Innovative Approach to Enhanced Well Integrity Evaluation in Unconventional Completions with Fiberglass Casings

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Abstract /

More wells are being completed with fiberglass casings to overcome the challenge of corrosion to the carbon steel casings. A fiberglass casing is expected to increase the longevity of the wells. The wells completed with fiberglass still require the operators to confirm that the casing is in good condition and also the annular cement sheath is able to provide mechanical support and zonal isolation. The evaluation poses a challenge as the properties of the fiberglass are very different to that of the carbon steel casing. Some studies were performed in 2018 to test the ultrasonic physics in fiberglass; this article will describe the challenges and how we have now developed an innovative data acquisition, processing, and interpretation workflow to properly evaluate both the fiberglass casing condition as well as the annular cement condition.

It was observed through surface experiments that the conventional ultrasonic technique applicable to carbon steel pipes has been proven to be invalid in fiberglass casings because the velocity and acoustic impedance of fiberglass are much lower than steel; therefore, there is no resonance in fiberglass. A new interpretation workflow was developed and applied to raw data to build specific parameters proper to the fiberglass samples to determine the acoustic properties: acoustic impedance, attenuation factor, and velocity. This is the first time that data has been acquired in a very large fiberglass casing.

Fiberglass casings were run in a water well, and wireline acoustic logs were successfully acquired for a cement and corrosion evaluation across 19" outer diameter glass reinforced epoxy (GRE) pipes. The interpretation workflow was applied to raw field data and a comprehensive cement map and corrosion answer products were obtained with an acceptable quality control level. The article will review the data from three wells.

This innovative data acquisition, processing, and interpretation workflow can be deployed in wells for decision making prior to completion and production. The new method also opens up future opportunities for the evaluation of non-carbon steel pipes, and with knowledge of mechanical and acoustic properties, the method can be adapted to perform a full evaluation. This method is expected to provide valuable information for wells planned to be completed with a fiberglass casing.

Introduction

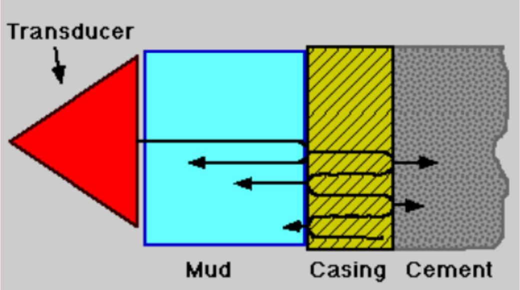
Cement provides mechanical support to the well construction in addition to proving the hydraulic seal for ensuring annulus integrity. This is needed to ensure that there is no flow of fluids between different reservoirs and also to the surface. The cement placement is often followed by running cement bond logs (CBLs) to confirm that the placement is sufficient for the continuation of drilling to the next section, as well as to ensure the well can be safely put on production.

Cement bond evaluation is performed using sonic and ultrasonic techniques. The ultrasonic technique provides a 360° azimuthal view. The principle is to make a small area of the casing resonate in its thickness mode, Fig. 1. Good cement behind the casing causes rapid damping of the resonance, while an absence of cement provides a slow rate of decay.

The core of the acoustic measurement technology is a rotating ultrasonic transducer immersed in the wellbore liquid, which provides full coverage of the cement and casing at high resolution. The transducer excites the casing resonance by repeatedly emitting short pulses of ultrasound, Fig. 1. The same transducer operates as a receiver to detect the echoes from the casing.

For decades, the acoustic-based measurement served to obtain the cement map in the annulus behind steel casings using the pulse-echo technique that is directed perpendicular to the casing wall[1, 2], Fig. 1. The frequency of operation is decided by the nominal wall thickness, and typically varies between 200 *kHz* to 500 *kHz*. The decay of the received pulses is used to derive the casing inner radii and annulus material acoustic impedance.

Fig. 1 *A schematic of the normal incidence pulse-echo time and frequency domain for cement and casing evaluation.*



The acoustic impedance of a material is defined as the product of its compressional velocity and density. The measurement of acoustic impedance provides a map of cement azimuthal placement with spatial resolution as high as 5° of the casing circumference by ~1” casing depth.

The classic resonance physics works well in steel casing. Figure 2 is the log data across the steel casing section from one of the real wells. The data clearly shows the casing inner radii, wall thickness, and annulus material impedance. The inner radii and wall thickness are close to the nominal expected values, and the annulus material across this section is liquid.

The steel acoustic impedance of 46 MRayl is much larger than that of both the wellbore liquid on the inside of the casing, and the cement in the annulus. The frequency range of the acoustic burst is matched with the steel compressional velocity of 5,900 m/s and the steel casing wall thickness to ensure a harmonic reverberation within the casing wall. The attenuation of this reverberation is a function of the acoustic impedance of the material on both the inside and the outside of the casing.

The parameters required for the calculation of the impedance of the outside medium and calculation of the casing thickness are the compressional velocity, shear velocity, acoustic impedance of the steel, and the acoustic impedance of the wellbore liquid inside the casing. These steel properties are well-known and are generally considered invariant between different carbon steel casing manufacturers. Some special consideration is needed for high chrome steel pipes.

The cement evaluation using resonance physics previously described does not work for fiberglass pipes[3]. This article describes the yard test to characterize the response of specific fiberglass pipes and the specific data processing technique used to evaluate the cement placement.

Yard Experiment

The glass reinforced epoxy (GRE) pipes are made by centrifugal spinning of a prepared mixture of fibers and resin inside an external mold at a high rotational speed, or by immersing continuous fibers in a polymeric matrix by winding wet fibers at various angles on an internal mold at a low rotational speed. The fiber-to-resin ratio, specifically, and the resin chemistry, in general, all vary between manufacturers. Surface inspection tests were performed to determine the compressional velocity, acoustic impedance, and attenuation factor of a GRE sample, and to investigate the feasibility of measuring the amplitudes of the two echoes in this unconventional nonmetallic media.

The surface testing equipment consists of a steel drum tank, Fig. 3, which contains an exchangeable 59 cm length of casing ranging in diameter from 5½” to 9⅝”, which is mounted in the

Fig. 2 *The ultrasonic log data using classic time and frequency-based processing to derive the inner radii, wall thickness, and annulus material impedance, across steel casing.*

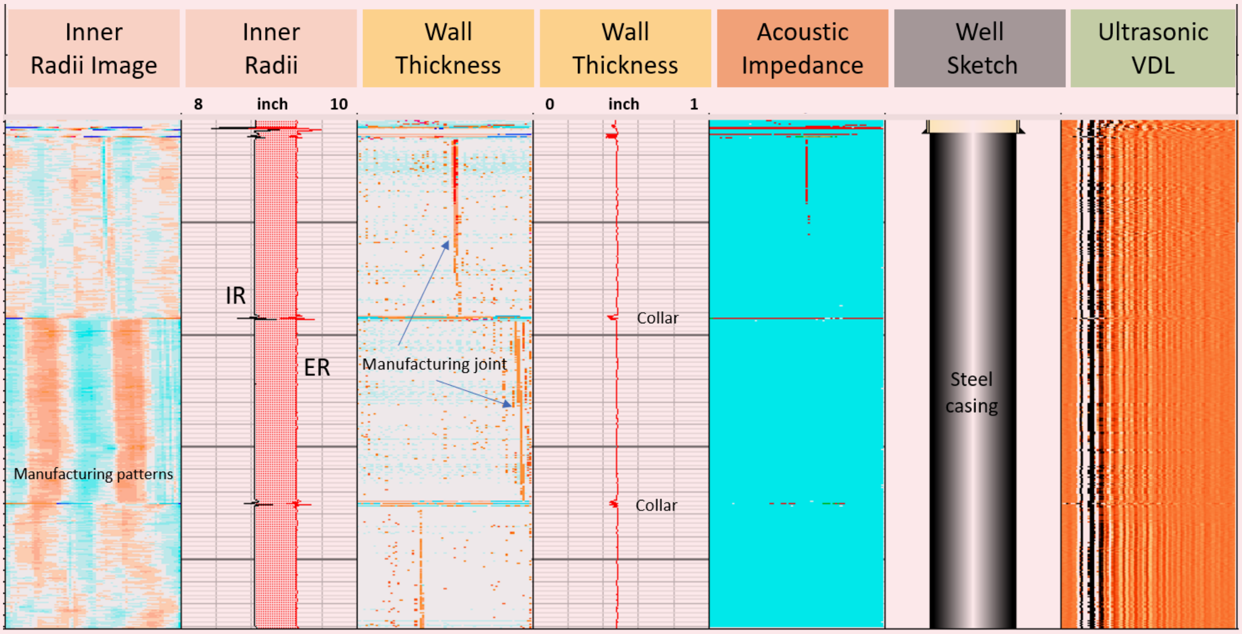
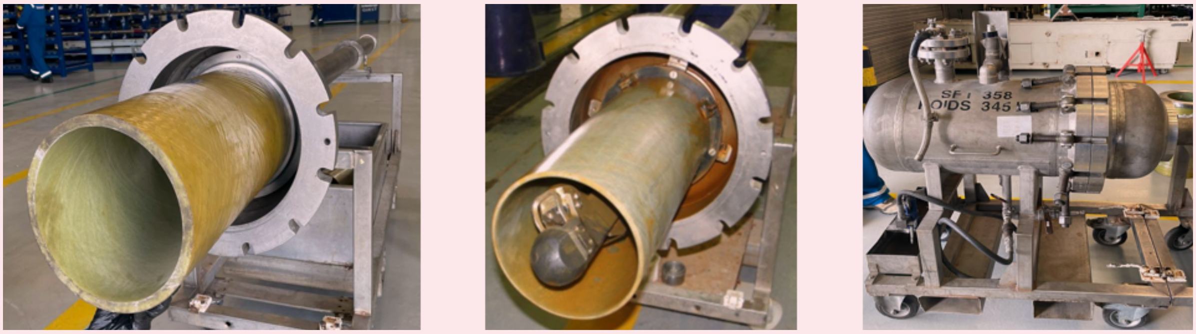


Fig. 3 *An image of a tank setup that is used in the controlled testing of the ultrasonic sensor against a casing sample to measure the acoustic impedance.*

Fig. 4 *An uncemented fiberglass sample mounted inside a test tank surrounding the ultrasonic tool.*



tank surrounding the rotating transducer. The tank is filled with liquid, usually water, and hydraulically sealed to the logging tool and the ultrasonic measuring transducer, Fig. 4. The water is de-aired by leaving it resting in the tank for 24 hours before the testing can commence, and 500 psi pressure is applied so the transducer is acoustically coupled to the water.

To validate the test tank operation for this application, measurements with the rotating transducer inside the tank were made of an uncemented GRE sample in a pressurized water column. The detection of the two amplitudes and log results are shown in Figs. 5 and 6, respectively.

Fiberglass Data Processing

With an increase in the number of wells completed with fiberglass, it is important to develop a reliable data acquisition and processing technique. The ultrasonic signal, Fig. 7, that typically resonates the steel pipe does not create any resonance in fiberglass casing. In the fiberglass casing, Fig. 8, the signal is reflected at the wellbore liquid to the inner surface interface, and the outer surface of the casing to the annulus material interface. The third reflection may as well arrive from the annulus material to the second casing (or competent formation wall) reflection. The processing for cement impedance evaluation focuses on the first two reflections.

The lower velocity of the fiberglass casing means the signal will arrive later compared to the steel casing. The processing and interpretation may be challenging in case of fast formations, leaving the classic CBL measurement prone to errors.

The amplitude of the first and second echo and the time gap between them, Fig. 8, is a function of the wall thickness and impedance of annular material. To obtain an accurate answer, the acoustic velocity, acoustic impedance and attenuation of the fiberglass casing must be known. These values are either provided by the manufacturer or estimated from the yard tank test.

The yard test of the fiberglass casing helped to obtain the parameters required to process the data. Knowing that the tank is filled with water, i.e., water on both sides of the fiberglass casing, it was possible to determine the fiberglass impedance and also the signal attenuation. This information is then used in acquiring the field logs for the same fiberglass casing, resulting in obtaining accurate casing and cement evaluation.

The new processing algorithm uses the amplitude of both peaks A1 and A2 for acoustic impedance and the time gap between them is used to determine the wall thickness. Further the transit time of the A1 peak is used to obtain the inner radii (to check

Fig. 5 *The uncemented GRE sample, amplitude vs. time, one recording from the sweep.*

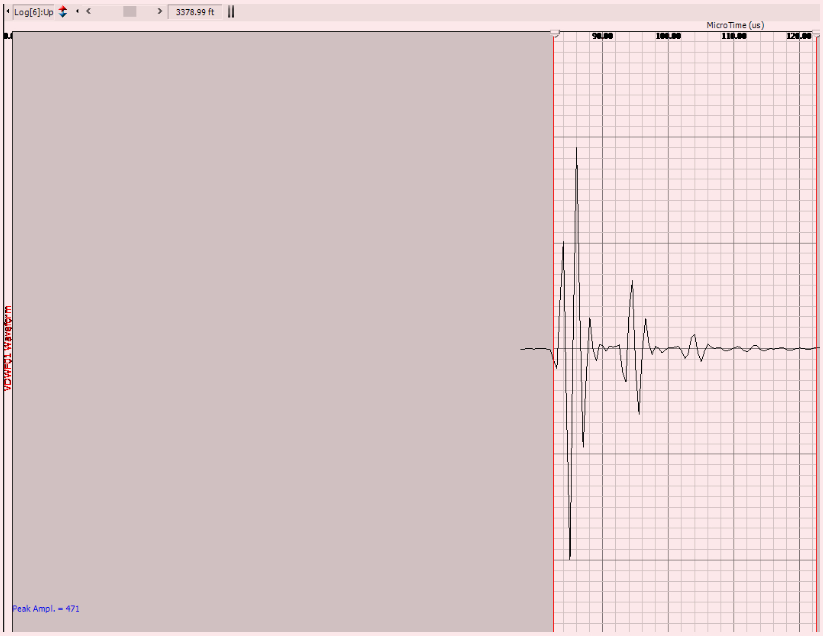


Fig. 6 *The uncemented GRE, acoustic impedance map (liquid); radius and thickness measurement.*

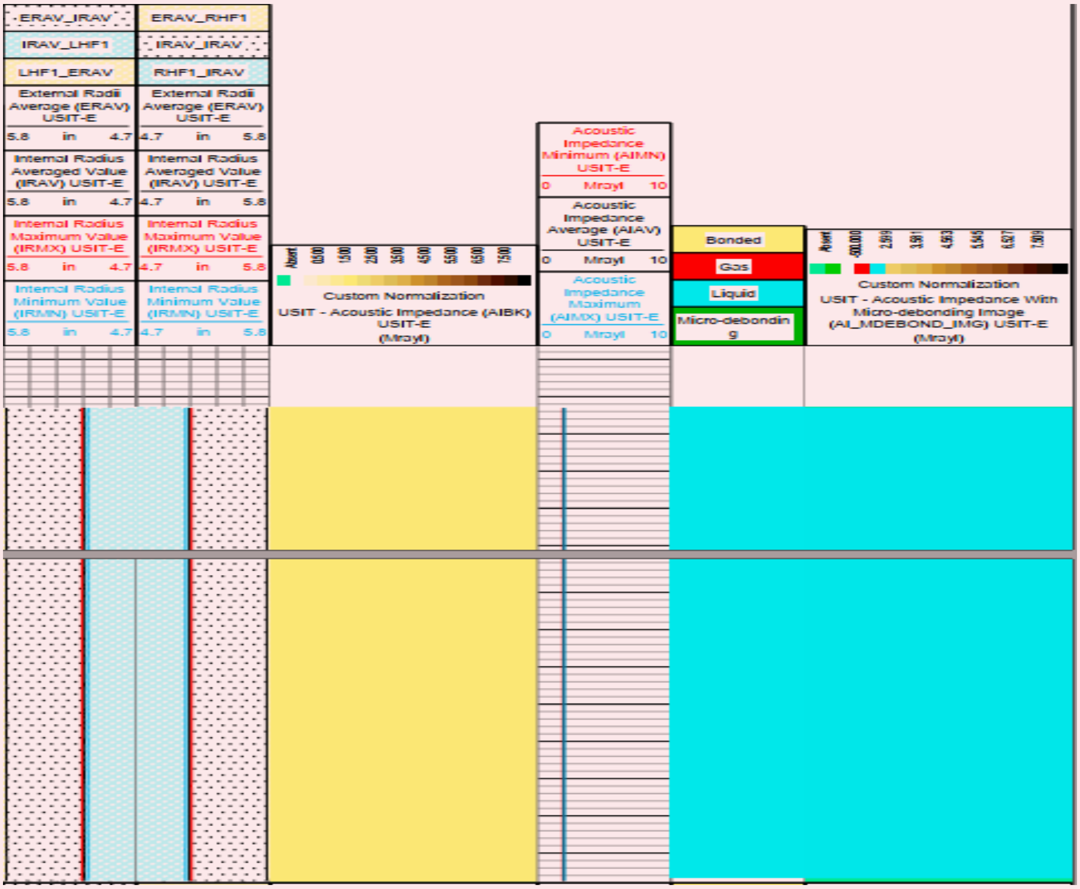


Fig. 7 *The ultrasonic waveform response in a carbon steel casing.*

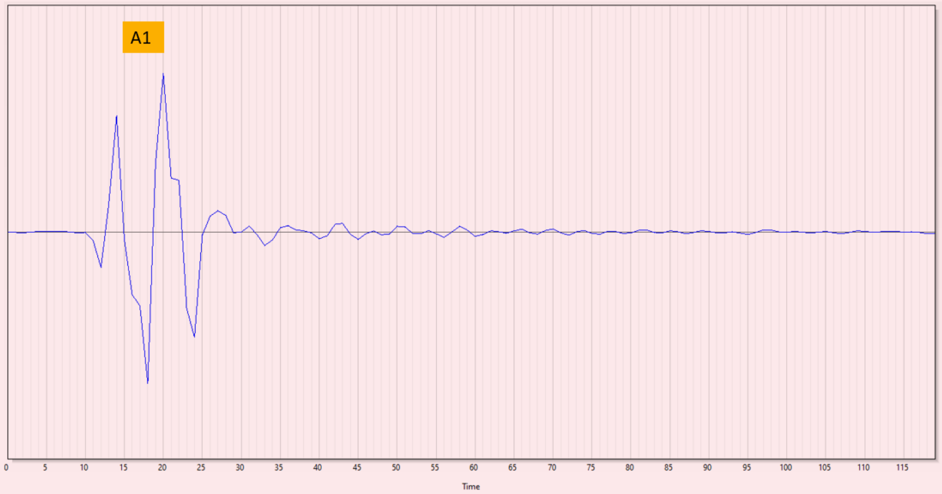
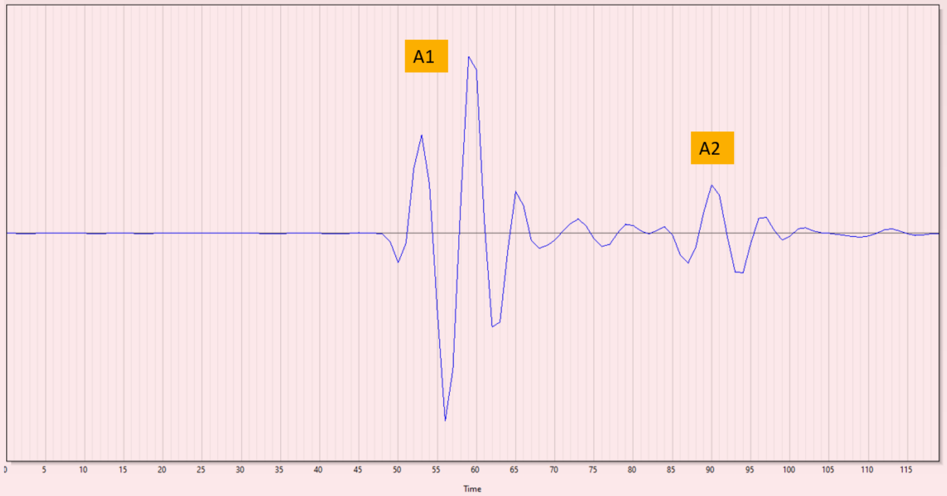


Fig. 8 *The ultrasonic waveform response in a fiberglass casing.*



for any defects such as wear groove, etc.).

The final acoustic impedance obtained via this new processing technique is combined with the CBL and the variable density log (VDL) data for a better understanding of the cement placement.

The third echo reflected of the third interface (cement and formation wall or cement and outer casing) is found to be very useful to enhance the interpretation of cement placement. The third echo further provides information on the casing geometrical position within an open hole borehole wall or within the outer casing. The standoff or eccentricity information helps in the understanding of the reasons behind good or poor cement placement, and the reason for any mud channels.

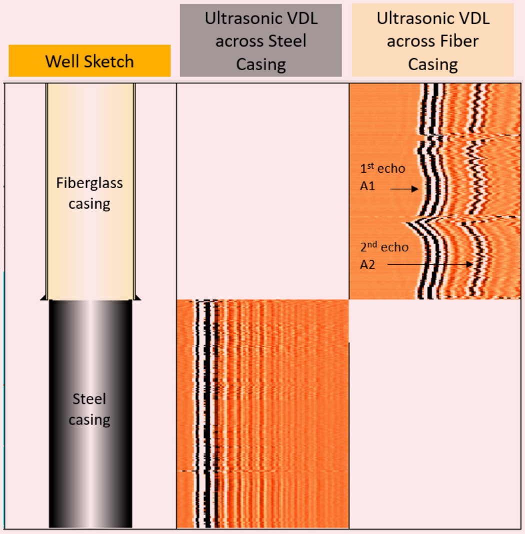
The data from the well completed with fiberglass casing at the top and steel casing at the bottom shows the single or double echoes as expected. This is illustrated in Fig. 9 via the waveform VDL across each section. The special processing based on the amplitude of the A1 and A2 peaks provided information on the acoustic impedance of the annular material.

Field Deployment Experience

The new process and tool were deployed in three wells that were completed with GRE casing. The results are shown in Figs. 10, 11, and 12. The imaging tool worked flawlessly. It was able to provide information about the conditions of the casing and the cement behind it. As seen in Fig. 10, the cement was absent on the top sections and was only across the last two joints. This was expected since the well went into total loss while drilling across the same depth.

In Fig. 11, the tool was able to distinguish small variations in the casing's internal diameter, and showed the presence of

Fig. 9 *The ultrasonic waveform response from real well data completed with fiberglass casing at the top and steel casing at the bottom, clearly showing the double echo response of A1 and A2 across the fiberglass section.*



small grooves along the axial axis of the pipe. This groove-like reduction in the internal diameter is probably due to casing wear from contact with the drillpipe's tool joints. Furthermore, the logs showed with high accuracy the cement distribution behind casings in all of the three wells.

Wells 1, 2, and 3 were successfully completed to meet their respective objectives. These wells provided invaluable lessons and serves as a benchmark for future well construction with fiberglass casing. A higher utilization and challenge level are expected in the area where a highly corrosion resistant yet cost efficient tubular is fundamentally required. Additional data from new wells will be analyzed to further advance this evaluation method for similar nonmetallic casing material.

Conclusions

A cement bond evaluation across fiberglass casing requires a new processing workflow, as the conventional pulse-echo resonance method does not work. The new processing workflow ensures the evaluation provides accurate information on the cement quality azimuthally. The casing condition is also evaluated simultaneously.

The tests carried out in the yard proved the concept, which was then used in real wells, providing clear information for the decision making process on well integrity. The logs were acquired

Fig. 10 *The cement and casing evaluation log based on the new processing technique across the GRE section in Well-1.*

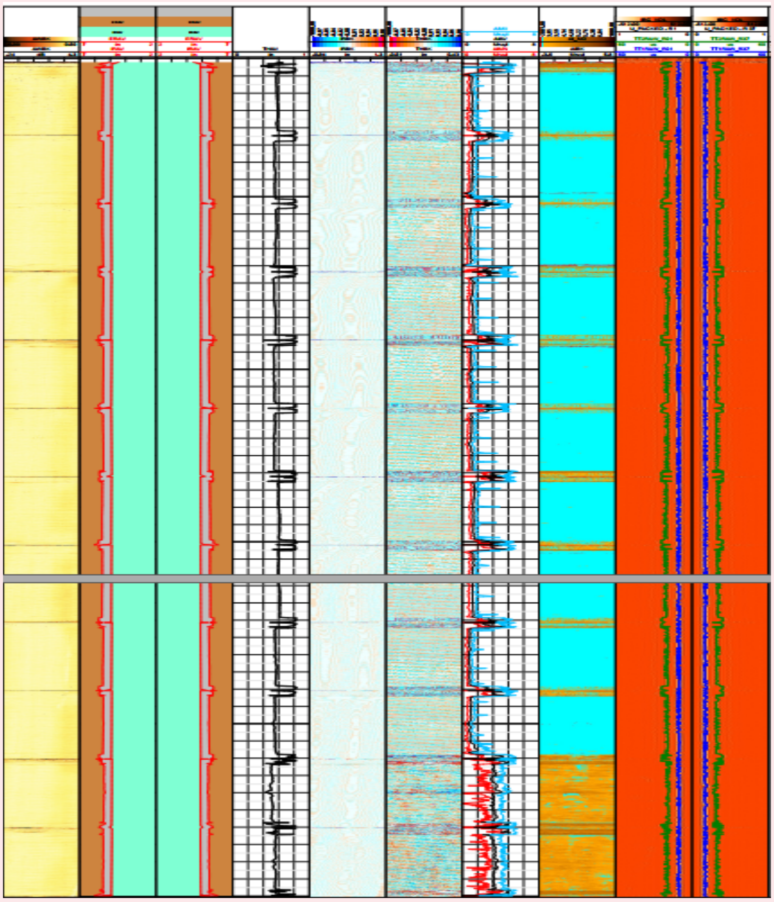
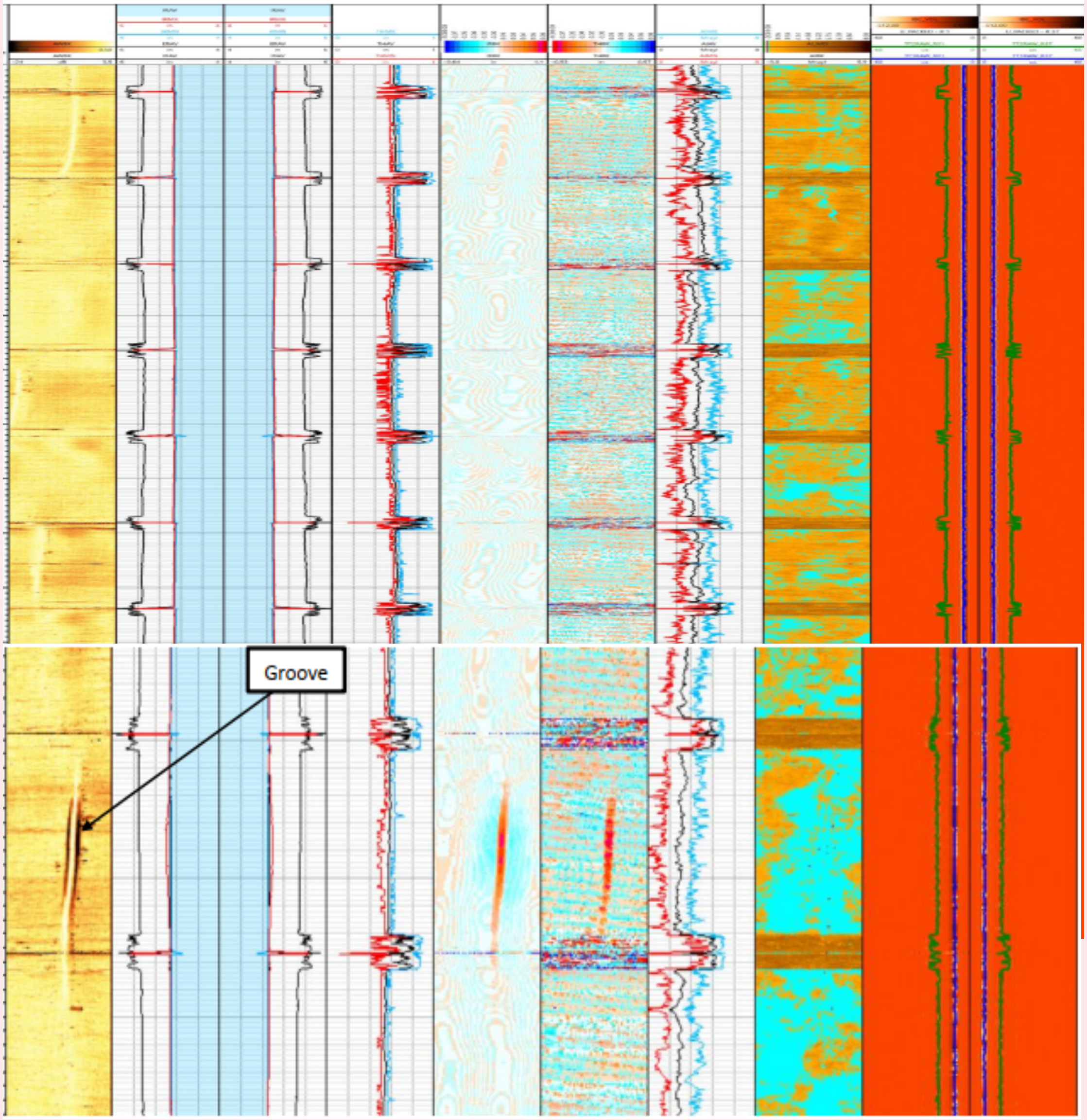


Fig. 11 *The cement and casing evaluation log based on a new processing technique across the GRE section in Well-2. The groove caused by drillpipe wear is noticeable.*



in large fiberglass casings for the first time. The technology and the processing can be used in future fiberglass applications.

Acknowledgments

The authors would like to thank and extend our appreciation to the field staff who supported these logging operations.

This article was presented at the International Petroleum Technology Conference, Bangkok, Thailand, March 1-3, 2023.

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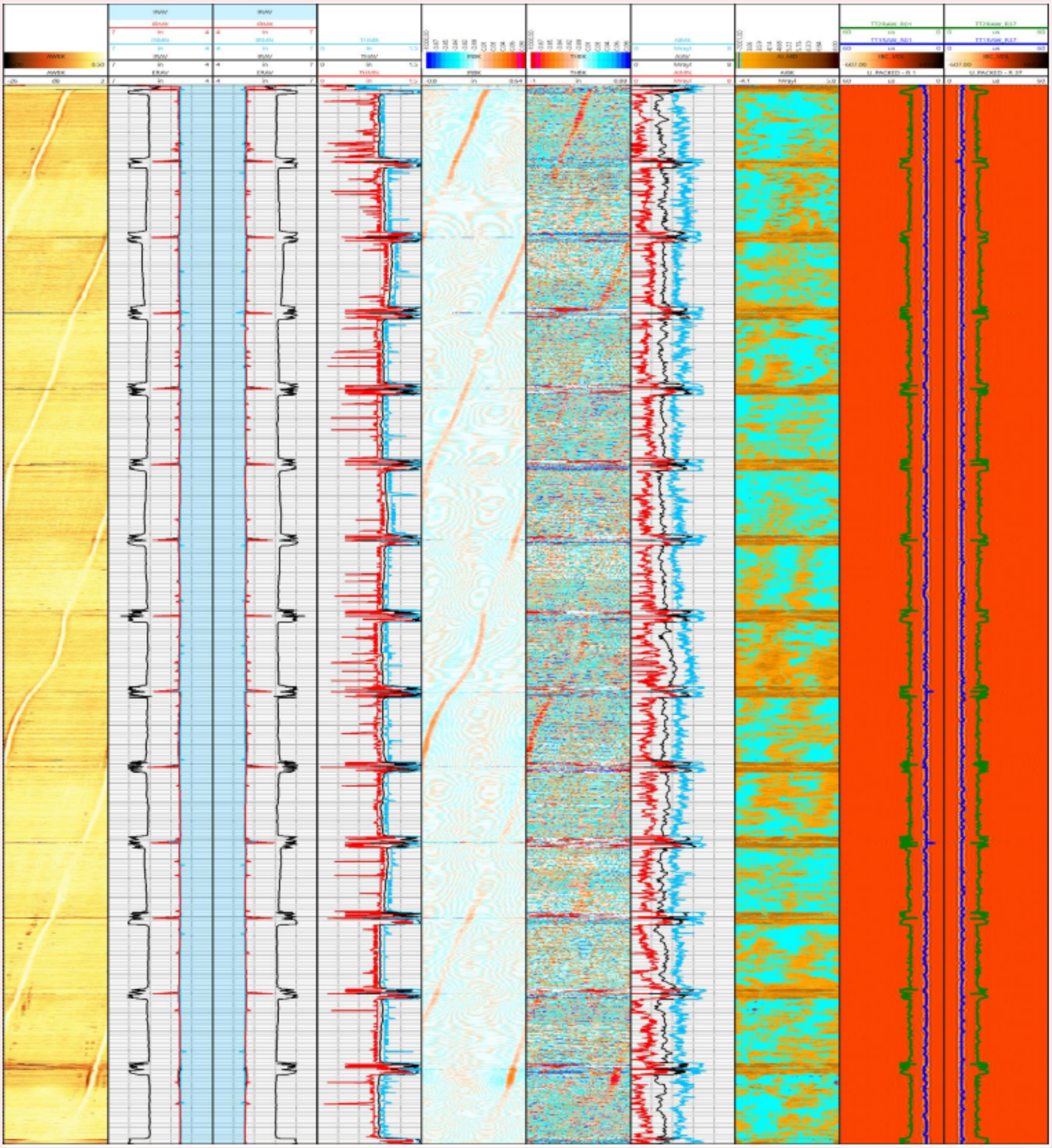
Fig. 12 *The cement and casing evaluation log based on a new processing technique across the GRE section in Well-3.*



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Ali A. Hijles is a Drilling Engineer working in the Drilling Technical Well Structure Unit of Saudi Aramco's Drilling Technical Department. He has 13 years of experience working in various engineering roles in Drilling and Workover (D&WO).

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In 2016, Ali joined the D&WO specialist program. After two years, he moved to the Drilling Technical Department, where he assumed the role of a Well Design Specialist, supporting all the various departments under the D&WO Admin Area in matters of well construction and design.

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Fauzia R. Waluyo is a Drilling Engineer working in the Drilling Technical Well Structure Unit of Saudi Aramco's Drilling Technical Department. Before joining Saudi Aramco, he worked for major energy companies in Southeast Asia and the Oceania region. Fauzia has 17 years of experience in drilling, completion, and workover covering onshore, offshore, exploration, and development campaigns with technical expertise in well design simulations, wellbore tubular, and positioning.

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Abderrahmane Benslimani is a Petroleum Engineer with 19 years of experience working for Schlumberger as a Well Integrity Domain Champion. He gained his experience largely focusing on the subsurface evaluation, conventional, unconventional formation evaluation, and production optimization of fields in the Middle East (KSA, UAE, Kuwait), Africa (Algeria, Libya), North America (Western Canada's Sedimentary Basin), and China.

Abderrahmane's work includes both open hole and cased logging services, starting from data acquisition, processing and interpretation, following high service quality standards. He exercises advanced interpretation skills in the well integrity domain (cement evaluation, corrosion monitoring, noise and leak detection techniques), analysis behind casing, and reservoir saturation linked to the production logging.

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