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Specifying Internals in Sour Water Strippers – Part 1

Kenneth E. McIntush, P.E., ken.mcintush@trimeric.com
John P. Farone (Trimeric Senior Associate, Consultant for Fractionation Research Inc. [FRI]), john.farone@trimeric.com
Brad D. Piggott, P.E., brad.piggott@trimeric.com
Carrie Ann M. Beitler, carrie.beitler@trimeric.com
Trimeric Corporation
100 S. Main St. (PO Box 826)
Buda, TX 78610
Main Phone: +1 512 295 8118

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Abstract

Sour water stripping is a common process in petroleum refineries and other processes where H_2S is present. While not a revenue generator, the sour water treating system is a critical unit operation and can be a significant bottleneck to facility production rates, if it is not adequately sized, or if it is forced to operate at partial loads due to maintenance issues. As a result, a balance must be struck between minimizing capital costs while still providing a reliable and flexible sour water treating system. This article on specifying internals in sour water strippers was originally prepared for the Brimstone Sulfur Recovery Symposium [1]; it has been edited and separated into two parts for publication in Hydrocarbon Processing magazine. Part 1 i) gives an overview of the auxiliary separation equipment needed to remove hydrocarbons and other contaminants from the sour water prior to the stripper and ii) reviews the design of sour water stripper columns containing trays. In Part 2, which will be published in a subsequent edition of this magazine, the internals for packed sour water stripper columns will be discussed, along with a summary of potential issues that may be encountered in operation of the sour water stripping system.

1 Introduction

Sour water stripping is a common unit operation in petroleum refineries and in some larger natural gas treatment facilities. The sour water stripper system receives sour water from different upstream unit operations, which in a petroleum refinery may include crude units, hydrocrackers, hydrotreaters, catalytic crackers, etc. The sour water streams from each of these unit operations will vary in composition but will generally have some fraction of ammonia (NH_3) and hydrogen sulfide (H_2S) present in solution. This article considers sour water strippers that have NH_3 and H_2S as the primary species to be removed; it excludes consideration of other species, such as cyanides, phenol, etc. All recommendations given are in this context.

The sour water stripper system collects the sour water streams from different unit operations, removes hydrocarbons/solids/etc., and removes the NH_3 and H_2S from the water by heating and stripping. The liberated ammonia and hydrogen sulfide, along with a large fraction of water, flow to downstream unit operations as a vapor for further treatment. The stripped water may be disposed of as wastewater, or if it meets specifications, it may be used in other process units in the refinery, such as the crude oil desalter. A typical, simple sour water stripper process flow diagram is shown in Figure 1.

Different variations of the process flow shown in Figure 1 exist. Two frequently encountered differences are:

1. The addition of live steam into the column instead of a steam reboiler. Live steam will not foul or have maintenance issues that would be associated with the steam reboiler in a sour water stripper, but all of the steam introduced into the stripper will need to be made up in the facility's steam system with fresh steam and additional stripped water will need to be disposed of in one manner or another.

2. A pumparound system in the top of the sour water stripper instead of the conventional overhead condenser and reflux drum. In this design, a stream of water from the stripper is cooled and pumped to the top of the sour water stripper to maintain the overheads temperature from the stripper at the same temperature it would be leaving the reflux drum in the conventional design. This design avoids the need for the stripper overhead condenser, which can be an expensive and maintenance-intensive piece of equipment. The downside to this option is that additional height is needed in the sour water stripper for the cooling section, and the liquid pumparound equipment is made of upgraded metallurgy.

The sour water stripper and associated equipment are not typically revenue generators in any facility, but, at the same time, the unit operation is critical to the rest of the facility's operation, since most of the sour water in the facility has to be treated in the sour water stripper before it can be reused or processed further. The sour water fed to the sour water stripper will also change over time, with increasing or decreasing amounts of NH_3 and H_2S present in the water and overall water flow rates varying, sometimes as frequently as day to day. So, the designer of the sour water stripper is challenged to design a flexible and robust system that can meet a variety of different feed conditions while also minimizing the cost of the equipment. Above all, the sour water stripper cannot be a bottleneck in the overall facility and must strip the sour water reliably in all operating conditions.

There is a long history of technical papers that thoroughly discuss many aspects of sour water stripping [2] [3] [4] [5] [6] [7]. This article is not meant to be a comprehensive review of sour water stripping. Rather, this article reviews a few of the key design choices available for

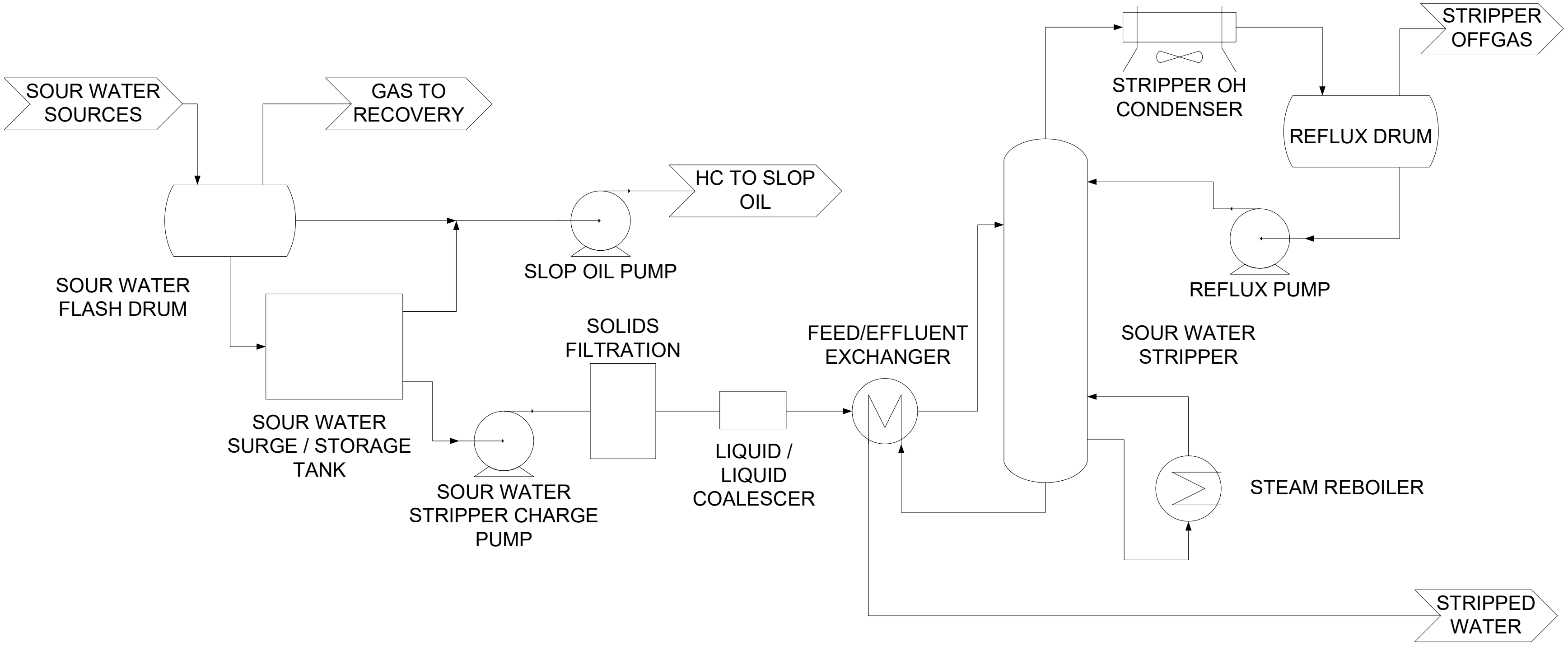

Figure 1. Simplified Process Flow Diagram for Sour Water Stripper.

the sour water stripper system, and then specifically focuses on some of the internals of the sour water stripper tower itself. The choice of internals in the sour water stripper can be difficult, with a range of different sources available in the literature, and few very thorough technical analyses completed to guide the designer to the “right” solution.

2 Auxiliary Sour Water Separation Equipment

In order for the sour water stripper tower (and the internals discussed later in this article) to function properly, they must not foul too quickly. Sour water stripping is generally considered a severe fouling service. The stripper functions much better if the chances for fouling and foaming are reduced by adequate pretreatment of the sour water. Thus, this section touches on the equipment upstream of the sour water stripper that reduces fouling and foaming issues in the stripper tower.

2.1 Sour Water Flash Drum

As shown in Figure 1, sour water is collected in a flash drum where hydrocarbon vapors and liquids are removed. The vapors are flashed at close to ambient conditions to remove as much hydrocarbon as possible. The flashed gas is typically sent to a low-pressure destination such as a flare gas recovery system, combustion device, or fuel gas as allowed by environmental regulations. At some sites, the flash gas is routed to the sour water stripper overhead gas line; however, this can result in a significant and variable quantity of hydrocarbons being fed to the downstream unit (e.g., a sulfur recovery unit [SRU], or other technology) that can adversely impact performance of that downstream unit [8]. Flash gas with no condensable hydrocarbons could possibly be routed to the quench tower in an amine tail gas treating unit (TGTU) [8] [9].

The sour water fed to the flash drum often also contains liquid hydrocarbon / oil that needs to be removed to protect the rest of the sour water stripper system from fouling and prevent foaming in the stripping column. The flash drum is usually a three-phase, horizontal vessel. A baffle system installed at one end of the flash drum is often used to skim oil from the water before it is pumped to the sour water surge tank. The oil overflows the weir into a collection compartment in the sour water flash drum for removal. Another means of collecting oil is to install a draw-off box in the sour water flash drum that could collect the oil overflowing to it. The minimum recommended residence time for the sour water inside the flash drum is 20 minutes with a liquid level of 50-60% being optimal. The sour water flash drum should include connections for level bridles on the hydrocarbon and water side of the vessel. High- and low-level alarms and pressure indication are also used. Demisting equipment or other similar plugging-prone internals are typically not used in the sour water flash drum, because they may rapidly plug or corrode. The hydrocarbons collected in the sour water flash drum are often pumped to a slop system for further processing.

2.2 Sour Water Surge / Storage Tank

The sour water from the flash drum is fed to a surge / storage tank. The tank is designed with several days of storage in case the sour water stripper goes down. With long residence times, dissolved hydrocarbon liquid and emulsions can separate from the water and collect at the interface level in the tank. The temperature of the sour water in the tank is usually less than in the flash drum, which reduces the solubility of hydrocarbons in the sour water further. Some in the industry have also observed that ammonia or amine-laden water increases the solubility of certain types of gasoline and higher boiling range aromatic hydrocarbons (similar to benzene) in the sour water, making it difficult to separate such that significant fouling was observed in the stripper [7]. The sour water surge tank may not remove all hydrocarbons that remain present in the sour water after the surge drum, but the tank does help by removing at least some of them.

The surge tank also allows for mixing of the sour water from different time periods, so the composition is more uniform. If the sour water composition changes considerably or rapidly, the stripper may not function appropriately. By keeping the sour water flow and feed composition consistent, the stripper will be easier to control, and a more consistent treated water product can be achieved. Short-circuiting, where the sour water entering tank inlet flows preferentially to the tank outlet without adequate mixing or residence time, is a common problem that results in higher variability in sour water composition and poor hydrocarbon separation. In the question-and-answer portion of a recent industry trade symposium [1], measures that were said to mitigate short circuiting included i) having the entry and exit on opposite sides of the tank and ii) having the entry and exit at different heights.

The surge tank can be a fixed or floating-roof-type storage tank. Floating roofs can be either open or internal. However, due to the potential for odors, a fixed-roof tank is often used. Figure 2 shows an example of a surge tank with both a fixed roof and an internal floating roof. The floating roof may have a double-seal design to minimize emissions.

Vacuum breakers and pressure relief valves should be installed on fixed roof tanks that are not vented to atmosphere. By letting air in, vacuum breakers can keep the tank from collapsing during pump-out or upon cooling; however, air ingress can lead to the formation of a dangerous combination of oxygen, hydrocarbons, and H_2S in the tank headspace that could lead to an explosion. Nitrogen or inert gas blanketing is often used for this reason. However, inert blanketing has its own problems. For example, using an inert blanket can lead to the formation of pyrophoric iron sulfides on exposed steel surfaces. If air is subsequently allowed into the headspace (e.g., due to a fault in the system, or due to accident) and thus creates an explosive mixture, then the pyrophoric material can ignite that mixture and cause an explosion; examples of explosions that have happened in SWS storage tanks are documented in the literature [10]. Much care is advised in designing inert blanketing systems for sour water tanks.

The tank may need to have roughly 3 days minimum retention time during normal operation at about 50 to 60% full, plus another couple of days of capacity for sour water storage. Whether the tank has a fixed or floating roof, it is common to allow a hydrocarbon layer to float above the sour water as a "blanket" to limit vapors from escaping that may be odorous or toxic. This layer may be a diesel range material and is sometimes also referred to as a rag layer. Oil skims should be used to remove oil as the floating layer grows. Floating skim nozzles with a non-metallic flexible hose are sometimes used. The design should include an automatic tank level gauge system, with provisions for measuring the thickness of the hydrocarbon rag layer on the aqueous layer as well. A literature source [11] reports that nuclear signals or sound waves can be used to measure the interface, but Trimeric is aware of successful measurement using capacitance probes as well. In a floating roof tank, the capacitance probe can be mounted on the floating tank roof. Level control is critical to minimize hydrocarbon carryover to the sour water stripper; the location of the control devices is vital to accurately measure the interface.

The tank is typically made from carbon steel, and a suitable durable coating may be used on all interior surfaces to minimize corrosion of the tank surfaces.

Solids and heavy oils will sink to the bottom of the tank. For this reason, the tank bottom should be designed to slope (e.g., about 3" for every 100") to a low point drain. The tank discharge to the pump is also generally elevated somewhat above the tank bottom to allow room for heavy materials to accumulate without exiting the tank with the sour water. The sour water is pumped using flow control to the stripper.

Angled ports are sometimes installed on the sour water tank so that it can be vigorously circulated (e.g., with a large portable pump) to stir up solids and then filter the solids out during turnarounds. This reduces the frequency with which persons will have to go inside the tank to clean it out. Images of the usually uninsulated exterior walls of the tank from a thermal camera can sometimes be used to evaluate solids levels. Also, the surge tank should have a bypass line around it so that it can be bypassed (e.g., for inspection), if needed.

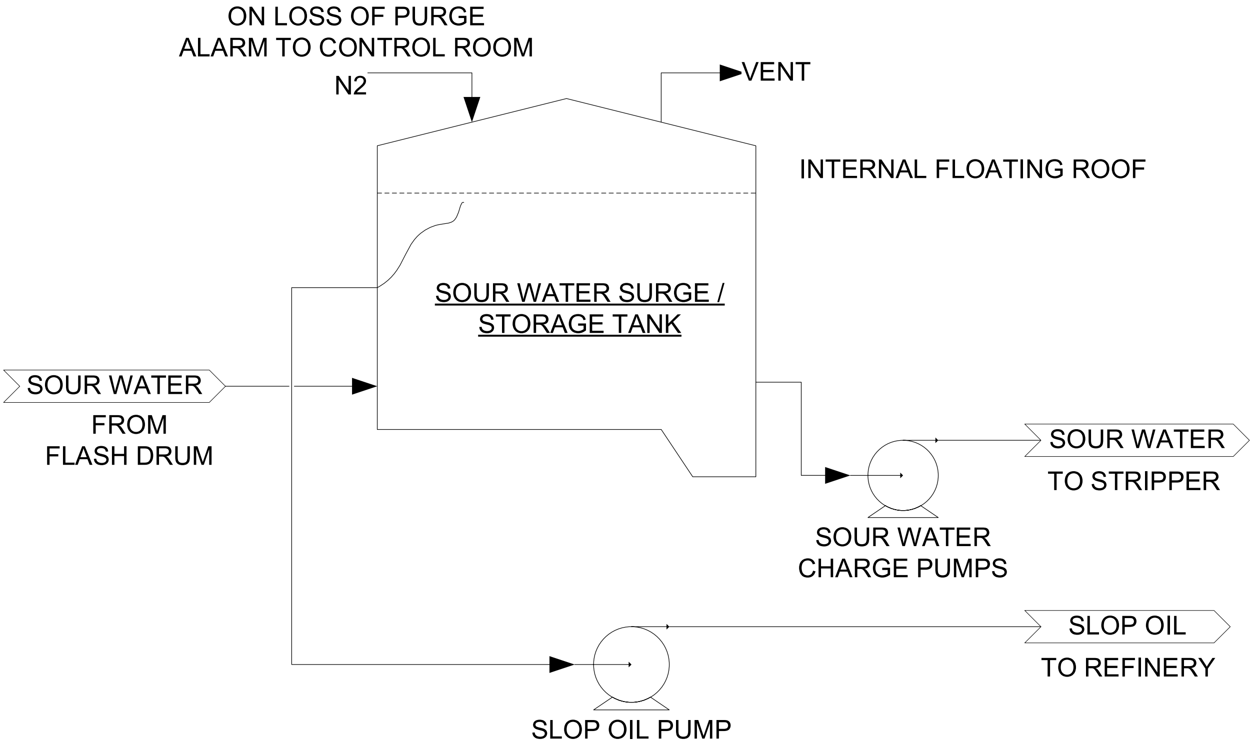

Figure 2. Simplified Schematic of Sour Water Surge Tank (Internal Floating Roof).

2.3 Sour Water Solids Filtration / Coalescing Filters

Additional solids filtration and coalescing technology may be installed downstream of the sour water charge pump and upstream of the feed/effluent exchanger. Solid particle filters should be used upstream of a liquid/liquid coalescer. Suspended solids removal i) improves the efficiency of the coalescer by weakening the hydrocarbon emulsion and ii) minimizes fouling from solids in the sour water heat exchangers, stripper reboiler (if used), and stripper trays or packing. Some refineries reportedly have used a strainer instead of a more expensive filter.

The liquid/liquid coalescer helps to control hydrocarbon fouling in the same sour water equipment. Disposable, microfiber-based coalescers are reported to give adequate separation of hydrocarbon emulsions [11]. During the question-and-answer portion of a recent industry symposium [1], use of liquid/liquid coalescers for partial treatment of the feed sour water was reported to increase the time between cleaning from once every 9 months to twice that length in a refinery with three sour water strippers.

Hydrocarbons in the stripper overhead gas can also cause operational issues in the downstream SRU or other processing technology. Hydrocarbons in the stripper bottoms that is routed to a water treatment plant can pose environmental/regulatory concerns as well. Thus, using filters and liquid coalescers can benefit not only the sour water stripper but also overall refinery operations.

3 Sour Water Stripper Diameter and Feed Water Feed Location

Many sour water strippers experience severe foaming, which needs to be accounted for when sizing the column. As such, the capacity should be de-rated to account for foaming, and a system factor of 0.6 to 0.7 is typically recommended. This can make the sour water stripper much wider in diameter than would be anticipated for a column that, at least on first appearance, is basically boiling water.

The location of the sour water feed in the stripper can vary based on several factors including whether trays or packing are used, number of trays used, the desire for lower steam usage, inlet H_2S and NH_3 concentration and treatment specification, as well as operating temperature and pressure. If a pumparound cooling system is used in lieu of an overhead condenser and reflux drum, the feed location will be below these trays as well. Optimal feed location can be determined in a process simulation, and the feed location is usually located within the top several trays in trayed columns. Also, if the column is constructed from carbon steel, it may be lined with a corrosion-resistant durable coating or made of corrosion resistant alloy above the liquid feed nozzle, where corrosion is more significant.

4 Tray Tower Design for Sour Water Strippers

Most sour water stripper systems are designed with trayed towers. (Note, Part 2 of this two-part series will discuss systems using packing instead of trays.) Trays can be designed to be fouling resistant. However, even in trayed systems, the selection of an inappropriate tray can lead to poor performance of the sour water stripper. General recommendations for sour water stripper tray selection include.

1. Trays should be a fixed-valve type and should be designed for vapor to flow horizontally out of the valves to minimize bridging of deposits on the fixed valves. Tray designs like this are readily available from major distillation internals vendors. Sieve trays can also be fouling resistant in some services; for example, the authors know of acceptable sieve tray use in aqueous systems with solid particles circulating (i.e., in slurry service). However, sieve trays have shown severe fouling in sour water stripper service, with vapor flow area decreasing by as much as 90%. This may be due to the vertical direction

of the vapor leaving the tray deck, which allows precipitation on the tray deck that can foul the tray [12, 13]. Figure 3 shows an example of fouling that can occur on sieve trays in sour water stripper service. This level of fouling occurred over a “typical” sour water stripper run between maintenance intervals of five months [13].

Figure 3. Fouling of Sieve Tray in Sour Water Stripper Service [13].

2. All trays should be constructed of 300-series stainless steel, or better. Depending on the sour water processing demand, the tower may be too small for personnel to physically install the trays. In this instance, cartridge trays could be used.

3. If a pumparound system is installed, the trays used for the pumparound loop should not be counted as active mass transfer trays.

4. In a fouling service like sour water stripping, the downcomers are potential traps for fouling material and can adversely affect the capacity of a tray. Special designs that are

available from the internals suppliers to address fouling material in the downcomers should be used.

Tray efficiency is reported in several different ranges for sour water stripping service, but generally will vary from 15-50% depending on different factors. The number of trays actually present in the sour water stripper will then also vary widely; a common range on the number of trays may be 20-60 actual trays installed. On a 24" spacing, this translates to 40-120 feet of height for trays, which may mean a sour water stripper as tall as 150 feet in some applications.

From the authors' discussions with a few refinery subject matter experts, a rough rule of thumb for design tray efficiency in sour water strippers is 3 actual trays per 1 theoretical stage or 33% efficiency. This is probably a conservatively low efficiency for most systems. For example, one subject matter expert (SME) acknowledged this rule of thumb, but noted that actual tray efficiencies experienced in sour water service (presumably well designed) were closer to 50%. In designing a trayed system, one could probably rely on the rule of thumb to result in a system with significant over-design built in. For a less conservative and perhaps more economical design, careful engineering analysis and comparison with the actual performance of other similar sour water stripper systems is needed.

Some factors that influence the efficiency of the trays are provided below.

1. Perhaps most importantly, tray efficiency is a chemical engineering factor that is applied to equilibrium-based designs to account for the fact that operating trays do not reach equilibrium conditions. Hatcher and Weiland [14] show that component efficiencies for H_2S and NH_3 will vary widely across the stripper column, and could depend heavily upon the stripped water specification for the water leaving the bottom of the stripper, the steam rate to the stripper or reboiler, etc. The efficiency of the tray then is not a static value throughout the stripper, varies from one component to another, and may be different in the top of the tower than it is in the bottom. In order to reduce uncertainty, the designer may need to do a more rigorous simulation of the column.

2. As mentioned in the introduction, the most important consideration for sour water strippers is that they work, and work reliably. As a result, designs for sour water strippers tend to be conservative, and one way of introducing conservatism into the sour water stripper design is to specify a low tray efficiency that, when installed, will allow the stripper to operate and meet specifications in a more heavily fouled state and to meet specifications if the impurities present in the sour water exceed the initial design values. If there is access to an existing stripper in the same service, then operating data can be obtained to verify the design parameters.

3. In a lot of instances, the actual composition of the sour water feeding the sour water stripper system may be uncertain. Crude oil slates in a refinery can change frequently, with the nitrogen and sulfur contents of the different hydrocarbon changing over time as the refinery processes different crudes, or different unit operations are added to the refinery. Ideally, the sour water stripper can handle most or all of these changes without major modifications to the stripper itself. A conservative estimate of tray efficiency will

provide more flexibility in the design to account for the uncertainty of the feed composition.

As mentioned above, numerous parties that Trimeric has been in contact with use an initial rule-of-thumb tray efficiency of 33%, or three actual trays in the sour water stripper for every equilibrium stage in the process simulation. To further refine the cost estimate or proceed with detailed design, it may be prudent to build a mass-transfer rate model of the sour water stripper. This can be more easily done once the column internals have been selected, since accurate information about the trays such as weir height, active tray area, etc. are critical to building an accurate mass-transfer rate model. Reliable estimates of the sour water composition will also be necessary to help ensure the appropriateness of the sour water stripper design.

Another important factor in the design of the column is the tray hydraulics. The actual hydraulics on the tray itself is dependent on the tray device such as fixed valve trays. The number of valves and size of the opening is important to maintain liquid on the tray and get proper contacting of the vapor and liquid; thus, the proper operating range for the design becomes important. If the trays are overdesigned, then the tray may weep or dump liquid resulting in poor operation. The design must account for the low-end as well as the high-end of operations. One reason that 24” tray spacing is often used is to give more capacity, especially when fouling or foaming is expected.

Even when the designer is confident in the design of the column, some additional precautions are recommended. These include:

1. NH_3 will be the more difficult component to remove in most sour water streams. NH_3 has a high affinity for water and will almost always strip out of the sour water after the H_2S is almost completely removed. It is possible to reach a stripped water condition where the remaining NH_3 is fixed in the stripped water, meaning that it is bound to a non-volatile or strong acid in the stripped water and will not come out of solution regardless of the energy input into the bottom of the column. In this case, it is prudent to install a nozzle in the lower section of the column to allow for caustic addition, if necessary under some, or all conditions. The strong base will displace the ammonia and allow it to be more easily stripped from the column. By placing the nozzle in the lower section of the tower, the caustic will not interfere with H_2S stripping.

2. Although trays can be designed for fouling service, some reduction in efficiency will likely be noticed over time. Even with adequate solids removal and hydrocarbon phase removal, some fraction of these materials will enter the column periodically. Some slightly-water-soluble hydrocarbons may enter the tower and precipitate in the lower section of the sour water stripper as the water heats to near boiling. Other salts may be present in the water that precipitate in the higher temperature areas of the sour water stripper. Adequate access to the column for quick maintenance and some additional design margin may be prudent to address fouling concerns. Figure 4 shows an example of fouling that can occur in sour water stripper service over a five-month period of operation, which corresponded to the 10-15% reduction in vapor flow area noted by the authors [13] [12].

Figure 4. Example of Tray Fouling in Sour Water Stripper Service [13].

5 Summary

Stripping sour water is a demanding process in a refinery or gas treating facility. The sour water will contain a multitude of contaminants in addition to the ammonia and hydrogen sulfide stripped out of the water in the process. These contaminants make reliable operation of the sour water stripper a challenge, but one that can be realized with appropriate design of the sour water stripper itself and the equipment that surrounds the stripper. Proper sizing and level control of the three-phase separators in the sour water system are critical to removing contaminants, such as hydrocarbons, that can severely impact sour water stripper performance by causing fouling and foaming in the column. Solids filtration and liquid/liquid coalescing equipment should also be considered as additional means to further clean the sour water prior to the stripper. The sour water stripper needs to be designed to handle variations in inlet feed composition and flow rates, plus allow a margin for fouling and foaming. The selection of tray internals should take into account the severity of the service and the presence (or absence) of good sour water cleanup steps prior to the stripper. Tray design should take into consideration: fouling, efficiency, and hydraulics among other factors. Part 2 of this article, which will be published in a subsequent issue, discusses the design of packed tower sour water strippers and presents operating problems that can occur in a sour water stripper system.

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