A Convincing Lesson on the Power of Convection Cooling

Figure 1. A set of 3-phase oil-filled circuit breakers (OCBs) seen from the outside (above) and another set (below) from the inside, with the oil drained, showing part of the bushing structure and contacts.

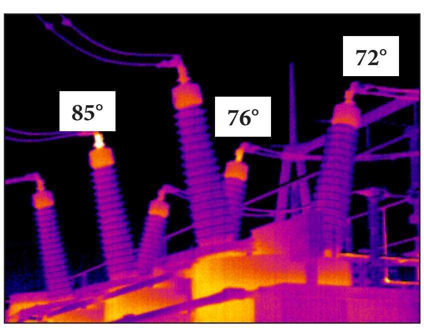

Figure 2. Taken during a 12MPH wind, two problems are seen; one obvious, one not. Both were given low priority.

Many factors influence the temperatures of surfaces we are inspecting with infrared thermography. One of the most significant is convective cooling by wind or air currents. Not fully understanding the complex relationship between surface temperature and convection can result in serious errors of interpretation. While the impact of wind is typically the most significant, air currents inside many plants are also common and, if not understood, confusing to interpretation. A simple, but convincing, example is offered here provide a valuable learning opportunity for all thermographers.

The Lesson

How often do we "learn" information but fail to incorporate it as knowledge? Having been involved in the business of training thermographers for nearly twenty years, we anticipate this by building plenty of "hands-on" activities into our work to drive home key points in an undeniable fashion. Once students are back on the job we know their continued learning will again be reinforced at the gut level by reality.

An excellent example recently came to us from one of our instructors who was doing a Level I onsite course at a large power plant on the coast of the Gulf of Mexico. During the class, the students conducted a hands-on field exercise and inspection of their large distribution substation. As is often the case along the coast, there was a steady 12 MPH breeze off the Gulf.

While inspecting a set of Oil filled Circuit Breakers (OCBs) in the switch yard, as seen in Figure 1 (left) for the powerplant, several students found a "hot spot" on the load side of the B-phase bushing; it clearly showed a temperature difference (ΔT) of 13°F over the normal phase. With loads running at maximum, as they were, this temperature rise was deemed a concern but not a high enough priority to warrant immediate concern. The students also noted an almost imperceptible anomaly on the line side B-phase which was indicated by a ΔT of only 4°F. Both anomalies can be seen in Figure 2 (left). Both appeared to be related to a threaded connection in the top of the bushing assembly.

The students had nagging concerns about the accuracy of the temperatures they had measured. "What if we're wrong?" they asked themselves in class that afternoon. They all felt assigning such a low repair priority for a piece of equipment that was this important might be a mistake. As part of the Level I course, they had just had an in-depth discussion on the impact of conducting a survey in the wind. They had learned about how Newton's Law of Cooling defines the relationships impacting convection, see Figure 3 (next page). They knew that the relationships determining "h" (velocity, orientation, surface, geometry, and viscosity) were interactive and complex. It was clear they were also difficult to quantify in a field situation like they had encountered without sophisticated software and the experience to use it. While they had heard of

$$q = h \bullet A \bullet \Delta T$$

In which:
q = heat energy transferred by convection
h = convective heat transfer co-efficient
A = area over which transfer takes place
T = the temperature difference between to surface and the convective medium

Figure 3. Newton's Law of Cooling

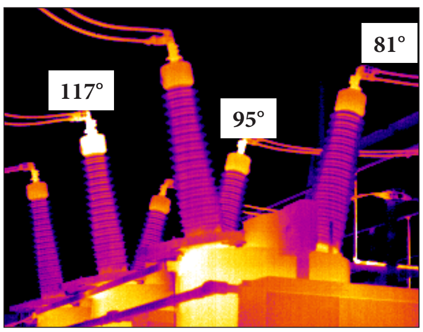

Figure 4. The same set of OCBs was re-inspected the next morning, this time with no wind. The results were alarming resulting in an order for repair during the next available opportunity.

programs that could make simple corrections for wind, they heeded the instructor's warning that things we not necessarily that simple.

Their intellectual understanding had been reinforced as they had watched a simple classroom demonstration with amazed disbelief. In the demonstration a 15MPH air current caused the temperature of a resistance heater to drop from 320°F to less than 140°F in a matter of minutes. Could the same thing be happening in the switchyard due to a 15MPH wind?

The Snell Infrared instructor discussed the situation and challenged the class to dig in deeper and really find out what was true about the OCB hotspots. Early the next morning they met again before class, grabbed the infrared cameras and headed back to the switchyard. The surface of the nearby Gulf was as close to a mirror as it ever gets. The electrical loads on the plant were at normal. Conditions for a follow-up inspection were perfect.

Although the students half expected it, they were, quite frankly, all rather shocked at what they saw, see Figure 4 (left). The ΔT on the load side bushing had increased from 13°F to 36°F. The line side bushing connection, which has been barely imperceptible the day before, now showed a ΔT of 14°. What had changed? Only the wind speed. It was a simple convective heat transfer problem: reduced wind meant reduced cooling!

Also now undeniably obvious was the fact that both problems stemmed from internal threaded bushing head connections, and were much more serious problems than they had initially appeared to be. There was little doubt that the heating at the source of the high resistance was hotter than it appeared on the bushing surface being observed. Later that morning, sobered by their learning experience, our trusty group of young thermographers made a recommendation to schedule further testing (ultrasonics and dissolved gas analysis) and, based on those results, make repair at the next available opportunity.

This is an experience from which we can all learn, whether we are new in this game or seasoned veterans. Thermographers may recognize that convective cooling has an impact, but how can we estimate what it will be? Unfortunately, it's not as simple as some would have us believe. The reality of heat transfer in and around a particular component is that it is usually quite complex. For that reason, thermographers should avoid using any of the simplistic software programs available that employ a single correction factor for all convective situations. These programs will produce results that will, in all probability, be inaccurate and should be considered highly suspect by an educated thermographer.

To make accurate temperature corrections of real-life situations requires a detailed analysis, skilled modeling, and confirmation of results for each situation encountered. Variables such as the shape of the components, their orientation, and precise local conditions involved are all necessary for an accurate correction calculation. Is it worth all this effort? That depends on the consequences of having inaccurate data versus accurate data. Situations like this set of OCBs probably warrant a careful analysis given the variability of the local conditions, and the cost and criticality of the equipment.

Beaufort's Wind Scale

4–7 MPH
- wind felt on face
- leaves rustle
- weather vane moves

8–12 MPH
- leaves in constant motion
- small flags are extended

13–18 MPH
- wind raises dust/paper
- small branches move

Figure 5. Beaufort's Wind Scale

Figure 6. The Kestrel 3000 is an affordable solution to gathering accurate local climatic data essential to diagnosing IR problems.

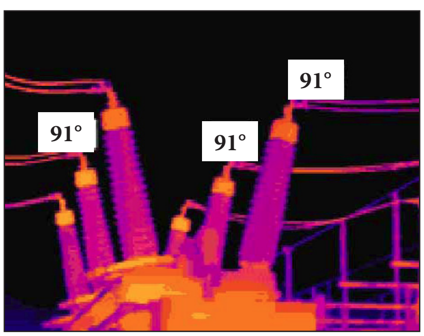

Image 7. A follow-up inspection, after repairs are made, is highly recommended. The thermal image, taken during ideal load and no-wind conditions, clearly shows the repairs were effective.

Thermographers must always be mindful that the components we are inspecting in these situations are being cooled by convection, either wind or air currents. It is likely that the cooling, even for air currents as low as 5MPH, will be significant enough that one or both of two things will be true:

- Any hot connections you find during convection will be hotter when convection is reduced.
- You may entirely miss some problems because they are simply being cooled below the threshold of detection.

Inspections conducted at times when convection is in excess of approximately 10MPH should be undertaken only with great caution. The exact nature of findings should be verified on a calm day or by other test methods. Wind speed should be measured or estimated at the site of the inspection; listening to the weather report in not sufficient. In fact in one instance the authors found winds of 18MPH at the upwind end of a large substation and only 5MPH winds in the downwind side! The structure of the substation itself had a huge moderating influence.

Two simple methods can yield an accurate understanding of local convective conditions.

- Use Beaufort's Wind Scale, a simplified version of which appears to here, to estimate wind speed based on its effect on the surroundings, see Figure 5 (left).
- Use any of the newly marketed handheld, electronic "weather stations" now available. These remarkable devicesm very accurately measure instantaneous, maximum, or average wind speeds, as well as air temperature, relative humidity, dew point, heat index, and other parameters.

We have used, and can recommend, the Kestrel Model 3000 as being rugged and reliable; cost is approximately $150, see Figure 6 (left). A new model, the Kestrel 5000, costs about $250 and can be left unattended to automatically make, store and display graphically a series of measurements over time. If you are unable to find these products locally, they are available on our website at www.snellinfrared.com.

By the way, the story of our friends at the Gulf Coast utility ended safely and happily. Shortly after the class, they took an unscheduled outage for other reasons, and followed the students' recommendation to make repairs. Damage to the threaded connections on both bushings was obvious and extensive, confirming their worst suspicions.

After the repairs were made, the students shot one last thermal image to verify they had been effective, see Image 7 (right). You can be certain the wind was not blowing when this last image was made! They'd learned their lesson well and would not make the same mistake again.