Quantitatively Correlating Gold Cup Pyrometer and Infrared Thermography Data of a Steam Reformer's Tubes

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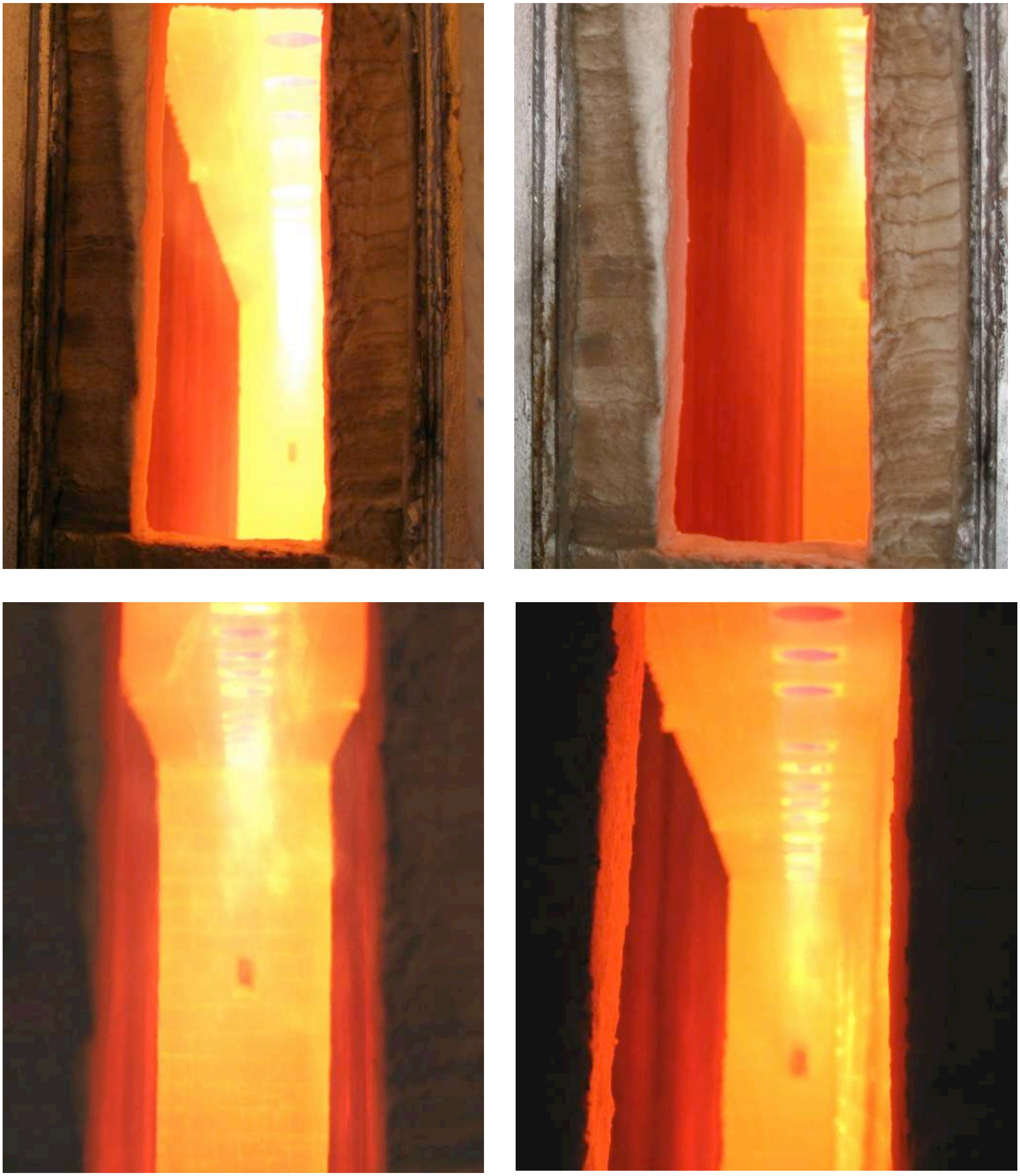
Abstract

Maintaining proper reformer and process heater tube temperatures within petrochemical plants is critical to the life of the tubes. Reformer and furnace tube replacement is extremely costly and time consuming. Furthermore, tube failures can potentially escalate to catastrophic failure of the vessel or even the plant. However, acquiring accurate tube temperatures is extremely difficult and often misunderstood. Plant operators and engineers routinely measure their own temperatures using handheld spot pyrometers or thermal imagers, however unless there is an accepted means of acquiring actual contact reference temperatures, any non-contact temperatures measured can be inaccurate within a range outside the acceptable error tolerances.

This paper will discuss an actual exercise conducted in 2008 on a multi-row box type steam reformer to determine the viability of acquiring quantitative temperature data within acceptable tolerances using a Gold Cup Pyrometer as the contact reference and a radiometric thermal imager as the non-contact working thermometer.

Introduction

Imagine if you can, a four to six inch diameter metal tube carrying highly flammable or explosive fluids such as natural gas, oil, or hydrogen. Now, take this tube and place it into a furnace that is being fired by high velocity gas burners at temperatures over 800°C (1472°F). You may think that is just crazy! Now imagine hundreds of these tubes inside a large reformer furnace. What would think now?



Visible digital photos inside a steam reformer showing refractory walls, gas burners, and vertical tubes

This is exactly the environment furnace and reformer tubes are under every day around the world. That is why frequent monitoring of tube conditions is very important simply from a safety standpoint. However, safety is rarely the driving force behind tube condition monitoring - money and profit are the motivation and necessity for monitoring.

What's Temperature Got to Do with It?

Process engineers are always looking for ways to increase a plant's production even by minute, single digit percentages. However, the aim is to be able to do this without significantly reducing the life of the furnace or reformer tubes. It is a balancing act between making profit by increasing production while maximizing tube life as much as possible. This is because re-tubing furnaces and reformers is extremely expensive.

So how does a process engineer increase production of a furnace or reformer without compromising tube life? It is mainly done by careful temperature control. You want to be just slightly below the maximum allowable operating tube temperature. Too low of a temperature and you are simply just losing too much money. Too high of a temperature and you are compromising equipment and personal safety and reducing the life of your tubes. Furnace and reformer tubes are temperature fragile. Industry rule of thumb states that for every 20°C above the maximum allowable temperature you operate halves the life of the tubes.

Temperature accuracy is very important to a process engineer. However, accurate tube temperatures are not easy to come by. Common practice is to monitor tube temperatures via non-contact means such as infrared pyrometers or thermal imagers. The main limitation of using these types of devices for furnace tube temperature measurements is that unless you input the proper parameters into these thermometers, you will not achieve accurate temperatures. Any qualified Level 2 thermographer will tell you that you must have some means of establishing an acceptable reference temperature to be able to quantify the parameters that need to be input into these infrared measuring devices.

The main question that must be answered before you start acquiring these reference temperatures is, "What is accurate for this furnace?" One company's perception of accuracy may differ greatly from another. In the world of furnaces and reformers, the accepted means of gaining accurate temperatures is via embedded or welded thermocouples, using a test coupon, or using a Gold Cup Pyrometer. Every single one of these methods has inherent flaws and limitations that equate to uncertainties and errors. So the next question should be how much money and time are you willing to spend on accuracy? Eventually it comes down to compromising and going with what is available at the most economical cost or simply just forgetting about accuracy all together.

Gold Cup Pyrometer - The Bigfoot of Furnace Tube Pyrometers

This paper discusses the most requested and most talked about means of gaining reference temperatures: The elusive Gold Cup Pyrometer. I say elusive because although it is mentioned in almost every piece of furnace and reformer tube literature you can find, and every plant and process engineer references this device, almost all of them will never actually see one used within their professional lifetime. This is because there are less than a handful of these devices throughout the world. Some refineries have one in-house but most do not. However this is quickly changing as plants are now realizing the importance of having such an important piece of equipment on hand.

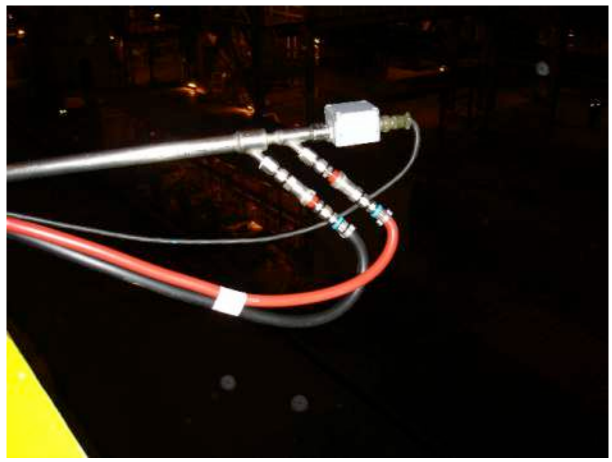
For this case study, my job was to use my shortwave thermal imager to determine the viability of using Gold Cup reference temperatures to calculate the parameters needed to survey the rest of the reformer's tubes.

The Gold Cup instrument used was about 4 meters (13 feet) long, and is capable of reaching almost 8 feet into the furnace. The Gold Cup at the end of the probe is placed in direct contact with the reformer tubes to eliminate the reflected radiation that interferes with other infrared measuring instrument readings. The probe is water cooled to prevent overheating. A millivolt reading is taken and then converted to a temperature reading. An average of 3 to 4 tubes were measured for each row. Before and after the survey, the probe's calibration was verified in a specially designed blackbody furnace.

Gold Cup Pyrometer probes in shipping case

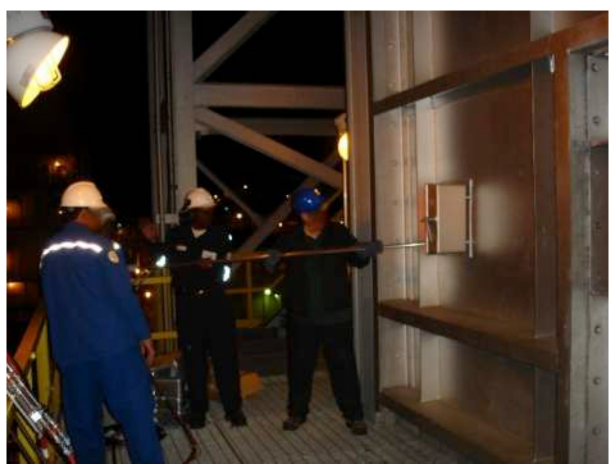

Gold Cup Pyrometer probe tip

Assembly of Gold Cup system showing cooling water hoses and regulator panel



Gold Cup probe water hose for cooling and electronic decoder for signal processing

Millivolt meter for measuring tube temperature



Inserting the Gold Cup Pyrometer inside the reformer to contact the tube wall

The Mission, Should You Choose to Accept It

As the thermographer, my goal was to establish a field adaptable procedure and a way to quantify accuracy and repeatability when using a thermal imager for accurate tube temperature measurement. If I could use the Gold Cup reference for one tube and calculate my thermal imager's calibration parameters using this reference, can I get repeatable and accurate temperatures for the other tubes measured with the Gold Cup? If I can achieve this goal, then to some degree of confidence, I should be able to measure the other tubes with the same degree of accuracy and error, provided I stay within the same or close to the same variables.

The field procedure for the thermographic survey was simple enough. Acquire radiometric thermal images of the tubes measured by the Gold Cup Pyrometer using apparent values (Emissivity = 1.00); acquire radiometric thermal images of any possible reflected radiation error sources for the field of view and angle of the inspection; transfer all images to the computer for proper quantitative temperature analysis using the imager's analysis software.

The Results

The following data are some of the actual Gold Cup temperatures compared to the corrected thermal imager temperatures:

Tube Location	GC Temp. °C	Corr. Imager Temp. °C	Difference (GC vs. Imager)
A7	**877.7**	**877.1**	**0.6**
A8	881.8	880.6	1.2
A9	886.0	886.9	0.9
B7	870.7	871.3	0.6
B8	874.9	872.8	2.1
C7	816.1	816.0	0.1
C8	821.6	823.2	1.6
C9	824.4	826.2	1.8
E7	854.8	855.8	1.0
E8	853.4	853.9	0.5
E9	859.6	859.3	0.3

From these data, we see that the average temperature difference between the Gold Cup Pyrometer and the corrected thermal imager is 0.97°C.

These results are based on calibrating and finding the average emittance value of the tubes using tube A7 alone as the reference. All other corrected measured temperatures were achieved by inputting the calculated parameters into the analysis software.

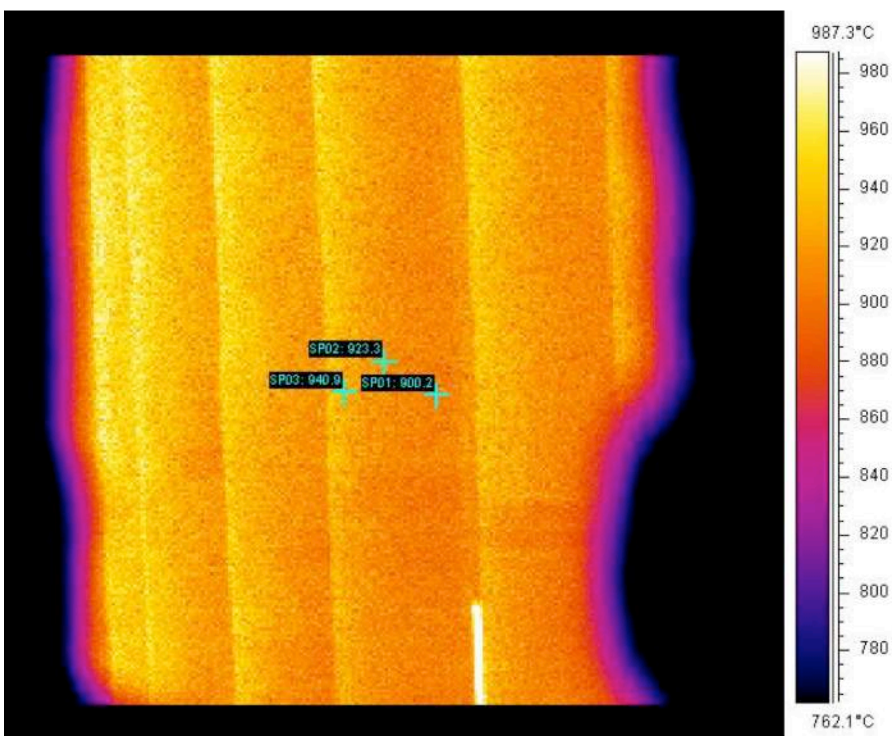
The Challenges

Although these results are very impressive and prove that a high degree of accuracy, repeatability, and certainty can be achieved between the Gold Cup and thermal imager, achieving these desirable results was a challenge.

Furnace and reformer tube inspection is both an art and a science. Simply understanding Level 2 thermography and temperature measurement is not nearly enough to carry out these surveys and achieve the above desirable results. The inspector must have a firm understanding of heat transfer, thermodynamics, geometry, operating processes and variables, and much more. The inspector must also have a keen troubleshooting skill with practical knowledge of basic physics. And most importantly, the inspector must be able to incorporate all of these abilities into a practical common sense approach.

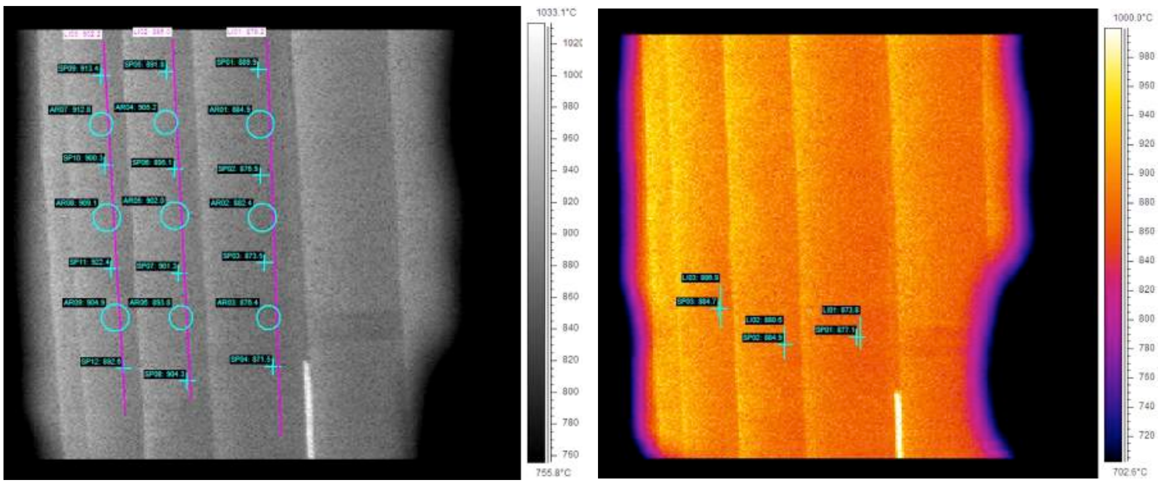
Some of the main challenges faced were:

Where to take the temperature data? This is probably one of the most important factors that will affect the measured temperature and is based on the tube diameter, field of view, and angle of view. Taking the temperature data from the wrong part of the tube can lead to large differences in temperature.



Same tube showing a 40°C temperature difference across the diameter

What analysis tool should be used and what should be measured? Should spots, boxes, lines, or circles be used? Should maximum or average temperature be used? From this reformer exercise, it was found that spots are not effective and using absolute or even maximum temperatures can result in large temperature differences. It should be understood that the Gold Cup Pyrometer measurement area has a certain spot size and the temperature is actually an average of that spot size. Therefore, it is very important to know the exact spot size ratio of the thermal imager because the spot size differs considerably compared to that of the Gold Cup.



Images showing various analysis tools used to determine the best one for the application

Another reason the spot tool was not ideal for this situation was that there were too many temperature changes over a small fraction of the tube surface (pixels to pixels) that a spot tool measures in absolute. This did not represent the tube temperature as compared to the gold cup measurement.

Which reflected temperature should be used? This is another important factor that was a challenge. A firm understanding of tube geometry and radiant heat physics is important. The wrong reflected temperature can lead to large errors.

You may be asking what about the emissivity? That is the first question all thermographers and engineers ask. In my opinion, knowing the emittance value of the tube is not as an important factor as the rest. For this application, emittance is just a number you figure out after you have properly identified all other variables. Emittance is only constant if everything else remains constant. You will notice, by keeping all controllable parameters constant (except for tube temperature, which I had no control of) for the above tubes, I was able to maintain the calculated emittance value from the reference (tube A7) to all other tubes listed and achieve the recorded accuracy. However, because of elevated tube temperatures and changes in viewing angle, I had to recalculate the tube emittance to match the Gold Cup for some of the other tube rows. This resulted in the ability to calculate the average emittance value of the tubes for various temperature ranges.

There are other critical variables and factors to be aware of for a proper quantitative furnace and reformer tube temperature survey using a thermal imager, but the ones I mentioned are a few of the main ones.

Conclusion

Based on this one exercise, accurate quantitative temperature data were gathered with an acceptable degree of certainty and repeatability. However, taking as many contact Gold Cup reference temperatures as practically possible will result in the ability to gain greater non-contact thermal imaging accuracy.

Assuming that the calculated average emittance value for one row of tubes will be the same for the other rows can lead to unacceptable accuracy errors and should be avoided.

Whenever carrying out furnace or reformer tube inspections, an important question should be: "Is it necessary to measure tube temperatures accurately?"

The answer mainly depends on which plant personnel you ask and what you need to achieve. For condition monitoring purposes, temperature accuracy is not as important as temperature trending. For troubleshooting of problematic tube and furnace conditions, temperature accuracy also is not as important as viewing and understanding the thermal profiles for the tubes and surrounding structures. On the other hand, if your goal is maximizing production while at the same time maximizing tube life, then accurate tube temperatures are of the utmost importance to you.

I believe that every plant with a critical furnace or reformer should consider investing in a Gold Cup Pyrometer. In my opinion, it is one of the easiest instruments to use and implement to achieve tube reference temperatures. Also, with the use of blackbody furnaces, calibration and temperature accuracy of this type of reference device can be quantified easier than the other means.

I also firmly believe that thermographers attempting to carry out any type of furnace or reformer tube survey, whether quantitative or qualitative, be properly trained by an experienced and qualified mentor. Small mistakes or assumptions may lead to large errors resulting in costly consequences. Reformer tube temperature measurement is very challenging and if attempted by any untrained and unqualified personnel, will yield misleading data with unacceptable errors and uncertainties.

This is not your average infrared thermography job!
If you can't take the heat, get out of the Reformer!