Test Results from R&D Test Fired Heater on Impact of Butter-pad on Tube Skin Thermocouple Accuracy

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I. Abstract

The criticality of tube skin temperature accuracy in fired heaters for applications that have continuous fouling /coking inside the tube, or that operate with tube skins very close to the creep is well established in the refining industry. Accurate tube skin thermocouples have been developed for process heaters operating under a wide range of operating conditions. The accuracy of the tube skin thermocouple has been established through extensive testing in an R&D test heater with installed reference thermocouples that are true representative of the actual tube metal temperature.

The reliability of the installed tube skin thermocouple is limited to a few turnaround cycles after which they need to be replaced. The replacement however is done at locations near the existing failed thermocouple and the product is required to be welded onto the tube surface. There are tube metallurgies that are faced with challenges of welding, after the process tubes have been in service, thus limiting the welding of new thermocouples on to the tubes with failed thermocouples.

One of the methods exercised to address the issue is to build a predefined thickness of weld material on the tube surface with weld material called the butter-pad and install the product on the same. The advantage of the process is that the failed product can be removed from the butter-pad and new product installed without causing any issue related to tube integrity or extensive post-weld heat treatment.

However addition of butter-pad does bring about an additional complexity in the measurement relating to the dimensions and properties of the material buildup over the tubes.

The paper discusses the effect of butter-pad on tube skin thermocouple measurement accuracy and possible remedial measures to address issues. Since heaters in various process applications have varying fireside and tube side conditions, it is important to understand the impact of the operating condition on the accuracy of the tube skin thermocouples installed on butter-pad. The effect of operating parameters on the accuracy of most commonly used design in the industry were evaluated in the test heater to gain insight into products characteristics. The learning from the test results are currently being used to develop new design concepts and improve upon the existing.

II. Introduction

To evaluate the impact of installing a tube skin thermocouple over a weld overlay (butter-pad) of specific dimension, testing was done at the WIKA R&D Center fired heater. The testing and analysis was done in the following sequence to understand the impact on accuracy of a tube skin thermocouple installed on a weld overlay.

The butter-pad of a fixed dimension and thickness was built along the length of the tube for products that are installed parallel to the tube axis. A circumferential butter-pad was also built to test products that are installed along the tube circumference. (Refer Fig-1 for drawing depicting the installed butter-pad)

Reference thermocouples were installed on the weld overlay and on the bare tube surface to understand the temperature variation between the bare tube and the surface of the butter-pad.

Products tested and developed earlier with known accuracy were installed on the butter-pad to understand the performance variation due to the additional metal over lay on the tube.

CFD simulation was validated with experimental data from the butter-pad testing and used for simulation of cases with installed product on the butter-pad.

The validated CFD model was used to study the impact of some key parameters of the butter-pad on the tube skin thermocouple accuracy.

III. Reference thermocouples [1],[2]

Peening is one of the widely used methodology for measuring true tube skin temperatures. However for a test setup running multiple tests would render the methodology infeasible due to the number of change outs and tube drilling required. As discussed in [1] the capacitance discharge methodology for attaching reference thermocouples to tube surface was evaluated as an alternative to the peened in methodology.

The average deviation between the peened and the capacitance discharge welded reference thermocouple is ~ 1.1°F (0.5 °C) and is independent of the variations in firing and process conditions.

For the current test and evaluating the accuracy of the TST (Tube Skin Thermocouple) the comparison shall be done using the capacitance discharge welded reference thermocouples.

It may be emphasized at this point that the WIKA R&D Test heater is repeatable within 1°F (0.5 °C) based on the various benchmarking / profiling tests done on the unit.

IV. Test results with butter-pad on tube

The butter-pad was manufactured using weld overlay on tube Outside diameter till the desired dimensions were reached, the surface of the pad was exposed to the fireside and was further surfaced to give it a uniform thickness over the tube. The image of the butter-pad built on the tube is appended in the table in Figure 1. The dimension of the butter-pad was chosen based on the ease of installation of different type of tube skin thermocouple assemblies and common industry knowledge.

Tests were done to understand the temperature distribution on the bare butter-padas compared to the bare tube under varying operating conditions to establish the base conditions before installing the tube skin thermocouples.

The below table constitutes the results from the tests done at varying operating conditions. The temperature measured is at the center of the weld overlay. The temperature at the weld overlay surface is ~ 4°F (2.2 °C) higher than the bare tube. The CFD Simulation results match closely with the test data.

S.No	Firing	Reference	Butter-Pad (Test)	Butter-Pad (CFD)
Units	MMBtu/hr	ºF	ºF	ºF
1	6.9	762	766	765
2	5.9	735	738	737
3	4.6	700	704	702

Table 1

This is lower than the expected surface temperature for a thickness of 0.196" (5mm). IR Scanning of the area revealed an emissivity of 0.67 to match the temperature and this was further validated with the CFD model of the setup.

The CFD model was run at emissivity of 0.45 and 0.85 at the max firing rate to understand the impact of emissivity on the surface temperature and the same is appended in the table below:

S.No	Emissivity	Butter-Pad Temperature °F	Butter-Pad Temperature Deviation °F
1	0.45	735	-27
2	0.67	764	3
3	0.85	785	23

Table 2

It is clear that having the butter-pad surface polished (emissivity = 0.45) compared to the tube reduces the surface temperature. Other interesting observation is that the surface temperature of the butter-pad varies from high at the edges to a uniform lower value moving towards the center.

The below graph shows the temperature variation of the butter-pad along the length and periphery of the tube for emissivities varying from 0.45 to 0.85.

It is interesting to see the temperature variation along the length and periphery of the weld pad and the impact of emissivity on the same.

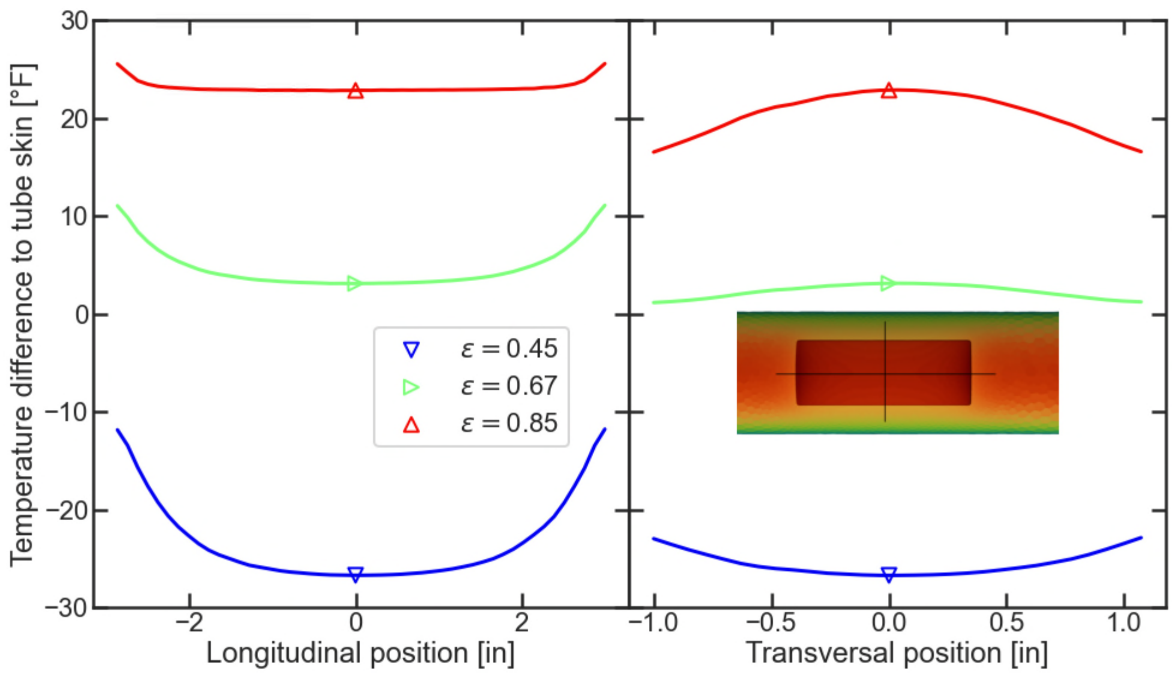


Chart 1

CFD simulation was done for high severity conditions to understand the impact of higher temperature on the butter-pad temperature as compared to the bare surface.

The below table represent two cases of alternative location with higher tube skin temperature for which CFD simulation was done to understand the impact on butter-pad temperature

S.No	Firing	Butter-Pad	Bare Tube
	MMBtu/hr	ºF	ºF
1	6.9	801	798
2	12.7	1003	1000

Table 3

The validated CFD model was used to simulate test run conditions for which product test data is available for bare tube installation.

V. Test Results with products installed on butter-pad

Once the data from the butter-pad was analyzed and vetted using IR thermography and CFD, the performance of the products welded on top of the butter-pad was simulated to understand the impact on accuracy.

The test points were kept the same as that with the high tube skin temperature with bare butter-pad to have a similar basis for comparison.

The deviation of the shielded and unshielded product when installed on bare tube are listed below.

S.No	Firing	Unshielded Deviation	Shielded Deviation
Units	MMBtu/hr	ºF	ºF
1	6.9	3	-1
2	12.7	3	-9

Table 4

It is apparent that the products are accurate within thermocouple standard limits of error (SLE) tolerance at the specified test temperature for high skin temperatures, the characteristics are similar for low severity operation as well.

The below table represents the temperature measured by the shielded and unshielded product when installed on butter-pad.

S.No	Firing	Bare Tube	Unshielded	Deviation	Bare Tube	Shielded	Deviation
Units	MMBtu/hr	ºF	ºF	ºF	ºF	ºF	ºF
1	6.9	797	817	20	797	819	22
2	12.7	1001	1027	26	1001	1022	21

Table 5

It is evident that both the shielded and unshielded product read higher by ~ 20 °F when installed on butter-pad. It is worthwhile to mention that the products tested were of high accuracy when installed on bare tubes and for products that read higher than actual on bare tube could have even higher deviation depending on the design of the product.

VI. Observations and improvements

It is observed that the surface finish of the butter-pad has impact on the temperature distribution and hence the accuracy of the product. Increasing the emissivity increases the deviation of the surface temperature of the butter-pad from the bare tube surface.

The product when installed on butter-pad read higher as compared to when they are installed on bare tube. The magnitude of deviation of the product temperature from the actual is product specific.

The shielded product appear to have a higher deviation as compared to the unshielded versions. Note that shielded products which read too low than actual tube skin can now potentially perform better when installed on the butter-pad, and contrary is true for the unshielded product that read too high than actual.

It is inferred that products that have been designed to read accurate on bare tubes will read higher when installed on a butter-pad and the magnitude will be determined by the emissivity, thermal conductivity and dimension of the butter-pad.

One of the options that was evaluated to improve the product performance whilst being installed on the butter-pad was to vary the thermal conductivity of the butter-pad through use of different weld material and reduce the emissivity of the butter-pad through surface preparation.

The below are results of CFD simulation with reduced emissivity from 0.67 to 0.45 and increasing the thermal conductivity by 20%.

Results of product accuracy with reduced emissivity and increased thermal conductivity.

S.No	Firing	Bare Tube	Unshielded	Deviation	Bare Tube	Shielded	Deviation
Units	MMBtu/hr	°F	°F	°F	°F	°F	°F
1	6.9	797	802	5	797	816	19
2	12.7	1002	1003	2	1002	1018	16

Table 6

It is observed that the change of butter-pad parameters has a significant impact on improving the accuracy of the unshielded product, whereas for the shielded product the effect is marginal.

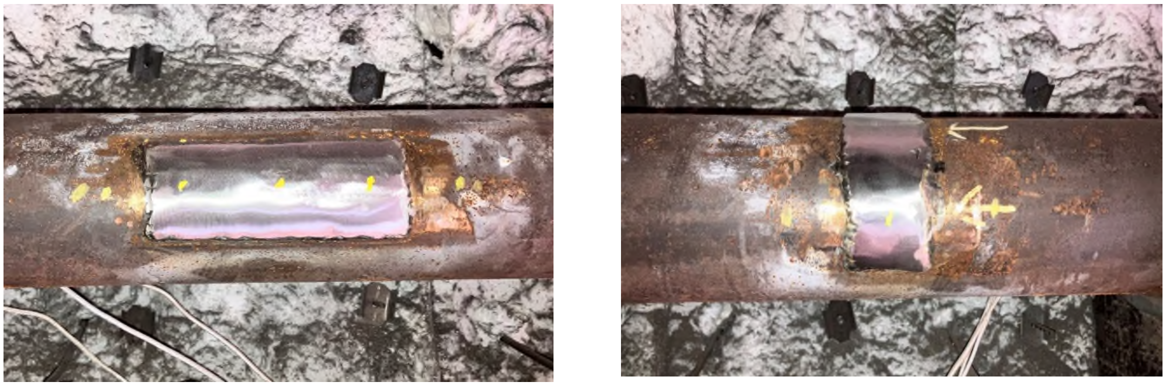
VII. Conclusion and next steps

The installation of tube skin thermocouple on butter-pad come with a penalty on the accuracy of the reading when compared to installs on bare tubes. This being said for product that normally read lower than actual would read higher than before and depending on the product design may come closer to actual or in other cases even start reading higher than actual. Contrary to that for products that read higher than actual will have an increment on the deviation.

Varying properties of the butter-pad can provide a solution for the composite of the butter-pad and the product to read accurate. However this solution shall be unique to the product being installed and would require testing and CFD analysis to arrive at an optimal solution.

The information and learnings from the project shall be used to guide customers with designs suited for the application under consideration optimized for the customer specific tube skin thermocouple product.

Figure-1 : Butter-pad installed on tubes, longitudinal and traverse



References :

[1] Effect of Operating Parameters on Fired Heater Tube Skin Temperature Measurement Accuracy, AFRC 2022.

[2] Manual on: The Use of Thermocouples in Temperature Measurement (fourth edition), ASTM Committee E20.