Effect of Operating Parameters On Fired Heater Tube Skin Temperature Measurement Accuracy & The development of new improved Tube Skin Thermocouple

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I. Abstract

Refineries are often faced with challenges to meet production target, improve efficiency, process opportunity crudes with limited information on fouling characteristics etc. The common parameter that often becomes constraining are the tube skin temperatures which are critical in maintaining the integrity and reliability of process fired heaters. Tube skin temperature is an important monitoring parameter in applications that have continuous fouling / coking inside the tube or that operate with tube skins very close to the creep.

It is a given that an inaccurate temperature reading (lower / higher) would either lead to operation in the unsafe zone, leading to rapid deterioration of the tube or at conservative levels, underutilizing the asset.

Products installed on tubes to measure skin temperatures are composites comprising thermocouple, insulation, shield etc. designed to meet accuracy and reliability. The reliability of tube skins is quantifiable through years of operation, recorded data etc. however the accuracy is often assumed to be within a certain range with no validation data available using a true reference.

The paper discusses the development and use of reference thermocouple for measuring true tube skin temperature in fired heaters with the prime objective to be used for evaluating tube skin thermocouple accuracy.

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 temperature measurement thermocouples. The effect of operating parameters on the accuracy of most commonly used thermocouple designs in the industry were evaluated in the test furnace 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

When a thermocouple is attached to a surface, its presence alters the heat transfer characteristics of the surface and normally will change the temperature distribution. This causes an error which is referred as perturbation error [1].

Thermocouples mounted on a surface, subject to radiant heating at temperature-rise rates up to 30 °F/s (16 °C/s) showed that a separated-junction thermocouple produced the least error. The thermocouple errors increased with increasing plate thickness and with increasing rates of temperature rise. Furthermore, the amount of bare thermocouple wire between the junction and the insulation had effect on the accuracy. The smallest possible installation helps to reduce perturbation errors. There are numerous other parameters which effect the measurement accuracy.

The aim of the study was to use the learnings from past industry experience and derive a methodology that is repeatable, reliable and measures accurate tube skin temperature. The initial part of the paper discusses the methodology arrived at for accurately measuring tube skin temperature.

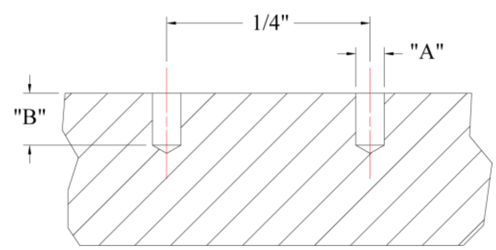
The developed methodology was used to benchmark different types of commercial tube skin thermocouples. The learning from the same was used to develop a novel thermocouple design that is robust and accurate for use in a wide variety of fired heaters in the Oil and Gas Industry. The later part of the paper discusses some of the learnings from the benchmarking study and its application to develop the new design.

III. Reference Thermocouples for accurate tube skin temperature measurement

There is no easy method of attaching a thermocouple to a surface so that it can be guaranteed to indicate the true surface temperature. To do this, it would be necessary to mount the measuring junction so that it could attain, but not affect the surface temperature. In most cases, the presence of the thermocouple will cause a perturbation of the temperature distribution at the point of attachment, and thus it only will indicate the perturbed temperature.

Peening is one of the widely used methodology for measuring true tube skin temperatures, however the same comes with its limitation of requiring drilling the tube surface to attach the thermocouples. The below table provides the guideline for attaching peened in thermocouples to surface for temperature measurement.

Wire Gauge	Drill Size “A”	Depth “B”
14	44	0.128”
20	65	0.064”
24	74	0.040”
28	79	0.025”
30	80	0.020”



As we would be required to do multiple tests in the test unit, and given that the peened in thermocouple may only last few of those, it became important that an alternative methodology of attachment be developed. The objective to develop an alternative methodology was to achieve same accuracy with negligible effect on the test section for repeated use, by avoiding drilling of the surface. Other important aspect to consider was to develop a process that is repeatable and easier to install.

Taking all the aspects into consideration the capacitance discharge methodology for attaching reference thermocouples to tube surface was evaluated as an alternative to the peened in methodology. To do a robust evaluation redundant pairs of capacitance discharge welded and peened in thermocouples were placed on the tube and tests conducted under varying process side and fire side condition.

The bridge wall temperature was varied from 1290 – 1500°F and with process temperature between 530 – 700 °F. The variation on the process side were important to understand if there was any correlation of the deviation between the peened and the capacitance discharge welded thermocouples.

The below sets of tests were done with the following variation to evaluate the impact on the deviation between the Peened and the Capacitance Discharge Welded Thermocouples. The firing was kept constant and the process temperature was varied.

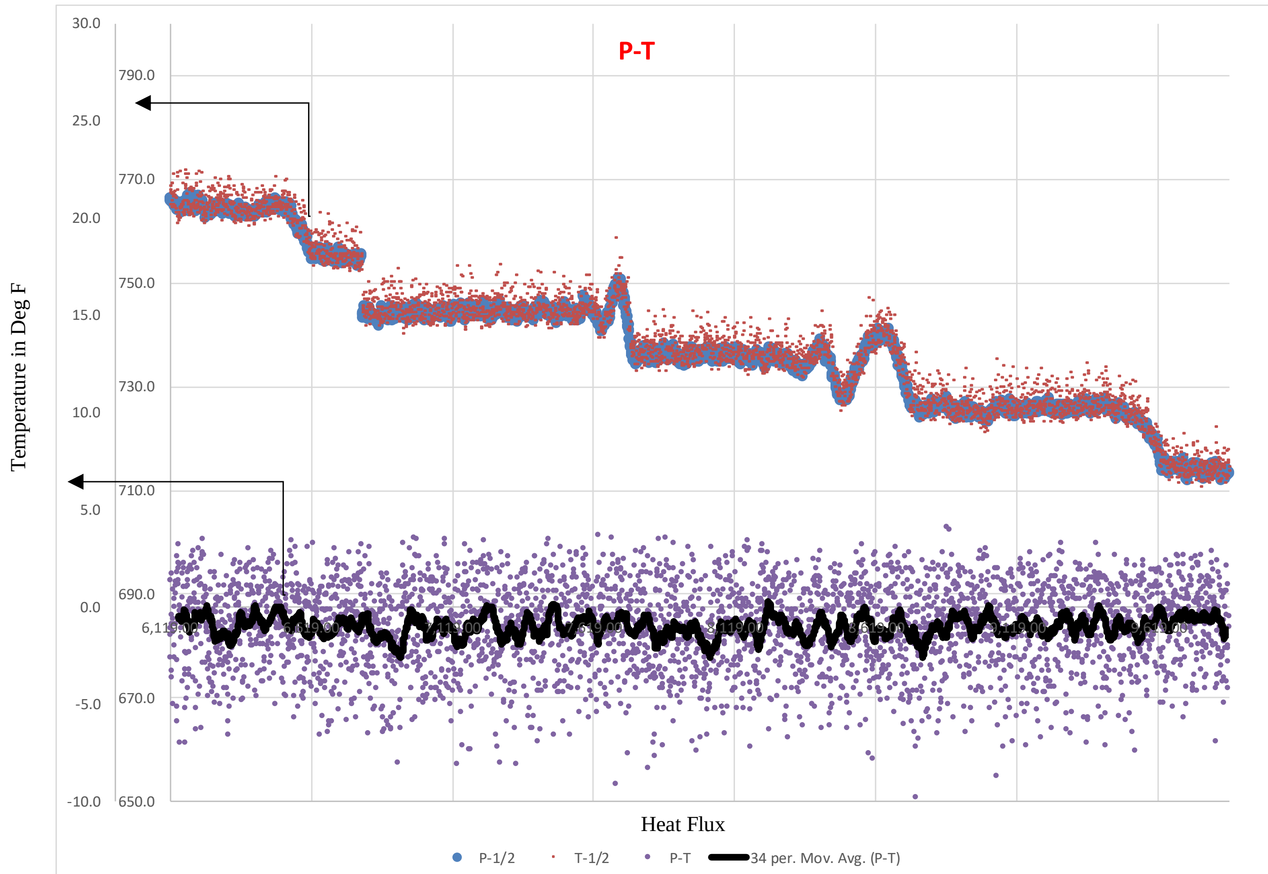


Figure 1 : Plot of Peened and Capacitance Discharge Welded Thermocouples temperatures at varying process temperature.

P-1/2 : Peened in thermocouple

T-1/2 : Capacitance discharge welded thermocouple

P-T : Deviation between the peened in and capacitance discharge welded thermocouple

Based on the various tests it was observed that the deviation between the peened in and the capacitance discharge welded thermocouple was within 1.5 °F for varying process conditions.

Similar test was conducted with constant process temperature and varying firing and the results of the same area appended below.

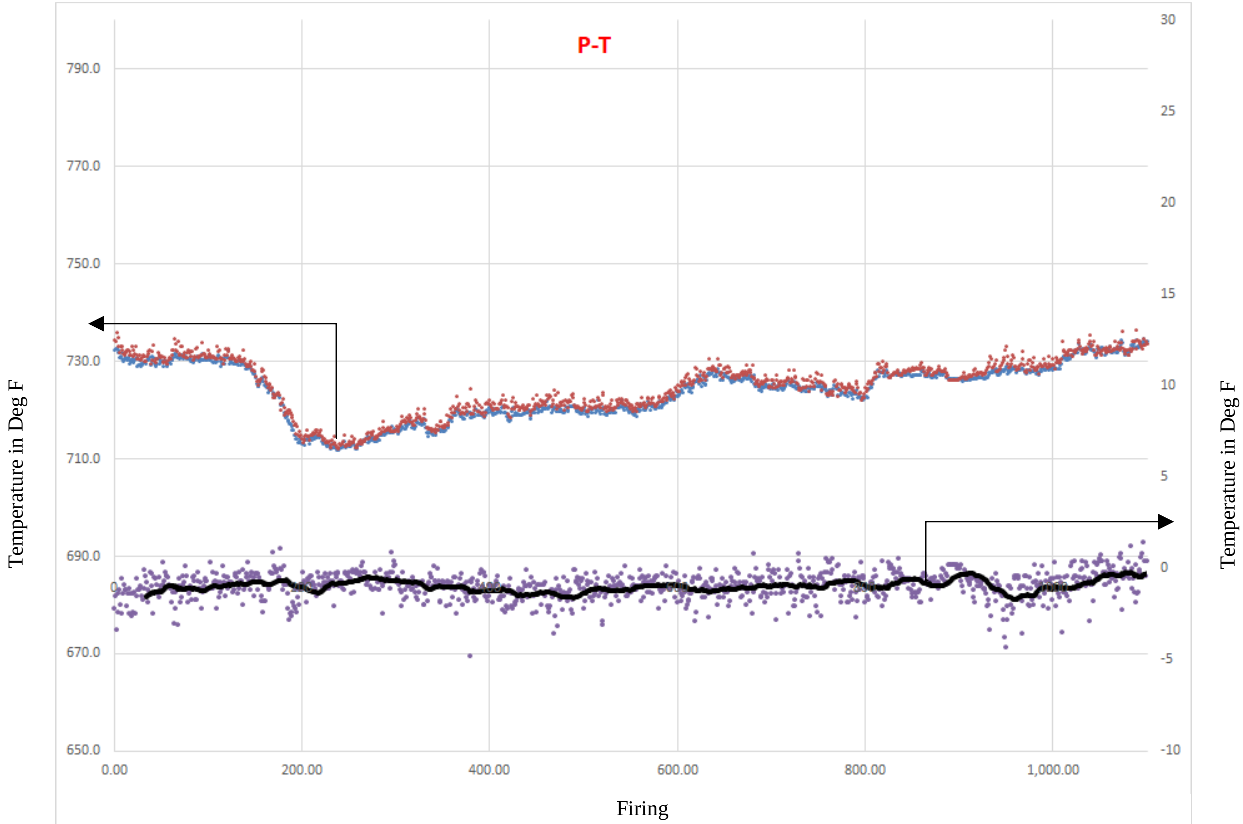


Figure 2: Plot of Peened and Capacitance Discharge Welded Thermocouples temperatures at varying firing.

P-1/2: Peened in thermocouple

T-1/2: Capacitance discharge welded thermocouple

P-T: Deviation between the peened in and capacitance discharge welded thermocouple

The average deviation between the Peened and the capacitance discharge welded thermocouple does not exhibit an increasing / decreasing trend with changing firing. The consistent deviation between the two indicate that the deviation is independent of the firing variation. The average deviation is ~ 1.1°F (0.5 °C)

There were multiple other tests conducted with varying process and fire side parameters and the deviation between the Peened and the capacitance discharge welded thermocouple was observed to be random and not exceeding 1.5 °F. Infrared images of the proximate regions from the references were used to validate the results and identify outliers, the images were further analyzed to get deeper insight into the temperature profiles and variation on the process tubes.

It is important to mention that the separating distance between the thermocouple conductors and the routing was same for both the types. Hence based on the information available from the literature, experimental results and data analysis, it is inferred that for a system with dominating radiative mode of heat transfer a separated junction, surface attached thermocouple with the thermocouple wires away from the junction along an isotherm for at least 20 wire diameters, a capacitance discharge welded thermocouple with 20 gauge wire would give similar temperature as measured by a peened in thermocouple of 20 gauge wire.

Based on the test data and ASTM guideline the capacitance discharge welded surface attached thermocouple is used as the standard reference for understanding the accuracy of the current and future commercial tube skin products. This sensor style will be referred to as the reference thermocouple sensor in testing data.

IV. Benchmarking commercial tube skin products

The development of the reference thermocouple to accurately measure the tube skin temperature lead to the multiple test runs to evaluate various types of tube skin thermocouples used in the industry. The thermocouples maybe broadly classified as the shielded or the un shielded type, both of which are designed to accurately measure tube skin temperature and at the same time be robust to last multiple turn around.
The accuracy of tube skin temperature measurements depends on multiple factors. The primary one, of course, is the precision or accuracy of the sensor itself. Yet the design and placement of the entire measuring system should likewise not be underestimated. The various tests confirmed that the following variables can affect accuracy at the measuring point itself:

- Size of the weld pad
- Relative position of the sensor and the heatshield
- Properties of the insulation
- …….

In addition, accuracy is effected by both the process and the firing conditions and each of these influences the incident heat flux on the tube. Tests in the WIKA unit showed that as the heat flux increases, so does the absolute temperature deviation of the test thermocouples compared to the reference.

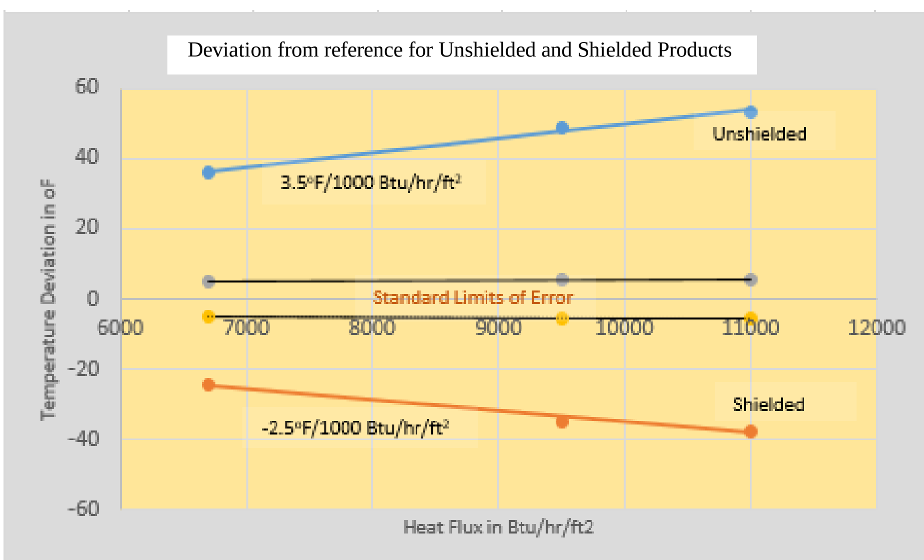


Figure 3

The Figure 3 above shows the accuracy of samples of shielded and unshielded products tested as a function of the absorbed heat flux.

The above tests provided insights into the impact of the various product types on measurement accuracy. Subsequent tests were conducted for each type of product to understand the impact of the sub component of the product on the accuracy, such as the shield, insulation, weld pad, thermocouple cable etc.
This lead to setting the targets characteristics for the new product, both in terms of accuracy and ease of installation. Given the level of measurement accuracy achievable through the reference thermocouples it was considered prudent that if the new product could measure within standard limits of error, and a design that could install with very low chances of installation error would be a pragmatic target to achieve.

Other aspect to consider was that given that there are multiple user using our products the enhanced product should have a similar geometry and installation procedure. Given the target of accuracy and installation, the most effective modification considered was to change the weld pad dimension and the attachment process.

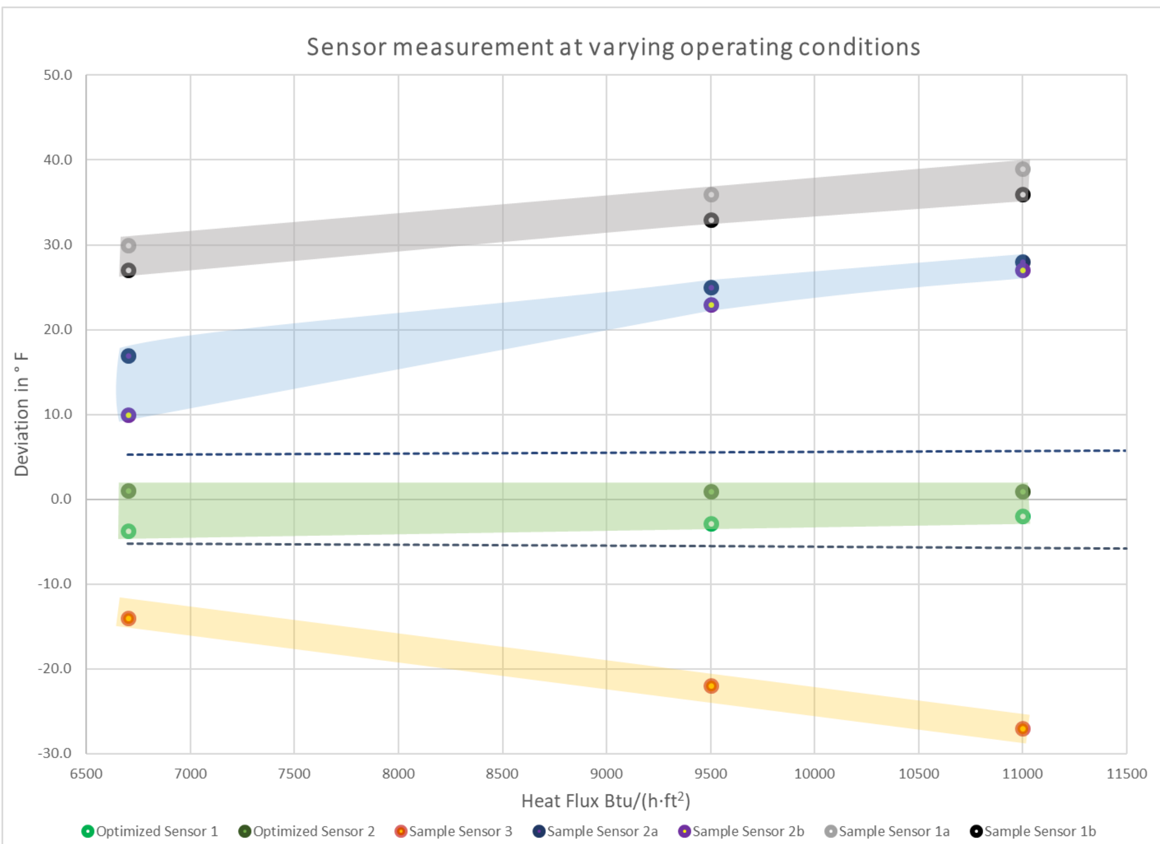


Figure 4

The Figure 4 above shows the accuracy of various test sensors during the development process of the shielded type design.

It may be noted that due to the accuracy desired, many variations of the weld pad were tested to arrive at the final configuration. The accuracy of the final product is represented by the green area, and is well within the accuracy level for the range of operation of the test heater.

Multiple samples of the final product were tested to establish repeatability, robustness of installation and accuracy before launching the same. A patent has been filed for the new design and is pending evaluation. The details of the product is available at the WIKA website https://www.wika.com/en-us/tc59_t.WIKA

V. Conclusions

Evaluation and development of tube skin thermocouples requires accurate measurement of the tube skin temperature. Accurate tube skin temperature measurement can be done using 20 gauge thermocouple conductors with a capacitance discharge method of installation, this attachment process gives accuracy within 1.5 °F as compared to a peened in thermocouple. This accuracy has been validated for bridge wall temperature variation between 1290 – 1500 °F and process temperature between 530-700ºF.

The reference thermocouples were used to evaluate shielded and unshielded tube skin temperature product performance at varying operating conditions. The revelation of the effect of operating parameters on the accuracy of tube skin thermocouples lead to the development of improved tube skin thermocouples that is almost heat flux neutral, installs in half the time of the original product and is easier to install.

The multiple tests conducted in the facility and the learnings are currently being used to improve different types of skin temperature measurement products and evaluate novel concepts that require rigorous testing.

References

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