NGATI TUWHARETOA GEOTHERMAL ASSETS CLEAN STEAM SUPPLY TO SCA HYGIENE AUSTRALASIA'S KAWERAU TISSUE MILL

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1. INTRODUCTION

In July 2009 Ngati Tuwharetoa Geothermal Assets Limited (NTGAL) signed an agreement to supply high pressure clean steam to SCA Hygiene Australasian's (SCA HA) Kawerau Tissue Mill. The steam supply, to be generated from geothermal energy, needed to be of a high grade, reliable and replace two natural gas fired boilers that supplied steam to SCA HA's mill. To meet this need, a new plant was built comprising geothermal separators, heat exchangers and a condensate stripping system to generate boiler feed water. To complete the plant NTGAL engaged Geothermal Engineering Ltd and Dobbie Engineers to project manage, design, supervise construction and commission the plant. This paper describes the process and outcomes achieved.

Figure 1 – NTGAL Plant Kawerau

2. DESIGN PHILOSOPHY

The steam supply system needed to meet a number of key design elements. These included:

- Minimum continuous supply of saturated steam of 26 tonnes/hr and 16 bar.g.
- The steam quality was set high to ensure there was no adverse effects to the paper making machinery.
- Reliability; this plant supplies SCA HA's entire steam demand and is required to operate continuously for 363 days per year without interruption.
- The plant should operate efficiently to minimize well draw-off.
- The plant needed to be integrated into Mighty River Power's operating and maintenance program.
- The plant needed to be operated and maintained safely.
- The plant's feed water system needed to be self sufficient to eliminate the need for condensate return from SCA.

SCA HA's main concerns were reliability and sustainability. Reliability was essential as this was to be SCA HA's sole steam supply system. Their tissue machines operate continuously for 363 days of the year and require a constant supply of steam to maintain production. Unplanned down time incurs considerable costs and was not acceptable. On this basis the plant was designed with 100% standby capacity. It incorporates two separation plants, two heat exchanger plants, two condensate stripping plants and two feedwater supply systems.

SCA HA has an ongoing commitment to sustainable operation. This initiative to replace natural gas use with geothermal energy immediately reduces SCA HA's carbon emissions by 39%, eliminating up to 17,000 tonnes/year of CO_2 emissions. At Kawerau, SCA HA produces 60,000 tonnes of tissue product per year. This product is marketed under the Purex, Handee, Deeko and Tork brands and SCA HA is confident that customers will value the lower environmental impact when they purchase these brands. This project with NGAL provides SCA HA with a significant step towards an environmentally sustainable plant.

3. SYSTEM DESCRIPTION

The plant is based on experience gained at Norske Skog Tasman (NST) and Carter Holt Harvey Tasman (CHHT). Historically NTGAL and the Kawerau Steam field has supplied up to 300t/hr of low pressure (6 – 8 bar.g) steam to the NST/CHHT paper mills for use in their papermaking processes. NST have for approximately 50 years used 6 – 7 bar.g geothermal steam to generate clean steam in five generators with a total capacity of 120 – 150 tonnes/hr. NST also treat the resultant geothermal condensate through a flash and steamstripping process to generate clean feed water.

The SCA HA's system is required to operate at significantly higher pressures than that used by NST and this creates a number of challenges.

Figure 2 provides a schematic flow diagram of the NTGAL/SCA HA system. It shows a single process line without the standby features. Typical operating pressures, temperatures and flow-rates are shown in Table 1.

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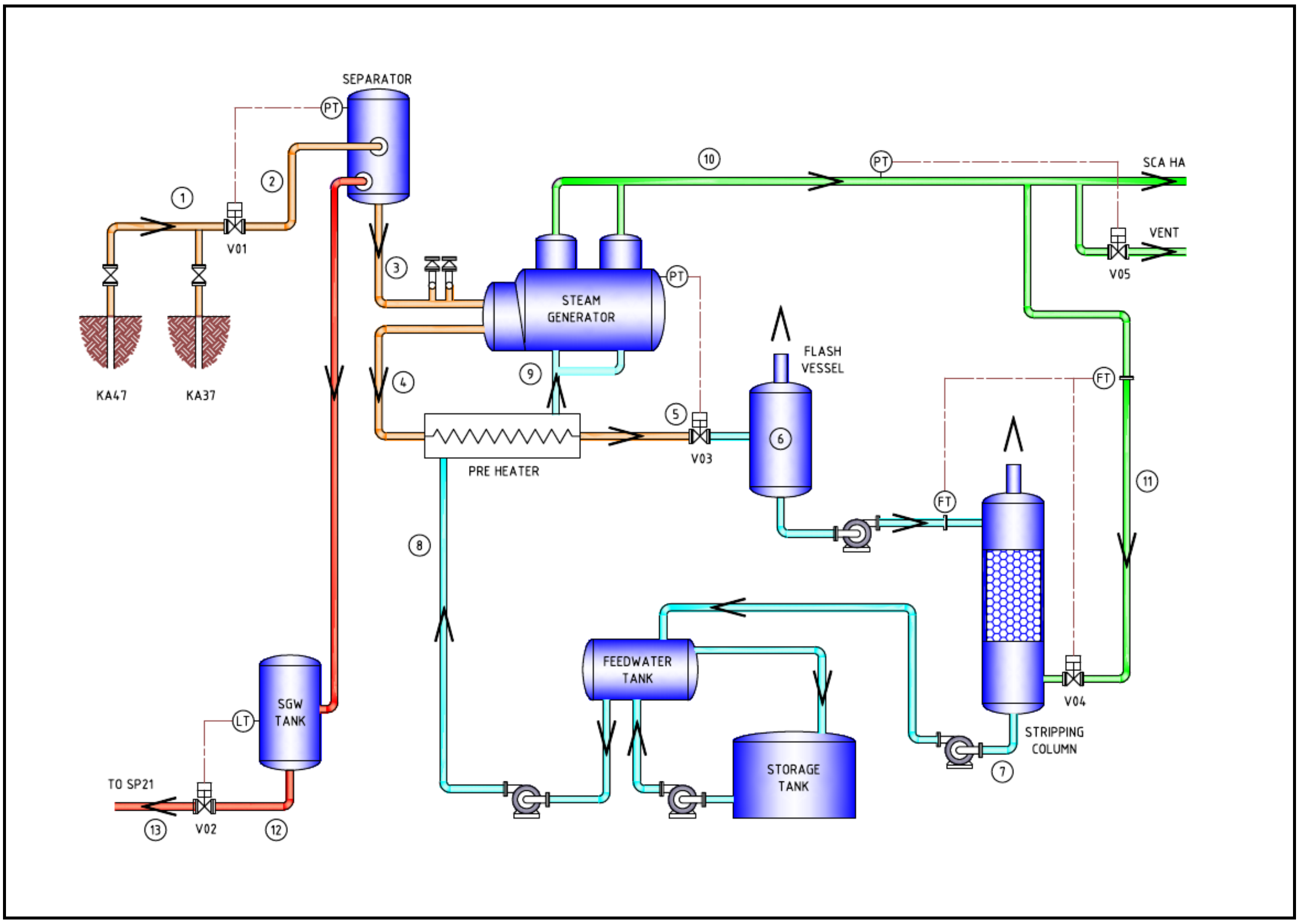

Figure 2 Flow Chart of Schematic Flow Diagram

1	2	3	4	5	6
2 Phase Geothermal 40 Bar.g, 252°C 250 tonnes/hr	2 Phase Geothermal 22 Bar.g 220°C 250 tonnes/hr	Separated Steam 22 Bar.g, 220°C 35 tonnes/hr	Steam/Condensate Mix 22 Bar.g 200°C 35 tonnes/hr	Sub-cooled Condensate 21 Bar.g 130°C	Flashed Condensate 0 Bar.g 100°C
7	8	9	10	11	12
Stripped Condensate 0 Bar.g 100°C	Feed water 16.5 Bar.g 95°C 28.5 tonnes/hr	Heated Feed Water 16.5 Bar.g, 190°C 28.5 Tonnes/hr	Clean Steam 16.5 Bar.g 200°C 28.5 Tonnes/hr	Stripping Steam 16.5 Bar.g 200°C 2.5 tonnes/hr	Separated Water 22 Bar.g 220°C 215 tonnes/hr
13					
Flashed SGW 12 Bar.g 192°C					

Table 1 – Typical Operating Pressures, Temperatures & Flow Rates

Two phase fluid is taken from one of two geothermal wells available. KA47 and KA37A. KA47 is the duty well and typically supplies two phase fluid at 40 barg. The two phase flow is throttled by Valve VO1 to provide a separation pressure of 22 bar.g. The separator water level is controlled by Valve VO2. At this point the 22 barg separated geothermal water (SGW) is flashed to approximately 12 bar.g and introduced to the lower pressure two phase main which supplies NST's low pressure separators (Separation Plant SP21). This provides energy recovery from the SGW.

From the separator the geothermal steam is piped to the clean steam generating heat exchanger. The geothermal steam passes through the tube bundle. Through this process approximately 90% of the steam is condensed. The shell side of the heat exchanger contains feed water and generated clean steam at 16.5 bar.g (200°C). This is then piped to SCA HA approximately 1.5km away at a rate of up to 26 tonnes/hr.

The geothermal condensate/steam mixture leaving the main heat exchanger is then passed to the Feed Water Preheater where it is sub-cooled in the tube bundle to a condition of 130°C, 21 bar.g. On the shell side the feed water is heated from 90°C to 180°C before being sent to the steam generating heat exchanger.

After the Feed Water Pre-heater, the geothermal condensate is transferred to the gas stripping plant where the dissolved H_2S and CO_2 gases are removed to allow it to be used as feed water. This process includes flashing the condensate across valve VO3 to atmospheric pressure in the flash vessel. VO3 is modulated to maintain the generated steam pressure. This process removes a majority of the gas. A steam stripping column then reduces the dissolved gas levels to acceptable levels. Throughout this process a quantity of dissolved ammonia (NH_3) is maintained to generate an elevated pH. A pH of 9 – 10 is maintained to minimize corrosion through SCA HA's condensate system.

From the stripping columns the treated feed water is pumped to the feed water storage tanks before being pumped to the heat exchangers as feed water. This process allows the plant to operate without additional feed water or condensate return from SCA HA and makes use of the remaining energy in the geothermal condensate. At SCA HA the steam condensate from the use of the steam, is added to the process water streams to further improve the efficiency of the system.

The plant requires electricity to run the compressed air system, the control system and operate the feed water transfer and pressurization pumps. Approximately 50kW of electricity is consumed. Electricity is provided from the main line with two independent feeds. To mitigate against loss of electricity, the control system has an UPS and the MCC is wired for the installation of a temporary (or future) standby generator. The air system also incorporates two larger receivers to allow 10 – 15 minutes of operation. In the event of an electricity cut, the control system continues to run, compressed air is available for the control valves for 10 – 15 minutes and the feed water system shuts down. The heat exchangers are able to continue operation for approximately 10 minutes before the feed water levels drop to unacceptable levels. After 10 minutes, if the electricity is not reinstated, the plant will shut down.

4. HEAT EXCHANGER DESIGN

The heat exchanger design needed to balance a number of factors to achieve an economic installation. Increased differential temperatures would reduce the heat transfer area but increase the separation pressure and the total quantity of geothermal fluid used. Some surface fouling could be anticipated, however selection of a high fouling factor would increase the heat transfer area. If low fouling factors were used, then the time between cleaning becomes unreasonably short. The extent of corrosion also needed to be considered to select material suitable for the duty.

Figure 3 'U' Tubes Steam Generating Hex

4.1 Fouling/Heat Transfer Co-efficients

To optimize the heat exchanger sizes, heat transfer co-efficients needed to be selected that provided a realistic period between cleaning (at least 12 months to allow for annual cleaning) without over sizing the plant. At the time of design the steam generating heat exchanger costs were estimated at $500,000 and decreasing the heat transfer co-efficients by 10% resulted in a similarly proportional increase in costs.

Norske Skog Tasman (NST) had been operating their heat exchanges for 40 – 50 years with little need for cleaning on the tube side (geothermal steam). After tube cleaning they had observed a moderate increase in output however this only lasted for a short period before the heat exchangers returned to their original performance. At this point the level of output plateaued and further reduction in performance was minimal. As a result NST have not cleaned the tube side surfaces for a number of years.

The cause of this rapid fouling and then stable operation is likely to be due to the formation of iron sulfides which then act as a corrosion barrier and provide a protecting barrier to the tubes (see Section 4.3).

The process conditions for the NTGAL heat exchangers were compared to the NST plant. While the NTGAL plant operated at higher temperatures and with high concentrations of NCG's it was considered that fouling rates should be comparable.

One area of difference was that the NTGAL heat exchangers are immediately down stream of the separators while the NST heat exchangers are at least 1,000m from the separation plant. In NST's case, any separated water carry over in the separators is likely to be scrubbed out before the heat exchangers. At NTGAL this was less likely to happen in the 15m of pipe available. On consideration this was believed to be of low risk as any SGW carry-over would soon be diluted by condensate and further deposition was unlikely especially within the large steam generating heat exchanger.

Knowing the maximum steam generation rates, process conditions and temperatures and heat transfer areas of the NST steam generating heat exchangers, it was possible to determine typical surface heat transfer co-efficients or fouling resistances. These co-efficients were then used for the design of NTGAL's exchangers.

Figure 4 Tube Plate, Steam Generating Hex

4.2 Selecting Operating Conditions

Selecting suitable geothermal steam conditions was critical to developing an economical and functional plant. Increasing the separation pressure and steam temperature increases the temperature difference which proportionally decreases the heat transfer area required, heat exchanger size, weight and cost.

Comparisons were made with Norske Skog Tasman's (NST) plant. They generate steam at 3.5 bar.g (148ºC) using geothermal steam at approximately 7 bar.g (170.4ºC). They operate with a temperature difference driving force of at least 22.4ºC. The NTGAL plant needed to generate steam at 16.5 bar.g (205.7ºC), to achieve a similar temperature difference the plant would require separated steam at 26 bar.g (228ºC). At NST 5 – 5.5ºC temperature difference was achieved per bar of pressure difference, for the high pressure the NTGAL plant operated at, only 2 – 2.4ºC/bar was achievable.

This identified that for a separation pressure of 21 bar.g the heat exchanger would need to be twice as big for a separation pressure of 26 bar.g. The consequence of increasing the pressure also had a significant impact on the plant design and quantity of geothermal fluid required. Based on an enthalpy of 1200 kJ/kg, 250 tonnes/hr of two phase fluid would be required to generate 35 tonnes of separated steam, at 21 bar.g. At a separation pressure of 26 bar.g this increased to 290 tonnes/hr.

Evaluating these parameters and reviewing the practical size of the plant for transport and serviceability, a separation pressure of 22 bar.g was chosen. This resulted in a heat exchanger with 662 25.4 mm diameter 'U' tubes with a shell diameter of 1400 mm and 11m long. Its transportable weight was 42 tonnes.

4.3 Corrosion

To evaluate the likelihood of corrosion, the NTGAL installation was at first compared to NST's plant. The NST heat exchangers use carbon steel tubes and channels, operate at a separate pressure of 7 – 8 bar.g and have not exhibited any corrosion problems in 40 years of operation. Review of the NTGAL operating conditions identified that separated steam at 22 bar.g would contain considerably higher levels of CO_2 and H_2S. This would impact on the chemistry and corrosion rates as the condensate formed and would significantly lower pH levels.

To review the corrosion risk and identify suitable construction materials, Quest Integrity (Keith Lichti and Rosalind Julian) were engaged. Quest Integrity reviewed the chemistry and corrosion risk of both the NST plant and the proposed NTGAL plant and evaluated this against the knowledge that the NST plant has exhibited minimal corrosion.

Quest Integrity also considered the corrosion risk for the plant in the operational state and in the standby state.

In the operational case, Quest Integrity modeled the corrosion chemistry using software in the form of Potential pH Roubaix diagrams to identify the stability of iron sulphide corrosion products. The NST case showed marginal stability however given the low levels of corrosion exhibited it was assumed that the deposition of iron sulphides provided a barrier to further corrosion. Analysis of the NTGAL conditions showed that with a pH of 4.7, limited stability was likely. These analysis conditions were for relatively low condensate temperatures of 120ºC at the outlet of the steam generating heat exchanger. In practice the temperature would be 200ºC + at the outlet of the steam generating heat exchanger and 130 - 140º at the outlet of the feed water preheaters. This would result in a pH of 5.6 at the outlet of the steam generating heat exchanger and significantly less risk of corrosion in this vessel.

Quest reviewed the risk of corrosion in standby modes. In all cases, it was identified that the standby vessels needed to be stored in the absence of oxygen and kept at operating temperatures.

Quest reviewed the use of either 316 stainless steel or higher grade duplex alloys (2205 or 2507). These alloys would significantly increase the heat exchanger costs by 50 to 100%. In the operational state, Quest concluded that corrosion was unlikely however any storage of the heat exchangers in a drained state would put them at significant risk of crevice corrosion at the site of any solid deposition. The risk of corrosion in the stainless steel alloy tubes would significantly increase if any separated geothermal water was to contact the tubes. Based on the performance of the NST heat exchanges and Quest Reliability's evaluation, it was decided to proceed with carbon steel tubes for both the steam generating heat exchanger and pre-heaters. The higher temperatures and pH in the steam generators means that they are less likely to experience online corrosion, however fouling will occur at relatively low rates and cleaning should be limited if possible to 5 to 10 year periods. The lower temperature pre-heaters are at risk of erosion corrosion when the pH drops below 5. These vessels are relatively small and it may be necessary to schedule regular re-tubing (maybe 2 – 5 years). This will be assessed with plant operation.

Tables 3 and 4 demonstrate the chemistry predicted for both plants. The values of H_2S (mol/kg) and ratio of CO_2 and H_2S tend to control the pH of the condensate. The values for the NTGAL condensate are approximately twice that of the NST and suggest lower pH and higher corrosion risk

	T°C	P(total) Bar Abs	P gas Bar abs	pH	H_2S Mg/kg	NH_3 Mg/kg	Total Carbonate (as CO_2) Mg/kg
Inlet	170	7.9					
Ex Generator	159	7.9	1.85	5.7	52.3	30	673.6
Ex Pre Heater	120	7.9	5.89	5.0	143	30	2297

Table 3 NST Gas Concentrations in the liquid phase after the two heat exchangers respectively

	T°C	P(total) Bar Abs	P gas Bar abs	pH	H_2S Mg/kg	NH_3 Mg/kg	Total Carbonate (as CO_2) Mg/kg
Inlet	217	22.1					
Ex Generator	202	22.1	5.7	5.6	109	43.5	2039
Ex Pre Heater	120	22.1	20.1	4.7	291	47.3	7371

Table 4 NTGAL Gas Concentrations in liquid phase after the two heat exchangers respectively

5. CONDENSATE RECOVERY

The recovery and treatment of the geothermal condensate was key to the success of the project.

The geothermal condensate is potentially a source of high grade feed water however it contains high levels of hydrogen sulphide (H_2S), carbon dioxide (CO_2), ammonia (NH_3) and potentially geothermal solids if separated geothermal water is carried over from the separator.

Norske Skog Tasman have proven the operation of geothermal condensate treatment and have successfully operated a condensate stripping plant for more than thirty years. The NTGAL system however operates at different conditions; the separation pressures are higher and consequently the steam contains higher concentrations of non-condensable gases (NCG's) also the separator is immediately before the heat exchanger (NST's are 1000m apart) and any separated geothermal water carry-over would contaminate the condensate and cause fouling in the heat exchanger.

The NTGAL system also needed to rely on producing sufficient condensate to feed the heat exchangers. From initial reviews it was not obvious if this could be met.

To evaluate the stripping process for NTGAL's operating conditions, GNS Science were commissioned to model the system, their brief was to:

1. Confirm that the stripping process would meet the desired feed water quality objectives,
2. Identify likely stripping steam flowrates.
3. Perform a mass and energy balance to identify if the process ran with an excess or shortfall of feed water.

5.1 Condensate Treatment

Table 5 shows the typical Kawerau separated steam compositions at a separation pressure of22 bar.g 220°C:

Gas	Concentration (ppm)
CO_2	27 x 10^3
H_2S	510
NH_3	49
CH_4	300
N_2	290

Table 5 Typical Kawerau separated steam compositions

The concentration of CO_2, H_2S and NH_3 in the final condensate is the key to its quality and suitability as feed water. The H_2S is the most difficult to strip and a maximum allowable concentration of 0.1 ppm was set. The CO_2, while at high concentrations in the geothermal steam would be easily stripped to low levels before the H_2S limits were met. Maintaining the NH_3 levels at 8 – 10 ppm are key to the process. These levels have been identified by NST to achieve condensate pH levels in the range of 8.5 to 9.5. If these levels can be maintained, then the addition of expensive water treatment chemicals (Amines) can be eliminated.

GNS Science used the modeling code CNDSR (Weres, 1993) to model the stripping plant. As the final process conditions were unknown, their modeling reviewed the processes sensitivity to the incoming condensate temperature (120, 145 and 160°C were used) and the quantity of stripping steam required (3 & 4t/hr). A 3 stage stripping column and stripping pressure of 0.7 bar.g was used based on the experience gained by NST.

The modeling predicted that the design parameters could be met for stripping steam flows of 4t/hr and condensate temperatures above 145°C.

At temperatures below this limit and at 3 tonnes/hr of stripping steam, the remaining H_2S levels exceeded 0.1 ppm. This stripping rate related to a ratio of 0.114 tonne per tonne of condensate (or 11.4%).

GNS's modeling was able to confirm that the H_2S and CO_2 levels could be reduced to satisfactory levels while maintaining the NH_3 concentration. The plant would however need to develop a system of measuring and controlling these parameters to achieve the desired outcome.

5.2 Condensate Flows

If the NTGAL plant could be self sufficient in feed water production, it would not require condensate return from SCA. This would eliminate the need for a 1.5 km return pipe (80 mm diameter) and a pumping system.

GNS Science were commissioned to perform a system mass balance. The incoming flow of geothermal steam and consequently the condensate flow is a function of the rate of steam generated and the performance of the heat exchangers. At the outlet of the heat exchangers the condensate is flashed to atmospheric pressure. At this point any un-condensed steam and a percentage of the condensate will be flashed off. The quantity of condensate lost here is dependant on the heat exchanger approach and its outlet temperature.

Condensate is also lost through the stripping process (3 – 4 tonnes/hr predicted), flashing of the condensate leaving the stripper and boiler blowdown. The latter was difficult to identify as it depended on the final feed water quality. A blowdown rate of 1% was used based on NST's experience.

Based on the predicted operating parameters GNS predicted a 0.5 tonne/hr shortfall in flow. This could have been offset by raising the flash/stripping pressures and then cooling the condensate without flash or maintaining pressure in the feed water tanks. This was not adopted due to the added complexity of the system.

To provide assurance of the feed water supply, an 80mm condensate return main was installed from SCA AH to the NTGAL plant.

6. PLANT OPERATION

At the time of writing this paper, the plant has been in operation for 12 months. After the initial commissioning period, several months were spent refining controls and stabilising plant operations. During this time the plant has provided reliable operation except for failures in the electrical supply system and a premature burst disk failure. The following points have been learnt:

6.1 Operating Conditions

The final plant operating conditions are shown in table 1. Operation of the heat exchangers has stayed stable throughout this period and no measurable reduction in performance has been noted. The condensate leaving the preheater is being cooled to 135 – 140°C which is lower than anticipated.

6.2 Controlling Feed Water Quality

The steam stripper was operated over a range of stripping steam/condensate ratios and operating pressures to determine the most efficient and effective operating point. Operating the stripper at atmospheric pressure (rather than 0.7 bar.g) simplified the control strategy and appeared to have little influence on the output. The final stripping steam to condensate ration was 9% compared to GNS's predicted 11%.

During commissioning it was possible to determine a relationship between the conductivity of the condensate and generated steam and the NH_3 levels in the condensate. This also closely correlated to the pH levels. This provided a simple and useful tool to evaluate and monitor the system performance.

Conductivity levels below 15μs/cm^2 indicated low NH_3 levels and low pH (7 – 8.5). Conductivity levels above 30 – 35 μs/cm indicate high NH_3 levels and pH levels above 9.5 to 10. Conductivity levels are now constantly monitored and alarmed if they are outside these limits.

6.3 Flow Meters

Within the steam system, pitot tube flow meters were selected to minimize system pressure drops. This was particularly important around the heat exchangers where 1 bar pressure drop meant a 20% increase in heat exchanger capacity. Generally the results from these meters have been inconsistent and they are being changed to orifice plate installations.

6.4 Condensate Flow

Once the system was fully commissioned and operating in a stable state, it was found that the plant ran with a small surplus of condensate. The primary areas of saving were within the blowdown system and the reduced stripping steam flows. The high quality feed water allowed the blowdown to be programmed to operate daily or when conductivity levels exceed 250μs/cm. The return condensate system which can supply up to 9t/hr for short periods proved useful during the commissioning stages when condensate production was lost or at times when upset conditions occur within the condensate system.

7. CONCLUSION

The NTGAL clean steam system has proved in 12 months operation, to be a reliable steam source for SCA HA's Kawerau tissue mill. It has provided NTGAL with an additional income source and met SCA HA's requirements to significantly reduce their carbon footprint in line with their long term sustainability goals. The plant is now entering its first 12 month inspection period and the condition of the heat exchanger tubes will provide interesting feedback on the design predictions.