Using Electromagnetic Telemetry for Abandonment Cement Slurry Design on Coiled Tubing

Josh Anderson[1] Toby Ryan[2] Derek Belle[2]

[1]Western Energy, 132 Rakaunui Road, Taupo, New Zealand

[2] MWDPlanet 207 Stage Coach Lane Rocky View, Alberta Canada

Josh@westernenergy.co.nz, Toby.Ryan@westernenergy.co.nz, Derek@mwdplanet.ca

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ABSTRACT

For many years the Coiled Tubing (CT) industry has been developing Electronic Bottom Hole Assembly Technology (E-Coil) where fibre-optic or wireline cable convey operating parameters and sensor readouts from the tools downhole through the CT and back to the surface unit where they can be interpreted. This technology requires a high setup cost to install the telemetry cable, purchase the electronic tools and costly reel management programs to prevent failures of the cable inside the string.

Using Electromagnetic (EM) technology from the drilling world, signals containing packets of information can be sent directly from the downhole tools to the surface through the formation rock and existing well casings. This technology requires limited setup cost, and tool purchase is much lower than the e-coil equivalents. The use of new EM technology in conjecture with the right operational planning provided a cost-effective solution to reducing the risk of the flash setting of cement during geothermal plug and abandonment operations with CT. There are limitations of the system due to signal delay, but in the instance of determining the downhole temperature of a static fluid column prior to cementing or to prevent damage to BHA components due to exposure to a temperature above the rated limits, the technology is more than capable of providing this data in nearly real-time. This available signal technology displaces the alternative practice of running memory gauges that could not be cemented through and required an additional CT cycle out of the hole to interpret the data and run back in to perform the cementing operation.

In our experience, the tools are designed to be run on large diameter equipment that is standard in geothermal environments. Building custom made components to adapt the tools to be run on the coiled tubing was a challenge but accomplished using proven industry components as well as new innovations. Limitation on the tool is defined by the battery limitations with the electronic components capable of being flasked to prevent damage in extreme environments.

1. TECHNOLOGY

Electromagnetic [EM] telemetry is a method of transmitting information from downhole to surface using very low-frequency electromagnetic waves that propagate along the wellbore and through the formation. The electromagnetic signals attenuation properties are described by the skin depth factor defined as [2]:

$$\delta = \sqrt{\frac{\rho}{\pi \cdot f \cdot \mu}},$$

Where f is the frequency, μ is the magnetic permeability and ρ is the bulk formation resistivity. The estimated attenuation to the downhole hole signal can be estimated as:

$$\alpha = e^{-TD/\delta} ,$$

Where the estimated attenuation α is shown to have an exponential decay with respect to total depth [TD] and the skin depth factor, due to the exponential nature of the signal attenuation very low-frequency signals are used to reduce the signal attenuation over greater depths.

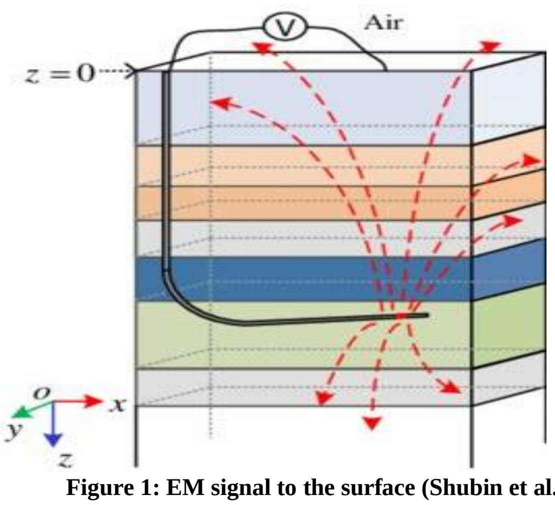

Figure 1: EM signal to the surface (Shubin et al., n.d.)

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On the surface a receiver is connected to ground stakes that measure the now significantly attenuated electromagnetic waves. The data to the surface is received with data rates up to 16bits/sec, but commonly data rates are received 4-6 bits/sec.

Figure 2: EM Data Dashboard snapshot from live cementing operations. Top shows received data and temperature and pressure trends. The bottom shows the received signal in both the time domain and frequency domain.

EM is primarily used in drilling applications. It has been used rarely in well intervention applications as most transmitters do not perform well in casing. The patented hybrid H-bridge on the Pegasus EM transmitter allows the transmitter to continue to transmit in casing, allowing a connection between downhole and surface even in the casing, whereas a conventional EM transmitter would only transmit while outside of the casing with the electrodes conducting directly into the formation rock.

For the CT cementing application, only pressure and temperature sensor was incorporated to reduce the size of data packets sent from the BHA. In conventional drilling applications, several sensors are included for orientation of the BHA, allowing for directional drilling and dogleg severity control, these sensors, and others can be incorporated into this technology to expand the well intervention capability.

While the data rate is significantly slower than wired and fibre optic solutions, the wireless solution allows operators the ability to significantly reduce overall cost, installation time, and reliability. Additionally, temperature limitations are a common challenge in the geothermal well services environment, and the Pegasus EM System has a higher temperature rating than commercially available wired telemetry tools. Although normally suitable, the downside of wireless electromagnetic telemetry is that the signal is heavily dependent on the formation resistivities, wellbore fluid resistivities and surface-level noise sources.

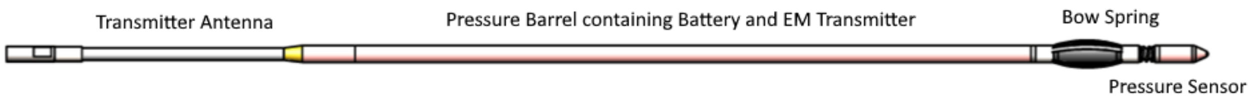

Figure 3: EM Tool Schematic

Alterations to the conventional Pegasus EM system were undertaken to ensure that the tool chassis would fit into the 2-7/8" OD BHA required to be run on the coiled tubing. In addition to standard tool design considerations, a high temperature battery was required due to the potential for elevated temperatures in the geothermal environment. Batteries for this technology must be selected for the anticipated temperature range and are available for tools in a range from 20*C to 180*C.

2. APPLICATION

2.1 Wellbore Conditions

The temperature dynamics of a geothermal well differ from that in the oil and gas equivalents due to localized hot rock formations that exist behind the well casings and cause conductive heating of the water column inside the wellbore casing. The heating can cause the water to reach levels much higher than boiling in very narrow casing intervals. Geothermal well reservoirs rarely have formation pressure gradients high enough to handle the hydrostatic column of fluid to surface and, in turn, rely on continuous water injection at a high rate to provide well control during the placement of fill material or gravel into the wellbore. This gravel base provides a base for cement plugs as well as reducing and communication between production zones.

Often these hot zones have little impact on heating the wellbore until the lower production feed zones of the well are sealed by mechanical means and the water column inside the casing can reach the surface. The common presence of corrosion-related communication with the wellbore through the casing is the exception to this and can cause cold water inflows, hot water inflows and even steam into the casing section. Once sealed, the water column can heat quickly inside the casing, and to measure the static water temperature prior to cementing a wireline pressure, temperature, spinner (PTS) survey is normally conducted. The survey also provides flow measurements inside the wellbore casing to help with the identification of any inter-wellbore flow or temperature influx that can help identify any previously unknown or unmeasurable casing damage prior to run in the hole with CT for cementing.

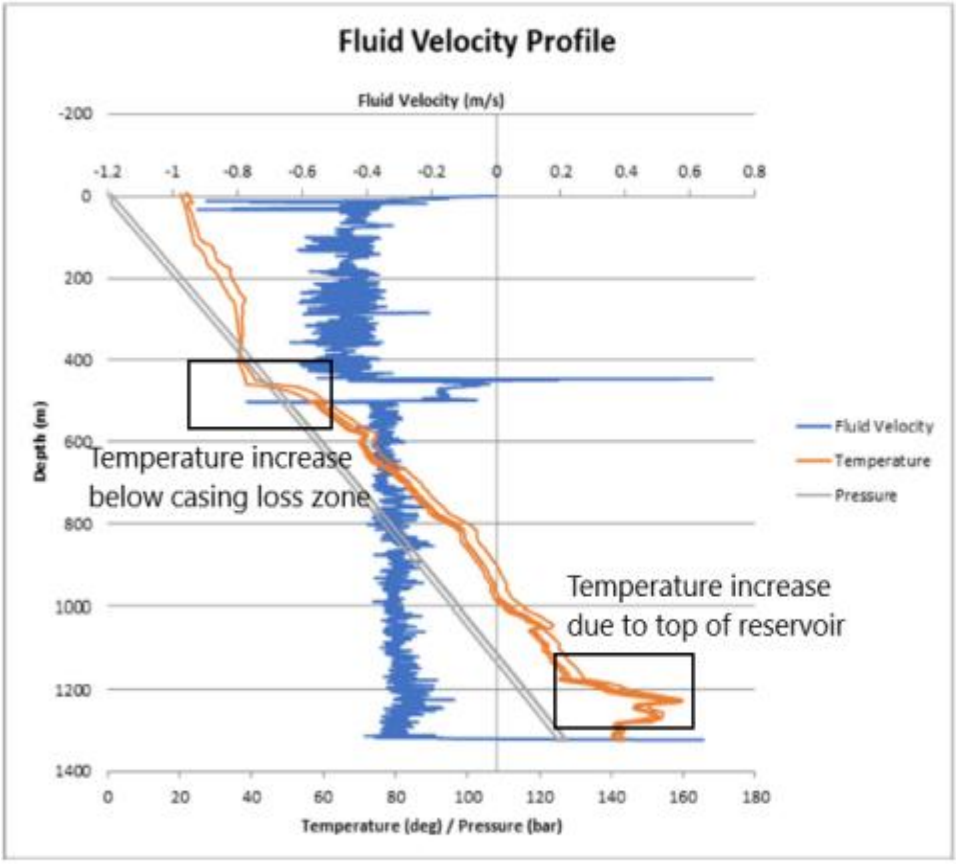

Figure 4: Generic Well Profile Pre-Cementing

2.2 Measurements

Using the Pegasus EM system for CT in conjunction with a pre-run Wireline PTS allows the downhole temperature to be predicted at each interval during the run in hole and effective cooling of the wellbore performed prior to the cement being pumped downhole. Once at the predetermined depth for the planned cement plug, a volume of water is pumped to cool the wellbore to a sufficient level for cementing. A series of retarders and additives are blended into the cement to make up the recipe to prevent wellbore cement setting prematurely during placement. This recipe is usually provided and tested prior to site operations as a range of temperatures compatible with the estimated downhole temperature based on drilling records and known reservoir data for a particular well of the field. The Pegasus EM system allows for accurate and frequent temperature readings during the downhole pumping of cooling water and can reduce the time to cool the wellbore to a sufficient temperature as opposed to when based on modelling estimations or the previous static well WL measurements.

2.3 Cementing Risks

When evaluating the risk/reward of running the tool, assessment can be made into the potential reservoir temperature versus the cement temperature recipes available for use. If the projected wellbore temperature, in a static condition, is much higher relative to the available cement recipes or the reduction in additives provides cost or logistical savings, then use of the tool can be easier to justify the risks to cementing without any downhole temperature data can be costly and include wasted cement plugs and potentially stuck coiled tubing when used in this application.

3. OPERATION CASE

3.1 Pre-Operational

In the lead up to deploying this system in a well, two major operational risks were identified as potential hazards that could jeopardize a successful operation:

1. Excessive pressure across the tool due to the small clearance between the 1.875" OD pressure housing and the 2.125" ID gap sub.
2. Tool erosion from high flow velocity of the abrasive fluid (i.e., cement) between the 1.875" OD pressure housing and the 2.125" ID gap sub.

To understand these risks, hydraulic modelling, calculations, and review of references and best practice were undertaken.

3.1.1 Pressure Drop Assessment:

Using MEDCO's "Liquid Flow Computations" module, hydraulic pressure drop was modelled for a fixed ID of the outer pipe and fixed OD of inner pipe. The model was run with three separate geometries to simulate the pressure drop across the entire tool assembly using both water and cement at their planned flowrates (plastic viscosity and yield point of proposed cement blend were determined via testing in WES cement lab), and a third simulation was run to model the effect of a reduction in the ID of the gap sub.

Fluid	Density (ppg)	Pump Rate (bbl/min)	Pressure Drop (psi)
Water	8.33	4	409
Cement	15.6	2	132
Sensitivity Study for Reduction in Gap Sub ID to 2"			
Cement	15.6	2	732

Table 1: Fluid Modelling

Results from the modelling showed that the pressure drop across the tool was suitable for the planned operation. But of particular interest was the tolerance sensitivity that showed a drastic increase in pressure drop with only a small change in gap sub ID.

3.1.2 Conduct a yard test to compare modelled values to empirical data

A yard test was set up at Western Energy's (WE) yard to allow for comparisons between the modelled values of pressure drop for pumping water to empirical data obtained from the physical tool. The tool was assembled as it would be during deployment in the well, however, it was positioned horizontally during the yard test. Freshwater was pumped at various rates through the assembled tool, with results showing that the actually measured pressure drop was lower than that modelled. The measured pressure drop with 4bbl/min of freshwater during the yard test was 145psi, as opposed to the modelled 409psi pressure drop. The discrepancy between modelled and measured values was accounted for using a very conservative estimate of 1mm absolute roughness of the tool surface during modelling, whereas the measured values corresponded to modelled values with 0.5mm absolute roughness.

3.1.3 Tool Erosion Assessment

The equivalent ID of the annular space between the antenna and the gap sub was calculated to be 1", which, when pumping at the expected cement pump rate of 2bbl/min, gave a fluid velocity of 34ft/sec. When compared with industry standards and best practices, this was found to be within the acceptable range. However, it was noted to inspect the tool after every run to assess if any erosion had occurred.

3.2 Rig up

Prior to deploying the tool, several site preparations are required to ensure the safe and effective operation of the tool.

1. Receiver stake placement.
2. Sufficient space for tool assembly.
3. Suitable equipment for safe connection of the tool to the CT.

Figure 5: NZ Operations site

3.2.1 Receiver Stake Placement

To receive clear packets of data from the transmitting tool, with minimum noise, correct antenna placement is essential during rig up. The first of the antennas should be placed on the BOP, or as close to the wellhead as practical, with the second antenna connected to a metallic stake (approx. 1.5m length) placed as far from the wellhead and any electrical noise as possible. The key to positioning the antenna is to minimize impedance between the two antennas. Therefore much trial and error are required to find a location for the outlier stake and antenna that will provide an optimal surface impedance.

Figure 6: Sample location of outlier antenna approximately 100m from wellhead

3.2.2 Tool Assembly

The length of the tool, and the delicacy of the lithium-ion battery, means that a suitable area for assembly of the tool is required. Key features of an assembly area are sufficient length to allow insertion of the battery and wireless transmitter into the pressure housing, stable ground for tool stands and personnel, and sheltered from potential rain to ensure battery and transmitter are kept dry. The tolerances between the pressure housing and battery/transmitter assembly are extremely tight. Therefore it was required to have three personnel involved in the assembly process; two crew to push the battery/transmitter assembly into the housing and ensure no bending of the battery, and a third to provide stability to the housing during insertion.

3.2.3 Connection to Coiled Tubing

As with the assembly of the tool, the 12ft length of the completely assembled tool requires that special precautions and methodologies are undertaken during the make-up to the coiled tubing string. The weight and length of the fully assembled tool within the BHA pup-joint meant that manual handling was not an option. Therefore the use of a lifting sub and telehandler was required for transporting the tool from the assembly area to wellhead.

3.3 Operational Challenges

During the operation of the EM Telemetry tool, several operational challenges were encountered and required onsite problem solving to ensure the tool operated as required.

3.3.1 Erosion of the beryllium-copper section of the downhole antenna

Despite the pre-operational reviews of the erosive risks of pumping cement through the restrictive annulus between the tool pressure housing and the pup-joint, some erosion was encountered following several runs. Temporary repairs were performed on-site using a water weld product, allowing for subsequent runs to be performed. Further optimization of the BHA is required to reduce the erosion effects of the cement. A tougher material such as SS306 could be used to significantly increase the erosion resistance of the pressure housing.

Figure 7: Erosion patterns on the BeCu25 downhole antenna

3.3.2 Battery function at lower temperatures

In designing the tool, the properties of the lithium-ion battery were manipulated to allow it to operate at temperatures of up to 180 °C, this, in turn, set a lower operating temperature of 60 °C. Due to the distance from the high-temperature reservoir, when circulating water to find a downhole temperature, the temperatures of the wellbore fluid was such that the lower operational limits of the battery were not reached; therefore, consistent and accurate data packets were not received. Despite this lack of accurate downhole temperature readings on the final cement plug, having the lower operational temperature limits of the tool meant that a reasonable assessment of downhole temperature could be made

4. CONCLUSION

The use of new EM technology in conjecture with the right operational planning provided a cost-effective solution to reducing the risk of the flash setting of cement during geothermal plug and abandonment operations with CT. Investigation into the use of conventional methods left several operational challenges and, in the desired application, provided excess parameters, extensive setup time and reduced temperature ratings. Despite modelling the erosion parameters, the cement slurry caused significant erosion to the Pressure Barrel of the downhole transmitter but did not affect the performance of the tool.

A broader range of sensors incorporated into the BHA would allow for more extensive CT applications for the tool but requires additional development of sensors and potentially an increase in signal frequency to provide as close to real-time sensor readout as possible at the surface. While the extreme temperatures provide significant challenges for downhole electronics, flasking may allow for broader use of wireless technology.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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