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ACHIEVING A COMPREHENSIVE FIRED HEATER HEALTH MONITORING PROGRAM

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INTRODUCTION

For the past 30 years, infrared (IR) thermometry has been used to monitor tube metal temperatures in refining and chemical furnaces. Tracking temperature levels and variations determine performance capability limits and reliable tube life. However, the application of IR thermometry has often been characterized as highly operator dependent, which can result in less-than-optimal data accuracy as a consequence of poorly applied and interpreted results.

IR thermometry is an excellent diagnostic tool for detecting tube hot spots from internal fouling or non-uniform heat distribution in fired heaters, but to ensure the full capability of IR thermometry, operators should employ the right instruments for the job and implement a proven methodology to measure accurate temperatures in a repeatable process. With an effective IR thermometry health monitoring program, operators can manage the mechanical integrity of fired heaters and optimize production rates.

INSTRUMENT TYPES

IR thermometry is primarily accomplished with two instrument types: thermal imaging cameras and pyrometers. A thermal imaging camera forms a two-dimensional thermal image of the target surface, while a pyrometer provides only a single target point temperature. Because each instrument has its own inherent advantages and disadvantages, an effective inspection program should incorporate both types of instrumentation. For example:

Figure 1. Imaging camera

Figure 2. Pyrometer

- The imaging camera should be used to provide meaningful images and measurements for a historical record that can be used to assess tube creep damage rates and long-term performance changes.
- The pyrometer should be used for accurate field measurements to compare specific tubes and troubleshoot real-time performance issues.

MEASUREMENT FACTORS

All infrared measurements, whether made by an imaging camera or pyrometer, are subject to measurement factors which can affect the accuracy and repeatability of the measurement. The fired heater's environmental measurement factors are the target tube's emissivity, target reflectance, and the flue gas effect on the measured temperature. The instrument factors affecting the temperature measurement are the instrument infrared wavelength, calibration, size of source effect, vignetting, and the emissivity setting. Each of these factors must be understood to achieve an effective infrared inspection program. Without an adequate understanding, measurement errors as much as 180 °F can occur, which also affects the repeatability of the measurements.

Fortunately, a comprehensive and effective infrared health monitoring program designed for fired heaters (or reformers) can account for these measurement factors. By following simple field data collection practices and then applying rigorous correction calculations, the tube's surface temperature can be accurately measured. This process allows any operator using either IR instrument to collect repeatable tube temperature measurements. The correction calculations employ algorithms based on well-established physical principles of blackbody infrared radiation and radiation exchange, including a specific geometrical model of the subject fired heater and characteristics of the measurement instruments. Software is now commercially available that can automate the rigorous correction calculations.

Infrared measurement factors that should be considered are:

- True tube temperature—desired outcome
- Environment factors—tube emissivity (including angle of incidence), target reflectance (including fired heater geometry) and flue gas absorption and emission
- Instrument factors—wavelength, calibration and size of source effect, vignetting and instrument emissivity setting

ENVIRONMENTAL FACTORS

Emissivity (ε). As an environmental factor, emissivity refers to the ratio of radiation flux emitted by the target tube to that emitted by a blackbody at the same temperature as the target. For example, an **ε** of 0.85 absorbs and emits 85% of a blackbody radiation amount at same temperature and reflects 15% of the surrounding radiation. Emissivity is a surface phenomenon and is affected by radiation wavelength. Target tube **ε** is typically 0.85 (@ 1μm), 0.82 (@ 3.9μm), but it can vary depending upon the condition of the tube's surface.

Reflection. Reflection errors occur inherently due to the emissivity of the target tube. The reflected radiation from the tube is captured by the instrument and must be removed from the measured radiation to achieve the desired outcome. Imaging cameras that include reflection error correction assign one number to describe all of the surrounding objects. Reflection error cannot accurately be represented by one number. The effective background temperature depends on the geometry and position of the target tube and is a weighted average of the sum of all of the surrounding surfaces like walls, the floor, roof and tubes.

Flue gas effect. Absorption and emission errors can be introduced via flue gas (atmospheric) as the target radiation travels from the tube to the instrument. Specifically, spectral emission lines, at which radiation is absorbed and emitted by flue gas, must be taken into consideration. By selecting the appropriate instrument, the flue gas effect can be minimized, but not eliminated. The magnitude of flue gas absorption and emission errors is affected by the flue gas temperature and the travel path length. Operators who measure the same tube over two different path lengths should be able to identify the effect.

INSTRUMENTAL FACTORS

Wavelength. The wavelength of the instrument is chosen based on the expected target tube temperature and to minimize the flue-gas emission errors. For fired heater applications, either a 1μm or 3.9μm wavelength instrument should be used.

Emissivity setting. Most instruments have the ability to set an emissivity value. Since the instrument is calibrated to a blackbody temperature, the emissivity value of the target tube must be applied to correct the indication. As discussed, reflection errors significantly affect the radiation from a target tube's surface, causing the target tube's apparent (or effective) emissivity to be higher than its inherent surface value. Setting the instrument's emissivity value to the inherent target value will not adequately correct the indication from a blackbody value to the target's value. For this reason, it is recommended that the instrument emissivity setting be set to 1.0 (assumes the target is a blackbody) and then apply correction calculations outside of the instrument for target emissivity and reflection error. The tube's radiance temperature (i.e. total emitted and reflected radiation) is measured when instrument $\boldsymbol{\varepsilon}_1 = 1.0$.

Size of source effect. Ideally, the instrument should detect only the radiant flux within its well-defined field of view. Yet, the reality is that some of the flux that is within the field of view will miss the detector, and some of the flux from outside the field of view will be detected. This phenomenon is called size of source effect (SSE). Some factors of SSE correction to consider are:

- Imaging cameras have a large SSE correction, primarily due to the large surface area covered.
- Pyrometers usually have a small SSE correction (i.e., can be ignored).
- SSE correction for each instrument must be laboratory measured and then applied to radiance temperature measurements.
- The SSE typically causes the radiance temperature to be higher than the actual radiance value.
- To minimize SSE error, operators should keep lens dust and scratch free and ensure that the field of view is well overfilled with neighboring objects at the same temperature as target area.

Vignetting. Vignetting refers to the obscuring of the lens' field of view, resulting in a reduction in radiation falling on the detector (i.e., temperature reading will be low). This is a common problem for operators when they are working with furnaces and are looking through a sight door. Capturing portions of the sight door wall in the image will lead to vignetting.

PROVEN METHODOLOGY

To correct for common problems and ensure reliable and repeatable results, the following field data collection procedures should be followed:

- Set the instrument emissivity to 1.00 and the background to ambient.
- Determine the effect of flue gas absorption or emission on the thermometer readings.
  - Select the target tube that is viewable from two different sight doors.
  - Sight doors should have different path lengths to target tube and similar background.
  - Open sight doors and wait for the furnace to reach equilibrium; then take a series of measurements.
- Measure short-term target temperature fluctuations by selecting one tube and record the temperatures.
  - Can be the same tube used to measure flue gas effect.
- Measure radiance temperature of target tubes.
  - Take readings quickly to avoid target influence from open sight door.
  - Ensure that the tube is in focus and avoid viewing through flames.
  - Ensure that the edge of the sight door does not overlap the field of view.
  - Target tubes should overfill the focus circle and avoid capturing non-uniform temperature objects in field of view.
- Record the radiance temperatures of each surrounding object.
  - Follow image-sighting guidelines of the target tube.
  - Dividing the surrounding object into sampling parts increases the accuracy of the target tube temperature.

After the above field procedures, the collected data should then be corrected with rigorous calculations. For example, operators should correct the radiance measurements for emissivity and reflection error, SSE, flue gas emissions and other instrument and environmental errors. They should calculate the uncertainty associated with these factors. And they should calculate the effective background temperature taking into account the geometry for each target tube.

IR TEMPERATURE CORRECTION CASE STUDIES

The following two case studies show operational improvements using an IR temperature correction program to manage the health of reformers and fired heaters. Software is used to automate correction calculations in order to remove common errors from IR thermometry tube temperature measurements.

Reformer case study. The first case study focuses on a complex refinery with more than 40 fired heaters. The refinery's hydrogen reformer was challenged with tube metal temperatures that were limiting hydrogen production. In addition, poor heat distribution constrained output. The operator was also concerned with the equipment's creep damage rate.

- In 1998, the refinery implemented a full-time heater health monitoring program with an on-site contractor.
- In 2003, the operator shifted the program to part-time monitoring, serviced by an on-site NDE contractor.
- In 2011, the refinery implemented the above-described IR temperature correction program to improve accuracy and repeatability of IR measurements.

As part of the program implementation, the on-site NDE contractor was trained in proper IR data collection procedures and software applications. The IR camera SSE error was measured and corrections were applied. The corrected temperatures were well below operating limits, therefore the reformer operation was continued at the same production rate, and the creep damage rate concerns were alleviated (see **Table 1**).

Table 1. Uncorrected temperatures versus the corrected temperatures for the hydrogen reformer tubes.

Statistic, °F	Conventional Uncorrected Temperature	Corrected Temperature
Maximum	1757	1659
Average	1656	1574
Minimum	1547	1467
St. Dev.	63	41

Fired heater case study. The second case study focuses on a complex refinery with more than 20 fired heaters in practically all possible services. The refinery operator wanted to increase the plant's run length between decokes of the coker heater. The run length of the coker heater was limited by skin thermocouple indications (TI). The IR monitoring activities at the thermocouple locations indicated that the thermocouple readings were too high.

In 2010, the refinery began a heater health monitoring program with an off-site contractor performing periodic routine monitoring. In 2013, the refinery shifted the program to in-house NDE staff performing the routine monitoring and implemented the above-described IR temperature correction program to improve the accuracy and repeatability of IR measurements.

As a result, a significant difference between actual tube metal temperatures and skin thermocouple readings were documented. Specifically, the skin TI readings were reading higher than actual.

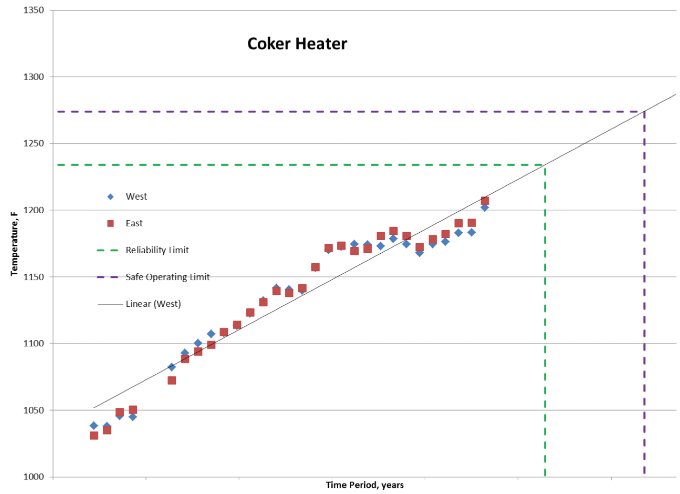


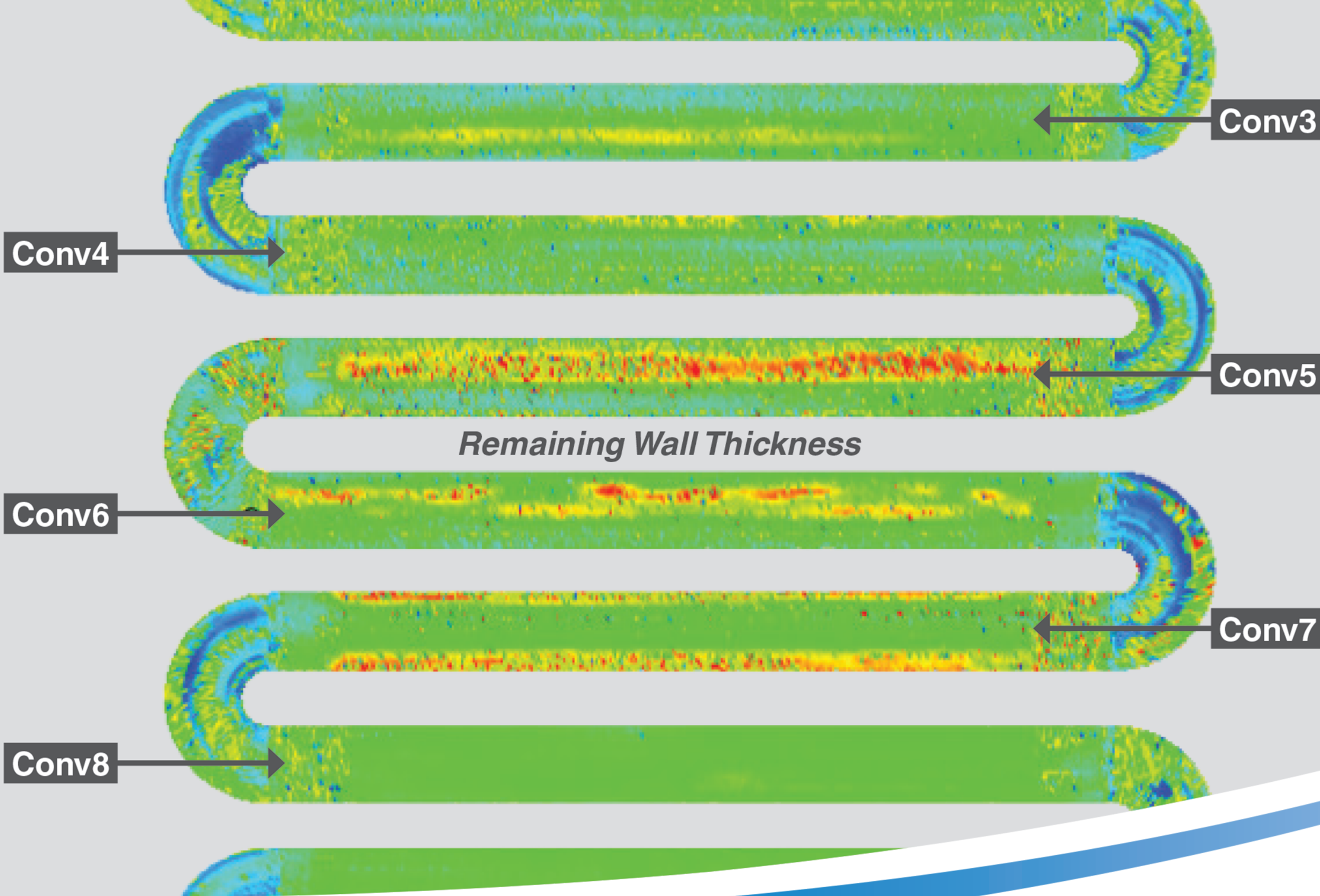
Figure 3. Tube metal temperature trend for coker heater allowing optimum de-coke planning to occur.

The IR temperature correction program confirmed the reading difference, thus the operator was able to gain confidence in the plant's tube integrity program by having accurate and repeatable data upon which to base decisions (see **Figure 3**).

CONCLUSION

Clearly, an effective infrared health monitoring program is an absolute necessity to monitor the integrity of the fired heater tubes, as well as provide a wealth of diagnostic information that may be used to evaluate the performance and reliability of major fired heater parts (e.g., tubes, tube supports, burners, refractory and structural systems). By fully understanding the IR measurement factors and employing field collection practices and IR temperature correction calculations, accurate and repeatable infrared temperature measurements are achievable.

For further information, see "Radiation Thermometry. Fundamentals and Applications in the Petrochemical Industry" by Dr. Peter Saunders, or email questions or comments to inquiries@inspectioneering.com. ■



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