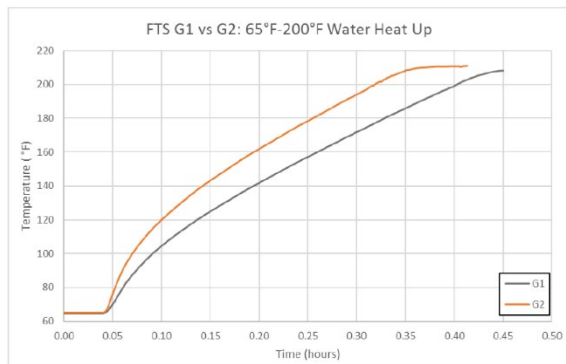
Date: 11/1/2021
From: Carson C. Hannah and Thomas W. Perry
Subject: Notice of product changes since white paper publication

The following technical publication was written by Carson C. Hannah and Thomas W. Perry of QMax Industries™ in 2017 and is based on testing and data processed in that year. It was published by Hydrocarbon Processing® in their September and October issues of 2018.

In this publication the effects of Heat Transfer Compound (HTC) thickness are discussed in relation to the performance of QMax CST and FTS products as they existed at that time. QMax Industries no longer manufactures, markets, or offers for sale, the FTS product as it is shown in this publication. As shown, it is the first generation of FTS (FTS G1).

QMax now manufactures the second generation of the FTS product, FTS G2, as seen below. FTS G2 carries a 10%-15% heat transfer performance advantage over the original FTS G1 product. Please contact QMax for literature on the performance comparison of FTS G1 and G2. QMax CST product has not been changed since the date of the following publication, so all data displayed is still relevant for the CST product.



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Understand the installation of steam tracing for long-term application success—Part 1

One of the most misunderstood and misused components of conductive steam tracing systems is heat transfer compound (HTC). HTC is a viscous mastic designed to fill small air gaps between the tracing element and the object to be heated. HTC is considerably more effective at transferring heat than static air, but it has relatively poor thermal conductivity compared to the other components in a steam tracing system. If used in very thin layers, however, HTC helps maximize the performance of heating systems. In this article, the authors discuss and demonstrate why the performance and success of conductive steam tracing systems are highly dependent upon proper installation and use of HTC.

Introduction. Around the world, sulfur operations rely heavily on high-performance steam tracing and jacketing to heat piping, equipment and vessels. Failure to properly heat these systems can cause sulfur to freeze and ultimately shut down a processing plant or even an entire refinery. To ensure that a steam tracing system will operate as designed, especially for critical processes like liquid sulfur and vapors with sulfur compounds, proper system installation is critical for long-term success.

To help understand how HTC thickness and installation quality affect tracing performance in critical operations, such as those involving sulfur, two high-performance steam tracing technologies were tested: fluid tracing system (FTS) and carbon steel tracing (CST). The systems were tested extensively with controlled HTC thicknesses for their effectiveness in melting elemental sulfur by tracing a sulfur-filled vessel in a controlled environment. The outcome of improperly installing HTC, regardless of the reason or steam tracing technology used, was consistent. As the HTC layer thickness between the tracing and pipe or vessel increased, the overall heat transfer rate from steam to process decreased. Increasing HTC thickness by only 1⁄16 in. from an optimal thickness of 1⁄32 in. increased the time required to melt elemental sulfur by as much as 70%.

Applying excess HTC between the tracing and pipe/vessel wall can have more damaging long-term effects than slowing down the heating time. As the system cycles thermally, thick layers of HTC will dry, weaken and fall away, leaving an open space between the tracer and the equipment. Compounds can also be eroded and displaced by excess moisture, creating undesirable air gaps. These complications transform the nature of the tracing system from conductive to convective, making it both ineffective and unpredictable.

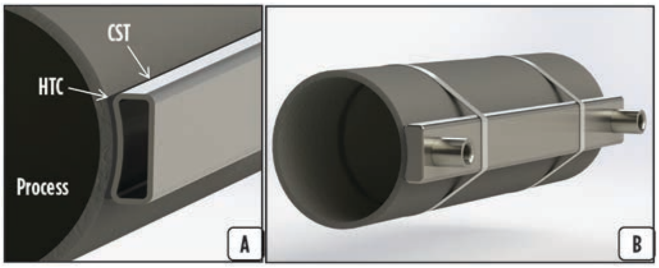

FIG. 1. View of CST profile mated to process pipe (A) and CST installation (B).

The keys to guaranteeing steam tracing performance are:

- Training and educating installers on the characteristics of HTC so that its capabilities are well understood and will be properly implemented in the field
- Using steam tracing systems that fit the surface of the traced equipment closely, allowing for excellent compression, containment and protection of thin HTC layers
- Avoiding the installation of trace elements over weld beads and uneven pipe surfaces, which creates gaps that must be filled with HTC
- Following the manufacturer's installation guidelines and, when in doubt, consulting steam tracing specialists for advice on installation methods.

Testing methodology. It is easy to loosely follow, or even disregard, the guidelines to an ideal installation of a steam tracing system. Typically, this is because an ideal installation is difficult to achieve in the field due to spatial limitations, complexity of piping, or prohibitive features like weld beads and uneven pipe surfaces.

When a steam tracing company models the performance of a steam tracing system, the thickness of HTC must be part of that model. If the thickness of HTC is greater than what is modeled, then the system will not perform as designed. Therefore, it is critical to a steam tracing system's success to ensure that the HTC thickness is never greater than what is specified, and that the HTC remains in place for the life of the system. The materials and methods described herein were selected because they represent common scenarios in field applications.

Technologies tested. FTS and CST have been used in an array of critical applications, including liquid sulfur transfer, rundown, tail gas, pit sweep gas, sulfur vent piping and sulfur tanks. Both FTS and CST performance have been verified in a wide variety of industries, and many leading producers include these systems in their corporate specifications. However, both technologies are characterized by installation challenges that will cause them to underperform if not properly understood.

CST systems consist of tracing elements that are individually fabricated from carbon steel boiler tubes or similar materials. The boiler tube is formed into a rectangular profile, with one side contoured to fit the outside diameter of a process vessel. Caps are welded to the ends of the formed tube, creating a vessel capable of holding pressure. Usually, female national pipe taper thread (NPT) connections are welded on at the inlet/outlet of the trace element. Once fabricated, it is essentially a four-part system consisting of tracers, HTC, stainless steel banding for fixturing and jumper hoses. The jumper hoses connect the outlet of one tracing element to the inlet of the next, allowing a fluid heating medium to flow through the system. The interface between a CST element and a process pipe is displayed in **FIGS. 1A** and **1B.**

Common installation challenges with CST include:

- Weld beads on the fabricated CST and process pipe create space that must be filled with HTC
- Potential for uneven distribution of HTC on the CST element
- Tracing elements that are bowed from forming and welding do not touch the process pipe along their entire length
- Ensuring that CST is mated to the pipe/vessel concentrically.

The tested CST elements were fabricated specifically for the testing apparatus used. Weld bead height was kept to a minimum to allow the contoured trace surface to evenly contact a pipe wall along the entire length. The resulting two sections of CST could be installed with nearly perfect pipe wall contact along their lengths.

FTS consists of four separate parts that are assembled during installation. A tube tracer contains the fluid heating medium. An FTS channel, extruded from aluminum to precisely fit the outer diameter of the process vessel, is installed over the tracer. The channel contains both the tracer and HTC, and compresses them when stainless steel banding is used to secure the system to a pipe or vessel. **FIGS. 2A** and **2B** show the assembly in relation to a process pipe.

Common challenges when installing an FTS include:

- Potential for uneven distribution of HTC on the FTS channel
- Ensuring that the FTS channel is mated to the pipe/vessel concentrically
- Bending the tubing tracers properly so that FTS straight channels and elbow components make full contact with the pipe/vessel.

Experimental design. To test each tracing system's effectiveness in melting elemental sulfur, simplified versions of the most common real-world installation challenges were simulated for each technology. While installation complications vary and require different corrective actions, many of them contribute to the common cause of poor performance with conductive heating systems: excessive HTC in gaps between the tracing element and the object to be traced.

These gaps are usually filled with additional HTC under the assumption that the system will still perform as designed. Al-

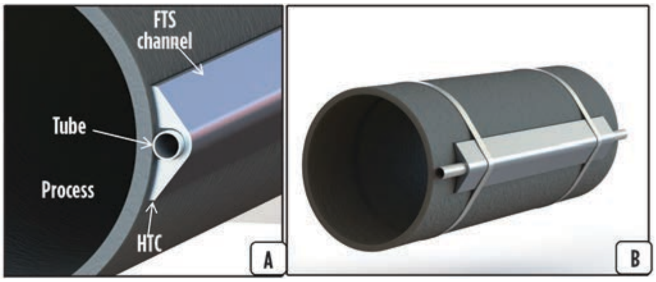

FIG. 2. View of FTS profile mated to process pipe (A) and FTS installation (B).

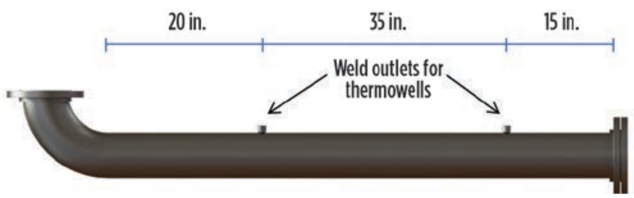

FIG. 3. Sulfur vessel for testing apparatus.

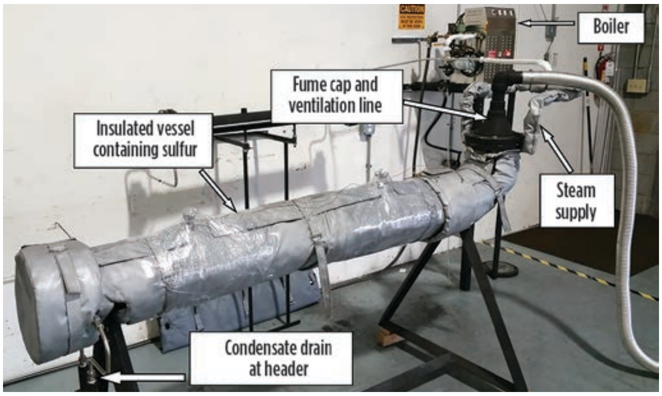

FIG. 4. Testing apparatus fabricated from 6-in. Schedule 40 carbon steel pipe.

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though HTC is many times more effective at transferring heat than air, it has poor conductivity when compared to the rest of a tracing system's components. This means that the rate of energy transferred from the heating medium to the process can be significantly impacted when HTC is used to remedy installation complications.

For tracing applications that require predictable melt-out and accurate thermal maintenance performance, systems must be installed with strong attention paid to the manufacturer's guidelines. The most effective way to evaluate the impacts of deviations from the optimal HTC layer thickness on melt-out time is to perform tests on CST and FTS, both installed with consistent HTC layers of verifiable thickness.

Testing apparatus. The testing apparatus used for the experiments discussed in this document was designed to evaluate and compare the effectiveness of steam tracing technologies when melting elemental sulfur. A vessel was fabricated from 6-in. Schedule 40 carbon steel pipe. Details of the vessel's construction are shown in **FIG. 3,** with all other hardware removed for clarity. **FIG. 4** shows an image of the entire testing apparatus with all hardware installed.

Two sets of legs support the vessel approximately 3 ft from the ground, and a customized fiberglass insulation blanket kit leaves only the fume cap exposed. During tests, a 4-ft-tall partition was set up around the apparatus. This partition allowed some loss of heat energy to the atmosphere as would occur in a field application, but it prevented excessive and random airflows from affecting the tests in ways that were not reproducible. A 68-in.-long straight tracer and a 6-in. side elbow element can be installed on both sides of the vessel.

The pipe spool portion of the apparatus was built specifically for testing tracing systems; there were no raised weld beads, and the sections where tracing could be installed were surface-finished to remove all paint, abnormalities and features that might interfere with installation. Carbon steel thermowells were inserted into the weld outlets specified in **FIG. 3** so that their tips were at the center axis of the pipe. The apparatus was filled with ≥ 99.5%-purity, ultra-fine powdered octasulfur. To ensure that the horizontal section of the vessel was filled entirely, a process of filling and melting was repeated until sulfur filled most of the 90° elbow.

Crystalline sulfur has a broad range of melting points spanning approximately 110°C–119°C (230°F–246°F), depending on the crystalline structure, gas content, purity, pressure and other factors.[1,2] Solid amorphous sulfur has a melting point as high as 120°C (248°F).[3] Solid sulfur is also an excellent insulator, having a thermal conductivity < 0.52% of the carbon steel used in CST and < 0.13% of the aluminum used in FTS. This makes rapid melting with bolt-on tracing systems like CST and FTS more challenging compared to jacketed pipe, so proper sizing and installation are compulsory for guaranteeing performance.

Part 2. For more details about the HTC testing with both tracing technologies, as well as the resulting conclusions, see Part 2 of this series in the October 2018 issue. HP

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Understand the installation of steam tracing for long-term application success—Part 2

One of the most misunderstood and misused components of conductive steam tracing systems is heat transfer compound (HTC). HTC is a viscous mastic designed to fill small air gaps between the tracing element and the object to be heated. HTC is considerably more effective at transferring heat than static air, but it has relatively poor thermal conductivity compared to the other components in a steam tracing system. If used in very thin layers, however, HTC helps maximize the performance of heating systems. In this article, the authors discuss and demonstrate why the performance and success of conductive steam tracing systems are highly dependent upon the proper installation and use of HTC.

To help understand how HTC thickness and installation quality affect tracing performance in critical operations, such as those involving sulfur, two high-performance steam tracing technologies were tested: fluid tracing system (FTS) and carbon steel tracing (CST). Part 1, published in September, examined HTC testing design and methodologies. Part 2 discusses testing with both tracing technologies, along with the resulting conclusions.

FTS and CST testing. Tests for both technologies were carefully set up, performed and documented to provide results that were comparable and reproducible. The standard test procedure started with the installation of each tracing technology on the testing apparatus, according to its respective installation guidelines.[4,5] Several optimal installations of FTS and CST that followed the guidelines were repeated to first establish an expectation for maximum performance (later tests involved modifications to simulate the effects of nonideal installations).

An optimal installation for the purposes of these experiments had an HTC thickness of 1⁄32 in. Trace elements were installed on each side of the straight section and on the elbow of the apparatus for all tests. During testing, steam was diverted to both "runs" of tracing from a single supply tube that was well insulated and close to the boiler outlet. At the end of the traced section, both runs were reunited to a properly sized condensate header that drained to an inverted bucket steam trap. After installing the tracing system, the apparatus was covered with the fiberglass insulation kit. Both connection heads of the thermocouple probes and the surrounding insulation were then wrapped in plastic film to protect the sensing elements from external convection. The entire apparatus was further isolated from excessive air flow by a 4-ft-tall partition that was set up as the last physical component of the test.

Saturated steam at 50 psig (approximately 298°F) is commonly used to heat liquid and vapor sulfur lines, so it was used as a heating medium for all tests.[3] Steam was applied to the system until the thermowell interior at the centerline of the apparatus reached a stable 100°F. Beyond this point in the tests, the steam lines were left open for continuous heat input. Thermowell interior, steam supply tube surface and ambient air temperature were recorded from this point until the average thermowell temperature reached 250°F.

To minimize uncertainty and maximize comparability of test results, the HTC needed to have a consistent layer of verifiable thickness along the length of the tracing elements. Consistency was achieved by using sets of contoured spacers between the tracers and process pipe at the banding locations. Three sets of round spacers, with diameters of 1⁄32 in., 3⁄32 in. and 5⁄32 in., were fabricated. The spacers, shown in **FIG. 5,** were used to simulate the HTC-filled gaps between the tracer and the pipe caused by uneven surfaces, weld beads, poorly formed tubing and bowed tracers.

TABLES 1 and **2** list the tests that were performed with FTS and CST systems, respectively. The tests only partially followed the respective installation guidelines because of the intentional spacing.

Several assumptions about the parameters of the tests and characteristics of the equipment and environment needed to be

FIG. 5. Spacers for maintaining consistent HTC thickness. Shown left to right: 1⁄32-in., 3⁄32-in. and 5⁄32-in. diameters.

defined before results could be analyzed and conclusions drawn:

1. The melting point of the sulfur was considered to be 248°F for all tests to ensure a valid comparison of the results. During testing, the sulfur melted between 238°F and 246°F, which was verified by briefly removing the fume cap and visually inspecting the sulfur; however, some variation was encountered. This range is also encountered in the melt-out procedures of sulfur recovery operations, usually with monoclinic sulfur having varying concentrations of S_λ and S_π allotropes. However, for the purposes of maintaining consistency in the criteria for these experiments, it was most accurate to assume that the total volume of sulfur was melted when the thermocouple probe measurements averaged 248°F.
2. The internal temperature of the thermowells was considered to be synonymous with the temperature of the sulfur. Statements about the sulfur temperature during tests refer to the internal temperature of the thermowells. It is unlikely that the temperature on the inside wall of the thermowells was more than 2°F–3°F cooler than the sulfur, meaning the sulfur was melted when the sensors reached an average temperature of 248°F and were at least 245.5°F individually. Since the sensors and thermowells maintained their positions between tests and the main objective of the tests was comparison, this assumption was reasonable.
3. Steam was generated with a boiler that utilizes a thermomechanical pressure switch to regulate heating. The switch allows the boiler to heat in cycles, causing the pressure to vary about the setpoint by +3 psig to –4 psig. This translates to approximately +3°F to –4°F about the target temperature of approximately 298°F, so the average steam tube temperature varied between tests.
4. Tests took place over the course of a year, from July 2016 to July 2017, and were performed in no particular order once optimal installation results were established. Several test factors were variable over the course of a year:
    a. The testing environment was subject to seasonal variations in temperature. Testing was conducted indoors, but not in a temperature-controlled environment. Therefore, ambient temperatures for each test fluctuated similarly to how they would in the field. The custom insulation blanket of 1¼-in. thickness was used to mitigate the effects of the changing ambient temperatures.
    b. Variances exist in the thermophysical properties of HTC because HTC is continuously manufactured in batches. To prevent aged and deteriorated HTC from affecting test results, fresh compound was used for every test. Over the course of a year, it is possible that the compound between tests varied in thermal conductivity. The same manufacturer and compound formula were used for all tests to minimize these variations.

TABLE 1. Tests performed with fluid tracing system (FTS)

Test	General description
FTS-A	Optimal installation that partially followed manufacturer's guidelines; HTC thickness maintained at 1⁄32 in. (0.031 in.)
FTS-B	Standard installation that partially followed manufacturer's guidelines; HTC thickness maintained at 3⁄32 in. (0.094 in.)
FTS-C	Modified installation that partially followed manufacturer's guidelines; HTC thickness maintained at 5⁄32 in. (0.156 in.)
FTS-D	Non-standard installation; no HTC used, and no intentional space created between tracer and pipe (bare tracer on pipe)

TABLE 2. Tests performed with carbon steel tracing (CST) system

Test	General description
CST-A	Optimal installation that partially followed manufacturer's guidelines; HTC thickness maintained at 1⁄32 in. (0.031 in.)
CST-B	Ideal installation that partially followed manufacturer's guidelines; HTC thickness maintained at 3⁄32 in. (0.094 in.)
CST-C	Modified installation that partially followed manufacturer's guidelines; HTC thickness maintained at 5⁄32 in. (0.156 in.)
CST-D	Non-standard installation; no HTC used, and no intentional space created between tracer and pipe (bare tracer on pipe)

Measures and measurement devices. In all tests listed in **TABLES 1** and **2,** the most critical measure was the temperature of the sulfur at the center of the apparatus. Other measures of concern were the temperature of the steam tube throughout the melting cycle and the ambient temperature near the apparatus. Two ungrounded, 20-gauge, J-type differential thermocouple probes were used to measure the temperature of the sulfur at the center axis of the apparatus.

Another 20-gauge, J-type differential thermocouple with an exposed junction was used to measure the surface temperature of the steam supply tube. The exposed junction was electrically isolated from the stainless-steel tube with a polyimide film of 0.002-in. thickness, and well insulated from the environment with high-density glass fiber.

A differential, 30-gauge, T-type thermocouple, also with an exposed junction, was used to measure the ambient temperature. The exposed junction was covered with low-density, open-cell foam that allowed air contact but prevented convective effects from causing significant errors in measurement.

Temperature measurements were logged to Excel files with a dedicated USB data acquisition (DAQ). All thermocouples used have standard limits of error purity, and the DAQ has a cold junction compensation with an accuracy of ±1.8°F.

Measurement locations and rates. The J-type thermocouple probes were used to measure the sulfur temperature at the locations specified in **FIG. 6.** The sensing portion of the probes was protected from conductive and convective effects by the thermowell, which encapsulated its entire length, and by the connection head. As previously mentioned, the connection head and surrounding insulation were wrapped in plastic film for further protection from air flow.

Steam tube temperatures were measured approximately 6 in. prior to a tee that diverted steam to both runs of tracing. Six in. of thermocouple wire preceding the junction were routed under the insulation of the steam supply tube to protect it from environmental interference. The junction was secured on a vertical section of tubing to prevent condensate drainage from causing significant measurement errors.

Ambient temperature was measured outside of the 4-ft-tall partition, but within 3 ft of the testing apparatus. Measurements were taken at all locations simultaneously during every test. These measurements were recorded at 60-sec intervals.

Data analysis. For all tests, temperature data at each location was recorded from the time the sulfur stabilized around an average of 100°F to the time it averaged 250°F. For greater comparability, a normalized time frame was established for each data set. This time frame started at zero, when the average sulfur temperature was 105°F, and finished when it reached 250°F. It was verified for each test that when the average of both sulfur temperature measurements was 248°F, each individual measurement was at least 245.5°F.

The normalized data sets were compiled into separate documents for CST and FTS so that each technology could be analyzed individually. A representation of the time required by each system to melt the sulfur by heating it from 105°F to 248°F, dependent on the thickness of the HTC layer, was one of the desired results. The development of a general linear relationship for CST and FTS that demonstrates the increase in sulfur melt time as HTC thickness increases was also a desired result of the analysis.

Results and conclusions. The results of CST and FTS sulfur melt testing verified that the thickness of the HTC applied during steam tracing system installation has a direct impact on the time required to melt sulfur by heating it from 105°F to 248°F. In general, increasing the HTC thickness caused a proportional increase in melt time. Increases in HTC thickness had comparable effects on both CST and FTS, and individual results for each system demonstrate the impact of those effects on performance.

CST testing results. The temperature/time relationship of CST tests A–D is shown in **FIG. 7,** and the melt time results are tabulated in **TABLE 3.** When the HTC layer between the CST tracers and the process pipe was 1⁄32 in., 2 hr and 24 min were required for the sulfur to heat from 105°F to 248°F and melt. Increasing the HTC layer thickness from 1⁄32 in. to 3⁄32 in. increased the required melt time by 70% to 4 hr and 3 min. Further increasing that layer to 5⁄32 in. caused the melt to require 5 hr and 12 min, 117% more time than an ideal installation. With bare CST installed directly on the pipe, 4 hr and 7 min were required to reach the melt-out criteria.

FTS testing results. The temperature/time relationship of FTS tests A–D is shown in **FIG. 8,** and the melt time results are tabulated in **TABLE 4.**

With an HTC layer thickness of 1⁄32 in. between the FTS channel and pipe, 2 hr and 26 min were required for the sulfur to increase in temperature from 105°F to 248°F and melt. At a 3⁄32-in. HTC thickness, the time required for melt-out increased by 43% to 3 hr and 29 min. Installing the FTS with a 5⁄32-in. thick HTC layer caused the melt time to increase to 5 hr and 34 min, taking 129% longer than the ideal installation in Test A. The FTS installed on the bare pipe with no compound required 4 hr and 36 min to melt the sulfur.

Conclusions. Based on the empirical evidence from testing two high-performance steam-tracing technologies, it is ap-

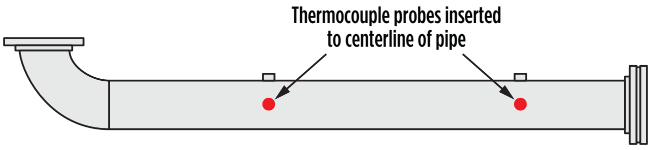

FIG. 6. Thermocouple probe measurement locations.

TABLE 3. Time to melt sulfur, using CST with various HTC thicknesses

Test	HTC layer thickness, in.	Time to heat sulfur from 105°F to 248°F
CST-A	1⁄32	2 hr, 24 min
CST-B	3⁄32	4 hr, 3 min
CST-C	5⁄32	5 hr, 12 min
CST-D	No HTC; bare CST tracer on pipe	4 hr, 7 min

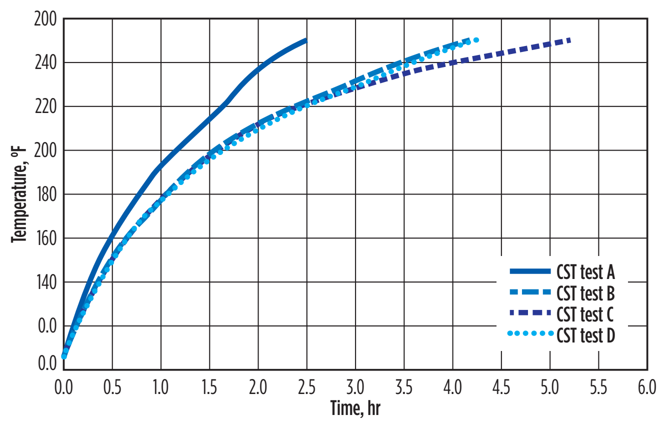

FIG. 7. Temperature with respect to time for CST tests.

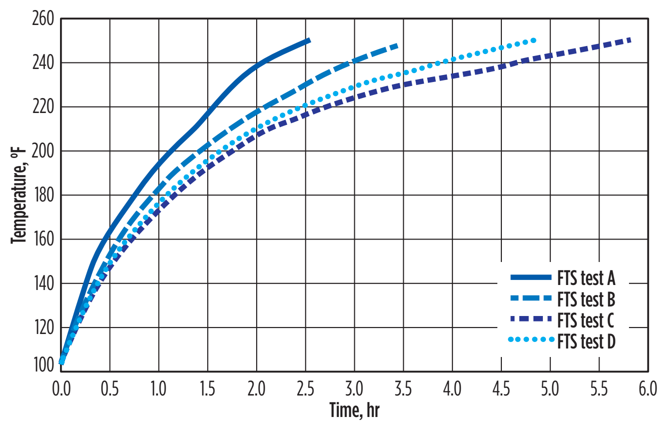

FIG. 8. Temperature with respect to time for FTS tests.

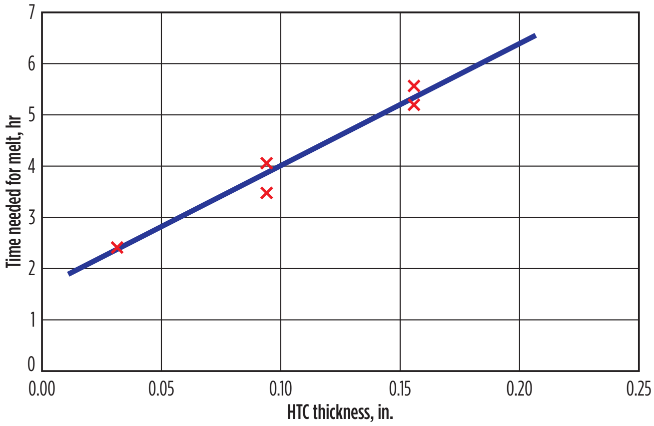

FIG. 9. Time required for sulfur melt-out as a function of HTC thickness.

TABLE 4. Time to melt sulfur, using FTS with various HTC thicknesses

Test	HTC layer thickness, in.	Time to heat sulfur from 105°F to 248°F
FTS-A	1⁄32	2 hr, 26 min
FTS-B	3⁄32	3 hr, 29 min
FTS-C	5⁄32	5 hr, 34 min
FTS-D	No HTC; bare FTS tracer on pipe	4 hr, 36 min

parent that installing CST and FTS with a HTC layer just 1⁄16 in. thicker than an optimum thickness of 1⁄32 in. has a noticeably negative impact on the rate of heat transfer into a solid sulfur process.

FIG. 9 is a graphic representation of the time required to melt the sulfur in the testing apparatus using the FTS and CST system with increasing HTC thicknesses. The trend in **FIG. 9** suggests that, for each 1⁄16 in. added to the HTC thickness, the time required to melt elemental sulfur in a 6-in. pipe will increase by an average of 1 hr and 30 min. Using HTC to fill even larger gaps than were tested, due to installation complications or failure to follow installation guidelines, could easily cause melt-out times to increase by several hundred percent compared to an optimal installation.

Discussion. The theoretical implications of increasing the thickness of conductive heat transfer components are understood by engineers and heat transfer specialists, and it is their responsibility to pass this conceptual understanding to the personnel that install and maintain steam tracing systems. Proper installation of conductive steam tracing systems is compulsory for achieving the designed level of performance, and one of the most critical factors in installation is the correct use of heat transfer compound. The use of HTC in thick layers, or to fill gaps that are caused by installation complications, typically stems from the misconception that HTC can conduct heat as well as other system components. As a result, the HTC can become a significant limiting factor of performance for an otherwise properly designed system.

Long-term effects of using thick HTC layers can be more harmful than the conduction issues discussed in this article. Thick layers of compound can eventually dry out, even if the compound is of the non-hardening variety. Thermal cycling and process vibrations can cause the dried compound to crumble and fall away. HTC that is not well compressed and contained by the tracing system is also susceptible to erosion from moisture, which can displace it and leave an air gap between the tracer and the process vessel. Both scenarios effectively transform the system from conductive to convective in nature, dramatically decreasing its ability to transfer heat.

Providing education and thorough training to installers about the capabilities of HTC is one of the most effective ways of ensuring tracing system performance. While HTC can limit performance, it can also maximize a tracing system's effectiveness if used as a thermal bridge in thin layers. Hands-on training workshops that utilize discussion of how HTC can affect tracing system performance from a conceptual standpoint, as well as familiarize installers with guidelines and best installation practices, are essential.

One provider has also revised its fabrication specification for CST. Welds on the trace cannot be modified or ground for safety reasons, so a method of fabrication has been developed to build CST tracers that are not subject to the standoff effect of weld beads on contoured surfaces.

Key installation practices that maximize conductive steam tracing performance are:

- Ensuring that the tracing elements are contoured to fit the pipe/vessel surface as closely as possible
- Using the recommended HTC layer thickness; if more than the recommended amount is needed to fill a gap, an installation complication exists that should be solved in another way so that performance is not affected
- Avoiding installation of trace elements over weld beads and uneven pipe surfaces that create gaps between the tracer and the pipe. HP

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