Fired Equipment Operational Excellence Leveraging IR Thermography

Grant Jacobson, Becht, gjacobson@becht.com

Abstract

Infrared (IR) Thermography is a mature technology regularly used to inspect equipment in industrial applications from electrical equipment to heaters. One of the specialized branches of the field is its use on fired equipment to monitor conditions inside a firebox while in operation. Accurate thermography in these conditions is difficult but can be achieved with the proper equipment and analysis techniques. Most owner/operators may use IR Thermography for regular inspection, but this presentation will focus on applications past simple inspection. The data provided by thermography, while a heater is online, can be used to debottleneck equipment to capture more rate or margin while keeping it safe and reliable. This presentation focuses on a basic overview of the technology and real-world case studies of novel applications of IR to debottleneck equipment or prevent equipment damage. Units presented will include a steam methane reformer, delayed coker, crude atmospheric heater, and olefin cracker heater.

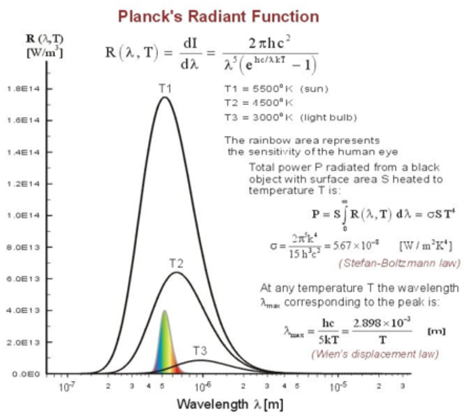
Introduction

Fired equipment (fired heaters, fired boilers, flares, and thermal oxidizers) are critical components in almost every major refining or chemical process unit developed. These fired systems tend to be a complex interaction of many disciplines including process engineering, combustion engineering, metallurgy/mechanical engineering, operations and inspection all playing a role in how the systems are operated and maintained. These core disciplines must interact consistently and effectively together to maximize the value of fired equipment while keeping it safe and reliable. “Siloling” information and not understanding the holistic nature of the equipment tends to lead to poor safety, reliability, and optimization of fired equipment which can easily cost a medium sized refinery (say 150 MBPD crude charge) 1 to 10 million dollars per year. A critical tool in monitoring and remaining proactive of process and mechanical concerns on fired heaters and boilers is infrared (IR) thermography. It is one of the most important tools to leverage across the cross functional support teams to maintain safety and reliability while challenging the equipment to valid operating limits to maximize margin capture. Many organizations use IR thermography via an inspection department, but the data may be of dubious accuracy and is commonly not acted upon or shared outside of the inspection department. By achieving high accuracy with IR thermography and engaging cross functional support teams there is money to be made!

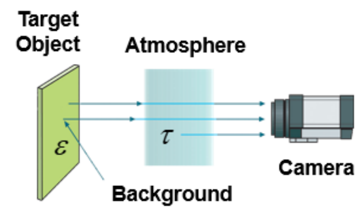
Discussion

High temperature IR Thermography was pioneered as a method for understanding tube temperatures inside fired equipment while in operation in the 1970-1980s. The initial urgency of its development was tied to tube failures resulting in safety and reliability events. A method to accurately measure and monitor tube metal temperature was needed to identify issues and prevent failures proactively.

Over time the equipment used for high temperature thermography has improved and it is now a mature technology. While the equipment continues to improve, completing accurate analysis of the data remains very challenging. It is complex to accurately measure tube wall temperatures due to the variable nature of surface scale, combustion characteristics, and reflected radiation. The underlying physics of how to correct for these factors can be understood by correct application of Planck’s Radiant Function and the Stefan – Bolzmann equation, shown below. Also critical to the analysis is understanding the underling process conditions of the subject heater. This complexity for correcting the data has led to inaccurate uses of thermography through industry, which in general erodes the technology's overall credibility. Given the correct equipment, proper application in the field, and correct data analysis, thermography can be very accurate. Some applications, with adequate data and leveraging the proper tools can be consistently accurate to within 5 degrees C of true operating conditions. This provides a very valuable tool to keep equipment safe and reliable, but also challenge operating conditions to capture high margin opportunities.



$$\Phi_{object} = \varepsilon \times \sigma \times T^4$$
$$(Stefan - Boltzmann\ equation)$$

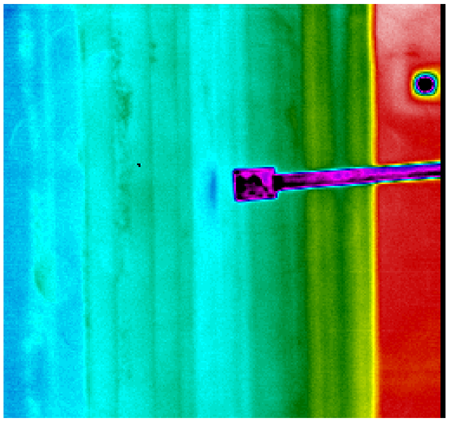
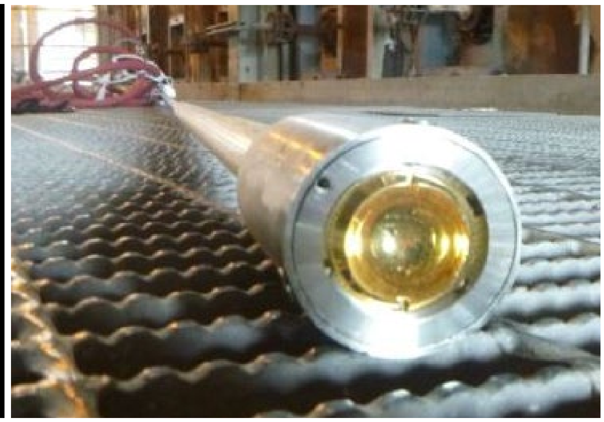


$$\Phi_{total} = \varepsilon \times \tau \times \Phi(T)_{object} + (1-\varepsilon) \times \tau \times \Phi(T)_{Background} + (1-\tau) \times \Phi(T)_{atmosphere}$$

The most common high temperature camera in use is the FLIR GF309. The older generation cameras, the FLIR/Intrametric PM series, are also still used but less commonly. Other technologies can be leveraged alongside the high temperature IR cameras to improve the correction quality. The most used tools for these corrections are handheld pyrometers and goldcup pyrometers. The goldcup pyrometer is a unique tool as it is water cooled to survive within a heater in operation and touches the tube to obtain a very accurate measurement of the tube temperature. The goldcup can routinely reach accuracy of 2-3 degrees C when applied correctly. By combining these different measurement tools, more complex situations can be monitored with high accuracy.

Above – High temperature IR camera and handheld pyrometer

Below – Goldcup pyrometer side view, head view, and IR image while in use



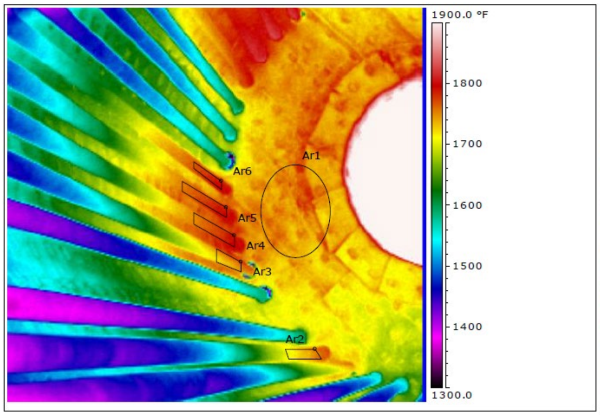
So how do you apply these tools to find high value improvements? Typically, areas of improvement are found by applying IR thermography on heaters with a history of poor reliability or of consistently being a limit for the associated process unit.   Routine IR checks tend to catch opportunities as well if the data is reviewed by process engineers and operations staff who are familiar with the process unit operation. Partnering with an IR provider who has a broad background in heater design/operations and process unit operations will also help flag opportunities for improvement and guide where focus will provide high value.

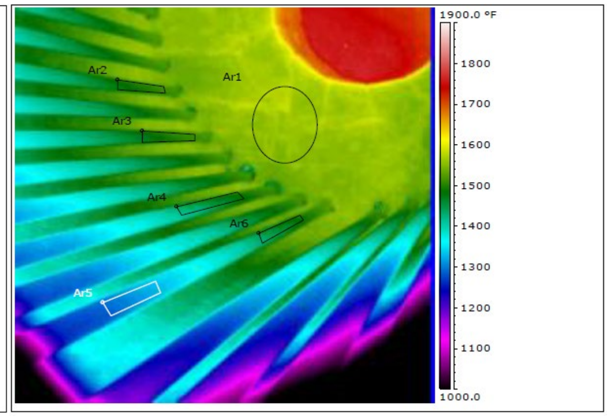
Case Studies

Steam Methane Reformer (SMR) – Hot Tubes Due to Catalyst Poisoning

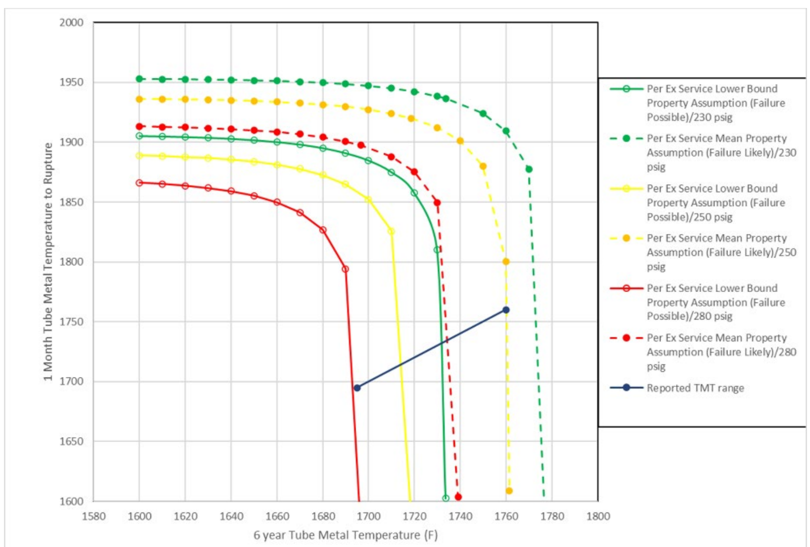
Steam methane reformers are one of the most severe firebox environments encountered in many refining or petrochemical facilities. The tubes tend to be a high alloy to survive temperatures up to 930 degrees C. To complicate matters each tube is filled with a catalyst which provides an endotherm when converting steam and natural gas to hydrogen and carbon dioxide. Short operation past the design maximum temperature of the tubes can lead to a quick and unexpected failure. The creep damage is exponential so operating just 40 degrees C over maximum design temperature can shorten tube life from 10 years to less than 1 year. Failures also tend to cause collateral damage to nearby tubes, with the leak of high purity hydrogen typically forming a blowtorch to then impinge and fail nearby tubes.

If the catalyst within the tubes is damaged or poised unexpectedly, tube temperatures can be quite high unexpectedly. The two IR images below are an example of one of these events, with the left side showing poisoned catalyst with hot tubes and the right showing that same area at similar hydrogen production but with healthy catalyst and much cooler tubes.





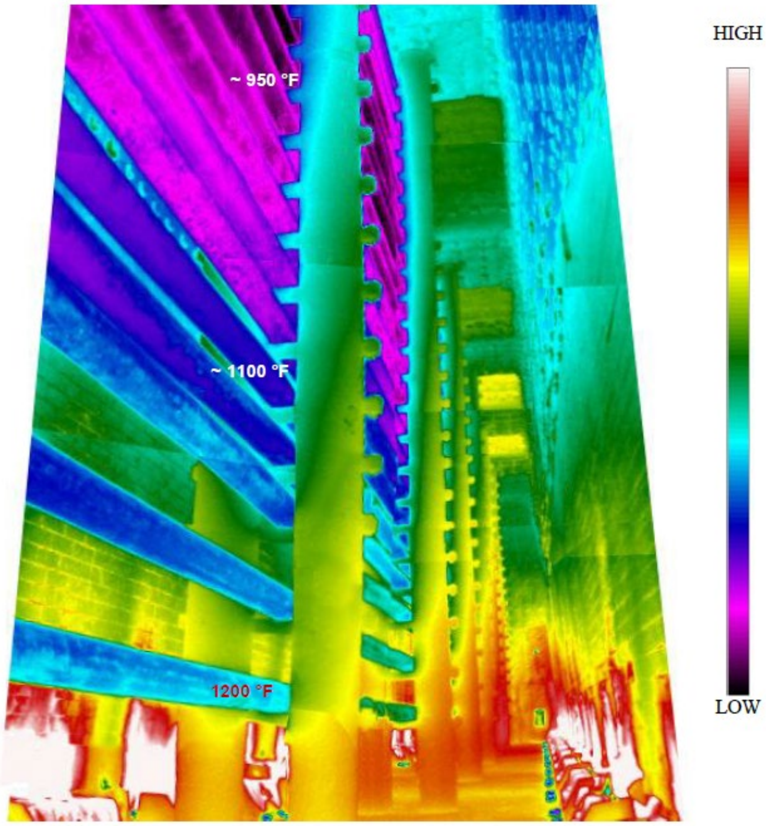
While the hot tubes could be noticed in the visible spectrum when looking into this firebox, IR thermography allowed measurement of the temperature excursion to then help quantify risk and drive optimizing the path forward. In this example, shift cases examining the expected time to failure at different temperatures and pressures were conducted based on the metallurgy and operating pressure, see example below.



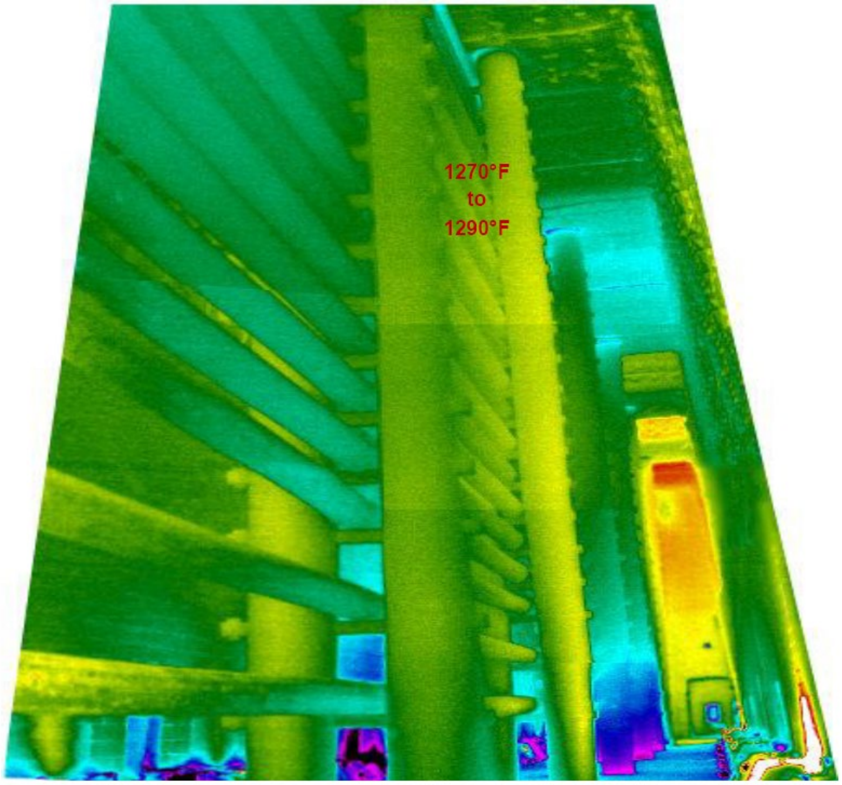
These cases helped show how long the tubes could be operated in this manner vs risk of a tube failure. This helped confirm the unit could operate for a few months with a low likely hood of tube failure but shouldn't run until the next major planned turnaround for this unit. The site then planned a limited scope catalyst change out before the next unit turnaround. Additional stress inspection of the tubes was also conducted, and spare tubes were on hand incase damage due to the temperature excursion was higher than expected. The additional time to perform a planned outage vs an emergency outage saved on costs and provided time to schedule the extra offline inspection and procure spare tubes. The extra stress inspection of the tubes showed no unexpected damage, and no tubes were changed out during the quick outage. Having the high accuracy IR data to support the tube life calculations was critical in understanding risk and optimizing the outage.

Delayed Coker – Accidental Heat Soak

In this example routine thermography caught an accidental temperature excursion on a traditional four cell delayed coker heater. Under normal operating conditions the temperature profile tends to present as sown in the composite IR image below.

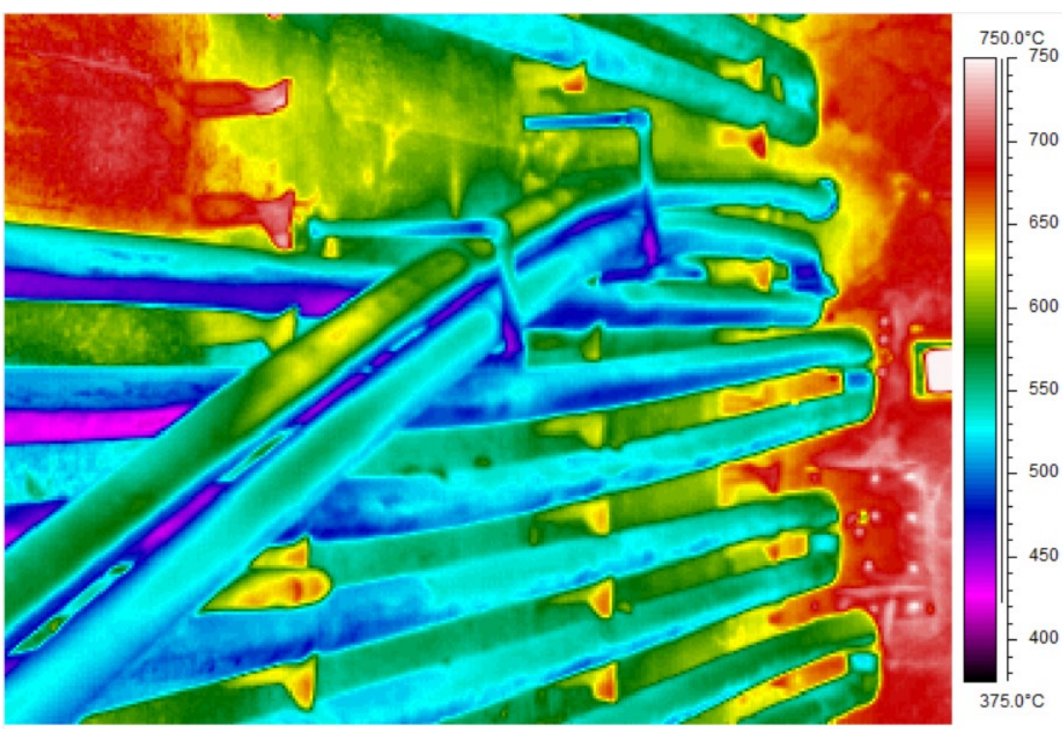


This heater block happened to have mule ears and one of the four passes had suffered a leak at one of these connections. There were only a few weeks left before a major turnaround, so the site decided to keep the cell with the mule ear leak in a hot standby mode until the outage and run the unit at lower throughput on the remaining three cells. The offline cell had boiler feedwater flowing through it to keep the tubes cooled while some burners remained online due to an integrated vent stream which had to be routed to the burners for destruction from a Merox unit. There were tube skin thermocouples installed across the pass, but primarily on the lower elevations as these are the highest heat flux locations during normal operations. The as found conditions of the pass operating in the hot standby mode is shown below. The water flow was low enough with the burners still online, that tube temperatures were operating near 690 degrees C. This was over the established maximum temperature of 675 degrees C and unfortunately due to the tube skin thermocouple placement it was not caught before the check with thermography. Short operation above 675 degrees C would not have caused any major damage, but operating in this manner for weeks will remove useful life from the tubes. By catching with the IR scan action was taken to lower temperatures and prevent damage.



Crude – Jumped Tubes and Leveraging High Accuracy IR to Bridge to Outage Window

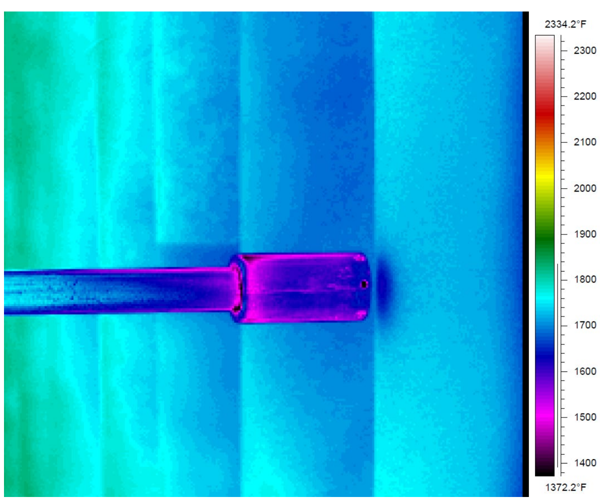
At times through operational upsets heater tubes can move away from supports and deflect in or down into the firebox. This example shown below is a case where a quick thermal cycle resulted in two tubes moving and partially falling on one wall of a four-pass cabin style crude heater.



The movement was caught quickly by the operations team and hooks and shelves were added to ensure the tubes remained secure and supported. As part of the stabilization effort a detailed creep and stress assessment of the deflected tubes was conducted. This assessment utilized previous operating temperatures, measured with thermography and tube skin thermocouples, to understand what conditions the shifted tubes could operate at and for how long. The analysis showed the tubes could operate safely to an upcoming planned maintenance window with the new supports if temperatures remained below 43 degrees C. Weekly temperature checks leveraging high accuracy thermography were utilized to ensure the updated operating temperature limit was adhered to until the shutdown for repair. With help from accurate IR the risks for continued operation were well understood and the system remained safe and reliable until the repair could be completed.

Olefin Cracker – Goldcup Pyrometers Combined with Thermography

Olefin cracking heaters are like the previously mentioned SMRs as they operate at very high temperatures with high alloy tubes to allow these operations. The extreme temperatures prevent practical use of tube skin thermocouples as the instruments can not remain reliable at the normal operating temperatures. Added to the complexity of this system is the propensity for coke to form internally which acts as an insulating later and increases the tube wall temperature. To ensure maximum operating temperatures are not exceeded non-contact pyrometers are an effective tool. Unfortunately, these pyrometers require proper adjustment of the target tube emissivity, reflected temperature, and viewing angle effects. In most cases without adjusting for these key parameters the temperature measurements will be higher than actual. Most operators conduct temperature checks with these pyrometers on a set frequency and this data is used to decide when a heater needs to be decoked.



The goldcup pyrometer, shown above in use, when paired with high temperature IR cameras can be used to back calculate the required corrections for more accurate use of non-contact pyrometers. Once these correction parameters are developed, they can be used by the operations team for more accurate tube temperatures. With the improved accuracy the system can remain reliable but decokes are not started before they are required. This helps capture increased run time and margin by preventing furnace downtime when cracked feed is not being produced for the downstream process equipment. While the IR thermography is not used routinely, it is a critical piece for developing the right corrections to make the non-contact pyrometer a more accurate tool.

Conclusion

High temperature thermography is a very helpful tool when used correctly as a method to help frame risk and optimize heaters. Thermography may only tell the user temperatures, but if this data is integrated into the bigger picture of a subject heater it will identify and capture opportunities for better operation or understanding risk of operating conditions.

Author Info

Grant Jacobson is currently the Division Manager for Becht Fired Heater Services. His previous experience was in process engineering and operations management at Valero and ExxonMobil. He participates as a voting member on API 560 and holds a bachelor's degree in Chemical Engineering from the University of Nebraska.