SUMMARY DOCUMENT

Determine the Inside Wall Temperature of DSTs using an Infrared Temperature Sensor

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Introduction

Corrosion in DSTs is one of the primary concerns at Hanford and other sites. It is managed by stringent operating specifications as given in OSD-T-151-00007 “Operating Specifications for the Double –Shell Storage Tanks” (OSD) [1]. One of the important parameters specified by OSD is the temperature which plays an important role in corrosion. In general, the tank temperatures are determined by various processes such as: the physics behind the problem, taking samples at different locations, using some measurement devices and finally modelling. Most of these methods are approximations on the actual temperatures at various locations inside the DSTs. Hence, there is an immense need for measurement and calculations of actual temperatures inside the tanks. Of particular interest is at the interface of the tank waste and the inner walls since it accounts for the region highly prone to corrosion.

It is known that the actual temperatures in the tanks are measured more than 10 feet away from the wall due to technical and equipment constraints [2]. The tank-wall interface temperatures are then predicted using mathematical models. Most of these models have not been validated. This defines the purpose of the present task.

Present work is a supportive effort by FIU-ARC for DOE which investigates in the use of an infrared (IR) sensor to measure the outer wall temperatures of the primary shell in the DST. This process is practical since the sensor is expected to “piggy back” on the scheduled inspection tools passing through the annulus of the DSTs.

This document provides a summary of an experimental setup to represent the DSTs using rectangular tanks, calibrating and conducting emissivity adjustment tests on the mini IR sensor, defining the test procedures based on various parameters, conducting the experiments and analyzing the results obtained.

Method and Benefits

This method of measuring the wall temperature can be used with the current inspection equipment or the sensor can be attached to an annulus inspection camera. In FIU, two robotic inspection tools are being developed and the IR sensor can easily be attached to them as a built-in or as a separate module. “Piggy Backing” of the sensor to pre-scheduled operations allows to collect temperature data with minimal impact on tank farm operations. The temperature results thus obtained will serve multiple purposes as: (a) ensuring that the limits are met and if not, immediate corrections can be made (b) physical properties can be empirically calculated, validation/evaluation of the current thermal modeling capabilities (c) temperature gradients would help in the estimation of solid waste levels in the tanks (d) the IR sensor can also be used to calibrate other equipment (e) expensive and time consuming thermal modeling can be minimized or avoided in certain conditions.

Raytek Miniature Infrared sensor

The IR sensor chosen for the present tests is the Raytek MI3 [4]. It is a pyrometer (non-contact sensor) that includes a digital screen for temperature display (Figure 1). It primarily consists of two parts: the sensing head and the digital communication box. Based on the specifications of the present task, the product has variable (adjustable) emissivity. The spectral range of the MI3 series is 8-14 µm with a response time of 130 ms and an accuracy of 1^{o}C. It is 0.55 inches in diameter and 1.1 inches in length and has a distance spot ratio of 22:1. Also, a 98-foot cable is available for the sensing head and will need to be integrated with the tether of the inspection tool on which the sensor will be placed.

IR sensor emissivity configuration

The sensor needs to be adjusted for emissivity to correlate with the test material since each material has its own emissivity. The procedure adopted for calibrating the emissivity includes a number of steps and is described in detail next. Using literature values, the emissivity of the carbon steel material is used as a starting point for the IR sensor. The tank wall temperatures are measured using that emissivity value. The measured values are then compared to the actual temperatures on the wall obtained using a laser gun (non-contact pyrometer) or a thermocouple. In case of discrepancy, the emissivity is to be adjusted again and the process repeated until the exact emissivity of the material is obtained. This procedure ensures that the most accurate measurements are taken by the Raytek MI3 sensor.

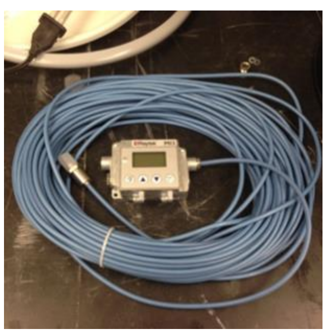


Figure 1. a) Raytek Sensor [4] **b) Sensor Head [4].**

Experimental Approach

For the present task, the Raytek IR sensor is to be attached to an inspection device and deployed into the annulus to scan the entire tank height for temperature measurement. A typical sketch of the process is as shown in Figure 2a.

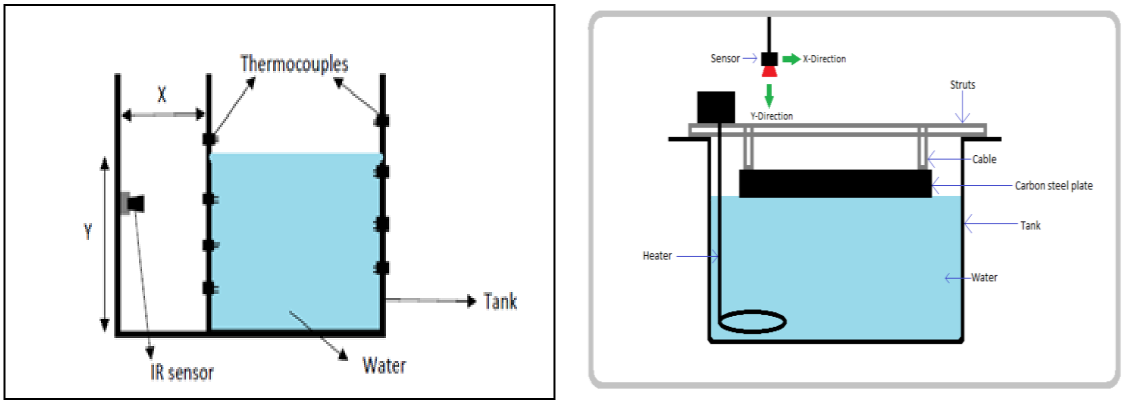


Figure 2. a) IR sensor through the annulus b) Test set up (block diagram).

Since the objective is to understand the thermal gradients in the tank, a test setup is established (Figure 2b) for the present research that represents the configuration of the tanks. The setup consists of a rectangular stainless steel tank of dimensions 2’x4’x3’. Fluid (water) is heated in the tank and a thick carbon steel plate of 7/8 inch thickness (replicating the maximum DST wall thickness) is suspended onto the fluid surface using strut channels and cables/rods. A side mount heater is used to increase the water temperature and measurements are recorded at various time intervals.

The Raytek IR sensor is used to measure temperatures on the outer surface (exposed to the atmosphere) of the plate while it transfers heat from the hot water to the ambient air outside. Heat transfer calculations provide a prediction of the temperatures on the inner surface (exposed to the fluid). Also, thermocouples are inserted at various set points to obtain accurate readings. To validate the use of the Raytek IR sensor, temperature measurements are also taken at the surface using thermocouples. Roller surface K-type thermocouples along with the universal thermocouple connectors (UTC-USB) were used to acquire the temperature data. Actual experimental set up including the Raytek IR sensor and the thermocouple is as shown in Figure 3.

Figure 3. Experimental set up including sensors.

To conduct the experiments, a test matrix is defined based on the experimental set up and approximations, and includes the following parameters:

- Temperature of water inside the tank – the temperature of the water bath in the tank is varied from 90°F to 130°F in intervals of 10°F.
- Measurement along the length of the test piece (x-direction) – These set points for temperatures represent the vertical height of the tank are specified in intervals of 6 inches starting from one end to the other.
- Distance of the IR sensor from the test piece (y-Direction) – The annulus of DSTs is approximately 3ft. wide, so the IR sensor is configured and physically placed to capture readings at distances of 2 in, 6 in, 12 in, 18 in and 24 in.

The matrix with the range of temperature values is given in Table 1, which represents the distances and temperature range.

Table 1. Test Matrix (Temperature in °F)

Distance	Y = 2	Y= 6	Y = 12	Y = 18	Y = 24
X = 0	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]
X = 6	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]
X = 12	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]
X = 18	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]
X = 24	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]
X = 30	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]
X = 36	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]
X = 42	[90 130]	[90 130]	[90 130]	[90 130]	[90 130]

*** Distance in inches**

Results and Discussion

Initial experiments are conducted as described in the test matrix by varying the heights from the test piece along the length intervals. Temperature measurements are obtained on the outer surface of the test piece at various time intervals. Sample set of test results obtained from the IR sensor and thermocouple at different time intervals are listed in Table 2 and 3. The temperature measurements using the thermocouple are taken as standard and are compared with those obtained by Raytek MI3 IR sensor.

From the tables, it is can be seen that the Raytek IR sensor has a maximum temperature variation of 10.2% from the thermocouple readings. This could be due to the sensitivity of the IR sensor which in turn is affected by the variation in the ambient temperatures during the experiments. In order to study the variations, an error analysis has been performed on different sets of sample data obtained from the both sensors. The average temperature measured at a particular height (y-distance) from the Raytek sensor is compared to that of the thermocouple. The average error obtained is 4.5%. It shows that the IR sensor is capable of predicting the temperatures within limits.

Table 2. Temperature Results Test 1 (IR Sensor and Thermocouple)

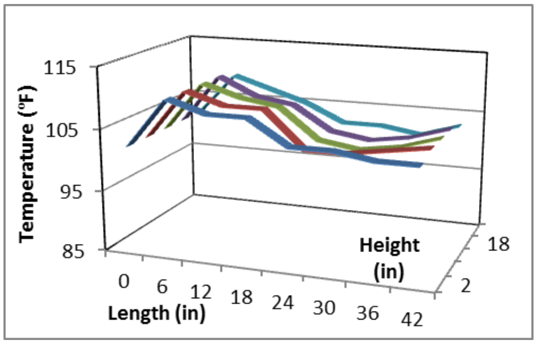
Distance*	Y= 2	Y= 6	Y= 12	Y= 18	Y= 24	TC@
X= 0	102	102	102	102	102	102
X= 6	110	110	110	110	109	100
X= 12	108	108	108	107	107	100
X= 18	108	108	107	106	105	101
X= 24	104	102	102	102	102	100
X= 30	104	102	101	101	102	100
X= 36	103	103	102	102	101	100
X= 42	103	104	104	104	103	99

*** Inches; @ Thermocouple**

Table 3. Temperature Results Test 2 (IR Sensor and Thermocouple)

Distance*	Y= 2	Y= 6	Y= 12	Y= 18	Y= 24	TC@
X= 0	120	118	115	110	115	110
X= 6	121	120	118	119	118	109
X= 12	117	116	115	115	115	108
X= 18	115	111	115	112	113	109
X= 24	109	107	107	106	106	110
X= 30	110	109	109	108	106	110
X= 36	106	104	104	103	104	109
X= 42	105	103	103	102	102	105

Temperature as a function of sensor height and test piece length is plotted in Figure 4 for the sample tests 1 and 2 respectively. It is evident from the graphs that the temperature contours represent similarity with changes in height. This shows that height is not a very significant parameter for the sensor in the given range (2in to 24in). Also, in both the graphs, there is a peak value for temperature at 6in length and then a gradual reduction. This is due to the maximum temperature near the heating coil underneath the test piece. The gradual reduction in temperature away from one end of the test piece is due to the heating effect occurring as a result of the side mount electric coil heater.



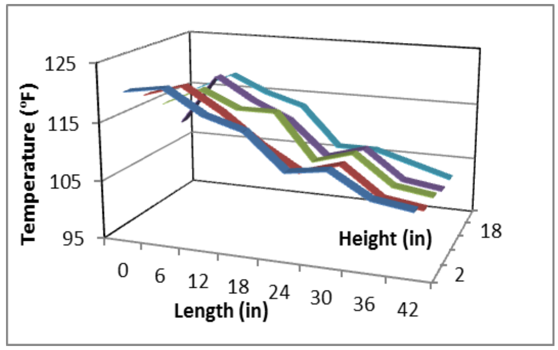


Figure 4. a) Temperature contours (Test 1) b) Temperature contours (Test 2).

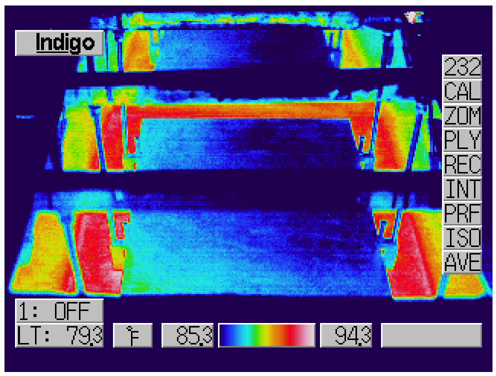


Figure 5. Temperature contours using thermal camera.

A thermal camera is also used to record the temperature profiles as a visual indication of heat transfer between water and the plate. A sample thermal image as recorded is shown in Figure 5. It provides the temperature measurements in the range of 85-95°F. Red color indicates maximum temperature while blue indicates the minimum. As expected, it can be seen that the water in the tank has the highest temperature (red) and the plate has the lowest.

Summary

Data presented is based on initial experiments. In future, thermocouples will be added on the inner surface of the test piece for accurate thermal measurement and validation. Also, temperature range currently being used for the tests is 90-130°F which is primarily due to the type of heater used. In future, actual temperature range as specified for the DST's (120-170°F) will be used with new heating options. Detailed investigation into the sensitivity of the Raytek sensors will be conducted. Finally, thermal modeling and simulation will be conducted to verify and validate the IR sensor measurements. To summarize, the present research work is based on bench scale testing and approximations and is being further extended to replicate the actual engineering scale testing and simulation which might result in future site deployment.

Works Cited

[1] OSD-T-151-00007, *Operating specifications for the Double-Shell Storage Tanks, Rev 1*, Washington River Protection Solutions, Richland, WA.

[2] Holsmith, B. (2015). *Double Shell Tank Primary Wall Temperature Measurements: Suggested New Technology White Paper,* Washington River Protection Solutions, Richland, WA, 2015.

[3] *The Principles of Noncontact Temperature Measurement,* produced by Raytek® available online at http://support.fluke.com/raytek-sales/Download/Asset/9250315_ENG_D_W.PDF

[4] www.raytek.com