# Thermal Maintenance of Field Erected Sulphur Tanks

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## Abstract

This paper will explore a method of tank heating which can minimize the corrosive environment affecting field erected sulphur storage tanks.

Field erected storage tanks have been used for years to store large volumes of molten sulphur. Traditionally, the sulphur is heated using a submerged steam coil and the tank is covered with several inches of insulation. These tanks commonly experience corrosion, especially in the vapor space above the normal liquid level. Root cause of corrosion appears to be linked to the formation of solid sulphur and the presence of liquid water. Potential results of the corrosion may be:

- Erosion of Tank Wall
- Thinning of Roof Plate
- Formation of Iron Sulphides
- Weakening of Support Structure
- Sulphur Fires
- Tank Failure

Corrosive conditions can be eliminated or at least minimized by employing a distributed external heating system. This alternative method of heating utilizes a high performance steam jacketing called ControTrace. The ControTrace uniformly heats the vessel from the exterior. The advantage of this method is that metal components are maintained at temperatures above both the dew point of water and sulphur freezing point. It also allows the elimination of submerged steam coils and associated steam leaks into the sulphur.

## Corrosion of Sulphur Tanks

Field erected sulphur storage tanks are commonly plagued with corrosion issues, especially in the vapor space above the normal liquid level. Corrosion in the storage tanks is experienced in two common forms; from the outside in, and from the inside out.

Corrosion on the exterior of the tank is linked to ambient water invading the insulation and becoming trapped between the tank surface and the insulation. If the tank wall is not hot enough to vaporize the water, the water is able to stagnate and constantly corrode the surface. Commonly this type of corrosion is experienced both on the tank roof and walls when inadequate heating is supplied, and the internal process temperature is not hot enough to maintain the tank wall temperature.

Root cause(s) of corrosion on the interior of the tank are currently under discussion in the literature (Reference 1). Two common ingredients appear to be solid sulphur and liquid water. Above the liquid level in the vapor space, sulphur vapors and entrained sulphur particles (sulphur fog) may be present. If the sulphur vapor contacts tank surfaces, including internal support members, below the dew point of the sulphur, the sulphur will condense. The sulphur fog will stick to any surface it contacts regardless of the temperature. If the surface is less than 120$^oC$, the sulphur will solidify. After freezing on the surface, the sulphur now acts as an insulator and allows the tank surface to cool further. The tank surface may cool below the dew point of water, and liquid water may condense onto the tank wall. The combination of solid sulphur and liquid water create what the literature refers to as "wet sulphur corrosion." This condition can be extremely corrosive. In addition to the corrosion, pyrophoric iron sulphides may form on the tank surface underneath the solid sulphur. If these iron sulphides are exposed to oxygen, they may ignite a sulphur fire within the storage tank.

The net result of both forms of corrosion is a reduction in tank life and an unsafe work environment. In some installations, sulphur fires have been reported to occur as regularly as monthly. In addition, tank life cycles have been reported to be as low as 5 years, while other tanks have a service life of 30 years. In order to maximize the service life of a sulphur tank, the corrosive environment in and around a sulphur tank needs to be minimized or eliminated all together.

## *Methods to Reduce Corrosion*

The sulphur handling industry does not seem to have settled on a solution to the tank corrosion problem. In fact, in some installations, repairs to sulphur tanks are so common it is considered a way of life. Several methods have been applied in an attempt to minimize the corrosion issue:

<u>Sealing Insulation</u> – To prevent ambient rain water from becoming trapped between the insulation and tank surface, the simplest solution is to properly seal the insulation. Experience with these tanks reflects that no matter how well the insulation is initially sealed; there remains a fair probability of developing leaks prior to the 20 to 30 year desired life.

<u>Increase Insulation</u> – Increasing the insulation thickness would decrease the heat loss to ambient, and raise the temperature of the vapor space. If the vapor space temperature can be raised significantly, the tank wall temperature will be hot enough to prevent the formation of solid sulphur. This solution will be explored in more depth later, but the results are that increasing the insulation thickness alone will not raise the vapor temperature appreciably.

<u>Internal Coatings</u> – In an attempt to prevent internal corrosion, at least one installation has tried the use of an internal coating. The coating has been in service for a relatively short time and effectiveness of the coating has not been determined. Ironically, the tank is in the process of being replaced due to exterior corrosion from water being trapped between the insulation and tank wall.

<u>External Coatings</u> – While external coatings may be a viable option to preventing external corrosion, they would provide no aide in preventing corrosion on the interior of the vessel. We are unaware of current installations using this method to prevent corrosion.

<u>Roof Steam Coils</u> – In an effort to prevent the build up of sulphur on the roof, steam coils have been used to heat tank roofs. Commonly the coils are fabricated from ¾" or 1" pipe and formed to lay on the roof. Localized gaps between the coil and roofs exceeding ½" are not uncommon. Such steam coils are never in good thermal contact with the roof. Their ability to transfer heat

directly to the roof is severely compromised. This limits the maximum roof temperature attainable. Typical roof coils may reduce the build up of sulphur on the roof, but can never completely eliminate it.

Pre-Heat Sweep Air – Another factor in preventing corrosion may be pre-heating sweep air. In pre-heating the entering sweep air, the interior vapor space should be maintained at a higher equilibrium temperature. This issue will be analyzed in depth below, however, the results indicated this can be helpful but is not by itself a solution.

Inert Gas Blanketing – Inert gases, such as nitrogen, have been used to create oxygen free environments to prevent oxidation of internal tank surfaces and components. Unfortunately the oxygen free environment encourages the formation of pyrophoric iron sulphides. If the iron sulphides are ever exposed to oxygen, there is a great chance of a sulphur fire or explosion. Due to these potential catastrophic results, the sulphur handling industry has appeared to settle on air blanketing sulphur tanks as a standard.

Each of the previous listed methods seems to be, at best, a partial solution to the problem of corrosion. It is the suggestion of this paper that if the thermal maintenance design for the tank is adequate, the environment for corrosion will be minimized, if not completely eliminated. To accomplish this, the tank wall, roof, internal support structure, and vapor space must be maintained at or above 120$^{o}$C.

## *Thermal Maintenance of Sulphur Tanks*

Traditionally, the thermal maintenance of sulphur tanks consisted of determining the heat lost to ambient under full tank conditions and sizing a submerged steam coil to replace the heat loss. This method ignores the temperature of the tank wall, internal support structure, and vapor space. If these components are allowed to exist below the freezing point of sulphur, solid sulphur can accumulate leading to excessive weight and/or corrosion. Numerous tank designs add a steam coil on the roof as mentioned in the previous section. This approach often prevents the gross collection of solid sulphur, but seldom, if ever, prevents the collection of enough solid sulphur to eliminate serious corrosion.

To prevent the tank wall and associated internal components from existing below the freezing point of sulphur, the internal vapors must be maintained at a temperature above 120$^{o}$C. Figure 1 shows a typical cross section of storage tank in the vapor space.

In Figure 1, the internal vapor is in direct contact with the tank wall and transfers heat to the wall via convection. It is important to understand that the tank wall temperature is dictated by the internal vapor temperature but not equal to it. Therefore, if the tank wall is to be maintained at or above 120$^{o}$C, the internal vapor temperature must be greater.

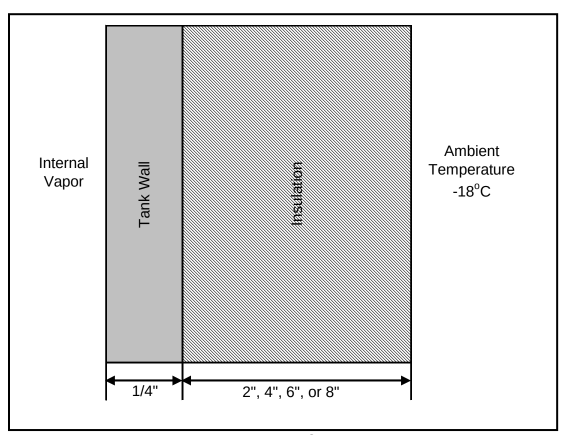
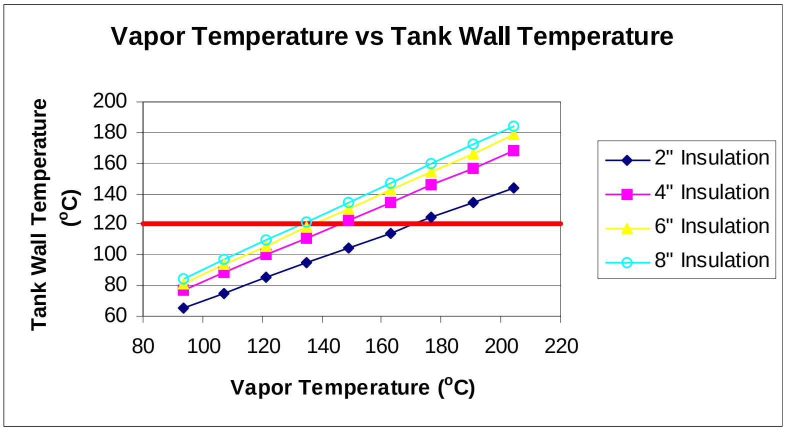


Figure 1 – Cross Section View of Storage Tank in Vapor Space

Performing an analysis of Figure 1, the tank wall temperature, as a function of internal vapor temperature and insulation thickness, was determined. The results are shown in Graph 1.




Graph 1 – Internal Vapor Temperature vs. Tank Wall Temperature

From Graph 1, two observations are very apparent. First, as the insulation thickness is increased, the tank wall temperature increases. The extra insulation impedes the heat loss from the vapor to the ambient, thus raising the tank wall temperature.

**The second observation is that if a tank wall temperature of 120°C is to be maintained the vapor temperature must be maintained between 132°C and 170°C depending upon the insulation thickness. If the vapor temperature is maintained at this elevated temperature, all internal tank surfaces will be maintained above 120°C and prevent the solidification of sulphur throughout the tank.**

## *Thermal Model*

To determine the internal vapor temperature of a sulphur tank, a computer thermal model was created to analyze an entire storage tank. The basic model is shown in Figure 2.

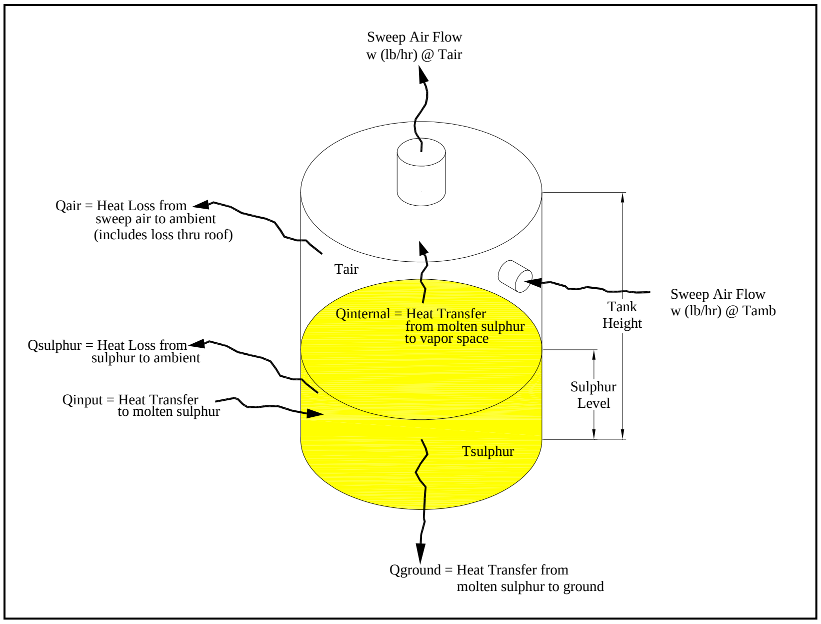



Figure 2 – Thermal Maintenance Model

The Thermal Maintenance Model in Figure 2 accounts for possible methods of heat transfer that include, heat loss from molten sulphur to ambient, heat loss from sulphur into the ground, heat loss from molten sulphur to the internal vapor, heat loss from the internal vapor to ambient, and heat loss in heating the ambient sweep air. In addition to modeling the various avenues of heat transfer, the model accounts for variables such as tank diameter, tank wall material, tank wall thickness, insulation type, insulation thickness, sulphur 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. Please note that the length of time a tank has been in service affects the heat loss into the ground. The two most common forms of heat input consist of internal submerged steam coils and external steam jackets. Each method of heat input can be applied separately or in combination with this model.

The model in Figure 2 performs an energy balance on the molten sulphur section and internal vapor section of the vessel simultaneously. The result of the calculation is the steady state equilibrium temperature of the molten sulphur, vapor space, and minimum tank wall temperature.

## ***Specific Analysis Results***

In order to present the range of temperatures and tank conditions that can realistically be expected, four tank designs, ranging in degree of sophistication, will be used as examples. Many other combinations could be chosen.

In selecting a tank to model for this paper, the dimensions chosen were those of a tank currently under construction for a refiner. The model tank is 35'-6" in diameter with a height of 28'. The tank is covered with 4" of calcium silicate insulation with a minimum ambient surrounding temperature of -18$^{o}$C. Heating medium is 50psig saturated steam.

Using the previously outlined tank parameters, this paper will analyze four thermal maintenance scenarios on the tank. They are:

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| *Sweep Air Flow Rate* | 0 cfm | 145 cfm | 145 cfm | 145 cfm |
| *Sweep Air Temperature* | n/a | 145 $^{o}$C | 145 $^{o}$C | -18 $^{o}$C |
| *Heat Source* | Submerged Steam Coil | Submerged Steam Coil | Submerged Steam Coil plus Large External Steam Jackets | ControTrace External Steam Jacket |
| *Operating Condition* | Best Case | Best Case | Best Case | Worst Case |

The four scenarios will be analyzed to determine the bulk vapor temperature, tank wall temperature, and molten sulphur temperature. A successful scenario will maintain all temperatures above 120$^{o}$C and minimize the chances of tank corrosion.

## Scenario1

The first scenario evaluates the simplest possible tank heat input and operating condition.  As previously stated, the thermal parameters for the first scenario are:

- Sweep Air Flow Rate = 0 cfm
- Heat Input - Submerged Steam Coil

Ignoring sweep air ensured that the result would represent the **best case** operating condition**.** Figure 3 shows the basic dimensional information of the model, and Table 1 shows the calculated temperatures for various sulphur levels.

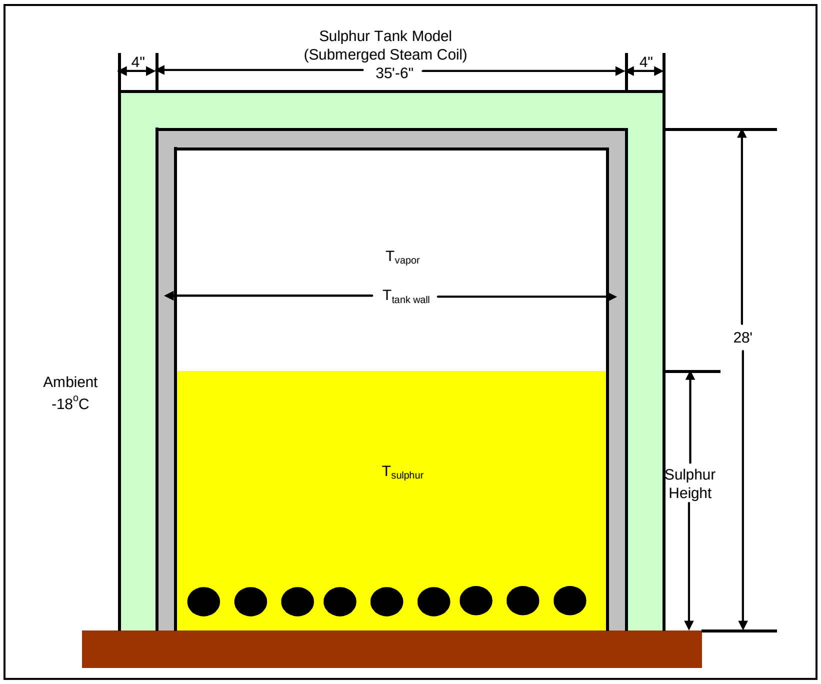



Figure 3 – Scenario 1, Sulphur Tank with submerged steam coil

| Sulphur Height ft | $T_{Vapor}$ °C | $T_{Tank\ Wall}$ °C | $T_{Sulphur}$ °C |
|---|---|---|---|
| 21 | 118 | 100 | 141 |
| 14 | 111 | 93 | 141 |
| 7 | 101 | 85 | 141 |

Table 1 – Results of Scenario 1

The results of Scenario 1 show that the internal vapor temperature of the sulphur tank is between 101°C and 118°C depending on the height of the molten sulphur.  Regardless of the sulphur height, the internal vapor is not hot enough to maintain the tank wall above the freezing point of sulphur.  This indicates that sulphur vapors have the ability to condense and solidify on internal tank surfaces.  Condensation of water vapor is also possible when the tank is less than 75% capacity because the wall temperature will be less than 100°C.

This analysis shows that the vapor space gas temperature and tank wall temperature are surprisingly low in a simple unventilated storage tank.

## Scenario 2

In scenario 2, the effects of preheated sweep air on a simple storage tank are considered. The thermal parameters of the system are:

- Sweep Air – 145cfm @ 145°C
- Heat Input – Submerged Steam Coil

From the analysis on Figure 1, it was shown that an air temperature of 145°C was required to maintain the tank wall temperature above 120°C with 4" of insulation. The sweep air was preheated to this temperature to provide the **best case** operating condition for this scenario.

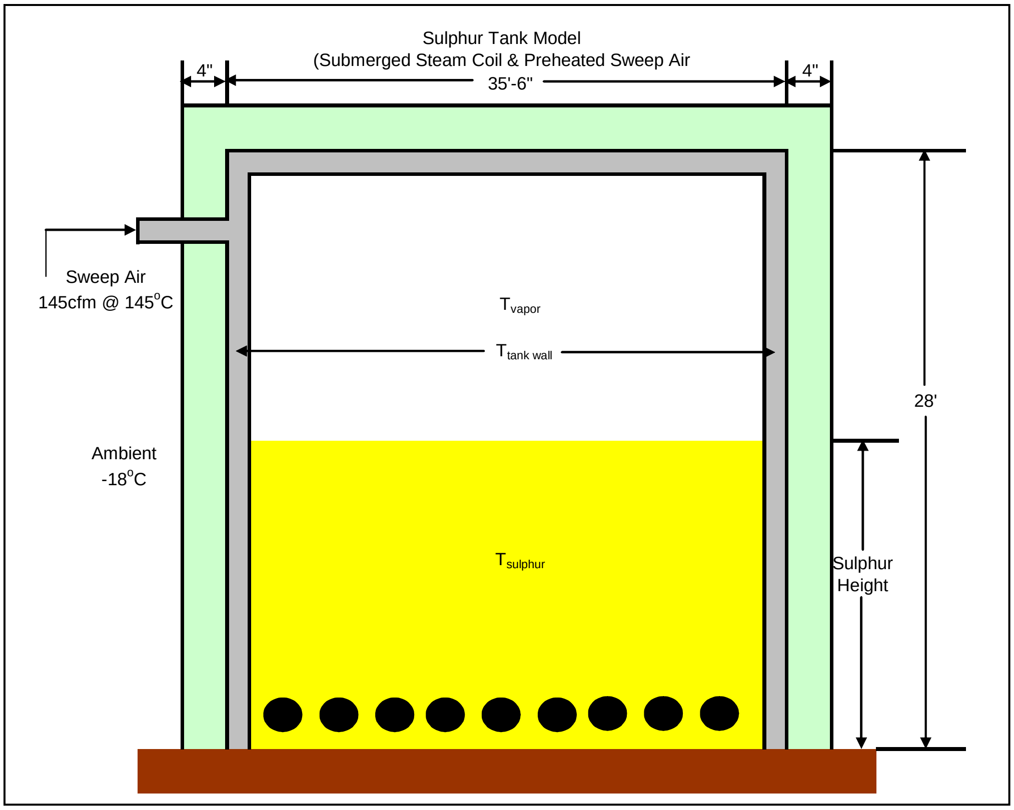


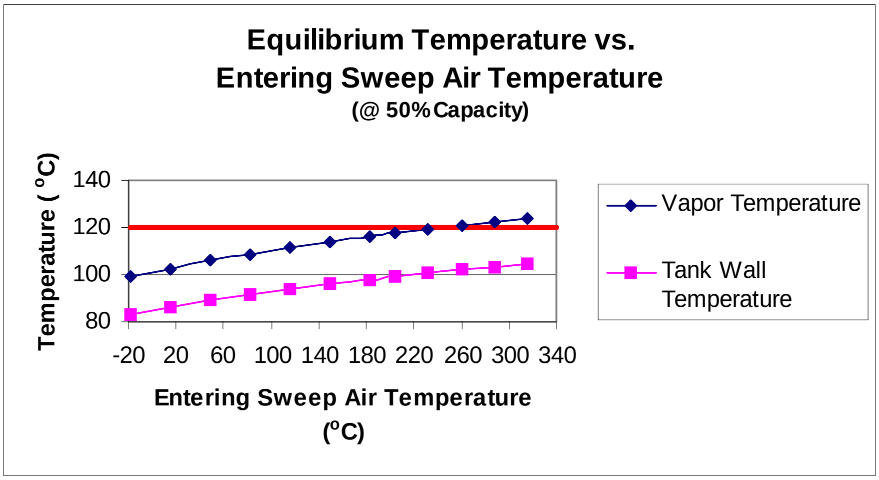

Figure 4 – Scenario 2, Sulphur Tank with Steam Coil Heating and Sweep Air @ 145°C

| Sulphur Height ft | $T_{Vapor}$ °C | $T_{Tank\ Wall}$ °C | $T_{Sulphur}$ °C |
|---|---|---|---|
| 21 | 120 | 101 | 141 |
| 14 | 113 | 95 | 142 |
| 7 | 103 | 87 | 142 |

Table 2 – Results of Scenario 2

The results of Scenario 2 are somewhat surprising because it was assumed, prior to modeling, that the heated sweep air would be able to maintain vapor temperature and the tank wall above 120°C. Results from the model show that the heat loss from the internal vapor is significantly greater than the heat transfer from the molten sulphur to the internal vapor. Thus, the equilibrium internal vapor temperature is significantly less than the sweep air entering temperature.

After determining that preheated sweep air was not able to maintain its temperature, the question arose, "Could the sweep air be preheated enough to make the equilibrium vapor temperature maintain the tank wall temperature above 120°C?" Graph 2 shows the equilibrium vapor temperature and minimum tank wall temperature as a function of the entering sweep air temperature.




Graph 2 – Internal Vapor Temperature & Tank Wall Temperature vs.
Entering Sweep Air Temperature

The analysis says that even if the preheated sweep air, under normal flow rates, exceeds 300°C, the equilibrium vapor temperature will not be able to maintain the tank wall temperature above 120°C. The resulting environment is still not hot enough to prevent sulphur from solidifying on internal tank surfaces.

Results of Scenario 1 and 2 reflect that the internal vapor alone will not maintain the tank walls and internal components above 120°C. To maintain the tank wall and internal components above 120°C, heat must be added to the vessel.

## *External Steam Jackets*

One method to apply heat to the vessel is to use an external steam jacket. The external steam jacket is simply an external chamber that is attached to the vessel and a heating medium is circulated through the chamber to transfer heat to the tank wall. Typically, heat transfer mastic is applied between the chamber and tank wall to improve heat transfer. An external heat jacket offers the flexibility of supplying heat to the specific parts of the vessel that require it. In addition, if the external jackets are sized correctly, they can completely eliminate the need for an internal steam coil and any chance of cross contamination.

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 is usually a large, flat, bendable steel sheet which contains steam passages. The other is a lattice work of rectangular tubing (trade name ControTrace) formed to fit a tank.

**It is important to understand that the distance between external steam elements is critical to maintaining the tank wall at elevated temperatures. Figure 5 shows a typical cross section of external jackets on a tank wall.**

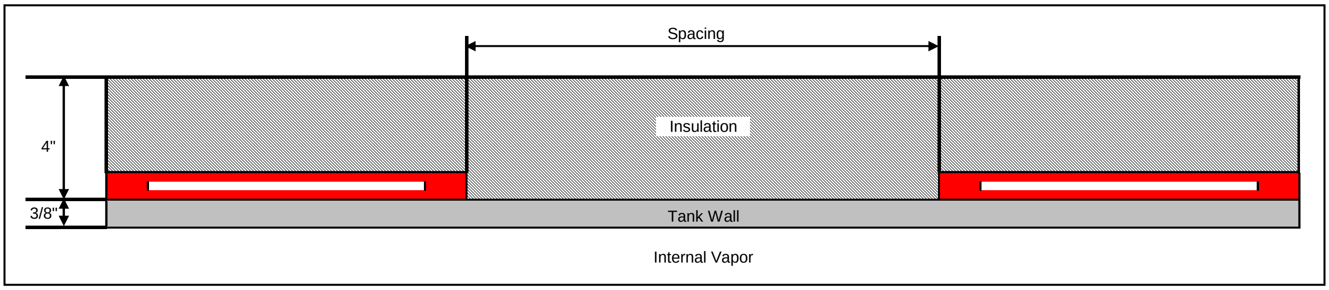
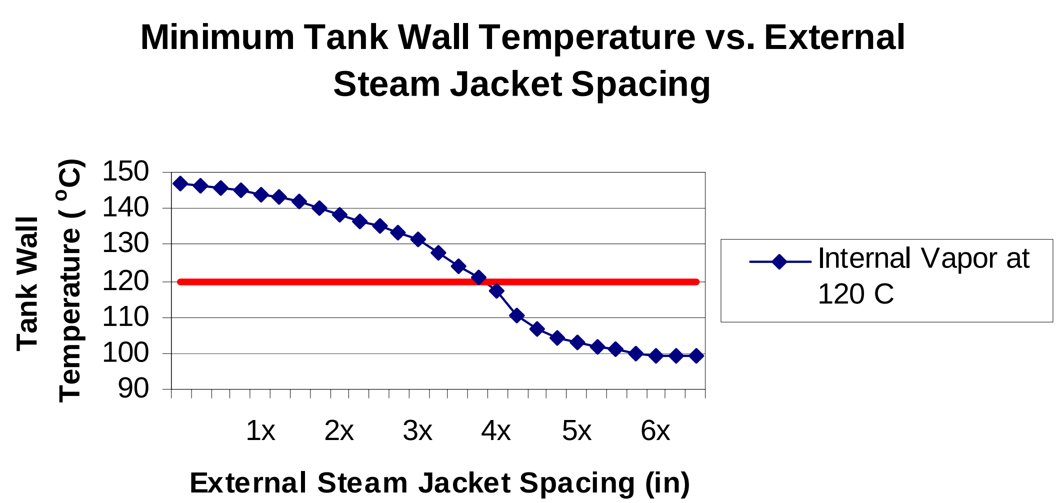



Figure 5 – Cross Section View of Tank with External Steam Jacket.

**If the steam jackets are spaced too far apart, some areas of the tank wall will not be adequately affected by the heat. Graph 3 shows the minimum tank wall temperature as a function of the spacing.**




Practical values of "x" will range between 2 and 10.

Graph 3 – Minimum Tank Wall Temperature vs. External Steam Jacket Spacing

From Graph 3 it can be seen that once the spacing between steam jackets exceeds a certain value, the minimum tank wall temperature will fall below 120°C (the freezing point of sulphur). The spacing on the graph is not specific. The actual spacing between steam jackets will vary from application to application because of variables such as tank wall thickness, insulation thickness, heating medium, internal process temperature, ambient temperature range, external wind conditions, sweep air flow rate and temperature and required tank wall temperature. This distance should be calculated when designing external steam jackets.

## Scenario 3

In scenario 3, large external heat jackets will be applied to the vessel in accordance with a design we have recently seen proposed. The large jacket panels cover 22% of the side wall surface area and 13% of the roof surface area. Figure 6 shows a graphic representation of the panels on the side walls of the tank only. The thermal parameters of the system are:

- Sweep Air – 145cfm @ 145$^{o}$C
- Heat Source – Submerged Steam Coil &<br>Large External Steam Jackets

The purpose of the external steam jackets is to heat the vapor space, and provide direct heat to the tank wall in an effort to raise their equilibrium temperature. The preheated sweep air represents the **best case** operating condition.

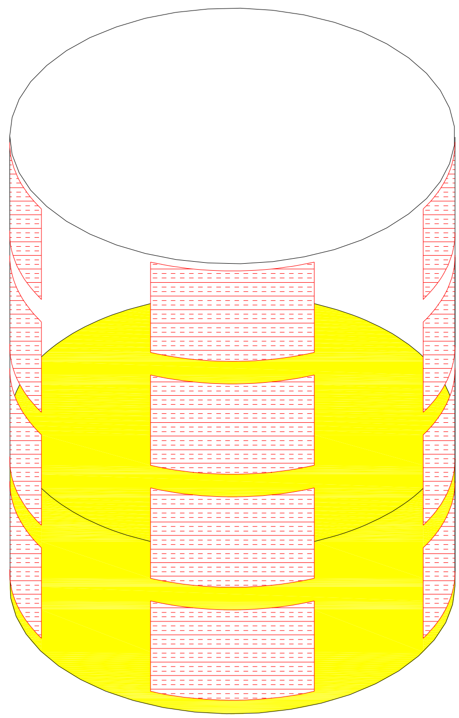


Figure 6 – Scenario 3, Large External Steam Jackets

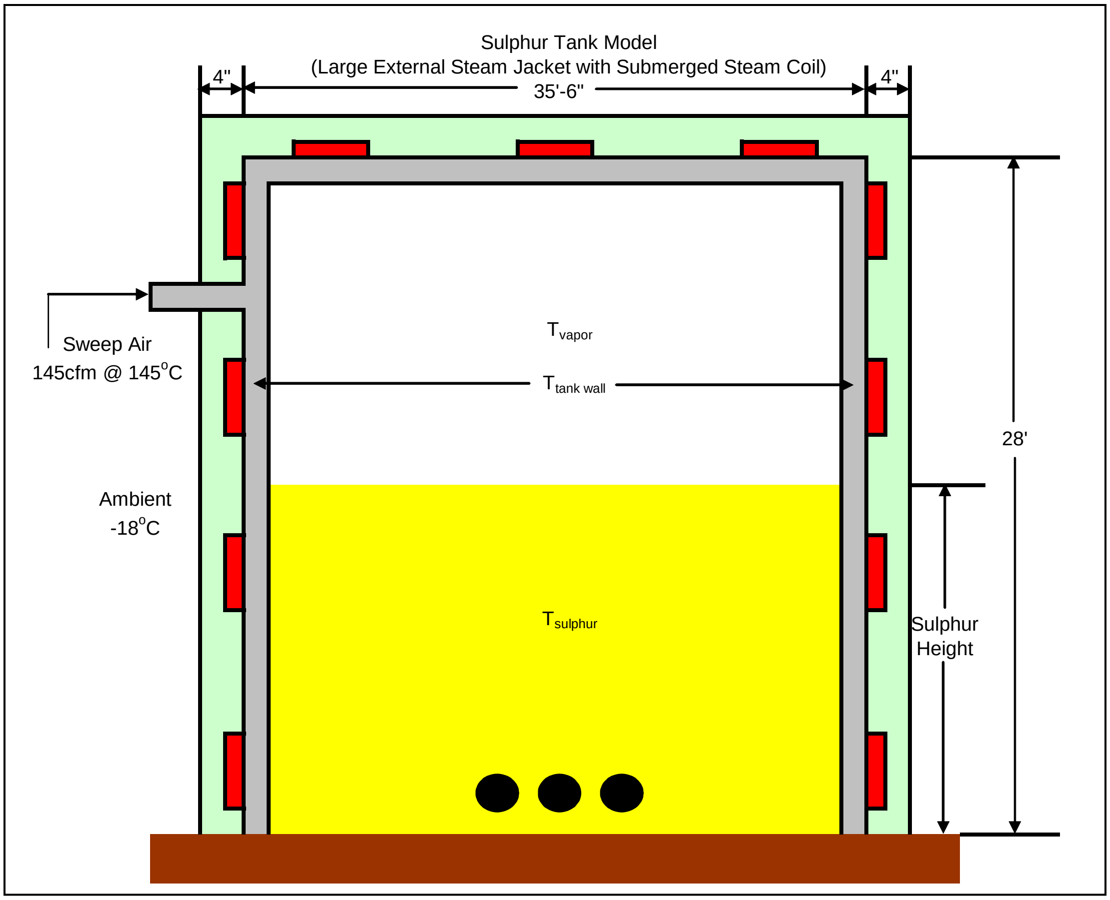



Figure 7 – Scenario 3, Sulphur Tank with Steam Coil Heating with Large External Steam Jackets and Sweep Air @ 145°C

| Sulphur Height ft | $T_{Vapor}$ °C | $T_{tank\ Wall}$ °C | $T_{Sulphur}$ °C |
|---|---|---|---|
| 21 | 122 | 101 | 138 |
| 14 | 119 | 98 | 138 |
| 7 | 117 | 96 | 137 |

Table 3 – Results of Scenario 3

The results of the scenario 3 show that the large external steam jackets are unable to maintain the preheated sweep air at its entering temperature. Due to large spacing between the external steam jackets, 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 tank wall temperatures shown in Table 3 represent the minimum tank wall temperatures at the mid point between the external steam jackets. The tank wall temperatures in some areas are well below the freezing point of sulphur. The external jackets provide localized sections of heat to maintain sections of the tank wall above 120°C, but not all sections of the tank. Large spacing between steam jackets allows cold spots to exist and the potential for sulphur to solidify on these sections of tank wall. *(Also note that the cold spots will not be able to remove any potential water trapped externally between the tank wall and insulation.)*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## Scenario 4

In the scenario 4, the storage tank was modeled using only external steam jackets to transfer heat to the molten sulphur and vapor space. The external jacket was modeled using ControTrace. ControTrace is a 2" wide by 1" tall rectangular tubing that can be fabricated in panels to form external tank jackets. A picture of ControTrace on a vessel is shown in Picture 1.

Picture 1 – ControTrace External Tank Jacket

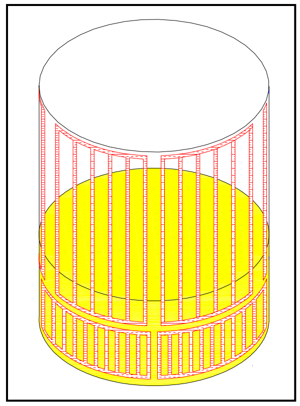

Figure 8 – Scenario 4 ControTrace Jacket

It was previously stated that if external steam jackets are sized correctly, they can eliminate the internal steam coil. Unlike an internal steam coil which has a constant heat transfer surface area in contact with molten sulphur, the heat transfer surface area of an external steam jacket directly contacting the liquid is a function of the sulphur height. To compensate for a reduction in heat transfer, the surface area coverage around the bottom few feet of the tank needs to be increased. The increased surface area coverage will maintain the molten sulphur at the specified maintenance temperature at low liquid levels

Due to the higher density coverage over the bottom few feet of the vessel, the external steam jacket for the remaining vessel is sized to maintain the minimum tank wall temperature above 120$^{o}$C. Figure 8 shows coverage on the side walls of our model in Scenario 4. ControTrace will cover approximately 20% of the surface area over the bottom 4' of the vessel. For the remaining portions of the vessel, the ControTrace will cover approximately 10% of the surface area. Together the ControTrace will cover approximately 13% of the side wall surface area.

Spacing of ControTrace on the roof is influenced by all items previously mentioned in the External Steam Jacket section and the roof construction as discussed later in this paper. Based on past experiences and common techniques for roof construction, the ControTrace was sized to cover 9% of the surface area to minimize cost and maximize performance.

The thermal parameters for scenario 4 are:

- Sweep Air – 145cfm @ -18$^{o}$C
- Heat Input – ControTrace External Steam Jacket **only**

The sweep air entering at the ambient temperature represents the **worst case** operating conditions for the tank. If the tank is successful under these conditions, it should be successful under all operating conditions.

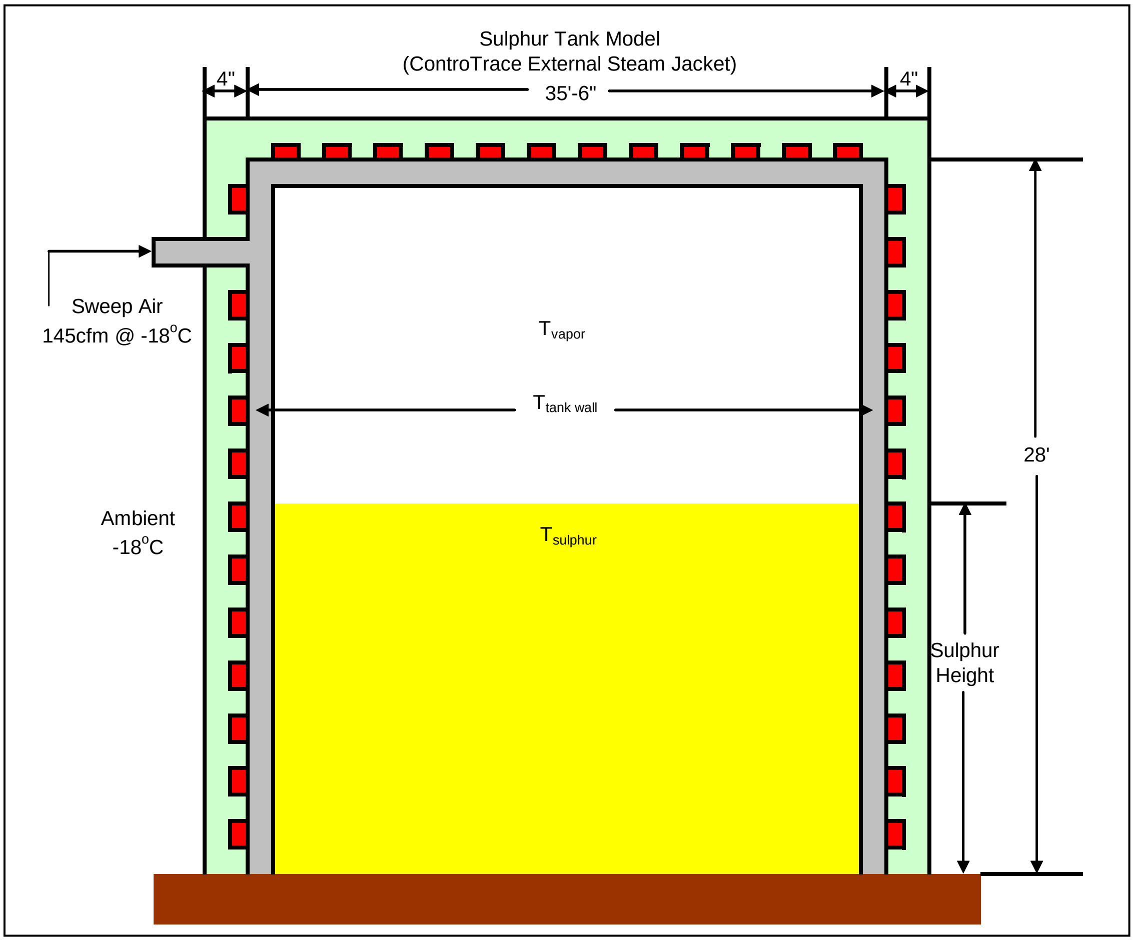


Figure 9 – Scenario 4, Sulphur Tank with ControTrace External Steam Jackets and Sweep Air @ -18°C

| Sulphur Height ft | $T_{Vapor}$ °C | $T_{tank\ Wall}$ °C | $T_{Sulphur}$ °C |
|---|---|---|---|
| 21 | 125 | 128 | 139 |
| 14 | 127 | 129 | 139 |
| 7 | 129 | 130 | 138 |

Table 4 – Results of Scenario 4

Results of Scenario 4 show that the internal vapor temperature and minimum tank wall temperature are maintained above 120°C for all sulphur levels. *(The tank wall temperatures shown in Table 4 represent the minimum tank wall temperatures at the mid point between the ControTrace elements.)* 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 sulphur, and will not allow sulphur to solidify. *(Any potential water trapped externally between the tank surface and insulation will be boiled off.)*


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## *Economic Drivers*

Evaluating the cost of an external steam jacketing system should include more than evaluating the initial capital cost. While external steam jacketing systems may have a moderate increase in initial capital cost, they have the potential to minimize repairs and extend the tank life significantly. Savings in repair costs and extending the tank life should easily justify any potential increase in initial capital cost.

### Thermal Maintenance Economic Drivers

The following design parameters should be given serious consideration when specifying an external steam jacket thermal maintenance system. Understanding these parameters will help to optimize performance and minimize cost.

Sulphur Maintenance Temperature – The higher the sulphur maintenance temperature, the more coverage required to meet the heat load. Sulphur maintenance temperatures have been specified as high as 145$^{o}$C. To minimize the cost, the sulphur maintenance temperature should be kept to a minimum.

Heating Medium – In a majority of sulphur applications, 50 psig (148$^{o}$C) steam is used as the heating medium. If there is a possibility of using a higher pressure steam, it would allow for the external steam jackets to be reduced in size. To minimize the steam jacket cost, higher steam pressure should be considered when available. The steam pressure should never exceed 75 psig (160$^{o}$C).

Sweep Air – In the previous analysis it was shown that an external steam jacket can heat sweep air and maintain it above a desired temperature. If the sweep air can be preheated, the heat load on the external jacketing would be reduced. The reduction in heat load could reduce the jacket size and cost.

Insulation – Careful consideration must be given to insulation thickness when developing a thermal maintenance system. An increase in insulation thickness may result in a reduction of size in the external steam jacket required to meet thermal maintenance requirements.

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

## Tank Design Economic Drivers

The physical design of the sulphur storage tank will affect the design of an external steam jacket system. Understanding the following parameters will help to optimize performance and minimize cost.

Tank Wall – As shown in Figure 10, commonly the tank wall thickness is reduced in thickness as a function of the tank height. During construction, the tank walls are built one of two ways; flush to the interior or flush to the exterior.

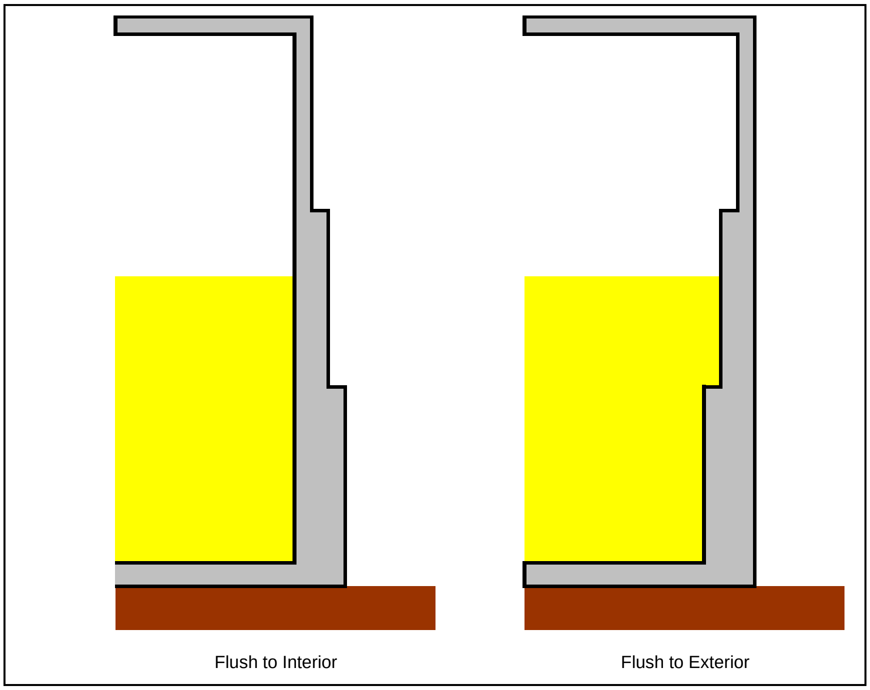


Figure 10 – Methods of Tank Side Wall Construction

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. Building the tank walls flush to the exterior may result in a smaller number of panels and lower cost. To minimize the cost, the tank walls should be built flush to the exterior.

Roof Plates – Tank roofs are commonly installed using either a lapped roof technique, or a seam welding technique. The lapped technique appears to be the most common technique of the two because it is typically less expensive. In this 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. Steam jackets must be made to fit each roof plate because the discontinuities are too large to bridge. The seam welding technique cuts and trims the steel plates to fit directly onto the support members. Each successive plate is cut to fit and the plates are welded into place. The end result is a smooth roof. Seam welding will reduce the jacket cost buy may not pay for the added labor.

## *Summary*

Corrosion associated with sulphur storage tanks is linked to two root causes; the presence of solid sulphur and the presence of liquid water. To minimize the chances for corrosion, all internal tank surface temperatures should be maintained such that solid sulphur and liquid water may not exist. Several conventional methods of corrosion prevention were outlined briefly, but no method successfully minimized the chance for formation of solid sulphur.

In an effort to understand the current thermal environment of sulphur storage tanks, 4 storage tank scenarios were modeled to determine the resultant equilibrium vapor temperature, minimum tank wall temperature, and molten sulphur temperature. Results of the analysis determined if there was potential for the formation of solid sulphur and liquid water.

Of the four scenarios analyzed, only Scenario 4 successfully addressed the thermal maintenance design of the storage tank. Scenario's 1 and 2 proved that the submerged steam coil can not transfer enough heat to the internal vapor through the molten sulphur to maintain the internal vapor and tank wall at required elevated temperature. Scenario 3 showed that if external steam jackets are spaced too far apart, the system will not maintain the tank wall at the required elevated temperature. The net result of Scenarios 1 thru 3 is the same. Localized cold spots may allow the solidification of sulphur on internal steel components. In addition to any surface corrosion that should occur, iron sulphides may form between the sulphur and steel interface and cause a sulphur fire.

Scenario 4 used an external heating jacket where the heating elements were spaced closely enough to ensure that the sulphur, internal vapor, internal support members, and tank wall temperatures were above 120$^{o}$C. Due to all internal surfaces being maintained above the freezing point of sulphur, any sulphur that contacts an internal surface will remain in the liquid state and simply drain to the bottom of the tank. The chances for the formation of iron sulphides will be minimized, if not completely eliminated, because solid sulphur will not be present on any internal surface.

For an external thermal maintenance system to be successful, the system must be designed for each installation. Included in the design must be the calculation to determine the spacing between heaters, the amount of surface area coverage, the equilibrium vapor temperature, the minimum tank wall temperature, and the molten sulphur temperature. The results of the calculations will result in an external thermal maintenance system that will minimize the chances of corrosion in a storage tank.

## *References*

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