

Molten Sulfur Storage Tank, Loading, and Vapor Ejection Systems Review

“Cameo” (short) paper

Kenneth E. McIntush, P.E. (Presenter), ken.mcintush@trimeric.com
Darryl Mamrosh, P.E., darryl.mamrosh@trimeric.com
Carrie Beitler, carrie.beitler@trimeric.com
Trimeric Corporation
PO Box 826
Buda, TX 78610
512 295-8118

Brimstone Sulfur Symposium
September 2015
Vail, Colorado

This version of the paper, which is for the official symposium archive, differs slightly from the version in the conference notebook handed out to symposium attendees in that a few typos were corrected in this version.

Abstract

Trimeric Corporation (Trimeric) has performed several studies for different refineries to evaluate the design and performance of molten sulfur storage tank and loading systems. Some of these units included vapor ejection and vent systems so that vapors from the sulfur tank and railcar or truck loading could be recycled back to the upstream Claus combustor, to the incinerator, to a caustic scrubber, or to another destination. The molten sulfur was degassed at some, but not at all of the refineries. This “cameo” paper (short paper) provides a generalized review of some of the findings for improvements. Key topics include: H₂S and SO₂ contents of the vapor streams, determination of the sweep air flow rate, estimation of the vent gas composition to the ejector and the associated piping design, heating options for internal piping in the sulfur tank, external sulfur piping layout and heating, and the snuffing steam requirements, controls and condensate management.

1.0 Introduction

In the past 10 years, Trimeric Corporation has evaluated several molten sulfur storage and loading systems for different refineries. Trimeric’s experience involved troubleshooting the sulfur tank design, vent systems, and designing and troubleshooting scrubbers in the vent system, including caustic scrubbers.

These systems typically include a sulfur storage tank with associated pumps, piping and instrumentation. Load-out stations for loading the product sulfur into railcars or trucks are also typical. Steam-driven ejectors (or other types of ejecting equipment) are sometimes used to recycle vapors from the tank and loading stations to the upstream sulfur recovery unit (SRU). Some refineries perform degassing of the molten sulfur, but many others do not. This paper assumes a system that does not have degassing.

Molten sulfur contains H₂S and SO₂, and the presence of these components must be accounted for in the design of the molten sulfur storage tank system. H₂S is flammable, and H₂S and SO₂ are both toxic and corrosive to some materials of construction if water is present. Proper design of the sulfur tank, loading area, ejectors, and associated piping allows for longer operation by avoiding sulfur plugging and corrosion issues. The design of the vent system should provide a safer environment for plant personnel by lowering and minimizing exposure to these harmful contaminants.

Trimeric’s review of a few of these systems helped bring the equipment up to better industry practices. This paper presents a few of the key results of Trimeric’s evaluations of different sulfur tanks, loading areas, and ejector systems with some process design and safety recommendations that could help others in the design and construction of similar equipment. Good practices, as understood by the authors, for the equipment in this type of system are noted as appropriate throughout the paper.

2.0 Example Sulfur Storage and Loading System

Figure 1 shows a simplified process flow diagram of a sulfur storage and load-out system with some design features that will be discussed later in this paper. Many different equipment variations exist to store and load molten sulfur. However, the overall system usually includes a molten sulfur storage tank, tank headspace ejector, loading spots, loading arms, loading ejectors with vapor recovery stations, and a sulfur loading pump.

In this example system, the molten sulfur storage tank has a working capacity in the range of 2000-3000 long tons. The tank is a low-pressure, cone-top, API 650 storage tank made of carbon steel. It has a total height of around 30'. The normal liquid level is 13-14' with a high liquid level of 25-26' and a low level of 1-2'. Internal heating, employing steam heating coils, for the tank is used to maintain a temperature in the tank of roughly 290°F, although external heating can be a valid alternative¹. Multiple temperature measurements are taken throughout the tank by thermocouples. The tank is insulated on the side and top, and steam coils are used for the internal sump. Condensate from the steam heater coils in the sump of the tank is sent to the condensate recovery manifold. The tank has a bottom that is sloped toward the outlet and pump suction. Around half a dozen air intake nozzles with rain caps are located on the cone roof of the tank. These nozzles should be sized to allow for proper sweep air to the tank as discussed later in this paper.

The tank operates at essentially atmospheric pressure. A steam-driven vapor ejector is provided to continuously pull fresh air into the headspace of the tank and to provide enough pressure downstream of the ejector to route the vent stream to the Claus combustor for this example. (An incinerator is another potential destination for the tank vapors, if environmental regulations permit such; caustic scrubbers are sometimes also used.) Multiple ejectors (two in this example) are installed with one being a spare. The use of continuous air sweep minimizes H₂S vapors in the headspace of the tank and minimizes tank emissions because the vapors are sent to the Claus burner.

The feed molten sulfur enters the tank through a dip tube that terminates about just above the tank floor. A vacuum break is used at the top of the dip tube piping. Filling with a dip pipe is meant to minimize agitation and H₂S degassing from the molten sulfur; it also prevents free fall of liquid sulfur that can lead to static discharge. Snuffing steam can be used to extinguish sulfur fires in the sulfur tank should they occur.

Several loading stations are used to load the sulfur from the tank into railcars or trucks. Counter-balance loading arms are located to access the top dome or hatch of the railcar or truck. Loading ejectors are installed at the sulfur loading stations to prevent harmful vapors from being emitted at the railcar or truck during loading. Each ejector uses motive steam and vents to the Claus combustor header. For reference, the ejector flow could reduce the capacity of the

upstream Claus sulfur recovery unit due to the presence of steam (which adds to the SRU hydraulic load and is a reaction product that can hinder the Claus reaction) and sulfur species.

Two molten sulfur loading pumps are used to transfer the molten sulfur from the tank to the railcars or trucks. One pump is operated while the other is a spare. With some pumps, if the pump is stopped and solids form, thermal expansion can ruin the seals and cause leakage.

3.0 H₂S and SO₂ Concerns

This section discusses the toxicity and other issues associated with H₂S and SO₂ in the tank and loading vapors as background for further discussions on the design of the storage tank, loading, and ejector systems.

3.1 H₂S Toxicity and Flammability

H₂S is highly toxic and even low concentrations can be lethal. H₂S has a threshold limit value, time-weighted average (TLV-TWA) of 1 ppmv per ACGIH, an OSHA permissible exposure limit (PEL) of 20 ppmv, and an immediately dangerous to life and health (IDLH) level of 100 ppmv². Most people can detect the unpleasant smell of H₂S at concentrations in the range of 0.0005 to 0.3 ppmv³. It has a strong rotten egg smell up to 30 ppmv and then has a sickeningly sweet odor up to around 100 ppmv. At concentrations above 100 ppmv, a person will lose their ability to smell the H₂S even if it is still in the atmosphere. At higher concentrations and durations of exposure, physical deterioration of the body can occur such as dizziness, lung complications, loss of consciousness and even death. H₂S is also a flammable gas.

The sulfur produced in the Claus process contains soluble hydrogen sulfide (H₂S) and hydrogen polysulfides (H₂S_x) often assumed to be on the order of 300 ppmw^{4,5}. (Oxygen enrichment and subdewpoint operation can produce higher levels, up to 450 ppmw⁶.) During storage of the sulfur, the H₂S_x compounds will decompose as the sulfur cools and is agitated. This results in the formation of dissolved H₂S in the liquid sulfur which will pass to the gas phase by physical desorption. The H₂S is emitted and accumulates in the vapor space above the liquid sulfur. H₂S_x is a heavy compound and it can take a long time to decompose to H₂S. The H₂S/H₂S_x chemistry is complex and has a significant impact on the degassing options used to release and remove the dissolved H₂S in a controlled manner⁶.

Because of the significant safety hazards of H₂S and environmental regulations, many refineries degas the molten sulfur so that it contains less than 10 ppmw total H₂S. Even with sulfur degassed down to 10 ppmw total H₂S, some additional H₂S will evolve in the storage tank and from the agitation and potentially cooler temperatures in the railcars or trucks. This can still lead to dangerous concentrations of H₂S in the storage tank vapor space and in the small vapor volume in a railcar or truck (hundreds of ppmv to low volume percent level) such that proper safety mechanisms need to be implemented.

Refineries that do not degas the molten sulfur have even higher levels of dissolved H₂S in the sulfur tank and at the loading area. The H₂S content in the sulfur coming from the combined SRU condensers may be on the order of 300 ppmw, and if that sulfur flows first to a sulfur pit prior to the sulfur tank, then the sulfur after the pit will have somewhat lower levels of H₂S⁴, even without degassing. Because of the higher H₂S concentrations in the un-degassed molten sulfur, safety concerns are even more of an issue, as is the case for the generalized example given in this paper. Loading could be especially dangerous as H₂S concentrations could reach the tens of volume percent levels, which could potentially cause an explosion as well as represents a very significant exposure hazard for personnel. Personnel should be instructed to wear appropriate safe breathing apparatus (e.g., SCOT air pack or supplied air) when in the sulfur loading area, especially when on the loading rack.

3.2 *SO₂ Toxicity and Corrosion*

That H₂S is present and is a danger around molten sulfur operations seems to be relatively widely known. On the other hand, the presence of SO₂ and its dangers around molten sulfur operations does not seem to be as widely known. However, just like H₂S, SO₂ is also found in the head space of tanks storing both un-degassed and degassed molten sulfur and may be present at significantly higher concentrations than the H₂S⁵. The SO₂ comes from the SO₂ that is physically dissolved in the elemental sulfur entering the tank from the Claus SRU. SO₂ is also believed to come from reaction of the elemental sulfur with oxygen from the air in the storage tank and loading area. Minimizing turbulence in the storage tank during either filling or removal of sulfur from the system is important. The formation of SO₂ may be minimized in a tank where there is no turbulence and mixing of air with the sulfur⁴. Since SO₂ may be formed primarily at the liquid-gas phase interface, minimizing turbulence (and, thus, the liquid interface area) should also minimize the reaction forming SO₂.

SO₂ is not flammable, but it is toxic at similar levels to H₂S. SO₂ has a threshold limit value, time-weighted average (TLV-TWA) of 0.25 ppmv per ACGIH, an OSHA permissible exposure limit (PEL) of 5 ppmv, and an immediately dangerous to life and health (IDLH) level of 100 ppmv; SO₂ and H₂S both have an IDLH at 100 ppmv². For this reason, as with H₂S, appropriate SO₂ monitoring may be prudent.

SO₂ will also form highly corrosive sulfurous acid if water is present; the sulfurous acid will condense at an elevated dewpoint over that of pure water⁴. Sulfurous acid can corrode carbon steel and even some stainless steel materials found in sulfur handling systems, requiring monitoring for safety and prevention of leaks. Aluminum materials may be more resistant to corrosion under such conditions and may be used in some areas of concern⁴. Aluminum is also resistant to H₂S corrosion.

3.3 *Monitoring and Containing H₂S and SO₂ Emissions*

Because H₂S and SO₂ are dangerous and are also associated with strong odors, accidental releases should be avoided through proper design of the sulfur handling equipment and controls. It is also important that safety measures are put into place to contain and to monitor for possible emissions. The use of head space ejectors and a vapor recovery system minimizes exposure to the harmful vapors in the tank and during loading. Ventilation fans are sometimes also used in close areas to dilute and disperse vagrant emissions from loading operations. Personal protective equipment and ambient air monitoring should also be used.

4.0 **Sulfur Tank Sweep Air Flow Requirement**

Because H₂S is flammable, it is important to ensure that the flow rate of sweep gas is calculated so that the vapor space in the storage tank stays well below the lower flammability limit (LFL) of H₂S. Sweep air sufficient to stay below 25% of the LFL is a common target. Other sulfur species (e.g., sulfur vapor and/or mist) may also be present, but are usually at very low levels and are not typically taken into account when calculating the air flow to maintain less than 25% of the LFL. Commonly accepted design practice is to conservatively assume that all H₂S present in the initial rundown sulfur coming from the combined SRU condensers (300 ppmw) evolves at each point in the process⁴. For instance, with this refinery example it was assumed that the tank was continuously operating with feed sulfur that contained 300 ppmw H₂S and that all of the H₂S would exit with the sweep air.

The flammability envelope of H₂S becomes larger – the LFL decreases and the UFL increases – with operating temperature, as approximated by the following equations⁴:

$$\text{LFL (T)} = \text{LFL (25}^\circ\text{C)} \times \{1 - [0.75 \cdot (T - 25)] / \Delta H_c\} \quad \text{Eqn. 1}$$

$$\text{UFL (T)} = \text{UFL (25}^\circ\text{C)} \times \{1 + [0.75 \cdot (T - 25)] / \Delta H_c\} \quad \text{Eqn. 2}$$

Where:

LFL = Lower flammability limit, % volume

UFL = Upper flammability limit, % volume

T = Temperature in °C

ΔH_c = Heat of combustion, kcal/gmol

As can be seen from Equations 1 and 2, the actual operating temperature of the system must be considered to design a safe storage system.

At 175°F, the LFL value for H₂S is approximately 4 vol%, while at 280 and 330°F it would be about 3.7 and 3.4 vol%, respectively⁴. At a conservative design temperature of 330°F,

choosing a basis of 25% of the LFL would result in a requirement to provide enough air to result in a concentration of H₂S of 0.85 vol%. In actuality, the amount of H₂S in the un-degassed molten sulfur entering the tank would likely be lower, and not all of the H₂S present would evolve. Since the design sweep air flow rate is fixed at the highest H₂S content (300 ppmw) and less H₂S actually evolves from the sulfur, the H₂S content in the tank vapor space would likely be much lower (~0.1 to 0.2 vol%) but still a hazard to human health.

The sweep air estimated as described above (to achieve 25% of the LFL) should also enter the tank in a manner that provides reasonable velocity and prevents dead space and pockets of high H₂S in the system⁴. Modelling of the vapor flows (e.g., via computational fluid dynamics models) may be necessary to ensure that there are no stagnant areas or areas that may contain an explosive mixture in the tank headspace at all operating levels.

5.0 Ejector Design

This section presents several design issues associated with the ejector system including: estimating the vent gas composition to the ejector, sizing the ejector, and designing the ejector piping.

5.1 Ejected Tank Vapor Composition, Sizing, and Steam Pressure

In order to size the ejector, the vapor characteristics of the storage container must first be known. Based on measurements⁵ taken in 1981 in storage tanks containing un-degassed sulfur, the ratio of SO₂ to H₂S at the highest point above the sulfur level in the sulfur tanks generally ranged from 0.7:1 to 5.5:1 (SO₂:H₂S). For this refinery example, a mid-point ratio of 3.5 was used to estimate SO₂ concentrations in ejected gas streams.

It is common to assume that the gas entering the ejector is saturated at its temperature and pressure with elemental sulfur vapor. Since the stream is unlikely to be fully saturated under at least some conditions, the assumption of saturation should, in theory, give a higher elemental S vapor concentration than actual. Literature sources⁷ contain data on elemental sulfur vapor that may be present as S₁, S₆, and S₈. However, submicron mist/fog is thought to be a real problem with some molten sulfur systems, with higher quantities of mist/fog/particulate being associated with higher sweep air rates. Thus, the actual amount of elemental sulfur (as vapor, mist/fog, or solid particulate) traveling through the tank vent system is an unknown.

As discussed previously, the H₂S content of the ejected gas stream should be conservatively based on the H₂S contained in the combined sulfur streams from the SRU condensers (roughly 300 ppmw H₂S in the liquid phase). The sweep gas air rate necessary to stay below 25% of the LEL should be used and water vapor from the inlet air included in the material balance calculations. Table 1 shows the estimated ejector suction stream composition for this refinery example on both an elemental-sulfur-free basis and on a basis that includes elemental sulfur vapors.

Table 1. Approximate Ejector Suction Stream Composition

Component	S-vapor-free basis mole %	With S vapor as S₆ & S₈ mole %
Dry air	90.32	90.308
Water vapor from inlet air	6.23	6.23
H ₂ S	0.77	0.77
SO ₂	2.68	2.68
S ₆	--	0.002
S ₈	--	0.01
Total	100.0	100.0

Notes: 1) Neglecting traces of COS, CS₂, and all other species that may be present.
2) Assumes 300 ppmw dissolved H₂S in sulfur and all evolves.
3) Assumes SO₂ concentration is 3.5 times higher than H₂S.
4) Saturated elemental S vapor.

The amount of motive steam for the ejectors is dependent on the manufacturer of the ejector, and the manufacturers should be able to provide curves to use for sizing estimates. It should also be noted that, while high pressure steam (≥ 150 psig) may be used as the ejector motive fluid, 70-150 psig steam is more common for ejectors. Consideration should also be given to steam jacketing the ejectors and downstream piping as the temperature drops when the steam pressure drops through the ejector steam nozzle.

5.2 Ejector Gas Piping

The design of the gas piping to and from the ejectors is very important for reliable and safe operation. In this refinery example, there are several low points and pockets in the ejected gas discharge piping as shown in Figure 2. The vent line from the molten sulfur tank comes off at higher than 30 feet, drops down to the ejectors at roughly 20 feet, drops another approximately 5 feet, and then rises back up into the piping in route to the Claus combustor. The concern with this is that liquids and solids could collect in the pockets / low point areas. In particular, the spare ejector could be in danger of accumulation of liquids and solids. Corrosion could occur due to sulfurous acid accumulation and the piping could plug or fail due to solids buildup or solid sulfur accumulation.

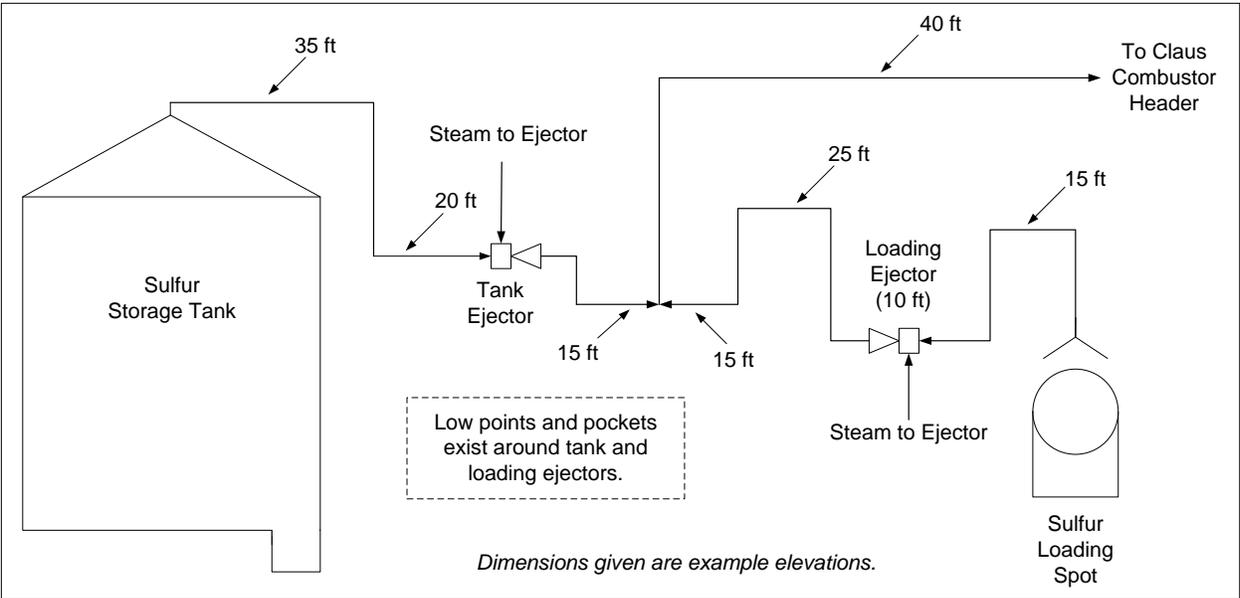


Figure 2. Example of Low Points and Pockets in Tank/Loading Area Ejected Gas Piping

In this example, there are also instances at the loading stations where the ejectors are located lower than the ejector suction piping (see Figure 2) and where the discharge from the ejector also rose away from the ejector up into pipe racks. This creates a low spot or pocket near the ejector, which could cause the suction to the ejectors to accumulate liquids and/or solids and plug and cease to function due to solid sulfur buildup and/or water condensation, especially during periods when/if the steam to the ejector is off because loading was not occurring at that station.

A better arrangement is where all ejectors are located at the highest point in the ejected gas piping so that any liquids can gravity drain in both directions away from the ejector back to either the source of the vapors (e.g., tank or loading area) or forward to the destination for the ejected gases (Claus combustor). Figure 3 shows an illustration of this arrangement. A gradual, step-wise sloping of the piping may be necessary if the distances between the source or destination and the ejector are long.

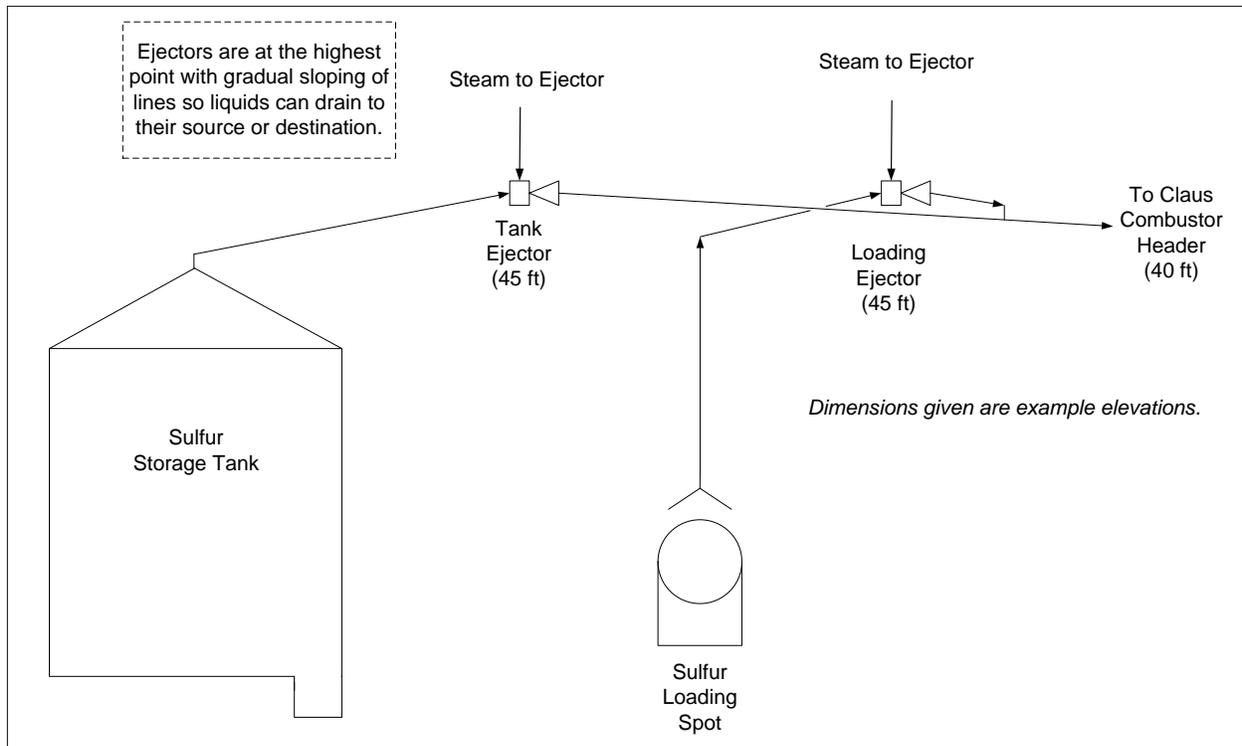


Figure 3. Example of Gravity Draining Pipe for Liquids around Ejectors

5.3 Ejector Emergency Block Valves and Flow Instrumentation

It is also important that appropriate automated emergency, steam-jacketed block valves are located in the ejected gas piping on the tank and at the loading stations.

At the tank, a lack of these automated block valves could allow the possibility of back flow of ejected gas (and/or gas from the Claus unit combustor) into the ejected gas lines, potentially to the tank and out the air intake ports. A low steam supply flow to the ejector and/or high tank pressure signal could be used to close an automated valve. An emergency service motor operated valve (MOV, steam jacketed) should be installed on the suction to the ejector as well as a diversion to the emergency vent to the atmosphere with its own steam jacketed MOV. Special valve selection is necessary in this service due to high fouling and corrosion potential.

If individual ejectors are used at the loading stations, automated emergency block valves (MOVs) are also needed in the ejected gas piping because similar backflow could also occur out of idle ejectors. Low steam supply flow to an ejector could close an automated valve designed for the severe service. An emergency service MOV should be installed in each loading station ejector line.

6.0 Sulfur Tank Design Issues

The design of the molten sulfur tank is important for proper operation. Several design considerations for the tank are discussed separately below.

The sulfur tank should include an overflow port. Overflow of the tank could potentially cause the tank to rupture if the excess sulfur could not adequately flow out of the existing vents. A properly sized tank overflow port should be designed with down-pipes and siphon break exterior to the tank. The overflow could be directed to a concrete pit or other safe location.

The sulfur inlet to the tank should not be located too close to the sulfur outlet to the pumps. There is concern that sulfur with high H₂S levels may short circuit from the inlet to the outlet, thereby raising the H₂S levels at the loading areas. The sulfur outlet should be 180 degrees from the inlet or a baffle could be installed to keep sulfur from short circuiting.

Lastly, air intakes and the rain covers on the air intakes should be steam-jacketed or heat traced. Invariably, there will be occasional reverse flow from the air intake nozzles and uninsulated rain hats will become coated with sulfur potentially plugging off the intake nozzle. Likewise, piping on vapor lines that may contain sulfur vapor should be steam jacketed.

7.0 Heating of Internal Tank Piping

This section discusses some issues with heating the internal tank piping. This includes the sulfur fill and recirculation pipes as well as the suction line to the sulfur pump.

7.1 *Heating of Sulfur Down-pipes in Tank*

Heating all of the pipes internal to the sulfur tank is good practice. For example, if the sulfur tank level is low, the pipes above the sulfur level will be exposed to the vapors in the tank and the air being drawn in through the air intake nozzles, which may under upset conditions be colder than the freezing point of the sulfur. (The melting point of monoclinic elemental sulfur, which is the typical melting point used, is roughly 246°F⁸.) The environment in the tank may not be warm enough to keep the sulfur molten. Without good heating of the pipes, there is potential for the part of the pipe above the sulfur level to begin to build up a solid sulfur layer inside the pipe. Re-melting a solid sulfur layer in an inaccessible pipe inside a sulfur tank vapor space could potentially be very difficult. Even if there was continuous filling and constant recirculation in the tank, heating would be required during equipment downtime. There may also be conditions where solid sulfur could build up in the down-pipes even with constant flow (e.g., localized cooling, inadequate flow, etc.). Therefore, good heating is particularly important for the down-pipes internal to the tank.

The molten sulfur tanks that Trimeric is aware of typically use steam jacketed piping for the down-pipes and other piping internal to the sulfur tank. Conventional externally steam-jacketed pipe is very likely the most reliable and proven method for heating lines internal to a

sulfur tank. It is the authors understanding that it is common practice to steam-jacket the downpipes.

7.2 Heating of Pump Suction Line in Tank

Trimeric reviewed a few other molten sulfur tank designs to determine typical practices for heating the pump suction line in the tank. In all cases, the pump suction line was heated and the heating mechanism was steam jacketing. This points to steam jacketing as a good practice for the pump suction piping in the molten sulfur tank.

8.0 Configuration of External Liquid Sulfur Piping

Elbows and tees should not be used in the liquid sulfur piping external to the tank, including the sulfur lines from the SRU and around the sulfur pumps. Sulfur lines are known for plugging, and cross connections are much easier to clean than lines with elbows. Flanged crosses are recommended for installation instead of elbows or tees everywhere in liquid sulfur piping. It is also recommended that all of the molten sulfur piping external to the tank should be steam jacketed.

9.0 Snuffing Steam Requirement, Controls, and Condensate Drains

Snuffing steam is required in case of fire in the sulfur tank. The snuffing steam rate is typically based on NFPA guidelines stating that a minimum of 2.5 pounds/minute of steam be used per 100 ft³ of tank head space⁹. Many refineries conservatively base the volume on the empty tank space and not just on the volume above the high liquid level in the tank – using the empty tank volume represents good practice. Verification of the correct interpretation and snuffing rate with the NFPA guidelines is recommended. Also, low snuffing steam pressure (70 psig) and careful design of the maximum flow that the system is capable of should be used to avoid the chances for tank rupture due to misoperation of the snuffing steam system.

Another potential issue is that the operator controls for the snuffing steam should be located at a safe distance from the tank to protect the operator from being too close to the tank in case of fire. A general rule is that there should be approximately 100 feet between the tank and snuffing steam controls. This could lead to a long dead leg downstream of the valve. In some cases, a rupture disc can be installed and replaced if the valve were ever opened.

Finally, it is important that the liquid water drains be adequate on the snuffing steam lines; this is needed to prevent operators from accidentally sending steam condensate (liquid) into the sulfur tank causing the liquid to flash to steam and potentially rupturing the tank. Providing for condensate drains and operating procedures to verify that the lines are clear of condensate before turning on the snuffing steam is recommended to avoid the possibility of tank rupture. Use of a steam trap ahead of the steam block valve is required and the operator should

be instructed to blow any liquid condensate out of the steam piping before the block valve to the tank is opened.

10.0 Conclusions

The design of molten sulfur tanks, gas vent, and loading systems requires attention to many details for safe and consistent operation. A few of those details have been presented in this paper. For example, whether or not the molten sulfur is degassed has a big impact on the H₂S concentrations in the vapor space of the tank and loading stations and resulting containment and monitoring mechanisms that need to take place. The sweep air flow rate and ejector composition and sizing are also very important design parameters. Proper arrangement of the ejector piping (e.g., avoid low points and pockets) will minimize operational issues (plugging and corrosion) and ensure appropriate distribution of flow. Appropriate heating of the tank internal down-pipes, pump suction lines, and external sulfur piping will minimize plugging and allow for longer duration operation at different operating conditions and avoid freezing during shutdowns. Attention to these details and following good practices demonstrated at other molten sulfur handling facilities will help make for smoother operations.

11.0 Acknowledgements

The authors would like to thank B. Gene Goar for his suggestion that Trimeric prepare this paper and for his review during its preparation. The authors would also like to thank Nate Hatcher of Optimized Gas Treating who reviewed a draft of this paper and provided valuable input.

12.0 References

- 1) Hornbaker, D., P. Kobylarz, "Thermal Maintenance of Field Erected Sulfur Tanks", Brimstone Engineering Sulfur Recovery Symposium, Vail, Colorado, 2006.
- 2) https://www.osha.gov/dts/chemicalsampling/data/CH_246800.html
https://www.osha.gov/dts/chemicalsampling/data/CH_268500.html.
- 3) Agency for Toxic Substances and Disease Registry (ATSDR), 2004. *Draft Toxicological Profiles for Hydrogen Sulfide*. United States Department of Health and Human Services. Public Health Service. September.
- 4) Johnson, J.E., N. Hatcher, "Hazards of Molten Sulfur Storage & Handling", Proceedings of the 53rd Laurance Reid Gas Conditioning Conference, 23 February to 26 February, 2003, Norman, Oklahoma, USA, pp 109-125.
- 5) Lagas, J.A., C. Butlin, E. Fitzpatrick, M. Wetzels, and W. Kijlstra, "Understanding the Formation of and Handling of H₂S and SO₂ Emissions from Liquid Sulphur During Storage and Transportation", Sulfur Seminar, November 7-10, 1999, Amsterdam, The Netherlands.
- 6) Fenderson, S., "D'GAASSTM Sulfur Degasification Sulfur Update, Brimstone Engineering Sulfur Recovery Symposium, Vail, Colorado, September 13-16, 2005.
- 7) Gas Processors Suppliers Association Engineering Data Books, Volume II, Sections 16-26, Twelfth Edition, 2004.

- 8) Freeport Sulphur Company, 1954, *The Sulphur Data Book*, McGraw-Hill Book Company, Inc.
- 9) NFPA 655, Standard for Prevention of Sulfur Fires and Explosions, 2007 Edition.