SUMMARY DOCUMENT

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

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Introduction

Corrosion in double-shell storage tanks (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: taking samples at different locations, using measurement devices and, finally, modelling. Most of these methods provide approximations of the actual temperatures at various locations inside the DSTs. Hence, there is an immense need for accurate measurements and calculations of actual temperatures inside the tanks. Of particular interest is the temperature at the interface of the tank waste and the inner walls since it accounts for the region that is highly prone to corrosion.

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

The present work is a supportive effort by the Applied Research Center (ARC) at Florida International University (FIU) for the U.S. Department of Energy (DOE) to investigate 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 developed at FIU-ARC 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

Measuring the wall temperature with an IR sensor can be used with the current inspection equipment or the sensor can be attached to an annulus inspection camera. At FIU, two robotic inspection tools are being developed and the IR sensor can easily be attached to either of them as a built-in or as a separate module. "Piggy backing" of the sensor to pre-scheduled operations allows for the collection of temperature data with minimal impact to ongoing tank farm operations. The temperature results thus obtained will serve multiple purposes, such as: (a) to ensure that the temperature limits are met and, if not, allowing for immediate corrections to be made; (b) to empirically calculate the physical properties and validate/evaluate the current thermal modeling capabilities; (c) to estimate the solid waste levels in the tanks using the temperature gradients; (d) to calibrate other equipment with the IR sensor; and (e) to minimize the need for expensive and time consuming thermal modeling.

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 the 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 ±1ºC. 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 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.

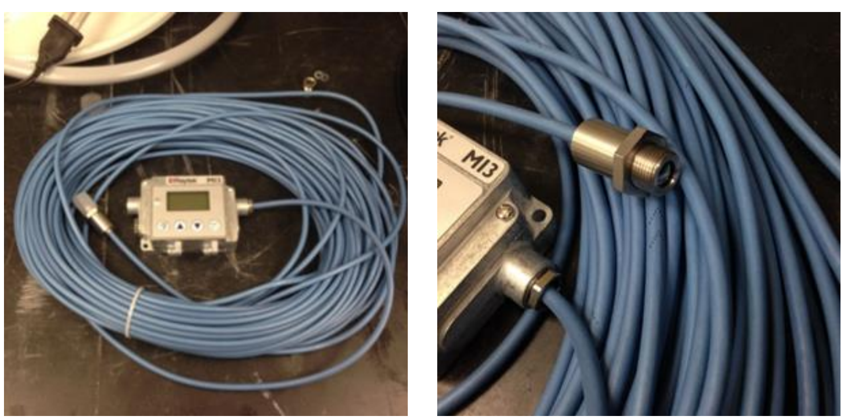

Figure 1. Raytek sensor [4] (right) and sensor head [4] (right).

Experimental Approach

The present task requires the Raytek IR sensor to be attached to an inspection device and deployed into the annulus to scan the entire tank height for temperature measurements. A typical sketch of the process is as shown in Figure 2 (left).

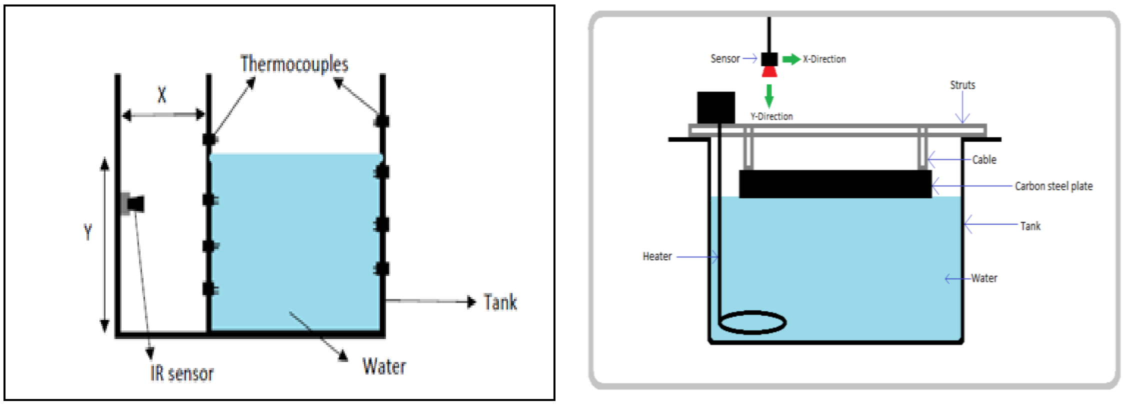

Figure 2. IR sensor through the annulus (left) and test set up as block diagram (right).

The objective is to understand the thermal gradients in the tank and, hence, a test setup has been established [Figure 2 (right)] for the present research that represents the configuration of the tanks. The experimental 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 1/2 inch thickness (replicating a section of the DST wall thickness) is suspended onto the fluid surface using strut channels and cables/rods. A side-mounted heater [4000 W immersion heater from Tempco (TAT 40002)] is used to increase the water temperature and measurements are recorded at various time intervals. The experimental set up of the tank is as shown in Figure 3(left). During the experiments, the tank is covered with insulation [Figure 3 (right)] to minimize the heat loss to the atmosphere and to acquire accurate data.

Figure 3. Experimental set up (left) and tank covered with insulation (right).

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 taken at the top surface using thermocouples. Initially, roller surface K-type thermocouples along with the universal thermocouple connectors (UTC-USB) were used manually to acquire the temperature data (results reported in the document FIU-ARC-2016-800006470-04c-245).

In the second stage of experiments, the process has been automated using permanently fixed hermitically sealed thermocouples (HSTs) [5] and the multiple channel data acquisition (DAQ) system from omega (OM-DAQ-USB-2401) [6]. The HSTs were fixed onto the outer and inner surface (in contact with water) of the plate using a thermally conductive epoxy (OB-101) [7] to obtain real-time temperature measurements for continuous monitoring. The plate's inner surface with fixed HSTs is as shown in Figure 4 (left).

The omega DAQ system is suitable for 8 differential or 16 single-ended analog inputs. It is user programmable for Type J, K, T, E, R, S, N, B thermocouples or voltage input and comes with customized Windows compatible software. It provides a 12-volt DC output for sensor excitation. Figure 4 (middle) shows the DAQ system attached to thermocouples while Figure 4 (right) shows the DAQ dashboard displaying temperature measurements.

Figure 4. HSTs fixed under the plate (left), DAQ system with thermocouples (middle), DAQ dashboard (right).

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

- Temperature of water inside the tank - the temperature of the water bath in the tank was varied from 120ºF to 170ºF in intervals of 10ºF.
- Measurements along the length of the test piece - the HSTs were glued to both inner and outer surfaces of the plate at 1, 2 and 3 ft. distances from one end of the plate.

- Temperature readings – outer (top) surface readings were obtained using both HSTs and the Raytek sensor while the inner (bottom) surface readings were obtained using the permanently fixed HSTs.

Results and Discussion

Sensor emissivity configuration

Initial experiments were conducted to determine the emissivity configuration of the Raytek IR sensor. Tests were performed to exactly determine the emissivity levels of two materials, carbon steel and stainless steel.

The first experiment conducted used the carbon steel plate. Since the emissivity value of carbon steel is not precisely available in literature, an initial estimate of 0.75 was chosen and a range of values above and below the initial estimate was recorded. The experiment consisted of the ambient temperature measurement on a carbon steel plate (1/2 inch thick) using both a Raytek and a hermitically sealed thermocouple. The second experiment was conducted on the tank wall which is made of stainless steel. Emissivity values were changed from 0.3 to 0.6.

The results obtained from these experiments are provided in

Table **1** and

Table **2**. In

Table **1**, the temperature was recorded at three different points using both sensors. It is evident from the data that the temperature readings are close when the emissivity value ranges from 0.76 to 0.79 and is almost precise at 0.78. Also, it is to be noted that for the emissivity change from 0.7 to 0.8, the temperature values are precise within a maximum of 2-3ºF. Hence, the emissivity of carbon steel can be taken as 0.78.

Table 1. Experimental Results with ½ in Carbon Steel Plate (Temperature Readings in ºF)

Emissivity (Raytek)	Raytek (point 1)	Raytek (point 2)	Raytek (point 3)	TC (point 1)	TC (point 2)	TC (point 3)
0.7	69.5	68.5	68.7	72.88	73.25	71.66
0.71	65.9	64.4	66.8	73.43	71.13	75.78
0.72	68.2	70.2	70.2	73.05	71.33	71.07
0.73	68.9	67.4	67.8	73.13	70.77	73.97
0.74	66.4	67.6	66.8	72.92	71.37	72.42
0.75	68.4	68.6	68.1	62.98	66.08	66.49
0.76	66.8	68.7	68.3	68.69	69.97	68.22
0.77	70.6	67.5	66.9	69.65	68.08	70.03
0.78	70.9	69.7	68.9	70.49	70.15	70.58
0.79	70.9	69.8	68.5	71.24	70.14	72.28
0.8	70.6	71.4	70.2	72.19	73.2	72.54

Table 2. Experimental Results on Stainless Steel Plate (Temperature Readings in ºF)

Emissivity (Raytek)	Raytek	TC
0.3	40.4	73.42
0.4	52.8	73.54
0.5	61.4	73.23
0.6	73.7	74.34

In the case of stainless steel, it is observed (

Table 2) that the emissivity value of 0.4 to 0.5 provided an inaccurate temperature reading; however, at emissivity of 0.6, both the Raytek and the thermocouple readings are close, within less than a 1ºF temperature difference. Hence, the emissivity of stainless steel can be taken as 0.6.

Engineering-scale experiments

Engineering-scale experiments to measure the tank wall temperatures were conducted using the set up described in the previous section. Initially, manual experiments were conducted and the results are presented in the report FIU-ARC-2016-800006470-04c-245. In this report, the results obtained by the automated real-time monitoring system are reported. As described in the experimental approach section, the temperatures were measured at 6 points on the plate using HST's and at 3 top surface points using the Raytek sensor. The results obtained are tabulated in Table 3.

Table 3. Temperature (IR Sensor and HSTs) in ºF

Data point	T1	T2	T3	B1	B2	B3	R1	R2	R3
1	111.14	104.23	106.07	114.67	109.28	108.78	109.2	106.4	104.7
2	115.35	111.12	111.19	120.1	115.34	115.12	116.7	112.7	109.9
3	123.27	111.83	117.29	130.2	126.05	125.4	132.9	128.9	124.6
4	132.12	116.57	125.98	140.32	135.96	135.27	143.9	141.7	133
5	142.09	132.99	137.44	150.06	145.25	144.53	152	145.7	141.7
6	152.91	142.71	138.7	160.17	154.42	153.67	157	155	153.1
7	162.73	151.41	148.01	170.05	164.45	163.6	165.2	167.2	166.2

@T – Top surface, B – Bottom surface, R – Raytek

In Table 3, columns T1, T2 and T3 represent the thermocouple readings while R1, R2 and R3 represent the Raytek sensor readings at the same locations. Hence, these can be directly compared. It is evident that the average difference between the corresponding readings for location 1 is 5.3ºF, while for locations 2 and 3 the average difference is 12.3ºF and 6.9ºF, respectively. It is also observed that the temperature difference increased with an increase in temperature. In most cases, the Raytek sensor showed a higher value. In addition, the temperatures at the top 3 locations (T1, T2 and T3) were compared to the bottom 3 locations (B1, B2 and B3) to investigate the heat transfer effects. From the results, it is seen that the average temperature difference was 6.5ºF, 11.4ºF, and 8.8ºF, respectively, for the three locations. According to theoretical calculations, the average readings can approximate to about 4-5ºF, taking into account the temperature gradients with location and time.

Summary

The data presented is based on engineering-scale experiments conducted to validate the use of Raytek mini IR sensors for use at the actual sites. HSTs were permanently fixed to the inner and outer surface of the test piece for accurate thermal measurements and validation. Also, a temperature range as specified for the DST’s (120-170ºF) has been used. The experiments were conducted to investigate the sensitivity of the Raytek IR sensor to different emissivity values and materials. A method has been established to accurately calibrate and test the Raytek mini IR sensor. The tests were conducted with hot water as the liquid medium. In future testing, real tank conditions may be stimulated by adding a slurry mixture to the tanks and investigating the effect of temperature gradients as measured by the mini IR sensor. In addition, integration of the IR sensor with inspection devices for deployment into the tanks and other pipelines will be investigated. To conclude, the Raytek sensor was calibrated and tested for temperature measurements and is found to be capable of temperature measurements in DSTs within specified limits.

Works Cited

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