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Inspect steam reformers and catalyst tubes with infrared thermography

Infrared thermography is a useful inspection tool to help locate problems in steam reformers while the units are online and fired. There are three main areas in a reformer that can be efficiently inspected with thermography. While there are common and codified inspection and diagnostic practices used in the industry today, some of these practices are unknowingly wrong and may have a large impact on the data collected over the years.

Before explaining how thermographers can inspect steam reformers, it is necessary to address what these units are, along with their main purpose in chemical and petrochemical plants. Steam reformer furnaces are used for hydrogen production. A hydrocarbon feedstock is mixed with steam and heated in the presence of a catalyst to produce crude hydrogen, which is then purified. The most common hydrocarbon feed is natural gas, but propane, butane or liquefied petroleum gas (LPG) are also used.

Steam reforming takes place in a steam reformer furnace. The furnace is usually a large refractory-lined box with gas burners, heating many catalyst-filled tubes that carry the feed (natural gas) and steam. Depending on the design, the reformer's firebox or cell may contain only a single row of tubes (**FIGS. 1** and **2**) or it may contain multiple rows (**FIGS. 3** and **4**), making it more difficult to obtain accurate temperature data.

Refractory and insulation problems.

The most obvious use of thermography on a steam reformer furnace is to consider refractory and insulation problems. Because of the high temperatures inside the reformer, the steel shell is lined internally with refractory material to prevent burn through, efficiency loss and structural failure.

When inspecting the refractory on a reformer, the key is to notice large differences in temperature. Many variations in temperature and thermal patterns will undoubtedly be found throughout various sections of the reformer, so knowing the construction, process flow, heat transfer principles and emissivity variables is very important in determining whether an indication is relevant or non-relevant.

Refractory furnaces are usually painted with a metallic silver paint (**FIG. 5**). Emissivity is an important issue when it comes to temperature accuracy. While many inexperienced thermographers and inspectors take emissivity for granted, temperature accuracy is an important aspect of reformer refractory inspection, as it assists design and plant engineers in troubleshooting safety and efficiency problems.

The low emissivity of the paint not only poses a temperature measurement problem, but it also poses a relevant indication determination challenge. Surrounding a reformer is a melee of hot flanges, piping, and vessels that can easily be reflected off the surface of the paint, resulting in false indications. Plant inspectors using spot radiometers often misinterpret reflection problems as true indications. Also, changes in paint surface conditions due to scrapes, scuffs and charring can result in emissivity changes and can show a $\Delta T > 40°C$, easily confusing an inexperienced thermographer and leading to data misinterpretation.

FIG. 1. A horseshoe-type design with one row of tubes per firebox/cell.

FIG. 3. Single firebox-type design with multiple rows of tubes in one firebox/cell.

FIG. 2. Side view of a horseshoe design reformer.

FIG. 4. Side view of single firebox/cell design reformer.

With reformers, the most common areas for refractory problems are at the peepholes (**FIG. 6**), burners, manways and penthouse roof flooring, although it is not uncommon to find problems in other areas.

Burner firing efficiency. Because the main driving force behind steam reforming is heat, a reformer has many burners (usually natural gas burners) that fire directly into the fire box. A reformer is usually fired from either the top or sides or sometimes both.

The way a burner fires is crucial to the reformer efficiency and to the service life of the refractory and catalyst tubes. Ideally, the flame will fire inside the box, but not impinge on the tubes.

FIG. 5. Low-emissivity silver paint common on reformers.

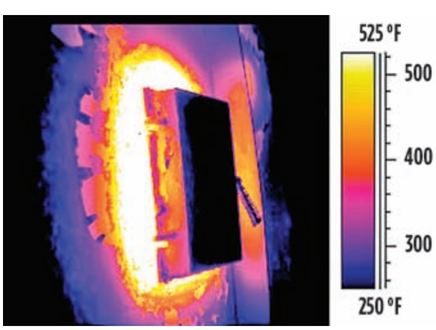

FIG. 6. Thermal image of refractory failure located around a peephole.

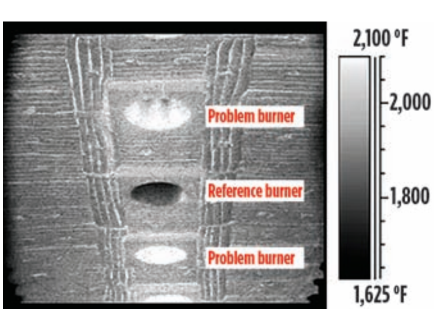

FIG. 7. Thermal image showing flame impingement on burner tiles due to improper or defective burner injector tips.

When inspecting inside a reformer with thermography, a 3.9-micron filter is used to see through the gas flames. Although the flames will not be visible during the inspection, the flame's thermal pattern from the surrounding tubes, walls and burner tiles can be observed.

Performing a thermographic survey of the burners and burner tiles can help determine whether the injectors used are functioning properly, if the burner is firing and if the burner tiles are overheating (**FIGS. 7** and **8**). Proper burner firing is important to maximize the efficiency and service life of the reformer and reformer tubes.

Reformer catalyst tubes. This part of the inspection is one of mystery, controversy and misconceptions. The main problem with inspecting reformer tubes is attempting to determine the tube surface's actual temperature. It is common knowledge that the most effective way to use thermography to ascertain temperature accuracy is via means of reference. This usually means using a contact thermometer or a known emitter.

The problem with reformer tubes is that obtaining reference temperatures is easier said than done. Depending on how many tubes and rows there are in the reformer, obtaining reference temperatures to cover all tube areas is usually impractical. One controversial issue is how to take the best reference temperatures. Some argue that embedded thermocouples are best, while others vow that a gold-cup pyrometer is better for the job. Some folks even fabricate their own reference coupon from the same tube material.

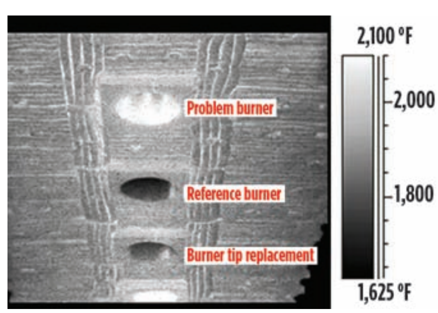

FIG. 8. Thermal image displaying replacement of a new design burner injector tip, solving the flame impingement problem of the burner tiles.

FIG. 9. Single-point (spot) infrared pyrometer.

It may be surprising to learn that although temperature accuracy is extremely important with reformer tubes—with the industry rule of thumb being that every 20°C rise above the maximum design temperature of a tube halves the tube life—temperature accuracy is not required to identify and diagnose most tube problems.

Single-point infrared pyrometers. Almost every petrochemical plant uses a portable, handheld spot infrared pyrometer to trend and monitor tube temperatures (**FIG. 9**). The main reason plant engineers and operators use these devices is because they are relatively inexpensive and easy to use. They are also very accurate and stable; they are almost never used properly by plant engineers and operators. Users have the notion that all they have to do is aim, pull the trigger and get a temperature. Many fail to understand that these instruments are infrared thermometers and are susceptible to the same errors as thermal imagers and other infrared thermometers.

Spot-infrared pyrometers are very useful to plant personnel and do help tremendously in "trending" reformer tube temperatures. However, knowing the equipment limitations and basic infrared theory is extremely important and definitely required before anyone uses these devices to monitor reformer tube temperatures.

Application and equipment training programs specifically geared to the plant operator and engineer on the proper use of spot-infrared pyrometers are important (**FIG. 10**). From observing a wide array of training programs across a variety of companies, it has been determined that temperature consistency within 1°C to 6°C has been achieved from operator to operator, where previously it was an average of 20+°C (**FIG. 11**).

On some reformers, temperature accuracy cannot be achieved on certain tubes using spot-infrared pyrometers, mainly because of spot size limitations. That is why it is better to be consistent and precise rather than accurate when it comes to operators and plant inspectors trending reformer tube temperatures on a frequent basis. With a consistent and precise temperature trend, inspector error, calibration drifts and minute variations in tube temperatures can quickly be identified. If problems can be identified quickly, then corrective measures can be taken and there will be much less chance for an actual tube problem to go unnoticed.

Accuracy can come later on, during troubleshooting or diagnostics of problems found during routine trending and monitoring. This approach is usually recommended because achieving temperature accuracy for most reformer tubes can be an expensive and a time-consuming job. This makes it impractical and unfeasible for most routine tube monitoring programs by operators and plant inspectors.

Although spot-infrared pyrometers are invaluable and extremely cost-effective tools, they should be used regularly by plant personnel to grasp the temperature trends of their reformer tubes. Complete thermographic survey using a radiometric imager should always be performed. This is because an imager will be able to locate and diagnose tube problems, while a spot-infrared pyrometer cannot. The pyrometer can only give a temperature measurement at the point it is aimed. To locate and diagnose tube problems, a complete thermal pattern and profile of all relevant tubes should be viewed.

Thermographic imaging survey. With reformer tubes, operators are looking for overheating problems. Some common problems that can be found with thermography are:

- Flame impingement (**FIGS. 12** and **13**)
- Gas flow restriction
- Burner associated issues
- External tube scaling
- Catalyst problems
- Afterburning (gas from burners or tube leaks).

Can thermography be used to locate reformer tube leaks? Finding such a leak is somewhat tricky, but not impossible. Although the leak may not be seen, there are some telltale signs to look for. These include: localized flame impingement, due to afterburning at a location where there is not supposed to be any; and localized cooling of the refractory wall or an adjacent tube, indicating that a surrounding tube is leaking (**FIGS. 14** and **15**).

As mentioned earlier, there are various reformer designs. This means that there

FIG. 10. Plant operators and inspectors approach a reformer for hands-on single-point infrared pyrometer training.

FIG. 11. Plant operators and inspectors applying the knowledge learned during training.

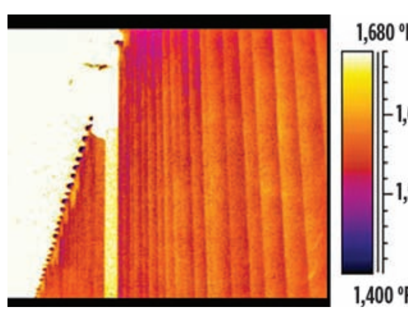

FIG. 12. Side view of reformer tubes in a certain row showing normal thermal patterns.

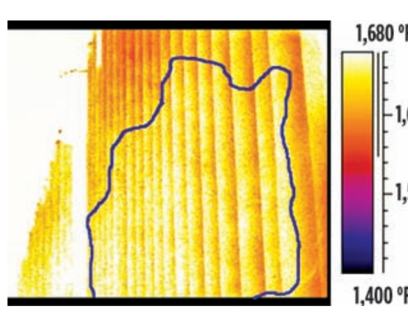

FIG. 13. Same reformer as Fig. 12, but a different row showing flame impingement problems due to damaged burners.

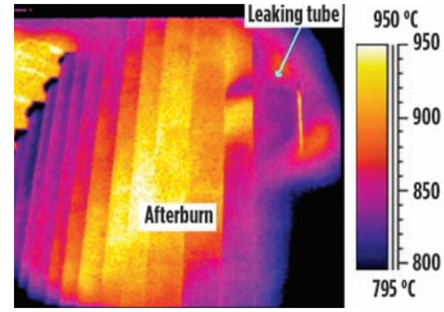

FIG. 14. Leaking tube detected by cool band on adjacent tube and localized afterburning of hydrogen gas.

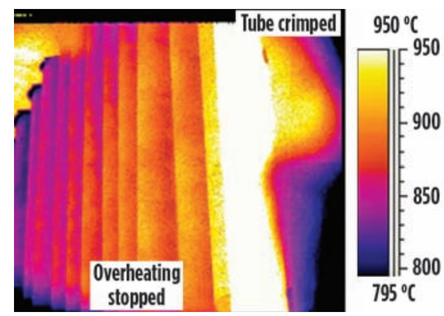

FIG. 15. The same leaking tube as Fig. 14, crimped while online. This stopped the afterburning and tube overheating with no downtime and no failures.

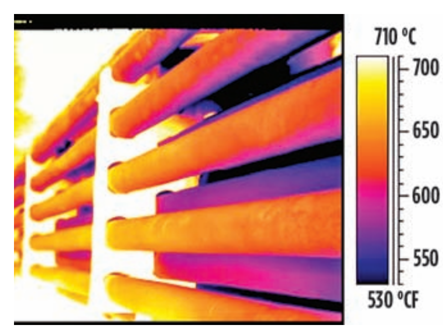

FIG. 16. Horizontal convection section reformer tubes in a horseshoe design reformer.

FIG. 17. Location of multiple reformer tube rows and pigtail tube sections within a single firebox reformer.

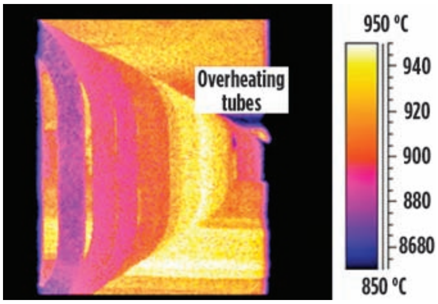

FIG. 18. An overheated pigtail tube section.

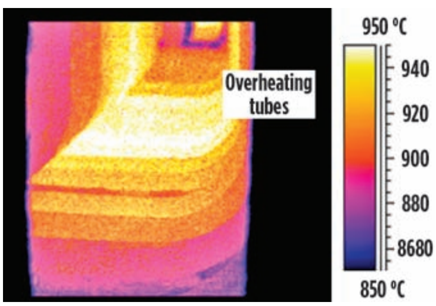

FIG. 19. Another overheated pigtail tube section.

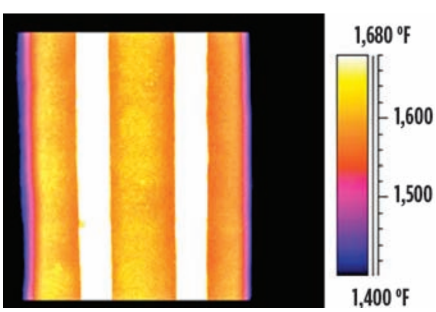

FIG. 20. Direct view of reformer tubes from peepholes give better temperature accuracy, but it is more difficult to diagnose problems due to limited field of view for a complete thermal profile.

are also various tube configurations. A reformer can have vertical tubes or horizontal tubes. One such example is the convection section within a horseshoe designed reformer (**FIG. 16**).

Pigtail-reformer tubes can also be

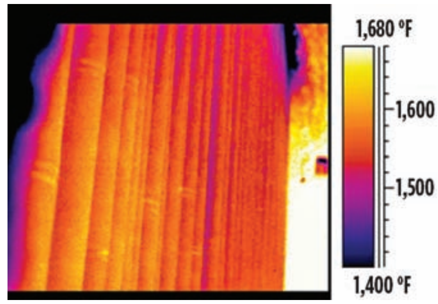

FIG. 21. The same reformer tubes as Fig. 20, with a side view from parallel peepholes to give a complete thermal profile making it easier to diagnose problems. However, this decreases temperature accuracy due to viewing angle.

inspected. Pigtail tubes are the smaller tubes that are external to the furnace and connect the reformer tube to the supply and exit manifolds (**FIGS. 17–19**).

A meaningful tube survey. Reformer tube inspection is sometimes said to be an art. There is so much that can happen inside a reformer and not all infrared equipment can effectively deliver useable data. To conduct a meaningful thermographic survey or even a spot-infrared pyrometer survey, know the equipment limitations. Limitations are what make reformer tube inspections difficult. Inspectors often run into problems because they do not identify these issues. The biggest limitations are:

- Untrained and inexperienced inspectors
- Equipment spot sizes
- Equipment wavelengths
- Equipment optics and imaging capabilities
- Equipment overheating
- Access
- Viewing angles
- Distances
- Fields of view
- Tube sizes
- Tube orientations.

To achieve a meaningful reformer tube survey, first determine the survey's desired result (**FIGS. 20** and **21**). Then identify any limitations before and during the survey, and know how to correct or avoid them. Reformer tube inspections may seem difficult and require thermographers who can think and adapt to ever-changing conditions, but the information that is gathered during a proper infrared survey is worth every penny to the plant and every eye-stinging bead of sweat to the thermographer.

Proper inspection and training. Steam reformer furnaces are high priority pieces of equipment. A failure in any of the three areas discussed can result in a loss in efficiency or even a total unscheduled plant shutdown. Repairs can be very simple to very extensive, requiring days and sometimes weeks of downtime. Proper and regular thermographic inspection of a reformer's three key areas is essential to the operation and life of the unit.

No matter what infrared equipment is used, proper training and experience are essential. Without proper training and guidance, too many important factors are frequently taken for granted or are unknown to the inspector. These unknowns may lead to premature failures or a loss in total confidence in the reliability and effectiveness of infrared technology. HP

SONNY JAMES is founder and owner of Thermal Diagnostics Limited and the NDE Institute of Trinidad Ltd. Both are located in Trinidad and Tobago. He is an American Society for Nondestructive Testing (ASNT) nondestructive testing (NDT) Level III certificate holder in various NDT methods (including infrared) and is American Petroleum Institute (API) 510 certified. Further, he is accredited as an American Welding Society (AWS) certified welding inspector.

Mr. James has over 20 years of experience inspecting reformer and heater tubes and has established tube inspection and monitoring training programs for the petrochemical and chemical industry. He is routinely called upon by plants around the world to help troubleshoot reformer and heater tube problems and to come up with solutions for in-house temperature monitoring and accuracy programs. Mr. James is considered as one of the few specialists and experts in reformer and heater tube temperature diagnostics.