

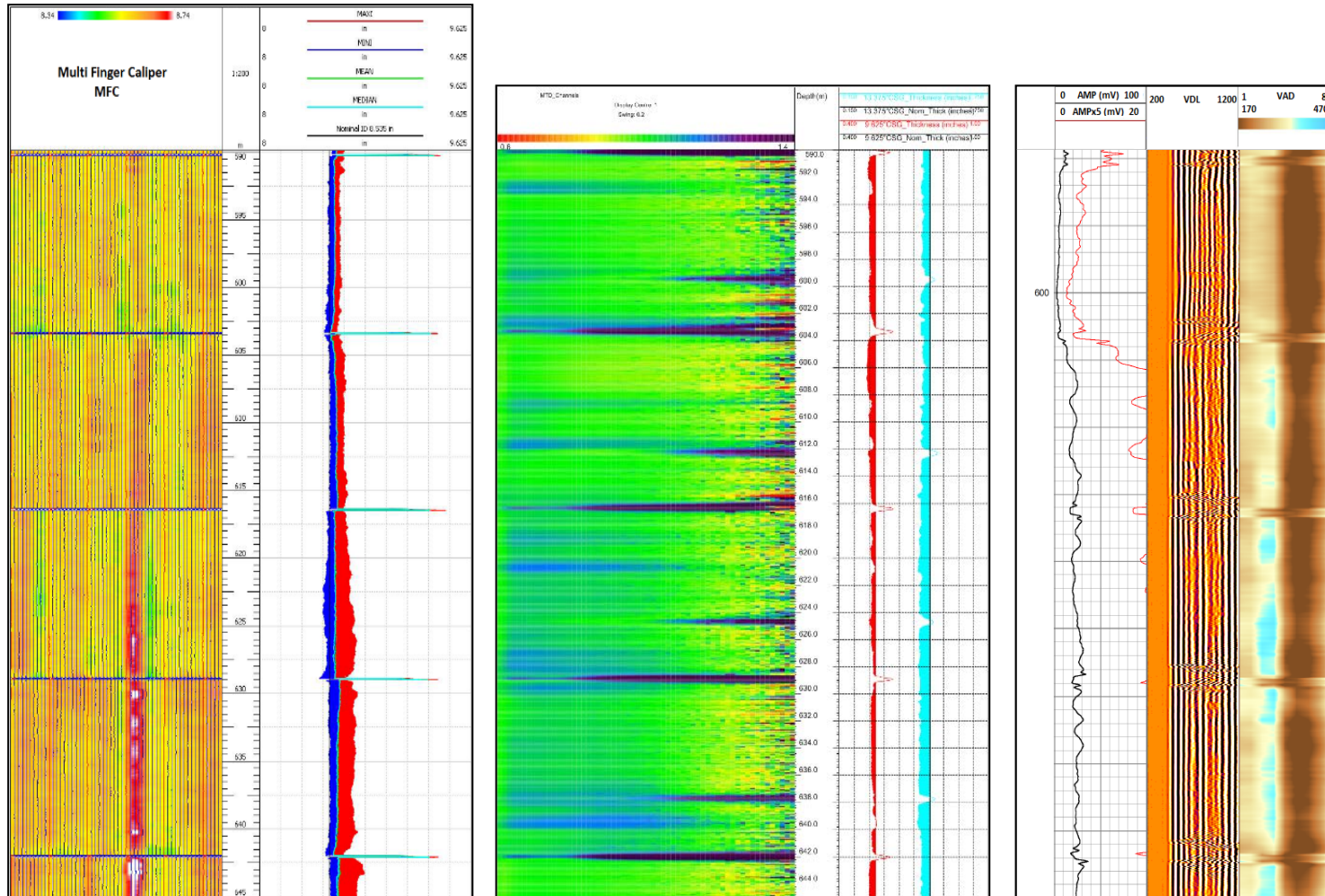


Figure 4 - MFC (left), MTD (centre) and RCBL (right) log result of Well A. From the MFC indicated that there is a groove damage on the 9-5/8" casing, while the MTD showing good thickness of the casing. Since there is a cement channel behind casing, high likely that the groove is not an erosion but a metal deformation going outside of the casing.

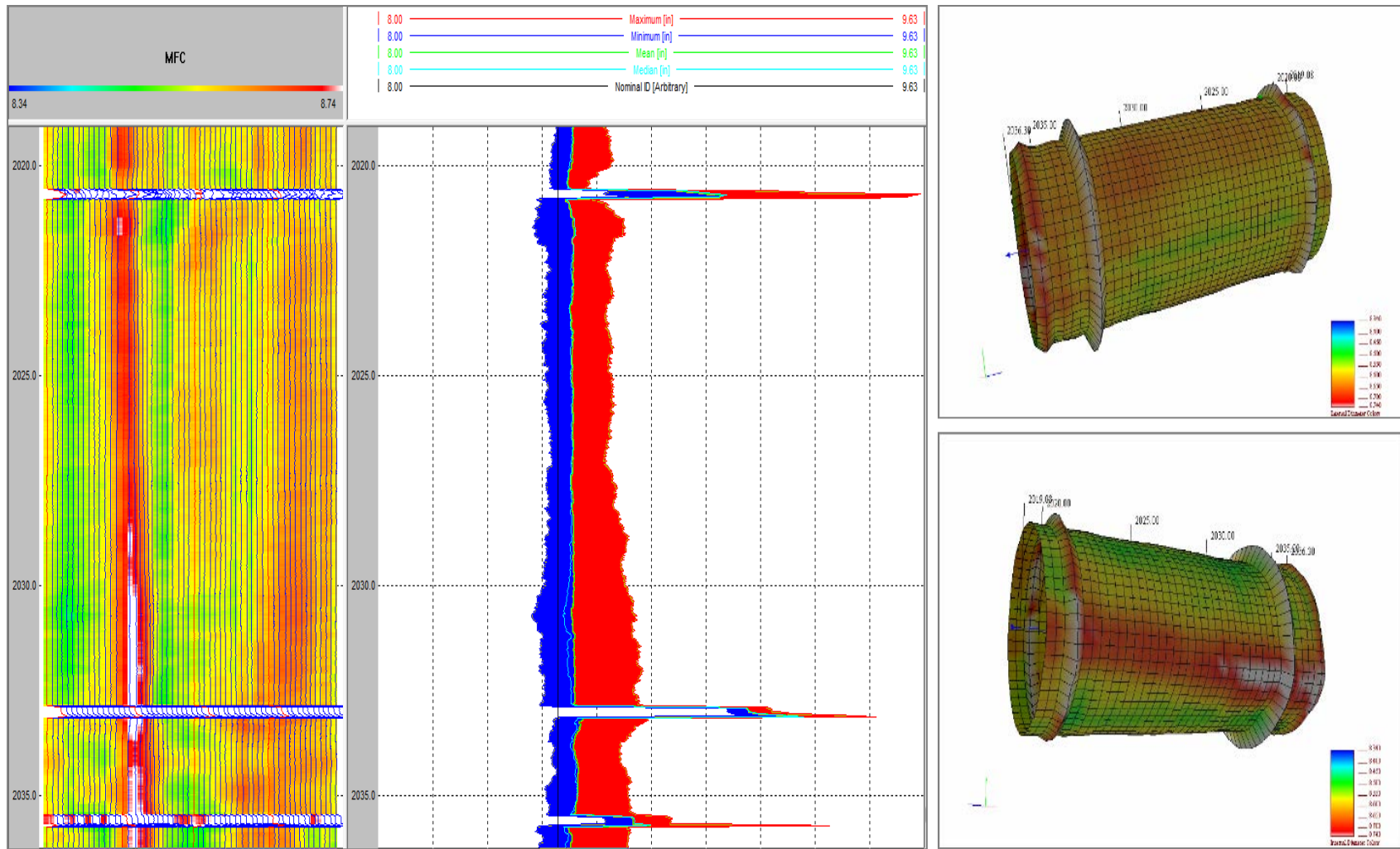


Figure 5 - MFC result as consideration for packer depth placement