THE IMPLEMENTATION OF A STEAM TRANSFORMER SYSTEM

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Abstract

Steam transformers are evaporators that operate as dedicated vapour and condensate producing cells. This practice is found in the sugar refining industry and beet sugar factories, but is generally not found in raw sugar factories. Green field investments often overlook the need for such equipment, but its application can have tremendous benefits for the safe operation of the boiler. This paper describes the evolution of a successful steam transformer station, detailing past failures, be they due to design, operation or material of construction related. The water chemistry aspect is also discussed at length. The station is now operational and performs robustly within design expectations. The use of this unit is directly in line with the operational target for zero effluent and maximum water recovery.

Keywords: steam transformer, heat exchanger, boiler, condensate, boiler feed water, zero effluent

Introduction

The Al Khaleej Refinery is a stand alone sugar refinery that processes VHP sugar into EEC2 sugar. It is located at the Jebel Ali port in Dubai. Municipal desalinated and de-mineralised water is available at a premium. A steam transformer may be described as a single effect evaporator that uses live or exhaust steam and delivers process vapour to the end user. It effectively de-couples the clean boiler steam/condensate circuit from the process vapour/condensate circuit. The Al Khaleej factory uses saturated steam at a pressure of about 140 kPa (a). A recently installed steam turbine operates with an exhaust pressure of 280 kPa (a).

History of steam transformation at Al Khaleej Sugar

The factory was commissioned in 1995. The steam transformer station consisted of a set of three plate type heat exchangers; each coupled to individual flash tanks. The principle of operation was to heat the water in the plate heater and flash the super heated water inside the flash tanks. These plate heaters were unreliable due to regular gasket failure. The steam pressure and temperature was 300 kPa (a) and 133 degrees Celsius respectively. Recurring gasket failures soon forced the refinery to abandon the plate heaters for shell and tube heaters. A recent post mortem showed that the plate heater gasket failure was probably caused by a combination of two reasons.

1. A malfunctioning desuperheater caused high temperatures subsequent gasket failure.
2. An insufficient total water pumping capacity causing premature vapourization inside the plates. The total pumping capacity was 900-1200 m^3/h. For the specific evaporation of 100 tons per hour the water requirement is 3300 m^3/h.

Overview of the steam transformer station

The schematic arrangement in Figure 1 shows how the station is integrated into the plant.

Boiler steam at 35 MPa (a) is reduced via a steam turbine and a pressure reducing desuperheater station (PRDS). The exhaust pressure is maintained at 280 kPa (a) to 300 kPa (a). The pure steam condensate is returned to the boiler. Using exhaust steam for energy, the steam transformer vapourizes a closed loop consisting of batch pan and evaporator condensates, transforming these condensates into 140 kPa (a) vapour. This vapour condenses at the batch pans and evaporators before returning to the steam transformer in a closed cycle.

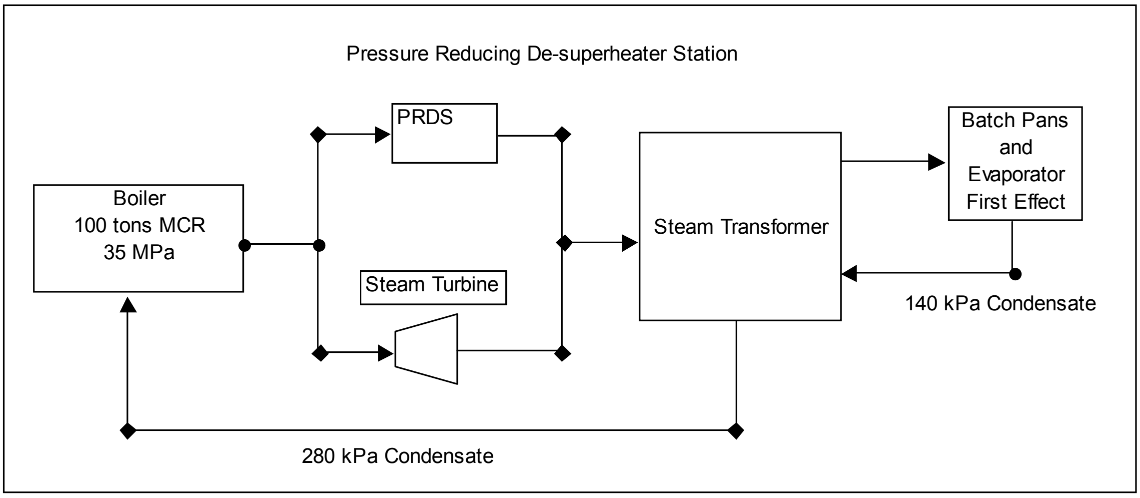

Figure 1: Layout of Steam Transformer in Relation to Steam Generation and Process Consumtion

Introduction of shell and tube heat exchangers

Due to the problems of gasket failure, the three 700m^2 plate heat exchangers were replaced with three shell and tube heaters, each with a heating surface of 600m^2. The identical configuration was maintained, i.e. heat and flash. The heat transfer area was reduced by 100m^2 each. The evaporative performance was poor, so a parallel bypass operation was established. This meant that, after pressure reduction and de-superheating, about 50% of the live steam was sent directly to the pans and evaporators, bypassing the steam transformer. The combined condensate from the steam transformer, evaporators and pans was sent to the boilers. Sugar contamination of the condensate was inevitable and resulted in costly boiler tube failure.

Table 1 illustrates the poor evaporative performance of the three shell and tube heaters in a heat and flash configuration. The evaporation rate for each heater was 5 tons per hour.

Table 1. Evaporation rate of the U Tube heaters.

Date (year 2001)	**Tons evaporation per day**
9 February	465
10 February	368
11 February	287
12 February	365
13 February	314
AVERAGE	**360**

An investigation was conducted in the first quarter of 2001 on the heaters and two major problems were discovered.

1. The heat exchanger end caps and pass baffles were internally corroded, allowing bypassing of the tubes.
2. The velocity of the water at 0.47 m/s was extremely low and hence suffered from a poor heat transfer co-efficient of 0.28 kW/m^2.ºC.

Table 2. Relationship between velocity, HTC and expected flashing performance (1 U Tube heater).

No. passes	1	2	3	4
Velocity m/s	0.47	0.93	1.40	1.86
Water flow	400	400	400	400
Flash tons/hr	4.2	8.7	13.9	15.4
HTC kW/m^2.C	0.28	0.59	1.25	1.63
Calc T2 ^{o}C	115	121	128	130

Table 2 illustrates the improvement in the heat transfer coefficient (HTC) with increasing velocity inside the tubes. The velocity was increased by increasing the number of passes. Because of the practical difficulties in converting the heat exchanger to four U Tube passes, it was decided to settle on three U tube passes for the following reasons:

1. Effectively, being a U tube heater, three passes would be equal to six-pass arrangement anyway.
2. The overall heat transfer coefficient (OHTC) with three passes was predicted to be 1.25 kW/m^2 ºC. As the outlet temperature was approaching the steam temperature, any further improvement in performance would be marginal.
3. There was a concern about the tube side pressure drop.

After the modification, the evaporation rate improved by 300% and was slightly better than predicted by calculations presumably due to the fact that the liquid commenced flashing in the tubes even before it left the heat exchanger.

The need for change

While the improvement from 15 to 45 tons per hour evaporative performance was seen as a milestone success, it was far short of the ambition of AKS to increase its sugar production to more than 2400 tons per day. Further, plans were underway to install a 5 MW steam turbine. The steam turbine manufacturer specified stringent steam quality requirements, which AKS could not consistently achieve without total steam transformation. Tenders were sent out for a 100 tons per hour evaporator, and it became apparent that the capital cost of a new evaporator would not meet the internal rate of return investment. The heat and flash system has certain limitations on the evaporation rate, due to the fact that the heat transfer drops off as the water travels through the tubes approaching the steam temperature. Also, the pumping cost of 3000 tons per hour of water is expensive, requiring capital and increasing operating expenditure. Several options were studied, and while some were elegant engineering solutions, the cost and time frame was prohibitive.

Options Considered

With the steam turbine installation day looming a decision had to be made quickly. Several solutions were looked at; the Roberts type evaporator and climbing / falling film evaporators were ruled out at the outset due to cost and the lead-time. The Balcke Durr plate pack looked promising, as it would have fitted snugly into the 3.8-meter diameter flash vessel. So did the use of an Alfa Laval type semi welded plate heater (available due to redundancy), which would have been installed as an external calandria, operating as a thermosyphon evaporator. However, with the three shell and tube heat exchangers, each weighing 40 tons already located at the steam transformer station, and the idea of retaining them in some form was appealing**.** A heat transfer consultant was approached for advice in utilizing these existing heat exchangers as evaporators. The answer was to convert them into kettles. In a kettle, the steam would flow inside the tubes, while the boiling liquid would remain on the shell side. Figure 2 illustrates the general arrangement of a kettle. The kettle conversion proposal was received with scepticism because in the year 2001, a new 35 m^2 kettle had failed. The tubes had cracked at the U bend. An investigation revealed that the tubes were badly fouled on the shell side, and the tubes had failed. The reason for the failure was poor level control that caused unequal expansion of the long tubes, causing stress at the U bend. Kettles, sometimes named “dirt collectors” in the petroleum industries have a reputation for fouling and there was a concern that these would foul quickly. Further, there remained still the manufacturing implications and the consultant was asked to look at converting the existing heater into thermosyphon re-boilers. The design that was finally settled on was a forced circulation re-boiler. The original pumps were retained because of the uncertainty of the expected performance and Kern’s (1950) postulation that the rate of sensible heat transfer is better in forced circulation re-boilers compared to natural circulation re-boilers.

Table 3. Evaporation rate of each heat exchanger after modifications (actual).

Modification	Evaporation TPH	OHTC kW/m^2.C
Original Design	5	0.41
Velocity Increase	15	1.23
Converted to Reboiler	50	3.69

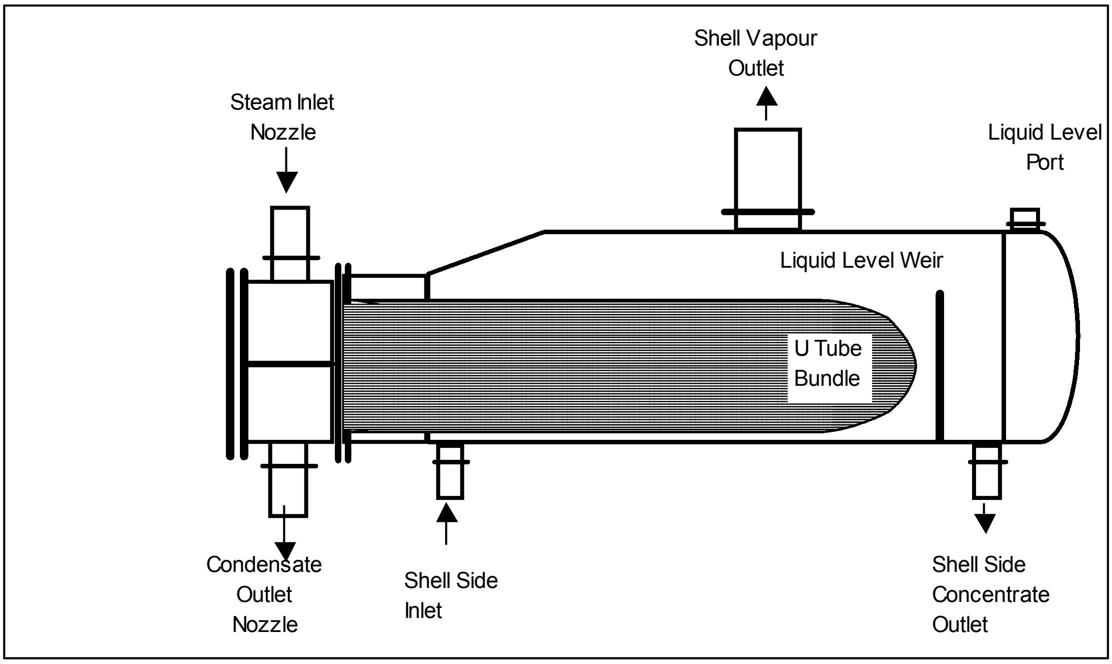

Figure 2: Typical Kettle Reboiler TEMA K Shell

Before the modification, the heat exchangers were used for heating water, ie the fouling product on the tube side. After the modification, the fluid boils on the shell side and discharged as a two phase mixture through the 1000 mm exit piping to the column. Figure 3 shows the configuration of the equipment before and after the modification. One of the main advantages of these evaporators is the extremely good heat transfer performance it operates at. However, the chief disadvantage is the fouling potential on the shell side, which is difficult to clean. Therefore the maintenance of the water chemistry is given the same care and attention given to a steam boiler. The evaporation rate of the new design increased dramatically from 15 to 50 tph (Table3). In the forced circulation reboiler, the water is pumped into the shell via the two original condensate outlet nozzles. With the transfer of heat to the water a change of phase takes place. A two phase water and vapour mixture escapes from the bundle via the large nozzle. This foam like vapour discharges tangentially into the column. Chevron plate separators and knitted wire demister pads ensures that no entrainment takes place.

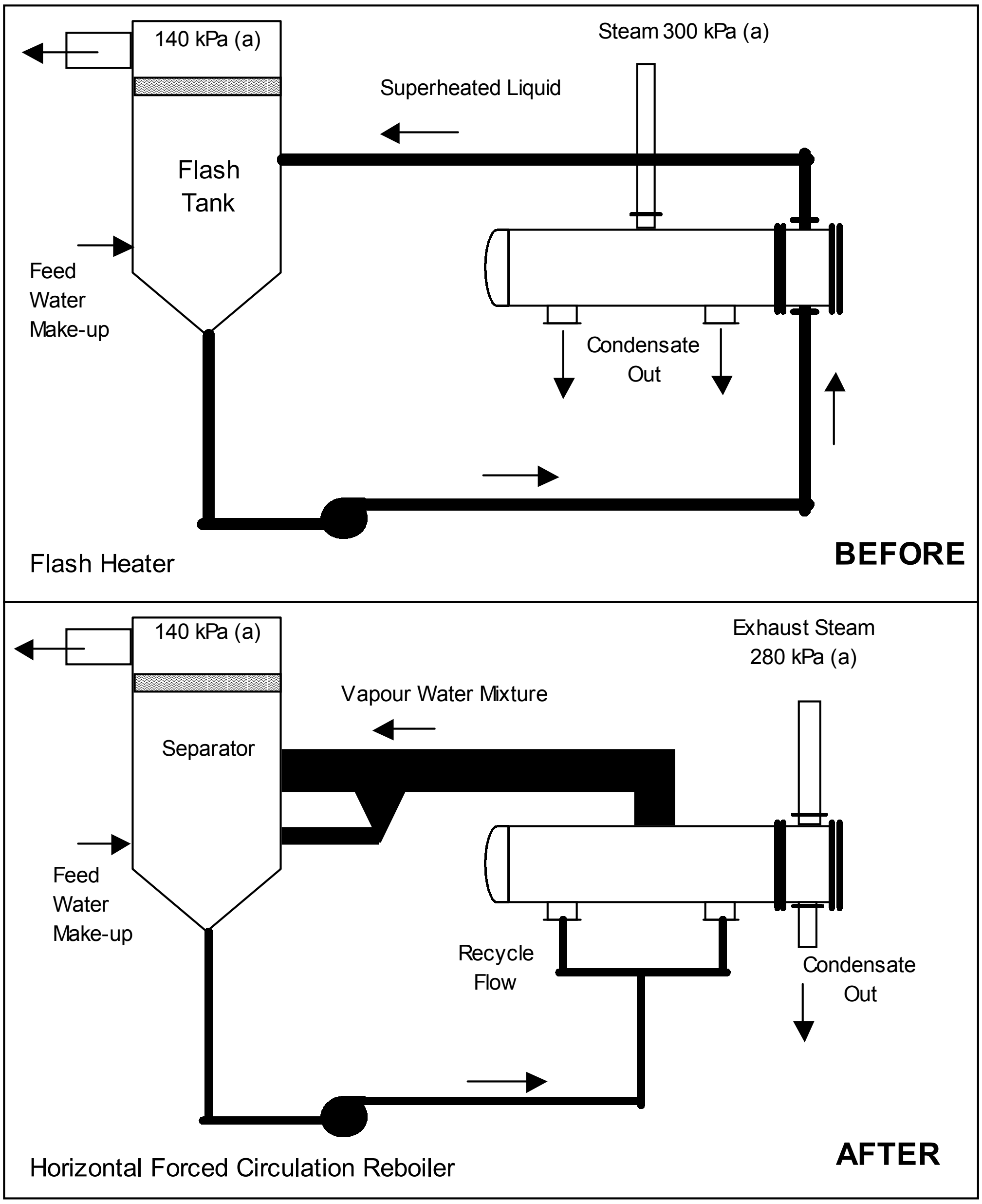

Figure 3: Schematic Arrangement of Steam Transformer Before and After Modifications

Detail of the steam transformer layout

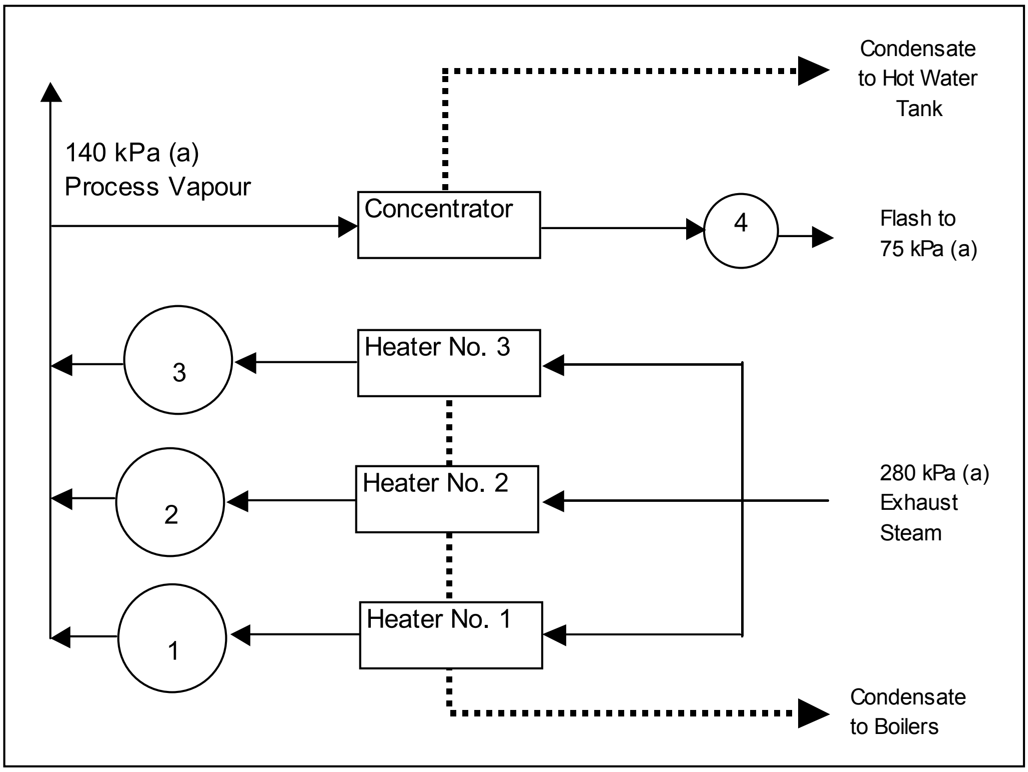

Figure 4: Schematic Arrangement of the Steam Transformer Station

The steam transformer station consists of four heat exchangers, three of which have been converted to forced circulation boilers as described above. The fourth evaporator has been retained in the old configuration and operates as a concentrator. As will be discussed in the water chemistry section, the total dissolved solids (TDS) in the steam transformer is maintained at 3000 ppm. The blowdown is sent to the concentrator and discharged at 10000 ppm. A schematic layout of the station is shown in figure 5.

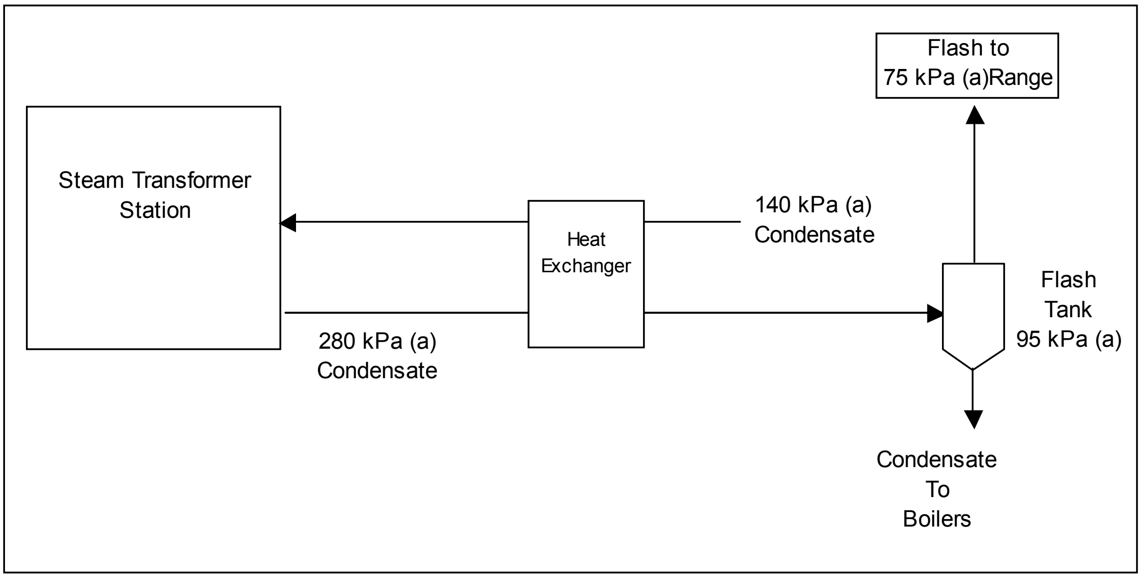

Figure 5: Energy and Water Recovery Configuration

Water chemistry: steam transformer

In the old configuration the water quality was maintained at a TDS of 10000 ppm. Now that the fouling liquid boils on the shell side, the TDS was reviewed to minimise fouling. At TDS 3000 ppm and pH 10, the Ryznar index was calculated to be slightly "corrosive", mainly due to the low calcium hardness. For this reason it was decided to maintain the TDS at 3000 ppm in the reboiler, and to concentrate this to 10000 ppm in a second effect concentrator, where the fouling liquid would be on the tube side.

Water chemistry: boilers

The most important benefit of the steam transformer is the high quality feed water returned to the boiler. Table 4 shows the improvement of feed water during the systematic evolution of the steam transformer station.

It can be seen that with the advent of total steam transformation (Table 4), the quality of condensate has improved. There has been a significant drop in return condensate TDS, from 18.5 ppm to 0.5-1.3 ppm. This has allowed the boiler station to operate at a favourable cycle of concentration. The cycles of concentration is the term used to describe the build up of TDS concentration by evaporation in the boiler. Evaporation increases the conductivity (or TDS) in the boiler and the cycles of concentration compare this to the feed water TDS content. For example say boiler make up water TDS = 60 ppm and the water in the boiler =3500 ppm. If 3500 is divided by 60, the resultant cycles is 58.3. Further, 100 divided by the cycles reflects the % blow down which is 1.7%. Thus the information of the cycles reflects the blow down rate. In this case the TDS of the boiler feed has reduced substantially, an improvement solely due to the implementation of the steam transformation process. The cycles of concentration have improved from 29.6% to 88.1%, and consequently the blow-down has improved from 3.4% to 1.1%. The improvement in energy saving is not as dramatic because the blow down is already recovered by flashing it into the low-pressure steam range. Another interesting observation is that the steam transformer has maintained an excellent condensate pH because the amine based corrosion inhibitor is almost fully returned to the boiler in the feed water. These amines are volatile and enter the steam system in the same manner that steam does. There are two ways that neutralizing amines reduce corrosion in a steam system. Firstly, by neutralizing the acids and secondly by elevating the pH into the alkaline range. This helps to stabilize and protect the magnetite layer on the steel surface. The pH control range in a softened make up boiler system is from 7.5 to 8.5, although a pH above 8.3 is recommended. In high purity water systems with a mixed metallurgy a pH range of 8.8 to 9.2 is generally recommended. At AKS, the pH is perfectly placed within the recommendations of boiler operational parameters.

Table 4. Comparison of feed and boiler water quality for different configurations.

	July 2000	**Oct 2001**	**Nov 2001**
	Partial steam transformation	**Full steam transformation**	**Full steam transformation**
Feed pH	9.0	8.7	9.3
Feed TDS (mg/l)	18.5	0.5	1.3
Boiler pH	10.3	9.8	10.8
Boiler TDS (mg/l)	757	16	116
Cycles	40.9	29.6	88.1
% Blowdown	2.4	3.4	1.1

Water and energy recovery

The condensate from the steam transformer is at 110 degrees ºC and will flash if exposed to atmosphere in an open tank. In order to prevent this, the condensate is flashed into the 75 kPa (a) header. As a result 2.4 tons per hour was previously lost to the 75 kPa (a) range. To minimise this "loss", the pressure in the flash tank was subsequently controlled to 95 kPa (a), resulting in the minimisation of the flash to 1.8 tons per hour. In order to further minimise the amount of flash and recover the heat from the exiting condensate, the steam transformer feed and the exit condensate are passed through a plate heat exchanger. The condensate and feed exchanges heat of about 20 degrees Celsius, the contribution of heat equivalent of 3.7 tons of steam per hour.

Water recovery

The concentration of the blow-down from the steam transformer is 3000 ppm. The fourth heater functions as a concentrator. This increases the TDS of the concentrate to 10000 ppm as shown in figure 4. This concentrator has been configured to operate as a second effect, which means that the evaporation is achieved without additional energy. The flash is discharged to the 75 kPa (a) range, substituting the normal letdown to that range. Other waste waters that are not fit for "cleaning up" in the steam transformers are sent to this concentrator. This includes wastewater from the activated carbon columns and water from the refinery and recovery house drains. Tests are being done to mix this concentrate with the outgoing molasses so that nothing is sent to the effluent lagoon. This is one of many continuous improvement practices to achieve zero effluent status.

Conclusion

The advantages of a steam transformer:

1. Protects the boiler from any sugar contamination from the process.
2. Reduces boiler water chemical costs.
3. Reduces water consumption and energy loss due to boiler blow down.
4. Stabilizes steam pressure by steam accumulator action.
5. Can be used for water recovery and effluent minimization.
6. It guarantees saturated quality vapour, i.e. prevents superheated steam from entering the process.

There are some disadvantages:

1. Heat losses due to radiation.
2. Electrical costs, four pumps, total installed power 127.5 kW.
3. Maintenance cost, pumps, valves etc.
4. Additional pressure drop increases turbine back pressure and reduces power output.
5. Additional capital cost.

At AKS, the steam transformer has proved to be a valuable asset and has contributed significantly to the over-all efficiency of the plant.

Acknowledgements

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