Optimization of Steam Generation and Consumption:
A Case study Elguneid Sugar Factory, Gezira State, Sudan

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Date of Examination: ..../November/2018
DEDICATION

My wife: Thank you for your unconditional support with my studies. I am honored to have you as my parents. Thank you for giving me a chance to prove and improve myself through all my walks of life. Please do not ever change. I love you.

My family: Thank you for believing in me; for allowing me to further my studies. Please do not ever doubt my dedication and love for you.

My friends: Hoping that with this research I have proved to you that there is no mountain higher as long as God is on our side. Hoping that you will walk again and be able to fulfill your dreams.
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Optimization of Steam Generation and Consumption
A Case study: Elguneid Sugar Factory, Gezira State, Sudan
Yousif Mohammed Karmeldin Hamed

ABSTRACT
In sugar industries, energy is normally produced by combustion of bagasse or furnace fuel. Reduction in steam consumption% cane in sugar processing is of vital important. Reduce the steam consumption% cane further by installing energy efficient equipments and waste heat recovery systems in the boiling house will increase performance. The objectives of this study are to optimize steam generation and consumption in Elguneid Sugar factory. The amount of bagasse produced and that used in production of steam or filtration in vacuum filters was first determined and the quantity of generated steam was secondly calculated. To identify the amount of the surplus of bagasse in Elguneid sugar factory, it was also intended to achieve low steam% cane. And to discuss various alternatives to reduced steam used in sugar process in Elguneid sugar factory. All calculations were done according to Hand Book of cane sugar engineering Hugot.E (1986).". The results obtained that the amount of (live steam reduced in pan washing, molasses condition, low grade sugar melting, superheating wash water system, massecuite& Molasses Pumps equal 1.61% cane and exhaust steam reduced in vapor demand for juice heating, pan boiling is equal 6.2% cane, bagasse consumed was equal to 36.58 tons/hr and (804.76 tons/day), where the surplus amount of bagasse was equal to 52.39 tons/hr and equal to (12152.58 tons/day). Also it was found that the amount of steam produced was equal to 95 MT/hr at high efficiency of boilers and actual amount of steam consumed is equal 90.8MT/hr and amount of steam losses was equal to 4.2 MT/hr. The designed sugar production of Elguneid sugar factory is 60000 tons of sugar / season but now increased to 90000 tons of sugar, which will need more amount of steam (energy), with the use of modern trends for reduction in steam consumption in sugar processes in Elguneid sugar factory. This study was suggested we can keep target to achieve steam% cane up to 37% and saving about steam 7.8% cane equal 15.375 tons of steam / hour and saving amount of bagasse equal 6.09T/hr, and this means that saving energy and reducing the load in boilers. The target to reduce steam consumption % cane in Elguneid sugar factory is 7.8% on cane. It is recommended that steam generation and steam distribution in Elguneid sugar factory, can be enhanced with help of boiling house (use of modern instrumentation, automation and optimization), by operating evaporator with maximum vapor bleeding arrangement.
المثلية التوليد والاستهلاك للبخار في صناعة سكر القصب

دراسة حالة: مصنع سكر الجنيد، ولاية الجزيرة، السودان

يوسف محمد كرم الدين حامد

ملخص الدراسة

تنتج الطاقة في صناعة السكر من حرق البقاس وكم يمكن استخدام الفيرسلاظروف محدد. إن الهدف الأساسي من هذا البحث هو حساب ودراسة كفاءة استخدام البخار، وتحديد البخار المنتج ومستهلك. كذلك ايجاد كمية البقاس المنتج من العصاره بعد استخلاص العصير من القصب وتوزيع كمية المستهلكة في المراحل البخارية المستخدم في مرشحات الطين، وكذلك حساب كمية البخار المستهلكة. هدف هذه الدراسة تقليل كمية البخار المستهلك بنسبة المئوية قصب في العملية الصناعية بمصنع سكر الجنيد. يوضع عدد من التوصيات لتقليص كمية الطاقة المستهلكة، وقبل ذلك تم حساب كل كميات البخار المنتج من المراحل البخارية وبخار العادم، أي مستخدم بواسطة التوربينات و البخار المنتج من عملية التبخر في المبخرات متعددة الكفاءة، وكذلك توزيع البخار في العمليات الصناعية. ومن الدراسة تم استبدال البخار الجاف في بعض وحدات العملية الصناعية ببخار العادم بنسبة 1.1% وكذلك تم استبدال استخدام بخار العادم في بعض العمليات بالبخار المنتج من المبخرات بنسبة 6.2%，كما وجد أن كمية البخار المنتج باقصي طاقة للمراحل البخارية 95 طن/ساعة ومستهلك منه 90.8 طن/ساعة وفائدة 4.2 طن، والبقاس المنتج الكلي 99.2 طن/ساعة ومستهلك منه 66.98 طن/ساعة. مصنع سكر الجنيد تم تصميمه على أعلى طاقة إنتاجية 6000 طن سكر في الموسم، حاليا أرتفع الإنتاج لأكثر من 9000 طن سكر بعد التوسع في الزراعة افقيا ورأسيا وادخال بعض المعدات وطقم مبخرات الا ان المراحل البخارية لم يتم تحليلها أو زيادة عدها، توصية هذه الدراسة لتقليل استهلاك البخار بنسبة 7.8% قصب. يحديث نظام توليد و توزيع البخار في قسم الإنتاج بواسطة أجهزة تحكم حديثة مع التشغيل الآلي للمبخرات لإنتاج أكبر كمية من البخار المولد، لتقليل الضغط على المراحل البخارية وزيادة كفاءة التشغيل و تقليل استهلاك البقاس و بالتالي حفظ الطاقة.
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APPENDIX

C.J: clear juice
M.J: mixed juice
A.H: Heavy molasses from A-massecuite
A.L: Light molasses from A-massecuite
B.H: Heavy molasses from B-massecuite
F.M: Final molasses from C-massecuite
C/F: Centrifugal machine
BX: (Brix) present dry substances determined by using a hydrometer, refractometer or derived from refractive index and reference to tables calibrated in term of present sucrose by weight in water solution.
Clarifier: A normal large-diameter tank used for settling suspended substance for thickening settled mud obtained from defecated juice.
Primary juice: All juice extracted before dilution begins.
Secondary juice: The diluted juice when mixed with third juice coming from mill No (3).
Mixed juice: All juice collected from milling house and send to processing house.
Clarified juice: The clear juice from clarifiers entering to evaporators.
Liming juice: The juice obtained by addition of milk of lime to mixed juice up to PH(7.8 – 8.2).
Liming: Treatment of mixed juice with milk of lime.
TCH: Ton cane crushed per hour.
TCD: Tone cane crushed per day.
CHAPTER ONE

1.0 Introduction

1.1 Historical background

Under the auspice of ministry of industry of government of Sudan, Sudanese Sugar Company Ltd. Manages activities of four cane sugar manufacturing units at Gunied, New Halfa, Sennar and Asalaya. With a total capacity of 355 tons sugar/year.

Gunied Sugar factory was the first unit to come into existence in the year 1962. The initial goal in starting such unit was to meet the local sugar demand, reduce import of white sugar and thereby reduce foreign exchange load on the exchequer. The plant was supplied by M/S Buckau Wolf and M/S BMA of Germany with rated capacity to process 4000 tons of cane per day with annual sugar production of 60000 tons.

(From Elguneid sugar factory manuals)

The scheme is situated on the east bank of Blue Nile River. 120 KM south east of Khartoum. Being unique with the tenancy system the schemes total area is 42816 feddans; and the number of tenants is 2511.

The irrigation scheme secured by pumps – all electricity driven on Blue Nile deliver water to cane fields through main major, minor and in field canalization network. The cane varieties grown are (CO 527) and (CO 6806). Though the plant was commissioned in the year 1962, it could only achieve its rated capacity in the year 1994 and produced 58600 tons of sugar. (from factory manuals). Since the year 1998 planned rehabilitation work in various sections of the plant was taken up and there after every year showed progressive improvement on all fronts [refer graphical representation for the last 10 years] namely agriculture, cane crushing and sugar processing. Now during this current campaign the factory is processing 4600 tons of cane per day at average recovery of 9.8% with sugar color to ICUMSA unit 340, while yield of cane per Fadden is 43 tons. The aim is to achieve improvement in sugar quality to have better standing in local as well as in international sugar trade.

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Cane is the source of sugar in all tropical and subtropical countries of the world. (from factory manuals). The factory delivery cane by tractors. The cane is weighed before it’s enter inside the factory. After the arrival of sugar cane to cane yard, then cane unloading in the feeder table, then the cane washed with sprayed clean water.

Cane continuously travels through a system of conveyors to the cane preparation unit.

Where the hard structure of the cane is broken into small pieces using two revolving knives driven by high-voltage electricity (6600kv). The cane crushed in multiple set of three-roller mills, driven by steam turbine using live steam (350 °C , 20 bar) consisting of six mills tandem.(from factory manuals)

Imbibition water system is used, which is introduced into the last two mills, imbibition water is between (25-29%cane) and( 70-80 °C) temperature. While the crushed cane travels from the first mill to the last one, the crushed cane (a bagasse) is exiting from the last mill, the bagasse is used as a fuel in the boilers for steam generation. The juice extracted from all mills called as mixed juice (86%cane) , then sent to process house (clarification).Clarification is done by (liming) using milk of lime(0.081%cane) and phosphoric acid are also added(0.010%cane) and heating, the temperature of the juice raised to(102-105 °C) in series of heaters, clarified juice is passed through two clarifiers, mud precipitate in bottom and clear juice in top side, then sent to evaporators and filtrate juice separated from mud in rotary vacuum filters.(from factory manuals).

Evaporation is one of the main methods used in the chemical industry for the concentration of aqueous solutions. The usual meaning of the term is removal of water from a solution by boiling the liquor in suitable vessel, the evaporator and withdrawing the vapors’. If the solution contains dissolved solids, the resulting strong liquor may become saturated so that crystals are deposited. Evaporation is carried out by adding heat to the solution to vaporize the solvent. The heat is supplied principally to provide the latent heat of vaporization, and, by adopting methods for recovery of heat from the vapor, the chemical engineer has been able to bring about great economy in heat recovery (Hugot, 1960).
1.2 Statement of problem

In the present scenario of cogeneration and energy conservation, reduction in steam consumption% cane in sugar processing is of vital important. Reduce the steam consumption% cane further by installing energy efficient equipments and waste heat recovery systems in the boiling house.

The steam% cane data of all sugar factories is not available; however the bagasse consumption for sugar processing is available in all sugar mills in Sudan. In general steam consumption in sugar factories varies from (48-52% cane).factories which have achieved steam% cane in the Range (40-42), are mainly due to lower mixed juice% cane (below 92) and high clear juice brix% (above 18) as result of lower application of imbibitions water% cane.

By reducing steam% cane for processing, sugar factories may able to save 12-14% bagasse which can be used to increases the economical feasibility of co-generation project or direct to market. We will discuss various alternatives to reduce steam consumption% cane.

Types of steam/vapors used in sugar mills, live stem produced from boilers temperature (320-350 °C) and pressure (17-20) bar, exhaust steam temperature(140-145 °C) and pressure(1.2-1.5) kg/cm², bleeding vapor temperature(110-112 °C) and pressure(0.7- 0.5) kg/cm².

Live steam – from boilers used for:
1- Pans washing.
2- Molasses conditioners.
3- Massecuite & molasses pumps.
4- superheating wash water system for high grade sugar.
5- Low grade sugar melter.
6- Centrifugals.
7- Dryers.

Exhaust steam – from power and mills turbines used for:
1- Evaporators.
2- Pans boiling.
3- Juice heaters

**Bleeding vapors – from evaporators’ vessel used for:**

1. Juice heaters
2. Pans boiling

**1.3 Objectives**

**Main Objective**

To study the steam production and consumption at Elguneid sugar factory in order to reduce the steam utilized although the factory.

**Specific Objectives**

- To determine and study the efficient utilization of steam.
- To determine the actual amount of steam produced and that consumed.
- To determine the amount of bagasse produced and used in steam production house.
- To reduce the amount of steam consumption% cane, result to save power and bagasse.
CHAPTER TWO
LITERATURE REVIEW

2.0 Production of cane sugar
2.1 harvesting

Cane grows very tall in good growing regions, certainly up to 3 meters high. Where possible the cane is fired before harvesting to remove the dead leaf material and some of the waxy coating. The fire burns at quite high temperatures but is over very quickly so that the cane and its sugar content are not harmed. In some areas burning is not permitted because of the objection by the local communities of the smoke and carbon specs that are released. Harvesting is done either by hand or by machine. Hand cut cane is a hard. Most machine-cut cane is chopped into short lengths but is otherwise handled in a similar way as hand cut cane. Machines can only be used where land conditions are suitable and the topography is relatively flat. In addition the capital cost of machines and the loss of jobs caused make this solution unsuitable for many sugar projects. (Galloway, 2005).

2.1.2 Extraction

The first stage of processing is the extraction of the cane juice after the washing by water to remove dirtiness, mud and sand and preparation by knives. In many factories the cane is crushed in a series of large roller mills, similar to a mangle [wringer] which was used to squeeze the water out of clean washing a century ago. The sweet juice comes gushing out and the cane fiber is carried away for use in the boilers. In other factories a diffuser is used as is described for beet sugar manufacture. Either way the juice is pretty dirty: the soil from the fields, some small fibers and the green extracts from the plant are all mixed in with the sugar. A typical mixed juice from extraction will contain perhaps 15% sugar by weight and the residual fiber, called bagasse, will contain 1 to 2% sugar, about 50% moisture and some of the sand and grit from the field as "ash". A typical cane
might contain 12 to 14% fiber which, at 50% moisture content gives about 40 to 42 tons of bagasse per 100 tons of cane or 10 tons of sugar. (Jambhale, 2005).

2.1.3 Liming

The factory can clean up the juice quite easily with slaked lime (a kind of chalk) which settles out a lot of the dirt so that it can be sent back to the fields. This process is known as liming.

The mixed juice from extraction is preheated prior to liming so that the clarification is optimal. The milk of lime, calcium hydroxide or Ca (OH)\(_2\), is entered into the juice to hold the required ratio and the limed juice enters a gravitational settling tank: a clarifier. The juice travels through the clarifier at a very low superficial velocity so that the solids settle out and clear juice exits.

The mud from the clarifier still contains valuable sugar so it is filtered on rotary vacuum filters where the residual juice is extracted and the mud can be washed before discharge, producing sweet water. The juice and the sweet water are returned to the process. (Jambhale, 2005).

2.1.4 Evaporation

Evaporation is a unit operation, any solution volatile solvent is removed and at the same time crystallization takes place, after the liming, the juice is transferred to clarifier, the juice coming out from the clarifier is known as clear juice and is of (14 to 18° Brix).

This juice is concentrated up into syrup (60-65°Brix) by boiling of the water using steam in a process called evaporation for the formation of crystal sugar this is done in two steps

1. From 15 to 60° Brix in a form of syrup in evaporators.
2. From 60 to 90° Brix for formation of sugar crystals in pans.

Concentration means removal of water from the liquid in the form of vapour. For this heat is to be applied to the liquid. Heating is done with the help of exhaust steam of about 0.4 to 0.8kg/cm\(^2\) Pressure(Yung etal, 2009).
2.1.5 Crystallization

The syrup is placed into a very large pan for boiling, the last stage. In the pan even more water is boiled off until conditions are right for sugar crystals to grow. Crystal formation is initiated by throwing some crystals into the syrup. Once the crystals have grown the resulting mixture of crystals and mother liquor is discharged in crystallizers and transferred to centrifugation to separate the two, rather like washing is spin dried. The crystals are then given a final dry with hot air before being stored ready for dispatch.

The mother liquor still contains valuable sugar of course so the crystallisation is repeated several times. However non-sugars inhibit the crystallisation. This is particularly true of other sugars such as glucose and fructose which are the breakdown products of sucrose. Each subsequent step therefore becomes more difficult until one reaches a point where it is no longer viable to continue. In a raw sugar factory it is normal to conduct three boiling. The first or "A" boiling
produces the best sugar which is sent to store. The "B" boiling takes longer and the retention
time in the crystallizer is also longer if a reasonable crystal size is to be achieved. Some factories re-melt the B sugar to provide part of the A boiling feedstock, others use the crystals as seed for the A boiling and others mix the B sugar with the A sugar for sale. The "C" boiling takes proportionally longer than the B boiling and considerably longer to crystallize. The sugar is usually used as seed for B boiling and the rest is re-melted. Additionally, because no one can get all the sugar out of the juice, there is a sweet by-product made: molasses. This is usually turned into a cattle feed or is sent to a distillation where alcohol is made. This is why rum factories in the Caribbean are always close to sugar cane factories. (Londhe, 2004)

Fig (2.2) Block Diagram for cane sugar
2.1.6 Storage
The final raw sugar forms a sticky brown mountain in the store and looks rather like the soft brown sugar found in domestic kitchens. It could be used like that but usually it gets dirty in storage and has a distinctive taste which most people don't want. That is why it is refined when it gets to the country where it will be used.

2.1.7 Affination
The first stage of refining the raw sugar is to remove the layer of mother liquor surrounding the crystals with a process called "affination". The raw sugar is mixed with warm, concentrated syrup of slightly higher purity than the syrup layer so that it will not dissolve the crystals, but only the surrounding (brown) liquor. The resulting mixture (‘magma’) is centrifuged to separate the crystals from the syrup thus removing the greater part of the impurities from the input sugar and leaving the crystals ready for dissolving before further treatment (carbonation). The liquor which results from dissolving the washed crystals contains some colour, fine particles, gums and resins and other non-sugar substances. It is discarded from the process. (Jambhale, 2005)

2.1.8 Carbonation or phosphotation
The first stage of processing the sugar-liquor is aimed at removing the solids which make the liquor turbid. Coincidentally some of the color is removed too. One of the two common processing techniques is known as carbonation. Carbonation is achieved by adding milk of lime [calcium hydroxide, \( \text{Ca(OH)}_2 \)] to the liquor and bubbling carbon dioxide through the mixture. The gas reacts with the lime to form fine crystalline particles of calcium carbonate which occlude the solids. The other technique, phosphotation, is chemically similar but uses phosphate rather than carbonate formation. Phosphotation is a slightly more complex process that is achieved by adding phosphoric acid to the liquor after it has been limed in the same way as above. (Kulkarni, 2009).
2.1.9 Aecolourisation

There are also two common methods of color removal from sugar syrup, both depending on absorption techniques with the liquor being pumped through columns of medium. One option open to the refiner is to use granular activated carbon [GAC] which removes most colour but little else. Granular activated carbon is the modern equivalent of "bone char", a carbon granule made from animal bones. Today's carbon is made by specially processing mineral carbon to give a granule which is highly active but also very robust. The carbon is regenerated in a hot kiln where the colour is burnt off from the carbon. The other option is to use an ion exchange resin which removes fewer colors than GAC but also removes some of the salts present. The resin is regenerated chemically which gives rise to large quantities of unpleasant liquid effluents.

The clear, lightly colored liquor is now ready for crystallization except that it is a little too dilute for optimum energy consumption in the refinery. It is therefore evaporated prior to going to the crystallization pan.

In the pan even more water is boiled off until conditions are right for sugar crystals to grow. Some sugar dust is added to the liquor to initiate crystal formation. Once the crystals have grown the resulting mixture of crystals and mother liquor is spun in centrifuges to separate the two, rather like washing is spin dried. The crystals are then given a final dry with hot air before being packed and/or stored ready for dispatch. (Hertzog and Broderik, 1941).

2.1.10 Recovery

The liquor left over from the preparation of white sugar and the washings from the affination stage both contain sugar which can be recovered. They are therefore sent to the recovery house which operates rather like a raw sugar factory, aiming to make a sugar with a quality comparable to the washed raw after the affination stage. As with the other sugar processes, one cannot get all of the sugar out of the liquor and therefore there is a sweet by-product made: refiners' molasses. This is usually turned into a cattle food or is sent to a distillery to make alcohol. (Karamarkar, 2003)
2.2 Material and Energy balance in Evaporation

Evaporation is one of the main methods used in the chemical industry for the concentration of aqueous solutions. The usual meaning of the term is removal of water from a solution by boiling the liquor in suitable vessel, the evaporator and withdrawing the vapors. If the solution contains dissolved solids, the resulting strong liquor may become saturated so that crystals are deposited. Evaporation is carried out by adding heat to the solution to vaporize the solvent. The heat is supplied principally to provide the latent heat of vaporization, and, by adopting methods for recovery of heat from the vapour, the chemical engineer has been able to bring about great economy in heat utilization. (Karamarkar, 2003)

The normal rate equation for heat transfer is given by:

\[ Q = UA\Delta T \]  \hspace{1cm} (2.1)

McCabe and Smith (1985)

Where \( Q \) is the heat transfer per unit time,

\( U \) is the overall heat transfer coefficient,

\( A \) is the heat transfer surface, and

\( \Delta T \) is the temperature difference between the two streams.

2.3. Types of evaporators

- Long-tube vertical evaporators
- Upward flow (climbing-film)
- Downward flow (falling-film)
- Forced circulation.
- Agitated- film evaporators.

(.Karamarkar, 2003).

2.4 Single - and Multiple - Effect operation

Most evaporators are heated by steam condensing on metal tubes. Nearly always the material to be evaporated flows inside the tubes. Usually the steam is at a low pressure, below 3atm abs; often the boiling liquid is under a moderate vacuum, up to about 0.05atm abs. reducing the boiling temperature of the liquid increases the temperature difference between the steam and the boiling liquid and thereby increases the heat- transfer rate in the evaporator. When a single evaporator is
used, the vapour from the boiling liquid is condensed and discarded. This method is called single-effect evaporation. To evaporate 1 lb of water from a solution calls for from 1 to 1.3 lb of steam. If the vapour from one evaporator is fed into the steam chest of second evaporator and the vapour from the second one sent to the condenser, the operation becomes double-effect. The general method of increasing the evaporation per pound of steam by using a series of evaporators between the steam supply and the condenser is called multiple-effect evaporation (Panda, 2011).

2.4.1 Multiple-Effect evaporators

Forward feed for triple effect evaporators

Considering three evaporators arranged as shown in Fig (2.1) in which temperatures and pressures are shown as \( T_1, T_2, T_3 \), and \( P_1, P_2, P_3 \), respectively, in each unit. Suppose the liquor has no boiling point rise, and that the effects of hydrostatic head can be neglected. Then the heat transmitted per unit time across each effect will be:

Effect (1) \( Q_1 = U_1 A_1 \Delta T_1 \) where \( \Delta T_1 = (T_f - T_1) \),

Effect (2) \( Q_2 = U_2 A_1 \Delta T_2 \) where \( \Delta T_2 = (T_1 - T_2) \),

Effect (3) \( Q_3 = U_3 A_1 \Delta T_3 \) where \( \Delta T_3 = (T_2 - T_3) \).

Neglecting the heat required heating the feed from \( T_f \) to \( T_1 \), the heat \( Q_1 \) transferred across \( A_1 \) appears as latent heat in the vapour D_1 and is used as steam in the second effect. Hence,

\[ Q_1 = Q_2 = Q_3 \]

So that \( U_1 A_1 \Delta T_1 = U_2 A_2 \Delta T_2 = U_3 A_3 \Delta T_3 \)

Equation (2.2)

(Collusion and Richardson, 2003) reported the following equations.

If, as is commonly the case, the individual effects are alike, \( A_1 = A_2 = A_3 \), so that:

\[ U_1 \Delta T_1 = U_2 \Delta T_2 = U_3 \Delta T_3 \]  \( \text{Equation (2.3)} \)

The water evaporated in each effect is proportional to \( Q \), since the latent heat is sensibly constant. Thus the total capacity,

\[ Q = Q_1 + Q_2 + Q_3 = U_1 A_1 \Delta T_1 + U_2 A_2 \Delta T_2 + U_3 A_3 \Delta T_3 \]  \( \text{Equation (2.4)} \)

If an average value of the coefficients \( U_{av} \) is taken, then:
\[ Q = U_a \left( \Delta T_1 + \Delta T_2 + \Delta T_3 \right) A \]  
\text{Equation (2.5)}

Assuming the condensate to leave at steam temperature, heat balances across each effect may be made as follows:

**EFFECT 1.** 
\[ D_0 \lambda_0 = W C_p (T_1 - T_f) + D_1 \lambda_1 \]  
\text{Equation (2.6)}

**EFFECT 2.** 
\[ D_1 \lambda_1 + (W - D_1) C_p (T_1 - T_2) = D_2 \lambda_2 \]  
\text{Equation (2.7)}

**EFFECT 3.** 
\[ D_2 \lambda_2 + (W - D_1 - D_2) C_p (T_2 - T_3) = D_3 \lambda_3 \]  
\text{Equation (2.8)}

The surface area of each calandria necessary to transmit the necessary heat under the given temperature difference can then be obtained as:

\[ Q = D \lambda \]

Where:
- \( Q \) is the heat
- \( D \) is total evaporation
- \( \lambda \) is the latent heat of steam.

**2.5 Temperature sensitivity**

Many fine chemicals, pharmaceutical products, and foods are damaged when heated to moderate temperatures for relatively short times. In concentrating such materials special techniques are needed to reduce both the temperature of the liquid and the time of heating. (Dani and Londhe, 2008)

**2.6 Scale**

Some solutions deposit scale on the heating surfaces. The overall coefficient then steadily diminishes, until the evaporator must be shut down and the tubes cleaned. When the scale is hard and insoluble, the cleaning is difficult and expensive (Karamarkar, 2003).

**2.7 Vacuum operation**

With number of heat sensitive liquids it is necessary to work at low temperatures and this is affected by boiling under vacuum. In addition, as will be seen later, the last unit of a multi-effect system usually works under a vacuum and this operation increases the temperature difference.

Table (2.1): Enthalpy data from steam tables
Between the steam and boiling liquid and therefore tends to increase the heat flux. At the same time, the reduced boiling point will usually result in a more viscous material and a lower film heat transfer coefficient table (2.1). Consider the operation of standard evaporator using steam at 135kN/m$^2$ or 380k with a total heat of 2685kJ/kg, evaporating liquor such as water (Jenkins ,1960).

### 2.8 Evaporation in sugar industry

The use of bagasse increases sharply and therefore its price increases also, which reduces the production cost of sugar. Efficient utilization of steam is very much essential to save bagasse for factories without cogeneration or cogeneration with back pressure route. In case of factories with cogeneration by condensing route, the steam saving in boiling house can produce more electricity for export (Payne-1990).

#### 2.8.1 Sugar boiling under vacuum

#### 2.8.2 In the early years of 19th century in sugar industry with open boiling, steam consumption was very high and bagasse produced to generate the required steam was not sufficient. Large quantities of extra wood
were required. Therefore steam saving was necessary. The multiple effect principle consists of the reuse of latent heat for successive operations are an enormous aid to steam economy. The history of multiple effect evaporator start with sugar boiling under vacuum. Haward and Englishman worked on improvements to the primitive open boiling process. In 1812-13, he took out patents relating to his invention of vacuum pan. It was really a single effect evaporator apparatus, which was a tremendous breakthrough. Steam of 15-30 psig was used. A vacuum of 24" was achieved and the condensate water was returned to the boiler. Howard also fitted a proof stick for sampling the massecuite. Immediately some 5% more of fine white sugar was obtained. Monsieur Degrand then further improved this vacuum pan in 1824. He introduced steam coils for heating and increasing the rate of evaporation. He also fitted sight glasses to enable the pan boiler to see what is going on inside. And in 1833, proved that there was great economy when the latent heat of the vapors from juice was utilized to heat the juice before it is entered the pan.

The syrup from last effect evaporator is of purity (78 to 86) % and temperature 57-60°C. In this range of purity and temperature the syrup becomes saturated of sucrose at about (77 to 80) percent dissolved solids (brix). Therefore evaporation can carried out safely without any spontaneous crystal formation up to 72-75 brix. But in raw sugar factories syrup brix is kept to about 65 to 67 brix so that it can dissolve false grain if any formed in crystallization process. In multiple effect evaporator or simply evaporator, water is evaporated and the solids in clear juice pass to syrup. Some of non-sugars deposit in the form of scale on the evaporator tubes. Some of the volatile substances are evaporated. However these quantities are much less and hence can be neglected in calculation. It means the tones of brix in the juice and syrup remains the same. therefore:

\[ E = J \left(1 - \frac{B_j}{B_s}\right) \]  
Equation (2.9)

Where:
Brix is the dissolved solids percent by weight in the liquid.

\[ E = \text{Weight of water to be evaporated \% cane} \]

\[ J = \text{Clear juice \% cane} \]

\[ S = \text{Syrup \% cane} \]

\[ B_j = \text{Brix \% Clear juice} \]

\[ B_s = \text{Brix \% Syrup} \]

(Kulkarni, 2009).

2.8.2 Multiple effect evaporation in sugar industry

The concept of multiple effect evaporators that the vapours produced from the juice are used to concentrate the same juice in the following vessel. This is possible when the following vessel works under lower absolute pressure that the preceding vessel. Therefore the juice in following vessel boils at temperature lower than the temperature of the vapours from the preceding vessel and the absolute pressure in the vessels successively goes on decreasing from the first vessel to the last vessel. The last vessel works under vacuum at about 63 to 66 cm Hg. Therefore the syrup boiling temperature in this vessel is only 57 to 60°c. Boiling under vacuum has two the following advantages: It gives the required temperature difference between the heating steam or vapours and the boiling juice in the successive vessel.

The boiling point temperature of juice goes on decreasing from the first vessel to the last one. The reducing sugars and sucrose are sensitive to temperature and therefore the juice should not be boiled at high temperature for large time. However to achieve maximum possible steam economy by profuse vapour bleeding the juice boiling temperature in the first vessel may be as 115-118°c.

Evaporator body consists of calandria having tubes that serves as heat exchanger. The heating steam is outside the tubes and the boiling juice passes through tubes. When two fluids of temperature difference, are located on opposite sides of solids surface the quantity of heat transmitted from one to other is given by expression. (Jenkins, 1966).
2.8.3 The coefficient of heat transfer

The coefficient of heat transfer is influenced by

- Condensate film around the tube.
- Scale outside the tubes.
- Thickness of the tubes.
- Metal of the tubes.
- Scale inside the tubes.
- Juice films inside the tubes.

The heat transfer coefficient from vapour to metal and across the metal is high. However heat transfer coefficient from metal to juice is considerably low. Further the coefficient of heat transfer of condensate film, scale from outside the tube and scale inside the tube are also considerably low and these reduce the overall heat transfer coefficient. The coefficient of heat transfer is high for higher steam/vapour temperature. Therefore coefficient of heat transfer is highest in the first effect and goes on decreasing in the following effect.

The (ΔT) temperature difference for each effect is assumed while designing the evaporator however it mainly depends on the operating conditions (Ataklti Kahsay and Nigus Gabbiye, 2015).

The exhaust steam low pressure steam (of about 0.5 to 1.2 Kg/cm²) produced by the prim movers called exhaust steam or simply exhaust used to heat, boil and concentrate the juice and massecuites in the boiling house.

In factory working the ideal situation is that the live or high pressure steam consumption of the prime movers and the exhaust steam demand in the boiling house are equal. However both these quantities vary in factory operations. When exhaust production is more than it is demand in the boiling house, the excess exhaust steam has to be blown off to atmosphere. In such situation lot of heat is lost. Further the exhaust condensate quantity is reduced. Hence more vapor condensate is to be diverted to boilers. To avoid such situation the exhaust production should be about 85 to 90% of the exhaust demand and the balanced
10-15% demand is to be fulfilled by bleeding high pressure live steam in the exhaust steam. The exhaust produced by the prime movers is generally of temperature 150-180°C and is supersaturated. Further on bleeding the live steam into exhaust, the exhaust becomes high supersaturated. Heat transfer coefficient of saturated steam is high and supersaturated steam up to 10-30°C also gives good performance at evaporator. However, the high supersaturated steam has very poor heat transfer coefficient. It behaves as a gas – bad conductor of heat adversely affects evaporator performance.

Therefore the exhaust mixed with the bleeder live steam should be desuperheated up to 10-30°C above the saturation temperature. In practice a set point of automation for the exhaust temperature should be about 15°C cheaper than the saturation temperature. For example the exhaust steam at pressure 1Kg/cm2 has saturation temperature 120°C it should be desuperheated up to 135±5°C (Karamarkar, 2003)

2.8.4 Boiling point of juice

The boiling point of juice depends on:

- Vapour pressure above the juice in the vapor body.
- Brix of the juice
- Hydrostatic pressure up on the juice.

Vapor pressure above the juice:

Boiling point of water or liquid depends upon atmospheric pressure or the vapour pressure (in case of closed vessel) over it. When vacuum is maintain in closed vessel, the boiling point of water or liquid is reduced. At atmospheric pressure pure water boils at 100°C, however when water boiled in a closed vessel in which the vacuum of about 30cm of Hg is maintained, the water boils at 85.5°C. This property of liquids is used in operation of multiple effect evaporators. Vapors formed from the juice used to boil the same juice under vacuum at lower temperature in the next vessel. (Baikow, 1982).
2.8.5 Elevation of boiling point due to dissolved solid

As concentration of dissolved solids in a solution increases, the boiling point of any liquid increases. Boiling point of juice under a given pressure is higher than water and it increases with concentration of the solution. For example under atmospheric pressure water boils at 100°C but clear juice boils at 100.25°C. This increase in boiling point is known as boiling point elevation (bpe) or boiling point rise (bpr). The boiling point thus increases with increase in brix of the juice or syrup.

Hugot gives the following formula to calculate bpe for juice or syrup of high purities at different brix at atmospheric pressure.

\[ \text{Bpe} \degree \text{C} = \frac{2B}{100-B}, \]  
Equation (2.10)

Where \( B = \text{brix} \)

The bpe may be different for different compounds of the same concentration. Therefore bpe for juice or syrup depends on concentration of sucrose as well as concentration of impurities. It is increases for low purities of juice or syrup.

At different pressure as the boiling point temperature of pure water changes, the bpe for juices also changes but the change so small that can be neglected. (Jambhale, 2005).

2.8.6 Effect of hydrostatic heat

Boiling point of liquids increases with increase in pressure above it. Now suppose juice particles are boiling at a certain depth below the juice level, then the total pressure exerted over the boiling juice particles will be equal to the vapour pressure above the juice plus the pressure of juice column (hydrostatic heat) over the juice particles. The total pressure exerted over the boiling particles is increased and hence the boiling point of these particles is increased. Thus the boiling point of the particles is increased due to hydrostatic head exerted by the juice column. The juice particles at different levels boil at different temperatures.

The increase in boiling point of juice due to hydrostatic heat decreases the temperature difference (\( \Delta T \)) in boiling juice and heating vapours and adversely
affects the rate of evaporation. Therefore while calculating the heating surface, the increase in boiling point has to be taken into consideration.

In the operation of evaporator the incoming juice is at a higher temperature and therefore flashes even before it reaches the bottom of the calandria. The juice is agitating continuously. Therefore the effect of hydrostatic heat is fluctuating. (Baikow, 1982)

2.8.7 Evaporator – construction

There are three types of evaporator bodies used in sugar industry

I. Robert type or conventional

II. Long tube vertical rising film evaporator (LTVRF) commonly called as Kesner or semikesner.

III. Long tube vertical falling film evaporator (LTVFFE or simply FFE)

According to number of effects connected in series the multiple effect evaporator set is called as triple, quadruple or quintuple effect etc. (Badger and France, 1923).

2.8.8. Construction of Robert type evaporator body

Robert type evaporator is a closed vertical cylindrical type body having saucer bottom and a dome at the top.

1. Calandria

The lower portion of the body has two horizontal plates with large number of holes to fit tubes. Brass or stainless steel tubes of 38-42 mm inner diameters are fitted vertically in these tube plates by expanding both the ends. This part of the body is called as calandria.

The thickness of the tubes varies from 1.5 mm to 2.5 mm. Generally length and diameter of the tubes are kept same for all evaporator bodies. However in some designs the length is kept in decreasing order from first to last body. According to Indian standard specifications the recommended height of the calandria for Robert type evaporator body is 2m and the ID and OD of the brass tubes are 42 mm and 45 mm respectively.
The length of the tube is kept 8 mm greater than the outer distance between the tube plates to fit the tubes properly in the tube plates. The holes to the tubes for fitting the tubes are in staggered arrangement maximum number of tubes can be fitted per unit area for a given tube diameter and ligament between the tubes.

Juice is continuously fed at the bottom of the vessel and the steam is admitted to the calandria. The juice passes through the tubes whereas steam/vapour is heating the juice from outside the tubes. The steam/vapours are condensed and latent heat of the same is given to the juice (Baikow, 1967).

2-Dawntak

A well called central well of 'central down take' is provided at the centre of the calandria (See Fig (2.1)) the juice collected in the central well goes to the next body. The diameter of the central well is about 20% of the vessel diameter. In some designs, for large vessel instead of one central down take number of small down takes are provided.

3- Steam or vapor entry

For efficient operation of the evaporator the steam/vapours must reach at each tube every moment without any hindrance and should also reach the far end portion of the calandria from the steam/vapours entry. For this purpose in some designs vertical baffle plates are provided at the vapour entry. These baffle plates give definite direction to the vapours so that the vapours are evenly distributed through the calandria. However after some years of use these baffles get corroded and the path of steam is changed. Therefore the corroded baffles should be replaced by new ones but it is very difficult.

Many times damage of calandria tubes near steam entry is observed. This gives sugar traces in condensate (Deebika and et al, 2009).
4- Non-condensable gas withdrawal

The steam or vapours contain some incondensable gases and these gases are bad conductors of heat and if accumulated in the calandria adversely affect the rate of heat transfer. Therefore, continuous removal of the incondensable gases from the calandria is very much essential. To remove the incondensable gases from the calandria taps are provided to the calandria shell few centimeters above the bottom tube plate and below the top tube plate. These taps are connected together by pipes (commonly called as ammonia pipes). A common pipe of these ammonia piping is connected to the vapour pipe of the last body that passes to condenser (Sinnott, 2005).

5- Film of condensate

A film of condensate on the outer side and juice film inside of the tubes reduces the rate of heat transfer. The greater the thickness of condensate film, the less is the rate of heat transfer. The thickness of the condensate film increases from the top to the bottom. Therefore the over all heat transfer coefficient is not uniform and is maximum at the top and minimum at the bottom. The juice film is not of uniform thickness along with tube length. It is maximum near the bottom and minimum near the top (Karmarkar, 2003).

6- Height of body

The height of the body above the calandria or height of the vapour space is generally 2.5 times the height of the calandria for vapour cell, first, and last effect, whereas for second or third effect it is 2.2 times. However, in some designs the height is being kept more than 3.0 times the calandria height. The evaporator body is fabricated of mild steel. The thicknesses of the plates are as follows:
Table (2.2): Evaporator thickness

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Evaporator body thickness in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Up to 800m²</td>
</tr>
<tr>
<td>Body plate thickness</td>
<td>12</td>
</tr>
<tr>
<td>Bottom saucer plate thickness</td>
<td>16</td>
</tr>
<tr>
<td>Calandria plate thickness</td>
<td>25</td>
</tr>
</tbody>
</table>

7-Vapor pipe

Vapor space of the body from the dome or top of the body is connected to the calandria of the next body by a vapor pipeline. The vapor space of the last vessel is connected to a condenser where the vapors’ from the body are condensed by cold water, creating vacuum of about 630-660mm of Hg in the vapor space of the last body.

8- Juice flow

The juice flows from the down take of one body to the bottom of the next body because of lower absolute pressure in the next body than the first body. There is also difference in boiling temperatures of the two bodies. This causes flashing effect of the juice when it enters the next body. This gives vigorous upward movement to the juice. There is continuous flow of juice from the first vessel to the last vessel.

9- Sight glasses

To observe the working of evaporator body it has provided three circular windows with toughened sight glasses. The height of sight glass is 1.5 m above the working platform.
There is also light glass with electric bulb arrangement in the back to allow light to pass into the vessel.
A vacuum brake valve is provided to each body.
A cold water connection of pipe size 75-100 mm diameter is provided to both calandria and the body to check the leakages. Generally, leakages are checked at 3Kg/cm² pressure.
Alive steam connection is provided for soda acid boiling.
Two manholes—one 200mm above the calandria and the other to the bottom saucer, are provided to go inside the body for mechanical cleaning and physical inspection.
The evaporator set is installed at height of 6 - 6.5m above the ground level of the factory.
Under the bodies of evaporator set a working platform is provided for cleaning, repair and maintenance.
A soda preparation tank of capacity 20m³ with pumping arrangement is provided at the ground level near the evaporator set.

10-Calculation of vapour pipe diameter

- The vapour pipe diameter should be minimum for which following points are to be considered.
- The vapour velocity should be as high as possible.
- The risk of entrainment should be minimum.
- The pressure drop in between vapour space of the first effect and the vapour side of the calandria of the next effect should be minimum for getting good performance of the evaporator set.

Arrangement of tubes

Taking above points into consideration, the approximate vapour velocities for each effect of the evaporator set are given below.
Table (2.3) Source of steam or vapour flow

<table>
<thead>
<tr>
<th>Source of steam/vapour</th>
<th>Quadruple m/sec</th>
<th>Quintuple m/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust steam</td>
<td>25-30</td>
<td>25-30</td>
</tr>
<tr>
<td>1st effect</td>
<td>30-35</td>
<td>30-35</td>
</tr>
<tr>
<td>2nd effect</td>
<td>35-40</td>
<td>30-35</td>
</tr>
<tr>
<td>3rd effect</td>
<td>40-45</td>
<td>35-40</td>
</tr>
<tr>
<td>4th effect</td>
<td>50-60</td>
<td>40-45</td>
</tr>
<tr>
<td>5th effect</td>
<td>……</td>
<td>50-60</td>
</tr>
</tbody>
</table>

While calculating vapour pipe diameter highest evaporation rate is considered. Further 10% excess vapours are considered margin. (Karmarkar, 2003)

Table (2.4) calculating of steam / vapor flow

<table>
<thead>
<tr>
<th>Volume of vapor (m³/sec)</th>
<th>Cross sectional area (m²)</th>
<th>Velocity of vapor (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V = (3.14D²/4) v</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where

\[ D = \] Diameter of the vapor pipe

\[ V = \text{Volume of vapors per sec.} \]

\[ v = \text{Vapors velocity} \]

Hence

\[ D = \]

Volume of vapours produced (V) is given by:

\[ V \text{ (m}^3\text{/sec)} = \text{Esp.} \ast S \ast Vsp/360 \]

Where
E = Evaporation rate in the body (Kg/m$^2$/hr)
S = Heating surface of the body (m$^2$)
Vsp = sp. Volume of vapours in the body

### 2.8.9 Condensate

The steam/vapour applied in the calandria gives its latent heat to the juice boiling inside the tube and gets condensed. The condensate thus formed descends down over the tube surface and gets collected on the bottom tube plate of the calandria. If the condensate is not removed effectively it gets accumulated in the calandria and covers the lower part, which adversely affects the working performance of the body. Therefore, it is necessary to remove it as quickly as possible.

To remove the condensate one, two or some time if the body is large, three condensate drain pipes are provided to the bottom tube plate. The condensate pipe is usually joined to the calandria through a cone. It gives more cross-sectional area at the outlet for easy flow of condensate. The diameter of the condensate pipe is kept such that the velocity of condensate will be about 0.5m/sec.

#### 2.8.9.1 Temperature of the condensate

The temperature of the condensate the formed is equal to steam (saturation temperature to corresponding pressure) or vapour temperature. When the condensate runs down over the tube surface, some heat of the condensate passes to the boiling juice and the temperature of the condensate comes down.

Let:
- $t_c =$ temperature of condensate.
- $t_v =$ temperature of vapour.
- $t_j =$ temperature of the juice.

If 1kg of condensate of temperature $t_v$ gives total heat that can be transferred to the boiling juice and cools down to the juice boiling temperature ($t_j$). Then the heat given by the condensate well is equal to:

\[
W \text{t. of condensate} \times \text{Sp. Heat of condensate} \times (t_v - t_j) = 1 \times (t_v - t_j) \]  
Equation (2.10)
However, in the short time of descending the condensate only part of the heat can be transferred. If only 40% of this heat get transferred to the juice, the heat transferred to the juice will be $(0.4(tv - tj))$. Considering this heat loss, the condensate water temperature will be dropped down and will be equal to

$$tc = tv - 0.4(tv - tj)$$

Equation (2.11)

The condensate from the first effect is under pressure of one kg/m². If is opened to atmosphere it vigorously boils with flashing, and heat is lost. Therefore, in many factories, it is send to the boilers in a closed loop without opening it to atmosphere.

### 2.8.9.2 Composition of condensate

Generally people think that the condensate as it is obtained from vapours is pure water but it is not so, the volatile nonsugar constituents of the juice of which boiling point is below that of water get evaporated and pass with vapours. Further these volatile compounds may get condensed along with vapours and pass with condensate or are dissolved in the condensate. Therefore, traces of aldehydes, organic acids, methyl and other alcohols, $O_2$, $CO_2$, $SO_2$ and $NH_3$ etc are found in condensate. Depending on the quantity of the different types of impurities, the pH of the condensate varies from 5.5 to 8.5. Acetaldehyde is formed by alkaline decomposition of reducing sugars. The condensate formed from the vapours from the first effect has higher aldehydes content than those of the next bodies. It is found in mixed juice as well as in clear juice. In alkaline solution it is transferred into paraldehyde ($C_6H_{12}O_3$) this at high temperature polymerizes to form complex organic compounds called aldehydes resin. This is not volatile; it remains in boiler water, and is responsible for coloration. The aldehydes concentration is higher in immature cane as well as cane harvested a few days after having rains.
The nature of acids is not known. They may be lower aliphatic acids such as formic or acetic acid. The amount of CO₂ can vary from 7 to 25 mg/lit (www.sugar process tech-.com-2017).

28.9.3 Utilization of condensate

All exhaust steam condensate (except of juice heaters) is send to boilers as boiler feed water. The temperature of exhaust condensate is high. The exhaust condensate is not contaminated because of entrainment. In case of first effect even if in case the tubes are leak, because of higher pressure to the steam side, heavy leakage of juice does not take place. If sugar test is observed that can be only due to traces of sugar and remedial action can be taken without any high risk of trouble of boilers. There is close circuit however; make up water is needed because of the following reasons:

- Exhaust of condensate of juice heaters is not send to boilers.
- Boiler water is lost due to boiler blow downs hence steam generation is always less than water feed to boilers.
- Losses in the steam cycle due to leakages.
- High- pressure steam used for centrifugals, sulphur burners, cleaning etc. Is lost to atmosphere.

Condensate from second effect is partly used as make up water for boilers. Because there is minimum possibility of entrainment from the first body (as there is no vacuum in the vapour space of the first body) and it is temperature is high. The remaining condensate from the second effect and the following effects is used for process such as:

- Imbibitions
- Wash water for rotary vacuum filter
- Seed washing in the pans
- Molasses dilution at pans stations
- Movement water for pans,
- Washing while masssecuite curing at centrifugals
- Melting of Sugar
2.8.9.4 Steam consumption at evaporator station

In past until 40 years back all the vessels from multiple effect evaporators were made of equal size, each supplying vapours to the following vessel without withdrawal of any vapours. No much steam economy was considered. Some 25 years back the bagasse saving was not economical for most of the factories because use of bagasse was limited and bagasse was fetching very low price. Even bagasse handling or transportation cost was not being recovered by sell of bagasse. Therefore, emphasis was not given in efficient use of steam and bagasse saving. Bagasse was generally saved only to run the boilers in mill stoppages, general cleaning, finishing the end process and starting the next season.

Now bagasse price are going up and factories can earn money on sale of saved bagasse. Therefore, efficient utilization of steam has become essential to save the bagasse for factories without cogeneration or cogeneration with back pressure route. In case of factories with cogeneration by condensing route the steam saving in boiling house can produce more electricity for export.

Rillieux in his second principle reported that 'there is steam saving when vapours are withdrawn from evaporator set'. Vapours from the last effect going to the condenser are lost. When these vapours are used for heating the raw juice by installing a vapour line juice heater (VLJH) in the vapour line going from the last body to condenser, these is complete saving of exhaust.

The main unit where the steam consumption can be reduced is the evaporator station. Under vacuum evaporation, some part of the vapours has to be condensed in the condenser. The steam consumption at evaporator station is the ' Vapours going to condenser from the last effect of evaporator'. Therefore, main principle in governing the steam economy measures is to reduce the quantity of vapours going to condenser from the last body of the evaporators. The evaporator steam consumption can be brought down by increasing the vapour bleeding from the evaporator set. This results in lower evaporation load to the last effect (www.sugarprocess tech-.com2017).
2.8.10 Different vapors bleeding system

Jambhale in -2005. Reported that: considering 100 t/hr plant and water evaporated 80% on cane in multiple effect evaporators the steam consumption percent on cane for different evaporator configurations and vapour bleeding systems is given by:

2.8.10.1 Vapor bleeding system case quadruple

Raw juice first heating (RJ1) from 30 to 42c in vapour line juice heater, vapours required 2.2t.

Raw juice second heating (RJ2) from 42 to 75c by vapours from the second effect, vapours required 5.9t.

Sulphited juice first heating (SJ1) from 73 to 90c by vapours from first effect, vapours required 3.5t.

Sulphited juice second heating (SJ2) on exhaust.

All pans on exhaust.

Fig (2.3): Evaporator set (vapour cell quadruple)

Table (2.5) Steam consumption percent on cane

<table>
<thead>
<tr>
<th></th>
<th>Steam used for juice heating</th>
<th>17.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Steam used at pan station</td>
<td>22.90</td>
</tr>
<tr>
<td>3</td>
<td>Miscellaneous use</td>
<td>4.000</td>
</tr>
<tr>
<td>4</td>
<td>Total</td>
<td>57.875</td>
</tr>
</tbody>
</table>
This vapor bleeding system was recommended in Indian standard Specifications in (1972) for plants of 1250 t/day capacity.

Vapor bleeding system case 2 – vapor cell plus quadruple:

Raw juice first heating (RJ1) from 30 to 42 c in vapor line juice heater, vapours required 2.2 MT.

Raw juice second heating (RJ2) from 42 to 75 c by vapors from second effect, vapours required 5.9 MT.

Sulphited juice first heating (SJ1) from 70 to 90 c by vapors from first effect, vapours required 3.5 MT.

Pan boiling by vapors from Vapor cell vapors required 22.9 MT.

The Sulphited juice second heating (SJ2) on exhaust.

Table (2.6) Water to be evaporated in Vapor cell

<table>
<thead>
<tr>
<th>Water to be evaporated in the VC (all vapours going to pans)</th>
<th>22.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to be in quadruple</td>
<td>57.10</td>
</tr>
</tbody>
</table>

Table (2.7) Water to be evaporated in each body of quadruple

<table>
<thead>
<tr>
<th>No. of Effect</th>
<th>Vapour bleeding</th>
<th>Water to be evaporated (t/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RJ2</td>
<td>SJ1</td>
</tr>
<tr>
<td>4th</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3rd</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>X +5.9</td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>X +5.9 + 3.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4x +11.8 + 3.5=</td>
<td></td>
</tr>
</tbody>
</table>
Water to be evaporated in the last body 10.45
Vapours consumed at VLJH 2.2
Vapours going to condenser 8.25

1  Steam used for juice heating 17.00
2  Steam use at pan station 22.90
3  Steam required for evaporation 8.25
4  Miscellaneous use 4.00
Total 52.15

This vapor bleeding system was recommended in Indian standard specifications (1972) for 2000 tcd.

2.8.11 Vapour used for pan boiling

As E. Hugot while calculating vapor requirement, he states that, in general about 120kg/M.T. cane by weight is the steam consumption at pans. Out of this quantity about 2/3rd Vapor are taken from quadruple set. And 1/3 from exhaust steam.

Hence:
Vapor required from evaporator to pans = 2/3*012*crushing rate (2.12)
karmarkar( 2000)

2.8.12 Specific evaporation coefficient of the individual body

Formula  \( C=0.001 \times (100-\text{Brix}) \times (T^\circ\text{C}-54^\circ\text{C}) \)  Equation (2.13)

Where
- \( C \): is specific evaporation coefficient.
- \( \text{Brix} \): is Average Brix of the body
- \( T^\circ \text{C} \): is Calandria temperature of the body
- 54°C: assumed temperature of the last body

Is constant depending on the cleanliness of the body surface.

2.9. Exhaust steam production

Come from mill turbines and power turbines beside make up from live steam.

Formula  (2.14) Hugot (1986)
Where
\( Q = \) exhaust steam from mill turbine
\( h_1 = \) inlet steam enthalpy
\( h_2 = \) outlet steam enthalpy

Turbine thermodynamic efficiency
Turbine mechanical efficiency
High speed Gearbox mechanical efficiency
Planetary gearbox efficiency
Formula (2.15) Hugot (1986)
Where
\( Q = \) exhaust steam from power turbine
\( h_1 = \) inlet steam enthalpy
\( h_2 = \) outlet steam enthalpy

Turbine thermodynamic efficiency
Turbine mechanical efficiency
Gearbox mechanical efficiency
Mechanical alternator efficiency

2.9.1 Gross or higher calorific value of bagasse is given by

Equation (2.16) Hugot (1986)
Where:
\( GCV = \) Gross calorific value of bagasse
\( w = \) Unit moisture % bagasse = 51% Bagasse
\( s = \) Unit pol % bagasse = 3.4 % Bagasse
\( = 2311.2 \text{ kcal } / \text{ kg} \)

Steam to bagasse ratio (S/B):
Steam to bagasse ratio is given by:
Where:
\( S/B = \) Steam to bagasse ratio
\( = \) Boiler thermal efficiency = 70%
\[ H = \text{Enthalpy of Superheated steam in kcal / kg} \]
\[ h = \text{Enthalpy of boiler feed water in kcal / kg} = 105 \text{ kcal / kg} \]

**2.9.2 Steam generation**

Today, co-generation is considered to be the simultaneous production of power and heat, usually in the form of electricity and steam. Co-generation requires considerable additional investment. This additional investment may be rewarding, and co-generation will be attractive, when Fuel is available at low cost; this arises in situation such as sugar factories, where bagasse is used as fuels. High-pressure steam is usually raised in a boiler and passed through a turbine to generate power. The low-pressure turbine, that exhausts steam, is then available for process heating.

Co-generation schemes need to be tailored to the particular user demands and considerable professional expertise is needed to understand and meet all requirements in a satisfactory way.

**2.9.3 Bagasses contents**

Bagasse is the fibrous residue of sugar cane remaining after the extraction of juice. It is well suited for use as a fuel, having adequate calorific value, is low in ash and virtually free of environmental contaminants such as sulfur. The fiber is composed of the cellulose-ligninpentosan complex common to the structural matter of plants. The fiber carries with it the absorbed juice and water not removed in the de-watering step together with a mixed product of disintegrated cane trash along with a small quantity of inorganic material termed ash. Typical properties of bagasse are outlined in table (2.8).

Table (2.8): Bagasse content at 150kg/m³ density

<table>
<thead>
<tr>
<th>Content</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>46 – 52</td>
</tr>
<tr>
<td>Fiber</td>
<td>40 - 48</td>
</tr>
<tr>
<td>Soluble solids</td>
<td>2 - 6</td>
</tr>
</tbody>
</table>

(Reports of Season (2017- 2018) of Elguneid Sugar Factory)
2.9.4 Use of bagasse as a fuel

Bagasse is burnt in suitable boilers to produce steam which in turn is transformed via prime movers, for example turbines, to mechanical or electrical energy. Exhaust steam from the turbines is used as a source of thermal energy, for example, in the heating cycle of the cane juice within a sugar factory. The ‘as fired’ analyses of typical bagasse, a medium volatile coal, fuel oil and pine wood are presented in table (2.9).

Table (2.9): Analyses of typical fuels as fired.

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Bagasse %</th>
<th>Coal %</th>
<th>Oil %</th>
<th>Wood %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>22.9</td>
<td>70.3</td>
<td>85.8</td>
<td>26.7</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2.8</td>
<td>4.0</td>
<td>10.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.0</td>
<td>0.5</td>
<td>2.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.0</td>
<td>1.8</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Oxygen</td>
<td>21.3</td>
<td>6.0</td>
<td>0.0</td>
<td>18.9</td>
</tr>
<tr>
<td>Moisture</td>
<td>50.0</td>
<td>6.0</td>
<td>0.4</td>
<td>50.0</td>
</tr>
<tr>
<td>Ash</td>
<td>3.0</td>
<td>11.4</td>
<td>0.0</td>
<td>0.4</td>
</tr>
<tr>
<td>GCV KJ/Kg</td>
<td>9,177</td>
<td>28,410</td>
<td>43,000</td>
<td>7,936</td>
</tr>
<tr>
<td>NCV KJ/Kg</td>
<td>7,409</td>
<td>27,385</td>
<td>40,887</td>
<td>7,936</td>
</tr>
<tr>
<td>Stoie.CO₂</td>
<td>20.7</td>
<td>18.8</td>
<td>16.1</td>
<td>20.6</td>
</tr>
</tbody>
</table>

(The ISSCT Combined Factory/Energy Workshop on Efficient)

For bagasse fuel, it is a usual practice to burn the fuel in a boiler to produce high pressure steam, which is fed into the turbine to generate mechanical and electrical power, and the exhaust steam leaving the turbines is used for heating in the sugar factory. This method allows the power turbo machinery to work in a clean steam environment, keeping the fuel and ash problems confined to the boiler stack.
systems. Modern boilers are highly developed and well understood. Usually it is possible to capture more than 85% of the lower heating value of the fuel as high pressure steam energy. Depending on the scale of operations, steam conditions, and turbine details, some 15-25% of the HP steam energy can be extracted as power. The balance is available in the LP turbine exhaust steam. The use of bagasse as an energy source has been ongoing for a long period of time. The quantity of excess bagasse was insufficient to warrant consideration of co-generation of electricity for export to the grid. For a factory grinding 300tc/h, when producing 95-100 tons bagasse per hour, gives a net surplus of 25-30 tons per hour or about 650 - 700 tc/day [12]. At this time of high production, the excess is resulting in a disposal problem; a problem that could readily be converted into energy and save the country a lot of foreign exchange. Bagasse is a by-product of cane sugar manufacture; hence the acquisition cost is low. However, there is the cost of conveying, storing and retrieving the material as required (.Mohapatra, 2018).

2.9.5 Co-generation systems

Most cane sugar factories have been designed to be energy self-sufficient, with sugar as the primary product. A bagasse-fired co-generation system, made up of “medium” pressure boilers (17-20 bar) plus small steam driven turbo-alternators, provides all the steam and electricity needed to run the Cane mills and factory, leaving little surplus bagasse as a “free” fuel. There are two types of bagasse-fired co-generation systems, which potentially offer much higher electricity production than those found in most sugar factories today:

(1) High-pressure condensing-extraction steam turbine system (CEST), and (2) steam-injected gas turbines run on gasified bagasse (GSTIG). “High pressure” (40-80 bar) refers to boiler pressures typical of condensing extraction steam turbines. “Medium pressure” (15-20 bar) refers to steam used for cane mills, which equals the boiler pressure in most sugar factories today. “Low pressure” (2-3 bar) refers to mill and turbo-alternator exhaust steam used in the process. High pressure or (CEST) co-generation
systems are now used in a few cane sugar factories and are being considered for several others. When small medium pressure turbo-alternators are replaced with a high-pressure (CEST) system, the total electricity production can be increased from about 20 kWh/t (just enough to run the factory) to perhaps 70-120 kWh/t. Thus, in addition to sugar making, about 50-100 kWh/t becomes available for export to the utility grid. Electricity and steam production in co-generation system is that the electricity (in kWh/t), and steam production (in kg of medium pressure steam produced per ton cane) [14]. For both (CEST) and (GSTIG) co-generation systems, the steam and electricity production can be varied over a range of operating conditions, so that more electricity can be produced when the steam demand is lower (Payne, 1990).

2.9.6 Steam usage
The sugar industry is a major consumer of steam, with the evaporators and vacuum pans consuming substantial quantities for concentration of juice and manufacture of sugar. Apart from these, the juice heaters, centrifuges, sugar dryers and sugar melting also consume some steam. The washing of pans and other equipment need some marginal steam. The steam consumption is discussed in detail below. In the case of old sugar factories the source of low-pressure steam and high-pressure steam are independent. Modern sugar factories use the combined unit type or the control unit type. Each boiler will distribute the high-pressure steam through the main or the common steam header, thereafter steam will be separated at several points for being directly consumed or conditioned before being used as per the requirement here-under.

1- High-pressure steam used directly at (20-30 bar) as superheated steams with a temperature of 350°C; for the steam turbine, the exhaust steam flow combined with low-pressure steam in the main line.

2- Medium pressure steam (17-20 bar) as superheated steam with a temperature of 300-350°C for the steam turbine, with the exhaust steam with a temperature of
140-125°C, for juice heater, evaporators, vacuum pans and heating elements in the process.

3- Low-pressure steam at (1-2 bar) as saturated steam originated from the superheated steam combined with the exhaust steam with a temperature of 120-125°C, for juice heater, evaporators, vacuum pans and heating elements in the process.

4-Make-up steam and desuperheated steam as low-pressure steam originated from the main line high-pressure steam, which has already passed through a pressure reducing valve and de superheated before being used as make up for the insufficient low-pressure steam.

Total energy in raw sugar factory with / without refinery: The modern cane sugar factories are designed to generate steam at around 30 bar or higher and 400°C. After the live steam is used in the mills and turbo-generators, the exhaust steam is used for all process requirements. The steam distributions based on a sugar factory with the operating conditions of table (2.5) is shown in Fig (2.2).

Table (2.10): The process parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane crushing rate</td>
<td>4700 tc/d</td>
</tr>
<tr>
<td>Actual crushing over 23hr</td>
<td>205 tc/h</td>
</tr>
<tr>
<td>Cane pol</td>
<td>12.5% on cane</td>
</tr>
<tr>
<td>Fiber</td>
<td>21.0% on cane</td>
</tr>
<tr>
<td>Imbibition water in fiber</td>
<td>200% on cane</td>
</tr>
<tr>
<td>Filtrate returned</td>
<td>15% on cane</td>
</tr>
<tr>
<td>Mixed juice</td>
<td>83% on cane</td>
</tr>
</tbody>
</table>
CHAPTER THREE
MATERIALS AND METHODS

In
Elguneid sugar factory

3.1 Materials:
1. Sugar cane
2. Mixed juice
3. Mixed juice
4. Lime
5. Syrup
6. Sugar crystals
7. Condensate water
8. Bagasses
9. Steam/vapor

Sugar cane

The cane is fired before harvesting to remove the dead leaf material and some of
the waxy coating. The fire burns at quite high temperatures but is over very
quickly so that the cane and its sugar content are not harmed, cane sugar
transported is arranged by tractors and trails and passed through weighbridge.
The first stage of processing is the extraction of the cane juice after the washing
by water to remove dirtiness, mud and sand.

Mixed juice

Juice received from milling Tandem is called as (Mixed juice). The composition
of mixed juice:

a-Water
b-Inorganic non sugars
c-Organic non sugars
d-Sugars

Out of these it is an interest to recover sugar to the maximum possible extent in
the form of crystal and eliminate maximum possible non-sugar. The water is
evaporated. It is therefore necessary to know the nature of non-sugar present in the mixed juice.

Table (3.1) Composition of Mixed juice

<table>
<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Soluble Solids (Bx%M.J.)</td>
<td>14° to 18°</td>
</tr>
<tr>
<td>2.</td>
<td>Water</td>
<td>82 to 86%</td>
</tr>
<tr>
<td>3.</td>
<td>Sucrose</td>
<td>11 to 14%</td>
</tr>
<tr>
<td>4.</td>
<td>Reducing sugars</td>
<td>0.5 to 1.5%</td>
</tr>
<tr>
<td>5.</td>
<td>Ash</td>
<td>0.5 to 0.7%</td>
</tr>
<tr>
<td>6.</td>
<td>Purity</td>
<td>80 to 84</td>
</tr>
<tr>
<td>7.</td>
<td>PH</td>
<td>5.0 to 5.4</td>
</tr>
<tr>
<td>8.</td>
<td>CaO content(mg/liter)</td>
<td>600 to 800</td>
</tr>
<tr>
<td>9.</td>
<td>P₂O₅ content(mgs/liter)</td>
<td>80 to 150</td>
</tr>
</tbody>
</table>

**Liming:**

The milk of lime, calcium hydroxide or Ca (OH)₂, is entered into the juice to hold the required ratio and the limed juice enters a gravitational settling tank.

**Syrup:**

After the liming, juice heated and clarified juice settled in clarifiers the juice is thickened up into syrup by boiling off the water using steam in a process called evaporation.

The clear juice has probably only 15% sugar by weight content but saturated sugar liquor, required before crystallization can occur, is close to 80% sugar content. Evaporation in a steam heated multiple effect evaporator is the best way of approaching the saturated condition.

**Sugar crystals:**

The syrup is placed into a very large pan for boiling, this is the last stage. In the pan even more water is boiled off until conditions are right for sugar crystals to grow.
**Condensate water**

The steam/vapour applied in the calandria gives its latent heat to the juice boiling inside the tube and gets condensed. The condensate thus formed descends down over the tube surface and get collected on the bottom tube plate of the calandria. The temperature of the condensate the formed is equal to steam (saturation temperature to corresponding pressure) or vapour temperature. All exhaust steam condensate (except of juice heaters) is send to boilers as boiler feed water. The temperature of exhaust condensate is high. The exhaust condensate is not contaminated because of entrainment. In case of first effect even if in case the tubes are leak, because of higher pressure to the steam side, heavy leakage of juice does not take place. Is close circuit however; make up water is needed because of the following reasons:

**Steam generated from boilers**

Co-generation is considered to be the simultaneous production of power and heat, usually in the form of electricity and steam. Co-generation requires considerable additional investment. This additional investment may be rewarding, and co-generation will be attractive, when fuel is available at low cost; this arises in situation such as sugar factories, where bagasse is used as fuels. High-pressure steam is usually raised in a boiler and passed through a turbine to generate power. The low-pressure turbine, that exhausts steam, is then available for process heating.

**Bagasse**

Bagasse is the fibrous residue of sugar cane remaining after the extraction of juice. It is well suited for use as a fuel, having adequate calorific value, is low in ash and virtually free of environmental contaminants such as sulfur.
3.2 Unit operation

Equipments and Apparatus:-

1. Unloading and handling of cane     2. Mills
3. Imbibitions water system         4. Juice
5. heater                           6. Boilers
7. Evaporators                      8. Power
9. Crystallization (pans)           10. Turbines

Unloading and handling of cane:

In Elguneid sugar factory the cane is transported by tractors and trailers to factory and passed through weighbridge for material balance. Unloaded in two feeding tables (6×12m) driven by motors (30HP, 1460 rpm), slope of feeding table = 12deg (forward slope).

Mills:

The mills are driven by steam turbine 700HP for each one, initial speed is 6260 rpm

- Number of mills tandem is 6 mills (3 rollers)
- Mill size = 914.4×1981.2mm (Baukou Wolf – German)
- Roller size = 1000(Di) × 1981(length)mm
- Mill speed varies from 5 to 6.25 rpm

(Jenkins, 1966)
Imbibitions water system:

The imbibitions water system is used in the factory, water is applied before the last mill and the juice obtained from the last mill returned as imbibitions before the 2\textsuperscript{nd} last mill and juice from it to preceding mill and so on up to 2\textsuperscript{nd} mill, wet cane crushing in first mill so all juice collected from mills tandem is called as mixed juice and sent to process house.

(Www.sugarprocesstech.com).

Juice heaters:

- There are number of 7th heaters for juice heating

- Heating surface area 200m\textsuperscript{2} for each one

- The tubes ID = 42mm, OD = 45mm and the length = 4m

- There are two heaters for raw juice heating from 30\degree C to 45\degree C by 3\textsuperscript{rd} body vapor (heater No 1) and juice heating from 45\degree C to 70\degree C by 2\textsuperscript{nd} body vapor (heater No2)

- There are three heaters for treated juice heating, two are under operation and one standby.

Heating from 70\degree C to 85\degree C by 2\textsuperscript{nd} body vapor, in heater No3 and heating from 85\degree C to 105\degree C by 2\textsuperscript{nd} body vapor or exhaust steam.

There are two heaters for clear juice heating by exhaust steam in heaters No6 and No 7 before sent to evaporators.
Fig (3.1) Juice heaters

**Evaporators:**

One is identical vessel of 1100m$^3$ for each and the other set are (1600, 1400, 1200, 1100, 1100) m$^3$ respectively, One is vapor cell and 4$^{th}$ (quadruple effect).

Tubes diameters is 42ID, 45ODmm and 2m length. Calandria tubes are brass. Juice interring through distribution system installed below baffle of the bottom cone, the cone is located below the calandria.

Steam interring outside surrounding path for proper distribution.

Central down take is for fast circulation of juice from the top to the bottom of calandria, this concentrated juice and sent to next body.

Incondensable gases are withdrawal out by( small pipe length) from calandria to atmosphere in case of vapor cell and first body, 2$^{nd}$,3$^{nd}$ and 4$^{th}$ bodies the gases
removal pipes connected to the last body vapor to condenser through the regulating valve.

Fig (3.2) Evaporators set

Crystallization (pans):

The total numbers of pans in Elgeneid sugar factory are (10).

No 1- capacity 25ton

The tubes number of tubes 270,( 89mmID – 102mmOD- length 1320mm – H.S area 110m²).

The pan No 2 to 10 capacities is 50 ton for each one (tubes number 568, 89mmID – 102mmOD- length 1320mm – H.S area 250m²).
Number 2, 3, 4 for B- Mamssecuite.

Number 5, 6 for C- Massecuite.

Number 7, 8,9,10 for A- Massecuite

Fig (3.3) Pans of sugar crystallization

**Boilers:**

The boilers 4 No's with same specification.

Type - water tube.

Working pressure - 18 bar

Designed pressure - 21 bar

Capacity - 25 T/hr Evaporation and 31 T/HR ON furnace oil +bagase
Temperature - 370°C

Heating surface – 695m²

Grate heating surface – 22.5m²

**Power turbines:**

There are two power turbines, same specification:

Type – multi stage horizontal

Rankin steam cycle

Make - Siemens, Germany

Capacity – 2950Kw

Speed (RPM) – 8000/1500

Steam inlet pressure – 16.5 bar

Steam inlet temperature – 360°C

Back pressure – 3 bar

Steam consumption – 9.70 Kgf/KWH at 2495KW

Exhaust steam temperature – 125°C

Turbine gear system – hydraulic
3.3 Methods of Calculations

To achieve low steam consumption% cane, we discussed various alternatives to reduce steam, before that the calculations covered the steam produced from boilers, exhaust steam from mills turbines and power turbines, vapor generated from Evaporators and steam/vapor distributing, for calculation used equations (2.13 – 2.14 – 2.15 – 2.16 – 2.17) Handbook cane sugar engineering – (Hugot,1986)

Material and energy balance

In

Elgunied sugar factory

3.4 Material balances

The daily crushing capacity was 4715 tons of cane/day. The factory operates for 23 hours per day. Thus 205 tons of sugar cane was processed per hours.

Note: 1. All units unless otherwise mentioned are in ton per hour.
Sugar cane composition of Elguneid Sugar Factory as below:

<table>
<thead>
<tr>
<th>Composition</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>67.0</td>
</tr>
<tr>
<td>Sucrose</td>
<td>12.0</td>
</tr>
<tr>
<td>Fiber</td>
<td>19.15</td>
</tr>
<tr>
<td>Impurities</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Thus 205 tons cane feed per hour contained:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>137.35</td>
</tr>
<tr>
<td>Sucrose</td>
<td>24.60</td>
</tr>
<tr>
<td>Fiber</td>
<td>39.26</td>
</tr>
<tr>
<td>Impurities</td>
<td>3.79</td>
</tr>
</tbody>
</table>

**Milling plant:**

Water used in milling operation is 25 – 30% of sugar cane. Practical value is 27.5 %.

Therefore imbibition water used = 0.275 × 205 = 56.4 tons

Milling efficiency 93% i.e. 93% of sucrose goes into the juice. Thus sucrose amount in juice = 0.93 × 24.6 = 22.9tons Unextracted sucrose = 0.07 × 24.6 = 1.72tons

Assuming 70% of impurities stay in the juice and 30% goes with bagasse, Impurities in the juice =0.70 ×2.25 = 1.58tons

Impurities in bagasse = 0.30 × 2.25 = 0.675tons

The final bagasse from last mill contains the unextracted sucrose and impurities, fiber and 50% water.
Thus dry matter amount in bagasse = 39.26 + 1.72 + 1.58 = 43.695 Amount of bagasse = 50% dry matter + 50% water = 43.695 dry matter + 28.2 water = 71.895 tons

Overall output of mill or juice entering the clarifier will have the following composition:

<table>
<thead>
<tr>
<th>composition:</th>
<th>Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>= 137.5 + 56.4 – 43.695 = 149.305</td>
</tr>
<tr>
<td>Sucrose</td>
<td>= 24.6</td>
</tr>
<tr>
<td>Impurities</td>
<td>= 2.25</td>
</tr>
<tr>
<td>Thus total juice</td>
<td>= 175.485</td>
</tr>
</tbody>
</table>
% of solids in this juice = \( \frac{(24.6 + 2.25) \times 100}{175.485} = 15.3 \)

% Purity of mixed juice = \( \frac{24.6}{24.6 + 2.25} = 0.916 \) i.e. 91.6

Fig (3.5) Block diagram for material balance in mills house

Sugar cane → Bagasses
Imbibitions water
Raw juice

Clarifier:

Reagent used: lime 0.5 kg lime/ton of sugar cane

Thus lime added = \( 0.5 \times 205 = 102.5 \) kg = 0.1025 ton

Assume 6% efficiency of clarification process (impurities remove).
Therefore impurities removed = \( 0.06 \times 2.25 = 0.135 \)

Total sludge from clarifier = 0.1025 + 0.135 = 0.2375

Amount of clarified juice which was entering in the evaporator = 175.485 – 0.135 = 175.35 this clarified juice is fed to the first effect of the quadruple effect evaporator and analyses as follows:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>148.5</td>
</tr>
<tr>
<td>Sucrose</td>
<td>24.6</td>
</tr>
<tr>
<td>Impurities</td>
<td>2.65</td>
</tr>
<tr>
<td>Thus total juice</td>
<td>173.35</td>
</tr>
</tbody>
</table>

Fig (3.6) Block diagram for material balance in clarifier
Evaporators:

Typical evaporator load = 75 – 80% of clarified juice

Input to the evaporator = 148.50 water + 24.6 sucrose + 2.25 impurities = 173.35

Quantity of water to be removed = \( m_f (1 - \frac{X_j}{X_s}) \)
\[ m_t = \text{mass of juice input to the evaporator}. \ X_j = \text{Brix of juice}. \ X_s = \text{Brix of syrup}. \]

Water removed by evaporation = \(173.35 \times (1 - \frac{15.3}{60}) = 129.146\)

Hence water remaining in the juice = \(148.5 - 129.146 = 19.354\) output of evaporator analyses as under:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>19.354</td>
</tr>
<tr>
<td>Sucrose</td>
<td>24.6</td>
</tr>
<tr>
<td>Impurities</td>
<td>2.25</td>
</tr>
<tr>
<td>Thus total solution</td>
<td>46.204</td>
</tr>
</tbody>
</table>

\% solids in this concentrated solution\(= \frac{(24.6 + 2.25)\times100}{46.204} = 58.12\%\)

Fig (3.7) Block diagram for material and energy balance in Evaporators

Steam/vapor → Clear Juice → syrup

\(\text{Brix}^0 15 - 16\) → Condensate water → \(\text{Brix}^0 60 - 65\)
Crystallizer

Crystallization of concentrated juice is done in a vacuum pan crystallizer. Crystallization is done at vacuum not exceeding 635 mmHg.

Hence assume 580 mm Hg vacuum in crystallizer. Therefore absolute pressure = 760 – 580 = 180 mmHg

\[ \text{Absolute pressure} = (180 \times 1.013) / 760 = 0.2399 \text{ bar} \]

Thus boiling point (from sugar tables) at this pressure = 64°C

Boiling point rise = 4°C

According to the equation by Hugot [20], solubility of sucrose in water is given by:

\[ S = 64.18 + 0.1348 \times t + 0.000531 \times t^2 \]

Where S is % sucrose at saturation, and t is the temperature in °C. At 64°C, S becomes = 74.98 %

Therefore sucrose per kg of water = \( S / (100 - S) = 74.98 / (100 - 74.98) = 2.997 \text{ kg Sucrose/ kg of water} \)
The purity can be calculated as Purity = mass of sucrose / total mass of solids

\[
= \frac{24.6}{24.6 + 2.25} = 0.916 \text{ i.e. } 91.6\% 
\]

Hence the solubility is reduced by a factor called solubility coefficient. For purity of 91.6%, solubility coefficient = 0.95

Thus effective solubility = 2.997 \times 0.95 = 2.847 kg of sucrose/kg of water. Input to crystallizer = (19.354\text{water} + 24.6 \text{sucrose} + 2.25 \text{impurities}) sucrose content in feed. Assume 88.5% of sucrose is recovered as crystal with respect to initial.

Mass of sucrose crystal formed = 0.885 \times 24.6 = 21.77

Moisture associated with crystals = 1% of crystal mass

\[
0.01 \times 21.77 = 0.2177
\]

Sucrose in molasses = 24.6 - 21.77 = 2.83kg

Impurities left in molasses = 2.25 - 0.225 = 2.025kg

Total solid in molasses = 2.83 + 2.025 = 4.855kg

Water left in molasses = 4.855/2.847 = 1.705kg

Hence water to be evaporated = initial water – associated water – water in molasses

\[
19.354 - 0.2177 - 1.705 = 17.43 \text{kg}
\]

**Output of crystallizer**

(1) Solids = 22.009

21.77 sucrose + 0.2177 water crystals + 0.225 impurities

(2) Molasses = 8.56kg

(0.2177 water + 2.83 sucrose + 2.25 impurities)
(1) + (2) = Input to centrifuge = 22.009 + 8.56 = 30.569

**Centrifuge**

Assume 10% molasses adheres to the crystals.

Output of centrifuge:

\[ = (21.77 \text{sucrose} + 0.283 \text{water}) + 0.225 \text{ impurities} + 0.856 \text{molasses} = 23.134 \text{ ton} \]

Wet crystals from centrifuge analyses as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>21.77 + 0.283 = 21.678</td>
</tr>
<tr>
<td>Impurities</td>
<td>0.225+0.225= 0.45</td>
</tr>
<tr>
<td>Dry crystals</td>
<td>21.77+0.45 = 22.22</td>
</tr>
<tr>
<td>Water</td>
<td>0.2177+0.2222= 0.43199</td>
</tr>
<tr>
<td>Total</td>
<td>22.6599</td>
</tr>
</tbody>
</table>

**Dryer**

With a dryer, the moisture content may be reduced to between 0.2 and 0.5%. Drying by contact with hot air involves heating the air, to increase its capacity for absorbing water and bringing it into intimate contact with the sugar from which it evaporates the moisture.

Assume that the final moisture content is 0.2%. Mass of dry crystal is 22.419 (as calculated before).
Fig (3.8) Block diagram of pan house
Therefore final sugar produced = 22.6599\(\div (1 - 0.002)\) = 22.705 ton/h. Thus overall yield of raw sugar based on cane crushed = (22.705\(\div 205\)) \times 100 = 11.075\% . Thus moisture to be removed, \((m) = 22.705 - 22.419 = 0.286\ ton/h = 286\ kg/h\).

There are two possible methods of circulation of air and sugar, i.e. parallel flow and countercurrent flow.

For safety, the calculation is based on most unfavorable condition that is the ambient air fed to the heater before drying is assumed to be saturated. On the other hand, the air leaving a dryer is generally saturated; it is assumed that in case of countercurrent flow, it has absorbed only two-thirds of the quantity of water that it could have absorbed if it had left in a saturated condition.

### 3.5 Total steam generated from boilers in elguneid sugar factory

- For cane crushing rate 200 - 210 t/hr the average is 205 metric tons (MT)/hr
- Boiler capacity 25 MT/hr for one Boiler.

- With 95\% boiler efficiency for steam production, steam produced from four boilers; 
  \[=25 \times 4 \times 0.95 = 95\ \text{MT/hr}\]

- With 100\% boiler efficiency for steam production.
  
  \[\text{Steam produced } = 25 \times 4 \times 1.00 = 100\ \text{MT/hr}\]

  With considering steam leakages \(= 4.2\text{MT/hr}\)

  The actual steam required for process \(= 95 - 4.2 = 90.8\text{MT/hr}\)

### 3.5.1 Steam produced from boilers

Steam produced from boilers is 95 MT/hr

*Gross or higher calorific value of bagasse is given by:*

\[GCV = 4600(1 - w) - 1200s\]

From equation \((2.16)\) Hugot-1986, Handbook cane sugar engineering

Where:

\[GCV = \text{Gross calorific value of bagasse}\]

\[w = \text{Unit moisture } \% \text{ bagasse } = 51\% \text{ Bagasse}\]
s = Unit pol % bagasse = 3.4 % Bagasse

\[ GCV = 4600(1 - 0.51) - 1200 \times 0.034 = 2311.2 \text{ kcal / kg} \]

3.5.2 **Steam to bagasse ratio (s/b)**

Steam to bagasse ratio is given by:

\[
\frac{S}{B} = \frac{\eta \times GCV}{H - h}
\]

From equation (2.17) Hugot-1986, Handbook cane sugar engineering

Where:

\( S/B \) = Steam to bagasse ratio

\( \eta \) = Boiler thermal efficiency = 70 %

\( H \) = Enthalpy of Superheated steam in kcal / kg

\( h \) = Enthalpy of boiler feed water in kcal / kg = 105 kcal / kg

Steam temperature = 370 °C & Enthalpy = 3186.38KJ/KG = 761.054Kcal/kg

\[
\frac{S}{B} = \frac{0.70 \times 2311.2}{761.054 - 105} = \frac{1617.84}{656.054} = 2.4660
\]

Crushing rate = 205T/hr

Bagasse % cane = 44% cane by weight

Bagasse produced per hour = \( \frac{44 \times 205}{100} \) = 90.2T/hr

Bagasse used in filtration (Bagacillo) = (4 to 8) kg/ton cane crushing per hour(TCH), average 6kg/Tone cane hour.

Quantity of bagasse (Bagacillo) required = 6*205/1000 = 1.23T/hr

Bagasse required to steam production = 90.2/2.466 = 36.58T/hr

Total bagasse consumed = 36.58 + 1.23 = 37.81 T/hr

Surplus bagasse = total bagasse – consumed bagasse = 90.2 - 37.81 = 52.39T/hr

Surplus bagasse = 52.39*22 = 1152.58 T/day

3.5.3 **Exhaust steam**

**Exhaust steam from mill turbines**
The operating parameters of Gunied mill turbines are as follows:
- No. of turbines = 6.
- Inlet steam pressure = 17 bar
- Exhaust steam pressure = 1 bar
- Inlet steam temperature = $350^\circ C$
- Exhaust steam Temperature = $130^\circ C$
- Output power = 589 kw per turbine

The turbine efficiency was calculated as follows:

The actual and specific steam consumption for mill turbines was calculated by the steam turbine calculator as shown below:

Figure (3.9): Turbine Steam – Consumption Calculator (mills)

From the above figure the actual steam consumption for one mill turbine is 5.173 T/hr
T/hr; hence for 6 mill turbines will be:
\[ Q = \frac{860}{(h_1 - h_2)\eta_1 \times \eta_2 \times \eta_3 \times \eta_4} \quad \text{.....from Equation (2.19)} \]

\( h_1 = 3144.7 \text{ kj/kg} = 751.099 \text{ kcal/kg at t=350}^\circ \text{C & press.} = 17 \text{ bar} \)

\( h_2 = 2736.26 \text{ kj/kg} = 653.544 \text{ kcal/kg at t =130}^\circ \text{C & press.} = 1 \text{ bar} \)

\( \eta_1 = 0.93 \)

\( \eta_2 = 0.985 \)

\( \eta_3 = 0.985 \)

\( \eta_4 = 0.985 \)

\[ Q = \frac{860}{86.7} = 9.92 \text{ Kg/kw. Hr} \]

Where: - Q is power

For one mill turbine the actual steam consumption is:

\( Q = 9.92 \times 589 = 5842.88 \text{ kg/hr} \)

Where: - Q is amount of steam
For six mill turbine the actual steam consumption is:
\[ Q = 5842.88 \times 6 = 35057.28 \text{ kg/hr} = \frac{35057.28}{1000} = 35.057 \text{ T/hr} \]

Table (3.2) Comparing between computer and manual calculation, steam consumed in mills turbine in Elguneid sugar factory.

<table>
<thead>
<tr>
<th>Steam consumption calculated by computer, temperature 350(^0)C and pressure 17 bar</th>
<th>Steam consumption calculated manual, temperature 350(^0)C and pressure 17 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual steam consumption T/HR</td>
<td>One mill 6mills</td>
</tr>
<tr>
<td>5.173</td>
<td>31.0836</td>
</tr>
</tbody>
</table>

**Exhaust steam from power turbines**

The operating parameters of Elgunied power turbines are as follows:
No. of turbines 2
Inlet steam pressure = 18 bar
Exhaust steam pressure = 1.2 bar
Inlet steam temperature = 350\(^0\) C
Exhaust steam Temperature = 130\(^0\) C
Output power = 2.46 mw per turbine

The turbine efficiency was calculated as follows:

The actual and specific steam consumption for mill turbines was calculated by the steam turbine calculator as shown below:
From the above figure the actual steam consumption for one power turbine was found 21.96 T/hr; hence for 2 power turbines will be:

\[ 21.96 \times 2 = 43.92 \text{ T/hr} \]

**Exhaust steam from power turbine calculated by equation below**

\[
Q = \frac{860}{(h_1 - h_2)\eta_1 \times \eta_2 \times \eta_3 \times \eta_4} \ldots
\]

From Equation (2.15) Hugot.E-1986, Handbook cane sugar engineering

\[ h_1 = 3142.7 \text{ KJ/KG} = 754.6 \text{ kcal/kg at } t=350^\circ\text{C} & \text{ press}=18 \text{ bar} \]

\[ h_2 = 2739 \text{ KJ/Kg} = 652.2 \text{ kcal/kg at } t=130^\circ\text{C} & \text{ press}=1.2 \text{ bar} \]

\[ h_1-h_2 = 102.4 \text{ kcal/kg} \]

\[ \eta_1 = 0.93 \]

\[ \eta_2 = 0.985 \]

\[ \eta_3 = 0.985 \]

\[ \eta_4 = 0.965 \]

\[ Q = \frac{860}{89.1626} = 9.65 \text{ T/M W. hr} \]

\[ Q = 9.500 \times 2.46 \times 10^3 = 23.74 \times 10^3 \text{ Kg/hr} \]

For one power turbine the actual steam consumption is:

\[ Q = 23.74 \text{ Ton/hr} \]

Hence, for both power turbines the actual steam consumption is:

\[ Q = 23.74 \times 2 = 47.48 \text{ Ton/hr} \]
Table (3.3) Comparing between computer and manual calculation, steam consumed in power turbine

<table>
<thead>
<tr>
<th>Actual steam consumption T/HR</th>
<th>Steam consumption calculated by computer, temperature 350°C and pressure 17 bar</th>
<th>Steam consumption calculated manually, temperature 350°C and pressure 17 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>One power Turbine</td>
<td>21.96</td>
<td>23.74</td>
</tr>
<tr>
<td>Tow power turbine</td>
<td>43.92</td>
<td>47.48</td>
</tr>
</tbody>
</table>

Hence, for both power turbines and mill turbines the actual steam consumption is:

\[ Q = 47.48 + 35.057 = 82.537 \text{ Ton/hr} \]

Total Exhaust Steam Required to Process = 90.8 MT/hr

The make up steam from desuperheated steam = 90.8 - 82.537 = 8.26 MT/hr

3.5.4 Total vapor produced by evaporator

(Bleeding vapor)

\[ E = J (1 - \frac{B_j}{B_s}) \]

Total evaporation in evaporators percent cane = \( \frac{1 - \frac{15}{65}}{100} = 73.08 \) % on cane

Total vapour produced by evaporator = \( \frac{73.08}{100} \times 205 = 149.814 = 150 \) MT/hr

3.5.5 Raw juice heating

From 30°C to 65°C from 3rd Body vapour.

\[ \frac{195 \times 0.91(65 - 30)}{548 \times 0.95} = 11.93 \text{ MT/hr} \]

From 65°C to 75°C from 2nd Body vapour

\[ \frac{195 \times 0.91(75 - 65)}{539 \times 0.95} = 3.47 \text{ MT/hr} \]
3.5.6 Treated juice heating

From 70°C to 85°C from 2\textsuperscript{nd} Body vapour
\[
\frac{195 \times 0.91(85 - 70)}{539 \times 0.95} = 5.2 \text{ MT/hr}
\]
From 85°C to 103°C from 1\textsuperscript{st} Body vapour
\[
\frac{195 \times 0.91(103 - 85)}{532 \times 0.95} = 6.32 \text{ MT/hr}
\]

3.5.7 Clear juice heating

From 97°C to 112°C from exhaust steam
\[
\frac{195 \times 0.91(112 - 97)}{526 \times 0.95} = 5.33 \text{ MT/hr}
\]

3.5.8 Pan boiling

Steam required for massecuite boiling equal 120kg % m.t. cane by weight and that 2/3 from vapour cell and 1/3 from exhaust steam \ equation (2.17) \n
Total steam required for massecuite boiling,
\[
=0.12\times205=24.6\text{ T/hr}
\]

Steam required from vapour cell body
\[
=2/3\times24.6=16.4 \text{ T/hr}
\]

Steam required from exhaust steam,
\[
=1/3\times24.6=8.2 \text{ T/hr}
\]
Table (3.4): Total Exhaust Steam Required to Process mt/hr

| .i  | Evaporator = 45.46+16.40 = | 61.86MT/hr | = 30.18%cane |
| .ii | Clear juice Heating       | 5.33 MT/hr  | = 2.4% cane  |
| .iii| Pan boiling               | 8.2MT/hr    | = 4%cane    |
| .iv | +5% sugar dryers and centrifugals | 10.25 MT/hr | = 5% cane  |
| .v  | +2% steam losses due to leaking and in Blow down | 4.2 MT/hr | = 2.00%cane |
|     | TOTAL                     | 90.74 MT/hr | = 44.28%cane |

3.5.9 Vapour produced by each body of evaporator

- Assume vapour produced by 4ᵗʰ body = x MT/Hr
  - By 4ᵗʰ = x MT/Hr
  - By 3ʳᵈ = x+11.93MT/Hr
  - By 2ⁿᵈ = x+11.93+3.47+5.2 MT/Hr
  - By 1ˢᵗ = x+11.93+3.47+5.2+6.32MT/Hr
  - Total = 4x+ 35.79+6.94+10.4+6.32= 4x+59.45 MT/Hr

- 150 = 4X+59.45 +16.4MT/hr
- 4X = 74.15 MT/hr
- X = 18.54 MT/hr

Table (3.5): The vapor produced from each body mt/hr

| 4ᵗʰ  Body | 18.54 =x | 18.54 | MT/hr |
| 3ʳᵈ  Body | 18.54+11.93 | 30.47 | MT/hr |
| 2ⁿᵈ  Body | 18.54+11.93+3.47+5.2 | 39.14 | MT/hr |
| 1ˢᵗ  Body | 18.54+11.93+3.47+5.2+6.32 | 45.46 | MT/hr |

The following Schematic Diagram of Evaporators showing the Vapour bleeding system and the quantities of vapours.
Fig (3.12): Specific evaporation coefficient of the individual body

Formula  \( C = 0.001 \times (100 - \text{Brix}) \times (T^0 - 54^0 \text{C}) \) from equations (2.13).

(See section 2.8.11)

Table (3.6) **Specific evaporation coefficient "C" of the individual body is calculated as**

<table>
<thead>
<tr>
<th></th>
<th>v/c Body</th>
<th>( 0.001 \times (100 - 5.69) \times (128^0 \text{C} - 54^0 \text{C}) )</th>
<th>Kg/m(^2)/hr/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>v/c Body</td>
<td>( 0.001 \times (100 - 15.69) \times (128^0 \text{C} - 54^0 \text{C}) )</td>
<td>6.24</td>
</tr>
<tr>
<td>B</td>
<td>1(^{st}) Body</td>
<td>( 0.001 \times (100 - 19.18) \times (128^0 \text{C} - 54^0 \text{C}) )</td>
<td>5.98</td>
</tr>
<tr>
<td>C</td>
<td>2 Body</td>
<td>( 0.001 \times (100 - 26.63) \times (114^0 \text{C} - 54^0 \text{C}) )</td>
<td>4.4</td>
</tr>
<tr>
<td>D</td>
<td>3(^{rd}) Body</td>
<td>( 0.001 \times (100 - 38.84) \times (100^0 \text{C} - 54^0 \text{C}) )</td>
<td>2.81</td>
</tr>
<tr>
<td>E</td>
<td>4(^{th}) Body</td>
<td>( 0.001 \times (100 - 56.30) \times (90^0 \text{C} - 54^0 \text{C}) )</td>
<td>Kg/m(^2)/hr/°C 1.57</td>
</tr>
</tbody>
</table>

Vapour cell  =128\(^{0}\) C  401.15K  \( \text{cp} = 2.1685 \text{ kj/kg} \cdot \text{K} \)

1\(^{st}\) Body  =128\(^{0}\) C  401.15K  \( \text{cp} = 2.1685 \text{ kj/kg} \cdot \text{K} \)

2\(^{nd}\) Body  =114\(^{0}\) C  387.15 K  \( \text{cp} = 2.0860 \text{ kj/kg} \cdot \text{K} \)

3\(^{rd}\) Body  =100\(^{0}\)C  373.15 K  \( \text{cp} = 2.0287 \text{ kj/kg} \cdot \text{K} \)

4\(^{th}\) Body  =90\(^{0}\) C  363.15 K  \( \text{cp} = 1.9919 \text{ kj/kg} \cdot \text{K} \)

-Latent heat of evaporator – (kcal/kg vapors/steam) from steam table;
-Exhaust steam  526kcal/kg  = 2202.26kJ/kg.k

1\(^{st}\) Body vapor  532kcal/kg  = 2227.32 kj/kg. k
2\(^{nd}\) Body vapor \(539\text{kcal/kg} = 2256.69 \text{kJ/kg.k}\) 
3\(^{rd}\) Body vapor \(548\text{kcal/kg} = 2294.37 \text{kJ/kg.k}\) 
4\(^{th}\) Body vapor \(563\) \text{kcal/kg} \(= 2358.40 \text{kJ/kg.k}\)  

### 3.5.10 Brix of juice/syrup obtained from the individual body  

### 3.6. Considering 15% cane filtrate added to raw juice

\[
\frac{205(80 + 15)}{100} = \frac{205 \times 95}{100} = 194.75 MT/hr \approx 195 MT/hr
\]

From data there is:

1. Clear juice brix entering in v/c \(15^\circ\)
2. Quantity of clear juice \(195 \text{ MT/hr}\)
3. Brix of syrup leaving the last body \(65^\circ\)

Brix leaving the vapor cell

\[
\frac{15 \times 195}{195 - 16.4} = \frac{2925}{178.6} = 16.38
\]

1\(^{st}\) Body brix leaving

\[
\frac{15 \times 195}{178.6 - 45.46} = \frac{2925}{133.14} = 21.97
\]

2\(^{nd}\) Body brix leaving

\[
\frac{15 \times 195}{133.14 - 39.62} = \frac{2925}{93.52} = 31.28
\]

3\(^{rd}\) Body brix leaving

\[
\frac{15 \times 195}{93.52 - 30.47} = \frac{2925}{63.05} = 46.39
\]

(e) 4\(^{th}\) Body brix leaving

\[
\frac{15 \times 195}{63.05 - 18.54} = \frac{2925}{44.51} = 65.7
\]

For finding out the evaporation coefficient the average brix of the body is to be taken for calculations.

### 3.6.1 Average brix of juice/syrup of each body

(a) Vapour cell \((15+16.38)/2 = 15.69\)
(b) 1st Body = \((16.38+21.97)/2\) = 19.18
(c) 2\textsuperscript{nd} Body = \((21.97+31.28)/2\) = 26.63
(d) 3\textsuperscript{rd} Body = \((31.28+46.39)/2\) = 38.84
(e) 4\textsuperscript{th} Body = \((46.39+65.7)/2\) = 56.3
CHAPTER FOUR

Study case: calculation, result, suggestions and conclusion

4.0 Reduction of live steam consumption in Elguneid sugar factory

4.1 Pan washing

- Existing situation:

Routine practice to use 3kg/cm² steam pan washing before start of new strike. During sugar quality era, 3kg steam is to be replaced by exhaust steam to avoid caramelization. The main pan washing is to remove left over massecuite crystals from pan body as well as top tube plate of calandria. The second reason is to evaluate (empty, finish) the air entered during vacuum breaker operation. For pan washing steam required is 0.28% cane

- Alternative

To use 120⁰c exhaust to achieve 90⁰c temperature, for further reduction in steam consumption % cane, exhaust shall be replaced by 1st/2nd body vapors near to 100⁰c temperature.

- Precautions

While replacing exhaust steam by vapors near to 100⁰c temperature, one has to provide vapor inlet to washing coil from both side. The holes of washing coil shall be increased to 150% on cross sectional area basis. During pan dropping, vacuum break valve shall not be opened. The vacuum break is to be attained by closing condenser water valve and opening body washing valve.

- Opinion

for pan washing, exhaust steam shall be replaced by vapors near to 100⁰c temperature, as these vapors condense more quickly, better pan washing will be done in less time.
4.2- Molasses conditioner

- **Existing condition**
  
  It was routine practice to use 3kg steam for molasses tank conditioners. The conditioned molasses maximum temperature is 80°C. To use 160-180°C steam to achieve 80°C temperature is not advisable. The high temperature of steam also leads to caramelization of sugar and increases colorant load. Steam quantity required is 0.48% on cane.

- **Alternative**
  
  During sugar quality awareness, efforts were made to replace live steam by exhaust steam, further live /exhaust steam may be replaced by vapor (82-85°C).

- **Precautions**
  
  The major aim of molasses conditioner is to make the molasses crystal free. In general, we maintain 72-74° brix as well 72-74°C temperature for perfect conditioning and molasses conditioning just before feeding to pans.

- **Opinion**
  
  Modern molasses conditioners shall be provided with hot water addition. The retention time for these molasses conditioners shall be at least 15 minute to assure complete crystal free molasses. These molasses conditioners may be operated on second body vapor.

4.3 Low grade sugar melter

- **Existing statues**
  
  Similar to molasses conditioners, for low- grade sugar melter, 3kg steam is replaced by exhaust steam to avoid caramelization. Is common practice in India required is 0.5%cane.

- **Alternative**
  
  For sugar melting, the maximum temperature required is 85°C. This target could be achieved by using 2nd or 3rd bodies vapor .

- **Precautions**
While replacing exhaust steam and clear juice by 2nd body vapor and syrup, one should be increase retention time of melter to 25 minutes and multiple vapor coils shall be provided with fine vapor distribution arrangement.

- **Opinion**

For low-grade sugar Melter, exhaust steam plus clear juice may be used without a control system.

4.4- **Superheating wash water system for high grade sugar centrifugal**

- **Existing status**
Use of live steam for obtaining superheated wash water is common practices. Live steam required for superheated wash water is 0.2% cane.

- **Alternative**

Live steam may be replaced by exhaust steam by using PHE. Alternatively second body condensate may be heated by exhaust condensate through plate type heat exchangers.

- **Precautions**

One has to assure continuous availability of second body condensate for PHE.

- **Opinion**

Live steam maybe replaced by exhaust steam / exhaust condensate without control system for temperature as well as for pressure of water.

4.5- **Massecuite and Molasses pumps**

- **Existing status:** In general for all massecuite and molasses pumps, 3kg steam is routinely used mainly to remove any lumps / jamming in delivery lines. Steam required about 0.2% on cane

- **Alternative:** Live steam may be replaced by exhaust steam with good quality non-return valve.

- **Precautions:** Pipeline layout shall be studied for easy liquidation in case of gravity plants, the massecuite pumping may be totally avoided.
• **Opinion:** For massecuite and molasses lines, live steam shall be replaced by exhaust steam.

### 4.6- Centrifugals

- **Existing statues:** live steam / exhaust steam is used for washing of centrifugal basket, jamming of massecuite feed line to centrifugal, massecuite purging gate jamming. This quantity is very small and may vary from 0.05 to 0.10% on cane

- **Alternative**

The main aim of using steam at these points is to raise the massecuite temperature to 80-90°C for increasing fluidity as well as for melting the crystals at jamming point. First body vapor could do this work.

- **Precautions**

Line size need to be increased so as to assure the requisite quantity.

- **Opinion**

Live steam / exhaust steam may be replaced by first body vapors.

5-2 Proposals to reduce Exhaust steam in elguneid sugar factory.

After reducing the 3kg/cm² live steam load to minimum, the next target is to reduce the exhaust steam consumption to minimum or to reduce the vapour load at condenser to minimum.

Sugar factories in India adopted various modern concepts for reducing steam consumption for sugar processing up to 32-35% on cane. To achieve this one has to go for extensive vapor bleeding as possible.

1- vapour requirement for pan boiling

The major energy consumption in sugar industry is at pan boiling station, in general the vapor requirement at pan station is assumed 25% on cane, however due to introduction of short tube length (700-750mm) low head vacuum pan, the massecuite height above the top tube plate is considerably reduced.

This load to decrease in boiling point of massecuite and increased circulation of massecuite in vacuum pans. Due to all above, the use of second body vapor (140°C) for pan boiling is become general practice, for graining in batch type of vacuum pans, the vapor of (140°C) can be safely used, higher temperature vapors are only needed for a pan tightening. If we calculated material
balance and water to be evaporated (given in annexure 11) we may find that the vapor demand is as follows:

A m/c - 0.40 MT vapor / MT m/c
B m/c - 0.37 MT vapoure / MT m/c
C m/c - 0.40 MT vapor / MT m/c

pan vapor demand (% cane) = m/c% * specific vapor consumption of pans.

A m/c = 28% cane
B m/c = 13% cane
C m/c = 7% cane

28*0.40 + 13*0.37 + 7*0.40 = 18.81 says 19

The requirement of vapor for pan boiling may be reduced from 24 -25 to 19-20% cane.

2- Vapor demand for juice heating:
Vapor demand for raising juice temperature from 30, 35 to 105 – 114 0C is approximately worked out to 14.5% cane.

Use of hot condensate water for raw juice, to recover this heat few factories tried to heat raw juice first heating by using condensate water, this practice may save steam% of the order of 1.5 to 2 % cane

4.7- Flashing of exhaust condensates

Normally condensate is collected individually from evaporator /juice heaters and pans, and sent to over head tanks at process or used as boilers feed water, condensate going to tanks looses it's temperature by radiations while flowing through pipes and flash vapor in atmosphere.

Due to energy crisis and it's economy, modern sugar factories prefer use the vapor condensate from juice heaters / pans and evaporators is collected in flash tank depending upon pressure & temperature, the flash vapors is used back in evaporator (next vessel ) & heaters at corresponding temperature - pressure, this may result in saving steam 2.5 to 3.0% on cane.
**Table (4.1) Recommendation to reduce steam% cane in Elguneid sugar factory**

<table>
<thead>
<tr>
<th>Recommends</th>
<th>Reduction of steam % cane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reduction in live steam</strong></td>
<td></td>
</tr>
<tr>
<td>Use of live steam at molasses condition to be replaced by 1st vapor</td>
<td>0.46% cane</td>
</tr>
<tr>
<td>Live steam for melt preparation to be replaced by 1st body vapor</td>
<td>0.5% cane</td>
</tr>
<tr>
<td>Pan washing to be replaced by 1st body vapor instead of exhaust</td>
<td>0.25% cane</td>
</tr>
<tr>
<td>Superheating wash water system is to be replaced by exhaust steam</td>
<td>0.2% cane</td>
</tr>
<tr>
<td>Massecuite &amp; Molasses Pumps live steam is to be replaced by exhaust steam</td>
<td>0.1% cane</td>
</tr>
<tr>
<td>live steam /exhaust steam is to be used for washing of centrifugal basket replaced by 1st body vapor</td>
<td>0.1% cane</td>
</tr>
<tr>
<td><strong>Reduction in exhaust steam:</strong></td>
<td></td>
</tr>
<tr>
<td>Vapor demand for juice heating replaced by condensate hot water</td>
<td>1.2% cane</td>
</tr>
<tr>
<td>Flashing of exhaust condensates use instead of steam</td>
<td>2% cane</td>
</tr>
<tr>
<td>Pan boiling vapor reduced up to 21%</td>
<td>3% cane</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>7.81% cane</td>
</tr>
</tbody>
</table>

From the above recommendation reduction of steam % on cane in process become around **7.8%** on cane of steam saved.

Steam reduced % cane per hour = steam % cane * cane crushing per hour = 0.075*205
= 15.375 tons of steam / hour =15.99*22 = 351.78 tons of steam /day

From steam bagasse ratio equation (2.17)

\[ S / B = \frac{\eta \times GCV}{H - h} \]

Steam bagass ratio = 2.466
Bagass produced / hour = 90.2 T /h
Bagass required to produce 90 ton of steam = 90.2/2.466 = 37.58 T/h
15.375 ton of steam required X ton of bagass

\[ X = \frac{(37.58 \times 15.99)}{95} = 6.33 \text{ ton of bagass} \]

6.33 tons of bagasse saved /hour \(6.33 \times 22\) = 139.26 ton of bagass / day

Cash value in bagass = 139.26 \times 125 = 17407.5 SD/day

theoretical steam consumption in turbine (Hugot, 1986)

\[
Q = \frac{860}{(h_1 - h_2) \eta_1 \times \eta_2 \times \eta_3 \times \eta_4}
\]

Equation (2.14) Hugot

\[ \sum \eta \text{ Power Turbine Efficiency} \]

\( h_1 \) steam inlet enthalpy

\( h_2 \) steam outlet enthalpy

\[ Q = \frac{860}{(755 - 765) \times 0.95} = 11.32 \text{ kg/kw} \]

Actual sp- steam consumption = theoretical / the turbine efficiency = \[11.32 / 0.95 = 11.92\]

say = 12 kg / kw

So power saving/h = \[5380 \times 1/12\]

\[ X = \frac{6.33}{0.012} = 527.5 \text{ kw/h} \]

Power saving per day = \[527.5 \times 22 = 11605 \text{ kw/day} = 11.605 \text{ MW/day} \]

Cash value = \[11605 \times 380 = 4409900 = 4409900/1000 = 4409.9 \]

Saving: \[4409.9 \text{ SD/day} \]
CHAPTER FIVE

Conclusion and recommendation

5.1 Conclusion

The result obtained has led to following factors:

- The quantity of steam produced from boilers in Elguneid sugar factory is 95MT/HR.
- The actual amount of steam required for process is 90.8MT/HR.
- At present the boilers are operated at full capacity. But our proposal (alternatives) have a reduction in consumption.
- By our proposal steam reduction\% cane in process achieved 7.8\% on cane of steam saved on hour.
- The steam required is critical when compared to steam produced (steam\% cane=46\%) But we proposed a reduction in steam consumption in process upto 36-37\% cane.
- The quantity of bagasse to produced steam is 40.55\% bagasse produced.

5.2 Recommendations

To improve efficient utilization of steam produced in Elguneid sugar factory, the following recommendations are suggested for further study:-

With the help of modification of boiling house (use of modern instrumentation, automation and optimization), by operating evaporator with maximum vapor bleeding arrangement.

Rearrange of steam/vapor lines and improves steam stabilization system.

With use above proposals ( modern trend ) , Elguned sugar factory can keep target to achieve 7.8\% reduction in steam used in process and able to reduce bagasse, reducing load in boilers and energy saving
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