ThermoVault®
Performance Testing

Technical Bulletin TB-2011 2 of 2

Excutive Summary

prepared by:

Enviro Vault®

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T3H 4H9

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November 2011

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ThermoVault® Performance Testing Executive Summary

Objective

For years, Enviro Vault® has been able to offer freeze protection in tanks by installing a catalytic heater. The objective of this project was to expand that application and use multiple catalytic heaters installed in an Enviro Vault® to elevate and maintain tank fluid temperature in order to provide an alternative heat source to fire tubes while reducing the amount of energy required. Energy requirements, fuel efficiencies, and air emissions were measured and analyzed while comparing against a new conventional fire tube and burner management system. Sub-objectives included studying the impact of using tank insulation vs. no insulation and developing a catalytic heater sizing calculator. Resources from the Government of Canada National Research Council - Industrial Research Assistance Program (NRC-IRAP) and the Alberta Innovates - Technology Futures (AITF, formally the Alberta Research Council) were utilized for funding and performing the research and development, respectively. No previous data existed on catalytic heater performance in an enclosed space such as an Enviro Vault®.

Equipment and Test Methods

In order to conduct proper tests and obtain specific data, a new 400 bbl tank was constructed. Originally the tank was uninsulated. After the initial results were obtained, a 1.5□thick layer of urethane insulation was applied. The ThermoVault® was equipped with five (5) 24"x24" Cata-Dyne WX heaters with a total rating of 100,000 Btu/hr natural gas input. A 6" diameter fire tube was constructed with a new 250,000 Btu/hr conventional burner assembly and management system. Natural gas flow was measured with a gas meter and used in the calculation of energy input to the system. Temperature profiles were determined across the diameter and height of the tank and were used to calculate the energy absorbed by the tank water. A weather station was used to datalog ambient temperatures and wind speeds for the calculation of heat loss from the tank. Energy balance calculations were determined and combustion by-products were analyzed.

Results

	Catalytic Heaters	Fire Tube
Ambient Temperature	7 to 25ºC (44 to 77ºF)	-29.5 to -22.8ºC (-21 to -9ºF)
Duration of Test	118 hrs.	21 hrs.
Initial Temperature Recorded	10ºC (50ºF)	4ºC (39ºF)
Final Temperature Recorded	36ºC (97ºF)	15ºC (59ºF)
Temperature Rate Increase	0.24ºC/hr	0.52ºC/hr
Heat Transfer Rate - water	2,720 Btu/hr/sqft	3,400 Btu/hr/sqft
Heat Transfer Rate - oil (est.)	2,300 Btu/hr/sqft	3,000 Btu/hr/sqft
Estimated Tank Heat Losses	1.4%	6.5%

Note: The fire tube test was a shorter duration due to operating in cold weather conditions.

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The temperature step rate increases are not equivalent because of the fire tube test measured a fuel rate of 219, 423 Btu/hr compared to 84,400 Btu/hr with the catalytic heaters. If the number of catalytic heaters was increased to match the fire tube measured fuel rate, the temperature step rate increase would be comparable.

A milestone temperature of 21°C (70°F) was chosen because it was requested by a major producer in the United States for oil-water separation. If this test started at the same starting temperature as the fire tube test (4°C, 39°F) for comparison, it would take 74 hrs for the catalytic heaters to reach 21°C (70°F). Using extrapolation, it would take approximately 32 hours for the fire tube to reach 21°C (70°F). Heating with the catalytic heaters appeared to reduce the size of a cold, stagnant zone on the bottom of the tank that was present when heating with the fire tube.

Estimated tank heat losses were 44.5% for an uninsulated tank fire tube test. Enviro Vault® recommends that upstream aboveground storage tanks in cold weather climates need to be insulated.

	Catalytic Heaters	Fire Tube
Combustion Efficiency	86.8%	99.9%
Overall Efficiency	64.4%	61.8%
Stack Gas Concentration - CO_2	1.6%	5.0%
Stack Gas Concentration - NOx	Negligible	31 ppm
Stack Gas Concentration - CO	Negligible	161 ppm
Stack Gas Concentration - VOCs	35.5 ppb	80 ppb

Note: The combustion efficiency is the percentage of natural gas converted to CO_2. The overall efficiency is the percentage of fuel energy transferred to fluid in the tank. Because of the unburnt methane emissions from the catalytic heaters, GHG emissions were higher per unit of fuel consumed at 0.86 kg/year per Btu/hr vs. 0.46 kg/year per Btu/hr for the fire tube (at 100% runtime). NOTE: It is important to note that the efficiency of the burner may vary greatly over time without regular cleaning, maintenance and adjustment.

The ThermoVault® was able to achieve the desired tank fluid temperature though it would use as much fuel as the fire tube. The stack temperatures for the catalytic heaters were 72°C (162°F) vs. 283°C (542°F) for the fire tube. Stack heat losses were 33.3% for the catalytic heaters vs. 28.6% for the fire tube.

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Opportunity Going Forward

Due to the nature of catalytic heaters, the ThermoVault® is safe for use and meets regulations in hazardous areas (Class 1, Div 1). It can be used to heat light oil applications where fire tubes may not be allowed. The ThermoVault® provides an efficient alternative to a fire tube application for lower heating requirements. The need for expensive fire tube burner management systems is eliminated. Reduced NOx and CO emissions are achieved with catalytic heaters. The ThermoVault® eliminates low frequency noise pollution as are found with fire tube burner assemblies. Reduced accidents, injuries and operational costs by eliminating the possibility of fire tube failures are additional ThermoVault® advantages. As with every Enviro Vault® model, the ThermoVault® comes with an unmatched heated spill containment area for valves and piping including a high level shut down switch. The ThermoVault® test results demonstrate that this technology would be capable of heating an oil-water mixture to 21°C (70°F) and higher for separation as in the baseline application of a major producer in the United States.

Additional Notes

The ThermoVault® project was successful in achieving its objectives including the development of a catalytic heater sizing calculator and with the commercial sale of its first unit in June 2011. Five additional units have been requested for the end of the 2011. The catalytic heater sizing calculator analyzes heating requirements for a variety of tank sizes and applications. Calculations confirm Enviro Vault's recommendations for freeze protection. An 18" x 24" catalytic heater inside an Enviro Vault® is capable of providing freeze protection for tank fluids and valves in an insulated 400 bbl tank in most circumstances.

Enviro Vault® finds merit in pursuing additional testing for several reasons. The overall efficiency of five (5) 24"x24" catalytic heaters was comparable to the 250,000 Btu/hr fire tube but can be improved upon as only 84,400 Btu/hr of natural gas input was achieved when the heater manufacturer rating was at 100,000 Btu/hr. It is important to note that the new fire tube and burner management system were calibrated and tuned by the manufacturer multiple times to achieve maximum efficiency. This level of efficiency may not be indicative of what is found in real life field conditions. Fire tube systems require regular calibration, cleaning and maintenance. Ventilation could be improved in the ThermoVault® and Enviro Vault® is investigating air flow modelling to also reduce GHG emissions by allowing a cleaner burn of natural gas. Reducing stack heat losses through a heat exchanger system will be considered in future testing.

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1.0 Introduction

For years, Enviro Vault® has been able to offer freeze protection in tanks by installing a catalytic heater. The objective of this project was to expand that application and use multiple catalytic heaters installed in an Enviro Vault® to elevate and maintain tank fluid temperature in order to provide an alternative heat source to fire tubes while reducing the amount of energy required. Energy requirements, fuel efficiencies, and air emissions were measured and analyzed while comparing against a new conventional fire tube and burner management system. Sub-objectives included studying the impact of using tank insulation vs. no insulation and developing a catalytic heater sizing calculator. A milestone temperature of 21ºC (70ºF) was chosen because it was requested by a major producer in the United States for oil-water separation. No previous data existed on catalytic heater performance in an enclosed space such as an Enviro Vault®.

Resources from the Government of Canada National Research Council - Industrial Research Assistance Program (NRC-IRAP) and the Alberta Innovates - Technology Futures (AITF, formally the Alberta Research Council) were utilized for funding and performing the research and development, respectively. Test data was acquired by the AITF as an independent third party for verification. Results will be used to size multiple catalytic heaters for the ThermoVault®. Testing was conducted at the AITF Devon facility in Alberta, Canada from February to June 2011.

Due to the design of the catalytic heaters, the ThermoVault® is safe for use in hazardous areas (Class 1, Div 1) and meets regulations. It can be used to heat light oil applications where fire tubes may not be allowed. The ThermoVault® provides an efficient alternative to a fire tube application for lower heating requirements. As with every Enviro Vault® model, the ThermoVault® includes an unmatched heated spill containment area for valves and piping including a high level shut down switch.

2.0 Equipment Description

New Test Tank specifications include:

Size	400 bbl
Material	Steel
Dimensions	12’ diameter and 20’ height
Shell, Roof & Floor	3/16” shell and roof with ¼” floor A36
Insulation	1.5 inch thick layer of spray foam U factor of 0.1 BTU/hr/^{o}F/ft^{2} (R value =7)

ThermoVault® prototype specifications:

Vault Size	6’ wide x 6’ height - 1/2” roof - 1/4” shell - 12’ OD
Catalytic Heaters	Five (5) 24”x24” Cata-Dyne WX - 12V Total rating of 100,000 Btu/hr natural gas input

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2.0 Equipment Description
CONTINUED

Figure 1 displays the new 400 bbl insulated test tank with ThermoVault® rated to 100,000 Btu/hr and a new 6" diameter fire tube, burner assembly and management system rated to 250,000 Btu/hr. A weather station was installed to datalog ambient temperatures and wind speeds for use in heat loss calculations. A natural gas flow meter was installed to enable calculation of energy input to the system.

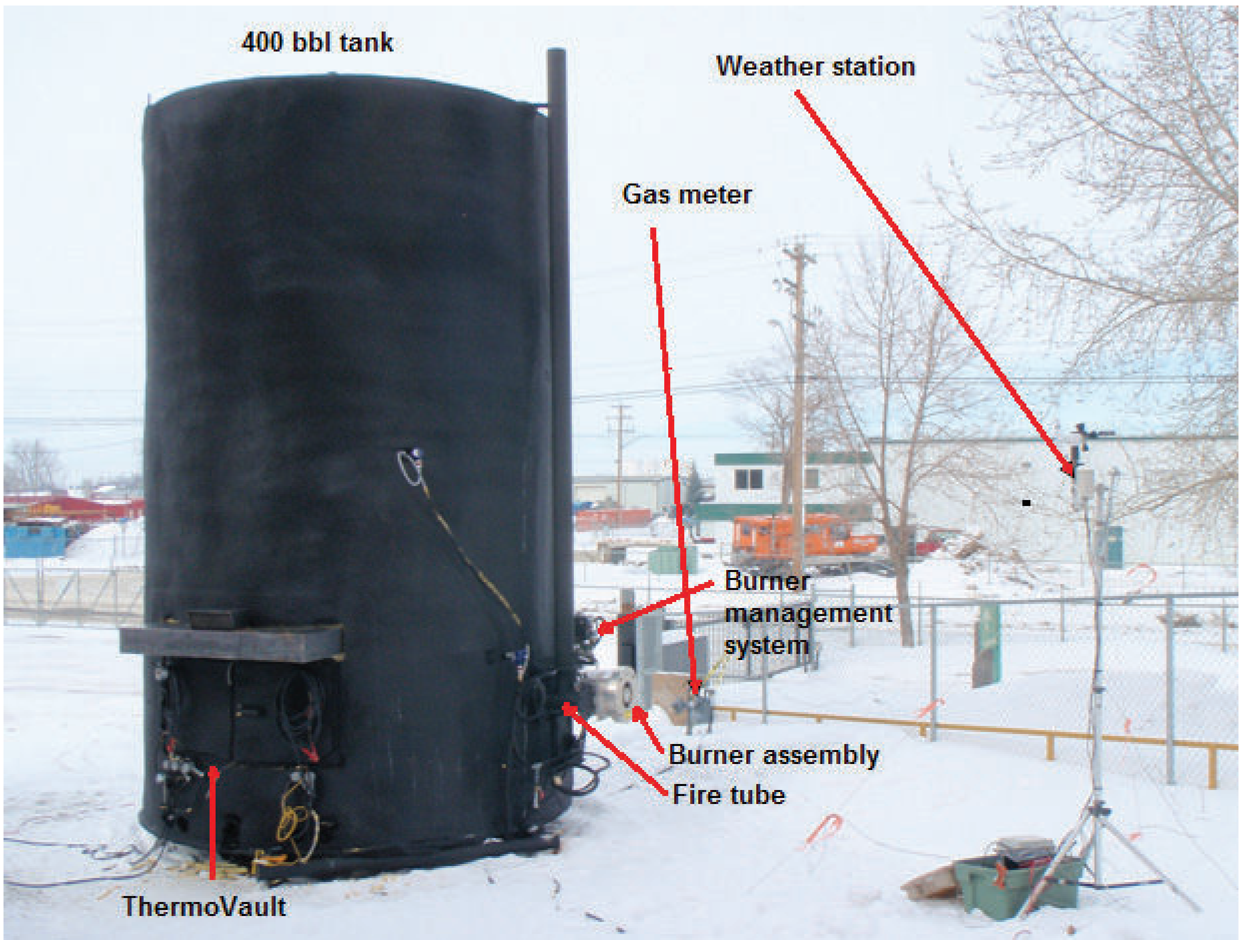

Figure 1: Insulated 400 bbl Tank Equipment

(Chambers, Nikoo, Segura; 2011); modified for additional labelling

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2.0 Equipment Description
CONTINUED

A total of nine resistance temperature detectors (RTDs) were installed in the test tank for measurement of the internal tank temperatures.

Figure 2 displays the location of the RTDs (labeled C1 to C9). C7 to C9 were located near the centerline of the tank, C6 was installed in the wall of the ThermoVault® and C1 to C4 were installed near the tank walls. C1-C6 temperature plots were used as lower readings for the worst case scenario since temperatures are normally measured on the exterior of field tanks. C7, C8 and C9 measured the same temperature step rate increase as C1-C6.

A thermocouple was also installed inside the ThermoVault® during one of the tests with the catalytic heaters to measure the air temperature near the center of the air space.

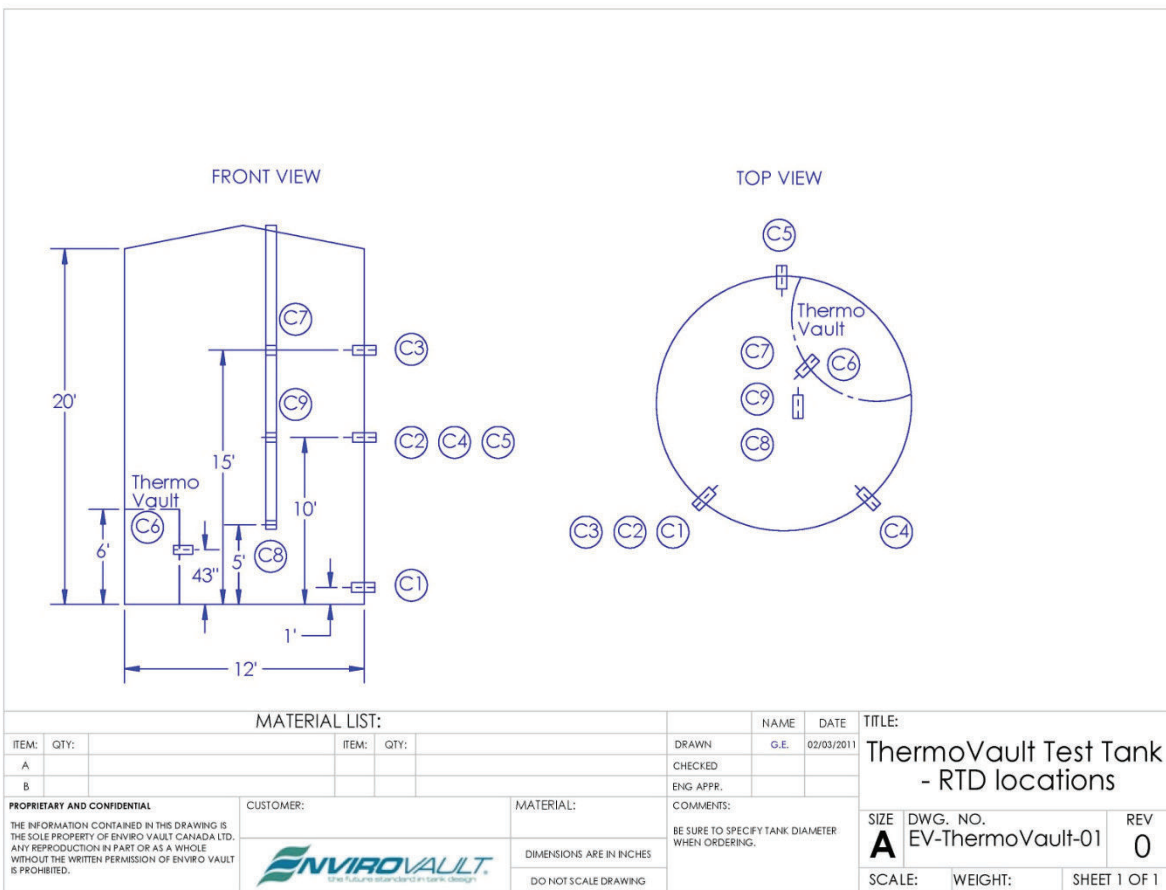

Figure 1: RTD Locations in Test Tank

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3.0 Testing Method

3.1 Temperature Profiles

Temperature profiles were determined across the diameter of the tank at three different RTD levels. The temperature increases from the start to the end of the test were used to calculate the energy absorbed by the tank water. The temperature profiles showed a higher temperature on the centreline of the tank relative to the wall. Figure 3 shows the measured tank temperatures with time during heating with the ThermoVault®. Figure 4 shows the measured tank temperatures with time during heating with the fire tube. In Figure 4, a stagnant zone was found below T1 with the fire tube test. In Figure 3, T1 did increase with time, indicating the lack of a stagnant zone at the bottom of the tank.

The five catalytic heaters were able to get to the milestone temperature of 21ºC (70ºF) in 49 hrs. If this test started at the same starting temperature as the fire tube test (4ºC, 39ºF) for comparison in Figure 3, it would take 74 hrs for the catalytic heaters to reach 21ºC (70ºF). Using extrapolation of Figure 4, it would take approximately 32 hours for the fire tube to reach 21ºC (70ºF).

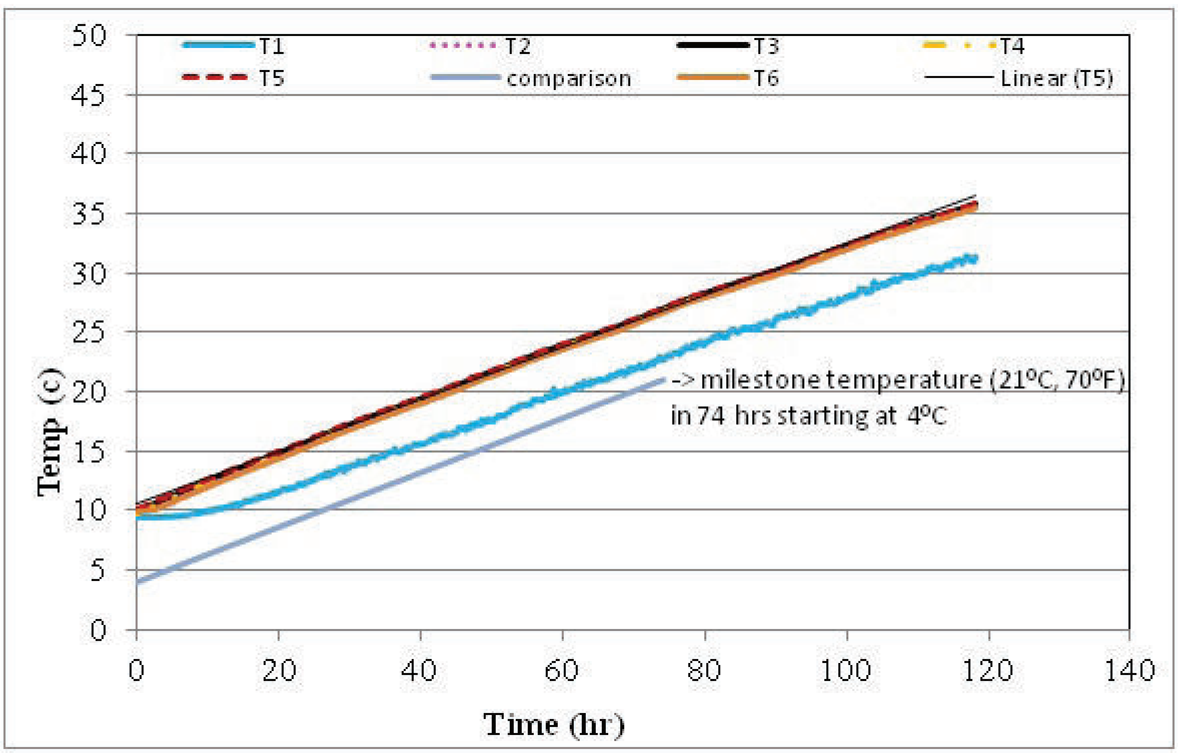

Figure 3: Temperature Profile versus Time (5 catalytic heaters)

(Chambers, Nikoo, Segura; 2011) modified to display a comparison temperature profile

Note: end of test at 118 hrs. The test recorded temperature data for five business days of operation.

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3.0 Testing Method
CONTINUED

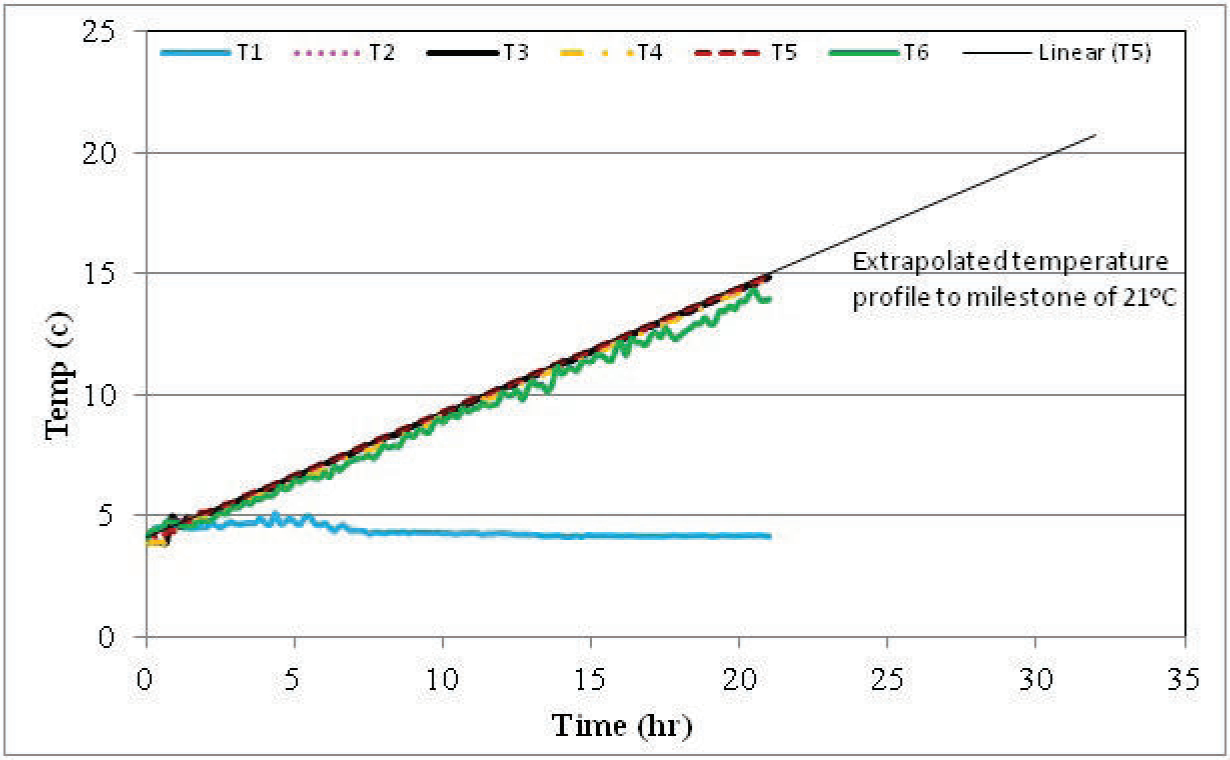

Figure 4: Temperature Profile versus Time (fire tube)

(Chambers, Nikoo, Segura; 2011); modified to display an extrapolated temperature profile
Note: end of test at 21 hrs. The fire tube test was a shorter duration due to operating in cold weather conditions.

3.2 Energy Balance Calculations

The overall efficiency represents the amount of energy transferred from the input of natural gas to the tank water. The energy transferred includes the heat added to tank water plus heat losses of the tank to the ambient air.

Overall efficiency (%) = $(Q_{H20} + Q_{wall}) / Q_{ng} \times 100$

where:

Q_{H20} = heat added to tank water (Btu)

Q_{wall} = heat losses from tank walls (Btu)

Q_{ng} = energy input of natural gas (Btu)

The tank was divided into three zones (top, middle, bottom) based on height. In the top and middle zones, the temperature gradient is almost constant at different diameters of the tank.

For the energy balance analysis, the heat lost from the tank walls was calculated from the weather data, the insulation thickness and thermal properties. The calculated heat loss is the variable with the least amount of confidence. This heat loss is strongly influenced by the assumed thickness and thermal properties of the layer of insulation on the tank.

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3.0 Testing Method
CONTINUED

Estimated Stack Loss:

Energy is lost in the stack gases leaving the fire tube or leaving the ThermoVault® exhaust vent. These stack losses were estimated based on the efficiency readings collected using the combustion flue gas analyser, as reported in Section 3.3. The catalytic heaters also have an additional energy loss in unburnt methane present in the flue gas.

Estimated Stack Loss (%) = 100 – combustion analyser measured efficiency

(Chambers, Nikoo, Segura; 2011).

3.3 Analysis of the Combustion By-Products

Commercial combustion analysers typically measure O_2, CO, CO_2 and NO_x concentrations and the ambient air and exhaust temperatures. The data was used to calculate efficiency assuming a typical natural gas composition for the fuel. These analysers are often used to check that a burner is operating at appropriate air to fuel ratio and obtaining a reasonable efficiency.

The combustion by-products were analysed using a Testo Combustion Analyzer Model 330-2L for these tests. The sample probe was installed through a fitting on the fire tube stack with sampling near the centreline of the stack. The sample probe was also inserted about 10 inches into the exhaust vent hood exit of the ThermoVault®. Several repeat analyses were taken for each condition.

(Chambers, Nikoo, Segura; 2011)

3.4 VOC Analysis

To collect detailed information on the hydrocarbon species present and the relative distribution of hydrocarbons in the combustion by-products, gas samples from the combustion exhaust were collected and analysed. One sample was collected from the ThermoVault® exhaust vent. One sample was collected from the fire tube stack. Gas samples were collected over a one hour period into evacuated Silco steel lined canisters (EPA Method TO-15).

The canisters were analyzed at Alberta Innovates – Technology Futures' Vegreville, Alberta, Canada location. The analysis method used a gas chromatograph to measure concentrations of light hydrocarbon gases (C1 to C4) and a gas chromatograph/mass spectrometer to measure concentrations of VOC's (equivalent to EPA Method TO-15).

(Chambers, Nikoo, Segura; 2011)

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4.0 Results and Discussion

Heat Transfer

The catalytic heater heat transfer rate is the amount of heat transferred from the catalytic heater to the fluid in the tank per unit of surface area of the heater (Btu/hr/ft^2). 84,400 Btu/hr of natural gas input was achieved for the catalytic heaters when the heater manufacturer rating was at 100,000 Btu/hr. There is potential for further improvement. A heat transfer rate of 2,720 Btu/hr/ft^2 was determined for water and 2,300 Btu/hr/ft^2 was theoretically calculated for oil. There was increased heat transfer through the top of the vault. 3,400 Btu/hr/ft^2 was calculated for the fire tube using water and 3,000 Btu/hr/ft^2 for oil.

The ambient air temperature during the catalytic heater test was 7 to 25ºC (45 to 77ºF). The test started at an internal tank temperature of 10ºC (50ºF) and the temperature recorded was 36ºC (97ºF) in 118 hrs at the end of the test with 1.4% of the energy input lost as tank heat losses. A temperature step rate increase of 0.24ºC/hr was achieved for the catalytic heaters. The ambient air temperature for the insulated fire tube test was -29.5 to -22.8ºC (-21 to -9ºF). The test started at an internal tank temperature of 4ºC (39ºF) and the temperature recorded was 15ºC (59ºF) in 21 hrs at the end of the test with 6.5% of the energy input lost as tank heat losses. A temperature step rate increase of 0.52ºC/hr was achieved for the fire tube. The temperature step rate increases are not equivalent because of the fire tube test measured a fuel rate of 219, 423 Btu/hr compared to 84,400 Btu/hr with the catalytic heaters. If the number of catalytic heaters was increased to match the fire tube measured fuel rate, the temperature step rate increase would be comparable. The five catalytic heaters were able to get to a milestone temperature of 21ºC (70ºF) in 49 hrs. If this test started at the same starting temperature as the fire tube test (4ºC, 39ºF) for comparison in Figure 3, it would take 74 hrs for the catalytic heaters to reach 21ºC (70ºF). Using extrapolation of Figure 4, it would take approximately 32 hours for the fire tube to reach 21ºC (70ºF).

Estimated tank heat losses were 44.5% for an uninsulated tank fire tube test. Enviro Vault® recommends that upstream aboveground storage tanks in cold weather climates need to be insulated.

Heating with the catalytic heaters appeared to reduce the size of a cold, stagnant zone on the bottom of the tank that was present when heating with the fire tube. The air temperature inside the middle of the ThermoVault® was 63ºC (145ºF). A hot surface warning will be used with future ThermoVault® units.

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4.0 Results and Discussion
CONTINUED

Efficiencies

The combustion efficiency was 86.8% for the catalytic heaters vs. 99.9% for the fire tube. The combustion efficiency is the percentage of natural gas converted to CO_2 during combustion. Increasing the combustion efficiency for the catalytic heaters will be investigated in the future. **The overall efficiency for transferring the fuel energy to the tank was comparable with 64.4% for the catalytic heaters vs. 61.8% for the fire tube in the insulated tank tests.** The overall efficiency is the percentage of fuel energy transferred to fluid in the tank (i.e. energy that heats the water plus losses through the tank wall). The ThermoVault® was able to achieve the desired tank fluid temperature though it would use as much fuel as the fire tube. The stack temperatures for the catalytic heaters was 72ºC (162ºF) vs. 283ºC (542ºF) for the fire tube. Stack heat losses were 33.3% for the catalytic heaters vs. 28.6% for the fire tube.

Stack Concentrations

CO_2 concentrations in the flue gas were favourable and analyzed at 1.6% for the catalytic heaters vs. 5% for the fire tube. Because of the unburnt methane emissions from the catalytic heaters, GHG emissions were higher per unit of fuel consumed at 0.86 kg/year per Btu/hr vs. 0.46 kg/year per Btu/hr for the fire tube (at 100% runtime). NOTE: It is important to note that the efficiency of the burner may vary greatly over time without regular cleaning, maintenance and adjustment. NOx and CO concentrations were favourable and found in negligible amounts for the catalytic heaters compared to 31 ppm (parts per million) NOx and 161.4 ppm CO for the fire tube. Total volatile organic compounds (VOC's) were 35.5 ppbv (parts per billion) for the catalytic heaters and 80 ppbv for the fire tube.

5.0 Conclusions

The ThermoVault® has safe operations for use in hazardous areas (Class 1, Div 1) that meet regulations. It can be used to heat light oil applications where fire tubes may not be allowed. The ThermoVault® provides an efficient alternative to a fire tube application for lower heating requirements. The need for expensive burner management systems with fire tubes is eliminated. Reduced NOx and CO emissions are achieved using catalytic heaters. The ThermoVault® eliminates low frequency noise pollution as are found with fire tube burner assemblies. It is important to note that the new fire tube and burner management system were calibrated and tuned by the manufacturer multiple times to achieve maximum efficiency. In real life field conditions, this level of efficiency may not be indicative of what is found. Fire tube systems require regular calibration, cleaning and maintenance. There is the potential for further testing of aged fire tubes and burners from the field.

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5.0 Conclusions
CONTINUED

The ThermoVault® project was successful in achieving its objectives including the development of a heater sizing calculator and with the sale of its first unit in June 2011. An additional five units have been requested for the end of 2011. This project was also successful in demonstrating that tank insulation reduces heat losses dramatically. Enviro Vault® recommends that upstream aboveground storage tanks in cold weather climates need to be insulated.

The ThermoVault® was able to heat the tank water up to 36ºC (97ºF) in five days of operation with a starting internal tank temperature of 10ºC (50ºF). The same milestone temperature of 21ºC (70ºF) can be reached but it takes more time with the catalytic heaters than the fire tube. The ThermoVault® test results demonstrate that this technology would be capable of heating an oil-water mixture to 21ºC (70ºF) and higher for separation as in the application of a major producer in the United States.

Reduced accidents, injuries and operational costs by eliminating the possibility of fire tube failures are additional ThermoVault® advantages. The overall efficiency of transfer of fuel energy to tank contents was comparable to the fire tube. As with every Enviro Vault model, the ThermoVault® includes an unmatched heated spill containment area for valves and piping including a high level shut down switch. The sizing calculator will be used to develop a database of various heating applications. Enviro Vault® finds merit in additional testing to improve on ventilation, increasing the overall and combustion efficiencies, and to reduce GHG emissions by allowing a cleaner burn of natural gas.

6.0 References

Chambers, Allan, Nikoo, Mehr, and Segura, Juan. Performance Testing of the ThermoVault® Tank Heater. Alberta Innovates - Technology Futures, June 2011: Edmonton.

7.0 Corrections to Last Technical Bulletin

The following corrections are noted for Technical Bulletin TB-2010 1of2: Heat Transfer with Catalytic Heaters:

Page 7:

"Rearranging Eqn. 4, the temperature difference is 48 °F (**26.7 °C**)."

"Rearranging **Eqn. 4**, the temperature difference is 202 °F (**112.2 °C**)."