

PREVENTING CORROSION IN SULFUR STORAGE TANKS

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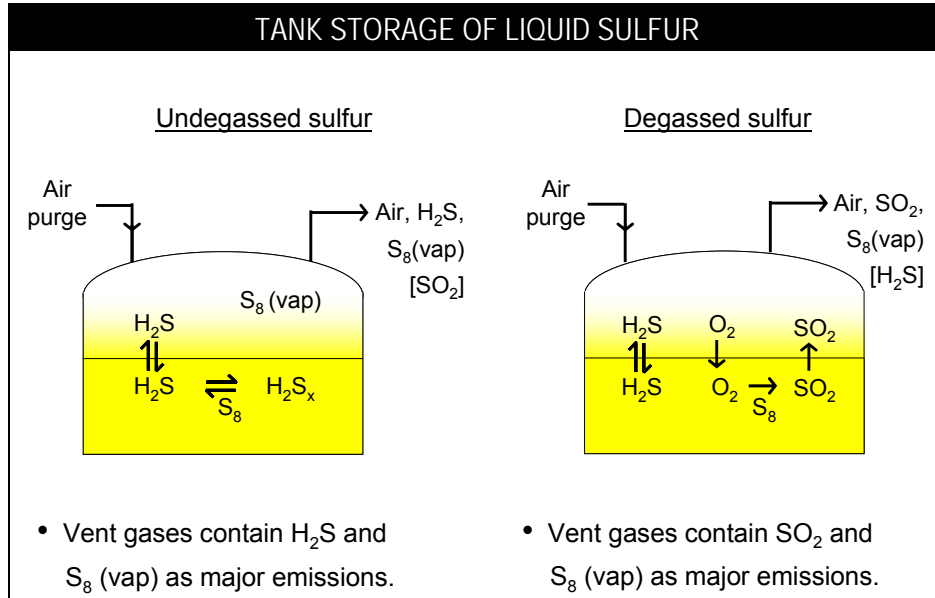
SUMMARY

Throughout the world, field-erected storage tanks are commonly used for the temporary storage of large volumes of molten sulfur. Unfortunately, tank life can be significantly limited by corrosion, especially in the vapor space above the normal liquid level. Several corrosion mechanisms are possible and will be reviewed. Most likely, corrosion results from the deposition of solid sulfur and formation of trace quantities of liquid water at cool metal surfaces. This combination leads to the formation of iron sulfide which, in addition to resulting in tank damage, is pyrophoric. If iron sulfide is suddenly exposed to oxygen, it can also ignite a sulfur fire within the storage tank. The best way to mitigate corrosion is to prevent the formation of solid sulfur on the tank wall/roof. Conventional heating technologies, such as internal coils, are effective in keeping the sulfur in molten state but do not maintain a sufficiently high tank wall temperature in the vapor space. By employing a distributed external heating system, the tank wall and roof temperatures as well as vapor space temperatures can be maintained at temperatures above the sulfur freezing point, thereby eliminating the primary corrosion mechanism. This paper will review potential corrosion mechanisms and operational data which illustrate the importance of engineered heating systems.

INTRODUCTION

Storage tanks for liquid sulfur are utilized in many refineries and sour gas processing facilities for temporary storage of liquid sulfur produced in the sulfur recovery plant. They are usually constructed from carbon steel and insulated and heated to maintain the liquid at a temperature $> 125^{\circ}\text{C}$. Depending on the facility, the tank may receive liquid sulfur which has been treated to remove H_2S dissolved in the sulfur or it may be filled with undegassed product¹. These two cases (Figure 1) present significantly different conditions in the tank as undegassed sulfur will slowly release H_2S causing that gas, along with sulfur vapor, to build up in the headspace of the tank. Usually, the tank will be drafted with air at a rate so as to limit the concentration of H_2S in the headspace. This sweep air, contaminated with small amounts of sulfur and H_2S , is then vented from the tank. If the sulfur is degassed, the liquid will contain < 10 ppmw residual H_2S and the small amounts released to the headspace tend to become oxidized to SO_2 before the sweep air vents to atmosphere. Thus, the major emissions from a sulfur tank receiving degassed sulfur are sulfur vapor with some SO_2 (Figure 1) although H_2S can also be present depending on the overall residence time of gases in the hot headspace of the tank¹.

Figure 1



A typical sulfur storage tank does not store sulfur for long periods. In a refinery, such a tank is used to store liquid sulfur only as a holding point before shipping, forming or blocking. Thus, the tank is rarely full or empty. It is normally receiving sulfur and may be pumped down from several times a day to once every two or three days. Tanks in a sulfuric acid plant are more likely to hold liquid for a longer period, but that is still usually a matter of days. Of course, all tanks are susceptible to unusual conditions that can cause them to remain in most any condition for extended periods, and they must be heated to withstand these conditions.

Different heating methods are employed to maintain the sulfur in molten state. These methods range from internal submerged coils to external heating panels. Saturated steam is most always the heating medium utilized. Historically, heating methods have not considered the temperature of internal tank surfaces. The relationship between these surface temperatures and tank performance will be explored in this paper along with the effectiveness of various heating methods to maintain these internal temperatures.

COMMON CAUSES OF FAILURE

1. External Corrosion

The primary cause of external corrosion of a sulfur tank is ambient water which invades the insulation and becomes trapped between the tank surface and the insulation. If the tank wall temperature is below 100°C, it will not vaporize the water; consequently, the water will be able to stagnate and continually corrode the surface. This type of corrosion is commonly experienced on the tank roof and walls when inadequate heating is supplied.

Other, less frequent causes of external corrosion of a sulfur tank result from interaction with either elemental sulfur or sulfuric acid that accumulates in the ground and base area surrounding the tank. Inevitably, some sulfur is spilled around a tank facility and, if not removed fastidiously, it can work its way into the surrounding base and soils. As is illustrated in Figure 2, contact of the sulfur with the steel will result in iron-sulfur contact corrosion at a rate, depending on temperature and other factors, of 50 – 300 mpy². The products, FeS and related sulfides, are readily oxidized by oxygen from the air so red iron oxide may be seen building up at the steel surface around ground level, although in most cases, it will not be visible because of the tank insulation. The chemistry of the sulfide oxidation is quite complex and further hydrolysis of ferric sulfates will cause the acidity of the surrounding area to increase very significantly (Figure 3). Thus the original FeS corrosion product may lead to tank corrosion by sulfuric acid.

Figure 2

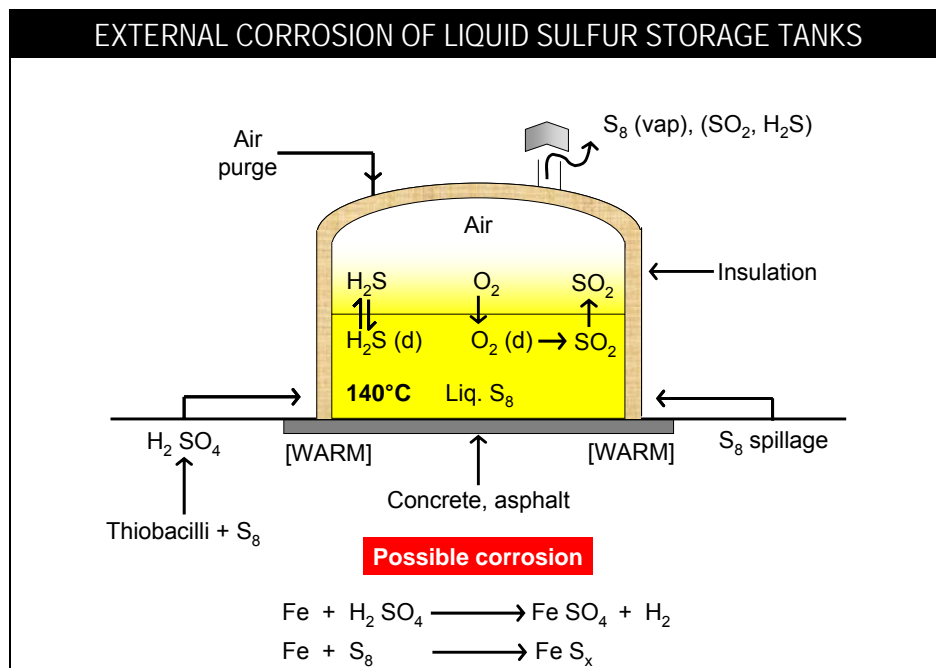
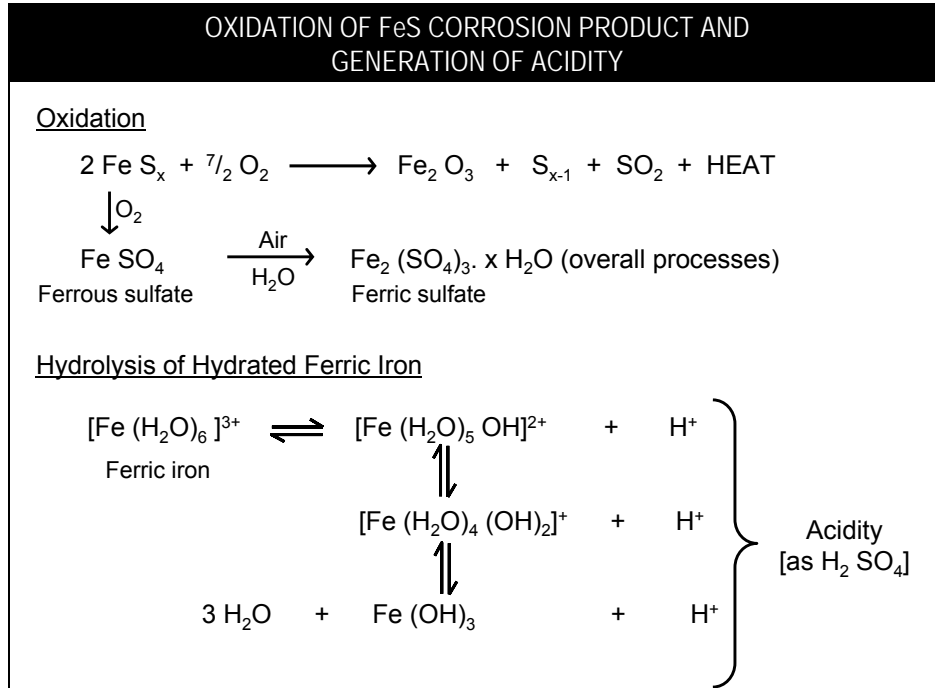


Figure 3



Another source of sulfuric acid is bacterial oxidation of the elemental sulfur that is spilled around the tank area. This process is a very well known phenomenon around solid sulfur storage areas and is due to digestion of sulfur by Thiobacilli and other naturally occurring bacteria found in soils throughout the World. These bacteria are distributed by the elements and will populate any area where sulfur is located, especially in warm locations (20 – 35°C). Thus, a hot sulfur tank may provide a comfortable location for these bacteria by warming the surrounding area creating conditions where sulfuric acid can be formed in ground water, puddles and the like. If water is allowed to drain towards the tank containing even a small amount of sulfuric acid, evaporation of the water will concentrate the acid and lead to classic acid corrosion of the steel.

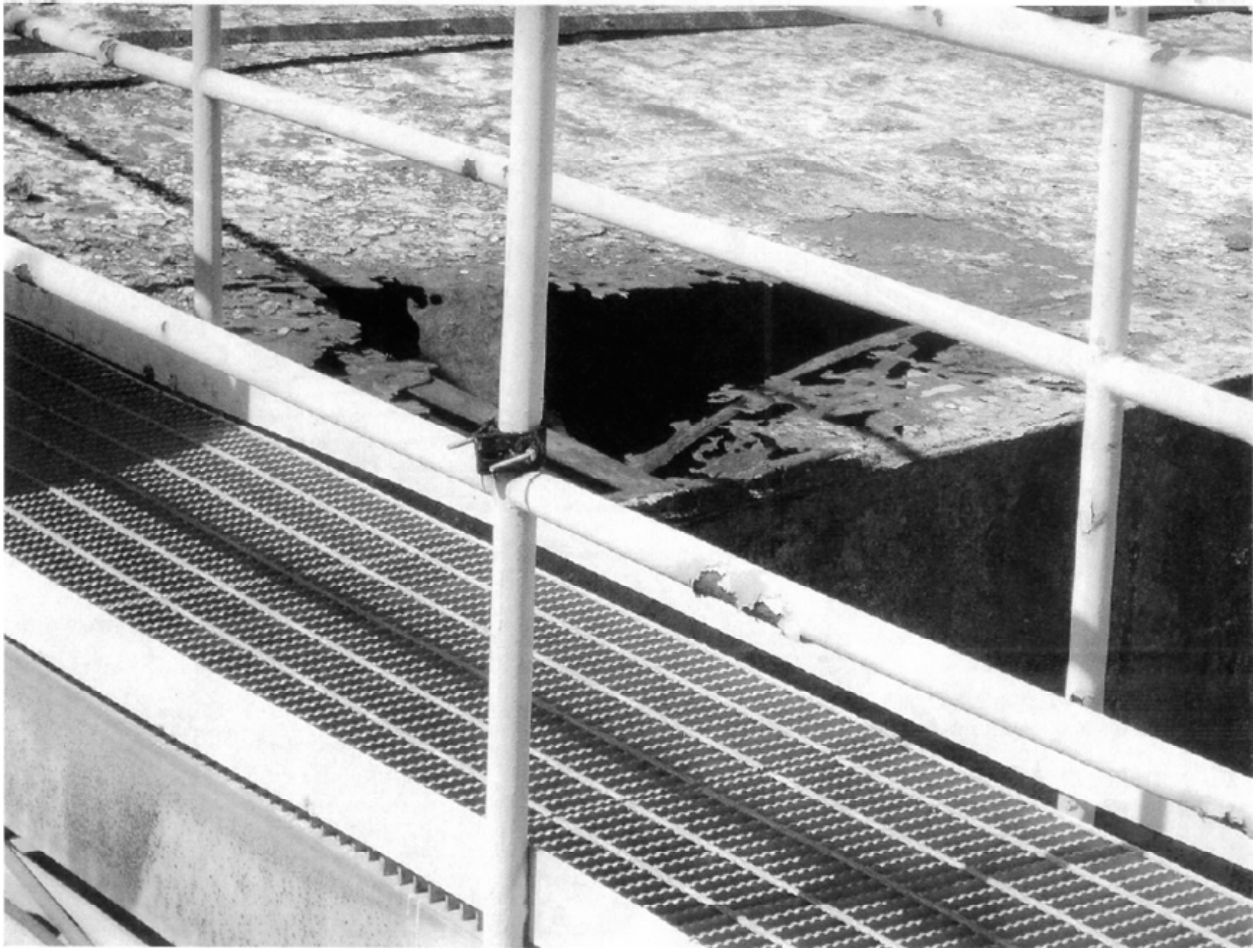
Clearly both construction of the base for the tank and the overall design around the base area are very important as sulfuric acid could lead to deterioration of concrete and corrosion of steel should acidic water be allowed to drain back towards the tank. Of course, of prime importance is general house-keeping around the tank as spilled elemental sulfur is the source of all of these problems. In particular, care should be taken to remove tank insulation that may become contaminated with sulfur to prevent iron-sulfur contact corrosion. The contaminated insulation should be replaced with clean insulation; there should be no areas on the tank which are left uninsulated and exposed to ambient.

2. Internal Corrosion

One major mechanism for internal corrosion of a sulfur tank is attack of the steel by solid elemental sulfur that builds up on the interior tank walls (including the roof, side walls, and vent nozzles) in the vapor space above the liquid level. This can contribute to the destruction of the

tank wall as shown in Figure 4. How can solid sulfur accumulate inside a tank designed to store liquid sulfur? Overall, either the heating system and/or the tank insulation are inadequate to maintain the inner steel surfaces $> 115^{\circ}\text{C}$. In particular, such a situation may arise at the interior walls in the vapor space in a tank that has a steam coil immersed in the bottom of the tank. In this case, there are many heat transfer paths by which the heat from the submerged coil can be lost before it reaches the inner surfaces.

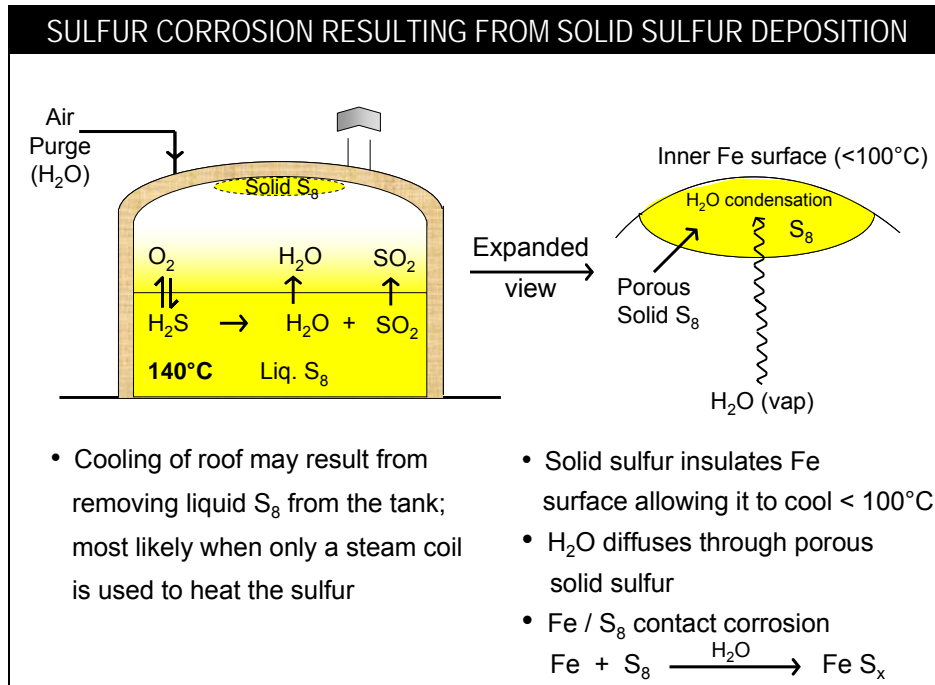
Figure 4



As is depicted in Figure 5, a layer of solid sulfur may form at the cooler wall surface in the vapor space and, because of its excellent insulating properties, further prevent internal heat transfer to the metal surface from the hot components inside the tank. If the steel surface temperature continues to fall, water may condense at the steel/sulfur interface creating an ideal condition for iron/sulfur contact corrosion and formation of FeS . At first glance, it may seem that water condensation would be very difficult, but there are several sources of water and mechanisms for formation of conducting films that enhance iron/sulfur corrosion. Water may enter the system with the air purge, but it may also be formed by oxidation of H_2S either in the liquid sulfur or in the headspace. Thus, the amount of water in a tank will be related to the amount of residual H_2S in the liquid sulfur with undegassed sulfur leading to the highest quantities. A leaking internal steam coil can be a very large source of water. Water, as with the other gaseous components in

the headspace, can diffuse through the solid sulfur and condense at the cooled steel surface thus creating the ideal conditions for iron/sulfur corrosion. In cases where SO₂ is present in the headspace of the tank, it too may diffuse through the solid sulfur combining with the water at the cooler steel surface creating a conducting microfilm of polythionic acids. Once iron/sulfur contact corrosion has commenced, the corrosion product, FeS_x, enhances the corrosion since it is able to conduct electrons between the iron and sulfur. Here, the sub-script x denotes that the iron sulfide is a non-stoichiometric substance being able to function as a semi-conductor.

Figure 5

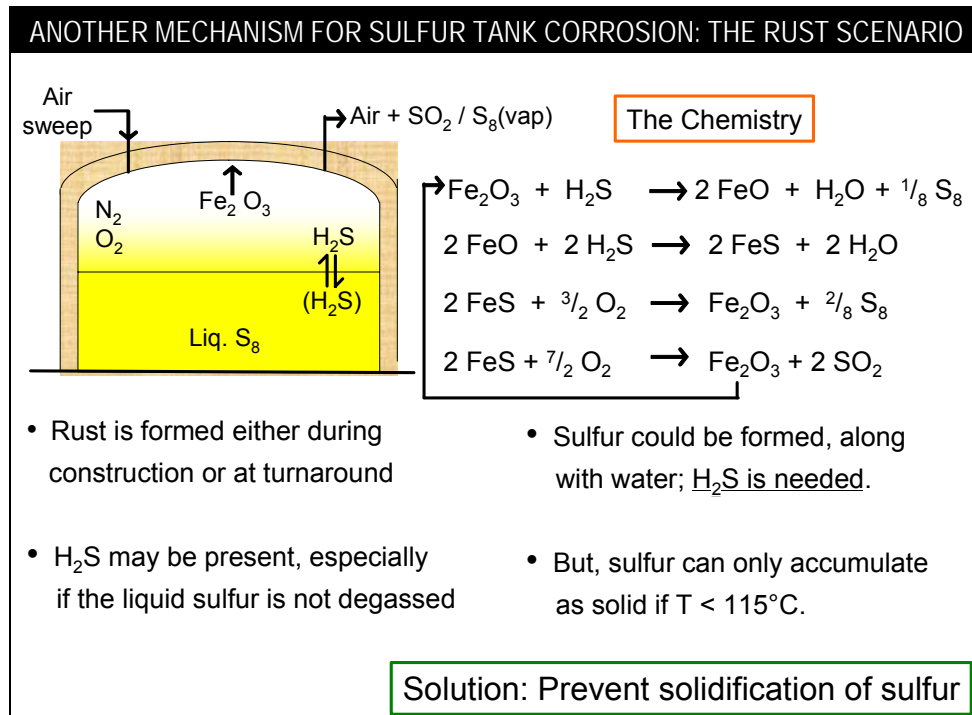


It is thought that the vent caps may be an “Achilles heel” in many sulfur tanks as they are more difficult to insulate and keep hot and are exposed to the rain and snow, thereby increasing the possibility of water condensation. It may be better to construct the vent cap from titanium or aluminum to prevent the formation of pyrophoric iron sulfides. While these materials may still be attacked by the acidic conditions that could occur at the vent cap, corrosion of titanium or aluminum does not lead to pyrophoric solids. Nevertheless, adequate heating remains crucial to preventing these corrosion mechanisms.

Another potential mechanism for internal corrosion of a sulfur tank presented in Figure 6 centers on the presence of a rust layer at the internal surfaces of the tank. Rust may be formed either during erection of the tank or, perhaps, during a turnaround period when the tank is exposed to humid air. The overall effect of the rust would be to convert any H₂S in the tank to sulfur and water directly at the steel surface. The detailed chemistry (Figure 6) shows how ferric iron can oxidize H₂S to elemental sulfur in a catalytic cycle driven by the oxygen from the air used to purge the tank. Of course, H₂S is required so undegassed liquid sulfur would be expected to be most troublesome. Importantly, the rust-promoted oxidation produces water at the steel surface

as well as the sulfur needed for corrosion of the steel. The steel surface must be < 115°C for solid sulfur to accumulate, so this mechanism for sulfur accumulation is only of interest for poorly heated/insulated tanks. [Note: The rust-promoted mechanism will still occur at a steel surface above 115°C if H₂S is present but should only lead to re-establishment of the original oxide (rust) film].

Figure 6

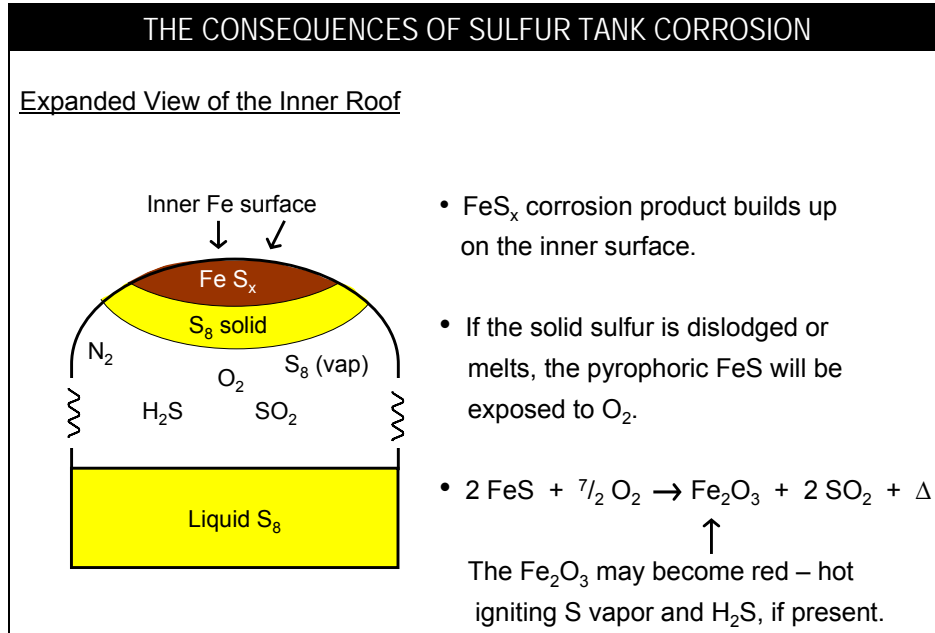


3. Consequence of Sulfur Tank Corrosion: Fire and Explosion

FeS formed by iron/sulfur contact corrosion is very pyrophoric such that a “quarter-size” lump will become red-hot when exposed to air. At least two scenarios can be imagined in which FeS that has built up inside a tank becomes exposed to air (Figure 7). Re-filling of a tank with hot liquid sulfur may melt the solid sulfur at the roof or at another location exposing the FeS to oxygen. In this case, as the FeS oxidizes it may ignite sulfur vapor or H₂S in the headspace of the tank leading to an “uncontrolled” combustion. Re-melting, in combination with mechanical vibration, could dislodge the red-hot corrosion product such that it falls into the liquid sulfur starting a fire in the tank. This type of ignition has been noted by numerous field workers whenever FeS and liquid sulfur come into contact in the presence of air.

In one case at a refinery, it is believed that removal of liquid sulfur from the tank caused air to be sucked back into the tank through the vent cap, dislodging FeS at that location; the rapid heating of the FeS, caused a detonation within the tank that damaged it beyond repair. Clearly, build up of FeS in a sulfur tank is to be avoided.

Figure 7



4. The Critical Elements of Sulfur Tank Corrosion (Figure 8)

Both external and internal sulfur tank corrosion can be complex processes with a variety of mechanisms in play. External corrosion may be prevented by ensuring that exterior wall surfaces are maintained > 100°C and that elemental sulfur does not accumulate around the base of the tank. Design of the tank base should be not just for structural integrity but also to prevent accumulation of water around its base. Internal corrosion is the most likely cause of destructive tank corrosion. It can largely be avoided by ensuring that sufficient heat is delivered to system to prevent build up of solid sulfur inside the tank and at the vent points. The rest of this paper is devoted to describing the best way of achieving this objective.

Figure 8

THE CRITICAL ELEMENTS OF INTERNAL SULFUR TANK CORROSION

- Fe / S₈ contact corrosion can only proceed if water can condense.
- Water is most likely to condense if solid sulfur accumulates at a cold surface (T < 115°C, 239°F).
- If the tank roof is not heated and insulated adequately, the inner roof surface temperature may fall well below 100°C.
- Fe / S₈ contact corrosion rates may exceed 300 mpy at 70 - 90°C.

Solution: Prevent solidification of sulfur

ENGINEERED SYSTEMS FOR SULFUR TANK THERMAL MAINTENANCE

1. Evolution of Heating Systems

Thermal maintenance technology for sulfur tanks has evolved in response to a growing understanding of potential safety and performance issues. The first generation of tank thermal maintenance consisted of an internal submerged steam coil and external insulation. The steam coil was designed to replace the heat loss from a full tank. This method focused solely on maintaining the liquid sulfur temperature and ignored the temperature of the tank wall, tank roof, internal support structure, and vapor space. Submerged coils were effective in maintaining the liquid sulfur temperature, but were prone to steam leaks over time. Furthermore, since the roof temperatures were not maintained above the freezing point of sulfur, tank roofs were known to cave in due to sulfur vapors condensing, freezing, and building up on the roof interior to a point which overstressed the roof's structural integrity. In response to roof collapse, the second generation featured exterior steam coils on the roof to keep the roof interior wall temperature above the sulfur freezing point. However, the interior wall temperatures in the vapor space above the liquid level were not completely addressed. Cool temperatures continued to allow the build-up of solid sulfur on the interior walls as well as the failure to vaporize any ambient water which had invaded the insulation. Additionally, more sour oil and gas led to excess buildup of H₂S in tanks which, in turn, led to the requirement for sweep air. The low interior wall temperatures were exacerbated by cold sweep air swirling through the tank. Consequently, the risk of internal corrosion, fire, and explosion remained (as previously discussed).

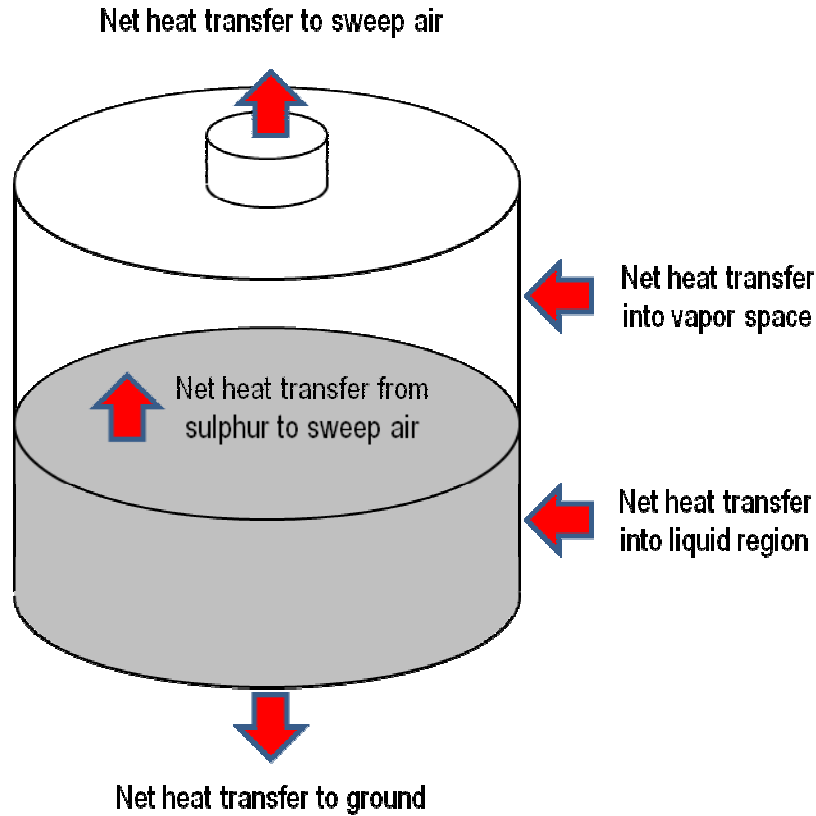
The third (and current) generation of sulfur tank thermal maintenance features the design of external jacketing to heat the tank shell and roof. An external steam jacket is simply an external chamber that is attached to the tank. A heating medium (typically steam) is circulated through

the jacket to transfer heat to the tank wall. Heat transfer mastic is commonly applied between the jacket and tank wall to improve heat transfer. External jacketing offers the flexibility of supplying heat to the specific parts of the vessel that require it. Additionally, if the external jackets are sized correctly, they can completely eliminate the need for an internal coil and any chance of cross contamination (steam leaks). External steam jackets are typically sized to cover a calculated percentage of the surface area to make up for heat lost to the ambient. After determining the amount of surface area required, the heated area is commonly distributed somewhat uniformly around the tank surface. There are currently two types of external jackets. One features a large, flat, bendable, steel sheet which contains steam passages. The other features a lattice work of rectangular tubing (trade name ControTrace) formed to fit a tank.

2. Tank Thermal Maintenance Model

A sulfur storage tank presents a complicated heat transfer problem. Heat is lost from the sulfur through the tank bottom and into the ground, through the tank walls to the ambient, and to the internal vapor. Significantly more heat is lost to the internal vapor when the vapor space is swept to prevent a build-up of H₂S in the tank. The sweep air dynamics have a large influence on the vapor space temperature, and the vapor space temperature has a significant influence upon the internal wall temperatures. In order to evaluate the thermal maintenance effectiveness of various heating systems, a finite-difference computer model was developed to account for all of these heat transfer paths. In addition to modeling the various heat transfer paths, the model accounts for variables such as tank diameter, tank height, tank wall material, tank wall thickness, insulation type, insulation thickness, sulfur level, ambient air temperature, sweep air entering temperature, sweep air flow rate, internal heat transfer coefficient, external wind conditions, heating medium, and length of time tank has been in service (since this affects the heat loss into the ground). The model allows for heating via internal submerged steam coils and/or external steam jackets. In the model, each method of heat input can be applied separately or in combination. The model performs an energy balance on the molten sulfur section and the internal vapor section of the vessel simultaneously. The result of the calculation is the steady-state equilibrium temperature of the molten sulfur, vapor space, and minimum local tank wall temperature. Figure 9 shows the model control volume and heat transfer paths considered.

Figure 9



3. Comparison of Heating Systems

In order to demonstrate the wide range of internal tank temperatures which can exist, the tank thermal maintenance model previously described was run for four heating scenarios on a representative tank. The representative tank has a diameter of 10.8 m (35.5 ft) and height of 8.5 m (28 ft). The tank is insulated with 100 mm (4 in) of calcium silicate insulation, heated with 3.5 barg (50 psig) saturated steam, and subjected to a minimum ambient temperature of -18°C. The four heating scenarios evaluated are shown in Figure 10.

Figure 10

	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>	<i>Scenario 4</i>
<i>Heating System</i>	Submerged Coils	Submerged Coils	Sheet Panels With Submerged Coils	ControTrace Panels
<i>Sweep Air Flow Rate</i>	0 cfm	145 cfm	145 cfm	145 cfm
<i>Sweep Air Inlet Temperature</i>	N/A	145°C	145°C	-18°C

Each scenario was analyzed to determine the molten sulfur temperature, bulk vapor temperature, and tank wall temperature. In order to be considered successful, the thermal maintenance system must maintain all temperatures above 120°C to keep the sulfur molten and prevent solid sulfur build-up on internal surfaces which can lead to tank corrosion.

Scenario 1

Scenario 1 is the simplest case, featuring no sweep air and heating via an internal submerged coil. Figure 11 shows the modeled temperatures for various sulfur levels.

Figure 11

<i>Sulfur Level</i>	T_{Sulfur}	T_{Vapor}	$T_{Min\ Wall}$
75%	141°C	118°C	100°C
50%	141°C	111°C	93°C
25%	141°C	101°C	85°C

The results of Scenario 1 show that the internal vapor temperature of the sulfur tank is 101 – 118°C depending on the sulfur level. This translates to an interior tank wall temperature of 85 – 100°C, which is significantly below the freezing point of sulfur. Furthermore, condensation of water vapor on the tank exterior will be possible when the tank is less than 75% capacity because the wall temperature will be less than 100°C. Therefore, based on the success criteria of maintaining all temperatures above 120°C, the use of internal submerged coils alone fails to address the corrosion mechanisms previously discussed.

Scenario 2

In Scenario 2, the same tank is heated via an internal submerged coil, and the vapor space of the tank is swept with air. The sweep air in this scenario is pre-heated to 145°C as a best-case operating condition; in actuality, sweep air is not typically preheated, especially to such a high temperature. Figure 12 shows the modeled temperatures for various sulfur levels.

Figure 12

<i>Sulfur Level</i>	T_{Sulfur}	T_{Vapor}	$T_{Min\ Wall}$
75%	141°C	120°C	101°C
50%	142°C	113°C	95°C
25%	142°C	103°C	87°C

Prior to modeling, it was assumed that the 145°C sweep air would be able to maintain the vapor and tank wall temperatures above 120°C. However, the results show that the walls in the vapor space lose heat faster than the sweep air can resupply it. Below 75% capacity, the vapor temperature is below 120°C, and at all levels the wall temperature is below 120°C. The results of

Scenarios 1 and 2 show that even with significantly preheated sweep air (preheated 25°C above the freezing point of sulfur), an internal submerged coil fails to address the corrosion mechanisms previously discussed. To maintain the tank wall and internal components above 120°C, heat must be added to the vessel (and not just to the sulfur).

Scenario 3

In Scenario 3, the tank is heated via large sheet panels applied to the exterior tank shell and roof along with an internal submerged coil. The panels cover 22% of the shell wall surface area and 13% of the roof surface area. Figures 13 and 14 show an example of exterior sheet panels applied to the shell and roof of a tank, respectively.

Figure 13



Figure 14



In Scenario 3, the sweep air is again pre-heated to 145°C as a best-case operating condition. Figure 15 shows the modeled temperatures for various sulfur levels.

Figure 15

<i>Sulfur Level</i>	T_{Sulfur}	T_{Vapor}	$T_{Min Wall}$
75%	138°C	122°C	101°C
50%	138°C	119°C	98°C
25%	137°C	117°C	96°C

The results of Scenario 3 show that the large sheet panels are unable to maintain the preheated sweep air at its entering temperature. Due to large spacing between the external steam jackets (reference Figure 13), the heat loss to the ambient exceeds the heat input capabilities of the steam jackets. The resulting equilibrium vapor temperature is significantly less than the entering sweep air temperature. The minimum tank wall temperature occurs at the midpoint location between panels. All minimum wall temperatures are well below the freezing point of sulfur; furthermore, below 75% capacity, the wall will not be hot enough in these locations to vaporize any liquid water which reaches the wall (inside or outside). So, while the sheet panels provide localized sections of heat to maintain sections of the tank wall above 120°C, they do not maintain all

sections of the tank above 120°C. The large spacing between panels allows cold spots to exist and the potential for sulfur to solidify on these sections of tank wall. Therefore, the distance between external steam elements is critical to maintaining the tank wall at elevated temperatures.

Scenario 4

In Scenario 4, the tank is heated via ControTrace panels applied to the exterior tank shell and roof. There is no internal submerged coil. The ControTrace panels cover 20% of the shell wall surface area in the bottom 4' of the tank; for the remainder of the tank, the ControTrace panels cover 10% of the shell and roof surface area. Figures 16 and 17 show an example of ControTrace panels applied to the shell and roof of a tank, respectively.

Figure 16



Figure 17



In Scenario 4, the sweep air is not pre-heated but enters at ambient temperature (-18°C). In contrast with the other three scenarios analyzed, this cold sweep air represents a worst-case operating condition for the tank heating system. Figure 18 shows the modeled temperatures for various sulfur levels.

Figure 18

<i>Sulfur Level</i>	<i>T_{Sulfur}</i>	<i>T_{Vapor}</i>	<i>T_{Min Wall}</i>
75%	139°C	125°C	128°C
50%	139°C	127°C	129°C
25%	138°C	129°C	130°C

The results show that the ControTrace maintains the internal vapor and tank wall temperatures above 120°C for all sulfur levels. Internal support members surrounded by the vapor will be maintained very close to these temperatures. Therefore, all internal tank surfaces will be

maintained above the freezing point of sulfur, and will not allow sulfur to solidify. Furthermore, any potential water trapped externally between the tank surface and insulation will be vaporized.

Together, all four analyses show that external jacketing is required to maintain all tank surfaces above 120°C to prevent the mechanisms previously discussed which can lead to external corrosion, internal corrosion, fire, and explosion. The external heating strategy must consider not just the heat required to offset heat loss to ambient but also the distribution of that heat to maintain the wall temperatures. Spacing of the external heating elements is critical. The ability to model the tank heat loss and predict tank temperatures for a given scenario is essential to a successful application.

4. Model Validation

Having established that the ability to predict sulfur tank temperatures is essential to successfully designing a tank thermal maintenance system, it seemed appropriate to validate the tank thermal maintenance model. Actual temperature data were collected from two tanks located in the US. The first tank was located in the Northeast, and the second tank was located in the Gulf Coast region. Both tanks are heated via ControTrace steam panels applied to the shell and roof exterior. Figure 19 describes these two tanks.

Figure 19

	<i>Tank 1</i>	<i>Tank 2</i>
<i>Location</i>	Northeast US	Gulf Coast US
<i>Heating System</i>	ControTrace Panels	ControTrace Panels
<i>Tank Diameter</i>	9.1 m (30 ft)	13.7 m (45 ft)
<i>Tank Height</i>	4.9 m (16 ft)	12.2 m (40 ft)
<i>Tank Start-Up</i>	August 2007	March 2007
<i>Temperature Measurement Date</i>	July 2008	July 2008
<i>Sulfur Level During Measurement</i>	50%	34%
<i>Sweep Air Flow Rate</i>	86 cfm	312 cfm

External tank wall temperatures were measured on each tank in several vertical locations. The temperatures were recorded at a single point in time on different days during July 2008. The measurements were made using Type-K thermocouples attached to the tank wall via high-temperature adhesive tape. The tank wall was accessed by cutting holes in the insulation. After attaching the thermocouples, the holes were reinsulated, and the thermocouples were allowed to reach equilibrium over the next three hours before recording the temperatures. All temperature locations were positioned midway between vertical ControTrace elements in order to provide the minimum wall temperature on each tank. Both tanks were equipped with internal thermocouples for measuring the molten sulfur temperature and a level sensor for determining the sulfur level in the tank. The refinery data logs were used to collect these data points in order to include them in the model. All wall temperature locations were taken above the sulfur level at time of measurement. The actual steam pressure in the header feeding the tank jacketing was recorded for the model. Other data collected and included in the model were ambient temperature, wind

conditions, insulation type and thickness, sweep air flow rate, and the length of time the tank had been in service. All of these conditions were input to the tank thermal maintenance model, and model predictions of minimum wall temperature were compared to actual temperatures measured midway between ControTrace elements. This comparison is shown in Figure 20 for each vertical temperature location.

Figure 20

<i>Temperature Location</i>	<i>Model</i>	<i>Actual</i>	<i>Delta</i>
<i>Tank 1 (ControTrace)</i>			
<i>63% of height</i>	133°C	132°C	-1°C
<i>75% of height</i>	133°C	133°C	0°C
<i>88% of height</i>	133°C	134°C	+1°C
<i>Tank 2 (ControTrace)</i>			
<i>68% of height</i>	143°C	140°C	-3°C
<i>95% of height</i>	143°C	143°C	0°C

The agreement between the model predictions and actual temperatures is excellent. The largest difference is 3°C, or 2% of the prediction. Considering the measurement technique, this difference may be entirely explained by the measurement uncertainty of the system. Therefore, these data confirm the validity of the tank thermal maintenance model presented in this paper and lend significant confidence to its use in the design of future thermal maintenance systems for sulfur storage tanks.

5. Tank Design Economic Drivers

To optimize tank performance and minimize installation cost, the following design parameters should be given serious consideration when specifying an external steam jacketing thermal maintenance system.

Heating Medium: In a majority of sulfur applications, 3.4 barg (50 psig) saturated steam is used as the heating medium. Using a higher pressure steam would allow the external steam jacketing coverage density to be reduced. To minimize cost, consider using a higher steam pressure when available. [Note: The steam pressure should never exceed 5.1 barg (75 psig).]

Insulation: Less conductive and thicker insulation reduces the heat loss from the tank, thereby reducing the required jacketing coverage. To minimize cost, consider increasing insulation thickness and quality.

Jacket Spacing: The previous analysis showed that the spacing of the external steam jackets is critical in meeting thermal maintenance requirements. This spacing should not be specified but calculated by the designer of the thermal maintenance system. The required spacing will be affected by all other design decisions.

Roof Plates: Tank roofs are commonly installed using either a lapped technique or a seam welding technique. In the lapped technique, standard size steel panels are laid across the support member and welded to the support members. The next installed plate overlaps the first plate and is welded in place. This results in height discontinuities between plates which require the external roof panels to be small enough to fit within a single plate. In the seam welding technique, the plates are cut and trimmed to fit directly onto the support members without any discontinuity between plates. The resulting roof topography is smooth, which allows for larger (and less) external panels which lowers cost. To minimize the cost, seam welding of the roof panels should be considered.

Sulfur Maintenance Temperature: Higher sulfur maintenance temperatures require more coverage required to satisfy the heat load. Sulfur maintenance temperatures have been specified as high as 145°C. To minimize cost, the sulfur maintenance temperature should be kept to a minimum (typically 132°C).

Sweep Air: Increasing the sweep air flow rate increases the heat loss from the interior walls and the sulfur, requiring a higher coverage density. Additionally, preheating the sweep air may help offset the additional heating burden due to sweep air. To minimize cost, higher-than-required sweep air flow rates are discouraged.

Tank Wall: It is common for the tank shell wall thickness to decrease as a function of the tank height. In other words, the lower portions of the tank are typically thicker than the upper portion. Depending upon how the tank is constructed, the tank shell wall will either be flush on the interior or flush on the exterior. If the tank walls are built flush to the interior, any external steam jacket will be limited in size due to the resulting steps in surface heights. On the other hand, constructing the tank walls flush to the exterior may result in less individual panels and lower cost. To minimize the cost, the tank walls should be built flush to the exterior.

CONCLUSION

Corrosion is believed to be the leading root cause of safety, performance, and longevity issues associated with sulfur storage tanks. The most likely corrosion mechanism results from the combination of solid sulfur and liquid water at metal surfaces. This mechanism can be eliminated by employing a distributed external heating system such as ControTrace to maintain the temperature of all tank internal surfaces above 120°C. Other technologies for heating sulfur tanks can be effective in maintaining the sulfur in molten state, but they do not adequately heat all tank internal surfaces. In order to successfully design an external thermal maintenance system, the designer must have the capability of modeling the tank heat transfer paths and predicting the tank temperatures for the entire range of operating conditions. The success of the system is sensitive to the spacing of steam elements. The tank thermal maintenance model presented in this paper has been validated with field data from multiple tanks; model predictions were within 2% agreement of actual data.

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