Hydrocarbon removal from sour water systems

A hydrocarbon and solids removal system allows stripper columns to operate as designed without exchanger fouling

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Sour water systems can be found in most refineries and gas plants around the world. Sour water is generated from many sources throughout the facility and is accumulated in large tanks for treatment within the sour water system. In this system, light hydrocarbons, hydrogen sulphide (H_2S), and ammonia (NH_3) are stripped from the sour water. The stripped gas is often sent to the Claus unit reaction furnace for destruction and conversion to nitrogen and sulphur. Examples of sources of sour water within the facility include:[1]

- Hydrotreater or hydrodesulphurisation units, where sulphur-containing hydrocarbons are reacted with hydrogen and H_2S is formed, and the hot gases from the reactors are quenched with water to reduce the temperature.
- The reflux water from the regenerator in the amine unit can be a source of ammonia.
- Steam is used in various processes throughout the refinery, where it may contact NH_3 and H_2S. When condensed and recovered, the condensed water can become sour, containing H_2S and NH_3.
- Wash water used throughout the facility may contact NH_3 and H_2S and become sour.
- Water is recovered in the crude, fluidised catalytic cracker, and coker units, and is also likely sour water.

These and many other sources of sour water are accumulated from throughout the facility and pumped into feed tanks to be treated in the sour water system. An examination of the various sources of sour water quickly indicates that it is probably highly contaminated with salts, solid particulates, and hydrocarbons. One method of handling these contaminants is to accumulate the water in large holding tanks, hoping that the solid particulates will settle to the bottom while the hydrocarbons separate and float to the surface, where they can be skimmed.[2] The solid particles are removed during turnaround when the tanks can be cleaned. The issue is that the approach does not work well, as solid particulates and hydrocarbons are not separated in the large holding tanks. Instead, they are pumped into the sour water system, perpetuating problems within it and others connected to it. This ongoing problem at the source of contamination inspired the design of the Torsep system, which aims to remove contaminants from the sour water system more effectively.

Case study

A refiner on the US Gulf Coast was forced to clean the heat exchanger in the sour water system approximately every three to six months due to fouling. The operators at the facility had come to accept this problem as the normal, routine course of operation. During a meeting to review operations and maintenance, it was discussed that operations should not have to accept heat exchanger cleaning every three months as routine and that the problem could be fixed. It was suspected that the problem was not only solid particulate fouling but also hydrocarbon fouling on the surfaces of the heat exchanger. To better define and understand the issues, in situ solids-loading samples[3] and bottle samples were taken from its sour water system. The results of this testing revealed that both problems were occurring.

This refiner originally took the approach of holding the sour water in large tanks with a long residence time (one to two days). However, even

with that residence time, the solids did not settle, and the hydrocarbons did not fully separate from the sour water. As the unit operated, hydrocarbons and solids were pumped with the sour water from the tanks to the feed/effluent heat exchanger and eventually to the stripper column. The heat exchanger fouled with coked hydrocarbons and solid particulates sticking to its surface, reducing heat transfer efficiency and necessitating cleaning.

To perform the cleaning, the system had to be shut down, drained, purged, and cleaned before reassembly. The cleaning process typically takes about a week, incurring significant operating expense for the refiner. As a result, the refinery staff were keen to find a solution. It was suggested that they remove the solids and separate the hydrocarbon liquid phase from the water. With a simple, cost-effective contaminant removal system, provided on a rental basis, they could evaluate this approach to solving their exchanger fouling problem. If successful, they could then consider installing a permanent system in the future.

Torsep contamination removal system

The system includes the Envision emulsion separator for liquid-liquid coalescing, where the oil phase is separated from the bulk sour water phase. Upstream of the emulsion separator is an Endur Tetra separator for the removal of solid particulates. The first stage removes solid particulates and protects the downstream emulsion separator from rapid plugging. The two separators are described in more detail in the following sections.

Endur Tetra solid separator

The operating cost of fluid quality management is highly dependent on the choice of element and vessel size. The vessel needs to be large enough and contain sufficient filter elements to allow for a reasonable time between filter changeouts. However, the larger the vessel, the higher the capital cost. Therefore, the Capex of the vessel must be weighed against the Opex of filter changeouts.

In this opportunity, an available rental unit was utilised, and the vessel size resulted in an expected changeout frequency of one to two weeks. This was sufficient to keep Opex low.

For solid particulate control, a suitable media configuration was applied to capture and retain the particulate contaminants in the inlet liquid flow with a defined level of efficiency. The media is a locked-pore configuration of cross-linked fibres, which prevents particulate release under higher differential pressure conditions.

In the Endur Tetra separator,[1] liquid enters the vessel through the inlet nozzle at the top, it is diverted by the inlet baffle, and passes through the solid particulate filter elements from outside to in. The particulate is retained by the media, and the clean liquid passes through the media into the riser, down the centre riser support, through the tube sheet, and into the outlet chamber, exiting through the outlet nozzle.

Some of the features of the separator and the filter elements include:

❶ **Preferred flow configuration**: The separator elements flow from outside to in. This flow configuration maximises dirt capture within a given vessel size, thereby allowing the lowest overall Opex for a given Capex.

❷ **Optimised element configuration**: The element maximises contamination holding capacity while also maximising packing density within a housing.

❸ **Ergonomic**: The elements are approximately 40in long and come with an ergonomic handle that allows easy removal and installation.

❹ **Coreless element configuration**: The Tetra element features a coreless design, making it lighter and providing a less strenuous changeout process. The coreless design will also have reduced disposal volume.

Envision emulsion separator

The Envision separator[1] is a single-stage, liquid emulsion separation system. The separator elements can capture and coalesce small, discontinuous phase droplets from a continuous phase, which may be aqueous or hydrocarbon in nature. In this case, the refiner needed to remove hydrocarbons from the sour water.

The liquid enters the vessel through the inlet nozzle located at the centre of the vessel head on one side. It travels through the tube sheet, down the riser, and through the separator element from inside to out. As the liquid passes through the media of the separator element, small, single-micron droplets of the hydrocarbon phase

(discontinuous phase) are captured by the tight media, where they are retained until they come into contact with additional hydrocarbon droplets and coalesce into larger droplets.

Once these droplets grow larger than approximately 1 mm, they force their way through the media as very large droplets. These droplets readily rise through the water phase and collect in the boot at the top of the vessel on the opposite side of the inlet. The hydrocarbon exits through the nozzle at the top of the boot, while the water exits from the nozzle at the bottom.

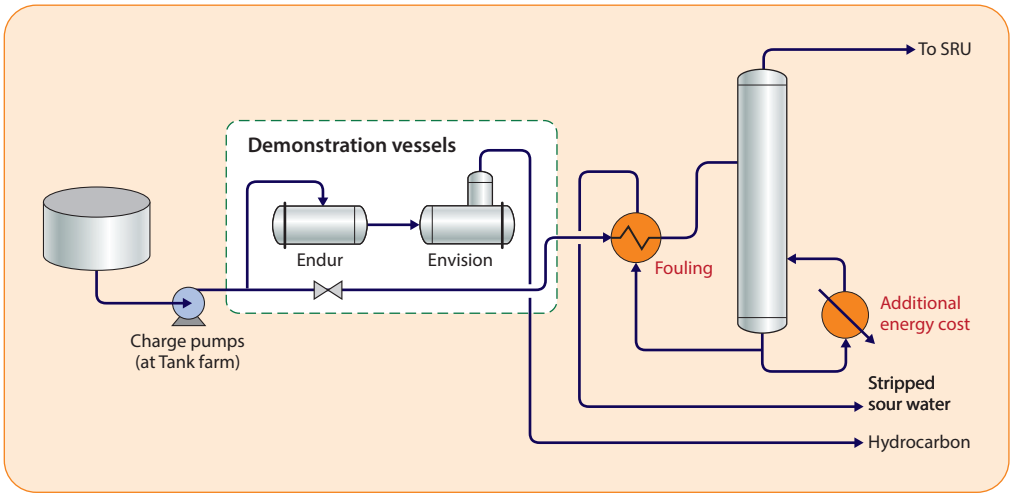

Figure 1 Simplified process flow diagram of Torsep installation

A baffle over the outlet helps ensure the longest possible separation time for the hydrocarbon droplets to rise to the top of the vessel, rather than be drawn out with the water flow. The residence time is typically of the order of seconds rather than minutes and is dependent on the media velocity, as well as the densities and viscosities of the two fluids.

The emulsion separator elements offer the following benefits:

❶ **Applicability**: The coalescing separator elements will meet a broad range of physical and chemical resistance requirements while allowing very high-efficiency separation of aqueous/hydrocarbon or hydrocarbon/aqueous dispersions.

❷ **Long online life**: Without particulate fouling, the elements are merely reclassifying liquid droplets, and will have extraordinarily long online life.

❸ **Ergonomic:** The liquid-liquid coalescing vessels are preferentially oriented horizontally, eliminating the need for expensive ladders and platforms, while making it easy for operators to replace elements.

❹ **Lower capital cost**: Since the coalescer is a single-step process, with liquid disengagement occurring once large droplets are created, the pressure vessel size is reduced by an order of magnitude relative to conventional corrugated plate or other coalescing devices.

With matched particulate removal from solid separators upstream (prefilters), the emulsion separator elements generally remain in service for six months to one year, possibly longer.

Performance evaluation

The system was installed on a rental basis to demonstrate its effectiveness to the customer. The design parameters for sour water service were based on an operating flow rate of 440 gpm (600 gpm max), at a temperature of 75-105°F, pressure of 140 psig, and design viscosity and density of 0.8 cp and 1.0, respectively. The system could handle a maximum of 600 gpm inlet flow, but the customer's sour water system operated at only 440 gpm. A process flow diagram of the system is shown in **Figure 1**.

The equipment configuration installed at the refinery is shown in **Figure 2**. The system was started in February 2019 and has operated nearly continuously since then. The only time the system has been bypassed is for cleaning and element changeout. As shown, the system was installed with one solid separator and one emulsion separator; therefore, during changeout of the elements in either vessel, both vessels were put into bypass. In an optimised installation, it is advised to have two solid separators so that when changing out those filters, the emulsion separator does not have to be put into bypass.

The performance evaluation criteria for the system were:

- Impact on heat exchanger fouling.
- Amount of hydrocarbon recovered.
- Filter changeout frequency.

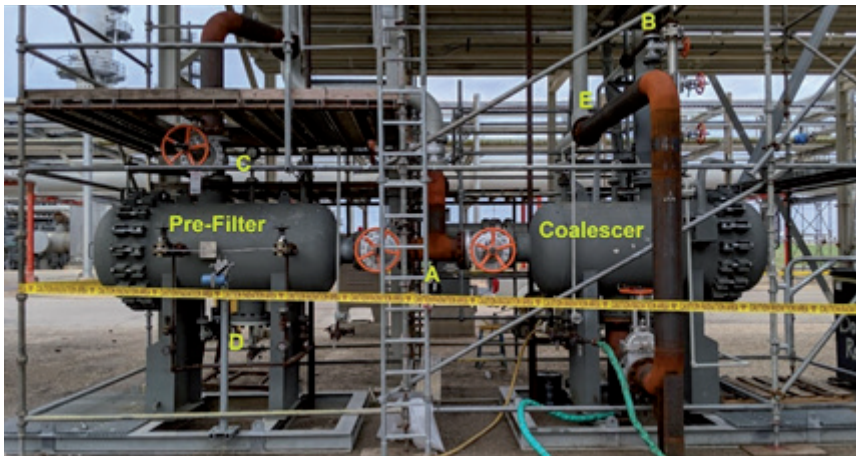

Figure 2 Installation at the refinery

Impact on heat exchanger fouling

As discussed previously, the pressure drop (dP) across the heat exchanger in the sour water system continues to rise until the operators are forced to shut down and clean the exchanger. The blue and green lines shown in **Figure 3** represent the dP signals in units of inch water column and PSI. Data provided by the refinery shows that the constant upward trend in the sour water exchanger's dP stopped within minutes of bringing the system online. Following the start-up, the upward trend stopped and even slightly reversed. The dP has remained nearly constant since the start-up, and the refiner has not had to shut down to clean the heat exchanger.

It is to be pointed out that the dP of the heat exchanger over time, as shown in Figure 3, is not normalised for flow. After the start-up of the solids and emulsion separation system, the operators were able to raise the flow rate through the exchanger because the dP was no longer rising. When the flow rate is increased, the heat exchanger dP will rise due to the increased flow. In addition, there are fluctuations in the flow rate during routine operation.

Since differential pressure is related to flow, and the flow through the unit has increased and fluctuated, the true trend in differential pressure is a significant downward decline when normalised for flow, as shown in **Figure 4**. The graph of the dP normalised negates the effect of the flow rate increase and shows that the dP consistently dropped over the entire time period and eventually levelled out. The system has not experienced heat exchanger fouling or dP increase since the start of the Torsep solid and emulsion separator operation.

Hydrocarbon recovery

Hydrocarbon recovery can be determined by plotting the level of the liquid-liquid interface in the boot alongside the percentage open of the boot level control valve (the 'dump' valve). These graphs[1] show the boot interface level as a line

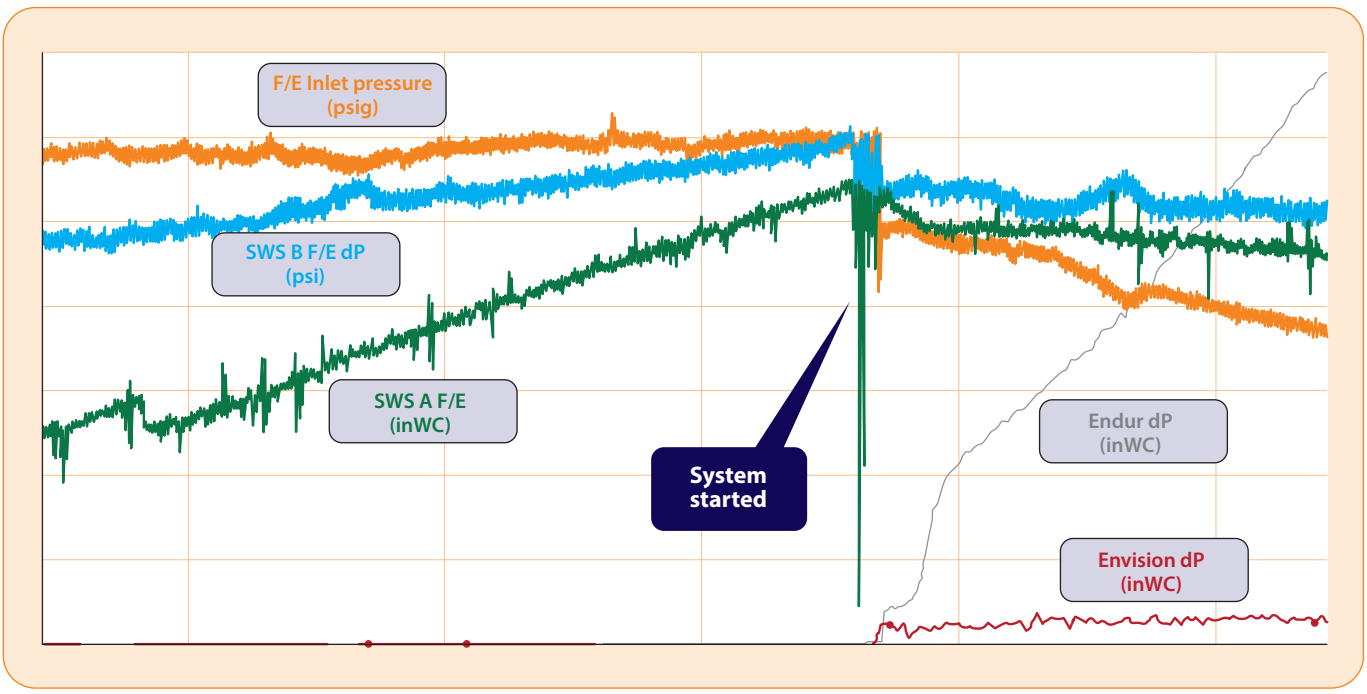

Figure 3 Operating data

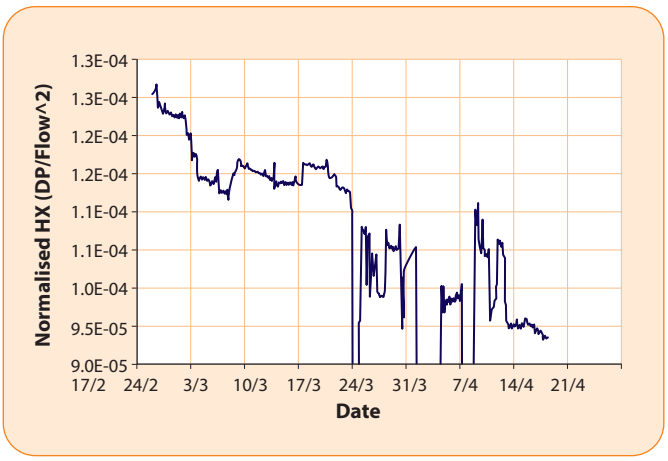

Figure 4 Differential pressure normalised for flow (dividing by the square of the flow in gpm)

and the valve percentage open as a column graph. The left axis represents the boot interface level, while the right axis indicates the valve percentage open.

In operation and as seen in this plot, the oil level in the boot builds until it reaches 80%. At this point, the valve opens, and oil is drained from the top of the boot. The frequency of oil dumping is not consistent but is seen multiple times. An 'upset' condition was seen between 25/3 and 27/3, when the valve was fully open, and the oil level dropped below the 80% mark. The refiner has not shared an explanation for this upset.

Typical process upsets in sour water systems have been previously noted to be related to level control failures, turnarounds, power failures, and weather, among others.

Filter changeout frequency

The solid separator elements were changed out on average every 10 days since February. The coalescing separator elements were changed out once since start-up. This changeout frequency met the expected target, and the customer is satisfied.

Recovered hydrocarbon

The recovered hydrocarbon is seen as a pale yellow, clear liquid.[1] Its boiling range was determined by simulated distillation.[1] The boiling range extends from 80-700°F. The specific gravity was measured at 0.8.

Summary

In summary, a picture is worth a thousand words. Samples taken from the inlet and outlet of the

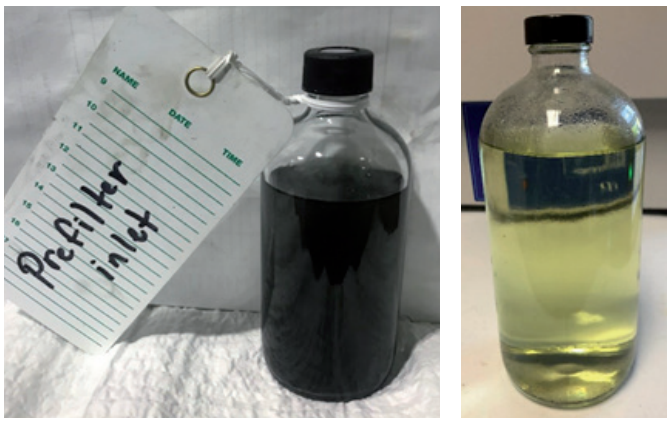

Figure 5 Left: inlet to system; right: water outlet from system

system are shown in **Figure 5**. The image on the left shows a sample of the inlet, which contains hydrocarbons and solid particulates. In contrast, the image on the right is taken from the water outlet and shows only a clear water phase.

The performance evaluation successfully demonstrated that heat exchanger fouling was mitigated immediately upon start-up of the hydrocarbon and solids removal system.

Hydrocarbon recovery was demonstrated, and the customer validated the filter changeout frequency as reasonable and acceptable, i.e., the solid particulate filters did not have to be changed out more often than expected. The Torsep system was so successful that the refiner is purchasing the rental system. In conclusion, this article illustrates a technique that can allow sour water stripper units to effectively remove solid and hydrocarbon contamination, thereby allowing the stripper columns to operate as designed, without exchanger fouling and likely without hydrocarbon excursions to the sulphur recovery unit.

[1]: Some charts and figures were edited from this article for want of space and are available on request. Endur Tetra, Envision, and TORSEP are marks of Transcend Solutions.

VIEW REFERENCES

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