TEST PLAN

Inside Wall Temperature Measurements of DSTs Using an Infrared Temperature Sensor

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Prepared by:

Aparna Aravelli, Ph.D.

Florida International University Collaborators:

Dwayne McDaniel, Ph.D., P.E.

Iti Mehta, DOE Fellow

Submitted to:

Terry Sams, Washington River Protection Solutions, LLC

Gary Peterson, Department of Energy, Office of Waste Processing

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FIU Applied Research Center
FLORIDA INTERNATIONAL UNIVERSITY

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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 tank temperature which plays an important role in corrosion. In general, the tank temperatures are determined by various processes including obtaining samples at different locations, using measurement devices and modelling. Most of these methods are approximations on the actual temperatures at various locations inside the DSTs. Hence, there is a 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.

Typical temperature measurements are taken 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 the use of an infrared (IR) sensor to measure the outer wall temperatures of the primary shell in DSTs. This process is very practical since the sensor can "piggy back" on typical inspection tools that pass through the annulus of the DSTs. This document provides the test plan for the initial phase of testing and validation of an IR sensor that can be used to measure tank wall temperatures.

Scope

This test plan outlines the use a non-contact pyrometer (IR sensor) to measure the outside wall temperature of a rectangular tank. The scope of the present test plan includes building an experimental setup to represent the DSTs using a rectangular tank, acquiring an IR sensor and conducting emissivity adjustment tests, defining the test procedures based on various parameters, conducting the experiments, and analyzing the results obtained and theoretical validations.

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. At 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 provides a means to collect temperature data with minimal impact on tank farm operations. The temperature results obtained will serve multiple purposes: (a) ensuring that the operation limits are met and, if not, immediate corrections can be made; (b) validation/evaluation of the current thermal modeling capabilities; (c) understanding temperature gradients and their impact on tank waste; (d) calibration of other equipment; and (e) reduction of reliance on expensive and time consuming thermal modeling.

Infrared Sensors

The non-contact IR sensors work utilizing optics. The radiation coming from the target surface passes through the optics with the atmosphere as the medium and the signal is converted into a temperature by the unit. The distance spot ratio is the ratio of the distance between the object surface and the diameter of the measurement spot. The spot size should be less than the target area or at least equal to for the measurement to be correct. If the spot size is larger than the object surface, the non-contact thermometer will tend to take into account the radiation coming from the other surfaces, giving incorrect measurements. This ratio is also known as the optical resolution of the thermometer.

Infrared radiation emitted depends on the temperature of the subject. Infrared radiation is emitted from subjects with a temperature greater than absolute zero and falls between 0.7-1000 µm on the spectrum. Due to its range, the human eye cannot detect such radiation unless the temperature is greater than 600℃. Radiation increases by a power of four of the temperature. The accuracy of the IR sensor measurement depends on the radiance difference per temperature difference. The higher that value, the better the accuracy of the measurement.

Emissivity, ε, is the relationship between the emissive power of a blackbody and the real emissive power. The value can vary between 0 and 1. A blackbody has an emissivity of 1, which means that there is no reflection. It is considered as an ideal body. Gray bodies have an emissivity of less than 1. The emissivity of non-gray bodies is a characteristic of wavelength and temperature. The components of emission are transmission, absorption, and reflection, as seen in Figure 1. That sum equals 1. When the transmission value equals zero, all the absorbed radiation is emitted by the body.

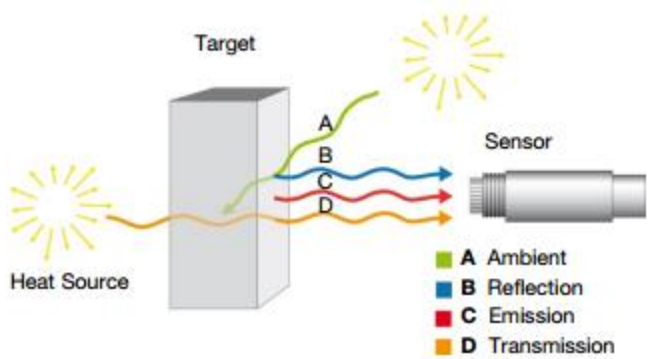

Figure 1. Emissivity [3].

Experimental Approach

The steps in our approach to evaluating the IR sensor include the following:

- Fabricate a mock-up test tank
- Obtain an IR sensor and configure for emissivity based on testing material
- Execute a number of tests that provide information on the IR's capabilities

Each of these items is explained briefly below.

Fabrication of the tank and test set up

As per the discussions with site engineers, FIU will initially begin with constructing a rectangular tank with dimensions 3 ft x 4 ft x 4 ft. The material of the tank will be PVC and one of the walls will be replaced by a carbon steel plate to replicate the DST tank material. In the initial stage of testing, only new carbon steel material will be tested.

The tank will be filled with water and maintained at a particular temperature for a specified time interval. The non-contact IR sensor will be used to scan from the top to the bottom of the tank, recording the outer tank wall temperatures at different points. Thermocouples will be attached at various points on the tank wall to ensure proper distribution of temperatures and to cross verify the IR sensor readings. The experimental results of the outer wall temperatures would further be used to calculate the inner wall temperatures using basic heat transfer relations. The calculated values may also be verified by placing thermocouples on the inner tank walls.

A block diagram of the test setup along with the IR sensor is shown in Figure 2.

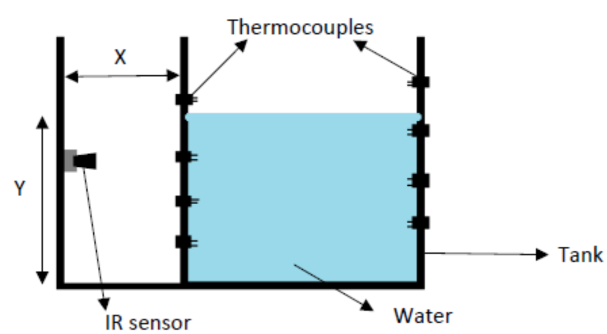

Figure 2 . Experimental set up.

Test Matrix

The important parameters considered to develop the test matrix are as follows:

a) Thickness of the plate (tank wall) - Three different tank wall thicknesses will be considered: 1/2 in, 3/4 in, and 7/8 in (based on 241 AN tank drawings).
b) Temperature of water inside the tank – the temperature of the water bath will be varied from 120°F to 170 °F in intervals of 10°F.
c) Points (heights) of measurement – The set points for temperatures along the vertical height of the tank will be at 1 ft intervals, starting from the ground to the top of the wall (1 ft, 2 ft, 3 ft and 4 ft).
d) Distance of the IR sensor from the wall – The annulus of DSTs is approximately 3 ft wide, so the IR sensor will be configured and physically placed to capture readings at distances of 0.5, 1, 1.5, 2 and 2.5 ft away from the tank wall.

A sample test matrix is given in Table 1 which represents the distances and temperature range. This test matrix will be repeated for three different thicknesses of the tank wall.

Table 1. Test Matrix for IR Sensor

Distance	Y = 1	Y= 2	Y = 3	Y = 4
X = 0.5	T=[120 170]	T=[120 170]	T=[120 170]	T=[120 170]
X = 1	T=[120 170]	T=[120 170]	T=[120 170]	T=[120 170]
X=1.5	T=[120 170]	T=[120 170]	T=[120 170]	T=[120 170]
X = 2	T=[120 170]	T=[120 170]	T=[120 170]	T=[120 170]
X = 2.5	T=[120 170]	T=[120 170]	T=[120 170]	T=[120 170]

X - horizontal distance in the annulus (ft.); Y- vertical height (ft.); T -temperature of water in °F.

IR sensor: Equipment and emissivity configuration procedure

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. 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°C. It is 0.55 inches in diameter and 1.1 inches in length. Also, a 98-foot cable is available for the sensing head which is one of the major requirements for it to be integrated with the tether of the inspection tool on which the sensor will be placed.

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

Schedule

The IR sensor temperature measurement test plan consists of the following five tasks:

1. Fabrication of the experimental test set up including a plastic tank with one metal wall (side)
2. Procurement of the IR sensor and configuring for correct emissivity
3. Execution of the test matrix
4. Data analysis of the results obtained followed by theoretical predictions
5. Final report preparation

Table 2 below lists the tasks and their projected durations.

Table 2. Experimental Tasks and Durations

Task	*Description*	*Duration*
1	Tank fabrication and test set up	8 weeks
2	IR sensor procurement and emissivity configuration	6-7 weeks
3	Test matrix execution	8 weeks
4	Data analysis and theoretical calculations	4 weeks
5	Final report preparation	2 weeks

Health & Safety

All project activities will be performed in accordance with ARC`s Project-Specific Health and Safety Plan (PSHASP) approved by Florida International University's ES&H Coordinator and Project Manager. ARC laboratory procedures will be strictly recognized, and operators will perform all tasks in compliance with OSHA guidelines obeying all the personal protective equipment requirements.

The expected hazards are common to all laboratory environments and include exposure to strong acids or bases, slips on wet flooring, injuries due to broken glass or plastic parts, pinches or punctures while dealing with equipment, and possible back injury while moving heavy objects or equipment. An eye wash chamber and a shower are located near the work areas for quick drenching to minimize the dangers due to chemical exposure. Other health and safety issues are discussed in detail in the PSHASP.

Waste Disposal

The hazardous waste products generated by ARC will be handled and disposed of in accordance with the FIU waste management program. All accumulated toxic or hazardous wastewater products will be stored in specified locations, in labeled receptacles with appropriate spill containers. As such, it will be collected and stored in appropriate containers pending collection by an FIU hazardous waste contractor.

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, WRPS.*

[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