REFEREED PAPER

THE OPERATIONAL CHALLENGES AND OPTIMISING THE ENERGY CONSUMPTION OF THE JUICE HEATERS DURING THE 2012 SEASON AT NOODSBERG SUGAR MILL

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Abstract

At Noodsberg sugar mill it was seen that the required mixed juice flow rates and outlet juice temperatures were not being achieved through the mixed juice heaters. This was the result of flow restrictions in the heaters and the challenge of extracting condensate at sub-atmospheric conditions. This was resolved by revising the cleaning regime and operating the heaters in a parallel juice flow configuration, together with modifying the condensate recovery system. When investigating these challenges, the vapour consumption across the heaters was calculated and optimal vapour configurations for the heaters were established which identified significant energy savings.

Keywords: mixed juice heaters, energy optimisation

Introduction

During the 2012 drought-influenced crushing season, the mixed juice heaters at Noodsberg sugar mill were struggling to achieve the desired final mixed juice temperature set points and flow rates. Together with this there was excessive water hammer on the condensate drain lines, resulting in numerous gasket failures and cracks in the pipe work. Investigations were carried out to find the root causes of the problems, as well as find the optimal vapour configuration to use on the mixed juice heaters to reduce the total steam demand.

Overview

The current mixed juice heating arrangement at Noodsberg is comprised of a multi-pass shell and tube heater that uses reject condensate to initially heat the mixed juice before the seven mixed juice heaters. The mixed juice heaters are vertically mounted shell and tube heaters, each with a 232 m^2 surface area. Four of the seven mixed juice heaters have an option of which vapour grades they can be operated on, as shown in Figure 1. The primary mixed juice heaters operate on 3rd effect vapour, the secondary heaters on 2nd effect vapour and the tertiary heaters on 1st effect vapour. The first three heaters have the capability to split the juice flow and operate in a parallel arrangement with respect to the mixed juice flow (Figure 2). Each heater has a set of isolation, bypass and parallel flow valves. The isolation and bypass valves allow heaters to be taken off range and cleaned while the other heaters are still in operation.

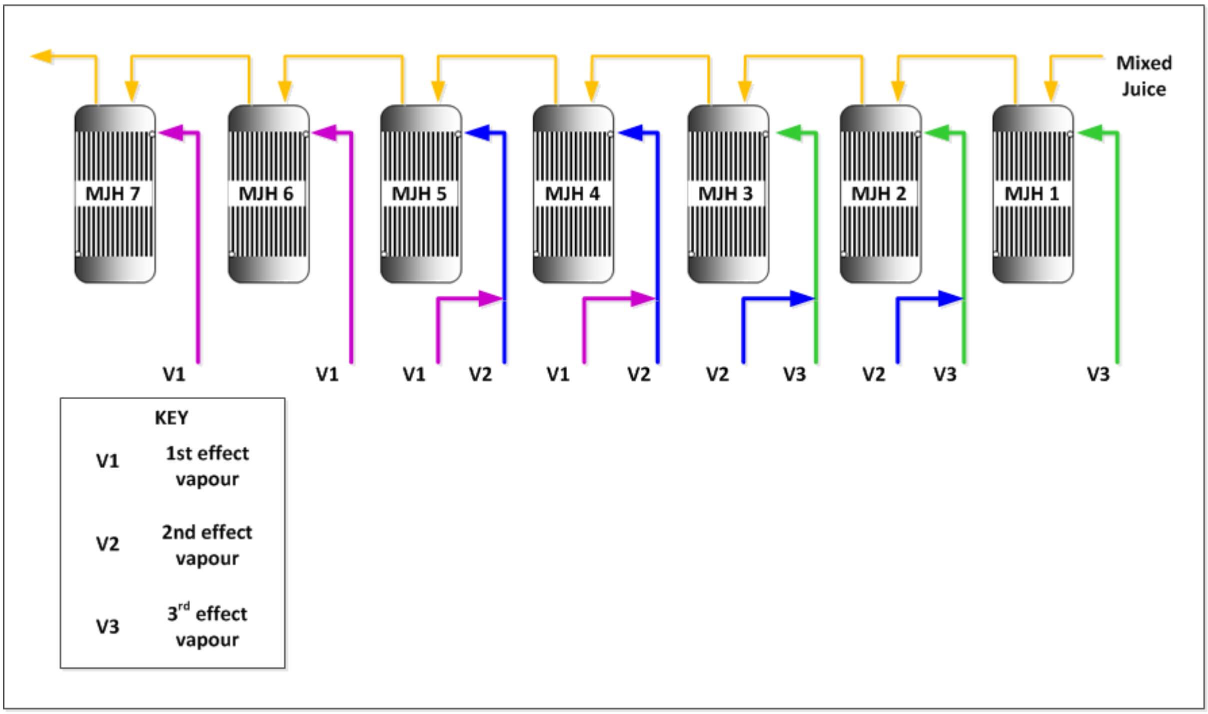

Figure 1. Available vapours for the mixed juice heaters.

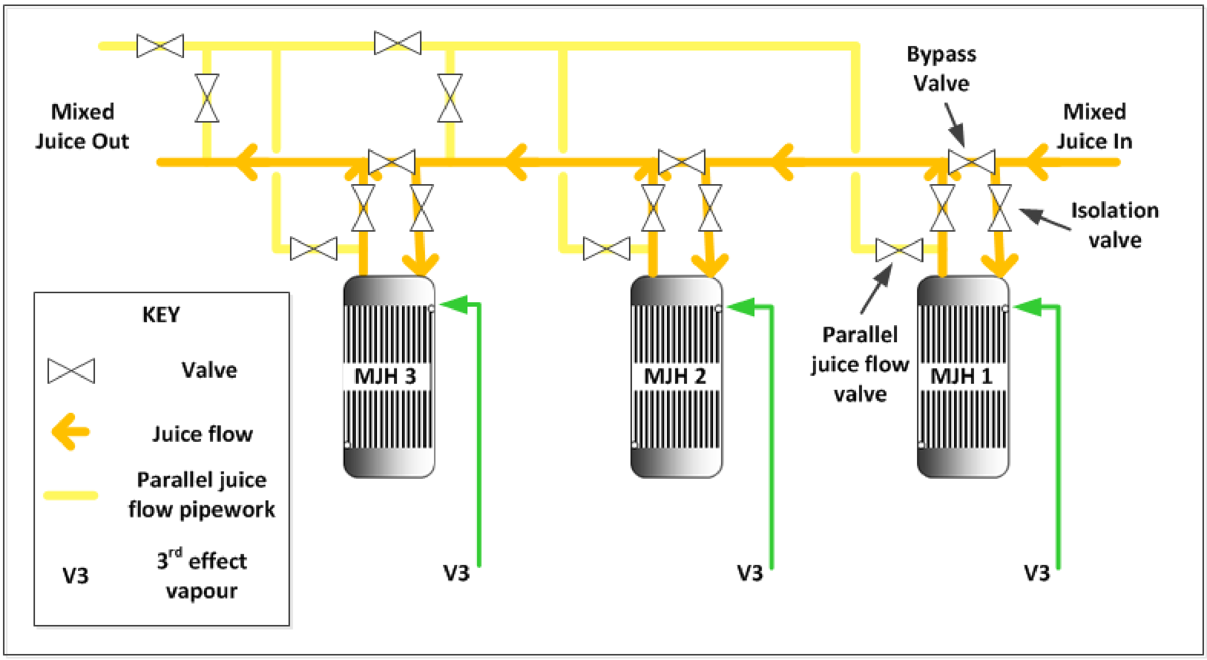

Figure 2. Primary heaters juice flow options.

In 2011, the condensate system at Noodsberg was upgraded to incorporate a flash recovery system as part of the Energy Reduction programme. With this upgrade, the vapour sent to the primary mixed juice heaters was changed from a combination of flashed vapours to a 3rd effect vapour.

There were some initial challenges surrounding this change in vapour to the primary heaters. The previous flash vapour was at a positive gauge pressure, whereas the 3rd effect vapour is very close to atmospheric pressure and can drop to below atmospheric pressure at times. This resulted in the incondensable gases having to be drawn out of the heaters using the vacuum in the 5th effect evaporator. The condensate drainage from the heaters was also hampered, as the primary and secondary heaters shared a common condensate drain manifold. With the lower pressure of the 3rd effect vapour compared to the previous flash vapour, the 3rd effect condensate was struggling to overcome the head losses and back-pressures in the drain line exerted by the 2nd effect condensate. This was evident even though the condensate was drained to a condensate vessel held at the 3rd effect vapour pressure. An attempt to resolve this problem was to install a second drain manifold which separated the 2nd and 3rd effect condensates and directed each condensate to their respective condensate vessels within the condensate system. An improvement was seen in draining the condensate from the primary heaters, however, it was not ideal and although the severity of the water hammer was reduced, it was still present.

The purpose of using lower grade vapours in mixed juice heating is to make use of the steam savings expressed by Rillieux's 2nd principle. This principle states that if vapours are withdrawn from a given effect in a multiple effect evaporator and used outside the boundary of the evaporator system in place of exhaust steam, then the steam savings will be:

$$Steam\ savings = \frac{(number\ of\ the\ bleed\ effect) \times (mass\ of\ the\ vapour\ bled)}{(total\ number\ of\ effects)}$$

Equation 1: Rillieux's 2nd principle

The other benefit of using lower grade vapours is that vapours with lower pressure possess more latent heat that can be used for heating. Provided the temperature driving force is sufficient, less steam is required for the equivalent amount of heat transfer. This is shown Table 1.

Table 1. Latent heat of vapours.

Vapour grade	Vapour pressure (kPa Abs)	Available latent heat (kJ/kg)
Exhaust	230	2194
1st effect	150	2229
2nd effect	120	2246
3rd effect	98	2261

For the above two reasons, the steam demand of the heaters can be improved by using lower grade vapours as much as possible rather than higher grade vapours. The steam demand of the heaters is here defined as the total quantity of vapour required to heat the mixed juice to 101°C.

Causes of poor heater performance

Investigations into why the mixed juice heaters were not achieving the desired set points revealed the following:

- High suspended solids, particularly sand, in the mixed juice was being deposited in the primary mixed juice heaters, causing flow restrictions and fouling.
- The gasket material used on the heater doors was incorrect for the application as the relatively high temperature was making them brittle, leading to pieces of gasket material breaking off and blocking sections of tubes causing flow restrictions.

- There was no regular cleaning of the mixed juice heaters, particularly the primary heaters, which resulted in the flow restrictions not being cleared.
- Due to the flow restrictions the operators were partially or fully bypassing heaters to achieve the flow set points. However, this reduced the available surface area to heat the mixed juice causing the final mixed juice temperature not to be achieved.
- The condensate from the primary heaters was not draining fast enough from the heaters which limited the amount of steam that could be used for heating.
- Higher grade vapour was used in the heaters to increase the temperature difference and heat the juice faster because temperature set points were not being achieved.

The solutions to these problems included:

- Reducing the flow resistance through the heaters
  - Revising the heater cleaning schedule and gasket material.
  - Running the primary heaters with the juice flow in parallel.
- Improving the condensate drainage from the primary and secondary heaters.
- Finding the optimal vapour configuration on the heaters to reduce the steam demand.

Reduce the flow resistance through the heaters

Cleaning schedule of mixed juice heaters

Noodsberg has historically suffered from high ash loading in its cane and, when high amounts of imbibition are added to the mills, the sand is washed out with the juice and sent to the juice preparation section. Here the sand tends to settle out in the primary mixed juice heaters. This is a result of the multiple direction changes that the juice undertakes as it moves through the multi-pass heaters. It was recorded during the 2012 season that heater number one once contained in excess of 50 kg of sand between cleans. These quantities of sand will reduce the available flow area and increase the flow resistance through the heater, as well as increasing the wear of the tubes and pipe work.

The other cause of the increased flow resistance in the mixed juice heaters was the fact that the door gaskets were becoming brittle and perishing. Portions of the gaskets would then block the entrances of sections of tubes and reduce the number of available tubes that the juice could flow through, thus increasing the flow speeds and flow resistance of the juice. The quality of the gasket material was addressed with the supplier and this problem ceased.

For these two reasons, high sand loading and gasket failures, the heaters had to be cleaned regularly. Upon inspection of the cleaning records, it was found that this was not being done. A revised cleaning roster was drawn up and implemented which involved cleaning two primary heaters, one secondary and one tertiary heater each week. It is essential to clean the primary heaters regularly as these heaters accumulate the most sand because they are the first heaters to receive the juice flow and they operate on the lowest grade vapour.

To accommodate the increased frequency of cleaning the heaters, additional labour was required; this was accomplished by reassigning current staff and using temporary labour. The results from the increased cleaning regime were positive, as the required final juice temperatures were being achieved.

Reduce mixed juice flow resistance

Due to the above-mentioned flow resistances, the operators would open specific heater bypass valves in order to obtain mixed juice flows greater than 330 t/h. This action led to some heaters being partially or totally bypassed and doing very little or no heating. This was particularly evident in the primary heaters. To prevent this from occurring, the pipe work that allowed the juice to flow in parallel through the primary heaters was recommissioned.

Because the parallel juice flow lines had not been used for a number of years, during an evaporator clean this pipe work was opened and cleared of any blockages and put back into service. When the mixed juice flow set point was not being achieved, two of the primary heaters were changed from having the juice flow in series to parallel. This change had to be gradual as the total flow resistance reduced drastically, which resulted in flow surges into the clarifier. These surges could disturb the settled mud and result in carry-over from the clarifier into the clear juice. The reduction of the flow resistance allowed the desired flow set points to be achieved.

In theory, running two heaters with the juice flow in parallel should not affect the steam demand of the heaters since there is a linear relationship between juice flow and steam requirements. However, by running the heaters in parallel the primary heaters were no longer bypassed and more 3rd effect vapour was used instead of higher grades. Using Rillieux's principle of vapour bleed savings, the total steam demand was reduced.

There were initial concerns around the residence time that the juice would spend in the heaters in parallel. As the sugars in the juice start to deteriorate under the conditions in the heaters, namely at high temperature and low pH, the residence time in the heaters governs how much degradation of the sugar occurs, so the shorter the residence time, the better. Running the heaters in parallel actually reduced this effect as it allowed high juice flows to be achieved which in turn reduced the overall residence time in the heaters.

Running the primary heaters in parallel allowed the heaters to be run at the desired conditions until the partially blocked heaters could be cleaned.

Improving the condensate drainage

The previous condensate removal system for the primary and secondary heaters comprised of two condensate drain manifolds that drained to the equivalent pressure evaporator level pots before entering the flash vessels (Figure 3). The only driving force to drain the heaters was the static head between the heaters and the evaporator level pots of 2.1 m.

This system was not ideal as there was evidence that the different pressure condensates were still mixing in the manifolds. This resulted in violent water hammer and back-pressure in the manifolds preventing lower pressure heaters from draining their condensate.

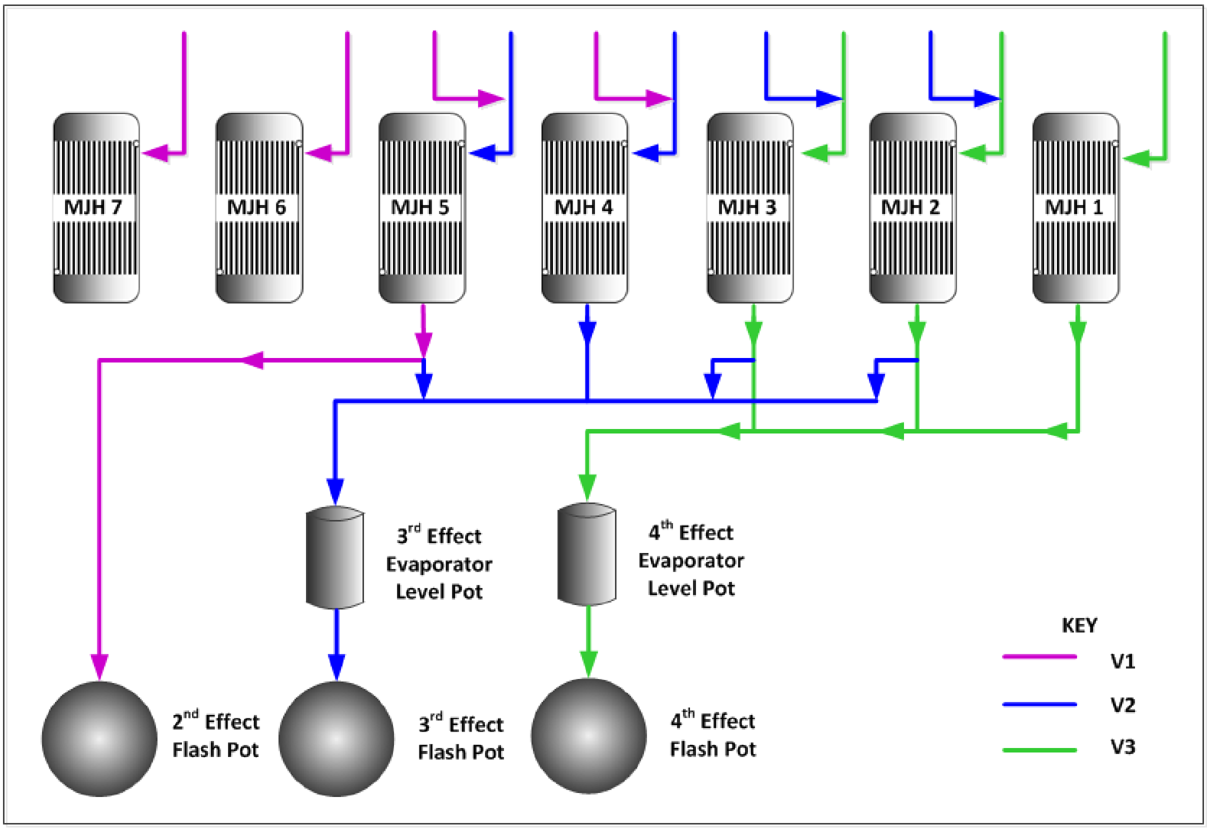

Figure 1. Manifold type condensate drainage system.

Further condensate drainage problems existed with the 2nd and 3rd effect vapour lines feeding the primary and secondary heaters. Condensate would build up in these vapour lines and limit the vapour flows into the heaters. This resulted in the tertiary heaters having to do more heating, which increased the steam demand of the heaters, according to Rillieux's 2nd principle. This problem was particularly evident when starting up the Juice Preparation section after an evaporator clean when the vapour lines were cold and more condensate would form. It could take up to two hours to drain the vapour lines, as the steam traps were underrated for this application. The condensate drained from the steam traps would be channelled to effluent and any thermal energy in the condensate would be lost.

The solution to this problem was to install two condensate level pots, one for the 2nd effect condensate and the other for the 3rd effect. The condensate from the mixed juice heaters and vapour lines drain into their respective condensate level pots which in turn drain to the relevant flash vessels in order to recover as much energy from the condensate as possible (Figure 4). To ensure that the heaters drained freely without the influence of any back pressure, each heater has a dedicated drain line into the respective level pot and discharges above the condensate level in the pots. This allows the condensate drainage from each heater to be monitored as well as easily identifying whether any heater has a tube leak present. To ensure that no flashing takes place inside the level pots, each pot is balanced back to its respective vapour pressure. The level of condensate inside the pots is controlled via a control valve on the discharge of the level pot. This ensures that the level does not rise too high and hamper the drainage of the heaters, as well as preventing the water seal from being broken between the heaters and the flash vessels.

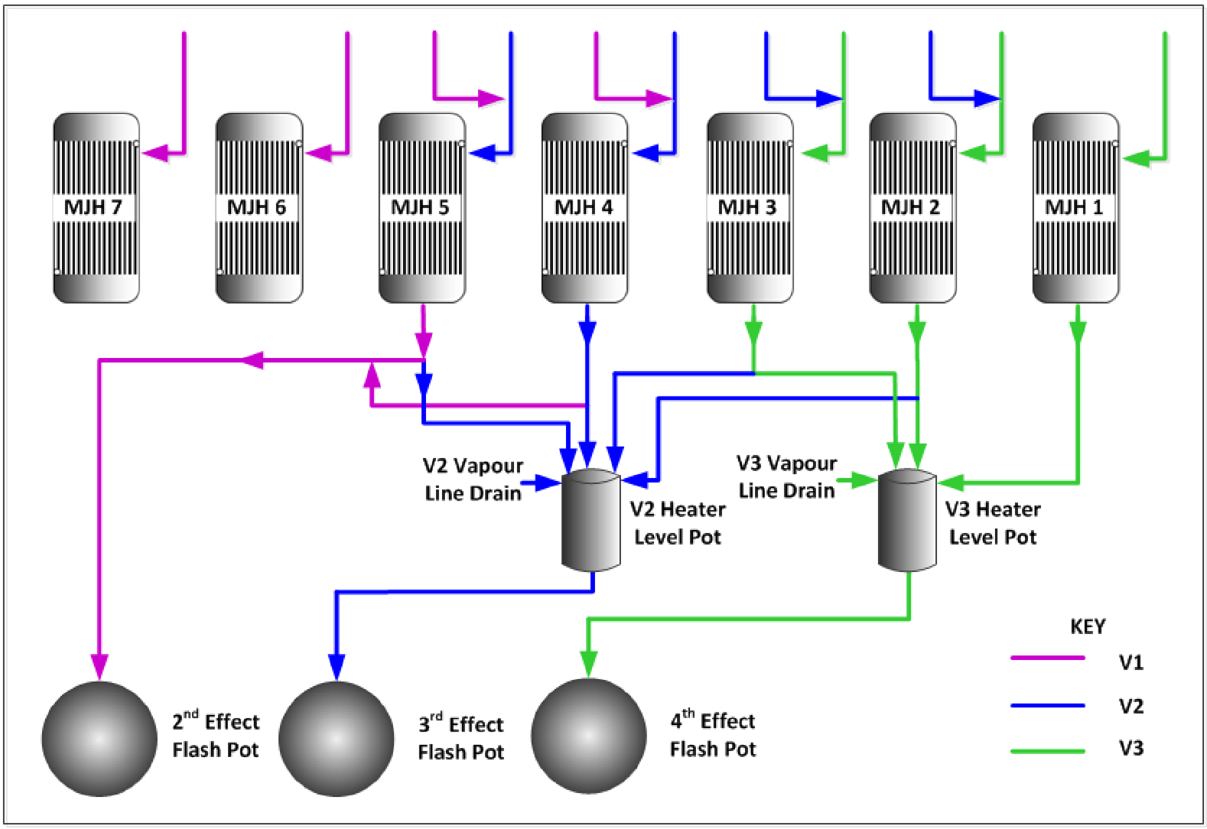

Figure 2. Dedicated level pot condensate drainage system.

The results from the installation of the mixed juice heater level pots has been positive, with the water hammer being eradicated and each primary and secondary mixed juice heater draining its condensate well. The steam traps on the 2nd and 3rd effect vapour lines to the mixed juice heaters are no longer required, which reduced the maintenance needed on the system, and the energy from the condensate is now being recovered.

Optimal vapour configurations on the heaters

Background

A trial was conducted on the mixed juice heaters to find what vapour configurations would result in the lowest steam demand whilst still maintaining the desired final mixed juice temperature of 101°C at a flow rate of 330 t/h. This trial was conducted in July of the 2012 season during the difficult mixed juice heater operation period, as excessive sand and deteriorating heater door gaskets were causing flow restrictions in the heaters. The results from the trial would then be compared to the designed performance of the heaters after the condensate system upgrade.

Method

A three week trial was set up to monitor the performance of the mixed juice heaters under different operational configurations. Averages of the eight hour shifts were captured as well as any changes that were made to the system during a shift. The data that was collected included the following:

- Mixed juice inlet temperatures into the first mixed juice heater.
- Mixed juice outlet temperatures from each mixed juice heater.
- Mixed juice flows.
- Mixed juice brix.
- The percentage that the bypass valve was open on each heater.
- The vapour grade used on each heater.
- The pressures of each vapour grade: exhaust, 1st, 2nd and 3rd effects.

From the captured data the quantities of steam used by each heater was calculated based on the conservation on energy equation.

$$\dot{m}_{vapour} = \dot{m}_{juice} \times \frac{\Delta h_{juice}}{h_{fg}}$$

Equation 2: Conservation of Energy

To be able to compare the steam demand of the heaters under different vapour duties a set of standard test conditions needed to be developed. As the process conditions of the factory changed depending on the production requirements, it was decided to capture as much data as possible and filter the results to find the conditions which were the most prominent, and use these as the standard test conditions. This resulted in the flowing:

- Mixed juice temperature into the 1st heater to be between 35 and 38°C (5% variance).
- Final mixed juice temperature between 99 and 101°C.
- Mixed juice flow 330 t/h.

The data was filtered to show only the scenarios which matched the mixed juice inlet and outlet temperatures. It was decided that, since the vapour flows are directly proportional to the mixed juice flow (see equation 2), that the vapour flows could be adjusted for a mixed juice flow of 330 t/h. This was accomplished by multiplying the calculated vapour flows by the ratio of the measured juice flow to the standard condition of 330 t/h. In each scenario, the adjusted vapour flows were summed to find the total flow for each vapour grade. The scenarios were then grouped according to the vapour configurations of the heaters and average vapour flows calculated for each heater configuration.

To be able to compare scenarios, the difference in vapour demands was calculated relative to a base case scenario and expressed as a coal savings. The chosen base case scenario involved three primary heaters on 3rd effect vapour, one secondary heater on 2nd effect vapour and three tertiary heaters on 1st effect vapour. The total vapour demand for each scenario was calculated with the use of Rillieux's 2nd principle, which states that for a five effect evaporator train a vapour bleed off the 1st effect will save one fifth of the exhaust steam that would have been used in place of the vapour bleed. Following this principle a bleed of the 2nd effect would save two fifths of the exhaust steam equivalent and a bleed of the 3rd effect would save three fifths. By using this principle an exhaust steam demand can be calculated for each scenario based on the following formula:

$$T_{Exh} = \frac{4}{5}T_{v1} + \frac{3}{5}T_{v2} + \frac{2}{5}T_{v3}$$

Equation 3: Exhaust Steam Demand

Once the exhaust steam demand has been calculated for each scenario the reduction in exhaust steam can be equated as a coal savings by using a coal to exhaust steam ratio of seven. To assist with realising the potential savings, the coal savings for each scenario are converted to a weekly coal savings with an operating time efficiency of 92%.

Results

The data from the five most common heater configurations are given in Table 2 in conjunction with the designed heater performance. Configuration A is the base case, which has been used for the comparison between different scenarios.

Table 1. Steam demands for different heater configurations.

		Configurations					
		A	B	C	D	E	Design
No. Heaters on V3		3	3	2	2	2	3
No. Heaters on V2		1	0	1	2	1	2
No. Heaters on V1		3	3	3	2	2	2
Juice Inlet Temp	°C	38.2	37.0	36.7	35.8	35.5	45.0
Avg V3 flow	t/h	9.08	13.81	10.43	8.89	13.12	15.81
Avg V2 flow	t/h	7.39	0.00	8.84	13.58	9.05	13.13
Avg V1 flow	t/h	12.18	15.11	9.45	5.47	5.29	4.60
Equivalent Exh flow using Equation 3	t/h	17.8	17.61	17.04	16.08	14.91	17.88
Diff in Steam Demand compared to A	t/h		0.19	0.76	1.72	2.89	-0.08
Coal savings compared to A	t/h		0.028	0.109	0.247	0.413	-0.011
Coal savings per week with 92% OTE	t		4.273	16.88	38.149	63.873	-1.728

Discussion

The chosen base case, configuration A, resulted in an exhaust steam demand of 17.8 tons per hour, with the 1st effect vapour doing the majority of the heating.

The next configuration, B, with six heaters online, used more 3rd effect vapour. However, with no heaters on 2nd effect vapour, the tertiary heaters were still doing the majority of the heating. This resulted in overall steam demand being slightly lower with a coal savings of 4.27 tons per week.

Configuration C replaced a 3rd effect vapour heater with a 2nd effect and reduced the amount of 1st effect vapour required. This reduced the total exhaust requirements and showed an increased coal savings of 16.88 tons per week.
By having cleaner heaters, configuration D allowed a 1st effect vapour heater to be replaced with a 2nd effect vapour, which resulted in considerable steam savings according to Rillieux's principle. The coal savings this configuration boasts are 38.15 tons per week.

Configuration E shows the best savings by having the 3rd effect vapour doing the majority of the heating followed by the 2nd effect vapour heater. This configuration shows a coal savings of 63.87 tons per week.

The final comparison is to compare the base case configuration with the designed performance of the heaters after the introduction of 3rd effect vapour heating on the primary heaters. At a first glance it appears that the design case is similar to scenario A; however, it should be noted that the design case is only heating the mixed juice from 45°C, where configuration A is heating from 35°C in this trial. Comparing the designed performance to the other scenarios, all the scenarios out-perform the designed performance.

This trial reveals that there is more than sufficient heating surface area for a mixed juice flow of 330 t/h, the desired final juice temperature can be obtained with five heaters. and that this will also reduce the total flow resistance in the system. Running only five heaters allows two heaters to be cleaned simultaneously, should the need arise. When the heaters become fouled and cannot be cleaned immediately, the vapour configuration can be changed to suit the next best case until the final juice temperature is achieved. This trial shows that the configuration that uses the least vapour is to operate two primary heaters, one secondary heater and two tertiary heaters, as long as the bypass valves are shut while the heaters are in a series juice flow configuration.

Conclusion

The initial problems surrounding the mixed juice heaters were addressed and positive improvements were achieved. These included reducing the flow resistance through the heaters by revising the heaters' cleaning schedule and gasket material, and recommissioning the parallel juice flow system through the primary heaters. The condensate drainage from the mixed juice heaters and vapour lines has been improved by installing the two condensate level pots; this has also eliminated the water hammer experienced in the section. Finally, a successful trial was conducted to quantify the vapour demand of the heaters under different vapour duties and an ideal operation configuration was established. The trial also verified that the heaters were out-performing the designed performance by utilising 3rd effect vapour for heating.

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