Infrared thermography as quality control for foamed-in-place insulation

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ABSTRACT

Since November of 1985, **FOAM-TECH** has been utilizing an I.S.I. Model 91 Videotherm Camera to quality control the installation of foamed in-place polyurethane and polyisocyanurate insulation. Monitoring the injection of foam into the walls and roofs of new construction and during the retrofitting of older buildings has become an integral and routine step in daily operations. The Videotherm is also used to monitor the injection of foam into hot water tanks, trailer bodies for refrigeration trucks, and pontoons and buoys for flotation. The camera is also used for the detection of heat loss and air infiltration for conventionally insulated buildings. Appendix A are thermograms of foamed-in-place insulation.

1. GENERAL INFORMATION ABOUT POLYURETHANE FOAM SYSTEMS

Polyurethane and polyisocyanurate foams are low density (1.3 lbs per cubic foot to 2.0 lbs per cubic foot) cellular plastic that is created from the chemical reaction of two basic components referred to as A and B. The A component is isocyanate and the B component is polyol. The two components, when combined and mixed in the correct weight ratios, usually 1:1 for foamed plastics, react to form a urethane polymer with specific characteristics intended for a particular application. The reaction between the components is exothermic and it is this characteristic of the product which makes it possible to use infrared scanning equipment to monitor the progress of foam injection. Typically, the exotherm of the reacting foam can be seen by the Videotherm through any surface in direct contact with the foam.

Two part plastic foams for insulation can be produced in any one of three basic ways: pour, froth and spray. Originally, "pouring" foam was the prevailing means of producing the product. This entailed mechanically pumping the two liquid components through high speed rotary mixers or high pressure impingement mixers into a mold designed to contain a volumetric expansion of 30x that could generate pressures up to 50 psi. This method had, and still has, the benefit of excellent flow characteristics resulting in a complete fill and uniform product. This method is still widely used for making higher density, urethane plastic parts for various industries. However, it has limited use for producing bulk, plastic insulation on a competitive basis.

"Spraying" foam is a very common means of producing the product and it is widely used to produce board stock or "sandwich " type panels by injecting the components through an impingement mixing head at high pressure and spreading a fan pattern of reacting foam on to a continuous conveyor. Different types of skins can be laminated to the reacting, rising foam while moving on the conveyor. Spray foam can also be applied on-site by mounting the necessary pumps and control equipment on a truck and spraying the foam over roof decks, a popular application for commercial buildings in the South and West, and on to the underside of roofs and the inside of walls for various types of buildings everywhere. The benefits of the spray foam process are inherent in the very means of producing the foam; very fast reaction times, no molds required, and the can-be-seen nature of the application. The basic disadvantages of spraying are the atomization of the foam during spraying that can result in messy and unhealthy overspray, and the lack of flexibility in the process and development of different types of foam. The foam has to stick when it hits the surface and has to set-up in 10 to 15 seconds.

"Frothing" foam is similar to pouring and during the past 20 years has been replacing pouring for competitive, high volume applications such as producing foam for flotation in boat hulls and buoys, and injection into refrigeration panels, truck bodies and hot water tanks. Frothed foams are similar to pour and spray foams in chemistry and in the use of R-11, a chlorofluorocarbon (CFC) with a boiling point of 75 - 77 degrees F, as an expansion agent. However, R-12, another CFC with a boiling point of -20 to -30 F, has been introduced into the B Side component as a pre-expansion agent which "froths" the foam immediately after the component is released from being under pressure. To prevent the R-12 from boiling, the vessels containing the R-12 have be pressurized to 40 psi.

The disadvantage of using pressurized containers is turned around somewhat by increasing the pressure further during the production process, up to 250 psi with nitrogen gas, and propelling the liquid components through a static, non-mechanical, mixer to mix and inject the reacting foam. The elimination of pumps and motors to move the liquid components, and the elimination of mechanical mixers is seen as a substantial benefit by manufacturers due a reduction in hardware costs and an increase in quality control due to the simpler means of production. Additionally, due to the vaporization of the R-12, the foam is "pre-expanding" immediately upon its' introduction into the static mixer and continues to expand as it mixes. The resulting foam leaving the mixer has a shaving cream type of consistency and expands less and generates less pressure than pure pour foam systems. The reduction in pressure, in many cases, reduces the need for molds and presses. For FOAM-TECH, for example, the wall and roof construction with its' framing and interior and exterior sheathing is, in effect, the mold which contains the foam.

2. DEVELOPMENT OF FOAMED IN-PLACE INSULATION BY FOAM-TECH

FOAM-TECH developed as an enterprise to bring foamed in-place insulation to the construction, marine and refrigeration industries with the development of frothing equipment that could be installed on trucks and be used reliably in the field on under a wide range of conditions, including winter operations.

The principals who now own and operate **FOAM-TECH** began using froth equipment in 1976 after using various type of pour systems and equipment for six years. In 1981, the first mobile frothing set-up was established by H.C. Fennell, now President of **FOAM-TECH**, once it became clear that there was a market for the higher cost, but higher quality insulation for residential construction. Since 1981, many improvements have been made to the equipment base, including larger mobile capacity, back-up systems and redundancy, more reliable temperature controls and injection equipment, temporary heating capacity for cold weather operations, ventilation equipment, lightweight, take-apart molding components, and, of course, infrared scanning equipment.

The latter was recognized as essential following a scan of prior work by **FOAM-TECH** by John Snell of John Snell Associates. His scan revealed voids and also demonstrated the feasibility of using infrared equipment to monitor foam injection. Although, in general, the voids were not substantial, they were embarrassing and considered unacceptable. Being able to monitor the injection process with a scanner provides substantial benefits, not the least of which is filling 99 % of the available volume and being able to prove it without having to go back after the installation is complete.

Another significant benefit of the application of infrared technology to the foaming process is an increase in knowledge and fundamental understanding of the flow characteristics of frothed urethane foam systems and the limitations of certain injection techniques. The development and use of new techniques and adapters has probably been speeded up by the use of the infrared camera. Lower density foams have better flow characteristics and can "travel" further in enclosed cavities. Higher density foams, especially the Class I foams with fire retardants, will generate higher pressures, not travel as far, can get "hung-up" on strapping, wiring, blocking and various other seemingly minor obstructions and thereby create voids.

3. CURRENT APPLICATION OF I.S.I. MODEL 91

The Model 91 is currently used very simply. Foam is injected into a cavity and within the 2 to 5 minutes the surface in contact with the reacting foam becomes warm enough to see the thermal signature of the foam behind the surface. The time lag between the initial injection and the detection of heat on the surface will vary with conductivity of that surface. The sheet metal jacket of hot water tank will reveal the foam behind it much quicker than the gypsum board on the walls of a house. And the gypsum board will reveal the foam behind it faster than pine paneling. Although the time lag will result in additional injection before the original injection is detectable by the Videotherm, the location of the foam and it's pattern of expansion in the enclosed cavity is detectable over a long enough time frame, 5 minutes to 2 hours, that enough information is conveyed to the installers to locate voids or even avoid creating voids while injecting foam.

The scanner is also sometimes used prior to beginning the work in older homes to locate and identify framing to avoid drilling unnecessary holes. Since the injection of foams occurs in "lifts" of 8" to 12" at a time to limit total expansion and pressure, there is time between shots to use the scanner. The relatively long time period in which the foam can be seen by the Videotherm avoids the necessity of viewing the injection process after every shot. The time window to detect the foam does vary with the thickness of the cavity section, the sheathing materials and ambient indoor and outdoor temperatures. Looking at a wall three times is usually sufficient.

4. TEMPERATURE PROFILES OF PLASTIC FOAM AND ADDITIONAL STUDY

More recent work with Lou Chiocchio of Preferred Foam Products using the Model 91 with an Exergen Model D501 Microscanner has helped identify promising areas of further investigation for the application of infrared technology in the quality control of foamed in-place insulation. Two part froth foams will generate a skin (surface of raw foam) temperatures of 70 F to 122 F from 0 seconds to 120 seconds from initiation of mixing. Core temperatures (from the approximate center) will be 125 F to 265 F from 60 seconds to 300 seconds from initiation of mixing.

Traditionally, the specifications provided by the manufacturer to end users of plastic foam systems has taken the form of time measurements versus phases of reacted foam development. They are "cream " time, "gel" or "string" time, and "tack-free" time. By comparing the manufacturer's specified times at 80 F versus the times developed by the producer in test shots, some form of quality control can be maintained.

These standards are somewhat subjective and have been in place since the development of polyurethane foams. Since the chemical reaction is exothermic, it should be possible to generate a time versus temperature profile of the reacting foam that will be the equivalent of the "cream, "gel," and "tack-free," standards. Since the reaction can be measured by temperature over real time, the resulting profile could conceivably be a far more accurate means of specifying the performance of the foam during it's creation. Assuming that the reacting foam is not stressed by out of spec. temperatures affecting the liquid components, or mold cavity or mold surfaces, then the physical characteristics of the reacted foam product may be predictable based on variations in the time versus temperature curve for a specific foam system. In other words, unless affected by extraneous temperature factors, the finished foam product will be everything it's going to be based on it's formative development, which occurs within 5 minutes and can be described thermally.

Whether or not infrared thermography can be used in this manner to quality control chemical foam systems, or be used to develop new foam systems using different blowing agents (current use of CFC's is being curtailed and substitutes will have to be in place in 3 to 5 years) is dependent on additional research with more sophisticated equipment. For infrared thermography to be used for such purposes is also a considerable challenge to the manufacturers. A matrix of 6 factors that could affect the thermal profile of a single system measured just every 10 seconds over 4 minutes could result in 720 potentially different profiles. The confidence in which manufacturers and producers have in eliminating some of these factors is a likely consideration in whether interest will be expressed in moving ahead with thermography as a quality control tool. Fortunately, the emergence of digital imaging systems and powerful desk top computers capable of storing and comparing information of this type may help.

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