Big Strides in Refractory Management: Improved Infrared Hardware and Software

By

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In 1983 we prepared to conduct an infrared inspection of the insulation system for two electrostatic precipitators at an 1800-Megawatt generating station in Louisiana. In order to perform this evaluation we used an Inframetrics 520, a colorizer, two monitors, batteries and related equipment, all mounted on a four wheel cart. This setup weighed 103 pounds.

At that time, the instrumentation provided isotherm measurements, rather than direct temperature measurements, so we brought a “portable computer” to perform temperature calculations. This computer was an Osborne1, and weighed 28 pounds.

We then proceeded to maneuver this unwieldy setup around the station to obtain the necessary viewing angles. One hike included carrying the equipment to nearly the top of a stack to view top surfaces of the precipitators.

Needless to say, inspection of large refractory and insulation systems was a cumbersome and often backbreaking process.

Why go to all this trouble?

The answer, as with most predictive testing applications, is money. Insulation/refractory system failures can result in expensive process interruptions. In many vessels, the question is not ***whether*** the insulation or refractory might fail, but ***when***. Traditionally, vessel operators have scheduled outages for physical inspection and repair. This is a potentially costly approach for the following reasons:

1. There may be no failures, in which case the process outage was unnecessary.

2. The failures may not be obvious from physical inspection (failure may occur at intermediate insulation or refractory layers).
3. Despite best efforts, a failure still may not coincide with the repair outage, resulting in an unplanned production outage.

The traditional method can be readily improved upon through the use of infrared inspections. The infrared imager produces a video picture of surface temperatures. Refractory or insulation failures typically cause a vessel's exterior surface temperature to rise. Thus, developing problems can be readily identified while the process is in operation. Using infrared, failures can be anticipated and repairs scheduled when needed.

Equipment Advances

In contrast with the scene described above, the current generation of infrared equipment and software has greatly facilitated every aspect of the inspection process. This includes both data acquisition and report preparation.

The newest instruments use focal plane array detectors. These detectors have resulted in the development of very small, highly portable instruments. The image quality of these instruments has made substantial advances over earlier instruments. The high portability of these instruments is of great value to vessel inspections. Generally, the vessel must be observed from various locations on a number of elevations. Obviously, climbing around process equipment is far easier and safer with a totally contained, six-pound package than with 100 pounds of instrument and cart.

Most focal plane instruments can produce at least a spot temperature measurement on screen. However, the most advanced instruments are completely radiometric, that is, a temperature measurement may be obtained at any pixel. Field temperature measurements can be made instantly so that temperature trends can be immediately evaluated. On board color display capabilities allow temperature trends to be more readily observed than traditional black and white images.

The use of additional infrared imager lenses is critical for minizing inspection time and assuring the best possible spatial resolution. We generally produce a hard copy report that shows all vessel surfaces. The images are obtained as a series of pictures saved to the built-in PC memory card. The evaluation process is accelerated by acquiring the smallest number of images consistent with a minimum spatial resolution (for example, detecting a minimum hot spot size of 2"). Reducing the number of images saves time during data acquisition and then saves even more time during report preparation. The use of a wide-angle lens permits a minimal number of images in confined spaces. The use of a telescope lens allows large surface areas to be viewed from a distance, often without changing the observation position, while retaining the desired spatial resolution.

Figure 1 shows all of the equipment required to perform a comprehensive survey: the imager, a telescope and wide angle lens (worn on belt) and a digital camera. The entire set of equipment weighs approximately 12 pounds.

Figure 1:Inframetrics Therma-cam, digital camera and lenses

Report preparation

Vessel reports should show all surface areas so that future performance changes can be readily spotted. Printed images should use a consistent temperature scale be used for an entire project, so that color infrared images from all vessel areas may be easily compared.

The most useful report presentation shows large surface areas. The use of large surface areas permits thermal trends and patterns to be readily seen. In general, images are taken of relatively small areas in order to maintain acceptable spatial resolution. In order to portray large surface areas, images must be grouped for display.

In the past, we achieved this effect by arranging color infrared and visual photographs side by side on the page. The visual photographs were important so that spatial relationships and locations on the individual infrared images could be understood. This process necessarily produced a disjointed view of the vessel.

The development of digital image processing permitted images to be easily printed with complete temperature annotations. With the current generation of infrared imagers, digital images are saved on PC cards. The images from these cards are then transferred to a host computer. The computer than colorizes the images, measures and annotates temperatures, and prints the final picture. However, this will still produce a presentation consisting of numerous separate images.

At least one instrument vendor has effectively solved the problem of showing a continuous large surface. The vendor has developed software that “mosaics” the individual images. The mosaic process operates by joining adjacent infrared images at three user selected “handles” on each image. A total of 16 images (a four image by four image array) can be joined into a single, continuous infrared picture. The software automatically adjusts the temperature span of the individual images to provide a single range for the entire picture. Although a large area is shown, the spatial resolution of the original images is retained. Any area of interest can be readily resized for closer study. Finally, image subtraction may be used to compare temperature changes between the large image areas over time.

Figure 2 shows a mosaic image of a refractory lined duct. The image consists of 4 individual images. The gradual temperature changes across the entire structure can be readily assessed in a single picture. This greatly facilitates present and future analysis.

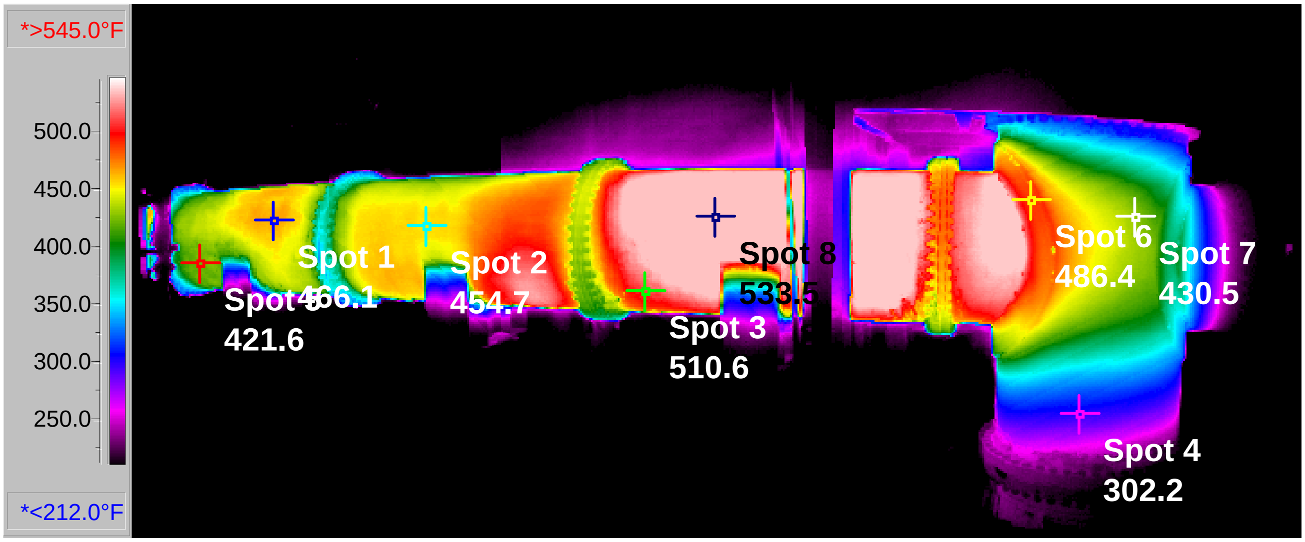

Figure 2:Insulated duct, 60' across, four images in mosaic

Inspection Considerations

In order to obtain useful results, the infrared thermographer must understand the construction of the vessel under study, the types of failures that might occur, and their range of impact on surface temperatures.

Vessel Surface Treatment-The most obvious characteristic and often most critical element of vessel construction is the exterior surface. All materials have a characteristic called emissivity. Emissivity describes the relative amount of infrared energy produced by a surface. In general, a surface that is not a shiny metal will have a high emissivity. A shiny metal surface will generally have a low emissivity. A material with low emissivity will emit a relatively low level of infrared energy when compared with a high emissivity surface at the same temperature. The low emissivity surface will reflect the surrounding temperatures. Thus, in general, for two surfaces with equal temperatures, the high emissivity surface will show a higher temperature in the infrared imager than the low emissivity surface.

Insulated vessels may be clad with shiny metal lagging or painted with aluminized paint. These surfaces can have a very low emissivity. As a result, the vessel will emit very little infrared energy. Much of what is seen in the infrared imager will be heat reflected from adjacent surfaces. Identifying refractory problems on these shiny vessels, without further surface preparation, may be impossible.

Low emissivity surfaces tend to become dirty over time. The dirt raises the emissivity wherever it accumulates. This produces hot spots in the infrared imager. These hot spots can be confused with refractory failure. Visual comparison between hot spots and dirt accumulations is usually sufficient to avoid characterizing dirt as a refractory failure. When in doubt, a surface temperature reading may be obtained using a thermocouple. Obviously, a real hot spot will have an elevated surface temperature, while the dirt spot will have the same temperature as adjacent, low emissivity surfaces.

On vessels with low emissivity surfaces, it may be practical to change the surface emissivity by applying temporary high emissivity treatments. These can include paint, masking tape, foot powder or other materials.

Vessel Construction-Often, the infrared thermographer is looking for a an outstanding hot spot as a sign of refractory failure. In fact, substantial refractory failure can result in small surface temperature changes due to the complex nature of an insulated vessel.

An insulated vessel often has several layers of refractory and insulation. Each component contributes a portion of the thermal resistance (R-value of the structure). The temperature gradient through the complex system can be calculated to determine the influence of each insulating layer on the exterior surface temperature. The data below is developed from an incinerator. The incinerator insulation system consists of firebrick, castable refractory and mineral wool. The outer wall of the incinerator is steel plate and is ignored.

These data are calculated assuming an interior temperature 1,550^{o}F. and an exterior ambient temperature of 82^{o}F.

Component	**R-Value**	**% of Total R**	**Layer Temp Change**	**Layer Temperature**	
			(Deg F.)	**In(^{o}F)**	**Out(^{o}F)**
CASE 1:Normal Operation					
Brick	0.48	0.03	40.27	1,550.00	1,509.73
Block	4.10	0.23	343.93	1,509.73	1,165.80
Wool	12.22	0.70	1,025.08	1,165.80	140.72
Air Film	0.70	0.04	58.72	140.72	82.00
Total	17.50	1.00			
CASE 2: Fire Brick Failure					
Brick	0.00	0.00	0.00	1,550.00	1,550.00
Block	4.10	0.24	353.63	1,550.00	1,196.37
Wool	12.22	0.72	1,053.99	1,196.37	142.38
Air Film	0.70	0.04	60.38	142.38	82.00
Total	17.02	1.00			
Case 3: Fire Brick and Castable Refractory Failure					
Brick	0.00	0.00	0.00	1,550.00	1,550.00
Block	0.00	0.00	0.00	1,550.00	1,550.00
Wool	12.22	0.95	1,388.46	1,550.00	161.54
Air Film	0.70	0.05	79.54	161.54	82.00
Total	12.92	1			

Using the infrared imager, with all components functioning and a surface emissivity of 1, we would read a surface temperature of 141^{o}F. If the interior firebrick fails completely, we would read a surface temperature of 142^{o}F. If the brick and castable refractory fails, we would obtain a surface temperature of 162^{o}F. As a practical matter, failure of the interior brick would not be detectable. A failure of the brick and a portion of the castable will be detectable. If the brick and castable fails completely, the mineral wool will be destroyed by the elevated heat. Thus, temperature increases greater than 20^{o}F would mean that a catastrophic failure of the system is developing that will result in failure of the steel shell.

Other Factors-Other construction characteristics of an insulated vessel will produce elevated temperatures. Structural components often short-circuit the insulation system. These include shelves and bolts that support refractory or insulation. The hot spots produced by these components generally produce a uniform pattern around the vessel and are readily discerned. Thermocouple wells, access doors, and other ports will produce hot spots. Corners in the vessel, where surfaces form at angles of 90^{o} or less will produce elevated surface temperature due to non-uniform radiant cooling.

Thus, by understanding the construction of the vessel, and the impact of different material failures, the nature of the failure can be predicted by the temperature increase that is measured.

Additionally, the impact of the environment on the vessel must be understood. The surface temperatures of adjacent high heat sources (such as stacks or other vessels) can reflect off the test vessel and produce the appearance of higher temperatures. These types of false heat readings can be easily determined by shifting the viewing angle. False heat signatures will disappear. Nearby vessels or structures can also prevent cooling of target vessel surfaces, resulting in higher surfaces temperatures along the common exposures. Elevated winds will cause temperature differences to diminish or disappear. Outdoor surveys should generally not be attempted in winds over 15 mph.

In summary, when equipped with current generation equipment and software and a thorough understanding of vessel construction, infrared testing provides a cost-effective means of evaluating the performance of insulated vessels.