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.

February 12, 2015

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.

Submitted by Dale Kunz, CET
President, Winterhawk Marketing Services Inc. and
Winterhawk Well Abandonment Ltd.

APPENDIX A

Eutectic Salt Study Reports Submitted to National Research Council Canada Industrial Research Assistance Program

January – December 2014

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	January 1 - 31, 2014
Report prepared by:	Dale Kunz

Project efforts in the first 10 days of January were dominated by raising private funds to match those pledged by the Petroleum Technology Alliance of Canada (PTAC). The effort was successful and Winterhawk was able to secure $100k in private financing. Once that funding was secured Winterhawk met with members of SAIT Polytechnic Applied Research and Innovation Services (SAIT) to discuss contract and schedule.

Additional meetings with SAIT were to facilitate Winterhawk's application for a research and development grant from the Government of Canada National Science Engineering Research Council (NSERC). Winterhawk and SAIT collaborated on NSERC application. Concurrently, SAIT prepared a draft R&D contract that Winterhawk reviewed with the understanding that the contract would not be signed until the NSERC application had been filed.

Winterhawk began pre-project research to locate key test equipment and material items such as an electric kiln and steel pipe casing. Winterhawk provided steel pipe casing specification and dimensions to suppliers for quotation and selected a local provider, Hallmark Tubulars to be pipe supplier. Winterhawk also calculated the amount of eutectic salt needed for the test program. Material orders were made pending project start-up.

Winterhawk updated various stakeholders by regular email and telephone communication.

Marc Godin, our contact at PTAC, reported that the association board decided to do an email poll of board members for approval of Winterhawk being project sponsor and providing "industry" funding to match PTAC grant. This approval is expected in early March.

No other government funding has been received for this project.

Dale Kunz

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	February 1 - 28, 2014
Report prepared by:	Dale Kunz

Fundraising continued to dominate Winterhawk activities.

The Company applied for NSERC funding in first week of February. With this filed NSERC application in hand, Winterhawk signed a contract with SAIT Applied Research and Innovation Services (ARIS) on February 3, 2014, later than had originally been anticipated. Because the ARIS contract could not be signed until the NSERC application was filed, the project work at ARIS could not commence. As a result IRAP expenditures were lower for the first two months of the year than had been anticipated.

The Petroleum Technology Alliance of Canada (PTAC) funding commitment received earlier has also been delayed by that organization's internal approval process.

However ARIS contractors ordered project materials included pipe, electric kiln, eutectic salt and miscellaneous test materials. The pipe and kiln were delivered in February. The ARIS fabrication lab has been working with Winterhawk on test-equipment design. Winterhawk submitted drawings and stress calculations for design purposes. ARIS also set up the power supply for electric kiln.

Winterhawk employees and consultants also attended SAIT safety briefing in order to be approved for laboratory work and acquire SAIT independent contractor identification tags

On the regulatory front, Winterhawk met with Doug Boyler, Chief Engineer at Alberta Energy Regulator (AER) to update on project status. AER confirmed its interest and willingness to observer ARIS testing at Winterhawk's invitation.

While Winterhawk applied for additional government funding, it was not received in February 2014.

Dale Kunz

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	March 1 - 31, 2014
Report prepared by:	Dale Kunz

On March 24 SAIT and Winterhawk conducted contract-review meeting to discuss reporting responsibility for "principal investigator" and project schedule. The two parties agreed to amend contract to reflect dual reporting need and SAIT /Winterhawk joint responsibility for project approval at designated project "gates."

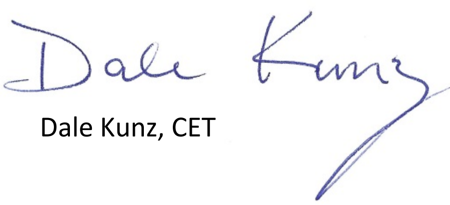
On March 25 Winterhawk and SAIT held a detailed-scheduling meeting to identify resources and resource availability. Project tasks were also identified and assigned. The team agreed to target mid-June as project end date with lab testing to begin as soon as possible in April.

At the March 25 meeting we also held a detailed test-casing design and fabrication meeting to discuss required pressure, temperature and testing instrumentation configuration. Test instrumentation thermocouples, high temperature strain gauges and piping flanges and caps were all specified. SAIT and Winterhawk agreed to machine all test pieces to specifications in one run to ensure that machining in separate runs would not delay future schedule.

In March the electrical kiln and power supply was set up at the SAIT ARIS lab. Winterhawk delivered salt and high-temperature protective blanket material to the ARIS lab.

SAIT ordered high-temperature PPE for delivery in early April as well as 600-lb weld-on flanges to be welded onto the test casing.

Winterhawk received confirmation that NSERC has granted funding for the project. We anticipate applying this funding to SAIT personnel expenses in March.



Dale Kunz, CET

Electric kiln used to melt eutectic salt

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	April 1 - 30, 2014
Report prepared by:	Dale Kunz

In April the team prepared the thermal-expansion data set for both sizes of casing and researched surface casing vent flow (SCVF) literature for comparison between expansion and SCVF micro-annuli size. The results were very interesting in that the thermal expansion increases in casing diameter were very similar to the micro-annuli sizes. The significance of this is that the thermal expansion may provide a means of closing the micro-annuli and stopping SCVF.

I contacted Ian Simister at Ceiba Energy and confirmed that Ceiba had six suspended wells available for field trials later this year.

I met with Doug Boyler at the AER and presented an updated ESP schedule and test detail for review and comment. Doug reaffirmed AER support for project and interest in participating in testing at SAIT.

We cut silicone-coated Kevlar material for the 4.5" seal elements and checked for fit in the 4.5" casing. The light-interference fit is consistent with the design. I also purchased 1" schedule-40 seamless steel pipe for the seal cores.

In consultation with Ron Quick, we decided to extend the IRAP contract to the end of August to be consistent with the SAIT contract and provide for unanticipated delays in R&D work. We then updated the schedule and published it to reflect extended end date.

The team received thermal exposure safety suits, which were the final outstanding material order to enable proceeding with testing.

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	May 1 - 31, 2014
Report prepared by:	Dale Kunz

In May we received first installment of the grant funding from the Petroleum Technology Alliance of Canada (PTAC). Winterhawk's financial strategy will be to use the PTAC funding for equipment, NSERC and IRAP funding for personnel.

The delivery of the weld-on strain gauge equipment was delayed due to a misunderstanding with the supplier of the high-temperature application. Research was done on strain gauges to compare weld-on versus clamp-on. It was determined that the clamp-on gauges are technically acceptable but will not be available until early July. After some discussion it was decided to proceed with thermal expansion and hydrostatic pressure testing and then do strain testing once the equipment was available.

The team assembled dry 4.5" seals on 1" Schedule-40 pipe and determined that the first tests would be done with a seal of 40 to 50 elements.

Dry assembly of 4.5" seal elements

I attended monthly meeting of Canadian Society for Gas Migration (CSGM) to investigate interest in eutectic salt solutions to surface-casing vent flows. The general discussion at meeting suggests that there is no reliable technology for repair of micro-annular leaks on suspended or abandoned wells. I have been invited to present at the group's fall meeting.

I presented a small-scale salt-melting demonstration to SAIT ARIS laboratory personnel. The purpose was to demonstrate the very low viscosity of the molten salt and the rapid phase change from liquid to solid.

We received die cutting tool for 7" seal element. Once the equipment has been set up we will be investigating different material weights for seal elements.

The test assembly pieces have been machined and are ready for welding.

Test equipment for assembly

Dale Kunz

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	June 1 – 30, 2014
Report prepared by:	Dale Kunz

The test spool and test-rack assembly was completed this month. All necessary equipment is now onsite, with the exception of high-temperature strain gauges, thermocouples and data-interface for the LabVIEW software. Difficulties with specifications on the high-temperature strain testing equipment continue to delay the thermal testing. The design of a clamp-on device and calibration is estimated to set delivery back until late July.

I met with Ron Quick and Michael Kerr from Innovates Alberta Technology Futures to discuss the field-trial phase of eutectic salt project. I sent information to Michael as follow up.

I also met with Ceiba Energy Services' CEO Ian Simister, and secured a written commitment to provide test wells for the field trial of eutectic salt abandonment plugs.

The assembled test spools and test rack shown below.

SAIT ARIS technician measuring 7" test spool diameter

The team hydro-tested all test spools to 3000 psi to ensure original integrity. The also took caliper measurements of diameters at atmospheric pressure and 3000 psi to compare to thermal testing expansion diameter to ensure that the casing would withstand pressure without losing elasticity.

Tested kiln heater and performed high temperature dry run using sand as media to ensure that proposed operational procedures would not endanger personnel.

Kiln test

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	July 1 - 31, 2014
Report prepared by:	Dale Kunz

Early July was plagued by equipment delivery delays. SAIT ARIS and SAIT's purchasing departments repeatedly failed to order and/or deliver material (thermocouples, data logger, software, strain gauges) to meet the project schedule. To discuss our concerns, Winterhawk called for a project review meeting, which was held on July 16. SAIT committed to improving their performance and a "make-up" schedule was agreed to.

The new schedule provided for the use of alternate magnetic-mount thermocouples on the test spools to allow for the temperature and thermal-expansion testing to proceed. The strain gauges were not expected to be available until early August.

The thermal testing began on July 21 with the fabrication and installation of a seal element for the 4.5" test spool. The data logger and thermocouples arrived on July 21, but SAIT ARIS technicians required a two-day familiarization period before they would use them.

Thermal testing with the first 4.5" test spool began on Thursday, July 24. Molten salt at ~300°C was poured into the test spool. The seal element performed as designed, creating a solid plug in the flexible labyrinth and effectively sealing the inside diameter of the test spool. The top of the spool was left open to observe the phase change and expansion of the salt.

The magnetic thermocouples were not properly calibrated and showed much lower temperatures than expected. A hand-held infrared pyrometer was used to collect thermal data as a back-up and provided accurate temperature data on the test-spool skin temperature.

Notably the temperatures recorded were much less than anticipated, with the highest casing surface temperature recorded ~220°C. After review it was concluded that the seal element and casing provided a sufficiently large "heat sink" to reduce the heating effect on the surface of the test spool.

An audible "crackling" was observed while the salt column was cooling and expanding. A volumetric expansion of ~6-8% was observed.

The 4.5" test spool top blind flange was installed on Friday, July 25 and hydrotest fluid was introduced to the test spool. It was immediately noted that the hydrotest fluid leaked from the test spool, which indicated that the salt plug had not made a leak-tight seal with the casing.

A pilot hole was drilled in the salt plug to ensure that the plug itself was not permeable and this was proven to be the case. The conclusion drawn was that the expansion of the salt plug had broken the salt column to casing seal and that this movement was the source of the noise mentioned previously. There was a micro-annular space left between the salt column and the casing.

The cold-test spool diameter was measured and compared with the pre-test dimensions and no change was noted.

On Monday, July 28 a second test was conducted on the second 4.5" test spool. In this test the spool did not have a seal element installed, but was instead filled from flange-to-flange with molten salt at ~300° C. The flange bolt and studs were tightened to torque specifications. The temperature of the test spool was measured with the magnetic thermocouples – again not indicating correct temperature but showing reliable trend lines. The temperature was measured with the hand-held infrared pyrometer. This test was done to examine the effects of containment of the axial expansion of the salt and prevent any movement of the salt to casing interface.

When the test spool cooled to ambient temperature, the casing diameter was measured and found to be 0.004" greater than the pretest diameter at the center point of the salt column. The conclusion was that the thermal expansion of the casing had been prevented from contracting by the solid expanding salt column.

Plans were made to perform a similar test on the first of the 7" test spools in early August.

Dale Kunz

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	August 1 - 31, 2014
Report prepared by:	Dale Kunz

The first testing of the 7" diameter casing began on Wednesday August 6. The test spool was prepared for a flange-to-flange fill test similar to that done on the 4.5" test spool the week prior. Due to an error in calculation, insufficient melted salt was prepared. The salt should have completely fill the tube, but it did not. While details of the thermal test were recorded, plans were immediately made to perform another test the following day, Thursday, August 7.

On the morning of August 7 Winterhawk's Principal Investigator, Dr. Roy Jeffries, received an email from SAIT ARIS staff member Mark Enabu advising him that – as directed by the SAIT ARIS HSE Manager – further testing was suspended pending the preparation and submission of a standard operating procedure (SOP). The email further stated that Winterhawk needed to provide a material data safety sheet (MSDS) for the salt and an explanation for the odour that the melting salt emitted. This was followed up by a more detailed email from SAIT ARIS staff member Brian Hughes, who also suggested that in the future Winterhawk would have to provide 24 hours' notice to SAIT ARIS to book the services of qualified SAIT ARIS overhead crane operators.

It must be noted that in June SAIT ARIS staff and Winterhawk performed a joint safety review trial-run to ensure that we met SAIT safety standards and the project was given approval to proceed. The SAIT ARIS HSE Manager was invited to this review but did not attend. It also must be noted that Dr. Alex Zahavich had met with SAIT ARIS staff to specifically request that Winterhawk be given priority support in the use of the overhead cranes.

SAIT ARIS Senior Project Manager Dr. Alex Zahavich was on vacation when this incident occurred and his designate was out of the office. Winterhawk decided to stand down until a review of the project could be undertaken.

After a meeting amoung Winterhawk investigators Dale Kunz, Denis Gaudet and Dr. Roy Jeffries, it was decided that due to ongoing disappointment with the services provided by SAIT ARIS, the project would be moved from SAIT to a private facility. IRAP ITA Ronald Quick was advised of this decision.

On August 15 Dale Kunz advised Dr. Alex Zahavich that the project would be moved. It was agreed that the SAIT ARIS/Winterhawk contract would not be cancelled as SAIT ARIS had still not delivered the strain gauge equipment and might be able to render some assistance in the set-up of same.

All of the Winterhawk equipment and material was moved from the SAIT ARIS facility on Thursday, August 21. The new R&D location is in a private facility two miles south of Okotoks.

Test planning at the new facility began on Monday August 25.

The strain gauge equipment was not available at August month end.

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	September 1 - 30, 2014
Report prepared by:	Dale Kunz

In late August the R&D team set up the new test facility in Okotoks, and the first thermal testing in the new location was done on September 3. Due to insufficient electrical service to the shop, we were not able to operate the kiln that we'd used at the SAIT-ARIS facility. We opted to use propane-fired heaters to melt the eutectic salt as this was a less expensive alternate to a portable electrical-power-generation unit.

The use of multiple heaters reduces the total time required for melting sufficient salt and enables man-portable weights of liquid salt. The total weight of salt for a 4.5" pour is in excess of 50 pounds (22 kg). Divided among three vessels, this allows for a safe to handle 15 to 17 pounds. The 7" vessel requires the use of four heaters.

Figure 1- Propane fired heaters melting salt

We found that the propane heaters took longer to melt the salt in the required volumes than did the electric kiln. It is also somewhat difficult to control the heater temperatures below 320° C. This lack of precise temperature control resulted in a molten salt that contained micro-bubbles of salt vapour, which inhibited the salt volumetric expansion effect.

The strain gauge test equipment was received from SAIT on September 9.

On September 15 IRAP ITA Ron Quick attended at test facility to witness a subsequent test session.

Testing through September was focused on modifying the heating equipment and heating procedures to improve salt-liquid temperature control.

Modifications to the heating system included adding insulation to aluminum heating vessels to minimize heat loss.

Figure 2 Heating vessels insulated to minimize heat loss

At month end, the testing had still not produced the expected 4.5" casing expansion. Analysis of the test data over the month showed that in the first testing we used liquid salt at ~ 350° C. In the second round of testing we introduced a 150 psi vapour pressure blanket to the top of the vessel. In the third round we reduced the salt temperature to ~ 325° C (below the published boiling point of 340° C) and removed the vapour blanket. In all cases the solid salt column volume was reduced from the liquid volume.

September testing used the 4.5" size test vessels to minimize salt consumption and reduce test time. The 4.5" test spool fill requires melting of one bag of salt, which takes about three hours. Once poured, the cooling time is an additional three hours before the test spool caliper measurements can be taken at ~ 110° C surface temperature. Cooling to ambient temperature requires another three to four hours. The 7" test vessel requires almost three bags of salt and the melting and cooling times are extended by about 30%.

Once the filled test spool has been examined, measured and analyzed the salt plug is removed by water solution which takes 24 hours in the water tank.

Dale Kunz

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	October 1 – 31, 2014
Report prepared by:	Dale Kunz

In October we experienced continued test anomalies that replicated those that occurred in September. After an analysis of several tests, the anomalies were attributed to the overheating of the salt solution during melting. This resulted in the creation of entrained sodium or potassium vapour "bubbles" in the melt solution. The entrained vapour bubbles collapsed during solidification and reduced the volume of the salt, which in turn defeated the liquid-to-solid phase change volume increase. Several test series were run in an attempt to better understand the incidence of vapour formation with mixed success.

Figure 1 below is typical of salt columns inspected showing a porous surface caused by the formation of the salt vapour bubbles in solution that attached to the steel casing. It is theorized that the bubbles in the solution collapse (no porosity is found in the solid) and take up the 6% volumetric liquid-to-solid phase change expansion that we expected. The bubbles on the surface of the casing are thought to be trapped by the faster cooling and solidification of the salt at that surface.

Figure 1 - Porous surface on salt column caused by entrained vapour "bubbles"

Continued test ambiguity led to the decision to decrease the size of two test spools sizes of 7" and 4.5" to 2" OD for this range of testing. This was done to:

- Reduce salt volume/consumption
- Reduce test turnaround time
- Allow for closer control of salt melting temperature by using smaller volume

Figure 2 - 2" test spool

Smaller test spools were prepared and a series of tests run that produced test results similar to the larger-diameter testing. The void-space formation at the top of the salt column, the lack of a seal between salt and casing, and the expansion of the steel casing all seemed to be consistent with some expansion of the salt column.

Paradoxically, the threaded caps on the test pieces were routinely seized on the test pieces when the solidifying salt penetrated the threads. These caps could not be removed by physical force and had to be released by soaking in water.

Testing with 2" test spools and smaller salt samples provided clear indications that the fired-propane heaters were overheating the salt solution during the initial melt. Therefore it was decided to return to the electric heating system. After some discussion about the use of an electrical generator for the existing kiln, a lower-voltage kiln was acquired in late October.

Figure 3 - Electric kiln provides better control of salt melting

The kiln in Figure 3 allows for close control of the melt temperature by the use of a thermocouple inserted in the vent holes. Smaller salt volumes take less time to melt reducing the test turnaround time.

Salt samples were sent to CoreLab for analysis of salt composition before and after the melting process. Unfortunately, after receiving the samples and working with them for two weeks, CoreLab advised that they could not do the analysis we had requested.

Figure 4 - Labyrinth mandrel produced a 400 psi medium pressure seal

A test mandrel using a fixed labyrinth seal was built as shown in Figure 4. The outside diameter of the mandrel labyrinth was approximately 1/8" less than the ID of the 2" test spool. The molten salt flowed around the labyrinth, filling the annulus and solidifying with a minimum of void spaces. This mandrel provided the first hydraulic pressure seal achieved in testing to date.

Analysis of the seal achieved suggested that the salt was confined to a small-volume section (contained by the washers top and bottom), the salt expansion was directed radially rather than axially and the seal occurred at the outside edge of the washer.

The seal held 400 psi hydraulic oil pressure prior to leaking. Given that the seal length was ~ 12” it is theorized that a seal of 72” length would provide 2400 psi if the labyrinth geometry were unchanged. It is also theorized that increasing the labyrinth density will increase the seal efficiency and the pressure that can be contained.

November testing will focus on alternate labyrinth arrangements. Spacing of the labyrinth elements and diameter of the mandrel will be varied to assess sealing effect.

Dale Kunz

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	November 1 – 30, 2014
Report prepared by:	Dale Kunz

In the first half of November we continued testing with the 2” test pieces and results continued to be erratic. Shortly after the tests, the pieces repeatedly exhibited an expanded diameter– typically 0.002” (which conformed to our expectations) – but then shrunk back to the original diameter in a matter of 24 to 48 hours. This was consistent with earlier larger-diameter tests that exhibited the same characteristic but after a longer length of time. Analysis of this phenomenon led to the consideration that the hoop stress in the expanded steel casing might be sufficient to plastically deform the salt column over time and cause the steel casing to return to its original diameter.

I presented the R&D team with a proposal to try using expandable pleated steel rings in a labyrinth seal-type of assembly as a reinforcing agent in the salt column. My intention is to accomplish two things:

1. Completely eliminate the possibility of micro-annulus formation between the mandrel and the casing to increase the seal strength of the salt column. Based on the rigid labyrinth tests done in late October, I expect that this would provide a robust hydraulic seal between the salt column and the casing.

2. Increase the radial strength of the salt column to prevent the salt deformation and retain the casing expansion as a permanent increased diameter.

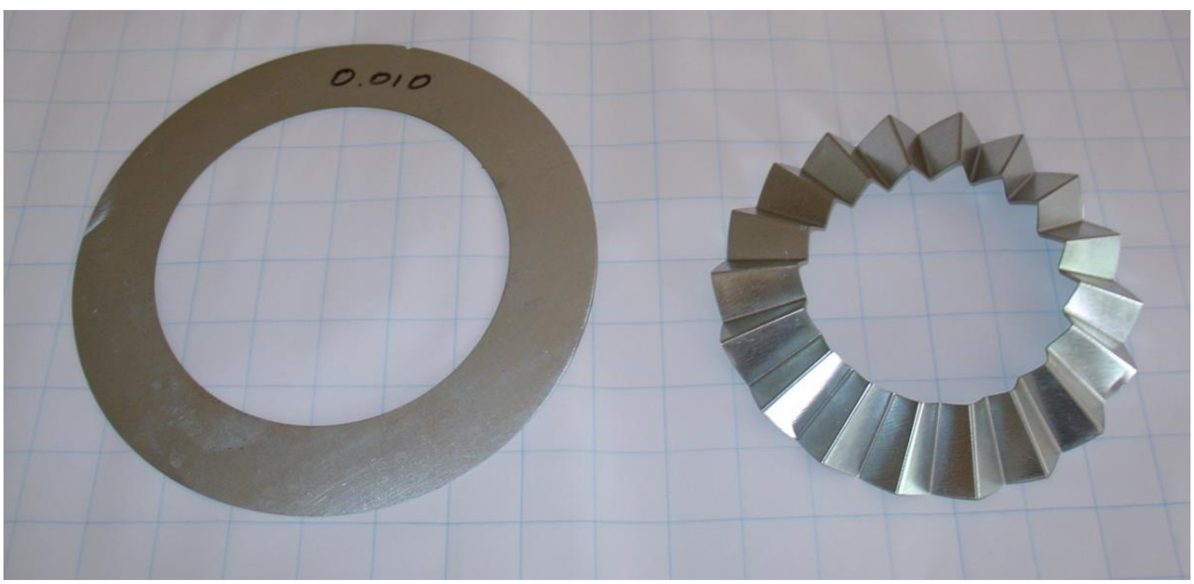


Figure 1 – Flat steel ring and pleated ring showing diameter decrease in formation.

The use of expandable steel rings mounted on a hollow steel mandrel with a relatively small combined diameter should produce a tool that can be run into the wellbore with a minimum of interference. The sequence would be as follows:

1. Place the mandrel.

2. Compress the rings to expand them to make contact with the casing wall.

3. Inject hot molten salt into the mandrel to force the salt behind the expanded rings' internal diameter and through perforations in the rings. This will thermally expand the casing and the steel rings.

4. Allow the salt to cool and "freeze," thereby permanently setting and retaining casing expansion. The solid-salt and expanded-steel-rings set should provide a permanent hydraulic seal inside the casing.

The permanent casing expansion should eliminate the casing-gas vent flow annulus between the casing OD and the primary cement job. By varying the compression force on the expandable rings, the amount of casing expansion may be controlled.

On November 25 the Winterhawk team visited the Red Deer shop of Basic Tool and Die, a company that manufactured pleated rings for Winterhawk for another project. Winterhawk was able to obtain the steel-ring-forming equipment manufactured by Basic, and we have located a Turner Valley machine shop that will be able to manufacture the pleated rings using the existing dies.

The Turner Valley shop has made up a small number of ~4" diameter pleated rings and testing with them will begin the first week in December.

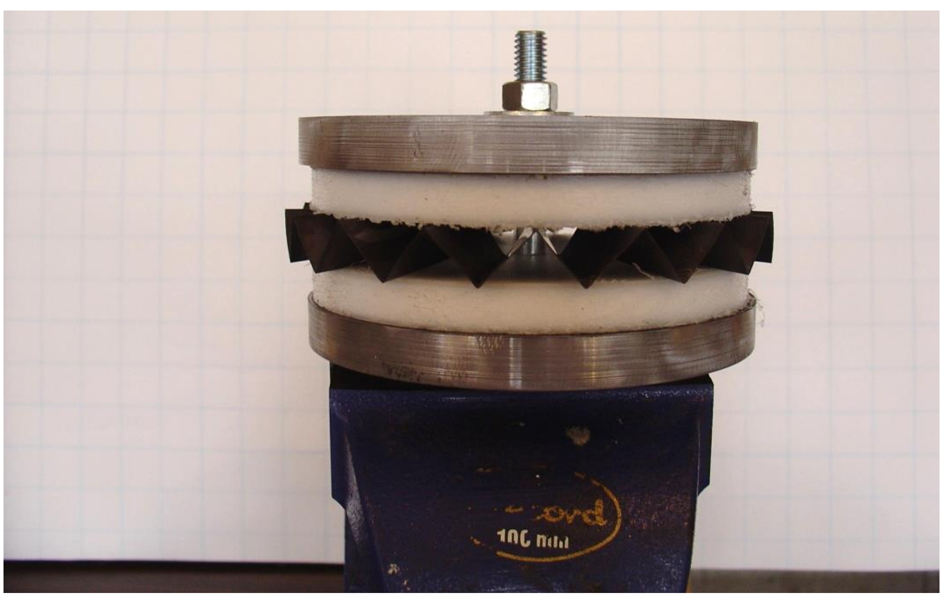


Figure 2 – Corrugated steel ring in test press without compression

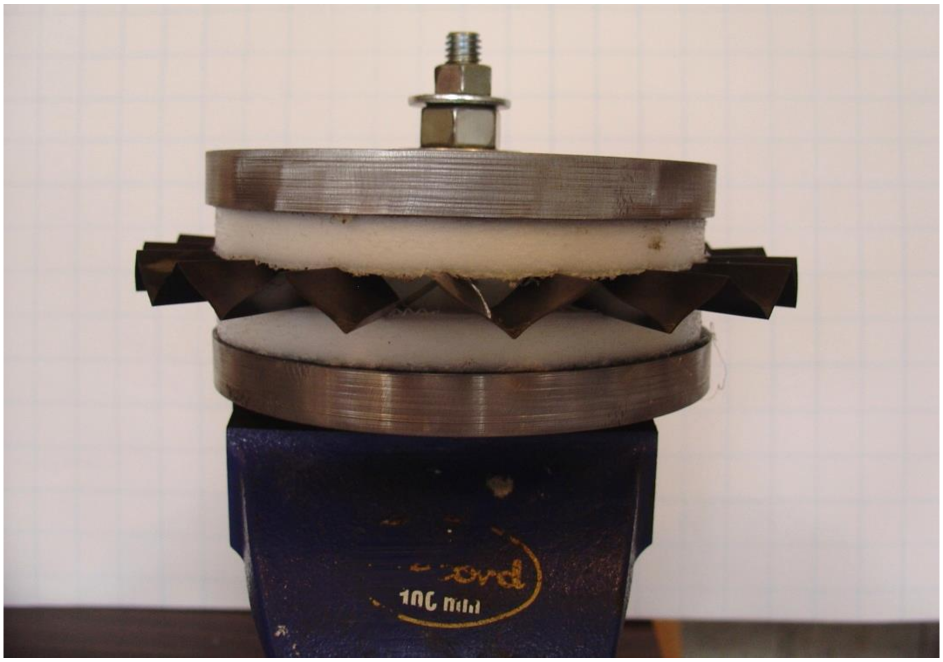


Figure 3 – Pleated steel ring under compression, showing an increase of ~ ½" diameter.

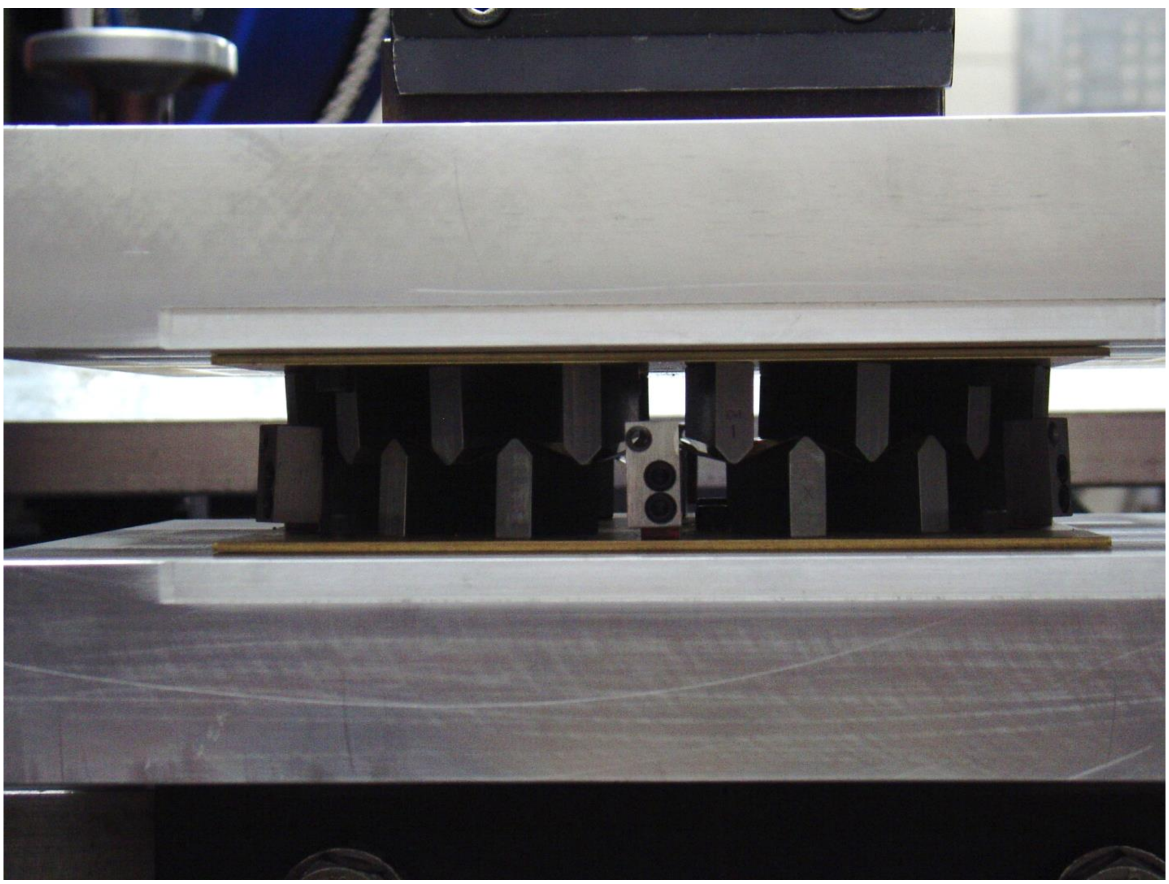


Figure 1 – Pleated-ring-forming die

We have ordered more materials to manufacture more pleated rings for testing. We anticipate doing further pleated-ring testing in January 2015.

On another front, Winterhawk has entered into a mutual confidentiality and non-disclosure agreement with Select Energy Services Inc. to explore opportunities and to begin development of the coil-tubing delivery and salt-pump systems.

Lastly, in light of the inability of test labs to analyze the eutectic salt, Winterhawk ordered a quantity of raw sodium nitrate and potassium nitrate to enable us to vary the chemistry of the eutectic material. With the assistance of IRAP ITAs Bob Golding and Ron Quick, we have also asked Secure Energy Services' New Technologies and Completions Lab to propose an alternate salt-testing protocol that will give us the means to determine the salt chemistry during testing.

Dale Kunz, CET

National Research Council Canada – Industrial Research Assistance Program	
Winterhawk Marketing Services Inc. – IRAP Project # 819259 Eutectic Salt	
Status Report for the Period of:	December 1 – 31, 2014
Report prepared by:	Dale Kunz

The first week of December was taken up with evaluation of the salt-and-pleated-ring plug system. A review of finite element analysis results for an earlier pleated-ring application confirmed that the rings could be manufactured with sufficient strength to withstand the contracting hoop stress of the steel casing when it cools from ~260°C. Installing a number of pleated steel rings assures that the outer diameter (OD) expansion of the casing can be permanently set and will effectively close any micro-annuli between the casing OD and the primary cement column in the wellbore.

Our calculations suggest that a one-meter long salt column will require 40 pleated rings of 0.020" thickness to retain the thermal expansion in the casing without any support from the salt column.

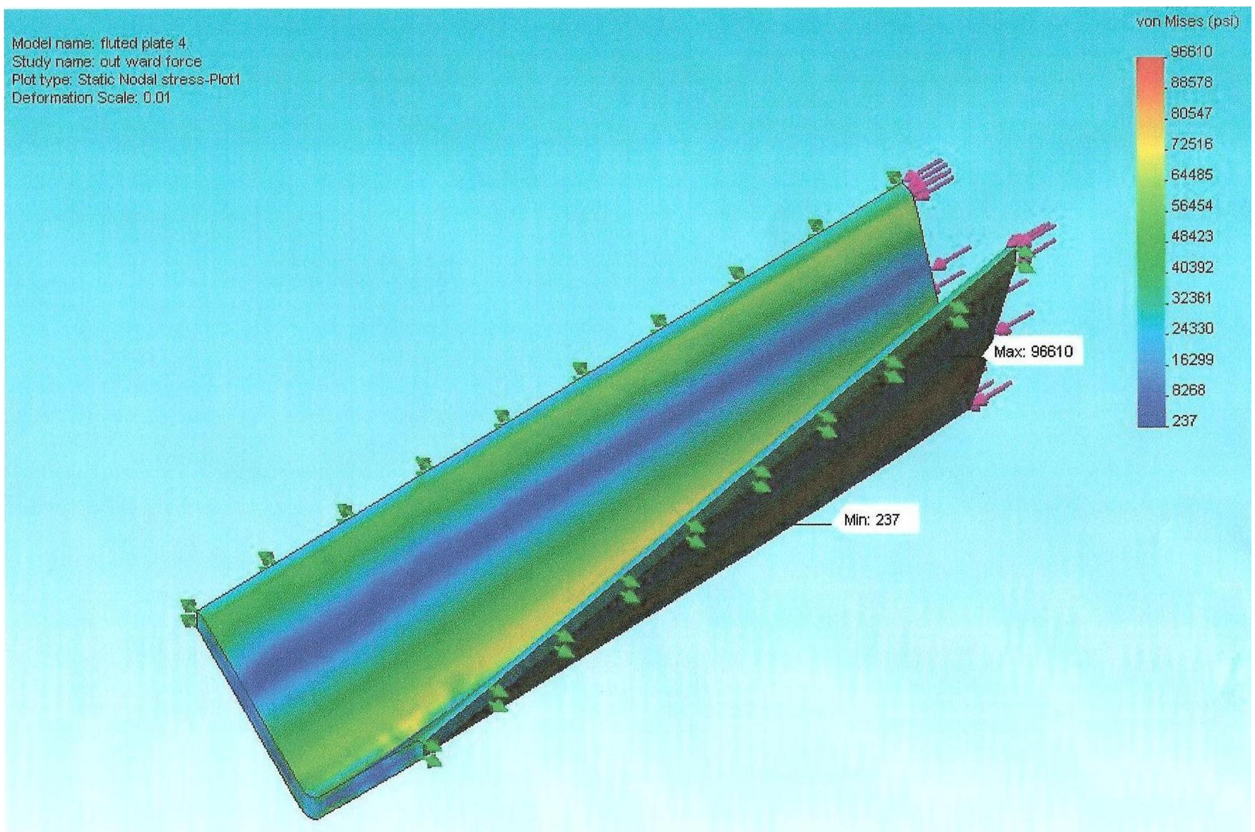


Figure 1 - Finite element analysis of pleated ring element

Our research team met with Select Energy Services Inc. to discuss Winterhawk's need for detailed engineering and manufacturing of prototype tools. The meeting was very productive and Select agreed to prepare a time and cost estimate for Winterhawk review.

Further to November discussions, Secure Energy also prepared a salt-testing protocol. The process was agreed upon and Winterhawk submitted salt samples to Secure for analysis. IRAP support for the testing process was arranged by Bob Golding and Ron Quick.

The salt testing revealed that we were misinformed about the salt composition. We had been told that the commercial salt was approximately 35% sodium nitrate and 65% potassium nitrate (the vendor does not release the actual composition, claiming proprietary rights). However our testing revealed that it was actually a 50/50 blend. The testing also showed some minor changes in the chemistry due to our melting process. The end result was that we ordered supplies of pure sodium nitrate and potassium nitrate so that we can blend our own mixtures for further testing. Delivery is expected in late January.

On December 11 I met with Doug Boyler at the Alberta Energy Regulator (AER) to update him on the design changes that we were contemplating and he continued to express strong support for the initiative. To help us move the project forward, Doug offered all AER support and assistance within his purview. Additionally Doug, who is also a member of the PTAC board, shared that the PTAC board has inquired about the project status at every monthly board meeting since we began.

Andrew Northcott of Hallmark Tubulars contacted me in mid-December to inform me that the weakening demand for vacuum-insulated tubular (VIT) casing had freed up material for our project. After some discussion we decided to order the custom sizes we require from the factory, and are expecting delivery of the material in late January.

In the last half of December we began testing the pleated-ring components. We used a solid threaded rod as the mandrel and a stack of six rings compressed/expanded inside of 4", schedule 40 casing with a simple threaded nut. We determined that the rings tend to expand sequentially, which is good news in that it indicates that the axial force required to expand the rings will be in the range that can be applied with either coiled or jointed tubing.

On the down side, we also determined that the expansion and contraction of the uppermost ring prevented the lower rings from fully expanding within the casing ID. This problem was discussed and we are considering several options are to resolve this issue. Unfortunately the number of tests was limited by the amount of steel material we had available to fabricate rings. We placed an order for sufficient steel to continue our tests and expect the steel to arrive in late January.

The decision to integrate the eutectic salt technology and the pleated-ring technology triggered the decision to create a new company with a mandate to research, develop and commercialize this method of well abandonment independently of Winterhawk Marketing Services Inc.

The new company is named Winterhawk Well Abandonment Ltd. It was incorporated on December 30, 2014 with a commitment from a private investor for $200,000 in capital to provide a sound financial footing upon which to continue the R&D work on this technology.

The project work expenses (with the exception of NRC funding on the existing CRA grant) will transition from Winterhawk Marketing Services Inc. to Winterhawk Well Abandonment Ltd. over the first three months of 2015.

Dale Kunz

Dale Kunz, CET