Understanding Installation of Steam Tracing for Long-Term Application Success

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Abstract

One of the most misunderstood and misused components of conductive steam tracing systems is heat transfer compound, or HTC. HTC is a viscous mastic designed to fill small air gaps between the tracing element and the object to be heated. Heat transfer compound is considerably more effective at transferring heat than static air, but 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. This paper discusses and demonstrates why the performance and success of conductive steam tracing systems is highly dependent upon proper installation and use of HTC.

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 like those involving sulfur, QMax Industries Inc. focused on testing two high performance steam tracing technologies: FTS (Fluid Tracing System) and CST (Carbon Steel Tracing). The systems were tested extensively with controlled HTC thicknesses for their effectiveness in melting elemental sulfur by tracing a sulfur-filled vessel in a QMax Industries Inc. facility. 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 increases, the overall heat transfer rate from steam to process decreases. Increasing HTC thickness by only 1/16-inch from an optimal thickness of 1/32-inch 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 heat up time. As the system cycles thermally, thick layers of HTC will dry, weaken and fall away leaving open space between the tracer and equipment. Compound 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.

The keys to guaranteeing steam tracing performance are:

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

Introduction

Discussed in this paper is the importance of properly installing conductive steam tracing systems in conjunction with the correct use of Heat Transfer Compound (HTC). An informed understanding of the use and capabilities of HTC has a large impact on applications that require process temperature maintenance such as those used in sulfur operations.

HTC is a viscous mastic, used as a thermal bridge between an external heating system and the piece of equipment meant to be heated; it is designed to fill small air gaps between heat transfer components because stagnant air acts as an insulator. If HTC is not well understood and/or mis-applied during installation, conductive heating systems could fail due to improper heat transfer from the heating medium to the process. System performance, regardless of the steam tracing system implemented, is maximized only when thin layers of HTC are used as a thermal bridge.

To evaluate the importance of HTC application and proper system installation, QMax Industries Inc. extensively tested several steam tracing systems. Two technologies outperformed all others and were evaluated further: FTS (Fluid Tracing System) and CST (Carbon Steel Trace). These systems were used to heat and melt elemental sulfur, and were intentionally installed with varying HTC thicknesses between the tracing and a process pipe. Tests were performed numerous times at a QMax Industries Inc. facility with the objective of understanding how the performance of each technology was affected by the thickness of the HTC layer used.

Materials and Methods

It is easy for the guidelines to an ideal installation of a steam tracing system to be loosely followed or disregarded. 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, the system will not perform as designed. Therefore, it is critical to a steam tracing system’s success to ensure 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 referred to in this paper were selected because they represent common scenarios in field applications.

Technologies Tested

The tests discussed in this publication involve two heat tracing technologies: FTS (Fluid Tracing System) and CST (Carbon Steel Tracing). These technologies have been used in an array of critical applications including liquid sulfur transfer, run-down, tail gas, pit sweep gas, sulfur vent piping, and sulfur tanks. Both FTS and CST performance has been verified in a wide variety of industries, and many leading producers include these systems in their corporate specifications. However, both technologies have installation challenges that will cause them to under-perform if not properly understood.

CST (Carbon Steel Tracing)

CST systems consist of tracing elements that are individually fabricated from carbon steel boiler tube, or similar. 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 NPT thread connections are welded on as 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 *Figures 1a* and *1b*.

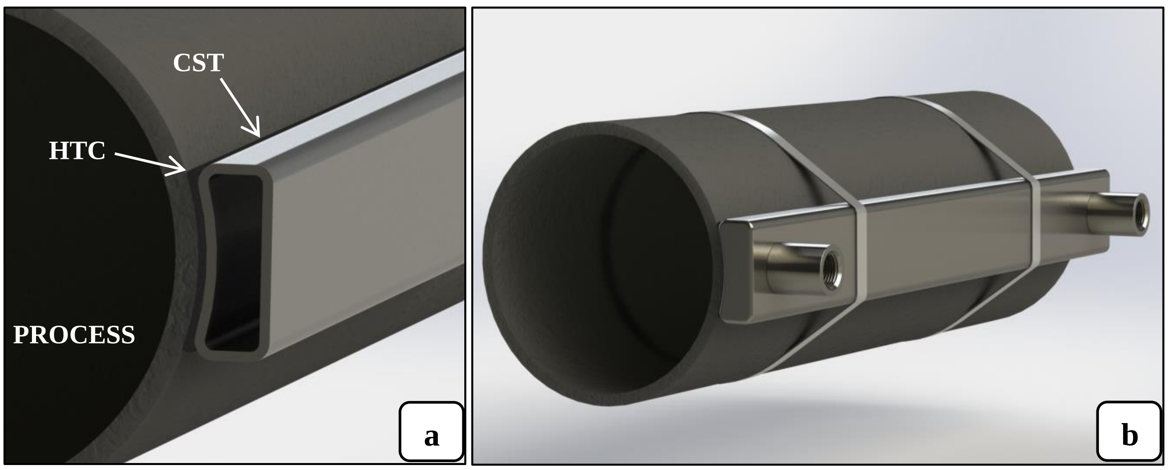

Figure 1: a) View of CST profile mated to process pipe
b) CST installation

Common installation challenges with CST include:

- Weld beads on the fabricated CST and process pipe create space that must be filled with HTC
- Even 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 CST are mated to the pipe/vessel concentrically

The tested CST elements were fabricated specifically for the testing apparatus that was used. Weld bead height was kept to a minimum such that they didn't prevent the contoured trace surface from evenly contacting a pipe wall along the entire length. The result was two sections of CST that could be installed with nearly perfect pipe-wall contact along their length.

FTS (Fluid Tracing System)

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 the tracer and

HTC simultaneously and compresses them when stainless steel banding is used to secure the system to a pipe or vessel. *Figures 2a* and *2b* show the assembly with relation to a process pipe.

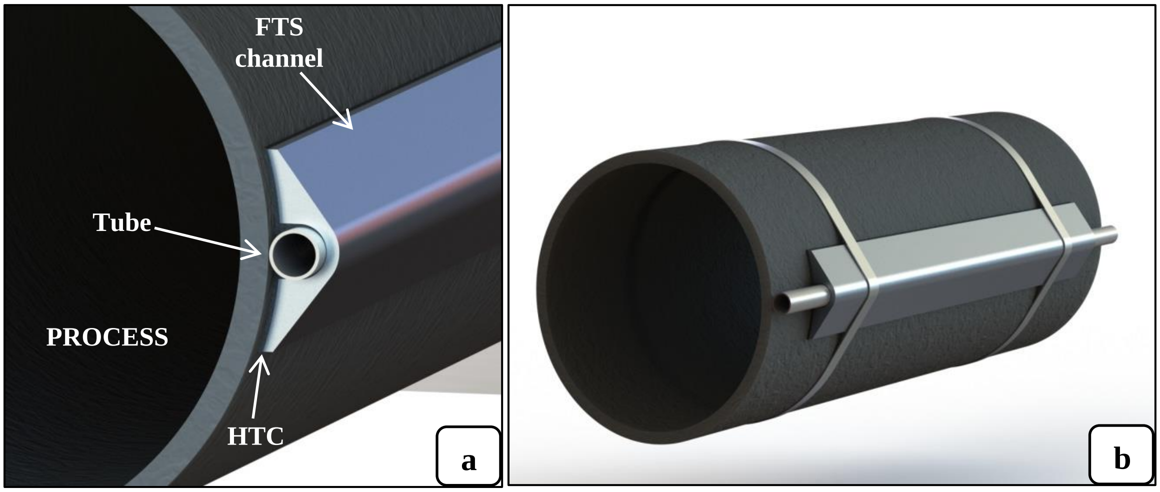

Figure 2: a) View of FTS profile mated to process pipe
b) FTS installation

Common challenges when installing FTS are:

- Even distribution of HTC on the FTS channel
- Ensuring 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 a common cause of poor performance with conductive heating systems: leaving 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. Although HTC is many times more effective at transferring heat than air, it has very 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 greatly 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 was 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. It is a vessel fabricated from 6-inch schedule 40 carbon steel pipe. Details of the vessel's construction are shown in *Figure 3,* with all other hardware removed for clarity. *Figure 4* is an image of the entire testing apparatus with all hardware installed.

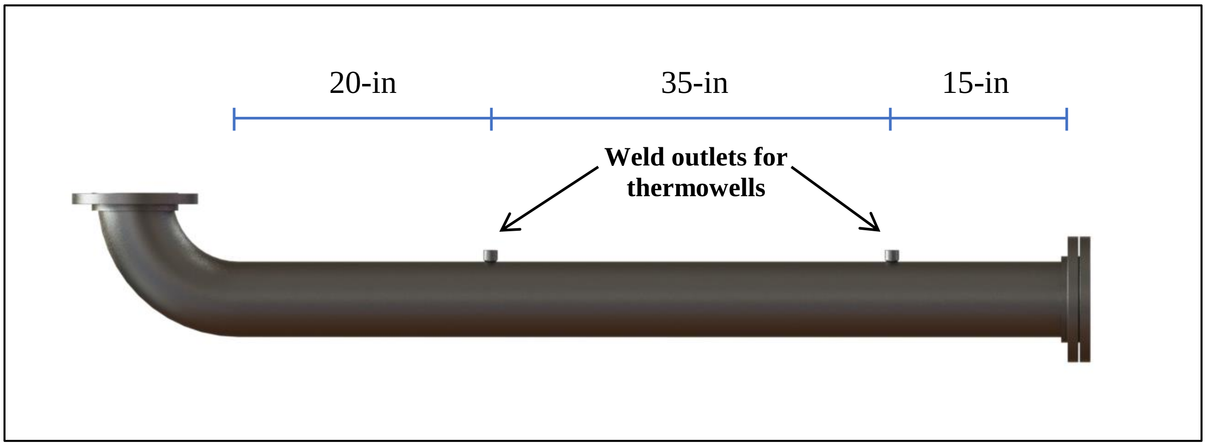

Figure 3: Sulfur vessel for testing apparatus

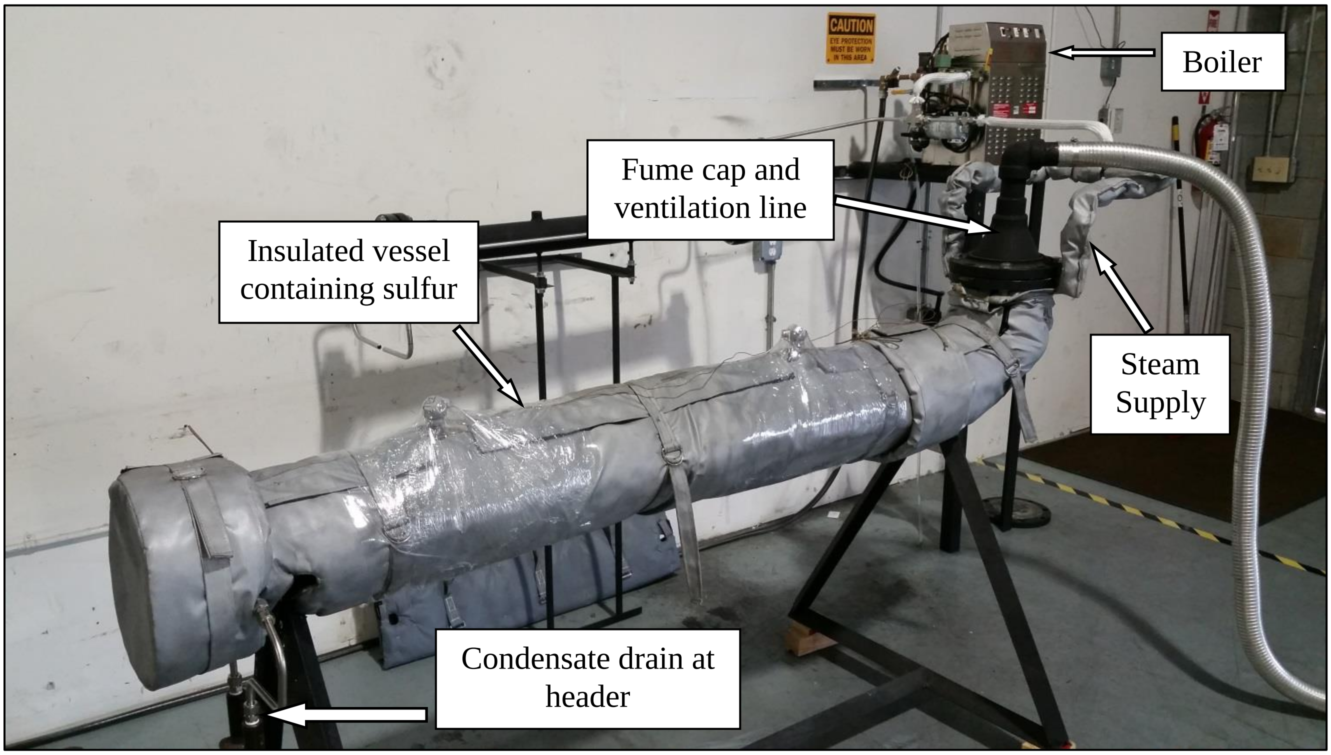

Figure 4: Testing apparatus fabricated from 6-inch SCH. 40 carbon steel pipe

Two sets of legs support the vessel about 3-feet from the ground, and a customized fiberglass insulation blanket kit leaves only the fume cap exposed. During tests, a 4-foot 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 prevented excessive and random airflows from affecting the tests in ways that weren't reproducible. A 68-inch long straight tracer and 6-in side elbow element could be installed on both sides of the vessel. The pipe-spool portion of the apparatus was built specifically for testing tracing systems; there are no raised weld beads and the sections where tracing can be installed were surface finished to remove all paint, abnormalities, or features that could interfere with installation. Carbon steel thermowells were inserted into the weld outlets specified in Figure 3 such that their tips were at the center axis of the pipe. The apparatus was filled with ≥99.5% purity, ultra-fine powdered octasulfur sourced from International Sulphur, Inc. To ensure 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 ≈ 230-246 °F depending on the crystalline structure, gas content, purity, pressure and other factors [1,2]. Solid amorphous sulfur can have a melting point as high as 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 is compulsory for guaranteeing performance.

Tests

Tests for both technologies were carefully set-up, performed, and documented in order to provide results that were comparable and reproducible. The standard test procedure started with installing 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 non-ideal installations). An optimal installation for the purposes of these experiments had an HTC thickness of 1/32-inch. Trace elements were installed on each side of the straight section and 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 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 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-foot tall partition, set up as the last physical component of the test.

Saturated steam at 50-psig (≈ 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 were fabricated, having diameters of 1/32-inch, 3/32-inch, and 5/32-inch. The spacers, shown in *Figure 5*, were used to simulate the HTC filled gaps between tracer and 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.

Figure 5: Spacers for maintaining consistent HTC thickness. Shown left to right: 1/32-inch, 3/32-inch, and 5/32-inch diameter

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-inch (0.031-inch).
FTS-B	Standard installation that partially followed manufacturer's guidelines. HTC thickness maintained 3/32-inch (0.094-inch).
FTS-C	Modified installation that partially followed manufacturer's guidelines. HTC thickness maintained 5/32-inch (0.156-inch).
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 1/32-inch (0.031-inch).
CST-B	Ideal installation that partially followed manufacturer's guidelines. HTC thickness maintained 3/32-inch (0.094-inch).
CST-C	Modified installation that partially followed manufacturer's guidelines. HTC thickness maintained 5/32-inch (0.156-inch).
CST-D	Non-Standard installation. No HTC used and no intentional space created between tracer and pipe (bare tracer on pipe).

Several assumptions about the parameters of the tests and characteristics of the equipment and environment needed to be 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 238-246 °F, which was easily verified by briefly removing the fume cap and visually inspecting the sulfur, but there was some variation. 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 definitely 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's unlikely that the temperature on the inside wall of the thermowells was more than 2-3 °F cooler than the sulfur, meaning the sulfur was definitely melted when the sensors reached an average of 248 °F and were at least 245.5 °F individually. Because 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 set-point by +3 to -4-psig. This translates approximately to +3 to -4 °F about the target temperature of ≈ 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. There are several test factors that were variable over the course of a year and must be noted:
    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 1-1/4-inch thickness was used to mitigate the effects of the changing ambient temperatures.

b. There are some variances in the thermophysical properties of HTC because it is manufactured in batches year-round. 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 was used for all tests to minimize these variations.

Measures and Measurement Devices

Equipment

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-inch 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 .csv files with a dedicated USB DAQ from Omega Engineering. All thermocouples used have standard limits of error purity, and the DAQ has cold junction compensation with 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 *Figure 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 was wrapped in plastic film for further protection from air flow.

Steam tube temperatures were measured about 6-inches prior to a tee that diverted steam to both runs of tracing. 6-inches of thermocouple wire preceding the junction was 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-foot tall partition, but within 3-feet of the testing apparatus. Measurements were taken at all locations simultaneously during every test. These measurements were recorded at 60 second intervals.

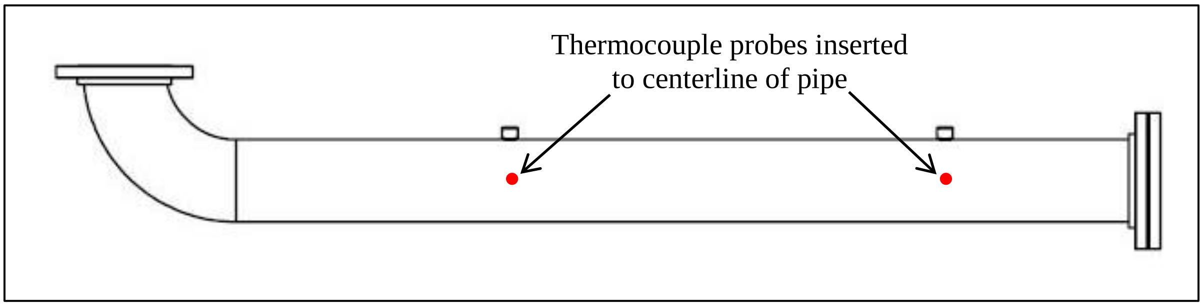

Figure 6: Thermocouple probe measurement locations

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 timeframe was established for each data set. This timeframe 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 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. 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 those effects have on performance.

CST Testing Results

The temperature/time relationship of CST tests A-D is shown in *Figure* 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-inch, 2 hours and 24 minutes were required for the sulfur to heat from 105-248 °F and melt. Increasing the HTC layer thickness from 1/32-inch to 3/32-inch increased the required melt time by 70% at 4 hours 3 minutes. Further increasing that layer to 5/32-inch caused the melt to require 5 hours and 12 minutes, 117% more time than an ideal installation. With bare CST installed directly on the pipe, 4 hours and 7 minutes were required to reach the melt-out criteria.

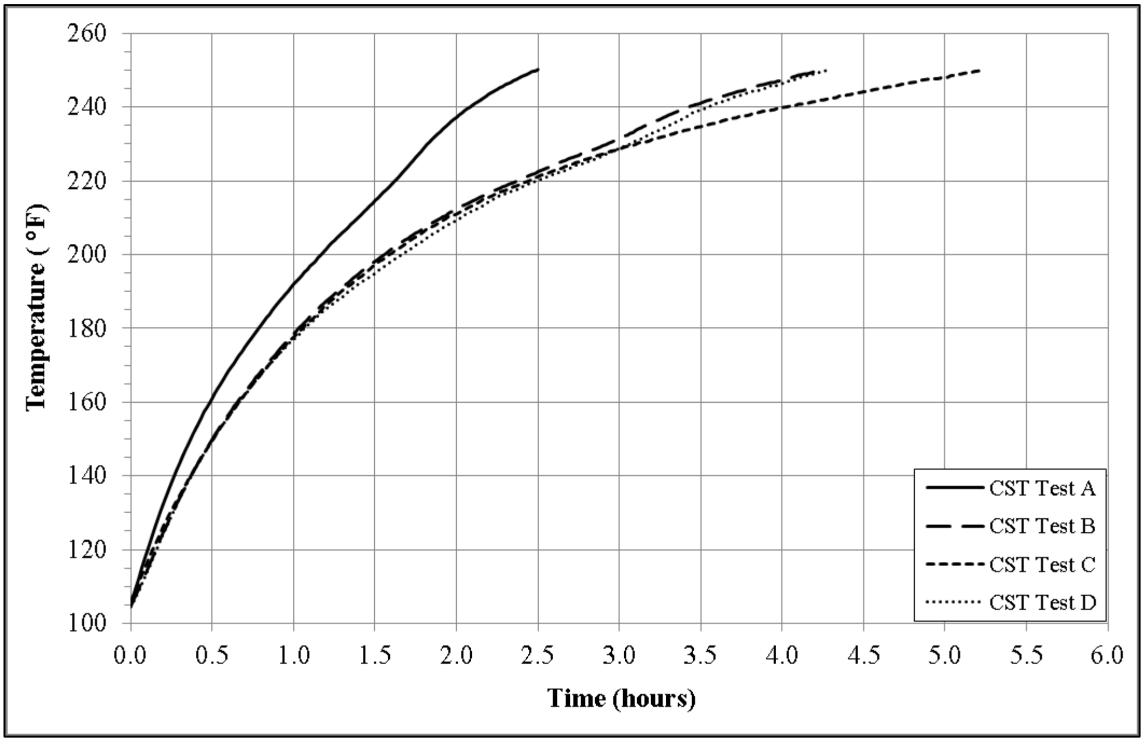

Figure 7: Temperature with respect to time for CST tests

Table 3: Time to melt sulfur using CST with various HTC thicknesses

Test	HTC Layer Thickness (inches)	Time to heat sulfur from 105-248 °F
CST-A	1/32	2 hours, 24 minutes
CST-B	3/32	4 hours, 3 minutes
CST-C	5/32	5 hours, 12 minutes
CST-D	No HTC – Bare CST tracer on pipe	4 hours, 7 minutes

FTS Testing Results

The temperature/time relationship of FTS tests A-D is shown in *Figure 8*, and the melt time results are tabulated in *Table 4*.

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

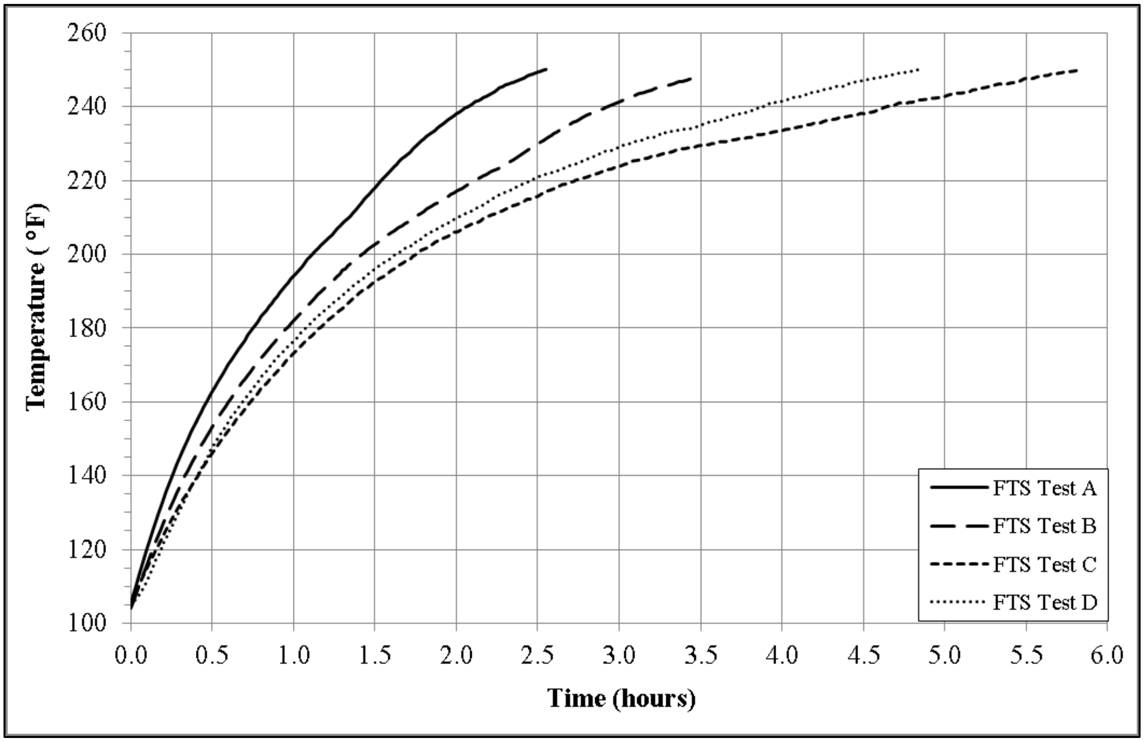

Figure 8: Temperature with respect to time for FTS tests

Table 4: Time to melt sulfur using FTS with various HTC thicknesses

Test	HTC Layer Thickness (inches)	Time to heat sulfur from 105-248 °F
FTS-A	1/32	2 hours, 26 minutes
FTS-B	3/32	3 hours, 29 minutes
FTS-C	5/32	5 hours, 34 minutes
FTS-D	No HTC – Bare FTS tracer on pipe	4 hours, 36 minutes

Conclusions

Based on the empirical evidence from testing two high performance steam tracing technologies, it is apparent that installing CST and FTS with heat transfer compound layers even 1/16-inch thicker than an optimum thickness of 1/32-inch has a noticeably negative impact on the rate of heat transfer into a solid sulfur process.

Figure 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.

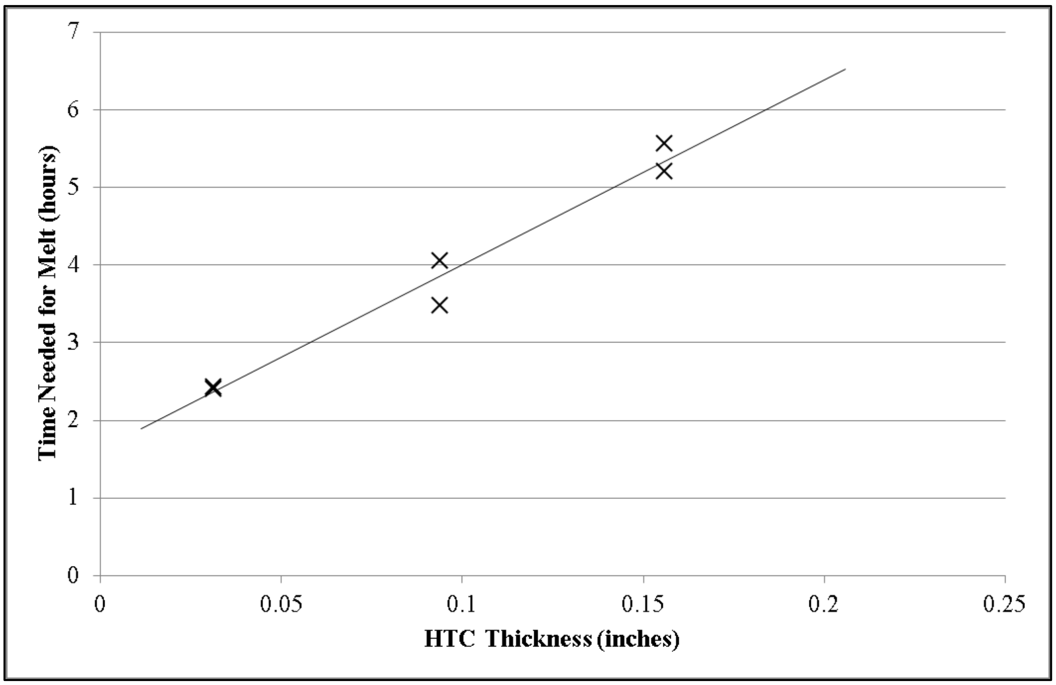

Figure 9: Time required for sulfur melt-out as a function of HTC thickness

The trend in Figure 9 suggests that for each 1/16-inch added to the HTC thickness, the time required to melt elemental sulfur in a 6-inch pipe will increase by an average of 1 hour and 30 minutes. 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 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 on to the personnel that install and maintain steam tracing systems. Proper installation of conductive steam tracing systems is compulsory for achieving the level of performance they are designed to provide, and one of the most critical factors in installation is the correct use of heat transfer compound. 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. Because of this, the HTC can end up being a significant limiting factor of performance for an otherwise properly designed system.

There are also long-term effects of using thick HTC layers that can be more harmful than the conduction issues discussed in this paper. 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 isn't 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 process vessel. Both of these 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, is an exercise that QMax Industries Inc. strongly believes in and facilitates.

QMax Industries Inc. 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 stand-off effect of weld beads on the 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, there is an installation complication that should be solved in another way so 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.

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