Eutectic Salt Replacement for Cement in Oil and Gas Well Abandonments

Final Project Report submitted to Petroleum Technology Alliance of Canada (PTAC) President Soheil Asgarpour, P. Eng.

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Introduction

In mid-2012 Winterhawk was made aware that a large and growing number of wells that had reached the end of their commercial life. These wells had been suspended by the operator but had not been abandoned. At that time the number of wells awaiting abandonment was in the range of 75,000.

When Winterhawk asked operators why they had not been abandoning wells, they replied that the process prescribed by the Energy Resources Conservation Board [(ERCB]; now the Alberta Energy Regulator [AER]) was problematic. The accepted technology was to utilize neat Class G cement, which was known to experience volume decreased over time. This volume decrease (of ½% to 1% over 20 years) led to the formation of micro-annular leak paths inside and outside of the well casing. Many operators chose to continue to pay the annual suspension fee rather than abandon wells using technology that was likely to fail at some point in the future.

Winterhawk had been developing technology for use in cyclic steam stimulation (CSS) wells that used a eutectic salt as the sealing mechanism. One of the unique characteristics of eutectic salt is that it increases in volume when it changes phase from liquid to solid. Winterhawk presented this CSS technology to the ERCB. During that meeting, questions were posed about the possible utility of the eutectic salt as a replacement for cement in well abandonments.

To address this possibility, Winterhawk proposed that a study be undertaken to determine if the eutectic salt would be a suitable replacement for cement in well abandonment. Interest and support was encouraging and Winterhawk was able to raise funds for research and development from private investors, the National Research Council – Industrial Research Assistance Program (NRC-IRAP) and the Petroleum Technology Alliance of Canada (PTAC).

The purpose of the study was to address four issues:

1. The mechanical-seal potential of the solid eutectic salt
2. The thermal expansion of the casing potential for damaging casing or primary cement column
3. The water solubility of the eutectic salt
4. The corrosivity of the eutectic salt

The study began in the second quarter of 2014 in the SAIT Applied Research and Innovation Services (ARIS) laboratory. In August 2014 the R&D was moved to a private facility due to incompatibility of SAIT protocol and commercial R&D requirements. The testing continues to be operated in this private facility.

Detailed monthly test reports were compiled for submission to IRAP. The reports for 2014 are attached as Appendix and a summary follows.

Mechanical Seal

The mechanical seal capability of the eutectic salt was anticipated to hinge on the volumetric expansion of the salt when it changed phase from a liquid to a solid. This expectation was based on earlier experimentation and research into the eutectic salt formula selected for testing. In tests for an alternate application the salt had demonstrated volumetric expansion in the order of 6%.

The salt testing results were very erratic, initially when the hot molten salt was poured into 4.5” and 7” diameter casing the results were consistent with expectations. The steel casing expanded as the result of the ~320°C temperature of the molten salt. When the salt solidified at 260°C the casing expansion remained and the casing expansion remained after the casing had cooled to ambient temperature. The salt plug did not provide a leak-tight seal.

The salt plugs were examined to ensure that the solid salt was not porous or permeable. It was confirmed that the salt was impermeable and that the leak path had to be a micro-annulus between the salt plug and the test-casing inside diameter (ID).

Subsequent tests were run with varying salt temperatures to determine if the lack of volumetric expansion might be caused by the formation of micro-bubbles in the molten salt. The results again were erratic, physical inspection confirmed that the salt was expanding, but not to the extent expected. In addition, it became apparent the hoop stress in the steel casing was sufficient to plastically deform the salt column and return it to the original diameter over time.

Secure Energy Services of Calgary was contracted to do an analysis of the eutectic salt mixture that we were using. It was determined that the salt concentration was a 35% sodium nitrate/65% potassium nitrate molar mixture (50/50 by mass mixture of the two compounds).

To allow us to blend the salt mixture to suit our purpose, we obtained separate supplies of sodium nitrate and potassium nitrate. Testing on modified salt formula continues.

Casing Expansion

The thermal expansion of the test casing was measured during each test. The expansion is remarkably consistent with 4.5” casing showing ~0.004” increase in outside diameter and 7.0” casing showing ~0.007”-0.008” increase in outside diameter. The testing was done with no constraint on the radial expansion of the casing.

Research into or knowledge of casing gas vent flow is very limited in determining the dimensions of the micro-annuli when casing gas flows to surface. Based on others’ field experience with pressurizing casing while doing cement squeeze operations, Winterhawk is confident that the casing expansion created by the eutectic salt plug will eliminate the micro-annuli.

Water Solubility

The eutectic salt is completely water soluble. The issue is whether or not the solution process ceases when the aqueous solution becomes saturated.

Winterhawk testing demonstrated that the solution of the solid salt was effected by three variables. The first was the surface area exposed to the solute, the second was the volume of the solute relative to the volume of the solid salt, and the third was the temperature of the solute.

Test coupons of 150 mg were prepared and immersed in 1 litre of fresh water. The test coupons dissolved completely in less than 48 hours.

Saturated salt solutions were prepared and the same test was run with a 150 mg coupon immersed in the saturated solution. The result was unexpected with the saturated salt precipitating on the container, reducing the saturation of the solute and over a much longer time period dissolving the test coupon.

This testing confirmed the water solubility of the eutectic salt and disproved the theory that the solution process would be eliminated in salt-saturated aqueous solution. Time did not permit the ongoing observation of the tests to determine if the system would at some point reach equilibrium with a transfer of solid precipitate equal to the mass of the test coupon, or if the system could be engineered to maintain the integrity of the seal system. The decision was taken to eliminate any potential for water contact with the salt in the design of the well-abandonment plug.

Corrosion

This testing was done to determine if a saturated-salt solution posed a threat to the casing. The corrosion rate observed was determined to be acceptable in static environments.

Conclusion

With regard to the objectives of the testing, the salt has not demonstrated the necessary properties to be used independently as a replacement for neat cement in oil-and-gas-well abandonment applications.

However, it has shown some remarkable properties related to the thermal effects of the high-temperature liquid phase that – coupled with a mechanical retainer – demonstrate high potential for use as an effective inner and outer seal system for well abandonment.

Recommendation

Winterhawk recommends that research continues into the utility of a eutectic-salt-sealed, mechanically reinforced well-abandonment plug. The design of this system has been shared with the AER and positive support for further research into this technology has been offered.

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