ENERGY MANAGEMENT THROUGH CONDENSATE AND FLASH STEAM RECOVERY SYSTEMS. A CASE STUDY OF NZOIA SUGAR COMPANY.

SOLOMON B. AMWAYI[1] (B. Tech. Chemical & Process Engineering)

[1]Production Department, Nzoia Sugar Co. Ltd, Box 285Bungoma-Kenya

Correspondent author Email: samwayi@yahoo.com or solomonamwayi@gmail.com

Tel: +254721808663

ABSTRACT.

Condensate and flash steam recovery system is one of the most crucial energy management systems in any industry. Globally, there has been a push for green energy consumption and conservation. The cost of steam rises with the increase in energy prices and so does the value of condensate. This recovery system has been applied by Nzoia Sugar Company in a continuous energy management improvement strategy. The aim is to reduce the three tangible costs of producing steam: fuel/energy costs, Boiler water make-up & sewage treatment, and lastly, boiler water chemical treatment. The steam and condensate system flow diagram was used to undertake the mass and energy balances to determine the amount of energy savings realized. The thermodynamic calculations were applied to determine the energy requirement and savings for the entire system.There has been great energy savings from this system amounting to 201470498KJ. The amount of condensate recovered is at 158430.22 Kg/Hr with heat energy of 59936.1884 KJ. Recommendations made if well adopted would reduce heat losses from the current 5% to 2% or below in the foreseeable future.

Key word: Condensate**,** Flash steam, Heat energy savings

1.0 INTRODUCTION.

Energy management includes planning and operation of energy-related production and consumption units. This is spearheaded by resource conservation, climate protection and cost savings, while the users have permanent access to the energy they need. It is connected closely to environmental management, production management, logistics and other established business functions. Nzoia Sugar industry is among the heavy duty energy consumption industries, with three water tube boilers producing steam at 27bar and flow of 27 tons/hr for the two boilers and 54tons/hr for the third. The steam is fed to the non-condensing steam turbines and produces3.0 MW electricity. The exhaust steam at between 1.0 -1.5 bar is channeled to the sugar processing plant for heating. In process design, energy balances are made to determine the energy requirements of the process: the heating, cooling and power required. In plant operation, an energy balance (energy audit) on the plant will show the pattern of energy usage, and suggest areas for conservation and savings. In order to manage the availed energy in the exhaust steam and condensate a number of systems have been employed to manage this energy effectively and efficiently. There has been reduction in energy demand to the entire process house by about 20%. The purpose of this project is to investigate the effectiveness and efficiency of the condensate and flash steam recovery system and determine the amount of energy saving achieved. It further proposes modern method of energy savings to be adopted to minimize heat losses and improve the energy management for the entire sugar processing plant.

1.1 Objective.

The main objective of this paper is to evaluate the energy management through condensate and flash steam recovery system. Specifically this project seeks:

- To develop an energy balance in the sugar process heating and condensing system.
- To determine the energy savings made in the sugar processing plant.
- To evaluate the methods used in energy recovery and conservation.
- Recommend the practical methods of energy recovery and conservation to be applied in the sugar plant.

1.2 Scope of the project.

This project is limited to the sugar processing plant, covering the steam and condensate generation and distribution. The calculations are centered on the energy balances amongst the various vessels in the sugar plant. The basis of the calculation applied is on an optimal set operational capacity of 136 tons of cane per hour (136TCH).

2.0 MATERIAL AND METHOD

2.1 Introduction.

General equation for the conservation of energy:

Energy out = Energy in + generation - consumption – accumulation (first law of thermodynamics)

Chemical reaction will evolve energy (exothermic) or consume energy (endothermic). For steady-state processes the accumulation of both mass and energy will be zero. (Coulson& Richardson, 2005)[1]

Forms of energy (per unit mass of material)

1. **Potential energy**

Energy due to position:

Potential energy = gz where z is height above some arbitrary datum, m,

gis gravitational acceleration (9.81 m/s2).

2. **Kinetic energy**

Energy due to motion:

$$kinetic\ energy = \frac{u^2}{2}$$

whereu is velocity, m/s.

3. **Internal energy**

The energy associated with molecular motion. The temperature T of a material is a measure of its internal energy U:

U = f(T)

4. **Work**

Work is done when a force acts through a distance:

$$W = \int_0^1 F dx$$

whereF is force, N,

xisdistance, m.

Work done on a system by its surroundings is conventionally taken as negative; workdone by the system on the surroundings as positive.

Where the work arises from a change in pressure or volume:

$$W = \int_0^1 P dv$$

where P is pressure, Pa (N/m2),

*v*isvolume per unit mass, m3/kg.

To integrate this function the relationship between pressure and volume must be known.In process design an estimate of the work done in compressing or expanding a gas is often required. A rough estimate can be made by assuming either reversible adiabatic(isentropic) or isothermal expansion, depending on the nature of the process.

For isothermal expansion (expansion at constant temperature):

P*v*=constant

For reversible adiabatic expansion (no heat exchange with the surroundings):

$$PV^{\gamma} - Constant$$

whereγ isratio of the specific heats, Cp/C*v*.

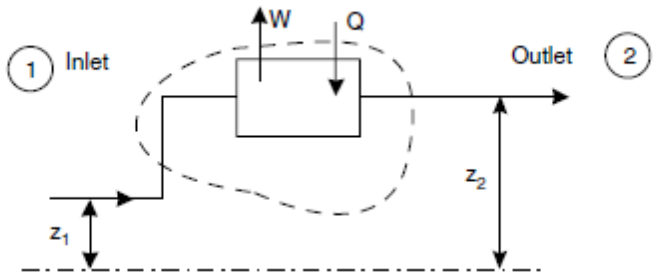
5. Heat

Energy is transferred either as heat or work. A system does not contain "heat", but the transfer of heat or work to a system changes its internal energy. Heat taken in by a system from its surroundings is conventionally taken as positive and that given out as negative.

6. Electrical energy

Electrical, and the mechanical forms of energy, are included in the work term in an energy balance. Electrical energy will only be significant in energy balances on electrochemical processes. (Coulson& Richardson, 2005)[1]

2.2 The energy balance



Source: Coulson & Richardson, 2005 p62[1]

General steady state process.

For unit mass of material:

$$U_1 + P_1V_1 + \frac{U_1^2}{2} + Z_1\,g + Q = U_2 + P_2V_2 + \frac{U_2^2}{2} + Z_2\,g + W$$

The suffixes 1 and 2 represent the inlet and outlet points respectively. Q is the heattransferred across the system boundary; positive for heat entering the system, negative for heat leaving the system. W is the work done by the system; positive for work goingfrom the system to the

surroundings, and negative for work entering the system from thesurroundings. In chemical processes, the kinetic and potential energy terms are usually small comparedwith the heat and work terms, and can normally be neglected.

Enthalpy, H is given by

$$H = U + Pv$$

Thus, $H_1 - H_2 = W - Q$

This simplified equation is usually sufficient for estimating the heating and cooling requirements of the various unit operations involved in chemical processes. For many processes the work term will be zero, or negligibly small, and above equation reduces to the simple heat balance equation:

$$H_2 - H_1 = Q$$

As the amount of water in steam increases, the latent heat decreases, providing less heat to transfer from the steam to the process / product being heated. During transport, radiant heat loss from piping causes part of the steam to lose some of its latent heat and revert back to water, thereby decreasing steam dryness. (TLV, 2015)[3]Proper measures should be taken to discharge all condensate within steam piping, including water droplets entrained within the flow of steam.

2.3 Extraction of Condensates:

This is done according to the pressure ruling in the calandria.

Methods of extraction.

		Method of extraction
a.	Calandria under pressure	Steam Trap
b.	Calandria under vacuum	Sealing legs
c.	Calandria under pressure or under vacuum	Pump Automatic monte-jus Siphon Flash vessel.

Source: Hugot, 1986[2]

i. Steam trap: This is a small vessel which the condensate passes. Itsfitted with a float actuating an outlet valve which does not open until the water attains a certain level in the vessel. (Hugot,1989)[2]

ii. Sealing leg: The principal difficulty to be overcome when condensates are to extracted from calandria under vacuum is the difference in pressure between the vessel and atmosphere. When the vessel is at a sufficiently high level, this difficulty may be solved

by running the condensate into a vessel placed below the evaporator at such a level that the condensate can flow to it by gravity.

iii. Condensate pump: condensate can be extracted under vacuum if these three conditions are satisfied. First, its necessary that the pump should be capable of delivering to a height equal to the geometric height of the delivery increased by the difference in pressure between atmosphere and the calandria concerned. Second, provide the pump with a small pressure equalization pipe putting the admission valve of the body of the pump in communication with the top of the calandria, otherwise air entering through leaks in the pump, would be entrained with water in the suction pipe and hinder the flow of water. Vapour formed in the pump from the hot water would accumulate and form a vapour lock. Third, for steam traps, it is necessary to provide a pump three or four times greater in capacity than would seem theoretically necessary. (Hugot,1989)[2]

The amount of energy that can be recovered will depend on the temperature, flow, heat capacity, and temperature change possible, in each stream. A reasonable temperature driving force must be maintained to keep the exchanger area to a practical size. The most efficient exchanger will be the one in which the shell and tube flows are truly countercurrent. Multiple tube pass exchangers are usually used for practical reasons. With multiple tube passes the flow will be part counter-current and part co-current and temperature crosses can occur, which will reduce the efficiency of heat recovery. Condensate should be withdrawn automatically and flash recovery carried out where possible. This is done through flash pots, siphon and u-bends.
There has to be a means of calculating the performance of the evaporators by considering three aspects i.e. Evaporation, Heat transfer and steam consumption, Sugar losses. (RASTIC, 1999)[9]

2.3.1 Flash steam.

Flash steam is a name given to the steam formed from hot condensate when the pressure is reduced.

It occurs when high pressure / high temperature condensate is exposed to a large pressure drop such as when exiting a steam trap.When hot condensate is discharged into a lower pressure environment, its enthalpy (total energy) remains the same, but its saturation point drops (the temperature at which condensate can exist in both the liquid and gaseous state). To compensate for the excess amount of energy, part of the water molecules absorb the excess energy as latent heat and evaporate to form steam. (TLV, 2015)[3]

The flashing of condensate under reduced pressure as it moves from the conditions of on effect to that of the next is used to recover part of the energy of the condensate. The vapour recovered is equivalent to the change in liquid enthalpy or sensible heat. (RASITC 1999)[9].

Calculating the % Flash Steam Generated

The % of flash steam generated (flash steam ratio) can be calculated from:

$$Flash\ \% = \frac{h_{f1} - h_{f2}}{h_{fg2}}$$

where:

- hf1 = Specific Enthalpy of Saturated Water at Inlet*
- hf2 = Specific Enthalpy of Saturated Water at Outlet
- hfg2 = Latent Heat of Saturated Steam at Outlet

2.3.2 Vacuum steam

Vacuum steam is the general term used for saturated steam at temperatures below 100°C. The higher the pressure, the higher the temperature of saturated steam. At regular atmospheric pressure, saturated steam is roughly 100°C. Saturated steam generated from boilers, however, is generally much higher in temperature because it is generated at higher pressures. This steam (positive pressure steam) is therefore frequently used in industry for heating processes requiring temperatures above 100°C.

Alternatively, producing saturated steam for heating processes below 100°C is also possible. Such steam is often referred to as vacuum steam because it requires pressures below regular atmospheric pressure. Vacuum steam is generally generated at higher pressures after which pressure is reduced by using equipment such as an inlet control valve. A vacuum pump is also usually used to help achieve lower pressures at start-up and enable the smooth release of condensate. (TLV, 2015)[3]

Use of vacuum steam requires careful temperature and pressure reading. To determine steam temperature, referring to a steam table such as the one above is recommended.

2.3.3 Vacuum Steam vs. Hot Water

Heating with vacuum steam offers the same advantages as heating with steam at temperatures of 100°C or higher:

Property	Advantage
Rapid even heating through latent heat transfer	Improved product quality and productivity
Pressure can control temperature	Temperature can be quickly and precisely established
High heat transfer coefficient	Smaller required heat transfer surface area, enabling reduced initial equipment outlay

Heating processes using steam generally use the latent heat of evaporation (Hfg) to heat the product. As seen in the table, this latent heat of evaporation is greatest at lower pressures. As saturated steam pressure rises, the latent heat of evaporation gradually decreases until it reaches 0 at supercritical pressure, i.e. 22.06 mPa (3200 psi).(TLV, 2015)[3]

Heat losses

Utilization of the heat supplied in the steam to a vessel of the multiple effects would not be 100%. Part of the heat escapes, by radiation and convection, to the ambient atmosphere. (Meade, 1977)[4]

2.3.4 Condensate removal through steam line.

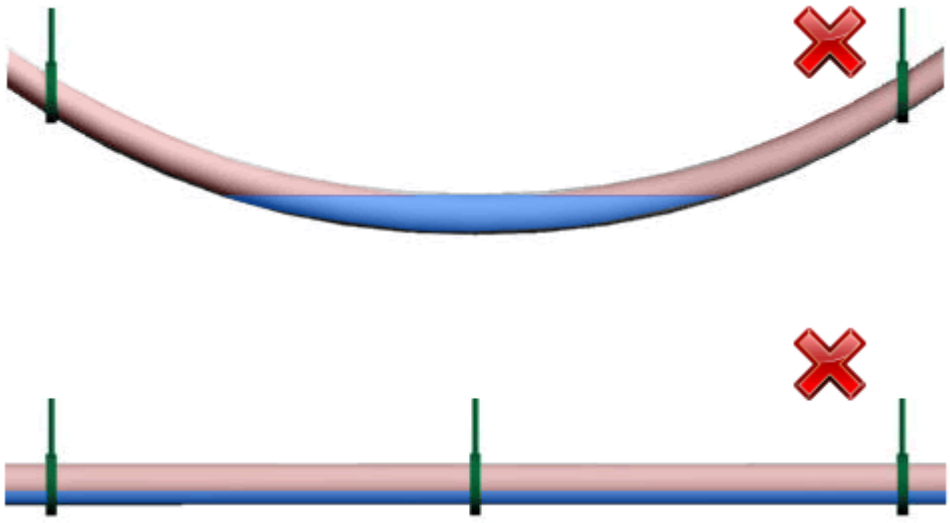
The flow of steam is typically much faster in steam distribution piping than in equipment and can reach speeds of over 30 m/s (100 ft/s). At these speeds, when the cross-sectional area of a pipe section is completely filled by water, slugs of condensate can be carried through the piping at high velocity causing water hammer, which can cause personal injury, as well as damage piping, valves, and equipment.

1. **Steam traps location/ condensate removal spots**.

Even in cases where a steam distribution piping run is set in a straight line, steam traps should always be installed at least every 30 to 50 meters (100 to 160 ft), and at the bottom of risers or drops. Special care must also be taken to install steam traps in locations where there is a chance of condensate pooling so that condensate does not close off the cross-sectional pipe area, possibly causing it to be propelled at exceptionally high velocity.

a. In Front of Pressure Reducing Valves and Control Valves - A steam trap should be installed immediately before pressure reducing valves / control valves to prevent condensate from pooling when the valve is closed. The trap also helps reduce erosion of the valve seat from condensate. Similarly, traps are also generally installed between two pressure reducing valves in a series installation to remove condensate trapped between the valves during operation or shut-off.
b. In Front of Manual Valves Closed for a Long Time - To help eliminate the pooling of condensate which could otherwise be propelled at high speed down the pipeline when the manual valve is opened. Similarly, a steam trap is needed at the end of a pipe run (end of main) to help drain the system for safe and effective operation.
c. At the Bottom of Vertical Lifts or Drops - Because dis-entrained condensate can accumulate there due to gravity and directional changes.

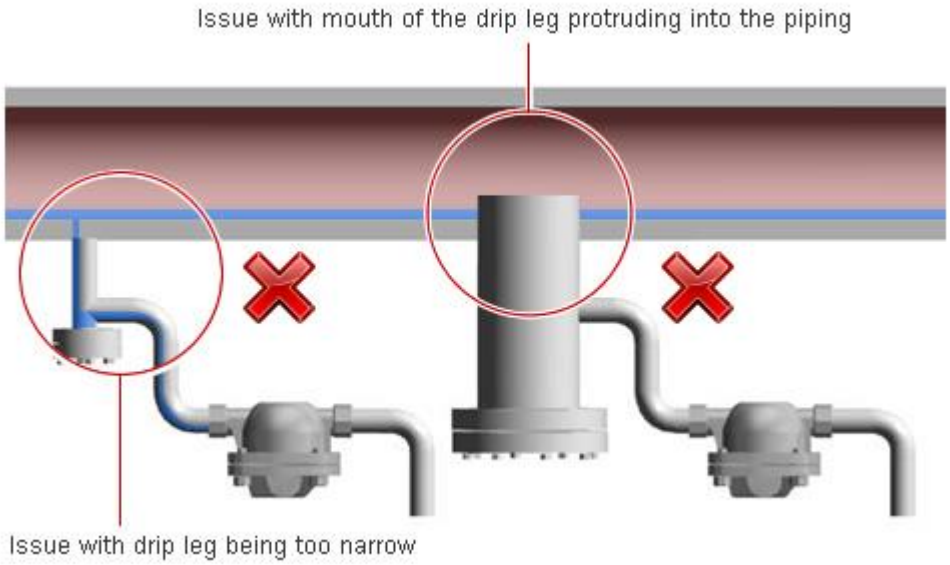
2. **Provide Proper Support and Inclined Steam Piping** - If piping support (e.g. pipe hangers) is set too largely apart, the piping can deflect under its own weight. This type of problem can cause condensate to pool at unwanted locations even if piping is set at a slight inclination, so it is important to both: Set piping support at appropriate intervals, and Set piping at a slope of no less than 1 in 100



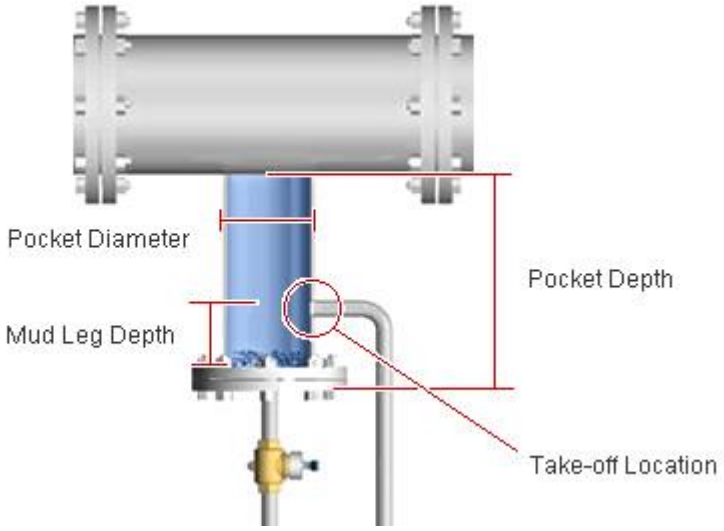
Source: TLV, 2014[3].

3. **Pay Attention to Drip Leg (Drain Pocket) Configuration** - Steam trap connection sizes for applications other than heating or process typically range between 15 mm (1/2 in) and 25 mm (1 in). Properly sized, wider piping called a drip leg (collecting leg, or drain pocket) is typically installed to help enable the efficient and effective removal of condensate.The connection between the piping and drip leg should be set roughly 50 to 100 mm (2 in to 4 in) from the bottom of the drip leg to help prevent dirt and scale within the condensate from flowing into the trap. With this type of setup, a blowdown valve is usually installed on the mud leg cover to allow for dirt removal. When sizing a drip leg, design with sufficient volume for the mud leg portion, and also for the back-up portion between cycles. The collecting leg can be especially important on start-up operation where slugs of condensate from warming up the piping or condensate released from previously closed valves can be experienced. Drip leg (drain pocket) size usually includes at least four factors: pocket diameter, pocket depth, mud leg depth, and take-off location.

Improperly Configured Drip Legs



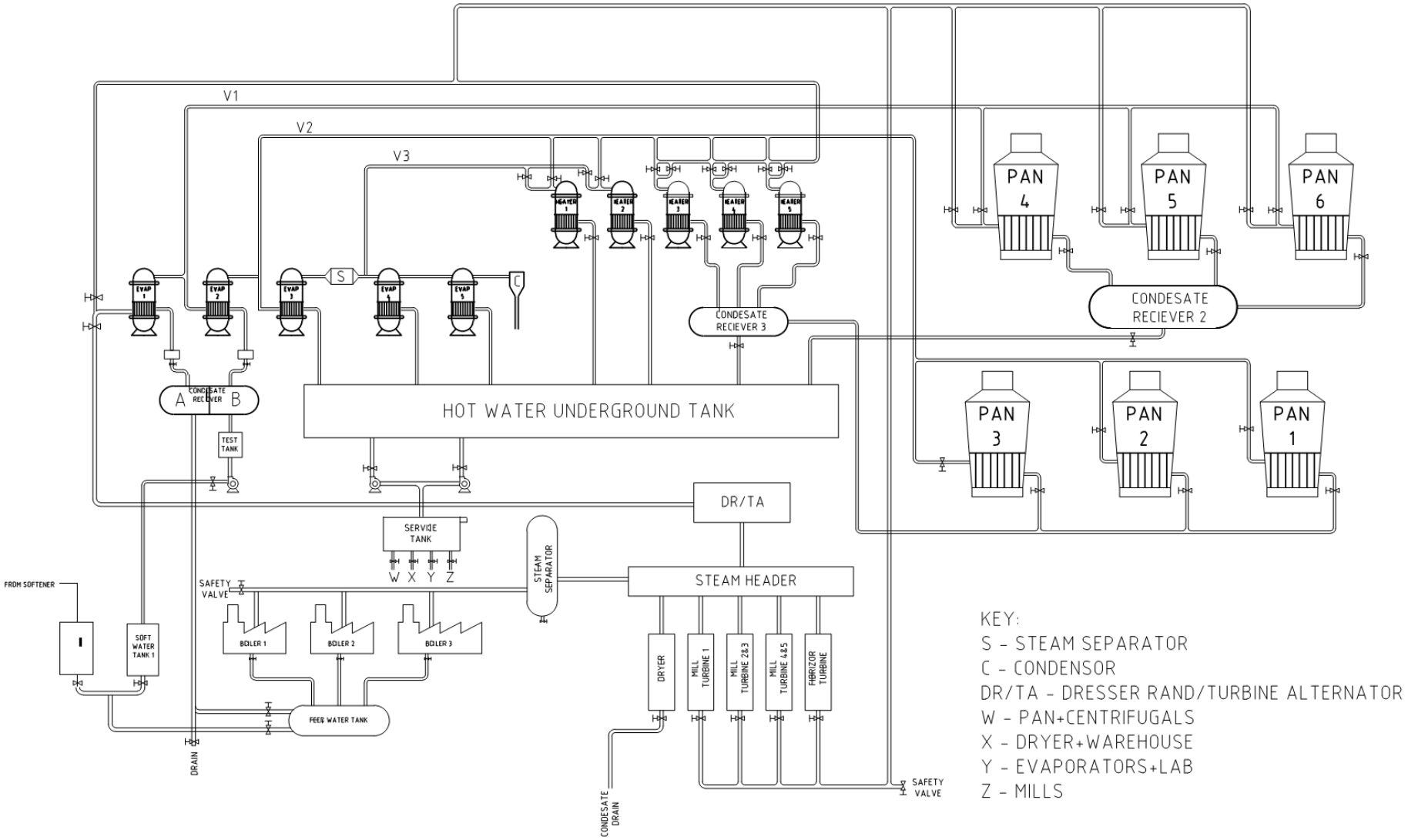
Properly Configured Drip Leg



Source: TLV, 2014[3]

4. Properly Remove Air and Condensate at End of Steam Line- At the end of steam distribution lines, it is important to remove the air that was initially present in the piping at start-up.

Fig 1: Steam distribution and condensate recovery system



Source: Author, 2015

2.3.5 NZOIA SUGAR APPLIED ENERGY MANAGEMENT SYSTEMS

1. **Siphons pipes**

Nzoia Sugar has applied the siphons on evaporator 3,4 and 5 condensate extraction system. The siphons provide a positive differential pressure that allows condensate to flow from the vessel calandria to the underground recovery tank. This system is the lowest in cost and most reliable. It requires no special equipment and relatively easy to implement. The positive differential pressure is created by the pipe design.

2. **Gravity return**.- Condensate Recovery Using Steam Trap Inlet Pressure

The basic equipment needed is just a steam trap and transport piping because the differential pressure is always positive from downward drainage by gravity to an atmospheric system or vessel. If the differential pressure across a steam trap is positive, then condensate can be transported and recovered with a very simple, reliable, and low cost installation. However, those systems where vertical and horizontal distances increase, the system backpressure will also increase hence need for Using a Pump to Overcome (Return Line) Backpressure. These pumps are either Electrically-powered Centrifugal or Turbine Condensate Pumps.

3. **Flash evaporation**.-

The condensate receivers tanks 1,2 and 3 each flashes vapour to the vapour from the condensate therein into the vapour system, used to supplement the energy need for heating /evaporation. Flash steam is no different from normal steam, it is just a convenient name used to explain how the steam is formed. Normal or “live” steam is produced at a boiler, steam generator, or waste heat recovery generator – whereas flash steam occurs when high pressure / high temperature condensate is exposed to a large pressure drop such as when exiting a steam trap.

High temperature condensate contains high energy that cannot remain in liquid form at a lower pressure because there is more energy than that required to achieve saturated water at the lower pressure. The result is that some of the excess energy causes a % of the condensate to Flash.(TLV, 2014)[3]

4. **Multi-jet condensors**-

Nzoia sugar installed and commissioned multi-jet condensors for the evaporator and all the 6 operated vacuum pans. This led the steam ejectors to be rendered obsolete which were previously utilizing live steam to boost vacuum creation thus reducing steam demand from the boiler. There has been a significant reduction in steam demand and or energy saving. The energy saving has made it possible to reduce steam demand load to the DresserRand Turbine Alternator. The makeup water for the boilers has equally reduced since the ejectors steam was one among the other sources of steam and condensate water loss.

5. **Multi-effect evaporators and vacuum pans**.

Nzoia sugar manages its exhaust steam by applying a multi –effect evaporation. Under this system quintuple effect is applied with vapour from the first effect bleedingto upper vacuum pans and the second effect bleeding to the lower vacuum pan and secondary heaters while the other effect bleeding to the primary heaters.

The change from quadruple effect to quintuple effect has also led to great energy utilization efficiency. According to Rillieux principle, one unit of steam will evaporate five units of water in a quintuple effect compared to four units in the case of quadruple effect.

$$steam\ saving = \frac{m}{n}$$

Where m is the position of the effect and n is the number of effect

Bleeding from one effect of a quadruple would result in a saving of one fourth of the weight of vapour withdrawn. (RASTIC,1999)[9].

The vapour bleeding also reduces the quantity of cooling water required in the evaporator and vacuum pan condensors, since; the amount of vapour going to the condenser is reduced.

3.0 DATA ANALYSIS AND PRESENTATION.

Condensate recovery energy balance

Basis: 136 tons per hour (TPH)

Taking the Cane constituents to be

CONSTITUENT	% COMPOSITION
Pol/ sucrose	12
Fibre	17
Trash/mud/wax	4
water	67

Source: Nzoia Sugar Lab analysis report

For good extraction water is applied as a solvent to diffuse the sucrose from the cane fibre. Optimal imbibition is 25ton per hour (TPH) for 136 tons of cane per hour (TCH). (Standard operating procedure manual, 2013)[7]

To prevent inversion process, lime is added to boost pH and flocculant during clarification process. Lime dosage is approximated to be 300 to 350kg per 8 hour of constant milling. Averaging about 40.625kg per hour. While flocculant is dosed at 5kg per 8 hour, averaging 0.625kg per hour. (JT supervisor report book, 2013)[8].

$$total\ tonnage\ of\ mixed\ juice = 25ton + 136tons = 161\frac{tons}{hour}$$

Considering chemical dosage: $Total\ tonnage = 161 + \frac{40.625+0625}{1000} = 161.04125\ Tons/hr$

From the laboratory weekly report,2014 the bagasse percent cane is range between 35-37 %.assuming the average of 36%.

$$Bagasse = 36\%\ of\ 161 = 57.96\frac{tons}{hr}$$

$$mixed\ juice = 64\%\ 0f\ 161 = 103.04\frac{tons}{hr}$$

$$total\ tonnage\ of\ mixed\ juice = 103.04 + \frac{40.625 + 0.625}{1000} = 103.08125\ tons/hr$$

Assuming 4% (from lab report, 2014) of cane milled is mud. Thus, 4% of 136 is 5.44tons/hr.

$$Clarified\ juice = mixed\ juice - mud$$

The mud extracted from juice clarification has some sucrose attached to it, in which some recoveries are made from extraction using mud filter press equipment. The target recovery is pol% cane of 3.0 and moisture content of 70%. Taking spray water ratio to mud added for sucrose recovery from mud to be 25% of mud.

$$spray\ water\ for\ mud\ filtration = 25\%\ \times 5.44 = 1.36\frac{tons}{hr}$$

$$sucrose\ recovery = \frac{12-3}{12} \times 100\ \times 5.44 = 75\%\ \times 5.44 = 3.851\ tons/hr$$

The spray water will diffuse the sucrose in the mud and form filtrate juice. The filtrate juice is approximately 1.36 tons/hr.

$$Total\ amount\ of\ clarified\ juice = mixed\ juice + filtrate\ juice - mud\ imputies$$
$$= 103.08125 + 1.36 - 5.44 = \mathbf{99.00125 tons/hr}$$

The company applies the quint effect evaporation, the evaporation from each body is calculated below:

Let e_i where $i = the\ vessel\ position$ 1,2,3,4, 5

$e_i = J\left(1 - \frac{BJ}{BS}\right)$where I = 1,2,3,4,5,

J is the clarified juice flow rate,

BJ is the clarified juice inlet brixes,

BS is the juice outlet brixes after evaporation

3.1 Evaporation from each body:

Evaporator 1:

$$e_1 = J\left(1 - \frac{BJ}{BS}\right) = 99.00125\left(1 - \frac{13.5}{23.5}\right) = 42.128\ tons/hr$$

Evaporator 2:

$$e_2 = (99.00125 - 42.128) \times \left(1 - \frac{23.5}{33.5}\right) = 16.977\ tons/hr$$

Evaporator 3:

$$e_3 = (99.00125 - 42.128 - 16.977) \times \left(1 - \frac{33.5}{43.5}\right) = 9.172\ tons/hr$$

Evaporator 4:

$$e_4 = (99.00125 - 42.128 - 16.977 - 9.172) \times \left(1 - \frac{43.5}{53.5}\right) = 5.743\ tons/hr$$

Evaporator 5:

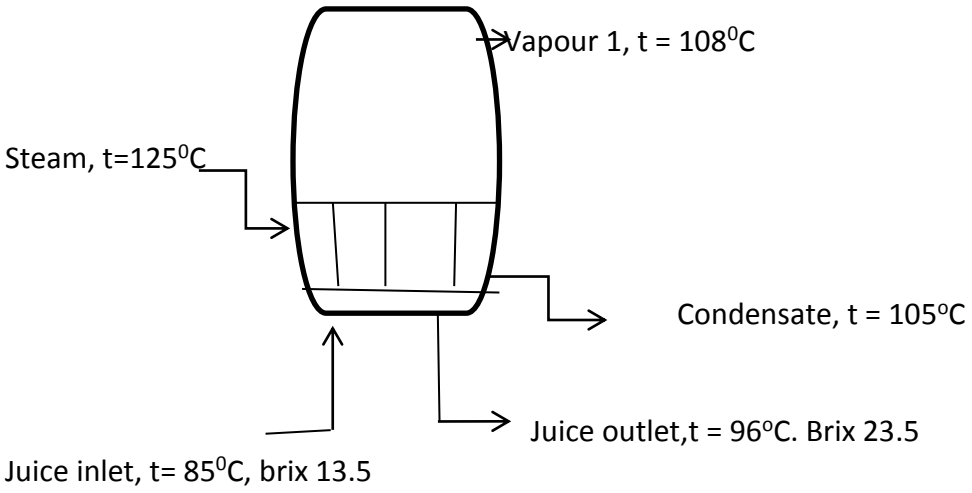
$$e_5 = (99.00125 - 42.128 - 16.977 - 9.172 - 5.743) \times \left(1 - \frac{43.5}{53.5}\right) = 3.934\ tons/hr$$

$$\boldsymbol{Total\ evaporation, E} = 100\left(1 - \frac{13.5}{63.5}\right) = 78.74\%$$

Where E is the mass of water evaporated % clear juice.

3.2 Evaporator Steam requirements.

1. Steam required by 1st body.



$$\text{Heat Entering} = \text{Heat Leaving}$$

$$\text{Total heat of steam} + \text{Total heat of Juice entering}$$
$$= \text{Total heat of vapour1} + \text{Total heat of Juice Leaving/exit}$$
$$+ \text{Total heat of Condensate} + \text{Heat losses if considered.}$$

Applying heat balance to determine the amount of heat required for evaporation and the amount of steam required and condensate generated.

Total heat of steam = $w_s \times h_g = W_s \times 2714.3$ ($from\ steam\ tables\ h_g\ @\ t = 125^0 C\ is\ 2714.3$

Total heat of juice entering = $W_j \times C_j \times t$

$C_j\ is\ the\ specific\ heating\ of\ juice\ @\ brix\ of\ 17.5$

$C_j = 4.187\ (1 - 0.006Bx)\frac{Kj}{kg}/^{o}C = 4.187\ (1 - 0.006 \times 13.5) = 3.848\frac{Kj}{kg}/^{o}C$

$W_j = 99.00125$ tons/hr

$$Total\ Heat\ of\ juice\ entering = 99.00125 \times 3.848 \times 85 = \frac{32380.092Kj}{kg}/^{o}C$$

$$Total\ Heat\ of\ vapour = W_v \times h_g = 42.128 \times 2689.3 = 113294.83\frac{Kj}{kg}/^{o}C$$

Heat of juice leaving

$C_j = 4.187\ (1 - 0.006Bx)\frac{Kj}{kg}/°C = 4.187\ (1 - 0.006 \times 23.5) = 3.597\frac{Kj}{kg}/°C$

$$Total\ Heat\ of\ juice\ Leaving = (99.00125 - 42.128) \times 3.597 \times 96.3 = \frac{19700.39Kj}{kg}/°C$$

Heat of condensate leaving: the amount of steam equals the amount of condensate generated

$$Total\ Heat\ of\ Condensate\ leaving = W_s \times h_f = 461.3\ W_s\frac{Kj}{kg}/°C$$

Performing heat balance equation.

$$2714.3W_s \times 32380.092 = 113294.83 + 19700.39 + 461.3W_s$$

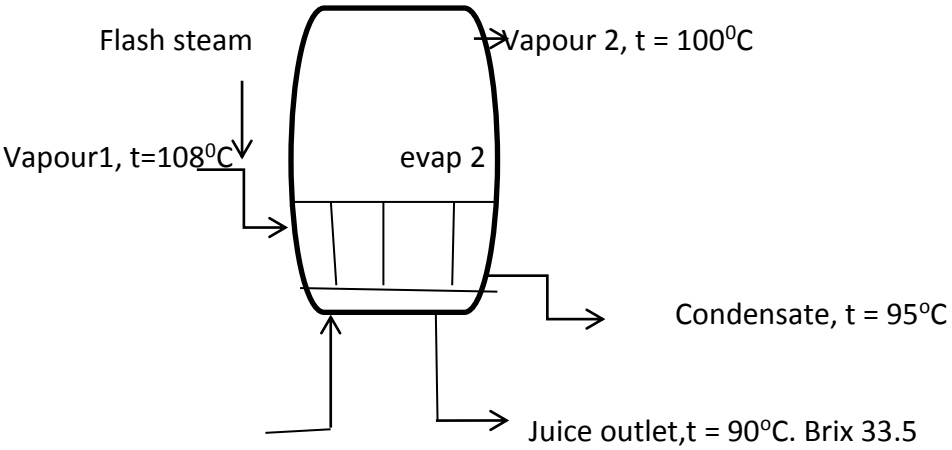
$$W_s = 44658\ kg$$

Assuming 5% heat loss

$$W_s = 44658 \times \frac{100}{95} = 47009kg$$

Therefore, the total steam required by evaporator 1 is 47009kg and the Total steam generated is 44658kg.

2. Steam required by 2nd body.



The condensate from first evaporator flashes into the this evaporator to add to the vapour 1

$$\text{Heat Entering} = \text{Heat Leaving}$$

$$\text{Total heat of vapour 1} + \text{Total heat of Juice entry} + \text{Total heat of Flash steam} = \text{Total heat of vapour 2} + \text{Total heat of Juice exit} + \text{Total heat of Condensate} + \text{Heat losses if considered.}$$

Applying heat balance to determine the amount of heat required for evaporation and the amount of vapour required and condensate generated. Assuming 5% heat loss.

Total heat of Vapour1 = $w_s \times h_g = 95\% \times 44.658 \times 2714.3 = 115154.449\ Kj$

Total heat of juice entering =Heat of juice leaving evaporator 1 less heat losses = $W_j \times C_j \times t$

$$Total\ Heat\ of\ juice\ entering = 95\% \times 19700.39 = \frac{18715.371Kj}{kg}/^{\circ}\text{C}$$

Total heat of flash steam.

$$Flash\ \% = \frac{h_{f1} - h_{f2}}{h_{fg2}}$$

Taking :

- hf1 @ t = 105 ^{0}C is 440.15 kj/kg/^{0}C
- hf2 @ t = 92^{0}C is 384.39kj/kg/^{0}C
- hfg2@ t = 92 ^{0}C is 2278kj/kg/^{0}C

$$Flash\ \% = \frac{440.15 - 384.39}{2278} = 2.447 \cong 2.5\ \%$$

Amount of flash steam = 2.5% of 44658 = 1116.45kg

$Total\ Heat\ of\ flash\ steam = W_v \times h_g = 1.11645 \times 2685.4 = 2998.114KJ$ (h_g @ $t =$ 105℃)

Assuming 5% heat loss; Total heat of flash steam consumed = 95% of 2998.114 = 2848.210KJ

$Total\ Heat\ of\ vapour2 = W_v \times h_g = 16.977 \times 2676 = 45430.452KJ$ (h_g @ $t = 100$℃)

Heat of juice leaving

$C_j = 4.187\ (1 - 0.006Bx)\frac{Kj}{kg}/^{\circ}\text{C} = 4.187\ (1 - 0.006 \times 33.5) = 3.345\frac{KJ}{kg}/^{\circ}\text{C}$

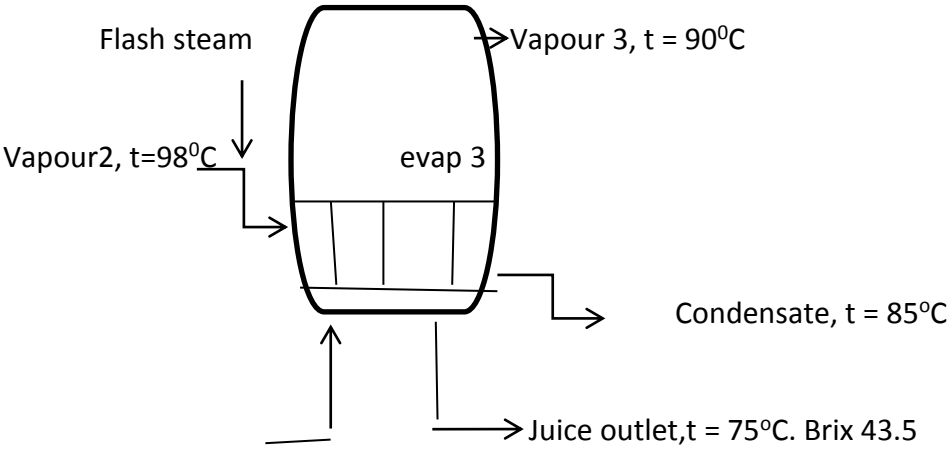
$$Total\ Heat\ of\ juice\ Leaving = (99.00125 - 42.128 - 16.977) \times 3.345 \times 90 = 12010.691KJ$$

$$Total\ Heat\ of\ Condensate\ leaving = W_s \times h_f = (42.128 + 1.11645) \times 398.57 = 18552.019KJ$$

Total amount of condensate generated = 42.128 + 1.116 = 43.244 ton/hr

$$Heat\ Loss = 5\%\ (\ 45430.452 + 12010.691 + 18552.019) = 3799.658\ KJ$$

3. Steam required by 3rd body.



The condensate from second evaporator flashes into the this evaporator to add to the vapour 2

$$\text{Heat Entering} = \text{Heat Leaving}$$

$$\text{Total heat of vapour 2} + \text{Total heat of Juice entry} + \text{Total heat of Flash steam}$$
$$= \text{Total heat of vapour 3} + \text{Total heat of Juice exit} + \text{Total heat of Condensate} + \text{Heat losses if considered.}$$

Applying heat balance to determine the amount of heat required for evaporation and the amount of vapour required and condensate generated. Assuming 5% heat loss.

$$Total\ Heat\ of\ vapour2 = \ 95\% \ \times W_v \times h_g = 95\% \ \times \ 16.977 \ \times 2676 = 43158.929\ KJ$$

Total heat of juice entering =Heat of juice leaving evaporator 2 less heat losses = $W_j \times C_j \times t$

$$Total\ Heat\ of\ juice\ entering = 95\% \ \times 12010.691 = 11410.156 KJ$$

Total heat of flash steam.

$$Flash\ \% = \frac{h_{f1} - \ h_{f2}}{h_{fg2}}$$

Taking :

- hf1 @ t = 95 ^{0}C is 411.43 KJ/kg/^{0}C
- hf2 @ t = 85^{0}C is 359.86 KJ/kg/^{0}C
- hfg2@ t = 85^{0}C is2294KJ/kg/^{0}C

$$Flash\ \% = \frac{411.43 - 359.86384.39}{2294} = 2.25\ \%$$

Amount of flash steam = 2.25% of 43244 = 972.99kg

$Total\ Heat\ of\ flash\ steam = W_v \times h_g = 0.973 \times 2283 = 2221.336KJ$ (h_g @ $t = 90$℃)

Assuming 5% heat loss; Total heat of flash steam consumed = 95% of 2221.336 = 22110.269KJ

$Total\ Heat\ of\ vapour3 = W_v \times h_g = 9.172 \times 2660 = 24397.52KJ$ (h_g @ $t = 90$℃)

Heat of juice leaving

$C_j = 4.187\ (1 - 0.006Bx)\frac{Kj}{kg}/$℃= $4.187\ (1 - 0.006 \times 43.5) = 3.094\frac{KJ}{kg}/$℃

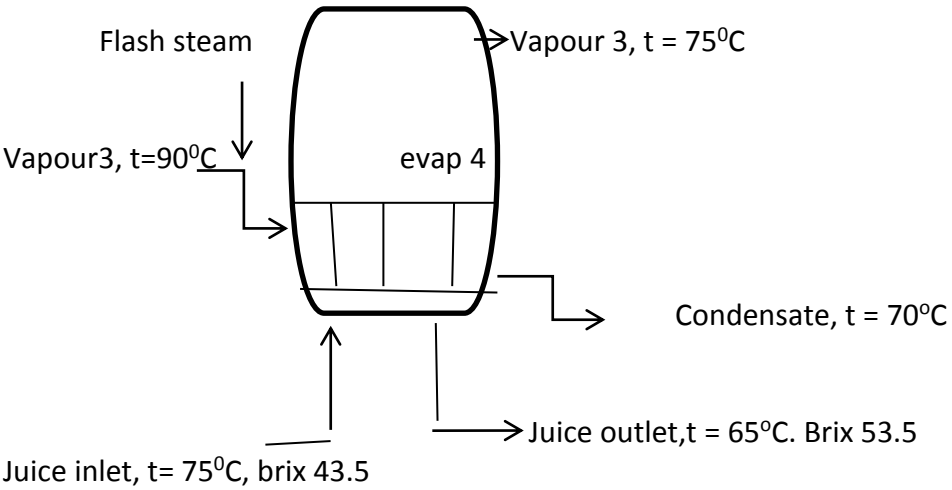
$$Total\ Heat\ of\ juice\ Leaving = (99.00125 - 42.128 - 16.977 - 9.172) \times 3.094 \times 75$$
$$= 7129.56KJ$$

$$Total\ Heat\ of\ Condensate\ leaving = W_s \times h_f = (16.977 + 0.973) \times 359.86$$
$$= 6459.487KJ$$

Total amount of condensate generated = 16.977 + 0.973 = 17.95 ton/hr

$$Heat\ Loss = 5\%\ (\ 24397.52 + 7129.56 + 6459.487) = 1899.302\ KJ$$

4. Steam required by 4thbody.



The condensate from Third evaporator flashes into the this evaporator to add to the vapour 3

$$\text{Heat Entering} = \text{Heat Leaving}$$

Total heat of vapour 3 + Total heat of Juice entry + Total heat of Flash steam
= Total heat of vapour 4 + Total heat of Juice exit + Total heat of Condensate
+ Heat losses if considered.

Applying heat balance to determine the amount of heat required for evaporation and the amount of vapour required and condensate generated. Assuming 5% heat loss.

$$Total\ Heat\ of\ vapour3 = 95\% \times W_v \times h_g = 95\% \times 9.172 \times 2660 = 23177.644KJ$$

Total heat of juice entering =Heat of juice leaving evaporator 3 less heat losses = $W_j \times C_j \times t$

$$Total\ Heat\ of\ juice\ entering = 95\% \times 7129.56KJ = 6773.082KJ$$

Total heat of flash steam.

$$Flash\ \% = \frac{h_{f1} - h_{f2}}{h_{fg2}}$$

Taking :

- hf1 @ t = 85 ^{0}C is 359.86 KJ/kg/^{0}C
- hf2 @ t = 80^{0}C is 340.49 KJ/kg/^{0}C
- hfg2@ t = 80^{0}C is 2305 KJ/kg/^{0}C

$$Flash\ \% = \frac{359.86 - 340.49}{2305} = 0.84 \approx 1.0\ \%$$

Amount of flash steam = 1.0 % of 17950 = 179.50 kg

$Total\ Heat\ of\ flash\ steam = W_v \times h_g = 0.1795 \times 2305 = 413.748\ KJ$ (h_g @ $t = 80$℃)

Assuming 5% heat loss; Total heat of flash steam consumed = 95% of 413.748 = 393.060 KJ

$$Total\ Heat\ of\ vapour3 = W_v \times h_g = 5.743 \times 2636 = 15138.55\ KJ$$ (h_g @ $t = 75$℃)

Heat of juice leaving

$C_j = 4.187\ (1 - 0.006Bx)\frac{Kj}{kg}$/℃= $4.187\ (1 - 0.006 \times 53.5) = 2.843\frac{KJ}{kg}$/℃

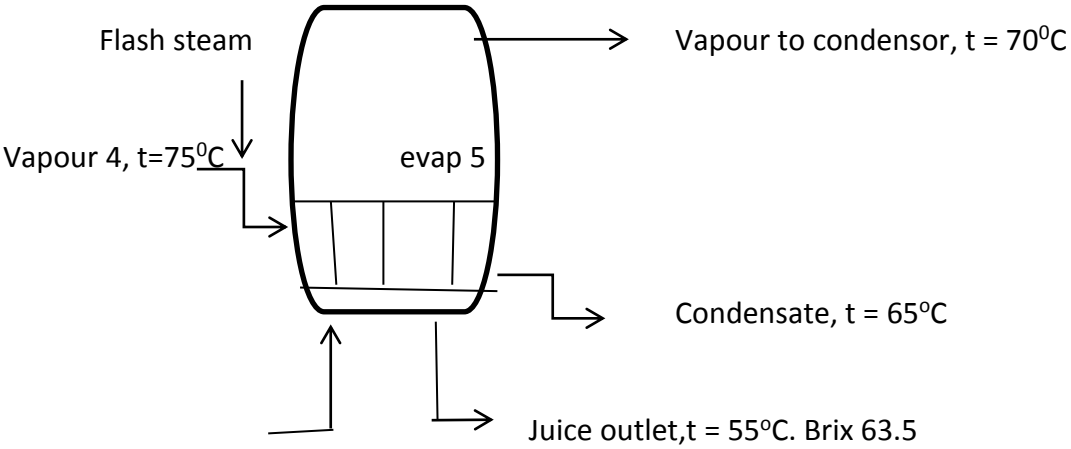
$$Total\ Heat\ of\ juice\ Leaving$$
$$= (99.00125 - 42.128 - 16.977 - 9.172 - 5.743) \times 2.843 \times 65$$
$$= 4616.41KJ$$

$Total\ Heat\ of\ Condensate\ leaving = W_s \times h_f = (9.172 + 0.179) \times 289.23 = 2704.590KJ$

Total amount of condensate generated = $9.172 + 0.179$ = 9.351 ton/hr

$$Heat\ Loss = 5\%\ (\ 15138.55 + 4616.41 + 2704.590) = 1122.978\ KJ$$

5. Steam required by 5th body.



The condensate from fourth evaporator flashes into the this evaporator to add to the vapour 4

$$\text{Heat Entering} = \text{Heat Leaving}$$

$$\text{Total heat of vapour 4} + \text{Total heat of Juice entry} + \text{Total heat of Flash steam}$$
$$= \text{Total heat of vapour 5} + \text{Total heat of Juice exit} + \text{Total heat of Condensate}$$
$$+ \text{Heat losses if considered.}$$

Applying heat balance to determine the amount of heat required for evaporation and the amount of vapour required and condensate generated. Assuming 5% heat loss.

$$Total\ Heat\ of\ vapour\ 4 = \ 95\% \ \times W_v \times h_g = 95\% \times 5.743 \ \times 2636 = 14381.623\ KJ$$

Total heat of juice entering =Heat of juice leaving evaporator 4 less heat losses = $W_j \times C_j \times t$

$$Total\ Heat\ of\ juice\ entering = 95\% \ \times 4616.41KJ \ = 4385.590KJ$$

Total heat of flash steam.

$$Flash\ \% = \frac{h_{f1} - \ h_{f2}}{h_{fg2}}$$

Taking :

- hf1 @ t = 80^0C is 340.49 KJ/kg/^{0}C
- hf2 @ t = 75^0C is317.58 KJ/kg/^{0}C
- hfg2@ t = 75^0C is 2319.2 KJ/kg/^{0}C

$$Flash\ \% = \frac{340.49\ -\ 317.58}{2319.2} = 0.987\ \approx 1.0\ \%$$

Amount of flash steam = 1.0 % of 9341 = 93.41 kg

$Total\ Heat\ of\ flash\ steam = W_v \times h_g = 0.0934 \times 2319.2 = 216.613\ KJ$ (h_g @ $t = 65$°C)

Assuming 5% heat loss; Total heat of flash steam consumed = 95% of 216.613 = 205.783 KJ

$Total\ Heat\ of\ vapour4 = W_v \times h_g = 3.934 \times 2625 = 10326.75\ KJ$ (h_g @ $t = 70$°C)

Heat of juice leaving

$C_j = 4.187\ (1 - 0.006Bx)\frac{Kj}{kg}$/°C= $4.187\ (1 - 0.006 \times 63.5) = 2.592\frac{KJ}{kg}$/°C

$$Total\ Heat\ of\ juice\ Leaving$$
$$= (99.00125 - 42.128 - 16.977 - 9.172 - 5.743) \times 2.592 \times 55$$
$$= 3561.327KJ$$

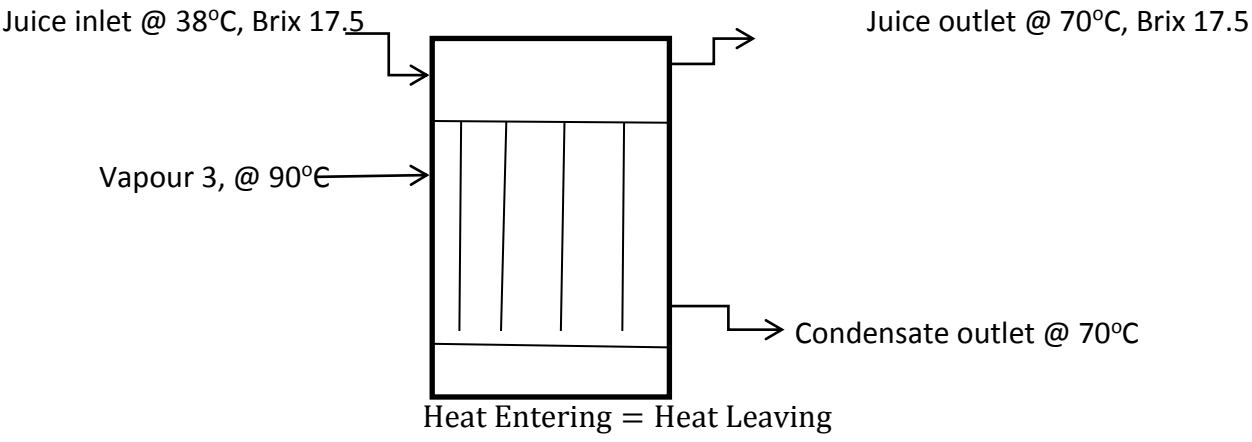
$$Total\ Heat\ of\ Condensate\ leaving = W_s \times h_f = (5.743 + 0.09342) \times 271.93$$
$$= 1587.098KJ$$

Total amount of condensate generated = $(5.743 + 0.09342)$ = 5.8364 ton/hr

$$Heat\ Loss = 5\%\ (10326.75 + 3561.327 + 1587.098) = 773.759\ KJ$$

3.3 Heaters steam requirements

1. Primary Heater steam requirement.



Heat Entering = Heat Leaving

Heat energy of steam/vapour + Heat energy of juice inlet = Heat Energy of juice outlet + Heat energy of Condensate + heat losses if considered.

Heat energy of vapour 3:$= W_s \times h_g$

Heat energy of Juice inlet $W_{j1} \times C_{j1} \times t_1$

Applying Heat balance

$$(W_s \times h_g) + (W_{j1} \times C_{j1} \times t_1) = (W_{j2} \times C_{j2} \times t_2) + (W_s \times h_f)$$

$$(C_{j1}) = 4.187(1 - 0.006 \times 17.5) = 3.747$$

Substituting values from steam tables:

Total mass of mixed juice = tons of mixed juice + filter spray water

$$W_{j1} = W_{j2} = 103.08125 + 1.36 = 104.44125\ tons/Hr$$

$$(W_s \times h_g) - (W_s \times h_f) = (W_{j2} \times C_{j2} \times t_2) - (W_{j1} \times C_{j1} \times t_1)$$

$$W_s(2660 - 376.7) = 2283.3W_s = (104.44125 \times 3.747) \times (70 - 38)$$

$$W_s = \frac{42264.8673}{2283.3} = 18.51\ tons\ or\ 18510\ kg$$

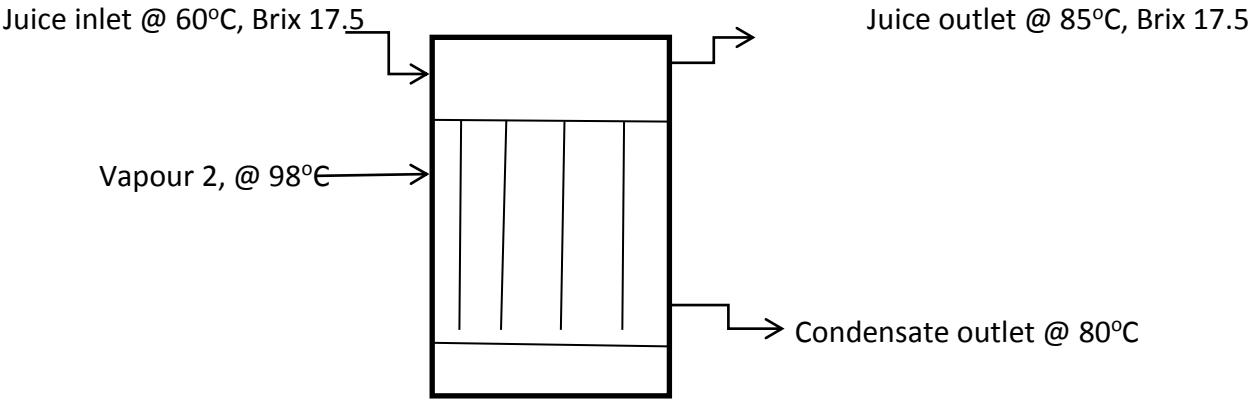
Therefore, Vapour 3 Heat energy$= 18.51 \times 2660 = 49236.6\ KJ$

Condensate Heat energy$= 18.51 \times 376.7 = 6972.717\ KJ$

$$Heat\ energy\ of\ juice\ inlet = 104.44125 \times 3.747 \times 38 = 14870.972\ KJ$$

$$Heat\ energy\ of\ juice\ outlet = 104.44125 \times 3.747 \times 70 = 27393.8955\ KJ$$

2. Secondary Heater 3, Steam requirement.



$$\text{Heat Entering} = \text{Heat Leaving}$$

Heat energy of steam/vapour + Heat energy of juice inlet = Heat Energy of juice outlet + Heat energy of Condensate + Heat losses if considered.

Heat energy of vapour 2:$= W_s \times h_g$

Heat energy of Juice inlet = $W_{j1} \times C_{j1} \times t_1$

Applying Heat balance

$$(W_s \times h_g) + (W_{j1} \times C_{j1} \times t_1) = (W_{j2} \times C_{j2} \times t_2) + (W_s \times h_f)$$

$$(C_{j1}) = 4.187(1 - 0.006 \times 17.5) = 3.747$$

Substituting values from steam tables:

Total mass of mixed juice = tons of mixed juice + filter spray water

$$W_{j1} = W_{j2} = 103.08125 + 1.36 = 104.44125\ tons/Hr$$

$$(W_s \times h_g) - (W_s \times h_f) = (W_{j2} \times C_{j2} \times t_2) - (W_{j1} \times C_{j1} \times t_1)$$

$$W_s(2673 - 340) = 2333W_s = (104.44125 \times 3.747) \times (85 - 60)$$

$$W_s = \frac{33264.0159 - 23480.4818}{2673 - 340} = 4.19354\ tons/hr\ or\ 4193.54\ kg/hr$$

Therefore, Vapour 2 Heat energy$= 4.19354 \times 2673 = 11209.332\ KJ$

Condensate Heat energy$= 4.19354 \times 340 = 1425.804\ KJ$

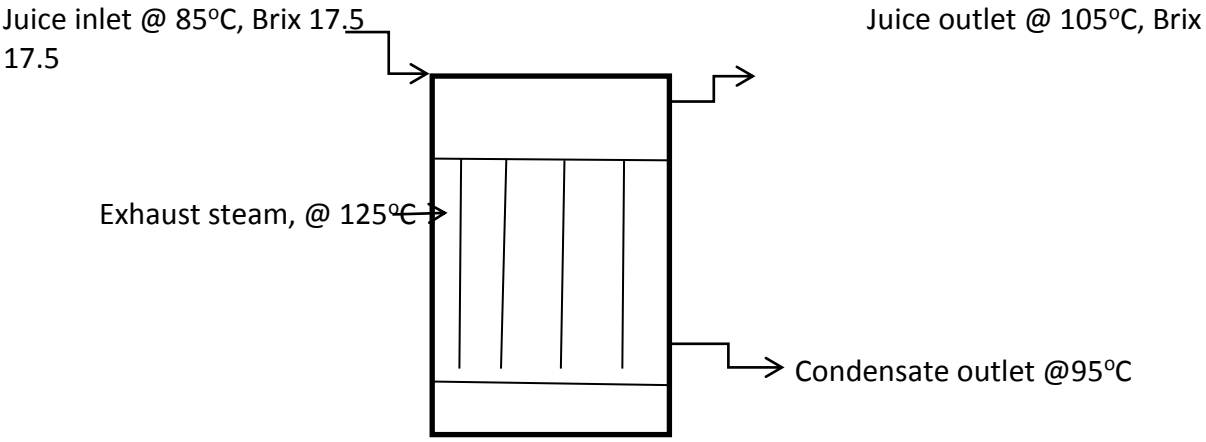
$$Heat\ energy\ of\ juice\ inlet = 104.44125 \times 3.747 \times 60 = 23480.4818\ KJ$$

$$Heat\ energy\ of\ juice\ outlet = 104.44125 \times 3.747 \times 85 = 33264.016\ KJ$$

Heat losses in vapour and condensate = 5% of heat received $= 5\% \times (11209..332 + 1425.804) = 631.757KJ$

Heat loss in the juice = 5% of heat received = $5\% \times 33264.0159 = 1663.201KJ$

3. Secondary Heater 4/5, Steam requirement.



$$\text{Heat Entering} = \text{Heat Leaving}$$

Heat energy of Exhaust steam + Heat energy of juice inlet = Heat Energy of juice outlet + Heat energy of Condensate + Heat losses if considered.

Heat energy of exhaust Steam:$= W_s \times h_g$

Heat energy of Juice inlet = $W_{j1} \times C_{j1} \times t_1$

Applying Heat balance

$$(W_s \times h_g) + (W_{j1} \times C_{j1} \times t_1) = (W_{j2} \times C_{j2} \times t_2) + (W_s \times h_f)$$

$$(C_{j1}) = 4.187(1 - 0.006 \times 17.5) = 3.747$$

Substituting values from steam tables:

Total mass of mixed juice = tons of mixed juice + filter spray water

$$W_{j1} = W_{j2} = 103.08125 + 1.36 = 104.44125\ tons/Hr$$

$$(W_s \times h_g) - (W_s \times h_f) = (W_{j2} \times C_{j2} \times t_2) - (W_{j1} \times C_{j1} \times t_1)$$

$$W_s(\ 2713.3 - 398.57) = 2314.73 W_s = (104.44125\ \times 3.747) \times (105 - 85)$$

$$W_s = \frac{41090.8432 - 31601.2577}{2713.3 - 398.57} = 4.099\ tons/hr\ or\ 4099\ kg/hr$$

Therefore, Exhaust Steam $= 4.099 \times 2713.3 = 11121.817\ KJ$

Condensate Heat energy$= 4.099 \times 398.57 = 1633.738 KJ$

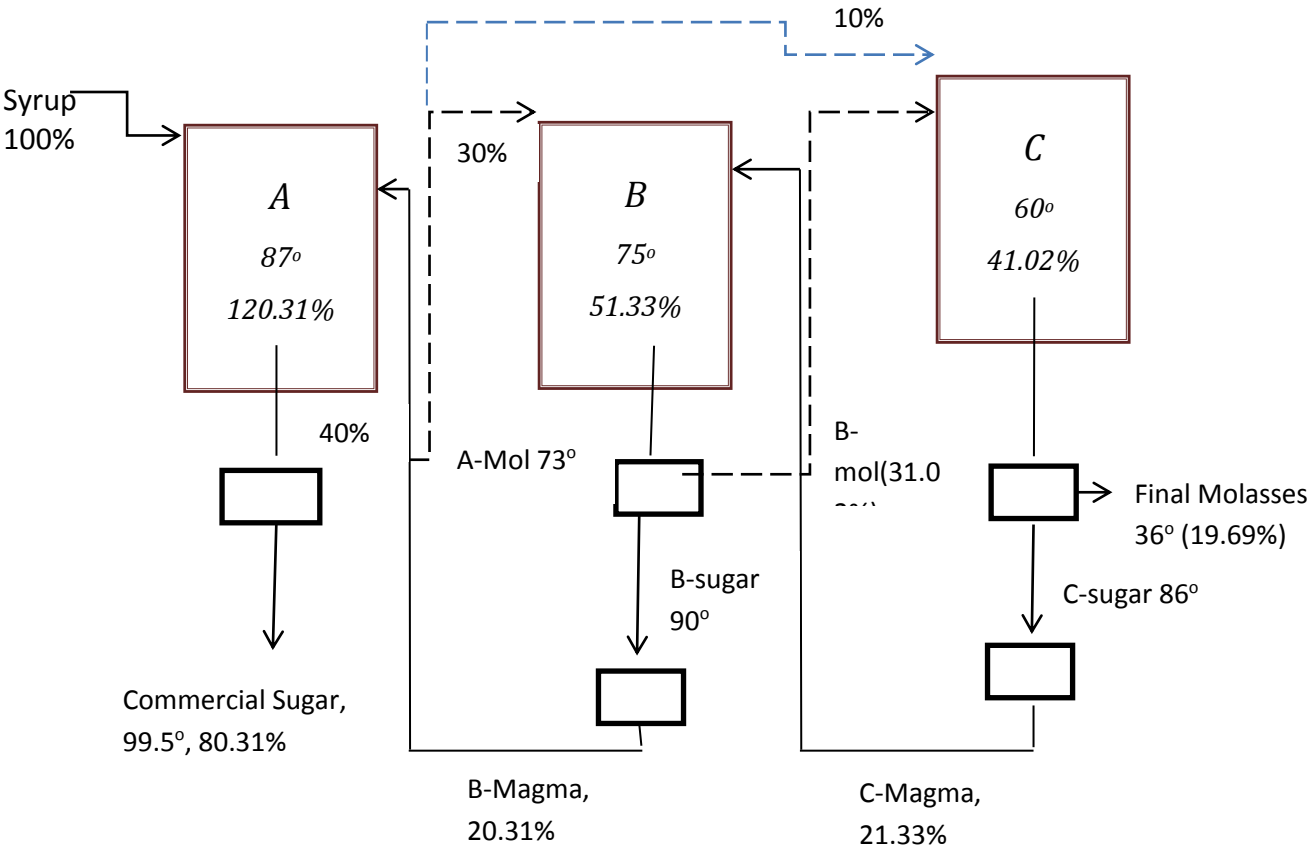
$$Heat\ energy\ of\ juice\ inlet = 95\%\ \times 104.44125 \times 3.747 \times 85 = 31600.815\ KJ$$

$$Heat\ energy\ of\ juice\ outlet = 104.44125 \times 3.747 \times 105 = 41090.843\ KJ$$

Heat losses in vapour and condensate = 5% of heat received $= 5\%\ \times\ (11121.817 + 1633.738) =\ \ 637.778 KJ$
Heat loss in the juice = 5% of heat received = $5\%\ \times 41090.843 = 2054.542 KJ$

3.4 Pan boiling steam requirements.

Nzoia sugar uses a three- boiling system to produce A,B and C sugar. The amount of steam required to evaporate 1 ton of water varies according to different authors but on the whole, we can assume 1.2 tonnes. This comprises losses by radiation and the preheating of the various products in the pan prior to evaporation. Due to the complexity of calculating the amount of steam required, from the batch processes involved in pan boiling a simple flow diagram below is adopted.

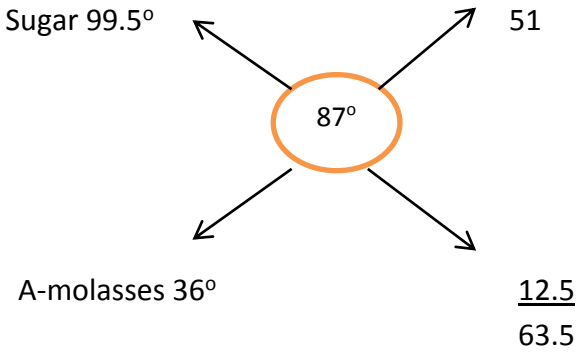


Source: Author, 2015

It's assumed from literature that 40% of the A-Massecuite is taken as A-Molasses

This can be calculated (Mass Balance) by means of Cobenze diagrams using brix balance.

a. Syrup entering boiling house yields two final products: sugar @ 99.5 °purity and Final Molasses @ 36° Purity.



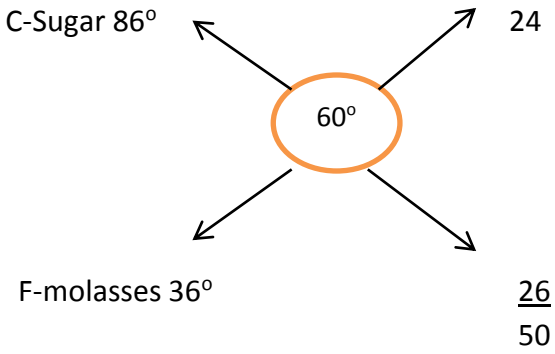
Source: Author, 2015

For every 100kg of brix contained in the syrup.

$$\frac{51}{63.5} \times 100 = 80.31\ kg\ Brix\ comes\ out\ in\ the\ Sugar$$

$$\frac{12.5}{63.5} \times 100 = 19.69\ kg\ Brix\ comes\ out\ in\ the\ Final\ Molasses$$

b. C-massecuite separates to two products.



Source: Author, 2015

If 'Y' kg of brix are contained in the C-massecuite, then

$$\frac{24}{50} \times Y = Kg\ Brix\ are\ contained\ in\ the\ C-Massecuite\ which\ is\ calculated\ as\ 19.69Kg$$

$$\frac{24}{50} \times Y = 19.69\%,\ \ then, Y = \frac{19.69\ \times 50}{24}$$

$$= 41.02\ kg\ of\ brix\ of\ c-Massecuite\ \%\ Brix\ in\ the\ syrup.$$

The C-sugar % brix is thus, 41.02 – 19.69 = 21.33%

c. B-Molasses is used to boil C-Massecuite, thus, it contain the same brix as the C-massecuite i.e. 41.02%.
d. The mass of brix in the A- Massecuite is the sum of the brix contained in syrup and b-Magma i.e. 100% + 20.31% = 120.31%
e. Since the A-Massecuite yield commercial sugar and A-molasses, the mass of brix in these two products must be the same as for A-Massecuite. 80.31% + 40% = 120.31%.
f. $Total\ mass\ of\ Brix\ in\ massecuite\ boiled\ \%\ brix\ in\ syrup = A + B + C = 120.31 + 51.33 + 41.02 = 212.66\ kg$

Steam requirements Calculations

Table: Target parameters for boiling house material

Parameter	**Range**	**Average**
Clarified Juice Brix	11 - 14	12.5
Tonnes of clarified Juice/hr	-	99.00125 Tons
A- Massecuite	92 -93	92.5
B- Massecuite	94 -95	94.5
C- Massecuite	96 - 98	97
A- Molasses	78 - 80	79
B- Molasses	80 - 82	81
B-Magma	92 -94	93
C-Magma	88 -92	90
Syrup	61-65	63.5

Source: Production Process Work Instruction Manual, 2013[6]

Calculations.

If you take a mass of a product "W" with a brix equal to "By", the mass of solid Or brix in the product will be equal to $\frac{W \times B_y}{100}$. This is the mass of solids (Brix)

If you know the mass of solid (Brix), $W = Solids \times \frac{100}{B_y}$

If you evaporate the by product to a brix "By^1", you shall have a new mass of product, 'W^1"

$W^1 = \left(solids \times \frac{100}{By^1}\right)$

The mass of evaporated water is equal to;

$$W - W^1 = Solids \times \left(\frac{100}{B_y} - \frac{100}{B_y^1}\right)$$

In the case of Nzoia Sugar,

$$mass\ of\ Brix(solids) per\ hour = \frac{99.00125 \times 12.5}{100} = 13.365\ tons$$

$$Evaporation\ of\ syrup\ in\ A - massecuite = 13.365 \times \left(\frac{100}{63.5} - \frac{100}{92.5}\right)$$
$$\approx 6.599 tons\ or\ 6599 kg\ of\ water\ evaporated$$

$$Evaporation\ of\ A - Molasses\ in\ B - Massecuite = \frac{30}{100} \times 13.365 \times \left(\frac{100}{79} - \frac{100}{94.5}\right)$$
$$\approx 0.832\ tons\ or\ 832kg\ of\ water\ evaporated$$

$$Evaporation\ of\ A - Molasses\ in\ C - Massecuite = \frac{10}{100} \times 13.365 \times \left(\frac{100}{79} - \frac{100}{97}\right)$$
$$\approx 0.314\ tons\ or\ 314kg\ of\ water\ evaporated$$

$$Evaporation\ of\ B - Molasses\ in\ C - Massecuite = \frac{31.02}{100} \times 13.365 \times \left(\frac{100}{81} - \frac{100}{97}\right)$$
$$\approx 0.844\ tons\ or\ 844kg\ of\ water\ evaporated$$

$$Evaporation\ of\ B - magma\ in\ A - Massecuite = \frac{20.31}{100} \times 13.365 \times \left(\frac{100}{92} - \frac{100}{92.5}\right)$$
$$\approx 0.0159\ tons\ or\ 159\ kg\ of\ water\ evaporated$$

$$Evaporation\ of\ C - magma\ in\ B - Massecuite = \frac{31.02}{100} \times 13.365 \times \left(\frac{100}{90} - \frac{100}{94.5}\right)$$
$$\approx 0.219\ tons\ or\ 129\ kg\ of\ water\ evaporated$$

$$Total\ Amount\ of\ water\ evaporated\ in\ pan\ boiling\ operation$$
$$= 6599 + 832 + 314 + 844 + 15.9 + 219 = \mathbf{8823.9kg\ of\ water\ per\ hour}$$

Amount of steam required by the pan station, assuming the 1 ton to 1.2 ton ratio.

$$8823.9 \times 1.2 = \mathbf{10588.68\ or\ 10.569\ tons/hr}$$

4.0 DISCUSSION AND FINDINGS

4.1 Waste energy savings/ economic calculations

1. **Flash steam/ flash evaporation.**

vapour type	% flash	Energy dispensed (KJ)	Energy savings (KJ)	Energy losses (KJ)	Condensate recovered (Kg/h)
Vapour 1	2.5	2998.114	2848.21	149.904	1116.45
Vapour 2	2.25	2221.336	2211.03	10.306	972.99
Vapour 3	1	413.748	393.06	20.688	179.5
Vapour 4	1	216.613	205.783	10.83	93.41
Total		**5849.811**	**5658.083**	**191.728**	**2362.35**

Source: Author, 2015

2. **Multi effect evaporation.**

Steam requirement is the amount of vapour supplied plus the flash steam.

Effect position no.	vapour Steam (Kg)	Flash Steam (kg)	Total steam Requirement (Kg/h)	Steam Savings(%)	Vapour energy (KJ)	Flash steam Energy	Total energy Requirement	Energy Savings
Evaporator 1	47009	0	47009	1/5	121215.2094	0	121215.2094	24243.0
Evaporator 2	44658	1116.45	45774.45	2/5	45430.452	2998.114	118152.563	47261.0
Evaporator 3	16977	972.99	17949.99	3/5	43158	2221.336	45379.336	27227.6
Evaporator 4	9172	179.5	9351.5	4/5	23177.644	413.748	23591.392	18873.1
Evaporator 5	5743	9341	15084	1	14381.623	216.613	14598.236	14598.2
TOTAL	**123559**	**11609.94**	**135168.94**		**247362.9284**	**5849 4/5**	**322936.7364**	**132203**

Source: Author, 2015

Amount of Condensate (Kg)	Heat Energy in cond.	Heat losses
44568	20559.2184	6060.76047
43244.45	18552.019	5907.62815
17949.99	6459.487	2268.9668
9351	2704.59	1179.5696
5836.42	1587.098	729.9118
120949.86	**49862.4124**	**16146.8368**

Source: Author, 2015

3. **Multi jet Condensors**.-
   These were supplied with 6bar steam at 200°C. Taking the same flow rate as that of live steam from boiler 1 or 2i.e 14-27 tons/hr.

$$average\ flowrate = \frac{14+27}{2} = 20.5\ tons/hr$$

$$Energy\ saving = W_s \times h_g = 20.5\ \times 2793 \times 10^3 = \mathbf{57256500}KJ$$

4. **Boiler feed water**. The boiler is feed by condensate at 85°C. The energy savings is equivalent to the amount of energy required to heat the water from room temperature to its feeding temperature. The condensate from evaporator 1 and 2 are pumped direct to the boilers. Assuming a min of 45m^3/hr flow rate for primary condensate.

$$evap\ 1\ energy\ savings = W_s \times C_{pw} \times (T_2 - T_1)$$

$$evap\ 1\ energy\ savings = 44658 \times 4.18 \times (85-38) = 8773510.68\ KJ$$

$$evap\ 2\ energy\ savings = W_c \times C_{pw} \times (T_2 - T_1)$$

$$evap\ 2\ energy\ savings = 43244 \times 4.18 \times (85-38) = 8495716.24\ KJ$$

$$Total\ energy\ saving = 8773510.68 + 8495716.24 = \mathbf{17269226.9}KJ$$

5. **Vapour bleeding in heaters and vacuum pans**

There is significant improvement in the specific consumption in exhaust steam by feeding vacuum pans and heaters with low-pressure steam (usually 1st effect and 2nd effect bleeding). This reduces the amount of steam extracted from non-condensing turbines and improves the efficiency of the machine. This saving can be estimated to be between 350 – 400 kg of exhaust steam per ton on cane crushed. (RASTIC, 1999)[9]

Taking a crushing capacity of 136 TCH (tons of cane per hour)

$$Amount\ of\ steam\ savings = 136\ \times \frac{350 + 400}{2} = 51000kg\ of\ steam$$

This steam is at 1.5 bar and 120 - 125°C

If steam contains 10% water by mass, it's said to be 90% dry, or have a dryness fraction of 0.9.

h = hf + X • hfg

From steam tables this is calculated as:

$$Total\ enthalpy = 504.7 + (0.9\ \times 2201.9) = 2486.41\ Kj/kg$$

$$Total\ energy\ savings = 2486.41\ \times 51000 = \mathbf{126806910}\boldsymbol{Kj}$$

Table: Summary of energy savings

ENERGY COMPONENT	**ENERGY SAVINGS (KJ)**
Flash steam	5658.083
Multi- effect evaporation	132203.02
Multi jet Condensors	57256500
Boiler feed water	17269226.9
Vapour bleeding	126806910
TOTAL	**201470498**

Source: Author, 2015

Table: Summary of condensate recovered

CONDENSATE SOURCE	**AMOUNT RECOVERED (KG)**	**HEAT ENERGY (KJ)**
Evaporator 1	44658	20600.7354
Evaporator 2	43244	18552.019
Evaporator 3	17950	6459.487
Evaporator 4	9351	2704.59
Evaporator 5	5836	1587.098
Primary heater 1 or 2	18510	6972.717
Secondary heater 3	4193.54	1425.804
Secondary Heater 4 or 5	4099	1633.738
Vacuum Pan boiling	10588.68	
TOTAL	158430.22	59936.1884

Source: Author, 2015

5.0 CONCLUSION.

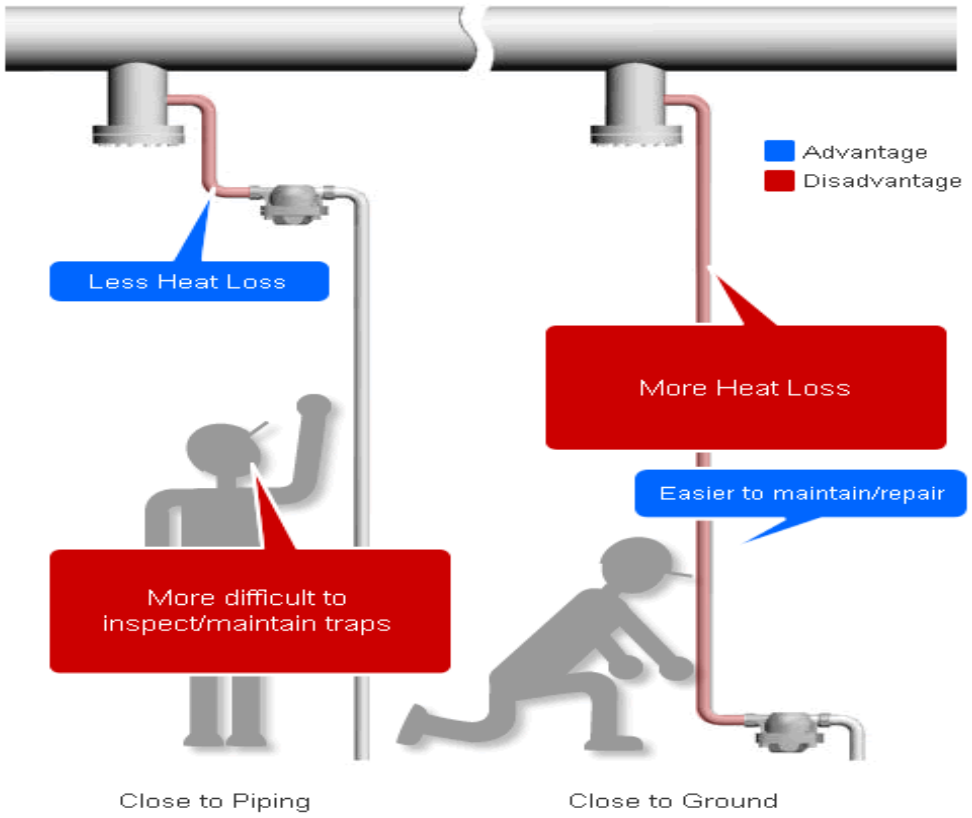
The condensate and flash steam recovery system can be concluded to have achieved great energy conservation leading to high energy savings. This has reduced the amount of energy required to heat the boiler water to the boiler feed water temperatures of 85^{o}C. There is also reduction in boiler water water-up since the condensate is recycled back to the boilers. Boiler water chemical treatment has also been reduced. However, a lot more has to be done to recover the heat losses by proper lagging of the heating vessels and all auxiliary pipes. Venting should also be well controlled to reduce energy losses related to venting large amount of flash steam to the atmosphere especially along exhaust steam line, heater, evaporators and pans. If this is done there would be great energy management leading to resource conservation, climate protection and cost savings.

6.0 RECOMMENDATIONS:

Since wet steam not only affects heat transfer efficiency, but can also cause erosion of piping and critical equipment such as turbine blades, it is highly recommended to take preventative measures such as using a steam separator to remove the entrained condensate.

Reusing flash steam generated by a higher pressure system for use in a lower pressure system can enable considerable energy savings in addition to improving a plant's working environment by reducing vapor clouds. When trying to implement a waste heat management system, condensate recovery systems and flash steam recovery systems are often evaluated together as a pair.

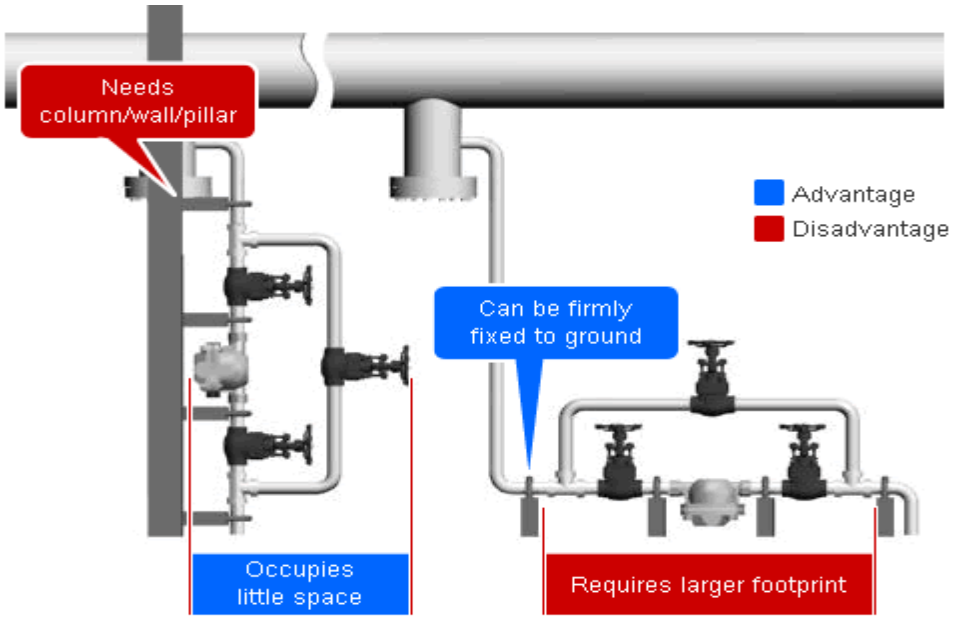
1. Trap Location: Close to Piping or Ground
   Setting Trap Close to Piping vs. Close to Ground



	Advantage	Disadvantage
Close to Piping	Less heat is lost through radiation	More difficult to inspect and maintain traps, which might lead to circumstances where a failed trap is simply forgotten.
Close to Ground	Easier to maintain and repair	More heat loss through radiation because the longer downpipe acts as a smaller bore extension of the steam line. (Insulation can help reduce heat loss significantly in cases where trap operation is not negatively affected by insulation.)

Use of traps that discharge condensate continuously, such as the Free Float® type. Other trap types such as disc, bucket, or balanced pressure thermostatic can be used provided that the collecting leg is adequately sized to prevent back-up into the steam main. Bimetal traps are not recommended for use on steam mains due to the possibility of large back-up distances which could pool condensate in the steam main itself. This is an especially worrisome situation when the trap is located close to the steam main.

2. Trap Orientation: Vertical or Horizontal



	Advantage	Disadvantage
Installed Vertically	Occupies little space	Needs installation against a column/wall/pillar. Its position can make maintenance tasks more difficult
Installed Horizontally	Can be firmly fixed to the floor/ground.	Requires a larger footprint added space.

3. Non-electric Steam or Air-Powered Mechanical Condensate Pumps.

Mechanical condensate pumps, also known as Secondary Pressure Drainers (SPD) were invented to overcome the aforementioned issues that can occur with electric pumps. With mechanical pumps those prior referenced problems, such as cavitation, are removed or significantly reduced.

A mechanical pump is used to transport condensate to a distant collection tank. This method doesn't require electricity, but requires a secondary pressure motive fluid such as steam. Mechanical condensate pumps rely on positive displacement for pumping and do not use impeller rotation, so there is no danger of cavitation. Furthermore, they are relatively unaffected by broad differences in back pressure, so TDH requirements are not as critical in their sizing. Additionally, they are well-suited for explosion proof areas and remote locations because they do not require any electricity. The types and capacities of mechanical pumps have

increased in recent years, making them one of the most commonly preferred methods for recovering condensate.

4. Heat losses prevention

Proper lagging of all steam, condensate pipe and heating vessels with fibre glass or ross wool material that has the least heat conductivity. This would reduce the heat lossand improve energy management

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