HIGH TEMPERATURE CASING CONDITION – MULTI FINGER (HTCC-MF) TOOL

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ABSTRACT

Knowledge of the integrity of casing is important to avoid blowouts and loss of production. There are different ways to measure casing condition, but contact methods are more accurate than non-contact methods. Multi-finger calliper logs are a useful and accurate way to monitor the condition of casing in wells. This paper presents a high temperature, high pressure geothermal multi-finger calliper. It can operate in high temperature wells and thus negates the need to quench the well beforehand. It provides 3D visualisation of the inside of the casing and can be combined with existing high temperature electromagnetic tools to measure the thickness of the casing.

1. INTRODUCTION

Multi-finger callipers are one of many useful downhole tools for assessing the casing that lines wells. It is important to know what the condition of the casing is because casing maintains the integrity of the well. It stops the high pressure steam inside the well escaping into the formation surrounding the well. Failure of the casing can lead to a blowout which results in a loss of production of the well and can be dangerous. So proper monitoring the integrity of the casing in a well reduces financial and safety risks for well owners.

1.1 History of multi-finger callipers

The history of multi-finger callipers dates back to early oil and gas pioneering. The earliest patent for a calliper tool was in 1868 (Caliper History, 2016). A purely mechanical multi-finger calliper that recorded data internally was patented in 1954 (Johnston, 1954). This type of calliper is still in use today and is particularly effective in geothermal wells because being purely mechanical, it is immune to temperature effects.

The down side of a purely mechanical calliper is the limited number of fingers and lack of smarts. Compensation of temperature drift for example is a challenging task for a purely mechanical calliper. Another limitation of a purely mechanical calliper is that it can only open the fingers once and cannot close them until the tool is out of the well. With the fingers open you cannot go back down the well to log a repeat section. A repeat run of a section of well is highly desirable to show that the tool is working correctly and is producing repeatable measurements.

Multi-finger callipers are relatively common in the oil and gas market but there is not much choice in the geothermal market. Geothermal wells have high temperatures to contend with and the diameter of the wells tend to be larger than their oil and gas counterparts. So it is difficult to use oil and gas technologies in geothermal wells. You can sometimes use oil and gas technologies in geothermal wells if the well is quenched beforehand to cool it down. However quenching is an undesirable choice for the asset owner. It is expensive and it damages the well.

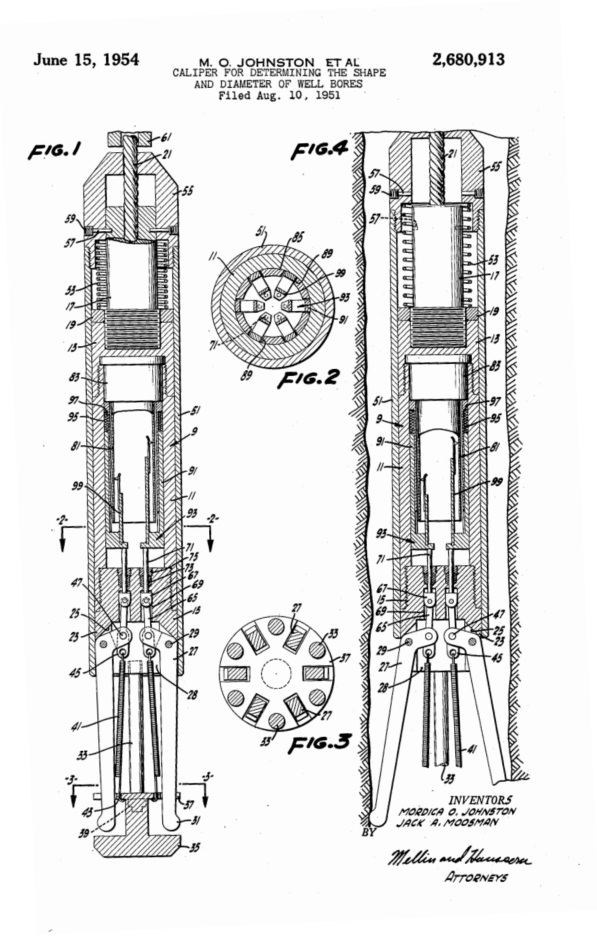

Figure 1: Early multi-finger calliper patent (Johnston, 1954).

2. MEASUREMENT TECHNIQUES

There are a few different ways to measure casing condition in high temperature wells – mechanical, electromagnetic, acoustic, and optical. All of these methods suffer from limitations. Electromagnetic methods have been used in geothermal wells for a long time and acoustic methods have been trialed with limited success. These types of tools can measure the thickness of the casing in addition to measuring the internal diameter. Thickness measurement is important to determine if any corrosion is occurring on the outside of the casing. Electromagnetic tools that run in geothermal wells provide qualitative rather than quantitative data. Acoustic tools have the advantage of providing quantitative measurements but based on analysis of logs, they have not been successful in cased geothermal wells. Optical methods do not work at high temperatures and when the well fluid is opaque.

2.1 The HTCC-EM electromagnetic tool

The author has actively participated in the design of MB Century's HTCC-EM tool. This tool has been in service in one form or another for over 25 years. It works on electromagnetic principals of generating oscillating currents in coils of wire, and these create a magnetic field that generates eddy currents in the steel casing. The eddy currents generate their own magnetic fields and the detection of these fields is what is used to determine the condition of the steel in the casing. It is difficult to obtain accurate measurements because of the changing electrical and magnetic properties of the casing but nevertheless the information it provides is very useful in monitoring the condition of casing in wells.

Figure 2: HTCC-EM tool.

2.2 The HTCC-MF multi-finger tool

The development of the High Temperature Casing Condition Multi Finger (HTCC-MF) tool was initiated by a demand for better and more accurate ways of monitoring casing condition.

There is a perception in the geothermal industry that contact measurements such as those given by multiple fingers that touch and slide up the well are going to give better results than electromagnetic or acoustic methods. This is backed up by experience in the oil and gas industry where multi-finger calliper runs are commonplace.

The HTCC-MF tool complements MB Century's existing electromagnetic (HTCC-EM) tool because the multi-finger calliper accurately measures the inside of the casing and the electromagnetic tool gives a qualitative measurement of the condition of the outside of the casing. Together they provide a comprehensive look at the condition of the casing.

3. HTCC-MF DEVELOPMENT

MB Century has spent the last few years developing the HTCC-MF tool. It has been a large undertaking with many technical challenges solved along the way. Making electronics work at 320°C and 350bar is one of the obvious difficulties, although the technology used to do this has been around for decades. There are many examples of downhole electronics safely protected from the harsh environment by heatshields or flasks. These are specially built evacuated vessels that usually have a thick outer layer of metal that acts as a pressure barrier and a thin inner layer of metal that is separated from the outer layer by a vacuum. The vacuum provides thermal insulation to keep the payload cool enough to operate the instrument for a finite time downhole.

3.1 Thermal design

Computer simulations of heat transfer into the flask helped to optimise our design. There are three ways heat enters the flask.

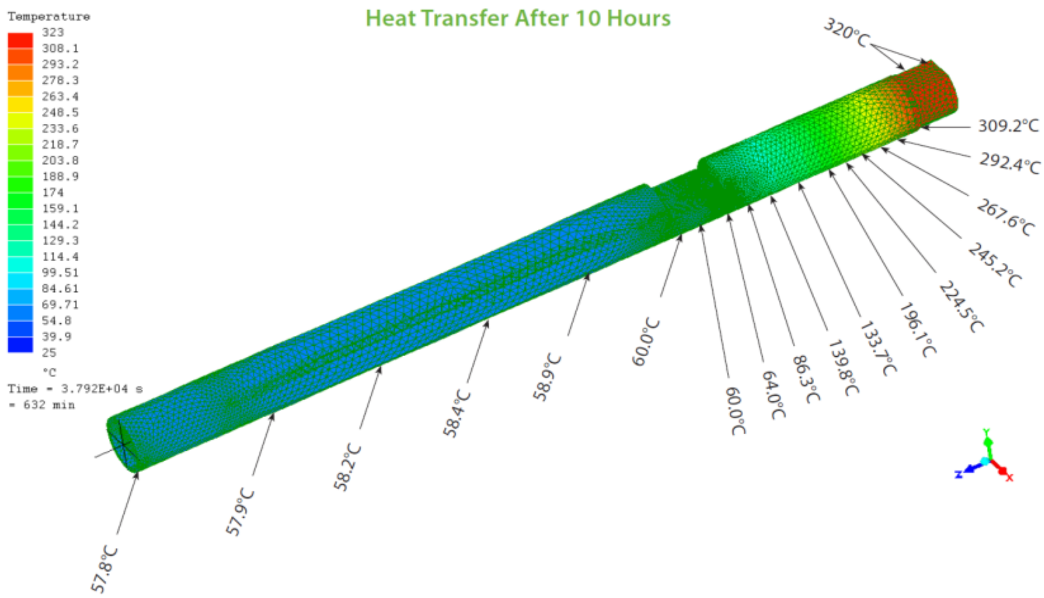

Figure 3: Thermal simulation of HTCC-EM flask payload.

1. Radiant heat from the well (though the vacuum barrier).
2. Heat conducted from the well into the flask.
    a. Heat conducted through supporting structures inside the flask
    b. Heat entering through the thermal insulator
3. Heat generated in the electronics.

The thermal insulator is a key part of the design. Sensor wires pass through the insulator and in the case of the HTCC-MF we need to pass hundreds of copper wires through it. This was one of the major technical obstacles to the project because of the quantity of wires, and because copper, being a good thermal conductor, conducts a considerable amount of heat into the flask. To overcome this obstacle, very small wire was used, together with a large flask containing a heat sinking material that can absorb a considerable amount of heat energy.

3.2 High temperature motor

Another challenge was providing the ability to open and close the fingers on command. To do this a high temperature motor was developed. The motor is outside the flask, in the bottom part of the tool. It can operate at temperatures up to 320°C and high well pressures up to 350bar. High temperature operation was achieved by careful selection and testing of exotic materials. High pressure operation was achieved by immersing the motor in oil and providing a mechanism to allow for expansion of the oil with temperature.

This is a unique achievement. One of the few other applications for motors operating at these sorts of temperatures and pressures is in robotic landings on the surface of Venus.

3.3 Other tool features

The calliper has 60 fingers and these are spread out around the circumference of the casing so there are 60 internal radius measurements around the circumference of the pipe. As the tool travels out of the well, measurements are made continuously in the vertical direction creating a 3D image of the inside of the casing. The fingers can be opened and closed multiple times to allow repeat runs on particular sections of a well. Repeat runs help to show that the tool is measuring real features and that the data can be relied upon. This data is either transmitted to the surface in real-time or stored in memory for later extraction.

The electronics are designed to be modular with each module performing a specific function. The modules can co-exist in the same flask or be in separate flasks. The HTCC-MF contains two modules in the same flask; the Controller Module and the Multi-Finger Module.

The Controller Module is the brains of the system. It can receive power and communicate over an e-line cable. It can store up to 10 hours of multi-finger data in memory for later extraction. It controls other modules that can be located elsewhere in the tool chain. The system can be set up to be fail-safe in the event of the e-line cable problem. The controller board stores data to memory as well as sending it up the e-line cable. If the e-line fails, a battery can seamlessly take over powering the tool and the run continues without data loss.

The Multi-Finger Module provides processing, data collection, and digital signal processing to collect measurements from all 60 fingers at a rate of 20 times per second. The measurements are sent to the Controller Module for storage and transmission. The Multi-Finger Module also contains a brushless DC motor controller to control the high temperature motor.

Inclination, and roll measurements are made concurrently with the finger measurements. The roll measurement allows the high side of the well to be determined and the inclination is useful to confirm that the casing is inclined the expected amount. The tool body temperature is measured and used to calibrate out temperature effects in the finger measurements. Other safety and performance measurements are made, including electronics internal temperature, flask internal pressure, battery voltage and diagnostic information.

3.4 Calibration

Achieving accuracy was a significant challenge for the project. During the HTCC-MF design phase, an error budget was created for each part of the measurement system (mechanical, sensor, electronics, and calibration residuals). Each team was responsible for achieving their individual accuracies so that the overall accuracy goal could be achieved.

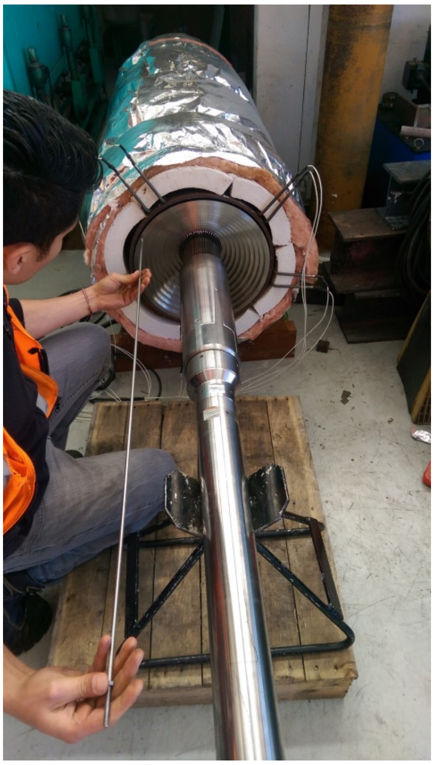

Figure 4: HTCC-MF being loaded into calibration oven.

Each finger is individually calibrated to correct for sensor temperature drift and non-linearity as part of the manufacturing process. The tool is calibrated in a specially designed oven that allows a calibration ring to slide over the fingers. In this way all the fingers are measured at multiple casing diameters and at multiple temperatures. The measurements are processed to create a set of multi variable coefficients for each finger. The calibration coefficients are applied by the SRO software in real-time as the data is collected.

Some multi-finger calliper tools have finger tips that wear down considerably during a run. It is normal practice to perform pre-run and post-run calibration to check tool accuracy and to compensate for finger wear inaccuracies.

During the pre-run and post-run checks, a calibration ring is passed over the tool and measurements are made at specific calibrated ring sizes. If finger wear has occurred during the run, the data is adjusted to correct for it. The HTCC-MF finger tips are hard enough that they do not show any measurable wear during a run; however pre-post run checks are still done to confirm proper operation of the tool and accuracy of the data.

3.5 Surface Read Out

The Surface Read Out (SRO) system connects to the e-line cable at the surface of the well. It sends power down to the tool and collects data from the tool. The SRO system also manages memory operation. Before a memory run, it synchronises time between the tool and the computer. After the run data is downloaded from the tool, and matched up with the surface data (depth, cable tension, and well head pressure). The SRO stores, and graphs data in various different ways. The most common way is to plot data vs. depth, but it can also plot with respect to time. The finger data can be cross-plotted to show the cross section of the well. The logs of repeat sections can be overlaid to instantly check repeatability.

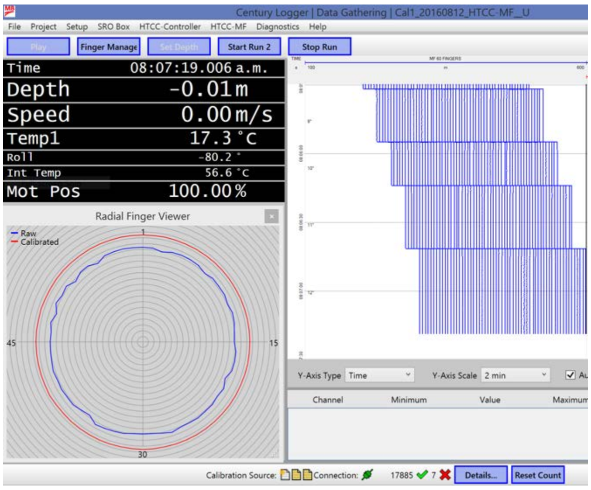

Figure 5: SRO software communicates with tool and presents real-time data to the field engineer.

Figure 5 shows a SRO session during a recent lab calibration. The blue traces are the HTCC-MF fingers being passed over a calibration ring to check accuracy.

3.6 Combining HTCC-MF and HTCC-EM tools

The HTCC-MF tool can be run in combination with the HTCC-EM Module. In this configuration, the Controller Module powers and collects data from both the Multi-Finger and EM modules. This allows the inside and outside of the casing to be logged concurrently.

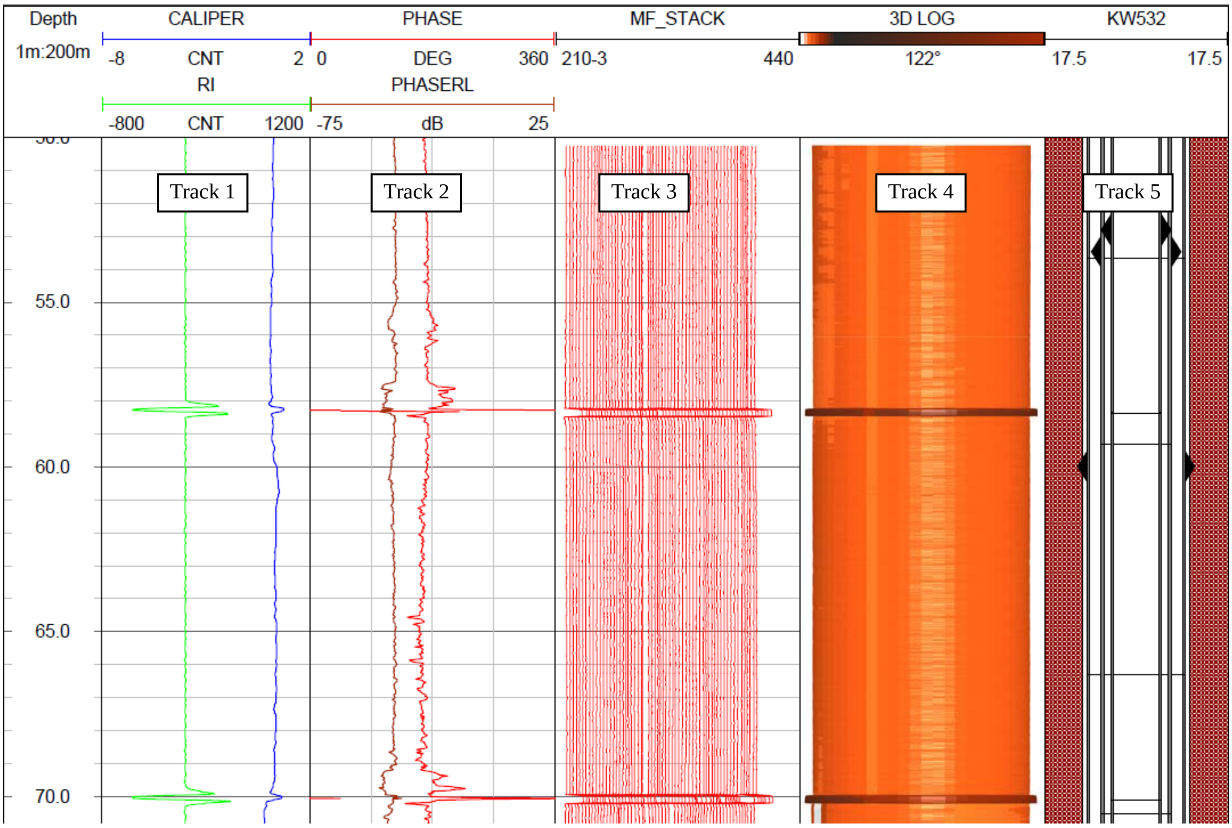

Figure 6: HTCC-MF log example showing HTCC-EM data in the left two tracks, HTCC-MF data in the middle two tracks and a well diagram in the right hand track.

Figure 7: HTCC-MF tool coupled to HTCC-EM tool.

When the HTCC-MF tool operates in tandem with the HTCC-EM tool, there are actually two callipers; a contact type calliper (Multi-Finger Module) and a non-contact type of calliper (EM Module). The electromagnetic calliper is not sensitive to scale – it only detects the steel of the casing. So it is possible to measure scale by using the multi-finger calliper to measure the inside surface of the scale and the electromagnetic calliper to measure the outside of the scale (because the scale is attached to the casing).

3.7 Report generation

After the run, the large data set (500MB is a common file size) is processed and presented in a report that summarises the condition of the well and shows details of any damaged areas that were found.

A considerable amount of analysis occurs in the post processing and presentation of the data. Statistics are compiled of each joint to provide an overall summary of the condition of the well and in depth analysis of specific areas of interest are made available to the client.

The report is presented to the client along with a log graphically showing all of the data collected. Figure 6 is an example of such a log. The log is customisable to suit the needs of the client and in this case contains HTCC-EM data in the left two tracks (tracks 1 and 2). These contain the curves CALIPER, RI, PHASE, PHASERL, which are from the Electromagnetic Calliper, Roughness Indicator, Phase Shift, and Phase Receive Level instruments respectively. The next two tracks contain HTCC-MF data. Track 3 (MF_STACK) contains a stacked log with a curve for each of the 60 fingers plotted alongside each other. This is useful because the response of each finger is clearly visible. Track 4 (3D Log) combines the 60 finger traces into a 3D log that gives a more visual representation of the casing. Finally track 5 contains a

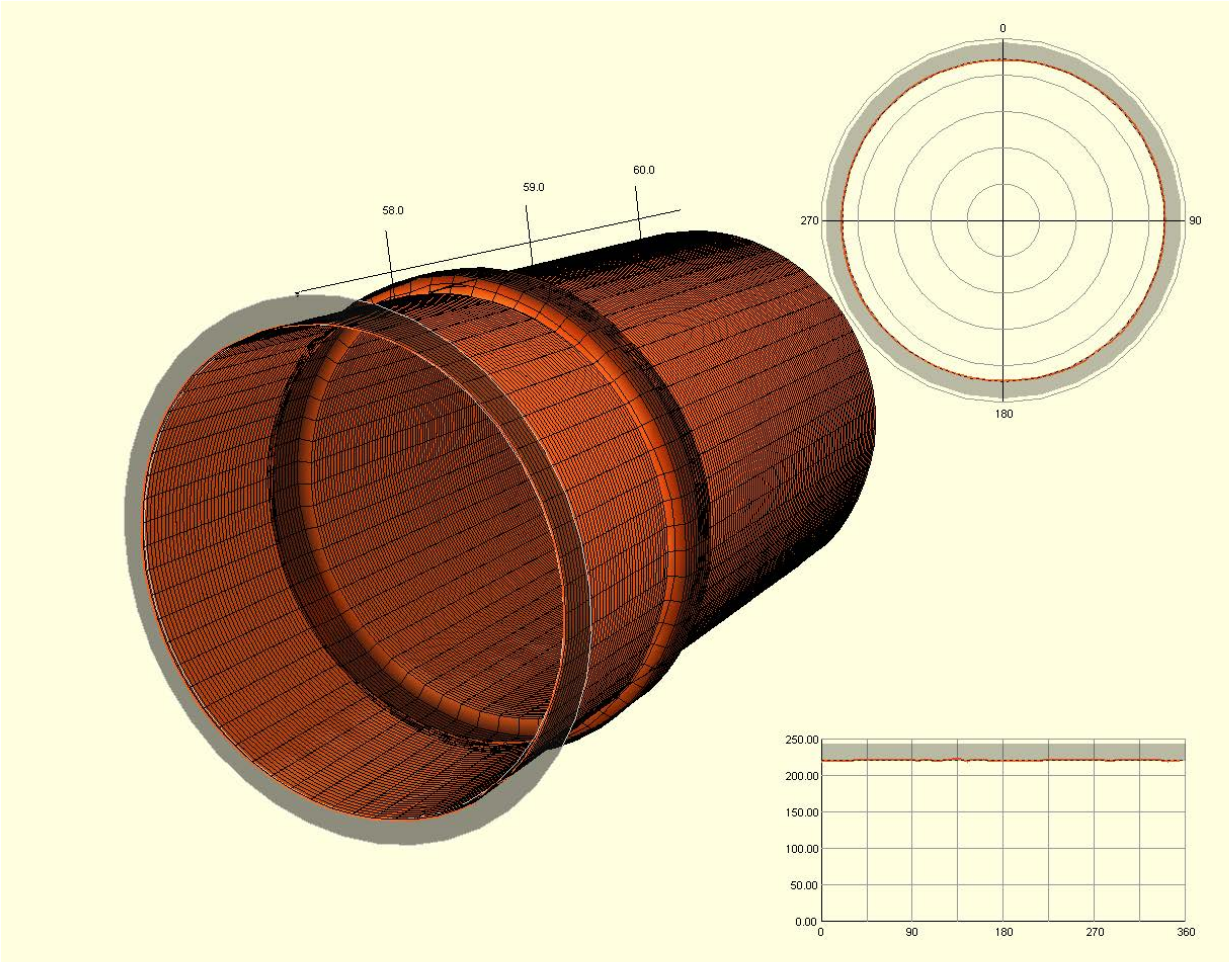

Figure 8: 3D representation of casing ID, giving engineers the ability to fly through casing to visualise defects. This view shows a normal buttress coupling gap at 58.4m. To the right are radial and flat cross section views of the casing.

well diagram constructed from casing tallies. This provides a useful reference of how the well was constructed.

As part of the job report, the log data is provided to the client so that engineers are able to "fly" through the casing using 3D software to visualise damage and areas of concern. Figure 8 shows a screen shot of the 3D visualisation software. In this example the gap in a buttress coupling is clearly visible at 58.4m. Radial and flat cross sections of the casing are also visible. These provide a more detailed view of a defect and are scaled to allow dimensions to be easily ascertained.

4. HTCC-MF SPECIFICATIONS

- 320 °C
- 350 bar
- Accuracy 0.5mm
- Range: 5-1/4" to 14"
- Casing sizes: 7" to 13-3/8"
- Max Tool OD: 5-1/4"
- Length: 2.8m (without centralisers)

5. CONCLUSION

The HTCC-MF is a large undertaking in downhole tool development and has presented many challenges along the way. The 3D data of the inside of the well will complement the data currently collected by the HTCC-EM tool. It will be a valuable resource in measuring the condition of casing and monitoring changes in the casing condition over time.

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