Molten is a MUST

Brandon Forbes, Controls Southeast Inc./AMETEK, USA, discusses the unique properties of sulfur and best practices for sulfur thermal maintenance in piping and storage.

Any facility using molten sulfur will be faced with the issue of reliably keeping the sulfur in a liquid state. Molten sulfur has some unique properties that result in a distinct set of challenges.

Thermal maintenance challenges

While sulfur can occur naturally in its elemental form, it is typically found combined with other materials in a larger molecule. Today, the most common producer of industrial use sulfur is the petrochemical industry. Sulfur compounds are prevalent in crude oil and natural gas. Refineries and gas plants must extract the sulfur from the feedstock to prevent contamination of the end products. The extracted sulfur is reduced to its elemental form and sold.

Temperature

Elemental sulfur melts at 247˚F. The resulting liquid has a low viscosity of approximately 10 cP and can be easily pumped. Thus, provided the sulfur temperature is maintained, storage and transportation through a piping system can be accomplished with relative ease.

When liquid sulfur reaches 318˚F a unique chemical change occurs. The most common allotrope of liquid sulfur is a ring of eight atoms. But at 318˚F, this ring breaks open and the sulfur atoms join together to form long polymer chains (Figure 1). This results in a rapid rise in viscosity with an almost immediate jump to 2100 cP at 320˚F climbing to a peak of nearly 100 000 cP at approximately 370˚F.

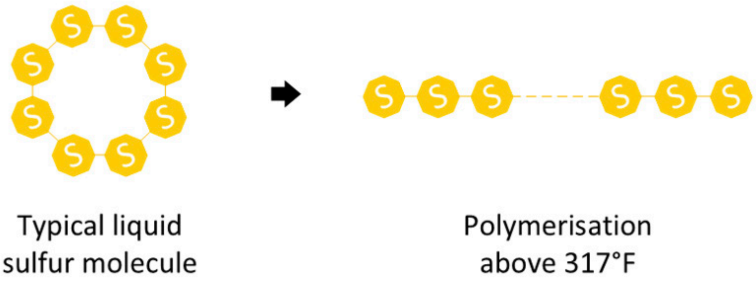

Figure 1. Sulfur molecular transition.

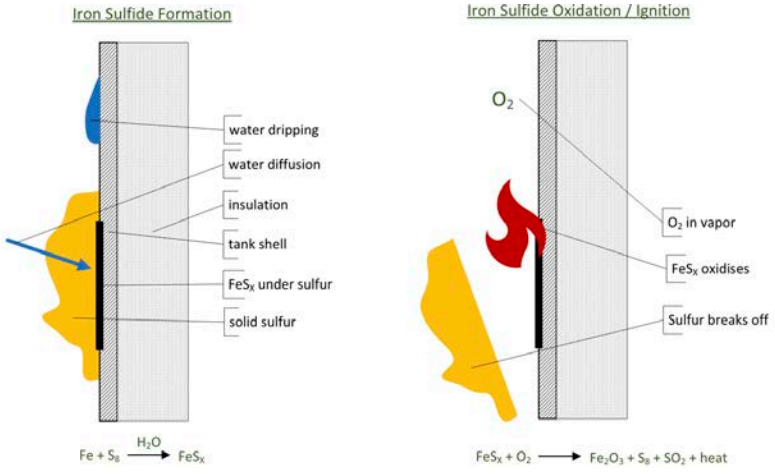

Figure 2. Iron sulfide formation and ignition.

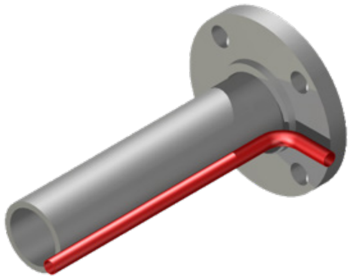

Figure 3. Tube tracing.

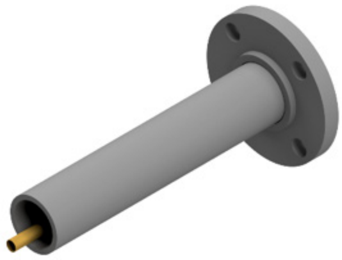

Figure 4. Gut tracing.

Corrosion and fires

Another concern with sulfur is its corrosion potential. When combined, sulfur, steel, and water react together to form various iron sulfides. This reaction can rapidly corrode through the carbon steel wall. Additionally, these sulfides are pyrophoric – when exposed to oxygen, a rapid exothermic oxidation reaction occurs. With a sufficient mass of accumulated sulfides, the temperature resulting from the oxidation reaction can be high enough to ignite the sulfur or any other available flammable material. This is primarily a concern in sulfur storage where sulfur, water, and oxygen frequently co-exist in the tank head-space.

One might attempt to stop the iron sulfide formation by removing water from the system (Figure 2). Unfortunately, this approach is not likely to succeed as there are numerous potential water sources, including:

- Leaking internal steam coils.
- Inadequate vent caps.
- Damaged tank roof or nozzles.
- Humidity in ambient air.
- Use of snuffing steam.

Thermal maintenance principles

Maintenance temperature

With a lower limit of 247˚F and an upper limit of 318˚F, proper sulfur temperature maintenance is critical. The heating fluid should be below the viscosity transition temperature (318˚F) to prevent unwanted temperature excursions. The target sulfur maintenance temperature should be at least 275˚F to provide an adequate safety factor against freezing. Even with this safety factor, uniform heating is critical. Any gap in the heating system or added heat loss path through valve stems, branch connections or supports needs to be carefully considered in the design of the heating system.

The flowing process fallacy

Many plants find that their heating system is 'adequate to maintain the temperature as long as the line is flowing.' This common sentiment reveals a misperception about pipe-line heat transfer. When molten sulfur is flowing through a line, the heat loss rate is very small compared to the energy provided by the hot, incoming sulfur. Thus, almost all sulfur lines will maintain their own temperature for as long as the line is flowing. The only real purpose of heating a sulfur line is to address start-up and upset conditions:

- To pre-heat the piping prior to start-up.
- To maintain the sulfur in a molten state when process flow stops.
- To re-melt a cold line when both the process flow and the heating system are disabled for an extended time.

Note that all three of the above criteria are essentially the same; the heating system must supply more heat to the line than is lost to ambient. Thus, any heating system designed to meet one of the above criteria will also be able to meet the other two criteria. The only caveat is that additional heat input may be required to achieve a specific melt-out time.

The weakest link principle

Even with a properly sized heating system, it is common for sulfur lines to plug when the process flow is interrupted. The issue is related to the age-old idea that a chain is only as strong as its weakest link. Any compromise along the length of the line may result in localised freezing that brings down the entire line. Common issues include:

- Gaps in the heating system application.
- Inadequately heated specialty components such as valves, instruments, nozzles, and adapter spools.
- Missing insulation.

- Unusually large pipe supports or nozzles that remove heat from a localised area.

Thermal maintenance of piping

Five different heating technologies are commonly considered for heating molten sulfur lines – tube tracing, gut tracing, electric tracing, jacketed pipe, and engineered bolt-on jacketing. The first three have proven inadequate for the task whereas the second two are capable, albeit that there are a few key differences between them.

Tube tracing

Tube tracing consists of tubing (typically ½ in. outer dia. [OD] stainless steel) banded to the outside surface of the pipe. With this design, the tubing and the pipe, two circles, only achieve point contact at best (Figure 3). Most of the heat transfer is less effective convective heat transfer rather than conductive heat transfer. The result of this is two-fold:

- The pipe temperature maintained is not consistent. It varies significantly based on ambient conditions, tubing contact, pipe features, etc.
- Either a very high heating fluid temperature (relative to the maintenance temperature) or an extremely large number of tracers is required to maintain a process temperature.

These properties of tube tracing make it ineffective in sulfur service. The sulfur cannot be reliably maintained within the 247°F to 318°F temperature window.

Gut tracing

Gut tracing consists of a small pipe run inside the process pipe; it is akin to conventional internal coils used for tank and vessel heating. With direct contact to the process, the gut tracing can provide a good amount of heat for the process. While under-sized gut tracing can be a problem, the most common issues are related to spool integrity. The gut tracing can rub on the inside of the pipe, thermal expansion can put undue stresses on the thru-wall connection points, and corrosion can occur on both the inner diameter (ID) and OD of the gut tracing. Also, with the pipe itself not heated, cold piping can lead to corrosion-under-insulation and the formation of iron sulfide (Figure 4).

Based on the concerns listed above, most facilities have moved away from gut tracing to more reliable heating methods.

Electric tracing

Where fluid heating media (e.g. steam, oil, or glycol) are not available, electric tracing is often used. With electric trace, the heat output is based solely on a signal received from a controller, and the controller can only see the temperature at the location of its sensor(s) (Figure 5). While the power output over a given length of electric tracing will be constant along its length, the power needs of the pipe are not. Some locations may experience additional heat loss due to fittings, supports, flanges, insulation variation, etc. These locations need additional heat, but the electric tracing will not provide it as the controller is not aware of the need.

In contrast, heat transfer from fluid tracing is proportional to the temperature difference between the heating fluid and the pipe (in accordance with the basic formula of heat transfer $q = UA\Delta T$). Thus, even a small drop in local pipe temperature will result in a significant increase in heat transfer from the tracer.

The end effect is that fluid tracing can reliably maintain a narrower temperature window than electric tracing can. Sulfur, with a 247°F to 318°F temperature window, is outside the scope of electric tracing's reliable operation.

Jacketed pipe

Jacketed pipe consists of a double-wall pipe with process in the core and the heating fluid in the annular space (Figure 6). Jacketed pipe provides maximum heat transfer due to the process being completely surrounded by the heating fluid. In this way, it is the most robust heating system available; it is insensitive to ambient conditions, insulation quality, and other variables. It provides the shortest melt-out time and reliable operation, and is therefore the go-to standard for sulfur application in many plants.

There are, however, other drawbacks that must be considered:

- Cost: jacketed pipe is the most expensive heating technology. A jacketed pipe spool is typically 3 to 5 times the cost of a process pipe spool with larger bore piping being even more.
- Adaptability: jacketed pipe is difficult to modify when field adjustments are required.
- Routing: jacketed pipe is stiffer than process pipe, often requiring more expansion loops and imposing higher stresses.
- Cross-contamination: jacketed pipe is considerably more reliable than gut tracing, but failures resulting in cross-contamination can still occur.

Engineered bolt-on jacketing

Engineered bolt-on jacketing consists of fabricated heating elements designed specifically for the piping on which it is to be installed. ControTrace® by Controls Southeast Inc has been designed so that the device can be tailored to the specific geometry and thermal requirements of each application (Figure 7). The heating elements are bolted (or banded) to the outside of the piping. The heating elements themselves are made to match the contour of the piping to provide maximum contact and conductive heat transfer.

The cost of engineered tracing is higher than that of tube tracing, but lower than that of jacketed pipe. However, in many cases the total installed cost will be competitive with tube tracing due to the more efficient circuitry and corresponding reduction in supporting infrastructure. These systems can be easily retrofitted to existing piping. The design is based on meeting the specific requirements of each application; melt-out and similar requirements are addressed from the start.

When compared to jacketed pipe, engineered tracing has two relative weaknesses: the first weakness is installation quality. Installation is typically performed in the field; proper training and supervision should be provided to ensure that everything is installed correctly. The second weakness is insulation. While jacketed pipe will operate well even with large sections of missing insulation, bolt-on systems will not. Maintenance of the pipe insulation is critical for reliable operation.

Thermal maintenance of tanks and vessels

When considering sulfur storage tanks, the industry best practice is to maintain both the liquid and the tank internal surfaces above the freezing point of sulfur. This is done to prevent corrosion and fires associated with the accumulation of iron sulfides, as discussed in the beginning of this article. Factors such as tank venting, ambient conditions, and insulation also affect the

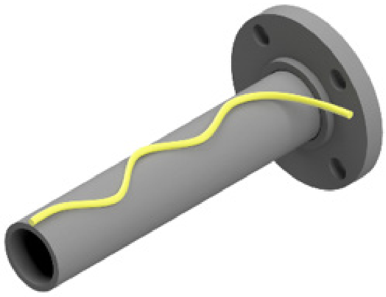

Figure 5. Electric tracing.

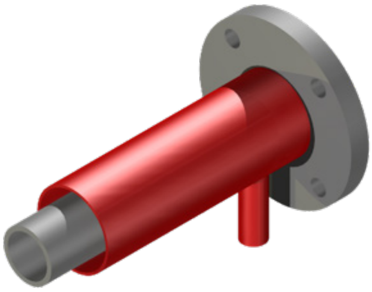

Figure 6. Jacketed pipe.

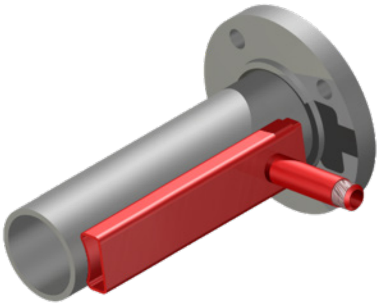

Figure 7. ControTrace bolt-on jacketing.

Figure 8. Horizontal vessel heated with ControTrace bolt-on heating panels.

Table 1. Tank heating technology comparison

Technology	Liquid temperature	Vapour temperature	Surface temperature
Internal coils	✓		
Panel coils	✓	✓	
ControTrace	✓	✓	✓

corrosion rate; but maintaining a uniform tank surface temperature is the only reliable method of preventing corrosion and iron sulfide build-up.

Internal coils

Internal coils are the least expensive tank heating technology. They are effective at maintaining the sulfur in a liquid state, but do not address the tank surface temperature. Another drawback is their lack of accessibility, as the tank must be taken off line and emptied to execute any repairs. This approach generally results in the highest long-term costs due to the repair complexity and shortened tank service life. Tanks heated with only internal coils are also more susceptible to tank fires due to the increased potential for iron sulfide formation.

External panel coils

Panel coils (or plate coils) are typically fabricated from two metal sheets that are welded together. The space between the sheets is 'expanded' to receive the heating fluid, in a similar manner to how batting is sandwiched between the outer layers of a quilt. These panels are then attached to the external surface of the tank. They can be attached to both the liquid and the vapour region.

Panel coils are effective at heating the tank liquid and, to some extent, the vapour in the tank head space, but they do not effectively address the tank surface temperature. The geometric limitations of fitting rectangular panels on tanks and vessels prevent them from being spaced as closely as would be necessary. The gaps between panels are left unheated and cold. Additionally, the panels cannot be readily formed to fit closely around nozzles and other attachments, leaving these areas, which are often the most critical, without adequate heat.

External bolt-on jacketing

Similar to its application in piping (described earlier), engineered bolt-on jacketing can be applied to tanks and vessels. ControTrace can be configured into heating panels that are attached to the outside of the tank. Each panel may consist of multiple parallel heating elements (Figure 8 and Table 1). These elements can be spaced precisely to achieve the desired surface temperature. The panels can also be fabricated in non-rectangular shapes to wrap around nozzles, conform to elliptical and conical heads, etc. Finally, the system can be optimised for the application by varying the element spacing to best address the different regions of the tank – liquid space, vapour space, roof, etc.

This approach results in the most uniform tank heating available. The liquid, vapour, and tank surfaces can all be maintained above the freezing point of sulfur. Tank service life is maximised, and maintenance of the heating system can be performed with the tank in full operation.

Conclusion

In conclusion, sulfur is a material with unique challenges for transportation and storage. These challenges can be addressed with good technology selection during the project planning phase. Choosing the correct technology and installing it correctly can have a significant, positive impact on the overall operation of a facility.