Workshop on Industrial Applications of Heat Flux Transducers—*R. L. Hauser and J. R. Mumaw*

This workshop dealing with the use of heat flux transducers was attended by seven representatives of users and suppliers of the devices. The focus of the group was the application of heat flux transducers to the measurement of energy flow in industrial insulation systems. Although most of the work to date has been on piping systems, many of the experiences would have parallel application in flat insulation systems, such as boiler insulation, precipitators, and large chemical storage vessels.

All of these systems found in industrial applications have several significant characteristics which separate them from other applications of heat flux transducers. The most significant characteristic is that the heat flux levels are substantially higher for industrial processes than for other applications. This is generally because of the higher temperature differences (either heating or cooling) that drive the insulation system and because the insulation thicknesses usually found in industrial systems do not have the high R-values found in residential systems. Heat flux transducers in industrial applications are generally used for the same purpose—that is, to monitor the installed insulation system to measure *in situ* performance. What the investigator is attempting to do is to confirm that the insulation works as its designer claimed or that it continues to work after several years of operation. To complete his study, the investigator also employs other auxiliary techniques to complement the heat flux transducer, such as thermocouples, infrared camera devices, and thickness probes.

The resulting discussion in the workshop focused on many areas of need or concern. These areas can be summarized by the following five topics:

1. Location—The best location on a pipe or other system must be selected to obtain the correct or average system result.
2. Construction of Heat Flux Transducers—New improvements in the design of heat flux transducers raise concern over the sensitivity and geometry of the sensor.
3. Instrumentation problems—The industrial environment provides special problems for sensors and auxiliary instrumentation.
4. Measurement/interpretation—Measurement and interpretation raise concerns over the stability and sensitivity to environmental factors of sensors.
5. New advances—This topic addresses the need for future work and information exchange with other researchers.

The following discussion summarizes the thoughts of the workshop members in more detail.

Locations

Since the primary use for heat flux transducers in industrial applications is to audit the heat flows from an installed system, it is very critical to the user that the measurement represent the system performance. Several factors associated with the location of the sensors influence the quality of the test data. These parameters include the location of the sensor about the pipe circumferences, the meter location in relation to the jacket, and the orientation of the sensor in relation to its calibration configuration.

The best understood of these three factors is the sensor's location on a pipe circumference. Experience in many laboratories has shown substantial differences in heat flow between the top, sides, and bottom of the horizontal pipe run. Many factors cause these differences, including changes in surface heat transfer coefficients, compression of insulation resulting from aging or mechanical abuse, and voids caused by poor or misfit insulation. Solutions suggested for this problem include preexaminations using infrared (IR) camera devices and other physical tests, multiple sensor positions, the use of belt-type sensors which wrap around the pipe, and positioning of the sensor at the side of the system thought to yield a near-average measurement for a "typical" system.

A second area of concern is the location of the sensor in relation to the insulation jacket. A location on the external surface has many advantages, including ease of installation, no violation of the system weather barrier, and the ability to obtain a result based on the entire system. On the other hand, there are problems with a matching of jacket/sensor emissivity, surface mounting technique, and data instability due to air film movement. Locating the sensor under the jacket eliminates many of these problems, especially those associated with the heat flow coefficient matching at the jacket surface. The primary problem is that installation of the meter under the jacket requires some disruption of the insulation jacket integrity, usually at a circumferential joint. Proper installation so as not to change the system characteristics or cause future damage due to weather requires knowledgeable, experienced personnel.

The third location-related concern is the similarity of calibration orientation to that seen in actual tests. Ideal calibration would be performed on a system having equal heat flux levels, similar orientation, and a similar environment, with the sensor located in the same position relative to the pipe and jacket. Of greatest concern here is that in some cases the sensors are calibrated flat at high flux levels in a hot plate or similar laboratory apparatus and then used in a circular, low flux, outdoor situation. Several papers presented in other workshop sessions have shown a significant influence of orientation on measurement results, thus demonstrating the need to calibrate and test under similar geometries.

Construction of Heat Flux Transducers

As discussed in the previous section, substantial disagreement exists over the type and location of heat flux transducers for piping situations. The two prime candidates now available for making measurements on pipes are the belt and the spot sensor. Basically these are similar types of apparatus, the only difference being in the active sensors. Both units are manufactured in different sizes and sensitivities. Belts or flexible spot sensors are best suited for industrial piping applications because of their ability to conform to the curved geometry. Concerns over sensitive changes with the bend radius reinforce the need for calibration at the same geometry as the tests, as discussed in the previous section. Particularly noteworthy is the observation that belt sensors are relatively insensitive to bending in one direction but can be very sensitive to bending in the perpendicular direction.

Another concern with the sensors themselves is an "apparent" zero offset. In some cases, researchers in the laboratory and field have observed a slight zero drift of the sensor output, which cannot be explained by instrument errors. One method of solution is to flip the sensor over so that the heat flow is in the opposite direction. In this case, if the offset is a sensor defect, the shift will reproduce in the negative polarity. If, however, the offset is in the same direction, the answer involves a nonzero heat flux of the system. Several examples of the difficulty of establishing the true zero heat flow condition were discussed in the workshop. If the zero offset concern continues, however, several of the explanations proposed will require further research. Among these explanations were the following: (1) sensor construction defects, including voids, bad electrical connections, odd number junctions, and so on; (2) moisture absorption in the meter resulting in a battery effect between the two dissimilar metals making up the meter; (3) other chemical contamination resulting from construction solvents, adhesives, or resins; and (4) nonconstant thermal conditions beyond the sensitivity of available temperature measurement equipment. The bottom line for industrial applications is that zero offset, if kept small, does not significantly affect the industrial user of sensors because of the rather high levels of heat flow generally observed.

Instrumentation Problems

In the previous section, we discussed some concerns about the construction and operation defects of the meters themselves in causing errors in the measurements. Once these are resolved, the accessory equipment must also work properly to obtain the correct heat flow measurement. In the industrial environment, conditions are not as ideal as in the laboratory. Of special concern to those making measurements in the field is the presence of electrical signals, which could superimpose voltages on the sensor output by an antenna effect. Heat flow sensors are usually rather high-resistance devices coupled to high-input impedance voltage meters. This combination permits an antenna effect to occur. The pickup in an industrial area can be significant because of nearby higher-voltage sources, exceeding 480 V, and the extensive use of high-frequency RF drying processes. Most commercially available digital voltmeters will reject some level of 60-Hz signal pickup. However, if the 60-Hz pickup is large or at high frequency as occurs with RF sources, the voltmeter will display a signal which combines the heat flow sensor output plus the antenna pickup. Simple auxiliary filter circuits can easily screen out the high-frequency signals if they occur and the frequency range is known. The 60-cycle rejection must be built into the voltmeter itself.

Measurement and Interpretation

Once equipment selection is complete and the meter has been properly installed and connected to a data collector, the primary problem is to conduct the test properly and interpret the results correctly. One must assume, at this point, that the location of the sensor is representative of the system component under study. Some factors must be considered, however, before this assumption can be confirmed. These factors include those items discussed previously plus the local environment, that is, (1) radiation sources, such as direct sunlight, adjacent hot and cold pipes, or equipment surfaces, and (2) the current environment, such as wind, humidity, temperature, and recent or current precipitation. Other system factors include the geometry, that is, the valves, fittings, joints, and saddles, and the insulation system's physical conditions, such as local abuse or excessive wear or weathering. In short, the measurement must be made in an area that properly represents the whole system under study. Tests at multiple locations, infrared examinations, installation records, system blueprints, and operator experience are all useful in determining this segment of data interpretation.

The second factor in performing the measurement and interpreting the results is establishing the onset of "equilibrium." In comparison with laboratory results at low temperature differentials, where true equilibrium can be established, a constant situation never occurs for *in situ* piping/equipment tests. This is because of the system's exposure to an ever-changing environment. Practice shows that the process system that is insulated must be operating under reasonably steady conditions before the heat flow sensor results can be accurate. Any changing condition such as start-up, shutdown, or transients between set-point conditions must be avoided. In general, what saves the industrial user of heat flux transducers is that the system temperature difference is large in comparison with the daily fluctuations in the ambient temperature. Pipes or other heated systems that operate for prolonged times at temperatures exceeding 300°F will provide an adequate driving temperature differential (a factor of ten times) to reduce the effect of changing ambient temperature. The other mechanism to offset the ever-changing nature of the environment is to obtain the data over a sufficiently long period of time so that the short cycles average out. Data taken by some researchers have shown testing times from less than ½ h for uniform, steady environments up to several days for more rapidly changing conditions. Mathematical screening techniques, data plotting, and other procedures have been shown to be useful in determining the duration of the test and the final result of the measurement.

Several other factors have been shown to adversely affect the results of *in situ* measurements on piping systems. High-radiation fields generated by solar or adjacent hot lines or equipment can yield incorrect results. Selecting areas to avoid adjacent equipment or, in the case of solar radiation, performing the tests during the early morning hours can be helpful in obtaining more representative results. Additional weather factors such as rain or snow have been shown to change the energy loss rates at the insulation surface significantly and should therefore be avoided whenever possible.

When interpreting the results of a heat flux transducer test, one must be careful not to conclude more than is reasonably certain. For example, unless several locations are examined; valves, fittings, and other details are considered; and operating conditions are characterized; the projection of a piping system's insulation performance is difficult if not impossible.

One significant detail arising from the discussion of data interpretation is that the draft of the ASTM recommended practice for insulated industrial systems, now being prepared, includes the requirement that fluted jackets must be specifically avoided to obtain good results. This is necessary because voids created between the insulation jacket and heat flux meter can cause substantial errors in the measurement. For similar reasons of thermal bridging, measurements on multilayer reflective systems must also be avoided. Although some tests have apparently been run using heat flux transducers on flat reflective systems, further work is needed to work out the special techniques required for this and other "special" nonhomogeneous systems.

Future Needs

The direct result of the workshop discussion is the appreciation that all is not known about the measurement of heat flow from industrial systems and that more research and development is needed. Tests at Pabco and other locations have shown that for uniform, well-fitting systems under "calm" conditions, test accuracies of as good as within 5% are possible. The converse of this is that large errors are possible for systems in which nonuniformity and changing environmental conditions occur. The ASTM task groups working on preparing recommended practices using the heat flux transducer need to search the literature for other areas of heat flux meter usage at substantially different flux levels, at different temperatures, or for other geometries. Suggested areas include the chemical producers and aerospace research and development facilities. The companies suggested include Du Pont, Dow Chemical, National Aeronautics and Space Administration, Pratt-Whitney, and Lockheed. The task groups also need to search out or encourage the development of new high-sensitivity sensor devices. This would be especially useful at the low flux levels seen in well-insulated buildings. Finally, we need to look at other uses for heat flux transducers such as the European use of the sensor as a metering device for utility district heat systems. Possibly some advances in these areas will aid our search for improved test capability.

In closing, the overriding need is for more test data from whatever source. Much of the data published thus far have limited distribution or are of questionable quality, or both. One ongoing research project sponsored by the Thermal Insulation Manufacturers' Association at PABCO has provided some test data on heat flux transducer data versus actual pipe loop losses measured by calorimetric means. Further work is needed, including quasi-testing by the ASTM Test for Steady-State Heat Transfer Properties of Horizontal Pipe Insulation (C 335-79) under real environmental conditions, to expand and support the development of an ASTM test method.