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**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING**  
**MITIGATING CONDENSATE RECOVERY PROBLEM FOR BOILER FEED**  
**WATER IN WONJI/ SHOA SUGAR FACTORY**

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Thesis Submitted to the school of Graduate studies of Addis Ababa University in partial Fulfillment of the requirements for degree of Masters of Science in School of Mechanical and industrial Engineering  
(Specialization: Thermal Engineering)

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**Mitigating Condensate Recovery Problem for Boiler Feed Water in Wonji/Shoa Sugar  
Factory**

This is to certify that the thesis presented by Hanfato Haile Balcha, titled as “ Mitigating Condensate Recovery Problem for Boiler Feed Water in Wonji/Shoa Sugar Factory” and submitted to the School of Mechanical and Industrial Engineering in the partial fulfilment of the requirements for the award of the degree of masters of science in Thermal Engineering with the regulations of the university, and meet accepted standards with respect to originality and quality.

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## DECLARATION

I hereby declare that the work which is being presented in this thesis entitled” Mitigating condensate recovery problem for boiler feed water in Wonji/ Shoa Sugar factory” is my original work and has not been presented for a degree in this or other Universities , and that all the source of materials used for the thesis work have been duly acknowledged.

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## Acronyms

<b>AVH:</b>	Andrew Van Hook
<b>GCV:</b>	Gross calorific value
<b>MW:</b>	Megawatt
<b>MJ:</b>	Megajoule
<b>PRDS:</b>	Pressure Reducing and De-Superheating System
<b>RO:</b>	Reverse Osmosis
<b>REF:</b>	Reference
<b>TCD:</b>	Tone of cane crushed per day
<b>WSF:</b>	Wonji- Shoa Sugar Factory
<b>DCS:</b>	Distributed Control System
<b>h:</b>	Specific enthalpy, (KJ/kg)
<b>m<sub>s</sub> :</b>	Mass flow rate of superheated steam, (kg/h )
<b>h<sub>s</sub> :</b>	Specific enthalpy at superheated steam, (KJ/kg )
<b>h<sub>cw</sub> :</b>	Specific enthalpy of the cooling water, ( KJ/kg )
<b>h<sub>d</sub> :</b>	Specific enthalpy at desuperheat condition, ( KJ/kg )
<b>m<sub>cw</sub> :</b>	Mass flow rate of cooling water, ( kg/h )
<b>Q<sub>s</sub> :</b>	Heat transfer rate, ( J/s )
<b>λ<sub>s</sub>:</b>	Latent Heat, ( J )
<b>m<sub>f</sub> :</b>	Mass flow rate of liquid, (kg/s)
<b>m<sub>cc</sub> :</b>	Mass flow rate of condensate, (kg/s)
<b>h<sub>v</sub> :</b>	Specific enthalpy of vapor, (KJ/kg )
<b>h<sub>f</sub> :</b>	Specific enthalpy of liquid, (KJ/kg )
<b>U:</b>	Overall heat transfer coefficient, ( W/ ( m <sup>2</sup> . ° C )
<b>A:</b>	Heat transfer surface area, ( m <sup>2</sup> )
<b>T<sub>b</sub>:</b>	Saturated temperature of steam, ( °C )
<b>T<sub>s</sub> :</b>	Boiling point of the solution at the prevailing pr., ( ° C )
<b>ΔT:</b>	Temperature Difference, ( ° C )

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## **Abstract**

Today the competitiveness of sugar industry is dependent on the efficiency of the factory. The major contributor for the efficiency is the energy performance of the plant as sugar factory is one of intensive energy demanding manufacturing sector. Usually clarifications, evaporation, pan Boiling, and crystallization sections of sugar factory use most of thermal energy of the steam to concentrate and crystallize. In addition to run the factory without interruption continuous and sufficient supply of feed water is important. However, boilers of most sugar factories in Ethiopia are unable to supply enough steam for their respective factory operation purposes besides their electric power generation are not even self-sufficient rather they need external power supply to run the factory like Wonji shoa Sugar factory due to different reasons; one of the reasons is shortage of condensate to the Boiler as feed water. This is mainly known when exhaust steam supplied to first effect evaporator and clear juice heater is recovered only 87.5 % of it. 6.1 t/h or 146.4 tons per day hot Condensate is lost. That is 146.4 tons or 149,082 liters of treated heated water is required per day.

Therefore, thermal energy performance of the factory can be improved by increasing the amount of condensate recovered and this is accomplished by avoiding intermittent crushing, reducing down times, crushing different cane varieties together, regular inspection and maintenance of leakages on steam-condensate lines and mainly manage exhaust steam temperature delivered to first effect evaporator and clear juice heater by controlling the amount of de-superheating water.

Therefore, Boiler stoppage because of the drop of over flow level of hot well tank as the result of low condensate recovery will be reduced to zero. Consequently, the performance of the Boiler steam generation will be improved by 5%, and the loss of condensate will be minimized to zero so that avoiding downtime will help the factory to save about 7,400,000 birr per day and minimizing condensate loss helps the factory to save 4,621,543.4 birr per day. Totally the factory can save 12,021,543.4 birr per day.

### **Keywords:**

Condensate, Boiler, steam trap, exhaust steam, hot well tank, make up water, evaporator, clear juice heater

# Chapter

## One Introduction

### 1.1. Background

Sugar factory uses a large amount of heat for the production of sugar from sugar cane. The competitiveness of any sugar factory in the world is based on proper management of this generated energy. The energy performance of the industry depends on this efficiency of the Boiler. Boiler uses bagasse /Fuel as an energy source to convert the feed water to steam, which used to transport heat from the energy source to the end use devices. Then this heat can either boil the process juice or generate electricity. One of the determining factors for Boiler efficiency is the therefore Boiler feed water Type, quality and quantity. (Chen and Chou 1993a)

Now (2021 G.C) Ethiopia has eight sugar factories ( Wonji, Methara, Fincha, Kesem, Arjo Dedesa, Omo kuraze-2, Omo kuraze-3 , and Tendaho sugar factories) which are under operation. Wonji/Shoa sugar factory is one of the factories running at this time. The Electrical and Thermal Energy demand of the factory is covered by burning its byproduct called bagasse.

In Wonji-Shoa sugar factory the Boiler is designed to use condensate and/or treated water as feed water. Using this feed water Boiler produces dry saturated steam for the purpose of generating electricity and reduced temperature and pressure steam for process heating. Exhaust steam is the result of steam, which leave prime mover after generating power, called turbine extract and obtained by reducing dry saturated steam temperature and pressure using device called PRDS. This exhaust steam is usually used as thermal energy for production process. The exhaust steam which is used here condensed and returned back to the boiler as feed water after it transfer its heat energy to the manufacturing process heat exchangers called evaporators and heater.

The volume of condensate recovered to the Boiler must be close enough to the feed water demand of the Boiler as using condensate benefits much as to improve the efficiency of the Boiler ultimately improve the performance of the factory.(Lawler 2011)

## **1.2. Problem statement**

Wonji- Shoa Sugar factory is like any advanced sugar factory established to use most of its condensate as feed water for the Boiler. At the moment the factory faces low performance of the Boiler. One of the reasons for the drop of the performance of the boiler is condensate recovered for the boiler feed water is lower than the exact required amount. .

This condensate recovery problem is managed by the factory by improving operation of evaporators & heaters by changing vapor bleeding arrangements that is recovering of vapor bleed from 2<sup>nd</sup> effect evaporator and pan beside 1<sup>st</sup> effect evaporator and also activity like cleaning of scales on evaporators were carried out to improve heat transfer performance.

However, the above problem solving activities which are carried out by the factory helps a little to improve the volume of condensate recovered.

Therefore, this paper is about to assess and identifies the exact causes of low condensate volume which is returned back to the Boiler and suggests possible solutions that increases condensate recovery which is important to improve Boiler performance.

## **1.3. Thesis Objective**

### **1.2.1 General Objective**

The main objective of this thesis is to study the actual condition of condensate recovery process and identifies main causes for the shortage and suggests mitigating mechanism with available data from Wonji-shoa sugar factory based on daily crushing activity of the plant with consideration of feed water requirement of the Boiler mitigate

### **1.2.2 Specific Objective**

Specific objective of this paper is:

- ✓ To study the water balance of Boiler steam, make up water, and condensate system using material balance.

- ✓ To identify the major loss contributing steam distribution and condensate recovery lines and equipments.
- ✓ To check exhaust steam property which is supplied to first effect evaporator and clear juice heater.
- ✓ To study energy and material balance of pressure and temperature reducing system ( PRDS).
- ✓ To suggest possible solution to recover maximum condensate for the Boiler.

#### **1.4. Significance of the study**

Even though sugar industry is self-sufficient on energy, its competitiveness mainly depends on their energy performance. The performance of the Boiler is largely related to the efficiency of energy used in sugar factory. One of Boiler performance determining factor is its feed water. So managing this can largely affect the energy performance of the organization.

In case of Wonji-shoa sugar factory one of the factors that affect the performance of Boiler is condensate which is returned back and used as feed water. So working to improve the condensate recovery helps to improve the performance of the Boiler.

The factory faces frequent Boiler stoppage due to condensate shortage. First this single production process stoppage requires a lot of time (at least 1-2 days) to get into normal crushing, and second condensate lost in the system has to be replaced by treated heated water. During this time monetary loss per day will be significant and it is about 7, 400,000 birr per day without considering other costs.

The main aim of this paper is to provide vital information to the Boiler and power plant of the factory with the view of solving loss of Energy, loss of production, unnecessary water treatment cost, leakages and many more. Therefore, as the result it is possible to maximize profitability and reduce cost of production by utilizing more condensate from the process.

#### **1.5. Methodology**

##### **1. literature survey**

Review different books in order to understand the principle of condensate generation and review different journals, previous research works, guidelines and articles in order to clearly understand exactly the problem and suggest relevant and feasible solution to the problem.

##### **2. Collect necessary data**

Necessary data are collected from different sources like daily production log sheet of extraction plant, daily steam generation log sheet from boiler plant, factory design documents from design departments and each equipment design documents from the design departments. Besides direct observation was another means of collecting data.

### **3. Analyze data**

Then collected data is analyzed quantitatively and qualitatively in order to identify the causes of the problem and to suggest possible solution according to the identified character of the problem.

### **4. Discuss the Result**

After detail analysis of these collected data outcomes of each phenomenon are discussed in detail. .

### **5. Conclusion and recommendation**

Based on the results conclusion are drawn out and recommendation will be forwarded to including future works.

# Chapter Two

## Review of the literature

### 2.1 Other industry experience on condensate recovery

Any industry which uses steam has to recovery maximum amount of condensate as much as possible. Otherwise the industry incurs additional cost to treat and heat water to use for steam generation. There are many industries in the world which faces different kinds of problem on condensate recovery. Since the cause of condensate recovery problem of each industry varies according to their specific problem they use different techniques to solve these challenges. Here are few of condensate recovery problem and their solutions.

Steam, which is generated in “La caleta” Hospital in Brazil, Sao Paulo has condensate recovery system to return condensate after energy in the steam is used in hospital kitchen and Laundry. Here the Hospital uses “flash tank “in condensate recovery system to improve the energy efficiency. In the process, the 29% of the steam used is lost due to different reason and only 71 % steam condensate reaches for recovery. This lost steam quantity is replenished by makeup water. (ENCIT, 2018)

On the investigation of the steam condensate recovery system of the Hospital three cases were chosen to identity the benefit of flash tank over steam trap to maximize or increase the efficiency of the steam system and energy saving ability. In the first case on the condensate return system “ flash tank “ is placed in order only to recover flash steam of condensate from the kitchen and steam trap is installed instead of “ flash tank” for condensate recovered from the laundry. In second case, the condensate return system “flash tank” is placed in order only to recover flash steam of condensate from the laundry and steam trap is installed instead of “flash tank” for condensate recovered from kitchen. Finally, in third case “flash tank” is installed to recovery flash steam of condensate from both kitchen and laundry of the Hospital.

From the above study of the investigator the third case, where “flash tank” installed to recovery from both steam end user departments, greatest fuel saving is seen, that mean it is evident that when implementing the Flash Tank to the condensate recovery system, it will be possible to improve the energy by 3.86% and boost the Economic value 4% by reducing fuel consumption. (Rosado and de Carvalho Jr n.d.)

Sakharkar et al, reviewed on condensate recovery technique and benefits of recovering it. According to reviewed works, they analyze the values of recovering condensate instead of dumping as it contains so much amount of energy. Besides condensate, which has higher enthalpy and gives off its sensible energy during heat transfer process, recovered in the heating process is approximately 90-95% from the total possible condensate generated in system. . Steam can transfer its major component of heat content 70% (latent heat) and store the rest heat 30% (sensible heat) when condensing. Normally condensate (at low temperature) has its own steam called “flash steam”. Condensate had lost many possible ways in the processes one of them is through steam tarps (when condensate flows from higher pressure to lower pressure). Therefore, implementation of condensate recovery technique helps used to improve water management and fuel cost. (Sagar 2018)

By Kelly Paffel, technical manager, Inveno Engineering, LLC, studied benefits of returning condensate for the Boiler. When steam is supplied to the process, the vapor releases the latent heat energy to the process fluid and retain its sensible heat. This sensible energy in the condensate accounts 16% of the total energy. In high-energy demanding plants, as much as possible maximum condensate has to be returned. The analysis was performed based on energy required to elevate the makeup water to that of the condensate being returned .the calculation did not consider chemicals, water and sewer costs and assume no condensate returned to the boiler. According to his work on typical operating steam, system about \$ 835,003/yr could be lost for not returning condensate to the Boiler. If the plants wants to establish corrective measure to solve which prevent Condensate to be returned are proper condensate pumps, proper installation and suitable design of steam tarps ( as many steam tarps have drain valves) , condensate line corrosion management( proper pipe material and layout) , condensate system insulation( condensate lines, condensate tanks, valves) , and finally leaks from malfunction in the steam and condensate system and flash steam losses from tanks that vent to the atmosphere. Based on this study, if these loss areas are managed properly, maximum amount of condensate is recovered and consequently highest return on investment is possible. (Efficiency and Energy n.d.)

Apoorva Vinayak Rudra , study condensate recovery factor calculation of a Distilled Fatty Acid (DFA) plant and suggesting methods to improve this factor. This factor is the ratio of the amount of condensate recovered to steam generated.in this study steam recovered in the form of condensate is low pressure steam. Based on the study as high pressure steam cannot be further converted into recoverable form and gets used in various processes and medium pressure steam

has to go into the vacuum processes to get converted into low pressure steam, (as high pressure and medium pressure are not useful for condensate formation and low pressure steam is the only steam that can be converted to condensate and can be recovered), getting maximum amount of low pressure steam helps to get necessary amount of condensate. In this work there are various reasons are identified which makes condensate unrecoverable and working to solve on these identified reasons can improve recovery. These are steam traps (if perfectly operational, can improve recovery by 10%), leakages in different parts and equipment of the system (this is managed using ultrasonic leak detector). Besides the study was also focusses on the finding of DFA plants, condensate loss due to overflow of condensate storage tank because of its pump cavitation problem. The possible solution suggested are use mechanical pump instead of centrifugal pump this improves condensate recovery by 10 %, diverting the path of the condensate from condensate tank directly to de-aerator improve the recovery by 10%, all leaks and losses due to poor function of steam tarps must be fixed this can improve the recovery 8-10%, and finally steam recovered from steam tarps diverted to condensate storage tank or de-aerator. (Rudra 2013)

The other related article which is revised is symposium on process modeling in sugar factory. In the article Sugar factories in 40 countries have been studied and Model is developed for sugar production process improvement and its new design. In the study the steam and condensate balance is carried out. According to the study steam generated from the Boiler is 208,413.8kg/h and to produce this amount of steam it uses 210,522.6kg/h of feed water from this 2,108.8 kg/h is Blow Down. Condensate returned from the first effect evaporator after exhaust steam being used is 152,760.6kg/h, condensate recovered from other sugar boiling heat exchangers( according to the reference expression “ Boiler storage tank” ) is 55,024.9 kg/h , and the rest of the feed water( treated water) is 2,737.1 kg/h . Therefore, based on the data the proportion of treated water to condensate is 1.3 %. That is the Boiler usually use condensate recovered from the process.(L. Warner Weiss, 2015.)

## **2.2 Sugar production process**

### **2.2.1. Cane preparation**

The process of reducing the cane fed to the mill into small pieces suitable for the subsequent extraction process is referred to as cane preparation. The intention is to reduce the sticks of cane to small particles, which enables the juice to be easily extracted, but which preserves the

characteristics required for feeding to or the characteristics for an open non-compact bed if diffusion is practiced. Cane harvested from sugar cane farm is weighed using an electric weighbridge and then unloaded onto cane carrier. Then passes through devices used for cane preparation like leveler, knives and Dis-integrator (fiberizer or shredder) and make cane ready for ease juice extraction by exposing cane cell, which has cane juice. If high extractions are to be achieved, it is essential that the cane is prepared in a heavy duty shredder or fiberizer so that most of the sugar-containing cells of the cane stalk are ruptured and exposed for easy squeezing out of the juice. Therefore, Cane preparation is the most important variable which affect extraction.

### **2.2.2. Juice Extraction**

Extraction is the process by which pressure is applied to the prepared cane to extra as much juice as possible from it. Sugar cane comprises fiber, dissolved solids, and water. Separation of liquid from fiber has to be effected. This is done when Prepared cane, Ruptured and fibred, is fed to the mill where it is subjected to repeated heavy pressure slowly revolving rollers to squeeze out (extract) the juice. Besides pressing hot water (imbibitions water) is also used to maximum extraction of juice from prepared cane. The extracted juice is sent to process and the fibrous material left after milling, known as final bagasse, is sent to the boilers to be used as fuel for the generation of steam.

### **2.2.3. Juice Clarification**

The purpose of clarification process is to remove maximum possible impurities from the juice as early as possible in the process. The mixed juice from the extraction plant reaches the clarification station as a complex mixture of the integral components of cane plant. The juice contains considerable colloidal matter, fine suspended matter and other soluble constituents. Thus the mixed juice is turbid and viscous in nature and is not fit to be worked up without suitable chemical treatment. It is opaque and contains sucrose, reducing sugars, organic and inorganic matter in solution.

The composition of mixed juice varies in types and quantities depending on:

- ❖ Variety of Cane
- ❖ Maturity of Cane,
- ❖ Harvesting Practices
- ❖ Intensity and Manner of Extraction

Raw juice (mixed juice) from extraction is heated to a temperature of 70-75 °C using vapor bled from 1<sup>st</sup> effect evaporator in first heater. Then heated raw juice sent to reaction vessel for sulphitation purpose. After completion of reaction the sulphited juice is heated to 100-105 °C

using vapor bled from 2<sup>nd</sup> effect evaporator in second heater. This heated sulphited juice is sent to clarifier tank for continuous settling for the purpose of separation of mud from clear juice. This Clear juice is heated using exhaust steam from Boiler to 105-115 ° C in third heater before entering to evaporator .The settled mud is filtered by vacuum filters and filtered juice is returned to be further processed while the Oliver cake is sent out.

#### **2.2.4. Evaporation**

Evaporation generally refers to the removal of water, by vaporization, from aqueous solution of non-volatile substances. The purpose of the evaporators is then to remove the water in the juice, making its concentration more. An evaporator consists of several vessels in series. These vessels are connected so that the vapour from one goes to the calandria of the following vessels and ultimately to the last vessel which is connected to a condenser. Steam is admitted to the first vessel. Juice enters below the calandria of the first vessel where it boils and goes out by means of a down take to the next vessels and ultimately out of the last vessels as syrup.

The First Effect Evaporator receives clarified juice at a brix of about 15<sup>0</sup> and a temperature range of 115 - 120<sup>0</sup>C.using exhaust steam evaporates as maximum water as possible from the juice. The vapor at 112 - 115<sup>0</sup>C heat the Second Effect Evaporator generates vapors at 100 – 101<sup>0</sup>C to heat Third Effect Evaporator. Vapors generated in this vessel are at about 90<sup>0</sup>C and are totally supplied to the calandria of 4th – effect. This is the last effect, which delivers syrup at a brix range of 60 – 65<sup>0</sup>.

Across a multiple-effect evaporators, the operating pressure and correspondingly boiling point of juice decreases from the first to the last effect. It increases the driving force for heat transfer, the total temperature difference between the steam and the juice, which in turn increases the rate of heat transfer thereby increasing the evaporation rate.

Water is the major constituent (85 %) of clear juice while the total dissolved solids in the clarified juice are only about 15 %.Clear juice is concentrated by Boiling under vacuum in these sequentially arrange evaporators by using exhaust steam from Boiler in case of first effect evaporator and vapor bled for the rest evaporator effects to syrup.

Each vessel that the juice passes through makes its concentration (brix) more and the last vessel makes the concentration to the maximum saturation, meaning to the point where sugar crystals are about to appear. This is now called liquor and is sent to the Pans.

This is the largest consumption of thermal energy in process. It is important that the evaporation station be as efficient as possible.

Condensates are removed from the bottom of the evaporator calandrias into condensate flash tanks by means of syphons. A syphon (U – tube) is inserted between a calandria and its condensate flash tank so as to balance the pressure difference existing between them. If they were absent, the condensates would cause the flash tanks to vibrate because of the turbulence in the flash tanks, which is in turn accounted to the pressure difference between the calandria and the flash tank.

#### **2.2.5. Pan Boiling ( crystallization)**

After concentration of clarified juice in the evaporators, the syrup from evaporator is boiled under vacuum in pans for further concentration and sugar grain formation (crystallized). Crystals are developed to a desired size and the crystallized mass is then dropped in the crystallizers to exhaust the mother liquor of its sugar as much as possible. Crystallization process not only removes dissolved sucrose from solution and recovers it as solid sucrose crystals, but it is also a very powerful purification process.

There are two stages of operations in the Pans. Firstly the sugar crystals are grown to a certain size, and once this is done, it is divided into parts and sent to dropping Pans where they are heated further to remove water and grown further to the required size with washing done to prevent false grains from forming before being dropped into coolers to allow the resulting massecuite to cool. A massecuite can be defined as concentrated sugar liquor in which crystallization has taken place. It is, therefore, a mixture of crystals and mother liquor. The process of forming crystals by evaporation and concentration is known as pan boiling.

Masseccutes, owing to their high concentration, must be boiled at reduced temperature, therefore, at reduced pressure under vacuum. The reason for boiling at a reduced pressure and a corresponding low saturated vapour temperature is the decomposition of sucrose by inversion and of reducing sugars forming acid products of very dark colour.

#### **2.2.6. Centrifugal**

The process of separation of sugar crystals from molasses in massecuite is carried out in a machine called Centrifugal. There are two types of centrifugals: the batch and the continuous. The batch produces sugar intermittently and is used to cure commercial sugar. The continuous

centrifugal produces sugar continually and is used for curing low grade sugar for re-processing purpose.

Centrifugal is where the massecuite is drawn from the coolers and into centrifugals which separate the solid crystals from the liquid part of the massecuite, which is now called syrup. On the high grade side, the resulting solid crystals are end product called sugar which is then sent to the dryer with the syrup being recycled back to Pans for further processing. On the low grade side, the resulting solid crystals (known as barley) is melted to form magma and recycled back to Pans for processing. The final molasses is sent to the distillery for making alcohol.

#### **2.2.7. Packing**

The sugar thus is separated from molasses in the centrifuge is dried, bagged (50 Kg and 100 Kg), weighed and sent to storage houses.

### **2.3 Sugar factory high pressure Boiler steam generation process**

The main purpose of a boiler is to transmit heat from the heat source, combustion, to the end users called devices (equipment) which uses heat. The water in the cane also is necessary for steam production, which is very valuable for factory, in addition to fresh water supplied. When water boils there is a point called critical point where liquid phases completely changed to gas (steam) by the given pressure and temperature. Steam generation is familiar process of boiling water to make steam. Thermodynamically, the heat energy used results in a change of phase from liquid to gaseous state, i.e. from water to steam. A steam generating system has to provide a continuous and uninterrupted heat source for this conversion.

Treated and preheated water is pumped into the Boiler at operating pressure to absorb heat released from fuel (bagasse) and this heat then change the state of the water from a liquid water to steam (gas). Steam produced in this process is transported to either turbine (prime mover) or generator to produce electricity or process heating purpose. (Hugot 2014)

### **2.4 Boiler system**

#### **A basic overview of a steam system**

Usually boiler is the heart of the steam system. The typical modern packaged boiler is powered by a burner, which delivers heat into the boiler tubes. The hot gases from the burner pass backwards and forwards up to 3 times through a series of tubes to gain the maximum transfer of heat through the tube surfaces to the surrounding boiler water. Once the water reaches saturation

temperature (the temperature at which it will boil at that pressure) bubbles of steam are produced, which rise to the water surface and burst. The steam is released into the space above, ready to enter the steam system. The stop or crown Valve isolates the boiler and its steam pressure from the process or plant.

If steam is pressurized, it will occupy less space. Steam boilers are usually operated under pressure, so that more steam can be produced by a smaller boiler and transferred to the point of use using small bore pipework. When required, the steam pressure is reduced at the point of use.

As long as the amount of steam being produced in the boiler is as great as that leaving the boiler, the boiler will remain pressurized. The burner will operate to maintain the correct pressure. This also maintains the correct steam temperature, because the pressure and temperature of saturated steam are directly related.

The boiler has a number of fittings and controls to ensure that it operates safely, economically, efficiently and at a consistent pressure.(Einstein, Worrell, and Khrushch 2001) (Anon n.d.)

## **2.5 Purpose of steam for sugar factory**

A mature stalk ( mature sugar cane), which is the main raw material for sugar production, is typically composed of 11–16% fiber, 12–16% soluble sugars, 2–3% non-sugars, and 63–73% water ( which has to be removed on sugar production process). This water removing process is carried out by using heat energy which is derived from the sugar cane by product called bagasse burning. Energy which is transported to sugar juice and syrup is using water. To transport the energy water has to be transformed to steam.(Chantasiriwan 2017)

The Steam generated in the high pressure Boiler is not only used for process but also for electric power generation.

Process steam refers to all exhaust steam used in evaporation, in the pan, in sugar dryer, in centrifugal machine, molasses conditioning, and in juice heating. This will also include the effect of any diffuser heating requirements. In most cases this represents something between 40 and 60 t steam/100 t cane.

In the absence of condensing turbines, all the exhaust steam produced should be used in the process house. In a diffusion mill the minimum exhaust steam production is estimated to be 37 t steam/ t of cane with full electrification. (Reid and Rein 1983)

Steam which is generated in the boiler has to be in proper temperature and pressure for the desired process condition. Suppose the steam which is needed for sulfur melting must be at 7 kg/cm<sup>2</sup> and temperature of 170<sup>0</sup> C. and for the evaporation process it has to be 1.5 kg/cm<sup>2</sup> and temperature of 130<sup>0</sup>C.

This exhaust steam which is produced either from power generation turbine or from de-superheating and pressure reducing devices usually used for different cane sugar producing processes like evaporation unit, preheating unit, clarification (sulfur melting), vacuum pans (crystallization, and low grade sugar melting), for sugar crystal separation( centrifugal separation) , molasses conditioning , sugar dryer, syrup clarification and extraction unit mill disinfection or mill sanitation as well as diffusion extraction, in case of refinery for further sugar boiling and crystallization.

The number of evaporator effects and the extent of vapor bleeding have the greatest effect on the process steam required. It is usual to adjust the number of effects and the vapor bleed arrangements to obtain the approximate exhaust steam usage that is consistent with the desired steam and bagasse usage. (Radovic et al. 1979)

Pan steam requirement, this depends largely on the type of boiling scheme in operation. Those schemes that use a minimum number of boiling and minimize the recycle of low-grade sugar use less steam. High exhaustion in the pans leads to lower requirements. For a given type of boiling scheme, the steam usage is determined by the dissolved solids or Brix rate to the pan floor. In addition, the purity of the syrup has an effect, which lowers purity generally requiring more recycling. The amount of steam required in the pan house varies widely.

Juice heating requirement, it is usual to use exhaust steam on heating clarified juice prior to the evaporators in order to achieve a temperature above the boiling point in the first effect. Otherwise raw juice heating is generally done using vapor 1 and sometimes vapor 2 on primary heating. (Peacock and Love 2003)

Thus, if sufficient exhaust steam is generated to meet peak demand (when all pans are on stream), then when some pans are down exhaust steam may be lost to atmosphere, or vapor lost to atmosphere (if the pans are operated on vapor.) This gives not only a loss in energy but also a loss in condensate for boiler feed water. To reduce this, therefore, it is common practice to generate less than the full demand of exhaust steam and make up the remainder by passing high pressure steam through a pressure reducing valve. To determine just how much exhaust steam

should be generated requires a careful study, not only of the steam requirements of the several stations, but also of the general experience of how the factory runs with respect to cane supply, juice quality, extraction plant time schedule and time efficiency. A general rule of thumb is that about 80% of the peak processing demand should be supplied as exhaust steam. This figure should be used only as a starting point and not as a valid figure for an individual factory.

Steam pressures, usually the optimum boiler pressure is around 32 kg/cm<sup>2</sup>. This makes possible the meeting of the power demands of the factory, outside requirements for irrigation pumps and still leaves some available for export of electricity. Of course, with a profitable export electricity market, it is advisable to use the greater power generating efficiency of higher pressure. In such cases 64 kg/cm<sup>2</sup> is reasonable. Exhaust pressures should be the minimum necessary to meet the processing uses because the higher the back pressure on the prime movers, the less their efficiency. The minimum is actually determined by the requirement for heating limed juice which must be flashed as it enters the clarifier. The minimum heating temperature is therefore 102° C. The first effect evaporator vapor used for heating therefore has to be about 108°C in order to give adequate heat transfer. This means a pressure of 0.35 kg/cm<sup>2</sup>. In order to obtain this pressure, the exhaust steam should enter the first effect of the evaporator at a minimum of 0.75 kg/cm<sup>2</sup> and preferably up to 1.4 kg/cm<sup>2</sup>.

Generally, the major user of exhaust steam is of course the evaporator. Although some factories still use exhaust steam on the pan floor, this is becoming less common. The deaerator generally runs on exhaust steam and the amount required depends on the temperatures of the condensates recycled to the deaerator. In the case of exhaust condensate from the 1st effect returned under pressure, the minimum amount of exhaust is required, 2 t /100 t feed water. Under less favorable conditions, with low temperature to water the deaerator, this can increase to 10 t exhaust steam/100t feed water.

## **2.6 Boiler feed water characteristics to produce quality steam**

Water absorbs more heat for a given temperature rise than any other common inorganic substance. It expands 1600 times as it evaporates to form steam at atmospheric pressure. The steam is capable of carrying large quantities of heat. These unique properties of water make it an ideal raw material for heating and power generating processes.

Since water absorbs more heat than any other inorganic substance, it is often used to transport energy. However, when water is being used in a boiler to produce large amount energy in the

form of steam, any impurities in the water can be a detriment to the boiler itself and equipment down the line. For this reason, it's essential to know the impurities present in the water and treat them accordingly.

Boiler feed water is a **combination of the boiler makeup water** (what is required to replace any lost water in the boiler due to evaporation or water loss in blow down and processing steam) **and condensate return water** (the distilled water created when the boiler is producing steam that condensates on the internal areas of the boiler). In case of higher-pressure boilers water quality require extreme purity.

The quality of water, which is supplied into the boiler, is important. It must be at the correct temperature, usually around 80°C, to avoid thermal shock to the boiler, and to keep it operating efficiently. It must also be of the correct quality to avoid damage to the boiler.

When we use make up water as Boiler feed water like natural waters contains varying amounts of dissolved and suspended matter and dissolved gases the amount of minerals dissolved in it ranges from 30 g/l in case of sea water to 0.005 - 1500 mg/l in fresh water. Since water impurities cause boiler problems, careful consideration must be given to the quality of the water used for generating steam.

Boiler feed water composition must have reasonable impurities concentration. Otherwise if the concentration exceeds the tolerance limits of the particular boiler design it must be treated to remove impurities. When we are dealing about feed-water purity we are taking about impurities based on the required quantity and its nature. : Some impurities like hardness, iron and silica are of more concern, for example, than sodium salts. The purity requirements for any feed-water depend on the purpose of the feed water as well as particular boiler design (pressure, heat transfer rate, etc.) can tolerate. Feed-water purity requirements therefore can vary widely. Most of the time those impurities need not be completely removed instead chemical treatment inside the boiler can effectively and economically counteract them. A low-pressure fire-tube boiler can usually tolerate high feed-water impurity therefore simple water treatment can have a no counter effect but in case of High-pressure water tube Boiler the purity must be high and keeping it must be mandatory.

Besides, Ordinary untreated potable water is not entirely suitable for boilers and can quickly cause them to foam and scale up. The boiler would become less efficient and the steam would

become dirty and wet. The life of the boiler would also be reduced. And this costs a lot. That is recovery condensate can help much to reduce these cost. (lenntech n.d.)

## **2.7 Steam distribution system**

The steam generated in the boiler must be conveyed through the pipework to the point where its heat energy is required. Initially there will be one or more main pipes or steam mains, which carry, steam from the boiler in the general direction of the steam using plant. Smaller branch pipes can then distribute the steam to the individual pieces of equipment.

The steam distribution system is an essential link between the steam-generating device Boiler and the final end user, power turbine, evaporator and other units in sugar factory can help to use steam and to recover condensate economically. What so ever the source is, a well and properly designed steam distribution system can reduce the losses and improve the efficiency of steam system. Therefore, it is very essential to adopt all possible measures including new technologies.

As steam condenses in a process, flow is induced in the steam supply pipe. Condensate has very small volume compared to the steam, and this causes a pressure drop, which causes the steam to flow through the pipes. The steam generated in the boiler must be conveyed through pipe work to the point where its heat energy is required. As a steam at high pressure occupies a lower volume than at atmospheric pressure, the smaller bore pipe work is required for distribution of a given mass of steam (Arunaprasad et al. 2017).

To ensure proper steam distribution system it is important for the steam leaving the boiler is delivered to the process in the right condition. Good quality steam means dry moisture-free steam, free from air, carbon dioxide and other non-condensable matter. To achieve this pipe work, which carries the steam around the plant normally, incorporates strainers, separators and steam traps.

The function of the steam distribution system is to get the steam to where steam is needed and return the condensate as efficiently as possible. Heat losses in steam distribution account 3 to 10% of the total energy generated in a boiler. Steam distribution management can reduce steam and heat loss by improving the insulation, detecting and repairing steam and condensate leaks, maintaining the steam traps and condensate pumps. So steam distribution network has to be well

designed. For optimum performance of the distribution and steam end use equipment, a supply of right quantity and quality of steam is of vital importance.

The losses in the steam distribution system can be in the form of:

- Pressure losses in the distribution pipe lines.
- Steam leaks in joints, valves, gauges, etc.
- Steam losses due to improper selection, incorrect location, wrong positioning and malfunctioning of traps.
- Inappropriate location and capacity of air vents.
- Poor dryness fraction of steam.

From the above steam distribution losses related to condensate recovery Steam losses due to external leakages can easily be identified and can easily be managed by plugging using online sealing techniques. The valves in the bypass around the steam traps as well as mal-functioning steam traps are the main sources of internal leakages. The one which is difficult to detect is hidden and invisible flash steam. Therefore, to avoid those losses it is mandatory to have improved steam distribution system.

Important measures, which needed to be carried out to avoid problem, related to improper steam distribution system:-

- Steam main line must be properly laid out during design,
- Operation of steam distribution system should be proper like adequate draining, and air venting,
- Proper Steam traps selection and installation,
- Insulation of all steam distribution system including pipes, flanges, and valves.

A practical steam distribution system should necessarily compromise between the above ideal conditions and several other factors. Lack of attention to these will significantly increase operating costs, either because of reduction in overall efficiency or increase in maintenance costs or both.(Leech III, Rancudo Jr, and Groman 1985).

**For proper steam distribution, the followings are important:**

1. **Steam piping layout:** Steam piping transports steam from the boiler to the end-use services. Proper layout can avoid mal operation of the distribution system.

2. **Steam pipe sizing and redundancy:** Proper sizing of the steam pipelines involves selecting a pipe diameter, which gives acceptable pressure drop between the boiler and the user.
3. **Steam pressure:** The steam distribution pressure should be adjusted in accordance with the pressure generated and the pressure required at the consumer side.
4. **Insulation:** A good and proper insulation can typically reduce energy losses by 90% and help to ensure proper steam quality and pressure at plant equipment. Insulation would also reduce leakages and other issues due to erosions or water hammering due to excessive condensate in steam.
5. **Steam Traps and strainers:** As steam moves throughout the system, steam loses a small part of heat through surfaces, due to condensation. The condensate may erode the pipelines (especially at bends and partially in open valves) and even lead to water hammering and can damage equipment, if not removed effectively. Steam traps are automatic valves that separate condensate from the steam. A leaky trap wastes energy by allowing steam to enter the condensate return. A mal-functioning trap may not expel the condensate from the steam line, thus reducing efficiency of the system.

## 2.8 Control of steam distribution process

Any steam using plant will require some method to control the flow of steam. A constant flow of steam at the same pressure and temperature is often not what is required - a gradually increasing flow will be needed at start-up to gently warm the plant, and once the process reaches the desired temperature, the flow must be reduced. Control Valves are used to control the flow of steam. The actuator is the device that applies the force to open or close the Valve. A sensor monitors conditions in the process, and transmits information to the controller. The controller compares the process condition with the set value and sends a corrective signal to the actuator, which adjusts the Valve setting.

Steam produced in a boiler by the process of adding heat to the water is often referred to as **live steam**. The terms live steam and flash steam are only used to differentiate their origin. Whether steam is produced in a boiler or from the natural process of flashing, condensate has exactly the same potential for giving up heat, and each is used successfully for this purpose. The flash steam generated from condensate can contain up to half of the total energy of the condensate. An efficient steam system will recover and use flash steam. Condensate and flash steam discharged to waste means more make-up water, more fuel, and increased running costs.

Steam generated from the Boiler before use of it for the process or other lower pressure steam demanding units its temperature and pressure must be conditioned in the following ways:

### **1. Pressure reduction**

As mentioned in steam generation, steam, which is usually generated at high pressure, must be reduced for proper heat transfer to the end user. This is achieved using a pressure reducing Valve.

- 2. Steam temperature control** is another important aspect of steam conditioning. It can be performed by several methods, including the addition of de-superheated water or low-temperature steam to the high-temperature steam flow (i.e., attemperation).

Condensate returned from the process is very important over makeup treated water as mentioned earlier to get the Boiler feed water with the above characteristics, which takes additional cost for treating the water to the standard water quality and to get suitable temperature for the Boiler. It should be also heated and this makes make up water more heat demanding than recovered condensate from the process which is also unnecessary cost.

## **2.9 Condensate generation**

In most sugar industry based on its behavior has a plenty of condensate can be recovered for the boiler with risk of contamination by sugar entrainment. This happen as the sugar cane has about 70% of water and during boiling of it in multiple effect evaporators each evaporator vapor bleed used to heat the next evaporator and condensed and this condensate may also be used as Boiler feed water.

We know that sugar cane contains about 70% water. When this harvested sugar cane crushed and milled sucrose in sugar cane is extracted along with water in it. For easy removal or vaporization of this water impurities in the juice is removed by clarification as they mostly tend to retard the water molecule removing process. Now almost most of water exists in extracted sugar juice which is clear is removed in multiple effect evaporators. During this evaporation process the solution will be concentrated by evaporating water. This water vapor which leaves the evaporator process in the form of condensate, commonly called process condensate. So we can understand that most of the water in sugar cane which is removed by this process makes it surplus water industry. So we can reuse this vapor condensate for the process. (V. Ranade 2014)

From huge amount of sugar cane water content, which is extracted by milling to sugar juice, recovered usually using multiple effect evaporators (seriously arranged evaporators). This is done when the vapor from the first effect is used to heat the second effect and continue up to the last effect. The first effect is normally uses exhaust steam, and the condensate from this is returned to the boiler feed water stream, as it is essentially have no contaminant unless there is a process leak because of tube failure. (Rein 2016)

The clarified sugar juice, with 12-14% sugars, is concentrated to about 55-60% sugar using multiple effect evaporators. In turn, a lot of water is generated in the form of process condensate.

For example

5000 TCD plant could generate about 1000 m<sup>3</sup> condensate per day of process condensate from second effect alone. This is the large amount of water that could be reused. These higher effect condensates (second effect and higher) could be returned to low-pressure boilers, because there is a threefold in reusing these condensates.

## **2.10 Normal Steam and condensate circuit in sugar industry**

Condensate is a valuable resource even in small quantity recovering it will help to gain a lot economically. When the Valve on the steam pipe serving an item of steam using plant is opened, steam flowing from the distribution system enters the plant and again comes into contact with cooler surfaces. The steam then transfers its energy in warming up the equipment and product (starting load), and, when up to temperature, continues to transfer heat to the process (running load).

The resulting condensation (condensate) falls to the bottom of the pipe and is carried along by the steam flow and assisted by gravity, due to the gradient in the steam main that should be arranged to fall in the direction of steam flow. The condensate will then have to be drained from various strategic points in the steam main.

There is now a continuous supply of steam from the boiler to satisfy the connected load and to maintain this supply more steam must be generated. In order to do this, more water (and fuel to heat this water) is supplied to the boiler to make up for that water which has previously been evaporated into steam.

The condensate formed in both the steam distribution pipe work and in the process equipment is a convenient supply of useable hot boiler feed water. Although it is important to remove this condensate from the steam space, it is a valuable commodity and should not be allowed to run to waste. **Returning all condensate to the boiler feed tank closes the basic steam loop, and should be practiced wherever practical.**

In sugar production process for power generation and process heating the steam from the boiler flows directly to the pressure reducing equipments either turbine or pressure reducer and de-super heater (PRDS) to reduce its temperature and pressure. This exhaust steam from either of these devices flow directly to heat exchangers, first effect evaporator and third stage heater or clear juice heater. (Hamilton Jr 1971)

Having distributed at a high pressure, it will be necessary to reduce the steam pressure to each zone or point of use in the system in order to correspond with the maximum pressure required by the application. Local pressure reduction to suit individual plant will also result in drier steam at the point of use. **This pressure also helps to recover condensate.**

**After the heat is transferred to the juice the steam will condensed and returned back to the boiler to be used as feed water.**

Generating and distributing steam at higher pressure offers three important advantages:

- The thermal storage capacity of the boiler is increased, helping it to cope more efficiently with fluctuating loads, minimizing the risk of producing wet and dirty steam.
- Smaller bore steam mains are required, resulting in lower capital cost, for materials such as pipes, flanges, supports, and insulation.
- Smaller bore steam mains cost less to insulate.

Steam is simply boiled water which is changed its states. The heat input to water to change the state is latent heat and sensible heat. As this steam condenses, it gives up its latent heat and retains the sensible heat. Industrial processes usually use steam in heating systems must recover condensate to maintain their efficiency.

Therefore, the amount of condensate produced must approximately equal to the amount of steam generated. To recover this much condensate steam supplied to the process must be in saturated form. If the steam which is supplied to the process is superheated, enough amount of condensate couldn't be recovered.

Total heat of superheated steam

Heat of superheated steam (  $h_{sup}$  ),

$$\begin{aligned} h_{sup} &= (h_f + h_{fg}) + c_{ps} (t_{sup} - t_s) \\ &= h_g + c_{ps} (t_{sup} - t_s) \end{aligned} \dots\dots\dots (2.1)$$

Where,  $c_{ps}$  = specific heat of superheated steam.

$t_{sup}$  = temperature of formation of steam, C

$t_s$  = temperature of superheated heat, C

## 2.11 Introduction to Condensate Recovery

Steam that has been condensed back into water by either raising its pressure or lowering its temperature.

Condensate is arguably the next most valuable resource available to our plant. Containing up to a quarter of the total energy of the steam from which it came, companies should be recovering every last drop.

The source of water for steam generation in the boilers is mostly the condensate from the heat exchangers in the boiling house of Cane Sugar factory and these condensates are of two types-

- (i) Water from steam condensed in the heat exchangers.
- (ii) Condensates derived from condensed vapor obtained from juice boiling in the evaporators.

The first type of condensate is ideally suited as boiler feed since it is highly pure being produced from boiler steam but the second type i.e. the condensate from vapor besides containing the volatile matter distilled off from juice in the different stages of evaporation is likely to be contaminated with sugar bearing juice. The juice contamination results from:

- (a) Entrainment from the evaporator bodies
- (b) likelihood of damage to calandria tubes of bodies in which juice boiling takes place

These two types of condensates are separately collected and the condensate from calandrias of bodies heated by steam is invariably sent to boiler feed tank. However not all the steam generated is condensed but due to—

- a. blow down
- b. direct use of steam in process
- c. leakage or loss to atmosphere

The deficiency in the condensate from condensed steam to the tune of 5-10% is made up from the condensate from second body of evaporator or other heat exchangers like juice heater etc. heated on vapor from first body of evaporator. It is only when both these condensates are not available at the time of commencement of the crushing campaign or on account of a prolonged stoppage that the sugar factory will resort to use of raw water.(Chen and Chou 1993b)

In regard to maximum use of condensate for boiler feed purposes following steps are considered essential—

1. Condensate from juice vapor to be used for boiler feed make up should be tested often for pH and sugar traces.
2. The above condensate should be completely isolated from condensate from steam.

Condensate rendered surplus after meeting the process demand should be separately stored in a tank to be used for boiler feed in the event of shortage of all condensates to avoid use of raw water as far as possible. At any time if condensate contaminated with juice the pH of boiler water goes down due to decomposition of the sugars and other organic matter, moreover the carbonaceous material gets deposited inside the boiler tubes. In such event the factory operation is disrupted until the boiler water quality becomes normal after the necessary blow down and replacement of contaminated water by pure good quality condensate.(King 1970)

Boiler water and boiler feed water quality norms have been specified for different pressures of boilers operation and it is absolutely essential to rigidly follow the quality standards of water for smooth boiler operation.

When a kilogram of steam condenses completely, a kilogram of condensate is formed at the same pressure and temperature. An efficient steam system will reuse this condensate. Failure to reclaim and reuse condensate could cause financial, technical, and environmental problem.

Saturated steam used for heating gives up its latent heat (enthalpy of evaporation), which is a large proportion of the total heat it contains. The remainder of the heat in the steam is retained in the condensate as sensible heat (enthalpy of water).

As well as having heat content, the condensate is basically distilled water, which is ideal for use as boiler feed water. An efficient steam system will collect this condensate and either return it to a deaerator, a boiler feed tank, or use it in another process. Only when there is a real risk of contamination condensate shouldn't not be returned to the boiler. Even then, it may be possible

to collect the condensate and use it as hot process water or pass it through a heat exchanger where its heat content can be recovered before discharging the water mass to drain.

Condensate is discharged from steam plant and equipment through steam traps from a higher to a lower pressure. As a result of this drop in pressure, some of the condensate will re-evaporate into 'flash steam'. The proportion of steam that will 'flash off' in this way is determined by the amount of heat that can be held in the steam and condensate. A flash steam amount of 10% to 15% by mass is typical. However, the percentage volumetric change can be considerably more. Condensate at 7 bar g will lose about 13% of its mass when flashing to atmospheric pressure, but the steam produced will require a space some 200 times larger than the condensate from which it was formed. This can have the effect of choking undersized trap discharge lines, and must be taken into account when sizing these lines.(Hamilton Jr 1971)

Steam produced in a boiler by the process of adding heat to the water is often referred to as live steam. The terms live steam and flash steam are only used to differentiate their origin. Whether steam is produced in a boiler or from the natural process of flashing, it has exactly the same potential for giving up heat, and each is used successfully for this purpose. The flash steam generated from condensate can contain up to half of the total energy of the condensate. An efficient steam system will recover and use flash steam. Condensate and flash steam discharged to waste means more make-up water, more fuel, and increased running costs.(Guo-dong 2011)

Note: The term 'trap' is used to denote a steam-trapping device, which could be a steam trap, a pump-trap, or a pump and trap combination. The ability of any trap to pass condensate relies upon the pressure difference across it, whereas a pumping trap or a pump-trap combination will be able to pass condensate irrespective of operational pressure differences (subject to design pressure ratings). (Rein 2016)

The steam supply to the evaporators is usually exhaust steam, which may be at a pressure between about 180 and 250 k pa. The corresponding vapor saturation temperatures are 1170C and 1270C. Here the pressure is expressed in k pa absolute values. It should be remembered that 100 k pa is equivalent to 1 bar.

The last vessel in the set of evaporators normally runs at a pressure between 12 and 17 kpa, corresponding to saturated vapor temperatures of 49<sup>0</sup>C and 57<sup>0</sup>C. this pressure range roughly corresponds to a vacuum of between 26.5 “ and 25 “ mercury in most sugar mills, which tend to be located close to sea level. The same vacuum at different elevations or atmospheric pressures

gives different absolute pressure and saturation temperature. This is a good reason to prefer the use of absolute pressure to vacuum in all cases.

The best performance from an evaporator set is obtained when it is run as steadily as possible. This is generally achieved through the use of automatic controls. The exhaust steam must be supplied at a steady pressure, which should be a prerequisite of any sugar mill steam supply and distribution control system. However the operation of batch pans supplied with vapor fed from the evaporators will always constitute a disturbance, which needs to be taken into account in the operation of the evaporators.

There is considerable evidence in the literature to show that there is an optimum liquid level in the tubes, generally assumed to be at a level one quarter to one-half of the height of the tubes from the bottom of the calandria (e.g. Guo et al 1983, Jones and pozzetti 2000). *Watson* (1986) reported a maximum at 25% and a slow drop off up to 50%. Very low liquid levels mean that there is insufficient liquid to evaporate and fully utilize the surface area; high levels are assumed to reduce evaporation because of a hydrostatic head effect. This effect is reportedly independent of liquor Brix. In practice this dependency on liquid level is not always as obvious as some of the literature reports indicate. Nonetheless the level in each vessel (assuming Robert evaporators) should be controlled at a steady value.

Boiler feed water levels and flows are critical to proper boiler operation. If feed water flows are reduced and the water level decreases to the point where the Boiler runs dry, the tubes will overheat and fail. If the boiler water level becomes too high, excess water will be carried over into the steam distribution system. This negatively affects process facility steam consumers and can damage turbines and other equipment.

De-superheated Steam Superheated steam might not be the best choice for heat transfer in some heat exchangers because the amount of energy given up by superheated steam is relatively small compared to the energy given up by saturated steam.

Also, some facility processes cannot tolerate the high temperatures of superheated steam. The process of cooling the superheated steam is called de-superheating. De-superheated steam is superheated steam from which some heat has been removed by the reintroduction of boiler feed water. Typically, de-superheating does not occur at the boiler but at specific points in the process where boiler feed water is injected into superheated steam.

An effective condensate recovery system is collecting the hot condensate from the steam using equipment and returning it to the boiler feed system.

Steam generation and condensate recovery systems can vary in complexity depending on the steam end usage and process requirements,

## **2.12 Condensate handling**

The condensate from each of the heaters was pumped to the process water tank for use throughout the factory. The condensate from first effect evaporator was pumped directly to the boiler water storage tank, if the control parameters were met these being calandria pressure and conductivity.

If either of these two conditions was not reached, the condensate was dumped to the 'hot well' Where the conductivity was again measured. If the conductivity from the hot well was below the set point, the condensate was directed to the boiler water storage or to the process water storage, as determined by the level in the boiler water storage tank. If the conductivity of the condensate in the hot well tank was above the set point, the condensate was directed to the process water storage tank.

The condensates from #2 and #3 evaporators were sent directly to the hot well tank where the final destination was determined by the conductivity. The condensate from #4 and #5 evaporators was pumped directly to the maceration tank. Any excess water from the maceration tank overflowed to the process water tank.

## **2.13 Boiler feed water Level control**

If the water level inside the boiler were not carefully controlled, the consequences could be catastrophic. If the water level drops too low and the boiler tubes are exposed, the boiler tubes could overheat and fail, causing an explosion. If the water level becomes too high, water could enter the steam system and upset the process.

For this reason, automatic level controls are used. To comply with legislation, level control systems also incorporate alarm functions which will operate to shut down the boiler and alert attention if there is a problem with the water level. A common method of level control is to use probes which sense the level of water in the boiler. At a certain level, a controller will send a signal to the feed pump which will operate to restore the water level, switching off when a predetermined level is reached. The probe will incorporate levels at which the pump is switched on and off, and at which low or high level alarms are activated. Alternative systems use floats.

It is a legal requirement in most countries to have two independent low level alarm systems.

## **2.14 Wonji-shoa sugar factory**

### **2.14.1. History and Location**

Wonji shoa sugar factory located in the Oromia regional state downstream of the Koka Dam in central Rift Valley of Ethiopia in the Awash River Basin, which is 110 Km southeast of Addis Ababa. It is situated at  $8^{\circ} 21'$  to  $8^{\circ} 29'$  N and  $39^{\circ} 12'$  to  $39^{\circ} 18'$  E.

In Ethiopia history Wonji is the first and the oldest sugar factory start crushing sugar cane in 1954 E.C producing plantation of white sugar and the second one is Shoa sugar factory commence production of the same sugar in 1969 E.C. After the commencement of the new sugar factory both are closed and stop production since 2006 E.C. The new Wonji Shoa sugar factory is starting to crush 6,250 tons daily with a potential of bagging 7,000 Quintal sugar daily.

### **2.14.2. Organizational structure of WSF**

#### **Sugar manufacturing process in Wonji shoa sugar factory**

Sugar production process in Wonji start from harvesting. Based on the cane harvesting scheme cane is burned and cut manually using cane cutting knives and transported to the factory using different types of trucks and trailers. After being weighed in the weighed bridge it will be mechanically unloaded onto two cane tables. These cane pieces are dropped over a continuous belt of steel plates called the cane carrier, moving over roller chains. Cane then pass through series of two rotating cane knife to reduce the size of the cane into small piece. Reduced cane passes through shredder for disintegration, rupture and for perfect exposure of inner material of sugar cane for juice extraction. This stage is cane preparation.

When prepared cane subjected to five heavy pressures slowly revolving roller mills which are arranged in a single train, the juice will be achieved by squeezing out between two rollers from exposed sugar cane fiber and leaves the dry pulp or bagasse for Boiler fuel. A countercurrent stream of maceration water is used to remove the juice from the crusher. Hot water is used for maximum extraction of the juice as the cane fiber which is already squeezed and leave the juice will be again squeezed after hot water added replace the squeezed juice in cane fibers cells. Unlike olds factory steam driven mills the power required to drive Wonji shoa sugar factory extraction unit is electrical. The efficiency of the extraction is depend on the roller groove meshing, the hydraulic press.

Mixed or Raw juice from milling tandem or extraction has many impurities like dirt, cane fiber, and other unwanted particles which are from the harvested farm, and from processing

machineries including roller chips. This impurity has to be removed by heating and purification using flocculants filter aids and lime as they inhibit the formation of crystal and can discolor the final product. The main purpose of clarification is to separate insoluble suspended matter and some soluble substance from cane juice, to obtain clear juice. The factory use dor clarifier for this purpose. Hydraulic press is used t extract juice from prepared cane.

The clarified juice is boiled in seriously arranged multiple effect vessels called evaporators with the steam fed to it to concentrate up to 60-65<sup>0</sup> brix called syrup. There are two lines one as a standby where each line has first effect semi-kestner evaporator and the rest four effect are Robert type evaporators. The process is, clear juice from clarification unit enters into tube of calandria and exhaust steam from the Boiler flow over the tube. Concentration is by using exhaust steam from the Boiler for the first effect and for the subsequent heating the vapor from preceding vessel is used.

The syrup produced in evaporator is further concentrated in Sugar Boiling unit which is conducted under vacuum called pan. Here the concentration raises dissolved sugar crystallizes and in crystallizer this concentrate crystal further grow continuously through cooling using stirrer then crystal with molasses called massecuite is produced. The massecuite is then put into centrifugal machine for separation of sugar crystal and molasses.

#### **2.14.3. Wonji- shoa sugar factory steam generation and distribution system**

Wonji Shoa sugar factory has two bagasse fired Boiler, which has the capacity of 130 t/h super heated steam with the pressure of 65 bar and a temperature of 510+/- 5 ° C. Theses Boilers are designed as Natural circulated, top supported, bi-drum, bagasse fuel, water tube and has furnace oil fuel firing option.

The bagasse which is used as fuel is derived from prepared cane wet milling process and its moisture must be 50 % with GCV of 9.5 MJ/kg. The moisture of the cane can increase up to 54 % and its GCV also can be 8.7 MJ/kg.

Steam distribution header receives steam from the boiler and distributes the same to various end users. Steam generated from Boiler at the outlet with a pressure of 65 bar are used in the factory for three purposes. The first one with the pressure of 64 bar and temperature of 505<sup>0</sup> C used for the turbine to generate electricity, the second one which could be extracted from Turbine or directly reduced in PRDS to the pressure of 9 bar/7 bar/ and temperature of 170 °C that is used to melt the process sulphur and the third one which could be extracted from Turbine or directly

reduced in PRDS to the pressure of 1.5 bar and temperature of 120 ° C is used for de-aerator, feed water and for the process.

Generated steam from the Boiler transported to Steam Turbine with the maximum flow rate of 164 t/h at 64 bar and 505 °C temperature is extract steam either to 9 bar at a flow rate of 19.8 t/h or to 2.6 bar at flow rate of 117t/h. The nominal capacity of steam Turbine is 30MW.

Condensate from turbine condenser shall be used as boiler feed water. Hence this water shall be used as cooling water for gland steam condenser. Also steam emanating from condenser steam jet ejector shall be used to further raise the temperature of condensate from turbine. The condensate from gland steam condenser and ejector steam shall be piped back to hot well of turbine condenser. The increase in the temperature of the condensate shall be advantageous for boiler operation.



Figure 2.1: Woni /shoa sugar factory first effect evaporator condensate flash tank

Clean condensate recovered from first effect evaporator and third heater (clear juice heater) is temporarily collected in the condensate flash tank before pumping to the hot well tank for the boiler feed.



Figure 2.2 : Wonji/shoa factory surplus tank for condensate and make up water

Two 150 m<sup>3</sup> hot well carbon steel tank receive and store both condensate and treated make up water. These tanks are suited to return surplus/excess feed water. After the feed water De-aerated and heated with 1.5 bar exhaust steam from 80-85 °C to 105 °C stored in De-aerator water storage tanks, which has the capacity of 120m<sup>3</sup>. The pumps shall draw feed water from de-aerated feed water storage tank and deliver the same to the Boiler top drums through economizer. The maximum efficiency of the pump shall be at operating capacity of 85t/h.

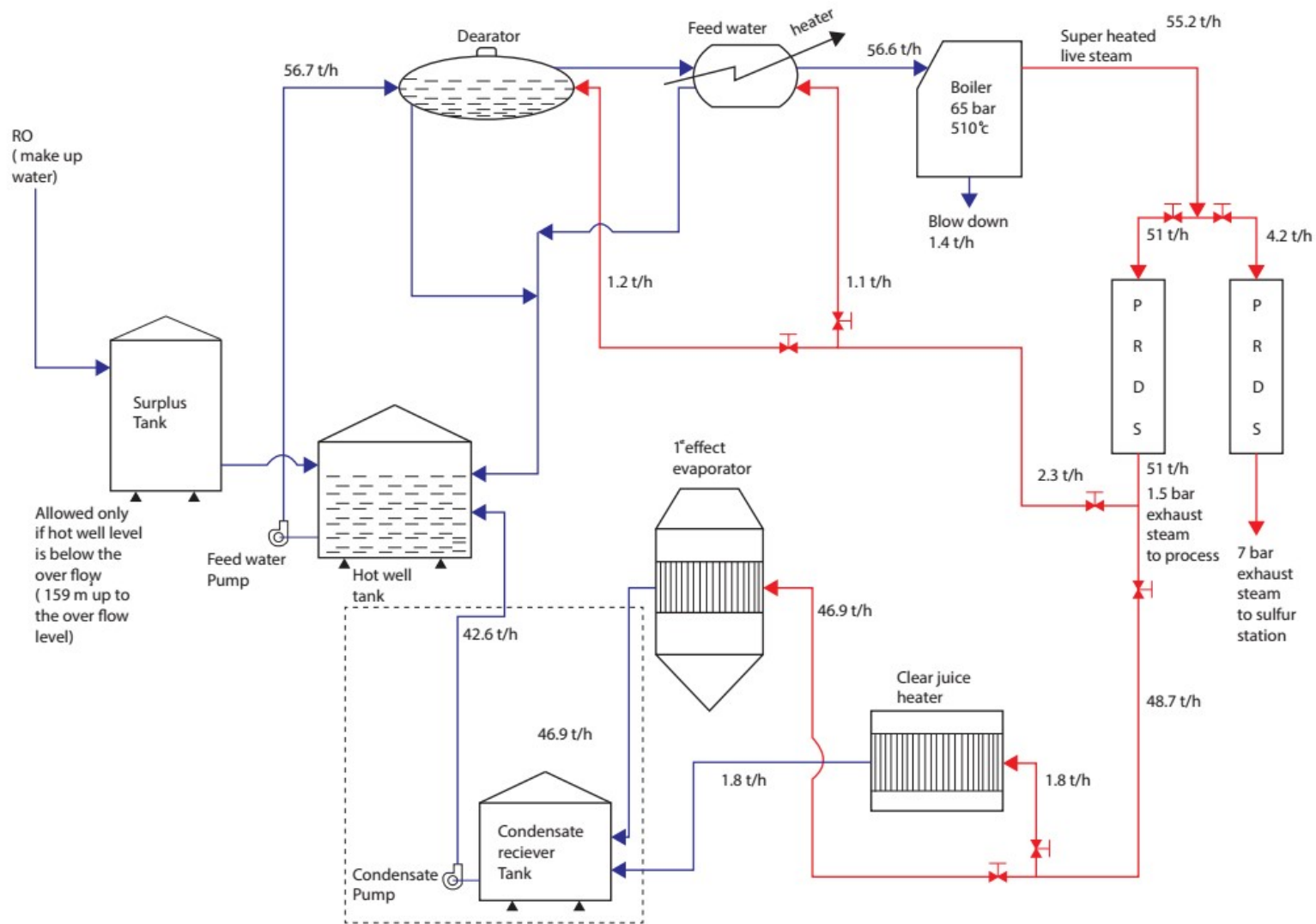


Figure 2.3: Schematic diagram of Wonji /shoa sugar factory steam condensate system

There are also two separated carbon steel fabricated surplus tanks to receive continuous and intermittent blow down separately from each Boiler. It is designed as flash tank to flash the steam which is used as motive steam to heat de-aerator.

Reduced pressure and temperature steam for the process goes to both clear juice heating and first effect evaporator. Exhaust steam used for clear juice heating uses Plate heat exchanger at the pressure of 1.5 bar and temperature of 130 °C and Exhaust steam for First effect evaporator, long tube rising film type vessel (semi-kestener) used to boil juice and condensate from both clear juice heater and first effect evaporator is collected in condensate receiver (condensate flash tank) as seen in figure 2.1 and returned back to the Boiler. Process exhaust steam condensate which is used as feed water enter hot well through its condensate header, pass through de-aerator flowing counter current to the motive steam.

### Schematic diagram of exhaust steam and condensate

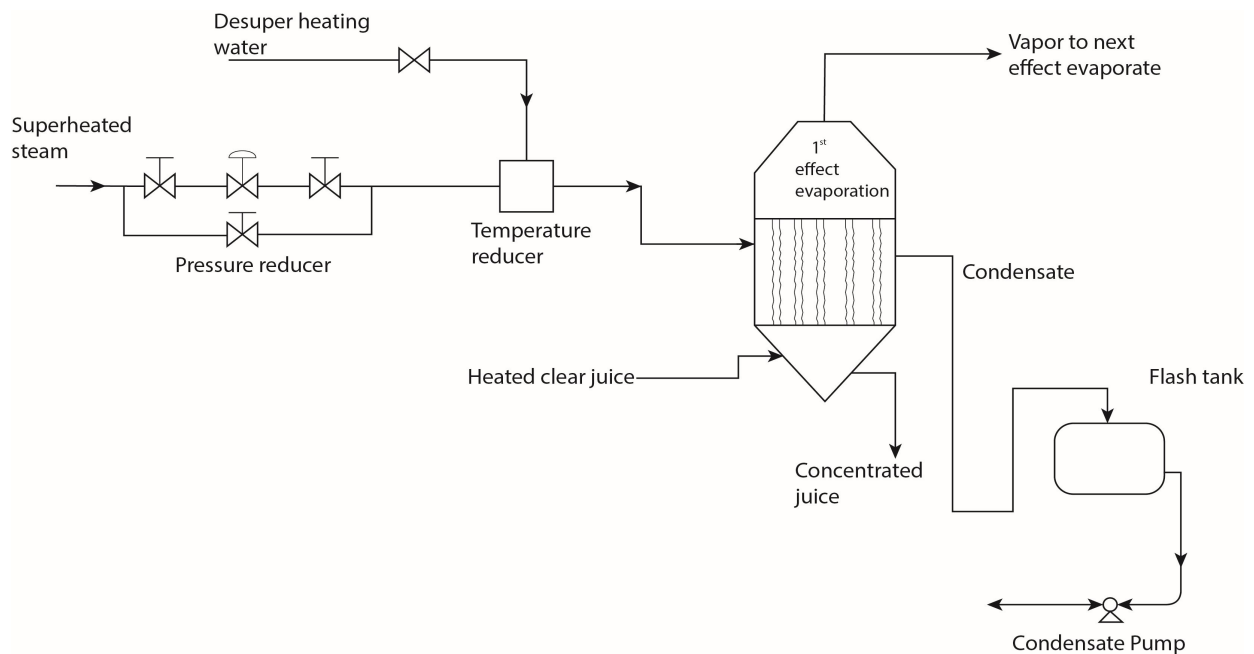


Figure 2.4 : Schematic diagram of Wonji /shoa sugar factory exhaust steam controlling unit, and first effect evaporator exhaust steam- condensate system

**Suppose 1t of saturated steam at a pressure of 1 bar (boiling point 100<sup>0</sup> C) requires the following energy.**

1. Heating fresh water ( assume 20<sup>0</sup>C ) to the boiling point of 100<sup>0</sup> C

$$Q = mc_p \Delta T = (1000\text{kg}) * 4.184 \text{ KJ/kg} \cdot \text{k} (100-20) = 334.72 \text{ MJ}$$

2. Evaporating water to steam at 1 bar

$$Q = m * \Delta h_v = 1000\text{kg} * 2260\text{kJ/kg} = 2260 \text{ MJ}$$

$$\text{Total energy Input: } \cong 2600\text{MJ}$$

To heat fresh water to boiling point consumes approximately 13% of the energy required for steam production. Consequently, it is important to recovery condensate prior to discharge it into the drainage system. Even if the condensate can only be recovered at a lower temperature of 60 to 80 <sup>0</sup>C, around 7-10 % of the energy consumption can be saved by simply collecting the condensate separately and returning it to a collecting tank for the boiler feed water.

In superheated steam sensible heat must be removed prior to condensation. As condensing is a goal. The latent heat of steam is recovered at rapid heat transfer rates. Here the question is on heat transfer rate.(Hamilton Jr 1971)

### **2.15 Main reasons to prefer saturated steam over super-heated steam**

1. The heat transfer coefficient of the condensing steam film (in case of saturated steam) is much higher than super-heated steam. It is around ten times more, ranging between 8000 to 10000 kcal/m<sup>2</sup>/hr/degree C against 1000 unit of super-heated.
2. The heat carrying capacity of saturated steam, (as latent heat/ enthalpy) is most optimal. The enthalpy of the super-heated steam increases very marginally on being super-heated and hence heat carrying capacity.
3. Super-heated steam is highly erosive due to high velocity and temperature and therefore it is very prone to causing leakages in pipe and further aggravating it at very faster rate, as has been observed in practice.

In power generation by steam turbine, super-heated steam is being used to avoid any damage to turbine blade due to condensation. Secondly, in case of steam turbine what matters is energy not

heat transfer coefficient, Therefore, for heat transfer equipments like exchanger or re boiler, saturated steam is preferred. (shakti kumar 2017)

### **Comparison of Saturated over Superheat Steam Conditions**

In a boiler, energy from the fuel is transferred to liquid water in order to create steam. Once the water is heated to boiling point, it is vaporized and turned into saturated steam. When saturated steam is heated above boiling point, dry steam is created and all traces of moisture are erased. This is called superheated steam.

Superheated steam has a lower density, so lowering the temperature does not revert it back to its original liquid state. Dropping the temperature of saturated steam, however, will revert it back to its old form of water droplets.

Superheated steam has more energy and can work harder than saturated steam, but the heat content is much less useful. This is because superheated steam has the same heat transfer coefficient of air, making it an insulator and poor conductor of heat.

Saturated steam is preferred for heating applications, while superheated steam is used mostly in power generation and turbines. If steam is needed for both power generation and heating, the steam can be superheated then desuperheated to its saturated condition.(NationWide Boiler , 2021.)

Although superheated steam contains a large amount of heat energy, this energy is in three forms;

1. enthalpy of water ( sensible heat) ,
2. enthalpy of evaporation (latent heat) and
3. Enthalpy of superheat (sensible heat). The bulk of the energy is in the enthalpy of evaporation, and therefore energy in the superheat represents a smaller proportion.

The coefficient of heat transfer when using superheated steam as the heating medium is variable, low and difficult to quantify accurately. This makes accurate sizing and control of heat transfer equipment difficult, and will also result in a larger and more expensive heat exchanger.

Once the superheated steam is cooled to saturation temperature, the heat transfer coefficient increases dramatically, and the temperature at which the steam condenses back into water is constant. This greatly assists accurate sizing and control of heat transfer equipment.

## **2.16 De-superheating process**

De-superheating process is the restoration of saturation state or reduction of temperature of superheated water.

Most of de-superheating system restores saturation state by discharging or reducing temperature to approximately 30C above saturation state.

### **There are two type of de-superheater**

1. Indirect contact type: - the cooling medium liquid is used to reduce the temperature of the superheated steam. Here the superheated steam is supplied to one side of the heat exchanger and a cooler medium is supplied to the other side. As the superheated steam passes through the heat exchanger, heat is lost from the steam, and gained by the cooling medium.
2. The temperature of the de-superheated steam could be controlled by either the inlet superheated steam pressure or the flow rate of the cooling water. Control of the superheated steam flow for this purpose is not normally practical and most systems adjust the flow of the cooling medium.
3. Direct contact type: the medium used to cool the superheated steam comes into direct contact with it. Most of the time the cooling medium is the same as the fluid (water) as the vapor to be de-supeheated, but in the liquid state.

When we select this type of de-supheater, a measured amount of water is added to the superheated steam via a mixing arrangement within the de-superheater. As it enters the de-superheatr. The cooling water evaporates by absorbing heat from the superheated steam. Then the steam temperature will be reduced.

Control of the amount of water to be added is usually achieved by measuring the temperature of the steam downstream of the de-superheater. The set temperature of the de-superheated steam would typically be 3°C above that at saturation. Therefore, in such arrangements the inlet pressure of the superheated steam should be kept constant.(King 2001)

Superheated steam would have to be cooled to its dew point to become saturated. The type of condensate recovered from the body of semi kestner. Vapor and liquid mixture proportion. The latent heat of condensation of the steam is transferred to the boiling solution (juice) through the heating surface in order to vaporize the water. Thus, the two enthalpy balance is required one for the liquid and another for the steam.

The following assumptions are required in order to make the enthalpy balance.

1. Flow of non-condensable is negligible.
2. The superheat and subcooling of the condensable steam is negligible.
3. No solid precipitates out from the concentrated solution.



Figure 2.5: Wonji shoa sugar factory 1.5 bar PRDS

**The enthalpy balance of the steam side**

$$Q_s = m_s(h_s - h_c) = m_s \lambda_s \dots\dots\dots (2.2)$$

Where

$Q_s$  = rate of heat transfer through heating surface from steam.

$M_s$  = flow rate of steam

$h_s$  = specific enthalpy of steam

$h_c$  = specific enthalpy of condensate

$\lambda_s$  = latent heat of condensation of steam

**The enthalpy balance for the liquid side is**

$$Q_s = (m_f - m_{cc}) h_v - m_f h_f + m h \dots\dots\dots (2.2)$$

Where

$Q_s$  = rate of heat transfer from heating surface to the liquid.

$h_v$  = specific enthalpy of vapor

$h$  = specific enthalpy of thick liquid

$H_f$  = specific enthalpy of feed

$m_f$  = flow rate of liquid feed

$m_{cc}$  = flow rate of concentrated liquid

The enthalpy balance at steam side and liquid side will be the same in the absence of any heat loss. Thus,

$$Q_s = m_s \lambda_s = (m_f - m_{cc}) h_v - m_f h_f + m h$$

Heat transfer rate based on overall heat transfer rate

$$Q_s = UA\Delta T \dots\dots\dots(2.3)$$

$$\Delta T = T_b - T_s$$

$W/r$

$U$  = overall heat transfer coefficient

$A$  = heat transfer surface area

$T_b$  = saturated temperature of steam in the shell

$T_s$  = Boiling point of the solution at the prevailing pr.

## Chapter Three

### Methodology and Data analysis

#### 3.1. Data collection

Data collected in Wonji shoa sugar factory for this thesis are mainly from factory design documents, from log data sheet which is from DSC, direct observation. These data are either primary or secondary as data collected directly from observation and measurement are primary and those data from log sheet operation data, archive design documents, and other researcher findings are secondary data.

##### 3.1.1 Design data

Factory design Crushing capacity is 261tch all design parameters are based on this value.

##### 3.1.1.1. Exhaust steam consumption

Table 3.1: Design exhausts steam parameters

S. No	Exhaust steam consumption	t/h	%cane
1.	Exhaust steam to effect-1	95.92	36.75
2.	Exhaust steam for clear juice heater	1.51	0.58
3.	Exhaust steam for variable pan steam demand	6.53	2.5
4.	<b>Process exhaust steam demand</b>	<b>103.96</b>	<b>39.83</b>
5.	Exhaust steam for Dearator	6.11	2.34
6.	Losses @ 1% on total demand	1.11	0.43
7.	<b>Total 1.5 bar process Exhaust steam demand</b>	<b>111.18</b>	<b>42.6</b>

#### Exhaust steam

Pressure (kg/cm<sup>2</sup>): 1.5

Temperature (°C): 115.87

Based on the above design data most of process saturated steam is supplied to the evaporator. That is from total process saturated steam of 103.96 ton/hr 95.92 ton/hr process saturated steam is to evaporator operation which is 92.3 %.

### 3.1.1.2. Clean and sweet condensate generation in WSF

Based on the existing design of the plant, 6250 TCD, the hourly crushing capacity would be 261 tch. So according to the design the condensate production at individual sections of the plant is given below.

Table 3.2: All design return condensate parameter

S.No	Description	Clean condensate		Sweet condensate	
		t/h	% Cane	t/h	% cane
1.	Raw juice heaters	-	-	18.5	7.09
2.	2 <sup>nd</sup> stage Sulphited juice heater	-	-	5.7	2.18
3.	3 <sup>rd</sup> stage Sulphited juice heater	-	-	12.7	4.87
4.	1 <sup>st</sup> stage Clear juice heater	-	-	6.98	2.67
	2 <sup>nd</sup> stage Clear juice heater	1.51	0.58	-	-
5.	1 <sup>st</sup> effect evaporator body	95.92	36.75	-	-
6.	2 <sup>nd</sup> effect evaporator body	-	-	78.85	30.21
7.	3 <sup>rd</sup> effect evaporator body	-	-	17.92	6.87
8.	4 <sup>th</sup> effect evaporator body	-	-	11.25	4.32
9.	5 <sup>th</sup> effect evaporator body	-	-	11.05	4.23
10.	Pans	-	-	64.12	24.57
	<b>Sub Total</b>	<b>97.43</b>	<b>37.33</b>	<b>227.07</b>	<b>87</b>

Thus, as per the design, 261 tch, total clean (exhaust steam) condensate generated is 97.43t/h (37.33 % on cane) and sweet condensate (from vapor bleed) condensate generated is 227.07 t/h (87% on cane). From table 3.1 and 3.2 it is clear that condensate supplied to the process must be returned back to the Boiler.

### 3.1.1.3. Feed water requirement for the Boiler

As per design parameter clean condensate shall be used as feed water to steam generation plant and sweet condensate shall be used for process usage since sweet condensate most of the time could have some trace sugar from vapor bleed entrainment.

Table 3.3 : Design feed water requirement

S.N	Description	t/h	% cane
1.	Total steam generation	163	62.49
2.	Blow down losses	3.26	1.25
3.	System losses	1.63	0.62
4.	De-superheating water for medium pressure steam	0.21	0.08
5.	De-superheating water for FW heater steam	1.48	0.57
6.	De-superheating water for Dearator exhaust steam	0.31	0.12
7.	De-superheating water for process exhaust steam	5.32	2.04
8.	<b>Total feed water requirement</b>	<b>175.31</b>	<b>67.17</b>

In the above table (table 3.3) total feed water required for the Boiler is 175.31 t/h.

### 3.1.1.4. Feed water balance

Now let us see feed water balance of the plant.

Table 3.4 : Boiler feed water balance

S. No	Feed water balance	t/h	% cane	Remark
1.	Condensate from process house	97.43	37.33	
2.	Condensate from turbine condenser	30.9	11.84	
3.	Condensate from Dearator	6.11	2.34	
4.	Condensate from FW heater	18.58	7.12	
5.	<b>Total clean condensate available</b>	<b>153.02</b>	<b>58.63</b>	
	<b>Make up Feed water from RO plant</b>	<b>22.28</b>	<b>8.54</b>	From total 175.3t/h water demanding and available 153.02 it need additional make up water.
	<b>Total Feed water available</b>	<b>175.3</b>	<b>67.16</b>	

According to the design of the plant export power has to be generated for National grid by operating power turbine. Medium pressure steam and exhaust steam is extracted from turbine and to be used in steam generation and process house and clean condensate shall be returned back to Boiler plant.

So we can see that clean condensate from the process house and condensate from the turbine (condensing mode) is returned back to the Boiler as feed water. Besides some extracted steam from turbine is also used to heat Boiler feed water and clean condensate is recovered from this too for Boiler feed. De-aerator also uses exhaust steam for heating. Its condensate is also recovered for the Boiler feed water.

When we sum up all condensate of exhaust steam, total feed water quantity available will be 153.02 t/h and the total feed water required by the Boiler is 175.3 t/h. the deficit, 22.28t/h shall be covered by RO plant as per design.

### 3.1.2 Actual condition of the plant ( data from Boiler operation)

From steam generation plant DCS data collected on different dates. It is noted that exhaust condensate flow meter reading are as follows:

#### 3.1.2.1 Steam generation and feed water supply

Table 3.5 : Steam generation and feed water supply data

Date	25/12/20 19	26/12/20 19	27/12/20 19	28/12/20 19	1/01/20 20	2/01/20 20	3/01/20 20	Average
Steam generation/ day (t/d)	1524	1127.2	1164	1406.4	1381	1476.7	1199.4	
Average Boiler steam Generation/hr (t/h)	63.5	46.9	48.5	58.6	57.54	61.5	49.9	55.2
FW consumption/day (t/d)	1567.2	1158.9	1212	1365.6	1423.2	1505.0	1280.8	
Average FW	65.3	48.2	50.5		59.3	62.7	53.3	56.6

consumption/hr (t/h)				56.9					
1.5 kg/cm <sup>2</sup> PRDS steam Supply / day (t/d)	1377.6	1026.6	1108.8	1284	1286.4	1432.5	1058.8		
1.5 kg/cm <sup>2</sup> PRDS steam Supply/hr (t/h)	57.4	42.7	46.2	53.5	53.6	59.6	44.1	<b>51</b>	

### From the above data

- Average steam generation is 55.2t/h.
- Average steam delivered to 1.5 kg/cm<sup>2</sup> PRDS is 51 t/h. The rest of generated steam goes to different processes like sulphur station and for preheating.
- Feed water required for the Boiler is 56.6 t/h.

Generally, from the above data we can see that unlike the same amount of condensate for a supplied steam as described in the design, actually due to many reasons less amount of condensate is recovered.

### 3.1.2.2 Factory actual operation data

- Crushing rate: 208 tch
- Pol % cane: 13.23
- Heated Clear juice : 205.25 t/h (98.68 % cane)
- Heated Clear juice (Bx) : 15
- Exhaust steam pressure: 1.5 kg/m<sup>2</sup>
- Temperature : 178.83 °C .
- Evaporation of first effect 72.95 t/h ( 35.07 % cane )
- Condensate of first effect: 72.11 t/h
- Outlet brix of first effect evaporator juice : 23.28 (Bx)
- Heating surface of first effect : 3000 m<sup>2</sup>
- Specific evaporation rate : 24.32 kg/h.m<sup>2</sup>/h

- Design coefficient: 5.26 kg/h.m.<sup>0</sup>C.

Table 3.6: Return exhaust condensate

Date	Return condensate flow to boiler , Totalizer reading, m <sup>3</sup>	Condensate recovered per day	Average condensate recovery ,m <sup>3</sup> /h
25/12/2019	1867422	1037	43.21
26/12/2019	1868341	919	38.29
27/12/2019	1869369	1028	42.83
28/12/2019	1870318	949	39.54
01/01/2020	1871361	1043	43.45
02/01/2020	1872438	1077	44.87
03/01/2020	1873541	1103	45.96
<b>Average</b>			<b>42.6</b>

### 3.1.3 Condensate recovery condition of the plant

- a. From the table 3.5 and table 3.6 we can see that; - average feed water supply to the steam generation plant (Boiler) is 42.6 t/h and exhaust steam supplied to the process house is 55.2 t/h.

Here we can clearly see that there is a huge gap between exhaust steam supply to the process house and exhaust steam condensate returned. About 12.6 t/h exhaust steam ( 22.8 % of the total generation) being used at somewhere else in the process or being lost through leakages, condensate drains, vents etc and creating shortage for steam generation.

When we see specifically see exhaust steam supply to first effect evaporator and clear juice heater 7.4t/h exhaust steam (14.5 %) is lost.

This is the first reason which shows the existence of condensate recovery problem.

- b. From Exhaust steam temperature and hot well tank level we can see that: - exhaust steam supply to first effect evaporator at constant pressure of 1.5 bar and the different temperature affects the percentage level of hot well, which is the mixture of treated water from RO plant

(constant supply) and recovered condensate from the process. The following table indicates the level of hot well tank in different exhaust steam temperature.

Table 3.7 : Exhaust steam temperature and hot well tank level

Range of dates of observation	Average temperature of exhaust steam , °C	Reaches 60 % of the total hot well level in, days	Remark
21/11/2019-24/11/2019	171	4	During this time the supply of treated water is kept constant.
30/11/2019-04/12/2019	152.5	5	
10/12/2019-14/12/2019	155	5	
17/12/2019-20/12/2019	163.4	4	
5/01/2020-09/01/2020	151.1	5	
13/01/2020-16/01/2020	168	4	
18/02/2020-21/02/2020	173.4	4	

The factory has two RO plants one as a standby with generating capacity of 30 m<sup>3</sup>/h each and when one of them runs can generate 600 m<sup>3</sup> per day of treated water in 20 hours with 4 hour generation time. However, unlike design system now both plants are under operation and they are generating only 14.87 m<sup>3</sup>/h treated water.

When we see table 3.5, 3.6, it is clear that about 12.6 ton/h of condensate is lost from the system especially in evaporation unit, and when we look at table 3.7 as make up water from RO plant is constant, hot well tank which is the mix of both condensate and make up water, the level drop of the tank shows that condensate recovered from the system is lower than the exhaust steam supply.

Therefore, this is the other reason which shows the existence of condensate loss in the system.

**3.1.4 Other possible reasons for condensate shortage for the Boiler are analyzed from the following tables :-**

**1. Intermittent crushing**

Table 3.8 : Effect of intermittent crushing on condensate recovery

Date	cane crushed per day	Down time	Cane Crushing rate	Daily Totalizer reading of Boiler	Quantity of condensate recovered per hour
	quintals	hour	tch		
21/11/2019	14004	17.25	58.35	1840561	24.12
22/11/2019	36254	9.17	151	1841505	39.33
23/11/2019	36087	10.25	150	1842437	38.83
24/11/2019	16659	16	69.41	1843079	26.75
29/11/2019	29361	12.5	122.33	1847094	32.42
30/11/2019	25648	15	106.8	1846211	28.01
1/12/2019	34985	10.63	145.77	1847114	37.63
2/12/2019	30684	12.51	127.84	1847909	33.13
<b>Average</b>	<b>27960</b>	<b>12.91</b>	<b>116.4</b>		<b>32.52</b>

**3.1.4.1 Leakages in steam and condensate system of the plant.**

Continuous leakage of exhaust steam from pipelines, through steam traps, valves, drains, vents are observed in the factory at different units and plants. The extent of leakage by observation might indicate the continuous loss of steam through these areas of the steam distribution and condensate return lines in 24 hours a day and 7 days of a week can affect the balance of condensate.

Some of these leakages are highlighted below:

1. Clear Juice heater steam and condensate lines ;
2. Evaporator exhaust steam header drain;
3. Near boiler exhaust steam header heavy leakage;
4. And every lines, valves , pump glands, flanges,



Figure 3.1: WSF different exhaust steam leakages, steam line drains, exhaust valve leakages at juice heater, juice heater condensate syphon, and exhaust valve leakages.

#### **3.1.4.2 Variation in cane quality especially in fiber % of cane**

The abnormal wide variation in cane quality parameters like fiber % cane affects material balance, evaporator balance and ultimately condensate balance.

Table 3.9: Cane fiber content and the corresponding condensate recovery

Date	Cane crushed per day	Average fiber% cane	Totalizer reading of the Boiler	Quantity of condensate recovered per hour
6/12/2019	34064	14.58	1851304	36.96
7/12/2019	35867	13.65	1852238	38.92
10/12/2019	33654	15.13	1854783	36.54
16/12/2019	30447	15.91	1859795	35.8
17/12/2019	31105	15.35	1860659	36.01
18/12/2019	30847	18.83	1861471	33.83
<b>Average</b>		<b>15.57</b>		<b>36.08</b>

### 3.1.4.3 Superheated temperature varies

Table 3:10 Superheated temperature of superheated steam

S.No	Superheated Temperature (°C)	Remark
1.	171	For pressure of 1.5 bar
2.	152.5	
3.	155	
4.	163.4	
5.	151.1	
6.	168	
7.	173.4	

The above data is used for material and energy balance to determine the amount of de-superheating water to condition the superheated steam favorable for heat transfer in evaporator.

### 3.2. Data analysis

The analysis is performed using the above data from the Wonji Sugar Factory as input and first using graphs to see the trend of condensate related to different parameters, and besides using

these data calculation of steam enthalpy supplied to the evaporator will also be carried out. Then analysis of the steam entering to the evaporator and the condensate leaving the evaporator based on the design and actual conditions will be performed. And at the end of the analysis the exact cause of the problem will be determined.

1. Exhaust steam temperatures effect which is identified in condensate tank level.

When we look at those random data, which is the temperature of exhaust steam produced in the PRDS for the evaporator and the level of hot well tank, which is the intermediate storage of feed water, we can see that when the temperature rises the corresponding tank level drop quickly.

Based on the data the level of hot well tank becomes lower and lower because of small amount of condensate returned from the evaporator.

Since most of the exhaust steam (1.5 bar) generated in the Boiler goes to the first effect evaporator the condensate recovered from this unit has large effect on the feed water tank level.

2. The balance of Steam generated and condensate recovered

Normally make up water is designed to supply feed water for the loss of steam in different points of generation and uses like in blow down, vents, and some unavoidable points. But in this case the steam supply and condensate recovery the loss is significant.

### **3.1.5 Exhaust steam temperature effect on condensate**

From factory loge sheet we can extract data which relates exhaust steam temperature of 1.5 bars, which is supplied to the process, to condensate recovered? Here most of exhaust steam temperature are beyond the expected design value (1.5 bar pressure and 110 °C saturated steam temperature).Based on enthalpy temperature graph this steam is superheated steam since saturated steam temperature is above design value at constant pressure. Based on heat transfer characteristic we know that superheated steam is less valuable. Consequently it will generate less amount of condensate. This causes condensate shortage for the Boiler.

When we look the steam distribution and condensate recovery systems in the first effect evaporator body, there are steam and flash steam leakages on those lines and condensate recovery system including storage tanks, valves and pumps.

According to table 3.7, temperature versus hot well tank level drop due to depletion of feed water shortage indicates that the exhaust steam supplied to the evaporator is one of the main reasons.

Therefore, the exhaust steam temperature has to be controlled by either power turbine or pressure and temperature reducing device called PRDS. If the plant uses power turbine exhaust steam temperature would have been easily controlled, but from the commencement of the plant the turbine operates only for a while with limited efficiency. This makes the plant to use PRDS till now and controlling exhaust steam temperature comes a challenge. As we can see in the above description this temperature has to be managed and we have to reduce to the desired parameter. This is done by de-superheating superheated steam in temperature and pressure reducing unit before it enters into the evaporation unit. Then after analyzing the problem and managing the temperature we have to keep and maintain it by developing a model in this unit. .

Therefore, let us analyzing PRDS and investigate to identify the exact problem on exhaust steam temperature.

### **3.1.6 Analyze the performance of PRSDS**

Earlier when discuss on condensate shortage , as seen in schematic diagram of steam and condensate circuit on figure 2.3 most of exhaust steam( 1.5 bar) generated is used in first effect ( semi kestener) evaporator and clear juice heater. And recovering this condensate help a lot to maintain boiler feed water supply. But to recovery the steam supplied the temperature of the steam must be to the desired value for given pressure. To control the temperature analyzing pressure and temperature reducing units as seen in schematic diagram on figure3.1 is important.

We know that when superheated Steam is supplied to the evaporator, total heat the sum of latent heat and sensible heat is delivered.

Therefore, heat available per kg of steam is

Sensible heat of superheated steam + latent heat of vaporization + sensible heat of condensate.

Even though superheated steam has larger heat content than saturated steam the useful energy is lower, beside the superheated steam is in entirely gas state which has lower heat conductivity that leads to steam without condensate. Therefore, steam which is supplied to the evaporator must be without superheated steam. (Einstein et al. 2001)

The energy supplied to steam loads comes from the latent energy in the steam and not from the sensible energy. Once the steam condenses it is no longer part of the heat transfer process. When the steam is being used at the pressure that the steam is being generated, it requires less steam (in tons) to supply the required latent energy at a lower pressure than at a higher pressure.(Rein 2016)

The capacity of each tank up to the overflow level shall be  $800\text{m}^3$ .

The temperatures of condensates from different calandrias are less than those of vapors and roughly correspond to the temperatures calculated by following formula—

Temperature of condensate = temperature of vapor - 0.4 [temp. of vapor - temp. of juice in the vessel]. This is formula is to calculate the total condensate in multiple effect evaporator. But in our case we only focus on the first effect evaporator condensate or clean condensate.

Thus the condensate from first vessel will be around  $95^\circ - 100^\circ\text{C}$  and as this is derived from condensed exhaust steam is sent to boiler feed tank. The condensate from second vessel is at about  $90^\circ\text{C}$  and is partially used to make up for the shortage of boiler feed water, the remaining being used in the process.

The exhaust steam from prime movers (power turbine) is usually at a higher temperature than corresponds to its saturation temperature and as it falls short of the process requirements, arrangements are provided for bleeding live steam at  $5\text{ kg/cm}^2$  in the exhaust. As superheated steam has poor heat transfer properties desuperheating of exhaust steam is effected in a separate unit known as desuperheater, wherein with addition of water the temperature of steam is brought down. With manual operation of this valve, the regulation of steam temperature is unreliable as many times the temperature on the exhaust line can be higher by nearly  $50^\circ\text{C}$  above the saturation temperature. Now a day's automatic control system which regulates the water valve operation on the basis of temperature at the outlet has proved to be beneficial and it is absolutely essential to install thermostatic control for desuperheating unit.(King 2001)

Therefore, steam supply of the plant is not consistent on its temperature and it has to be controlled.

This is done by developing a model to control the steam supplied to the evaporator which is especially in temperature and pressure controlling unit in shown in the schematic drawing.

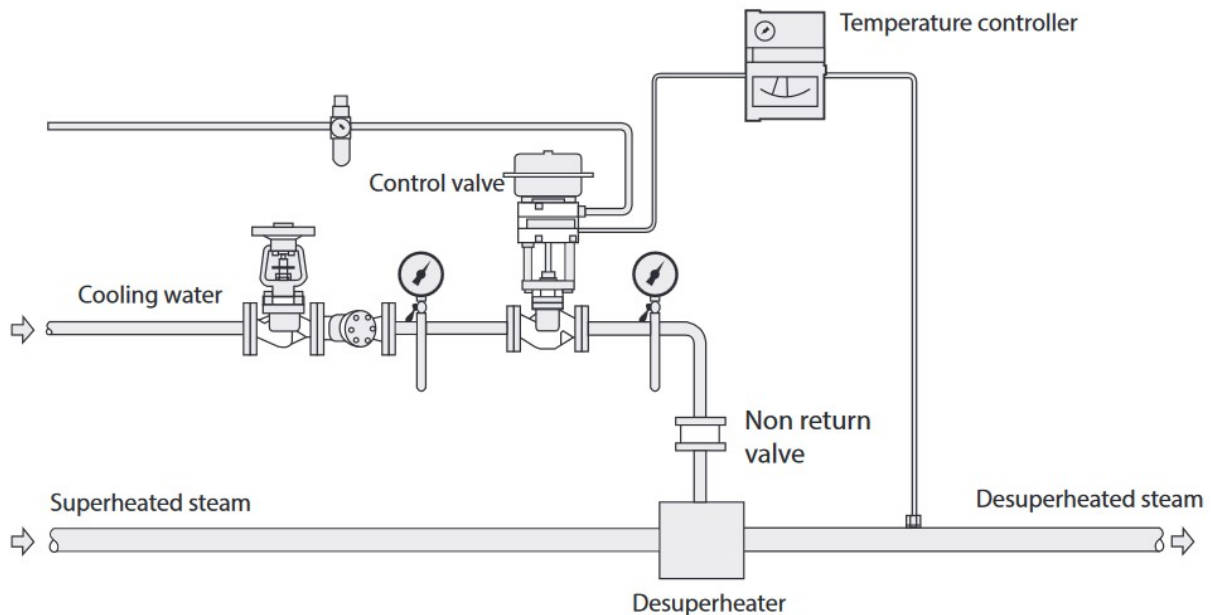


Figure 3.2 : - schematic diagram of temperature control unit

### 3.1.7 Effect of heat transfer and exhaust steam and condensate formation in semi-kestner evaporator Body

Based on the relationship of temperature versus heat content (enthalpy) of water the in the state of saturated steam if the temperature is above the saturation temperature keeping pressure constant make the steam will be in superheated state and steam on this condition has less valuable energy than the saturated steam. (Leech III et al. 1985) We can see in Wonji sugar factory saturated steam produced is usually above the out of the standard saturation state that is the pressure is controlled but the temperature is usually above the saturation temperature this makes the steam used in first effect evaporator leave without the energy being used consequently the steam leave along with condensate and the vapor leave the line at different points that leads to condensate shortage.

So in order to control the steam entering to the first effect is done in temperature controlling unit and so developing a model is important to control the temperature of saturated steam consistently

### **3.3. Alternative design for Wonji Shoa Sugar factory Boiler superheated steam to use steam for the process**

Wonji shoa sugar factory Boiler is designed to generate superheated steam of 65 bar pressure and temperature of 510°C for the purpose of producing 30 MW electricity to export it to Ethiopian Electric Utility National grid by operating DEC turbine. Medium pressure steam and exhaust steam is extracted from this turbine and to be used in process house.

Normally the factory pressure and temperature reducing device (PRDS) is designed to be used when the power turbine stop operation because of different technical reasons like maintenance.

However, since 2019 G.C boiler of WSF power turbine stop working due to turbine technical failure and since then the boiler which has a capacity of generating 64 bar pressure and 510°C temperature of superheated steam extraction and supply of medium pressure steam and exhaust steam to the process is carried out by using PRDS.

Process steam used in any factory originally steam generated in boiler is often generated at higher pressure than pressure required for the specific purpose. Whatever the needs for lower pressure steam, a pressure reducing station will be required.

High pressure steam can be reduced

Wonji shoa sugar factory requires additional pressure and temperature reducing devices besides the existing one. The existing PRDS has also be modified to reduce the pressure of new PRDS which will be installed to reduce boiler high pressure steam.

This can be done by designing and installing new PRDS, which reduces boiler live high pressure steam to a medium pressure. That is high pressure steam (65 bar) generated in the boiler can be reduced to medium pressure steam( 32 bar) , then this pressure is further recued to the required steam pressures 7 bar steam for sulfur melting station and 1.5 bar process steam using the existing PRDS.

On this new approach design to reduce high pressure steam, a step pressure reduction can be used to control the temperature as well as the pressure according to the demand of the factory different plants like sulfur station and evaporation station.

Therefore, as described in the schematic diagram in figure 4.2 wonji shoa sugar factory can install a new pressure reducing station which reduces pressure from 65 bar to 32 bar. The material of the pipes, valves, drains and flanges are the same as described in the factory design documents.

According to the design documents of the factory the following table describes the material and the size of this new pressure reducing station.

Table 11 pipe sizes and material of construction of pressure and temperature reducing station.

S.No	Steam pressure (bar)	Valve class	Material	Thickness (mm)
1.	65	Class 900	SA 335 P11 alloy steel seamless	21.44
2.	32	Class 900	SA 106.Gr B	10.64
3.	7	Class 300	IS 1539/I.S.2062	4.02
4.	1.5	Class 300	IS 1539/I.S.2062	2.4

Piping shall meet all the requirement of ASTM.

The drain connection shall be fitted with suitable valves, strainer and steam traps to prevent the steam from escaping through drain pipe. Steam traps shall be provided on all points likely to collect condensate and traps also be fitted at the end of high pressure, low pressure and exhaust steam and also upstream side of all isolating valves.

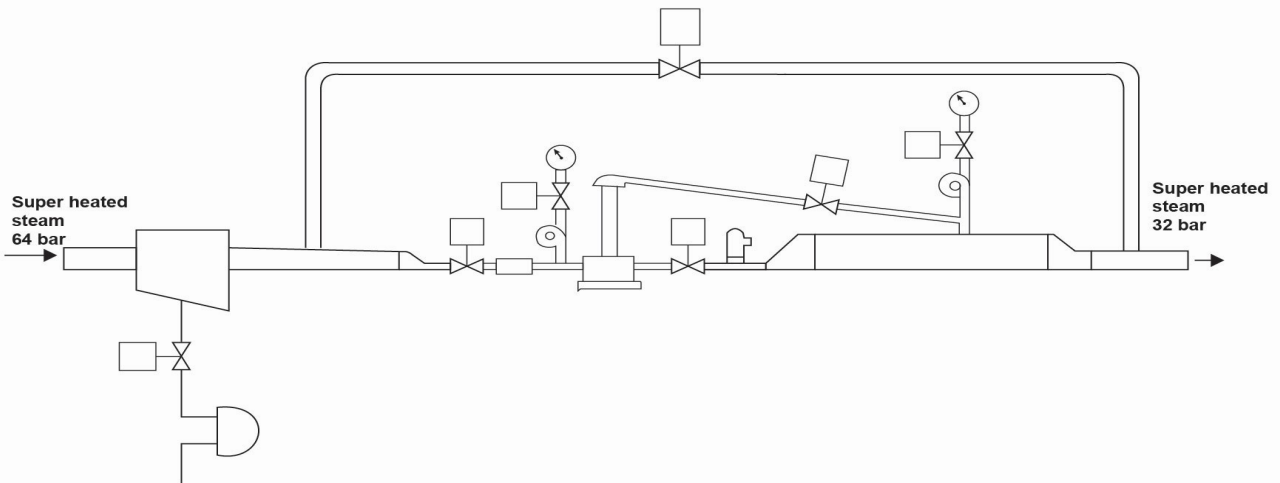


Figure 3.3: New approach of wonji/shoa sugar factory high pressure steam reducing station (65 bar to 32 bar)

This design is proposed since wonji/shoa sugar factory Boiler which was designed to generate high pressure steam which would produce 30MW electric power for its own and to export for the national grid but unfortunately the power turbine was mechanically failed and no stand by power turbine. Besides the factory uses extracted steam from the turbine for different purposes like sulfur station (sulfur melter), and process heating (evaporation) purposes. Since no power turbine is out of operation the factory has to find a mechanism to use this high pressure to the process and for sulfur melting. However, in addition to existing PRDS system additional pressure reducing system is included, which has the ability to reduce this high pressure live steam of 65 bar to intermediate high pressure steam 32 bar. On this design pipe size is selected from the graph on Appendix C.

This new design pressure reducing station will be incorporated on the generated live steam line as shown in the figure 3.4.

### Schematic diagram of step pressure reducing station

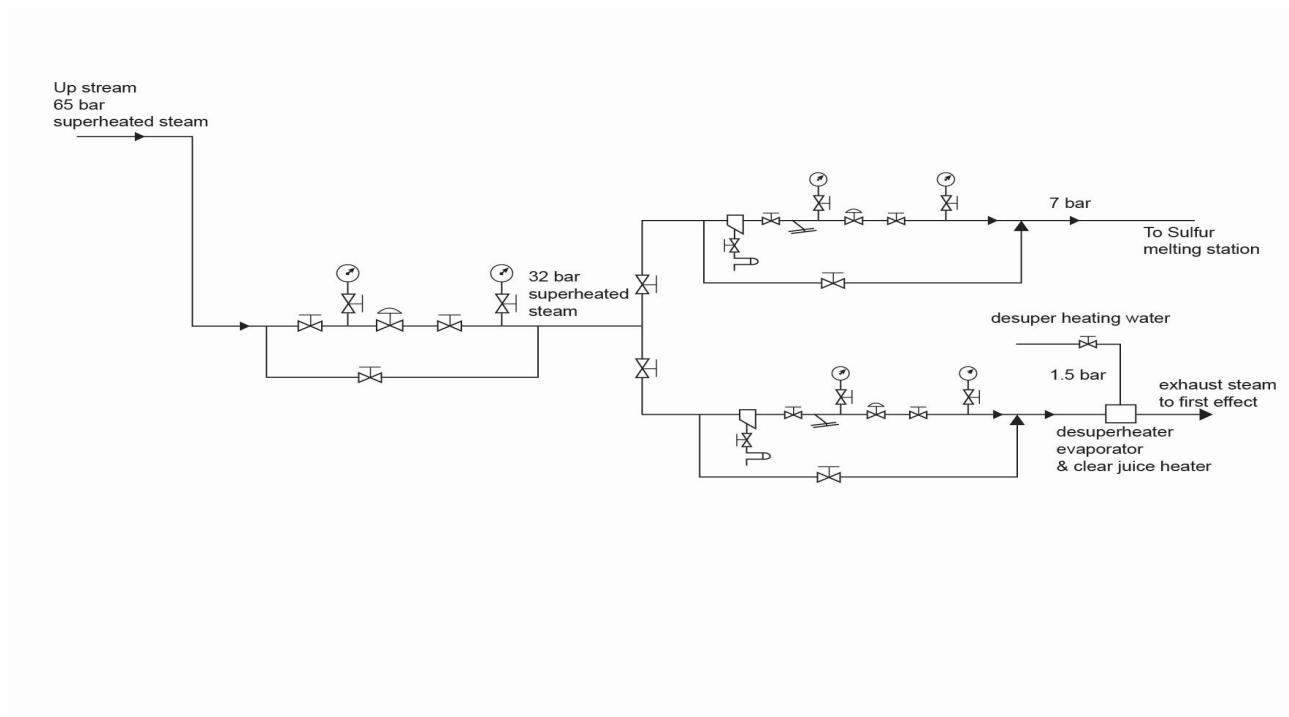


Figure 3.4: Schematic diagram of new approach to reduce wonji/shoa sugar factory high pressure steam

## **Chapter Four**

### **Mathematical modeling**

#### **4.1. Modeling of de-superheating steam unit**

Condensate recovered for the boiler is significantly depend on the exhaust steam quality ( temperature) which is supplied to the first effect evaporator since most of exhaust steam ( recoverable steam) generated is delivered. These exhaust steam temperature has to be continuously controlled during factory operation.

In order to control these exhaust steam temperature continuously modeling of the system is very important. The purpose of modeling of the de-superheating system is to control the flow rate of the cooling water to manage the steam temperature supplied to the evaporator.

#### **4.2. The temperature and pressure controlling unit based on Schematic diagram 3.1**

Cooling water heat content and temperature diagram if the temperature but the temperature of the exhaust steam for a pressure of 1.5 bar must be around 108-110<sup>0</sup> C . So in order to attain the temperature the amount of de-superheating (cooling) water required must be controlled.

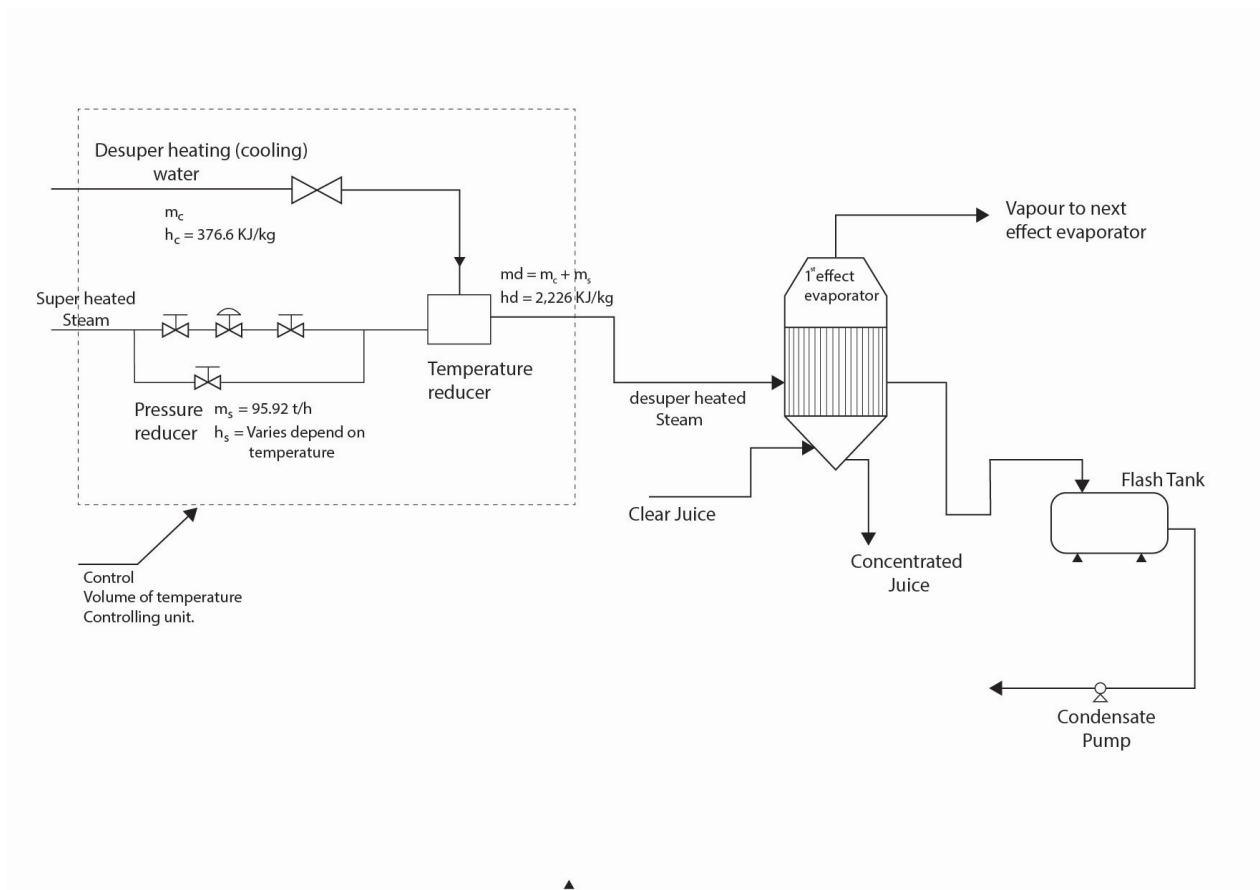


Figure 4.1 : Schematic diagram of wonji/shoa sugar factory control volume of temperature and pressure reducing unit

**To develop a model**

We use both mass and enthalpy balance for temperature control unit of de-superheater unit of the factory. Assume  $Q=W=0$  and  $K_E = P_E=0$ .

**Mass Balance**

$$m_{cW} + m_s = m_d \dots\dots\dots 3.1$$

Enthalpy Balance to the process= enthalpy out of the process

**Enthalpy in**

$$(m_{cW} * h_{cW}) + (m_s * h_s) = (m_d * h_d) \dots\dots\dots 3.2$$

From equation (3.1) and (3.2)

$$(m_{cW} * h_{cW}) + (m_s * h_s) = (m_s * h_d) + (m_{cW} * h_d) \dots\dots\dots 3.3$$

Manipulating equation (3.3) ,

$$m_{cw} = \frac{m_s(h_s - h_d)}{(h_d - h_{cw})} \dots\dots\dots 3.4$$

Then

$$m_{cw} = \frac{m_s(h_s)}{h_d - h_{cw}} - \frac{m_s(h_d)}{h_d - h_{cw}} \dots\dots\dots 3.5$$

Assume:  $h_{cw}$  ,  $h_d$  ,  $m_s$  are constants;

$$\text{Let } , \quad R = h_d - h_{cw}$$

Then equation (3.5) becomes

$$m_{cw} = \frac{m_s(h_s)}{R} - \frac{m_s(h_d)}{R} \dots\dots\dots 3.5$$

$$\text{Let } , \quad k = \frac{h_d}{R} , \quad M = \frac{m_s}{R}, \text{ and } \quad C = m_s * k$$

$$m_{cw} = M * h_s(T) - C \dots\dots\dots 3.6$$

Using equation we can now develop a model for table 3.5 enthalpy values

Where,

- $m_{cw}$  = mass flowrate of cooling water (kg/h)
- $m_s$  = mass flowrate of superheated steam (kg/h)
- $h_s$  = Specific enthalpy at superheat condition (kJ/kg)
- $h_d$  = Specific enthalpy at desuperheated condition (Kj/kg)
- $h_{cw}$  = Specific enthalpy of cooling water at inlet connection(kJ/kg)

**Actual condition for the model**

- $m_s$  = mass flowrate of superheated steam = 95.92t/h
- $h_{cw}$  = Enthalpy of the cooling liquid = 4.2 kJ/kg°C x 110°C =462 kJ/kg
- $h_d$  =Enthalpy at desuperheat condition(at 110°C / saturated steam )=
- $m_{cw}$  = mass flowrate of cooling water (kg/h)

In order to determine the flow rate of de-superheating cooling water in temperature pressure reducing system let us first determine the specific enthalpies of superheated steam, de-superheated steam and, de-superheating (cooling) water.

**a) Determination of specific enthalpy of superheated steam for corresponding temperature of constant pressure ( 0.15 Mpa = 1.5bar)**

To determine the enthalpies of superheated steam let us use data from Table 3.10 and determine enthalpy for corresponding temperature.

First we have to determine enthalpies of temperatures for 1 bar and 2 bar from superheated steam table then interpolating it to 1.5 bar.

- i. From superheated steam table of 0.1 Mpa or 1 bar

For temperature of **171<sup>0</sup>C**

For 150<sup>0</sup>C super heated steam enthalpy is 2776.6 KJ/kg

For 200<sup>0</sup>C superheated steam enthalpy is 2875.5 KJ/kg

**Interpolating**

$$\begin{aligned}h_{171} &= \{(2875.5-2776.6)/(200-150)\}*(171-150) + 2776.6 \\ &= (1.978)*(171-150) + 2776.6 \\ &= \underline{\underline{2,818.1 \text{ KJ/kg}}}\end{aligned}$$

For temperature of **152.5<sup>0</sup>C**

$$\begin{aligned}h_{152.5} &= (1.978)*(152.5-150) + 2776.6 \\ &= \underline{\underline{2,781.5 \text{ KJ/kg}}}\end{aligned}$$

For temperature of **155<sup>0</sup>C**

$$\begin{aligned}h_{155} &= (1.978)*(155-150) + 2776.6 \\ &= \underline{\underline{2,786.5 \text{ KJ/kg}}}\end{aligned}$$

For temperature of 163.4<sup>0</sup>C

$$\begin{aligned}h_{163.4} &= (1.978)*(163.4 -150) + 2776.6 \\ &= \underline{\underline{2803.1 \text{ KJ/kg}}}\end{aligned}$$

For temperature of **151.1<sup>0</sup>C**

$$\begin{aligned}h_{151.1} &= (1.978)*(151.1 -150) + 2776.6 \\ &= \underline{\underline{2778.7 \text{ KJ/kg}}}\end{aligned}$$

For temperature of 168<sup>0</sup>C

$$h_{168} = (1.978)*(168 - 150) + 2776.6$$

$$= \underline{\underline{2812.2 \text{ KJ/kg}}}$$

For temperature of 173.4<sup>0</sup>C

$$h_{173.4} = (1.978)*(173.4 - 150) + 2776.6$$

$$= \underline{\underline{2822.8 \text{ KJ/kg}}}$$

ii. From superheated steam table of 0.2 Mpa or 2 bar

a) For temperature of 171<sup>0</sup>C

For 150<sup>0</sup>C super heated steam enthalpy is 2769.1 KJ/kg

For 200<sup>0</sup>C superheated steam enthalpy is 2870.1KJ/kg

**Interpolating**

$$= \{(2870.1-2769.1) / (200-150)\}*(171-150) + 2769.1$$

$$= 2.02*(171-150) + 2769.1$$

$$= \underline{\underline{2811.5 \text{ KJ/kg}}}$$

For temperature of 152.5<sup>0</sup>C

$$= 2.02*(152.5-150) + 2769.1$$

$$= \underline{\underline{2774.1 \text{ KJ/kg}}}$$

For temperature of 155<sup>0</sup>C

$$= 2.02*(155-150) + 2769.1$$

$$= \underline{\underline{2779.2 \text{ KJ/kg}}}$$

For temperature of 163.4<sup>0</sup>C

$$= 2.02*(163.4-150) + 2769.1$$

$$= \underline{\underline{2796.2 \text{ KJ/kg}}}$$

For temperature of 151.1<sup>0</sup>C

$$= 2.02*(151.1-150) + 2769.1$$

$$= \underline{\underline{2771.3 \text{ KJ/kg}}}$$

For temperature of 168<sup>0</sup>C

$$= 2.02*(168-150) + 2769.1$$

$$= \underline{\underline{2805.3 \text{ KJ/kg}}}$$

For temperature of 173.4°C

$$= 2.02 * (173.4 - 150) + 2769.1$$

$$= \underline{\underline{2816.3 \text{ KJ/kg}}}$$

iii. Now interpolate to 1.5 bar superheated steam table

Interpolation of 1.5 bar will be the value between 1 bar and 2 bar and the values are tabulated as follows

Table 4.1 : interpolated Enthalpy of actual exhaust steam temperature

S.No	Temperature of exhaust steam, °C	Specific enthalpy, kJ/kg
1.	171	2,814.5
2.	152.5	2,777.8
3.	155	2,782.8
4.	163.4	2,799.6
5.	151.1	2,775
6.	168	2,808.8
7.	173.4	2,819.6

b) Specific enthalpy of saturated steam, which supplied to the evaporator body with temperature of 111.3°C and pressure of 1.5 bar from-saturated steam table is **2,226 KJ/kg.** and

c) The specific enthalpy of compressed cooling water (desupheating water) is.

$$h = C_p * \Delta T, \text{ where } C_p = 4.184 \text{ KJ/kg.}^\circ\text{C}$$

$$= 4.1284 \text{ KJ/kg.}^\circ\text{C} * (90^\circ\text{C})$$

$$= \underline{\underline{376.6 \text{ KJ/kg}}}$$

Then it is possible to use these values and average exhaust steam mass flow rate for different temperature to calculate the required mass flow rate of cooling water (de-superheating). The following data is generated.

From required saturated steam and de-superheating data s

R= 1849.4 and k = 1.203, M= 0.0518, C = 115.39

Then equation (3.6) becomes

$$m_{cw} = 0.0518 * h_g(T) - 115.39 \dots \dots \dots 3.6$$

Using equation (3.6) we developed a model and generate the table 4.1.

Table 12 : Mass flow rate of de-superheating water for corresponding temperature

S.No	Superheated steam temperature, °C	Corresponding specific enthalpy in KJ/kg	Mass flow rate required, t/h
1.	171	2,814.5	30.4
2.	152.5	2,777.8	28.5
3.	155	2,782.8	28.76
4.	163.4	2,799.6	29.63
5.	151.1	2,775	28.36
6.	168	2,808.8	30.11
7.	173.4	2,819.6	30.67

## Chapter five

### Result and discussion

Since most of condensate for the boiler is recovered from exhaust steam supplied to the first effect evaporator, the relationship of exhaust steam property (temperature) and condensate recovered were studied. In addition to that other contributing factors for condensate recovery problem was also addressed in this research works.

Different exhaust steam temperature from scada (DSC) which is supplied to first effect evaporator and respective condensate recovered is analyzed in this work are presented in figure. And in addition to this other contributing factors are also analyzed based on the trend on actual factory parameters with their respective condensate recovery are analyzed and presented in figure.

#### 1. Effect of exhaust steam temperature on condensate recovery

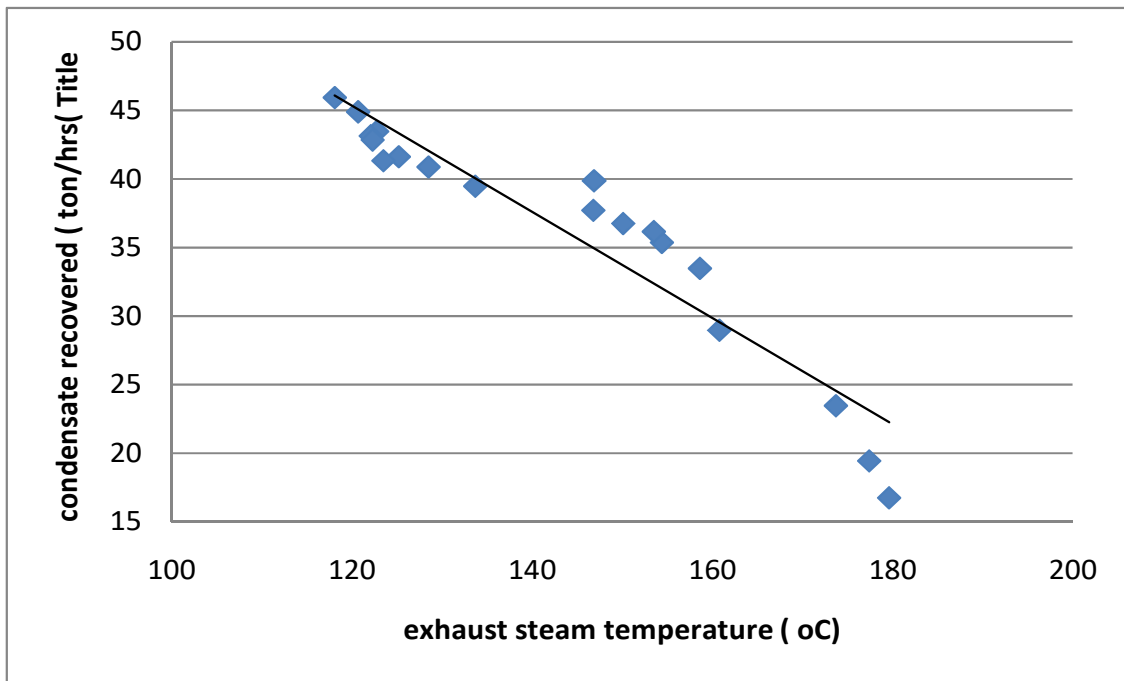


Figure 5.1: effect of exhaust steam temperature on condensate

In the figure since a huge part of the total exhaust steam generated is used by first effect evaporator, condensate which could be recovered is also take large part, and temperature violation from the design value is visible this paper mainly focuses on the exhaust steam temperature effect on condensate recovery. When we see the graph and based on the analysis done using energy and material balance it is clear that when temperature of the exhaust steam provided to the process especially to the evaporator increases the condensate recovered will be reduced.

Besides, from figure 2.3 schematic diagram the large amount of condensate is lost when exhaust steam condenses in first effect evaporator. From 48.7 t/h exhaust steam supplied to first effect evaporator and clear juice heater only 42.6 t/h of condensate is returned back to the hot well tank. That is only 87.47 % of condensate is recovered. The rest lost inside control volume in the figure 2.3. Based on material balance on this system 6.1 t/h of Condensate is lost that is 146.4 tons of condensate per day. So in order to replace this 146.4 tons of treated heated water is required. Cost of treated RO water production is 31 birr per liter. So to produce 146.4 tons or  $(146.4 * 1018.32 = 149,082 \text{ liter})$  of treated RO water costs 4,621,543.4 birr per day. That is without considering (calculating) the heat energy cost as the source of fuel is factory byproduct “bagasse”. Saving this amount of condensate could save approximately 4 million birr per day. Therefore, to solve this exhaust steam temperature supplied to evaporator and clear juice heater has to be managed and this enhance exhaust steam to release completely the latent heat. This could avoid the escape of flash steam along with hot condensate or boiled water.

## 2. Intermittent crushing

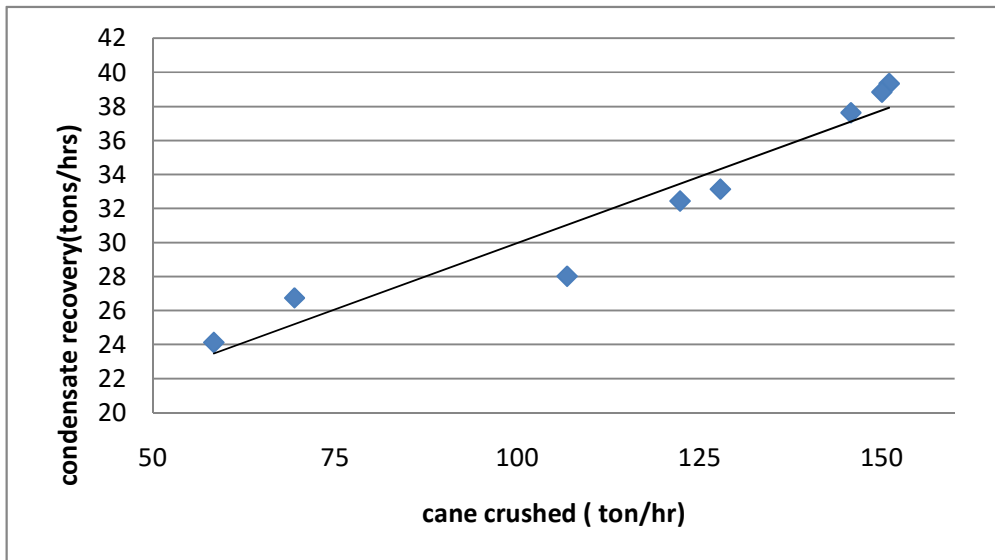


Figure 5.1: graph represents relationship between rates of crushing behaviors on condensate recovery

It is observed that can crushing operation every day is not uniform and crushing is very intermittent. This is visible when we look at cane crushing per day now is only 27,960.25 tons per day against design capacity 62,500 tons per day. This shows that the plant is operated around 50% of rated design capacity with nearly average 12.91 hours stoppage due to different reasons factory reasons.

Consequently this stoppage hampers the supply of juice flow to process house and this reduces the generation and supply of condensates from process house to steam generation plant.

If the plant is not in operation, no juice flow and no condensate return back to boiler, however, boiler working will continue to operate the pan boiling in process houses. During that time, vapor condensate is being taken back to the Boiler.

### 3. Daily crushing capacity

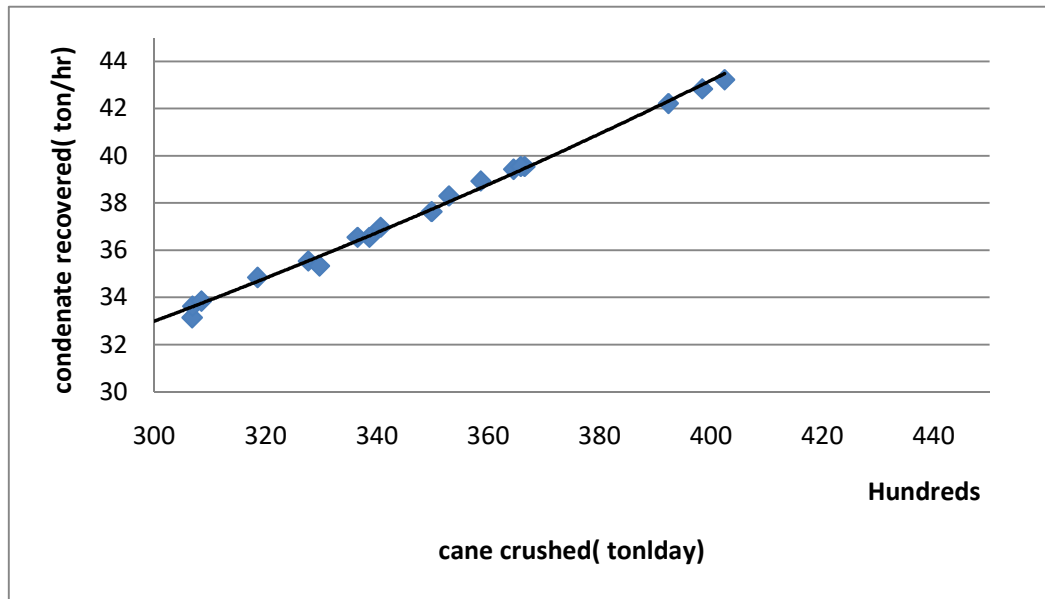


Figure 5.2: Wonji shoa sugar factory crushing rate trend on condensate recovery

Based on the graph here again the condensate is directly related to the crushing capacity of the plant. When the plant reduces its crushing capacity the quantity of juice in the process will be reduced and recovery of condensate will decline, consequently this leads the process to face shortage of condensate for the Boiler.

In addition to the total daily crushing ability problem if rate of crushing deviated from the design rate, condensate recovery will be affected a lot. That is if ton of cane crushed per hours decreases, the condensate recovery will decrease. The main reason for this is that as described on the daily crushing capacity problem the juice produced will decline and consequently recovery of vapor condensate decreases.

#### 4. factory down time effect on Condensate recovery

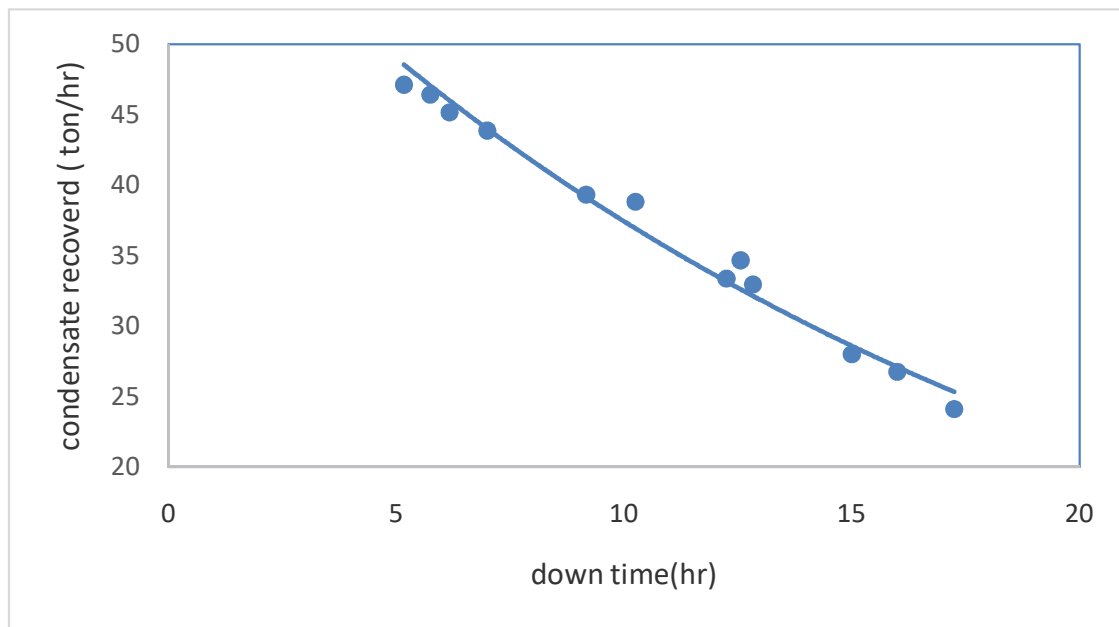


Figure 5.3: Wonji shoa sugar factory effect of down time on condensate recovery

From this graph we can see that when operating hour's drops the condensate recovery gets decline. As we know when the factory operates for longer hour the amount of cane crushed increases and this will lead to get more juice in the process. As the result since this process is evaporation process the vapor which is bled out and used for the heating purpose for the next evaporator condenses more than low crushing hour operation.

#### 5. Leakages in steam and condensate system of the plant.

Continuous leakage of exhaust steam from pipelines, through steam traps, valves, drains, vents leads not only more steam demand to process house, but also causes the loss of valuable condensate.

Usually in the design exhaust steam leakage is little so that make up water is used to fill this deficit. However, in this case leakage is beyond expected amount. Therefore, this is the other major factor that contributes to the shortage of condensate recovered.

## 6. Variation in cane quality especially in fiber % of cane

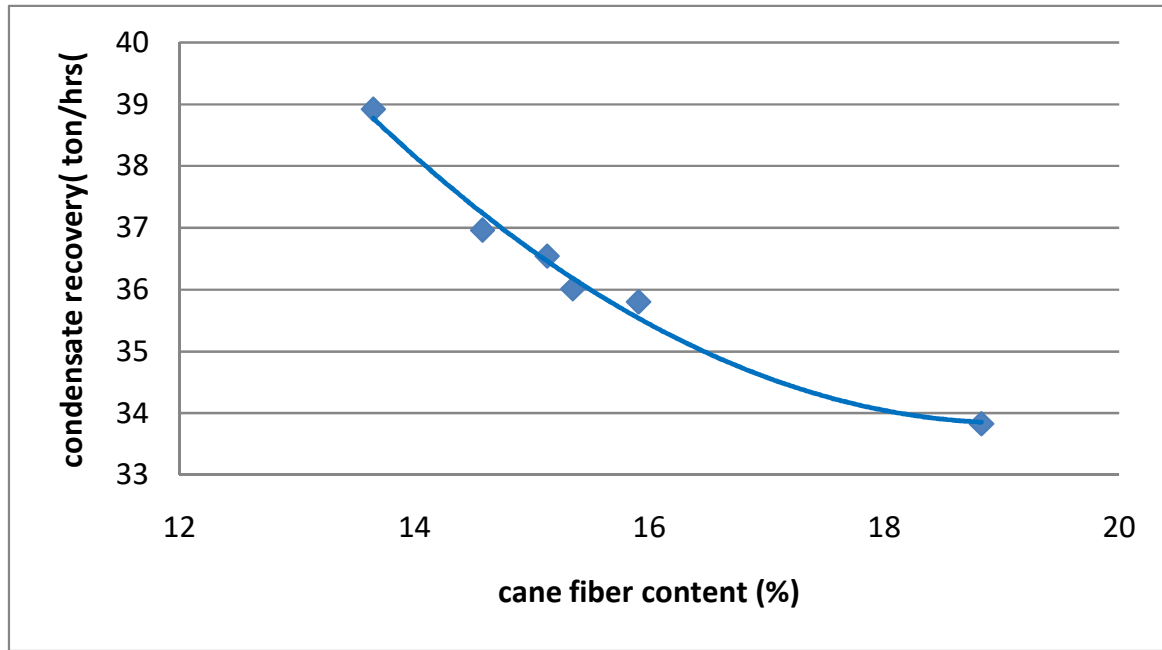


Figure 5.4 : Effect of cane fiber content on condensate recovery

Sugar cane has fiber which holds the sugar juice which is going to be extracted during milling operation of the process. The content of this fiber is usually constant. Due to many agricultural reasons like depending on cane Variety, and miss managements of cane plantation cane would have excess fiber. If cane fiber content becomes above the average value, the content of the juice will be reduced and this will affect the condensate recovered.

From the graph it is clearly seen that when the content of cane fiber increases the condensate recovered from the process becomes less. The main reason for this is that according to the structure of sugar cane fiber cell the sugar juice be present on this cell and during cane preparation and milling operation of sugar production process the cell ruptured in cane preparation stage and the juice resigned in the cell will be compressed out . Therefore, when the fiber in cane gets higher the space for the juice will be smaller and the amount of juice will be lower. Consequently, during crushing operation the quantity of condensate which is recovered from the process will be less.

## 7. Effect of exhaust steam pressure on condensate recovery

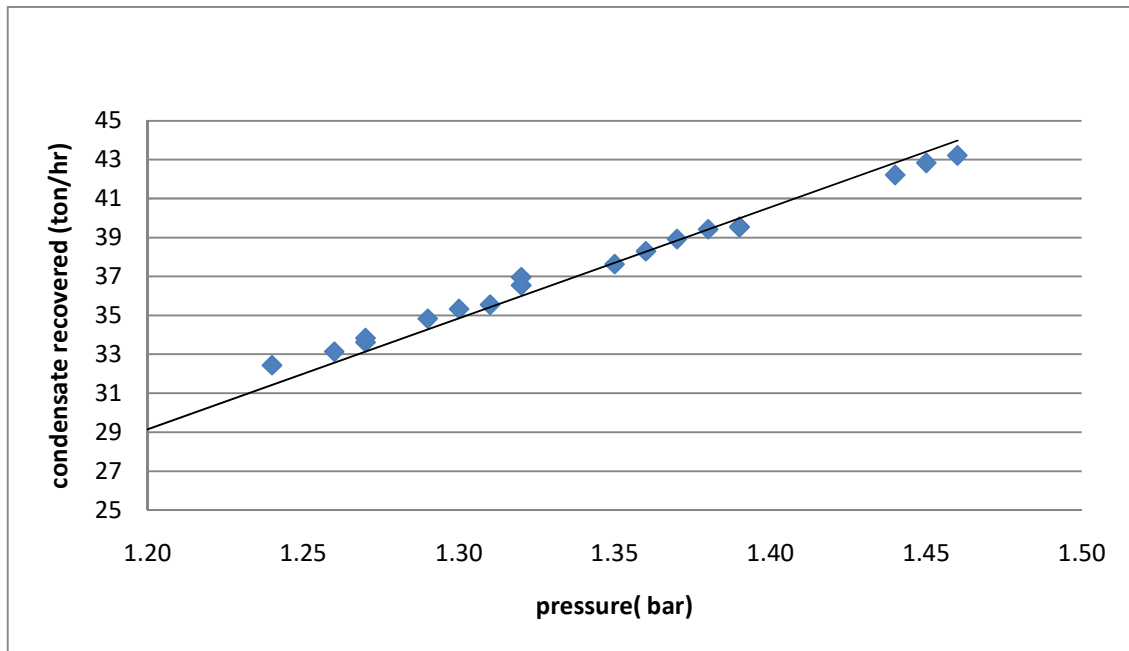


Figure 5.5 : WSF effect of exhaust steam pressure on condensate recovery

It is clearly seen in this figure if the pressure of exhaust steam provides to the process decrease from design value (1.5 bar) the condensate recovery will decline. As the pressure of exhaust steam has effect on heat transfer from one medium to other the steam which would be condensate will maintain its temperature without being reduced the steam will retain its states. So the vapor which leaves the evaporator along with the condensate will escape from the system through any opening and cause shortage of condensate.

## Chapter six

### Conclusion and recommendation

#### 5.1. Conclusion

The study was aimed to mitigate condensate recovery problem of the factory by collecting maximum possible condensate for the boiler. Mainly the influence of exhaust steam temperature on condensate recovery was studied. Finally reason for exhaust steam temperature elevation was examined. Besides other factors which contribute for condensate shortage like cane crushing rates, cane fiber content, operating hours or down time of the factory, exhaust steam pressure and condensate leakages were investigated.

The main reason for the shortage of condensate is the factory unable to maintain exhaust steam temperature to the design saturation temperature. Even if other parameters are also have effects on the condensate recovery.

The problem of exhaust steam temperature elevation from the design value is basically due to pressure and temperature reducing device operational problem.

Here PRDS uses valves to control the pressure and de-superheating water from de-aerator line is to control the temperature. Actually the pressure is well managed but the temperature is not.

These (design temperature violation) let the exhaust steam leave the evaporator without transferring its latent heat to the juice. That is as the exhaust steam only has time to release its sensible heat in superheated state. Then these causes condensate leave the evaporation carrying flash steam, which leave the condensate line at any pressure dropping points, that they are plenty including hot well tank.

superheated steam which has the combination energy of enthalpy of water, enthalpy of evaporation and enthalpy of superheat, has low potential to transfer heat, as it have lower heat transfer coefficient than saturated steam. The reason is that most of the energy which exists in enthalpy of evaporation transfer after enthalpy of superheat transfer completed.

That is why when the temperature of exhaust steam goes beyond the design temperature for the given pressure, the condensation process becomes ineffective. Consequently, condensate which leave the system can have large amount of steam, and this is then will flash out when there is a pressure drop.

The surface area of the first effect evaporator is larger than the second effect for the same flow rate, pressure and temperature of exhaust steam this will affect the heat transfer rate of the exhaust steam to the process juice which leads to the steam leave the evaporator without being condensed. Therefore, when the condensate leave the evaporator it is stored in flash tank for while , during this time the steam, which is not condensed , will flash out and leave the condensate returning line that lead to condensate shortage .

The other one is when the exhaust steam enters the evaporator the temperature is not to the required design temperature for the evaporator. So this cause latent heat of the exhaust steam can't be used and the steam leaves the evaporator without being completely condensed. This is the other major cause of the short of clean condensate for the Boiler.

Based on this thesis study because of the above identified reasons the factory loses every about 3,700 quintals and monetary loss is about 7,400,000 birr.

## **5.2. Recommendation**

Since most of condensate is recovered from the process especially from evaporator solving exhaust steam problem related to evaporator would be the main focuses of the solution. Therefore, based on the model developed it is possible to control the temperature of the exhaust steam which supplied to the evaporator by controlling the flow rate of de-superheating water it would be easy to get enough condensate for the Boiler. The program of the model is shown in Appendix B.

Besides to improve condensate recovery

- 1) Cane crushing capacity has to be maintained. The factory has to work on to keep the design daily crushing capacity.

- 2) Down time has to be reduced to minimum. The factory has to implement routine machinery inspection according to the standard inspection procedures and has also practice schedule preventive maintenance. Schedule preventive maintenance usually violation seen in the plant.\
- 3) Leakage in exhaust steam and condensate lines, valves, pump glands and pipes could be avoided by regular programmed inspection and schedule preventive maintenance.
- 4) In order to control exhaust steam pressure all valves in pressure and temperature reducing unit has to be controlled.
- 5) To control the cane fiber content as cane variety properties are known we can bend both high fiber cane and low fiber cane during crushing.

### **5.3. Future works:**

In order to solve this problem permanently additional program that relates the temperature of exhaust steam to the corresponding enthalpy is required and based on the result of the flow rate another flow control loop is needed to control it by setting the opening of the de-superheating flow valve.

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## Appendix A:

In the appendix, Wonji shoa sugar factory Boiler operation log sheet data

Date	Exhaust steam Pressure from 1.5 bar PRDS , bar	exhaust steam from 1.5 bar PRDS daily average temperature ,0C	level of hot well tank,%	down time	cane crushed per day ( quintal)	Daily average condensate totalizer reading of the Boiler	Quantity of condensate recovered per
13/11/2019						1832334	
14/11/2019	1.46	119.2	80	7	40125	1833387	43.87
15/11/2019	1.36	117.4	80	5.75	43056	1834501	46.41
16/11/2019	1.47	118.8	80	6.33	42568	1835587	45.25
17/11/2019	1.5	117.1	80	5.8	43624	1836714	46.95
18/11/2019	1.5	116.5	80	5.17	44768	1837845	47.12
19/11/2019	1.49	117.3	80	5.58	43587	1838964	46.62
20/11/2019	1.48	118.9	80	6.17	42984	1839477	45.17
21/11/2019	1.17	175.8	80	17.25	14004	1840561	24.12
22/11/2019	1.39	165.7	72.6	9.17	36254	1841505	39.33
23/11/2019	1.37	166.4	67.7	10.25	36087	1842437	38.83
24/11/2019	1.18	174.9	61.1	16	16659	1843079	26.75
25/11/2019	1.26	139.8	80	12.25	30568	1843880	33.37
26/11/2019	1.27	139.5	80	12.33	30107	1844693	33.87
27/11/2019	1.29	137.8	80	12.56	31785	1845525	34.67
28/11/2019	1.25	141.7	80	12.83	29947	1846316	32.96
29/11/2019	1.24	142.3	80	12.5	29361	1847094	32.42
30/11/2019	1.2	166.1	77.8	15	25648	1846211	28.01
1/12/2019	1.35	143.9	74.1	10.63	34985	1847114	37.63
2/12/2019	1.26	149.3	69.4	12.51	30684	1847909	33.13
3/12/2019	1.31	146.8	65.3	11.5	32768	1848762	35.54
4/12/2019	1.24	152.3	60.3	12.33	29348	1849540	32.43
5/12/2019	1.32	134.4	80	11.25	33865	1850417	36.54
6/12/2019	1.32	134.1	80	11.33	34064	1851304	36.96

7/12/2019	1.37	129.4	80	10.25	35867	1852238	38.92
8/12/2019	1.27	139.8	80	12.83	30687	1853045	33.62
9/12/2019	1.31	135	80	11.83	32785	1853906	35.87
10/12/2019	1.32	150.5	78.3	11.33	33654	1854783	36.54
11/12/2019	1.3	153.1	73.2	11.25	32965	1855631	35.33
12/12/2019	1.3	154.2	71.5	11.25	32746	1856476	35.21
13/12/2019	1.29	157.8	66.7	12.83	31854	1857312	34.83
14/12/2019	1.27	159.7	60.8	12.83	30561	1858126	33.92
15/12/2019	1.27	139.4	80	12.68	30435	1858936	33.75
16/12/2019	1.27	135.2	80	11.68	30447	1859795	35.79
17/12/2019	1.31	133.1	77.3	11.25	31105	1860659	36.01
18/12/2019	1.27	158.2	71.9	12.75	30847	1861471	33.83
19/12/2019	1.11	178.6	65	19.25	10958	1861918	18.62
20/12/2019	1.16	167.5	61.7	17.08	13274	1862485	23.62
21/12/2019	1.44	0	0	8.25	38125	1863477	41.33
22/12/2019	1.38	127.9	80	9.5	36451	1864423	39.42
23/12/2019	1.39	128.3	80	9.25	36657	1865372	39.54
24/12/2019	1.44	122.1	80	7.68	39235	1866385	42.21
25/12/2019	1.46	122.6	80	6.83	40247	1867422	43.21
26/12/2019	1.36	138.8	79.1	10.17	35294	1868341	38.29
27/12/2019	1.45	121.8	77.3	7.92	39847	1869369	42.83
28/12/2019	1.39	128.2	74.6	9.58	36583	1870318	39.54
1/1/2020	1.46	122.8	0	7.58	40489	1871361	43.45
2/1/2020	1.47	120.7	80	6.92	41894	1872438	44.87
3/1/2020	1.47	118.1	80	5.92	42978	1873540	45.92
4/1/2020	1.35	146.8	80	10.83	34786	1874445	37.71
5/1/2020	1.41	128.5	78.6	8.83	37865	1875426	40.87
6/1/2020	1.31	154.4	73.1	11.17	32385	1876275	35.37
7/1/2020	1.32	150.1	68.7	11.25	33781	1877157	36.75

8/1/2020	1.16	173.7	64.9	17.25	13496	1877720	23.45
9/1/2020	1.39	146.9	60.8	9.45	36813	1878677	39.87
10/1/2020	1.46	122.1	80	7.08	40182	1879712	43.12
11/1/2020	1.43	125.2	80	8.33	38644	1880711	41.62
12/1/2020	1.21	160.8	80	15.41	18956	1881406	28.96
13/1/2020	1.06	179.6	78.4	20.08	10251	1881808	16.75
14/1/2020	1.48	153.5	73.5	5.17	43165	1882675	36.16
15/1/2020	1.12	177.4	65.9	19.83	11265	1882695	19.45
16/1/2020	1.50	158.6	61.4	5.08	44102	1883498	33.48
17/1/2020	1.42	123.5	80	8.25	38368	1884490	41.33
18/1/2020	1.39	133.7	80	9.45	36469	1885437	39.46
19/1/2020	1.45	122.3	80	7.75	39876	1886465	42.83
15/2/2020	1.43	122.1	80	8.41	38995	1887472	41.96
16/2/2020	1.32	133.1	80	11.08	33781	1888353	36.71
17/2/2020	1.33	131.8	80	10.68	34585	1889253	37.5
18/2/2020	1.14	176.7	76.4	18.92	11856	1889776	21.79
19/2/2020	1.2	175.5	69.6	15.75	17477	1890435	27.46
20/2/2020	1.32	171.3	64.1	11.41	33697	1891315	36.67
21/2/2020	1.38	169.5	60.1	10.83	34548	1892216	37.58
22/2/2020	1.48	121.4	80	7.25	40791	1893266	43.75
23/2/2020	1.47	116.8	80	5.08	44574	1894405	47.46
24/2/2020	1.48	116.5	80	3.08	46255	1895604	49.96
25/2/2020	1.51	112.2	80	0	51278	1897169	65.21
26/2/2020	1.45	119.4	80	6	41768	1898243	44.79
27/2/2020	1.5	113.4	80	0	49985	1899668	59.37

## Appendix B:

In the appendix, the matlab code developed for the solution of model developed.

```
function result = setBreakpoint(filename, requestedBreakpoint)
%setbreakpointandreturnerror sets a breakpoint in the given file and
%
% This function is unsupported and might change or be removed without
% notice in a future version.
%
% This function tries to install a breakpoint in MATLAB from the
% information provided in the given Java breakpoint.
%
% If a 'MATLAB:class:NotOnPath' error is encountered during breakpoint
% installation, an appropriate dialog will be shown. If a
% 'MATLAB:lineBeyondFileEnd' is encountered, the error will be silently
% ignored. If any other error occurs, a dialog with that message will be
% shown.
%
% result = setbreakpoint(filename, requestedBreakpoint)
% filename is the MATLAB char array containg the file name to set the breakpoint in.
% requestedBreakpoint the com.mathworks.mde.editor.breakpoints.MatlabBreakpoint
% from which to derive the inputs for the call to
% dbstop.
% result a BreakpointInstallationResult with the status of the operation.
%
% Copyright 2009 The MathWorks, Inc.

import com.mathworks.mde.editor.breakpoints.BreakpointInstallationResult;
import java.io.File;

try
doSetBreakpoint(filename, requestedBreakpoint);
result = BreakpointInstallationResult.createSuccessfulResult(File(filename));
```

```

catch exception
    result = handleDbStopException(exception, filename);
end

end

function result = handleDbStopException(exception, filename)
%handleDbStopException handles exceptions that may be thrown when calling dbstop.

import com.mathworks.mde.editor.breakpoints.BreakpointDialogs;
import com.mathworks.mde.editor.breakpoints.BreakpointInstallationResult;
import com.mathworks.mde.editor.breakpoints.DbStopStatus;
import com.mathworks.mde.editor.breakpoints.MatlabBreakpointUtils;
import java.io.File;

message = "";
status = DbStopStatus.SUCCESS;

switch exception.identifier
    case 'MATLAB:lineBeyondFileEnd'
        % silently ignore this error.
    case 'MATLAB:class:NotOnPath'
        message = exception.message;
        status = DbStopStatus.CLASS_NOT_ON_PATH;
    otherwise
        message = exception.message;
        status = DbStopStatus.OTHER_EXCEPTION;
end

result = BreakpointInstallationResult(File(filename), message, status);
end

```

Appendix: C

