STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Heat Transfer Calculations for the Use of an Infrared Temperature Sensor

DOE-FIU SCIENCE & TECHNOLOGY
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Principal Investigators:

Meilyn Planas (DOE Fellow Student)
Florida International University

Terry Sams, Manager
Benjamin Holmesmith, Mentor
Washington River Protection Solutions

Florida International University Program Director:

Leonel Lagos Ph.D., PMP®

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ABSTRACT

Conservative heat transfer calculations were implemented to determine whether or not an infrared (IR) temperature sensor is capable of accurately reading the temperature of the inside of the primary wall of a double shell tank when placed in its annulus. The IR will be placed on the annulus inspection camera in order to “piggy back” on the scheduled annulus inspections. The primary goal is to determine if the inside wall temperature is below the allowable level to avoid corrosion. Subsequent benefits include validation of tank stratification and validation of tank temperature models.

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1. INTRODUCTION

The corrosion within double shell tanks (DST) at the Hanford site is managed by stringently following the operating specifications given in OSD-T-151-00007, "*Operating Specifications for the Double-Shell Storage Tanks*" (OSD). The OSD outlines specific temperature requirements for waste based on chemical composition and pH. Chemical composition, pH and temperature data are found via process knowledge, physical samples, measuring devices and modeling. Due to the complexity and size of these storage tanks, many of the methods allow for a great deal of uncertainty.

As one might expect, corrosion is a primary concern at the tank wall-waste interface. Although this interface might be where corrosion occurs, it is not where samples or measurements are taken. In fact, samples and temperature measurements are taken more than 10 feet from the wall due primarily to equipment and technical constraints. Those results are then fed to models to estimate wall conditions which for some, have never been validated with real data.

Temperature uncertainty can be reduced by using a non-contact infrared pyrometer (IR sensor). With only a few small upgrades to Washington River Protection Solutions' (WRPS) currently operational equipment – an annulus inspection camera and the ultrasonic testing crawler – real wall temperature measurements can be made. Furthermore, "piggy backing" on these already scheduled operations will allow temperature data to be obtained without impacting tank farm operations or adding additional jobs.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Office of Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2015, a DOE Fellow intern Meilyn Planas spent 10 weeks doing a summer internship at Washington River Protection Solutions at Washington State under the supervision and guidance of Terry Sams and Benjamin Holmesmith. The intern's project was initiated on June 1, 2015, and continued through August 6, 2015 with the objective of determining if an infrared temperature sensor placed in the annulus of a tank was accurate enough to measure the temperature on the inside of the primary tank wall. This was determined using heat transfer calculations.

3. RESEARCH DESCRIPTION

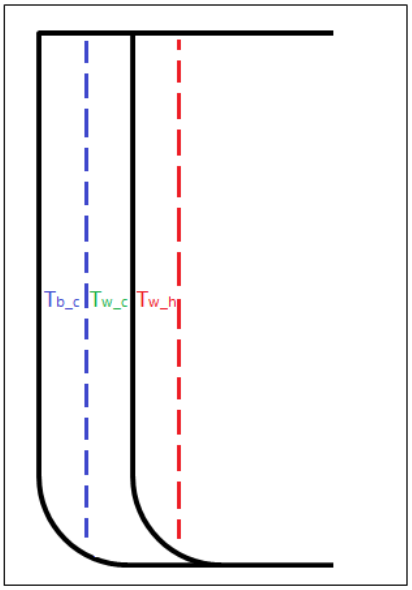
Initial heat transfer calculations were made in order to test the feasibility of using an infrared (IR) temperature sensor to derive the temperature on the inside wall of the double shell tanks (DST). This method is preferred because:

- It can be attached to an inspection camera and thus can be controlled remotely
- There is no impact on the tank farm operations as this can "piggy back" on the already scheduled tank inspections.

The collected data from the IR temperature sensor can also be used to:

- Map out waste stratification
- Validate currently used models
- Check that the temperature of the waste meets requirements to avoid corrosion.

The main objective of using an IR temperature sensor is to derive the temperature on the inside of the primary tank wall to ensure it is below the specified temperature, as is stated in OSD-T-151-00007 (OSD), in order to avoid corrosion. To derive this temperature it was assumed that the temperature on the inside of the primary tank wall was known, and then heat transfer was used to calculate what the temperature outside the primary tank wall would be. These initial calculations indicated that the temperature on the outside of the wall is so close to the temperature on the inside of the wall that they can be presumed equal. To perform the aforementioned calculations the temperature of the bulk air in the annulus, T_{b_c}, was assumed as well as the temperature of the boundary waste that comes in contact with the tank wall, T_{w_h} (Figure 1).



Where :

T_{b_c}	*temperature of the cold bulk air in the annulus*
T_{w_c}	*boundary temperature on the outside of the tank*
T_{w_h}	*temperature on the inside of the tank wall*

Figure 1. DST with labeled temperature variables.

Other assumptions were used in these calculations in order to obtain conservative results which included assuming that the bulk air in the annulus was not moving; the supernatant was treated as salt water (as it is less thermally conductive than water at high concentrations) (MIT, 2015), the tank wall is unblemished, and the thickness of the wall was assumed to be ¾ of an inch because this is the thickest boundary our IR sensor will encounter when measuring the temperature. It was also assumed that thermal conductivities and heat transfer coefficients will not change greatly over the temperature range used in the calculations (100Δ°F) and will be held constant.

Using the assumed temperatures (T_{b_c} and T_{w_h}) an overall heat transfer was found by means of Equation 1:

$$\boldsymbol{Q = U \cdot A \cdot (T_{w\ h}\text{-}T_{b\ c})} \qquad \textit{Equation 1}$$

where U is given by Equation 2 and is the overall heat transfer coefficient and A is the area were the heat transfer is occurring (namely the area of the annulus).

$$\boldsymbol{U = \frac{1}{\frac{1}{h_w}+\frac{d}{k}+\frac{1}{h_a}}} \qquad \textit{Equation 2}$$

This overall heat transfer coefficient was used because there are essentially three mediums the heat transfers through: the supernatant, which is substituted for salt water in this case, the mild steel tank wall, and the air in the annulus. These mediums are taken into account using their individual heat transfer coefficient or thermal conductivities; h_w is the heat transfer coefficient for salt water, k is the thermal conductivity for mild steel, h_a is the heat transfer coefficient for air, and d is the thickness of the material which in this case is the thickness of the tank wall (Green & Perry, 2008).

Assuming there is no heat stored in the tank wall the heat transfer found between the annulus and the inside of the tank wall can also be used for the next portion of the calculation where the temperature on the outside of the tank wall is derived. This temperature is labeled T_{w_c} and is found using Equation 3:

$$\boldsymbol{T_{w\_c} = T_{w\_h}\text{-}\frac{Q \cdot d}{k \cdot A}} \qquad \textit{Equation 3}$$

4. RESULTS AND ANALYSIS

Taking the difference between T_{w_h} and T_{w_c} (labeled X_1 in Table 1) it becomes clear that there is little to no temperature difference across the tank wall. This preliminary calculation leads us to believe that the IR temperature sensor can be used to measure the temperature on the outside of the primary tank wall and this measurement can be used as a close approximation of the inside tank wall temperature (Figure 2).

Table 1. Values assumed for T_{w_h} and T_{b_c} as well as the resulting rate of heat transfer

T_{w_h} (˚F)	T_{b_c} (˚F)	$\Delta T = T_{w\_h} - T_{b\_c}$ (˚F)	Q (Btu/hr)	T_{w_c} (˚F)	X_1 (˚F)
170	70	100	2.351×10^5	169.804	0.196
160	80	80	1.881×10^5	159.843	0.157
150	90	60	1.411×10^5	149.882	0.118
140	100	40	9.405×10^4	139.921	0.079
130	110	20	4.703×10^4	129.961	0.039
120	120	0	0	120	0

Where:		
	T_{w_h}	*temperature inside the primary tank wall*
	T_{b_c}	*temperature of the bulk air in the annulus*
	ΔT	*temperature difference between bulk air and inside of primary tank wall (T_{w_h}-T_{b_c})*
	Q	*rate of heat transferred*
	T_{w_c}	*temperature outside the primary tank wall*
	X_1	*temperature difference across the primary tank wall (T_{w_h}-T_{w_c})*

Figure 2 shows linear dependence between the calculated difference in temperature across the wall (X_1) and the difference in temperature between the bulk air and the inside of the primary tank wall (ΔT). At the maximum temperature difference of 100 °F the corresponding difference across the wall is also a maximum and is only 0.196 °F (see Appendix A. for calculations) thus showing that reading the temperature on the outside of the primary tank wall is essentially the same as reading the temperature actually inside the primary tank wall.

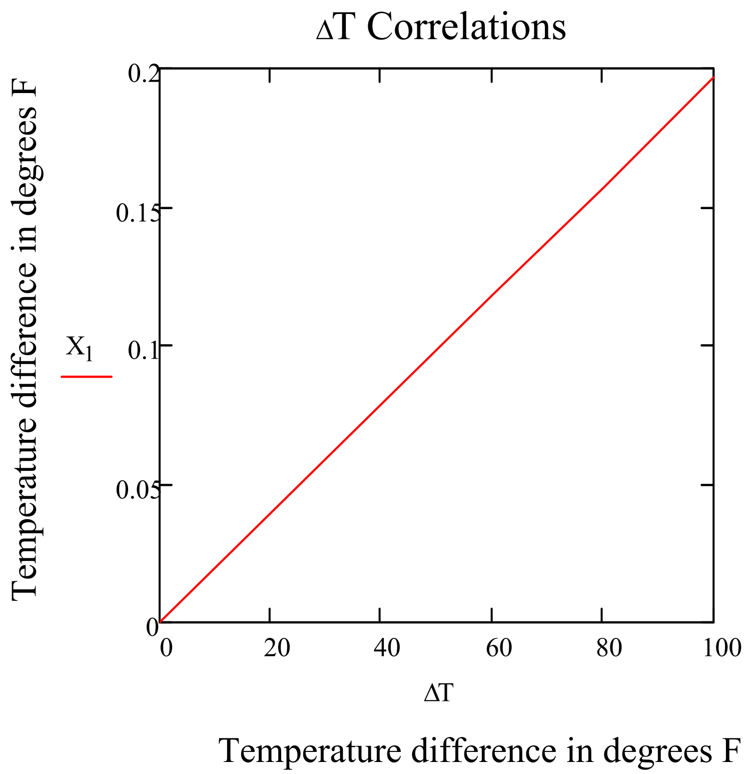


Figure 2. Linear dependence between X_1 and ΔT.

5. CONCLUSION

The conservative calculations preformed show that the infrared temperature sensor will provide a valid reading for the temperature on the inside of the primary tank wall. This permits the use of the Raytek IR sensor which can be strapped to the inspection camera and placed inside the annulus to record temperatures at different elevations. With this direct temperature reading it is possible to validate the simulated models currently being used for temperature and corrosion purposes as well as map the waste stratification based on large differences in temperature with respect to tank level.

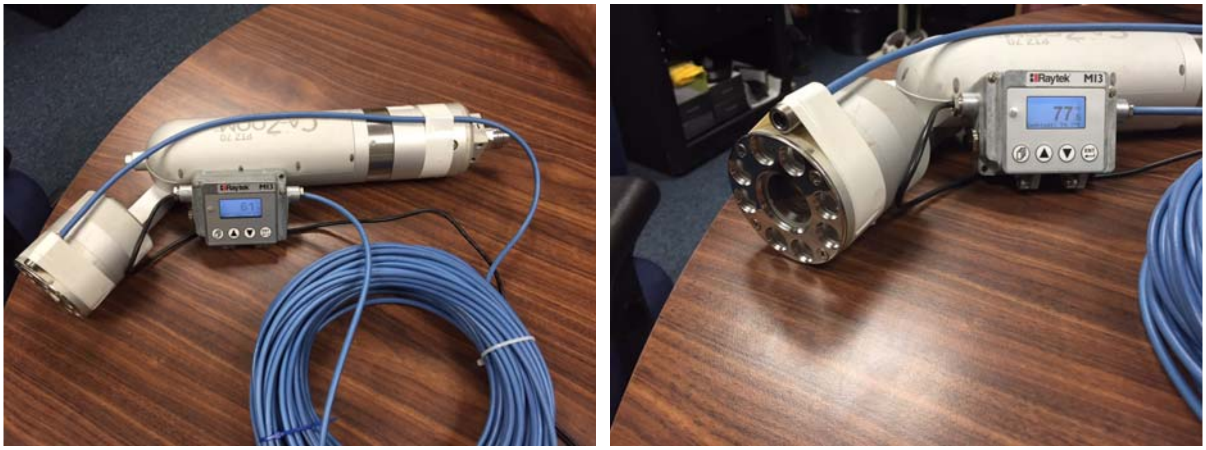


Figure 3. Infrared temperature sensor attached to the annulus inspection camera.

6. REFERENCES

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APPENDIX A.

Mathcad Code for Heat Transfer

VARIABLES

Q - rate of heat flow
A - area
d - thickness of wall
r - primary tank radius
c - circumfrence of main tank
h - height of supernatant
T_w,h - temperature of boundary inside the tank
T_b,c - temperature of the anulus
T_w,c - temperarture of boundary outside tank
k - thermal conductivity of mild steel
h_a - heat transfer coefficient of air
h_w - heat transfer coefficient of water (supernatant)
U - overall heat transfer coefficient for total Q
X - temperature difference across tank wall
* - citation

ASSUMPTIONS

T_b,c - for simplicity
T_w,h - point of interest because corrosion occurs at the tank wall
Steady state for supernatant & air
Supernatant treated as water
Unblemished tank wall
Tank wall 3/4 in

ASSIGNMENTS

$d := \frac{3}{4}\text{in}$

$k := 44.999 \cdot \frac{\text{W}}{\text{m} \cdot \text{K}}$

***McCabe, W.L., Smith, J.C., & Harriot, P. (2005) *Unit Operations of Chemical Engineering*. International Edition: McGraw Hill.**

$k = 26 \cdot \frac{\text{Btu}}{\text{hr} \cdot \text{ft} \cdot \Delta°\text{F}}$

$h_a := 7.9 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$ $h_a = 1.391 \cdot \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \Delta°\text{F}}$ ***engineering toolbox**

$h_w := 11.3 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$ $h_w = 1.99 \cdot \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \Delta°\text{F}}$ ***engineering toolbox**

$r := 35\text{ft}$

$c := 2 \cdot \pi \cdot r$

$h := 157\text{in}$

$A := c \cdot h$ $A = 2.877 \times 10^3 \text{ft}^2$

$$T_{w\_h} := \begin{pmatrix} 170 \\ 160 \\ 150 \\ 140 \\ 130 \\ 120 \end{pmatrix} °\text{F} \qquad T_{b\_c} := \begin{pmatrix} 70 \\ 80 \\ 90 \\ 100 \\ 110 \\ 120 \end{pmatrix} °\text{F} \qquad T_{w\_h} = \begin{pmatrix} 349.817 \\ 344.261 \\ 338.706 \\ 333.15 \\ 327.594 \\ 322.039 \end{pmatrix} \text{K} \qquad T_{b\_c} = \begin{pmatrix} 294.261 \\ 299.817 \\ 305.372 \\ 310.928 \\ 316.483 \\ 322.039 \end{pmatrix} \text{K}$$

use T in K

OVERALL Q

$$U := \frac{1}{\frac{1}{h_w} + \frac{d}{k} + \frac{1}{h_a}}$$

$U = 4.64 \cdot \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$ $U = 0.817 \cdot \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \Delta°\text{F}}$

$$Q := U \cdot A \cdot \left(T_{w\_h} - T_{b\_c}\right)$$

$$Q = \begin{pmatrix} 6.891\times 10^{4} \\ 5.513\times 10^{4} \\ 4.135\times 10^{4} \\ 2.756\times 10^{4} \\ 1.378\times 10^{4} \\ 0 \end{pmatrix} \cdot W \qquad Q = \begin{pmatrix} 2.351\times 10^{5} \\ 1.881\times 10^{5} \\ 1.411\times 10^{5} \\ 9.405\times 10^{4} \\ 4.703\times 10^{4} \\ 0 \end{pmatrix} \cdot \frac{Btu}{hr}$$

TEMP OUTSDIE THE TANK

$$T_{w\_c} := T_{w\_h} - \frac{Q \cdot d}{k \cdot A}$$

$$T_{w\_c} = \begin{pmatrix} 349.708 \\ 344.174 \\ 338.64 \\ 333.106 \\ 327.573 \\ 322.039 \end{pmatrix} K$$

COMPARISON

$$T_{w\_c} = \begin{pmatrix} 169.804 \\ 159.843 \\ 149.882 \\ 139.921 \\ 129.961 \\ 120 \end{pmatrix} \cdot {}^{\circ}F \qquad T_{w\_h} = \begin{pmatrix} 170 \\ 160 \\ 150 \\ 140 \\ 130 \\ 120 \end{pmatrix} \cdot {}^{\circ}F$$

$$X := T_{w\_h} - T_{w\_c}$$

$$X = \begin{pmatrix} 0.109 \\ 0.087 \\ 0.065 \\ 0.044 \\ 0.022 \\ 0 \end{pmatrix} K \qquad X = \begin{pmatrix} 0.196 \\ 0.157 \\ 0.118 \\ 0.079 \\ 0.039 \\ 0 \end{pmatrix} \cdot \Delta{}^{\circ}F$$

GRAPH

$$\Delta T := \frac{\left(T_{w\_h} - T_{w\_c}\right)}{\Delta°F}$$

$$X_1 := \frac{X}{\Delta°F}$$