Field Test for Real Time Monitoring of Piezoresistive Smart Cemented Well

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Abstract: In this study, a field well was installed and cemented using the smart cement with enhanced piezoresistive properties. The field well was designed, built, and used to demonstrate the concept of real time monitoring of the flow of drilling mud and smart cement during installation and hardening of the cement in place. The well was installed in clay soils partly submerged in ground water to investigate the sensitivity of the smart cement. The electrical resistivity of smart cement is being measured using LCR device at 300 Hz frequency. The well instrumentation was outside the casing with 120 probes, 18 strain gages and 9 thermocouples. The strain gages and thermocouples were used to compare the sensitivity of these instruments to the two probe resistance measure in-situ in the cement. The electric probes used to measure the resistance were placed vertically at 15 levels and each level had eight horizontal probes. Change in the resistance of hardening cement is continuously monitored since the installation of the field well over 4.8 years ago. The maximum resistivity changes were 8.5 times in the levels closer to surface while the minimum resistivity change was 2.6 times for levels under water. The maximum change in resistivity was about 850 % while the maximum change in temperature was 35 %, monitored using thermocouples and the maximum change in strain was 4.85 x E-4 %, monitored using strain gauges. The resistivity changes in the smart cement will be influenced by the cement curing, temperature, Insitu stress and water table fluctuation.

1. Introduction:

With some of the reported failures and growing interest in environmental and economic concerns in the oil and gas industry, integrity of the cement sheath is of major importance (Vipulanandan et al., 2015). Due to the losses and the number of unsuccessful cementing events, researchers are reviewing on the feasibility of monitoring of the installation process and as well as the cement sheath condition during its life time. Cement reinforcement between piping and earth is a standard for all downhole operations in the oil and gas industry, including drilling, fracking, and natural gas storage. And when this cement fails, the environmental consequences can be severe. The oil well operators are required to monitor their wells to prevent the occurring of disasters. Today, this is achieved through a process called wireline testing which was developed in the 1970’s and has been the industry standard for downhole monitoring ever since. The general type of wireline testing includes Cement Bond logs (CBL), Sonic and ultrasonic logs and Triple Combo. However, the wireline testing has two fundamental problems. First, to get well data using wireline testing, operators have to drop measurement tools into a well. But to do this, they must temporarily shut down that well. This costs millions of dollars over the lifetime of an operation because they aren’t producing in that time. The second problem is that it can only provide data while those tools are dropped in the well. So once they take the tools out and start producing again, operators no longer have any idea how the cement is doing. In other words, they can’t really monitor their well, they can only check in on it (Vipulanandan et al., 2016).

Real time monitoring of the cement during its installation and through the life of the well is hence gaining importance. The structural integrity of the infrastructure is essential for the safety, productivity and quality over the life of the well (Chung et al., 2003). Thus, there is need for monitoring damage nondestructively, so that timely repair of the oil wells takes place.

Real time monitoring gives information on the time, load condition or other conditions at which damage occurs, thereby facilitating the evaluation of the cause of the damage.

2. Objective:

The objective of the study was to compare the changes in resistivity, temperature and strain in field oil well for a curing period of over 4.8 years in the smart cemented well.

3. Experiment:

Raw Materials

Cement

To study the effect of smart cement, the class H oil well cement was used.

Smart Cement

Commercially available oil well cement (Class H cement) was modified with conductive fillers to make it a piezoresistive material. The Cement was modified by adding about 0.04% of conductive filler (CF), by weight, and the water to cement ratio was 0.38. Cement generally fails at 0.2% compressive strain. Monitoring this low strain needed very accurate measurements of the data which is not easy. The smart cement technology can monitor the changes in the cement at very high magnification of about 2500 times after one-day curing (Vipulanandan et al., 2014).

Resistivity

The LCR meter was used to measure the impendence (resistance, capacitance and inductance) in the frequency range of 20 Hz to 300 kHz. Based on the impedance (z) – frequency (f) response it was determined that the smart cement was a resistive material. Hence the resistance measured at 300 kHz using the two probe method was correlated to the resistivity (measured using the digital resistivity device) to determine the K factor for a time period of initial five hours of curing. This K factor was used to determine the resistivity of the cement with the curing time.

Field well

After careful review of various sites, Energy Research Park (ERP) at University of Houston was selected to install the field well. The selected site had swelling clays with fluctuating moisture conditions (active zone) which represents nearly the toughest conditions encountered. The oil well in the field is replicated by a model with about 40ft height and 9-5/8 in diameter representing the casing. The gap between the formation and the casing was cemented with smart cement. The casing was attached with steel angles which are used for the characterization of the bulk material with 120 probes (Vipulanandan et al, 2016). Arrangements are also made for observing the temperatures changes in the annulus using 9 thermocouples and also strain changes in the bulk material using 18 strain gauges (Fig. 1).

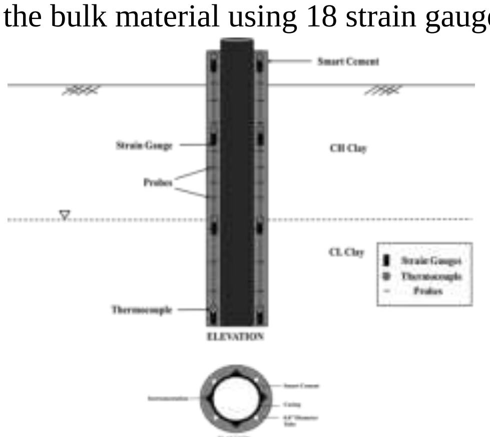

Figure 1:Profile of Strain gauges, thermocouples resistivity probes in the Field Well.

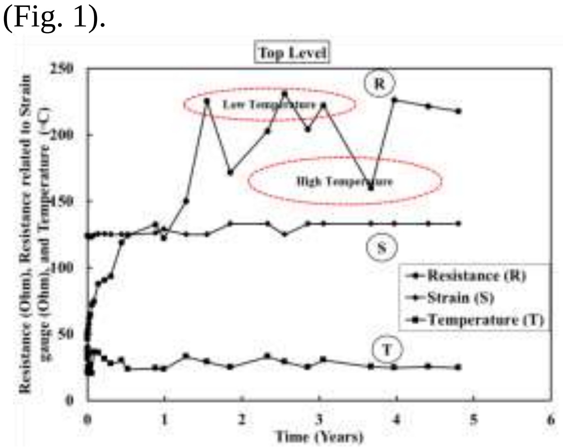

Figure 2: Variation of resistance, temperature and strain and gauge at top level of field well.

4. Results and Discussion:

The Field model measurements were carried out for a period of over 1750 days. The electrical resistance at all the levels increased with the curing period as observed in the laboratory. The resistance was influenced by the temperature, curing conditions, moisture and the stresses coming on to the cement sheath.

Resistance (R), Temperature (T), Strain (S)

The maximum resistance change was found to be at top level and it changed from 15.6 Ω to 564 Ω in 1750 days.

Top Level: The top level was about 1 ft. from the surface of the ground. The resistance in the top level changed from 22 Ω to 218 Ω, about 8.5 times change in the resistance. The change in resistance was maximum due to air curing conditions, moisture and temperature at the top level close to the surface. The temperature at the top level was 24 °C, a 32% decrease from intial temperature. The compressive strain at the top level was 3.3xE-6.

Middle Level: The middle level was about 15 ft. below the ground level. The resistance in the middle level changed from 26.5 Ω to 184 Ω, about 5.9 time change in resistance. The cement at middle level is cured under moist environment. The temperature at the middle level was 23 ^{o}C and changed 35% over 4.8 years. The temperature is maximum in the middle level. The compressive strain in the middle level is 3.65xE-6 (Fig 3).

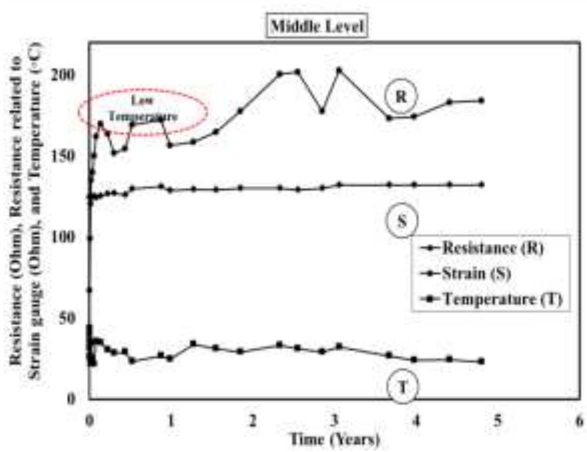

Figure 1:Variattion of resisitance, temperture and middle level in the Field Well.

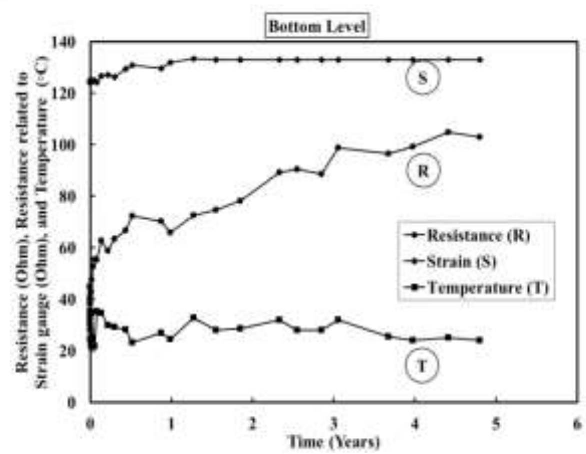

Figure 2: Variation of resistance, temperature and strain at the gauge at bottom level of field well.

Bottom Level: The bottom level was at 36 ft. below the ground and was under the water table. The electrical resistance changed from 28.2 Ω to 103 Ω, about 2.65 times change in the resistance. The change in the resistance was minimum due to under water curing of cement and reduced effective stresses at this level. The temperature at the bottom level was 24.5 ^{o}C, changing about 32% over 4.8 years. The compressive strain in the bottom level was 4.8xE-6 (Fig. 1).

5. Conclusion:

The maximum change in resistivity was about 850 % while the maximum change in temperature was 28 %, monitored using thermocouples and the maximum change in strain was 4.85xE-4%, monitored using strain gauges. Resistivity is the most sensing parameter compared to temperature and strain. The compressive strain increased with the depth from the surface.

6. Acknowledgment:

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7. References:

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