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Analysis of Heat Transfer on the Effect from Mineral Crust in Evaporator Semi-Kestner Quintuple Effect

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A B S T R A C T

Indonesia as a large population country has the potential to become one of the largest consumers of sugar in the world. Indonesia's national sugar needs amounted to 3.2 million tons per year while domestic production was around 2 million tons. In the sugar industry, the benefits of evaporator tools are to thicken clear juice whose dissolved solid number is 7 - 11 ºBrix into a thickened syrup with a dissolved solid of 55 - 60 ºBrix, this process occurs through the process of evaporation of water content contained in the material. In one sugar factory the type of evaporator used is a Semi-Kestner Evaporator with quintuple effect principle. One of the biggest challenges of evaporators is the decrease in heat value of the evaporator due to the onset of mineral crust that inhibits heat transfer. On September 7th, 2021 Q evaporator 1 is at 135874.8 Kw and on October 26th, 2021 Q evaporator 1 is at 121399.2 Kw. Based on the results of data observations on the evaporator carried out in the time span of September 2021 and October 2021, it can be concluded that the decreased heat transfer will cause the evaporator's performance in evaporating water from the sap material (clean juice), so that the material flow rate is getting bigger. Efforts that can be made to overcome this are to carry out mechanical cleaning or chemical cleaning per 28 days of the grinding process, to remove crusts on the tube calandria evaporator.

1. INTRODUCTION

1.1. Research Background

The evaporation process is important in making sugar. The demand for heat in sugar mills occurs in the processes of heating sap, evaporation, and crystallization. In the sugar industry, the benefit of an evaporator is to thicken the juice (clear juice) whose viscosity number is 7-11 ºBrix into thickened juice (syrup) with a viscosity number of 55-60 ºBrix, this process occurs through a heat transfer process then analyzed the parameters. In one of the observed sugar factories, the type of evaporator used is a Semi-Kestner type evaporator with the principle of quintuple effect. The pressure of each evaporator is made to decrease so that the boiling point of the juice solution decreases also by vacuuming the pressure on the evaporator numbers 3, 4, and 5. The use of this vacuum method is caused by steam entering each evaporator body, the pressure is reduced from evaporator 1 to evaporator 2 and so on, this is because heat transfer has occurred, and encounters other obstacles.

1.2. Literature Review

Sugarcane contains hydrocarbons present in plants due to the process of photosynthesis. Carbohydrates – these carbohydrates consist of monosaccharides (glucose, fructose), disaccharides (sucrose), and polysaccharides (cellulose). In photosynthesis, there is a reaction between CO_2 and H_2O assisted by sunlight and leaf green substances (chlorophyll) producing carbohydrate monosaccharides [1].

$$6CO_2 + 6H_2O + \text{calory} \longrightarrow C_6H_{12}O_6 + 6O_2$$

The evaporator is an important operational key in a sugar mill and is a major factor in determining the energy efficiency of the plant itself. The evaporator is the largest steam user to concentrate sap into a solid substance content with a concentration of 65-68%. The preparation of the position and number of evaporators determines the amount of steam to be used in sugar factories, therefore the need for precise determination in compiling and designing evaporators [2].

One of the types of evaporators to reduce installment cost with high performance used in sugar mills is a *semi-Kestner* series type evaporator (quintuple effect). In practice, the type of semi-kestner evaporator with a milling capacity design of 6000 TCD, each evaporator is arranged in series (Quintuple Effect) consisting of evaporator 1, evaporator 2, evaporator 3, evaporator

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4, and evaporator 5 has the ability to evaporate water differently from other evaporators due to differences in the cross-sectional area of the heater (heating surface), the number of calandria tubes, and the length of the calandria tube.

The formation of mineral crusts in the calandria evaporator is caused by the content of lime milk (CaO) and other mineral content in the sap derived from the imbibition water (imbibition water) mill and feed water head tank which is then attached to the calandria tube when it meets hot steam in evaporation. The amount of crust in general ranges from 200 – 800 g/m2 in dry conditions in a wide section of the hot cross-section. The formation of a crust on each calandria depends on the low speed of circulation of the material, on the part when the material is in a stagnant state, and when the stirring conditions are uneven [3].

1.3. Research Objective

This study aims to evaluate optimal parameters for evaporator operation, analyze the volume and temperature vapor in the evaporation process, then analyze CaO and SiO content in *clear juice*. This parameter means determining the maintenance schedule for the evaporator.

2. MATERIALS AND METHODS

2.1. Preparation of sample

The following sample such as clear juice, syrup, mineral crust, etc is taken while the sugar manufacturing process is ongoing from 7th September 2021 to 26th October 2021 in PT.Pratama Nusantara Sakti factory.

Fig. 1 Example of commonly formed crust in Evaporator

Compounds	Formed Place	Chemical Maintenance
Calcium Phosphate	At evaporators 1 & 2, reduced specifically to the next evaporator	Cleaned with caustic soda, or diluted acid
Organic Compounds (protein, gelatin compounds, polysaccharides)	The highest content in evaporator 1, reduced specifically to the next body	Cleaned with caustic soda
Silica	The highest content in evaporator number 5	Cleaned with caustic soda
Hydroxipatite (complex arrangement calcium phospate)	Found in evaporators 1 & 2	Cleaned with caustic soda
Calcium Oxalic	The highest content in evaporator number 5, usually bound to silica	Cleaned with EDTA
Calcium & Magnesium	Occasionally found on evaporator 5	Cleaned with EDTA
Carbonate	The highest content in the evaporator 5	Cleaned with caustic soda, or diluted acid
Sulfate	Found in evaporator 5 in the form of a hard crust	Cleaned with dissolved acid

After collection, the parameter in clear juice and syrup was taken into consideration to predict how much mineral crust was formed inside tube calandria in the evaporator. The parameter is affected by the CaO and SiO contained in the material, even though the mentioned compound does not have a considerable amount but it was accumulated inside tube calandria in an evaporator along with the sugar manufacturing process which usually takes 6 – 7 months [4].

2.2. Heat transfer in evaporator semi-kestner quintuple effect

The heat transfer in the evaporator is the most important thing in sugar factories, the ability to increase ^{o}brix from 10 ^{o}brix to 55 – 65 ^{o}brix and evaporating water contained in clear juice which will be turned into vapor to supply the sugar crystallization process in the factory are the main concern.

But the main obstacles in heat transfer for the evaporator are the mineral crust which is formed by the accumulated mineral content in the material through the evaporator. The mineral crust can be known by the decreasing heat transfer efficiency in the evaporator, while the evaporator was compiled with multiple effects from number 1 to number 5 with different amounts of tube calandria existing inside the body of the evaporator and with different heat cross-sectional areas in every evaporator.

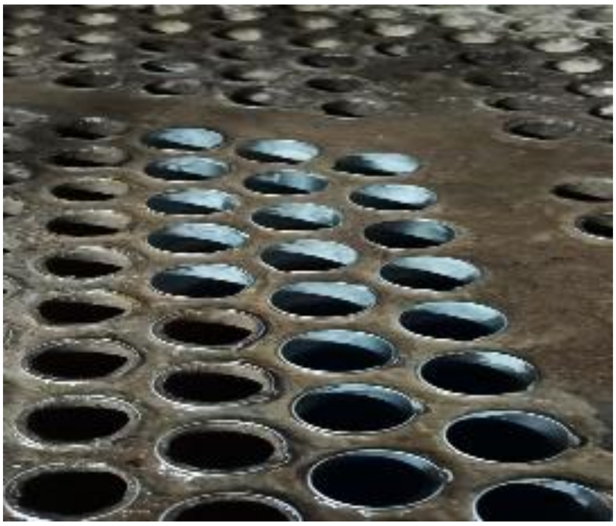

Fig. 2. Mineral crust formed in tube calandria evaporator

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2.3. Analysis data of CaO and SiO in clear juice

The sampling requires 5 liters for each with 5 variable which differs in time. The formation of crusts in the calandria evaporator is caused by the content of lime milk (CaO) and other mineral content in the sap which comes from the imbibition water (imbibition water) mill and feed water head tank which is then attached to the calandria tube when it meets hot steam in evaporation.

The use of lime milk aims as follows:

a. Inhibits the growth of the bodies of the trinkets, because it has been known that the remains of the nick develop well in acids
b. Reduces the degree of acidity in sugarcane juice.
c. Gives advantages to the working life of machines or equipment that are not acid resistant.

The amount of crust in general ranges from 200 – 800 g/m^2 in dry conditions in a wide section of a hot cross-section. The formation of a crust on each calandria depends on the low speed of circulation of the material, on the part when the material is in a stagnant state, and when the stirring conditions are uneven [3].

2.4. *Analytical methods*

All parameters in this study were conducted in triplicates and followed: CaO content was measured with titration method according to Philippines Sugar Technology. SiO content was measured with a spectrophotometer according to SNI official method 06-2477-1991. The pH value was tested by pH meter (Oakton PCSTestr 35 waterproof). Clear juice and syrup °brix was measured with a refractometer.

2.5. *Calculated total water evaporated and flow material*

The volume of total water evaporated and flow material was monitored every day but the data was taken per 7 days from 7th September 2021 to 26th October 2021; the vapor was measured based on the results noted from the pressure gauge in every evaporator body.

3. RESULT AND DISCUSSION

3.1. *Heat transfer in the evaporator*

The results of the calculation of the displacement of each series of semi-kestner quintuple effect evaporators are obtained from the comparison of the existing tv and ti temperatures along with the coefficient values obtained from the existing design table. In fig. 3. the heat transfer of each evaporator decreases with each data collection held every 2 weeks for 5 times. The decrease in heat transfer is caused by lime and silica contained in the juice (clear juice) over time it is accumulated

The heat transfer of each evaporator decreases every day due to the formation of a heat-inhibiting mineral crust layer. On September 7, 2021, Q evaporator 1 was at 135874.8 Kw and on October 26, 2021, Q evaporator 1 was at 121399.2 Kw, decreased heat transfer also means reducing evaporator performance in evaporating water from the juice material (clear juice).

On September 7, 2021, the total evaporated water (ME) of all semi-kestner quintuple effect evaporators was at 128.9 t/h, then dropped to 109.45 t//h on October 26, 2021. In some cases stated by Rein (2007), with an evaporator capacity of 8,000 m2 with the Robert evaporator type in its best performance, it can evaporate 950 t / h of water from the total evaporator quintuple effect. This difference in evaporation is quite large due to differences in the number of calandria tubes, material flow rate, and evaporator type. The total evaporated water based on the chart above drops on each date due to indications of heat transfer inhibiting factors, namely mineral crust in the calandria evaporator.

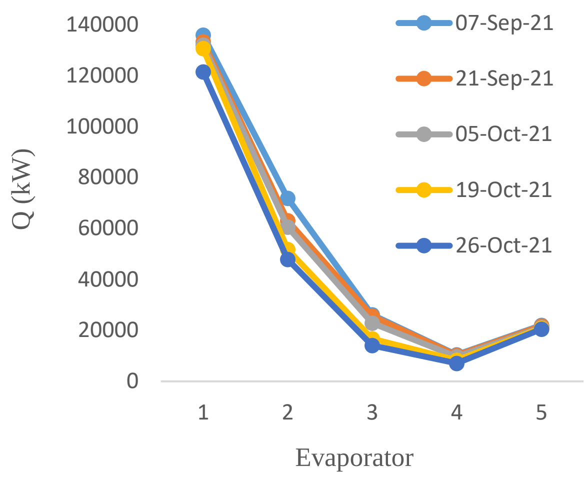

Fig. 3. Heat transfer of semi-kestner quintuple effect evaporator.

3.2. *Total water evaporated and the flow rate*

The results of the calculation of the total water evaporated by the evaporator are obtained from the calculation of the initial liquid flow rate, the initial solute content, and the final solute content. The total water evaporated from the initial clear juice flow rate of 150 t /h is different from each date, this is due to the decrease in evaporator performance every day due to the formation of heat-inhibiting mineral crusts on the calandria tube in each existing evaporator.

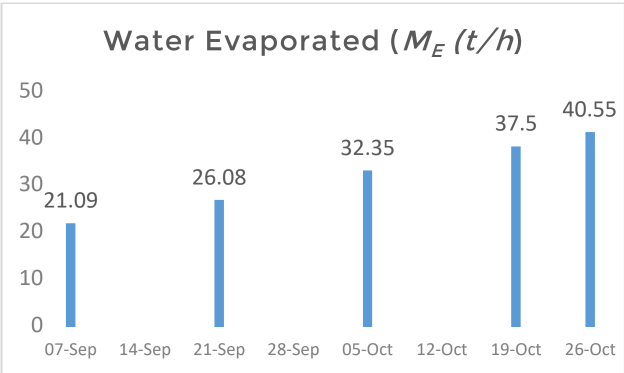

Fig 4. Total water evaporated comparison against time.

The amount of evaporated water will decrease further along with the decrease in heat transfer that occurs in the evaporator, and will increase the final flow rate of the material. So the greater the final rate of the material due to the presence of water content in the sap that is not thoroughly evaporated will complicate the process of crystallizing sugar. This difference has an inverse effect on the flow rate of the final material shown in the Figure 5

The effect of controlling the optimum condition parameters of each evaporator is very important because it can be seen from the heat transfer value in evaporator 5 even though there is scale / scaling on this evaporator the material level and the flow rate of this material is controlled very neatly to achieve the oBrix number on the syrup material sent to the vacuum pan for the further sugar crystallization process. Indeed, it cannot be denied that the °Brix number is low on each trial schedule carried out, but it is important to maintain each applicable parameter until there is a decision on the maintenance schedule step from the factory

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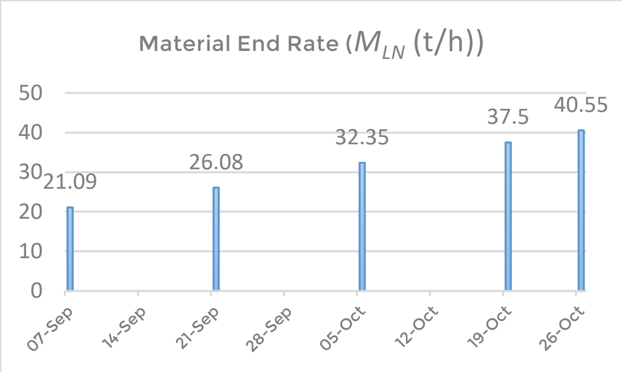

Fig 5. Comparison of Material End Rate Against Time

3.3. Evaporator Capacity

From the data obtained about the diameter and length of the calandria tube, the capacity of the semi-kestner quintuple effect evaporator can be calculated based on the cross-sectional area of the heater (heating surface).

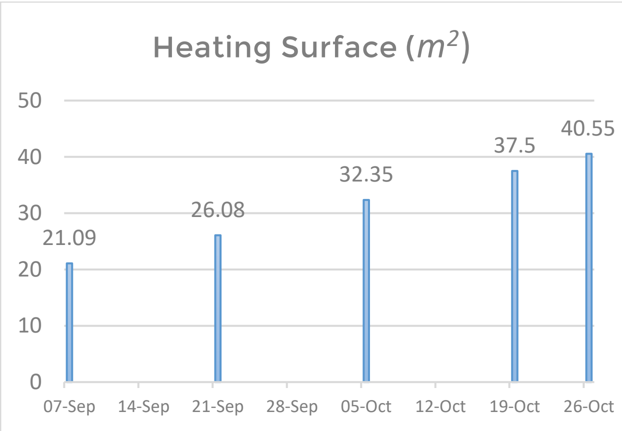

Fig. 6. Heating surface evaporator semi-kestner quintuple effect

The heating surface of each evaporator semi-kestner quintuple effect is different from one another, this is adjusted to the desired initial design to ease a load of evaporator 1 and others to be efficient in the use of existing exhaust steam and reduce losses. This is following what Rein (2007) reported, for quintuple effect evaporators have a heat cross-sectional area capacity of 8,000 m2 with a hot cross-sectional area in the evaporator the first was 4,000 m2. The area of the heat cross-section varies based on the desire and capacity of the plant to be designed by the management and based on the ability of sugarcane that can be provided for grinding [5].

3.4. Cao content in clear juice

The results of the calculation of the CaO content in the sap (clear juice) determine how much lime content is in it, the higher the content, the greater the potential to cause the formation of mineral crusts on the calandria evaporator tube which inhibits heat transfer.

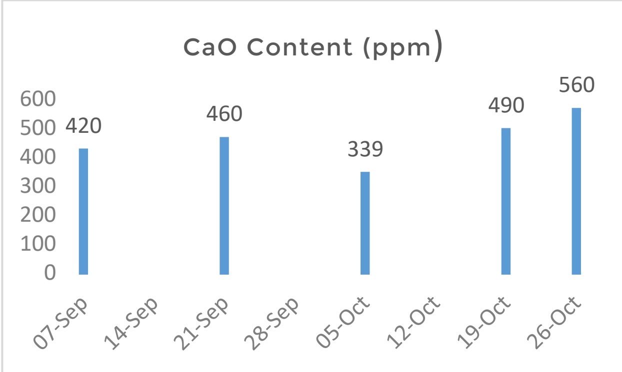

Fig 7. CaO content per time

The analysis of the calculation of CaO content in the juice (clear juice) on September 7, 2021 was at 420 ppm and on October 26, 2021 it was at 560 ppm. The CaO content tends to increase every day due to the pursuit of pH parameters so as not to inversion of residence time, decrease in sugar purity, and the acidity of the condensate water produced. The decrease in parameters on October 5, 2021 can occur because the juice of milled sugarcane juice has a greater level of acidity than usual because weather factors that cause wet or dry sugarcane and also the length of life of sugarcane affect this parameter.

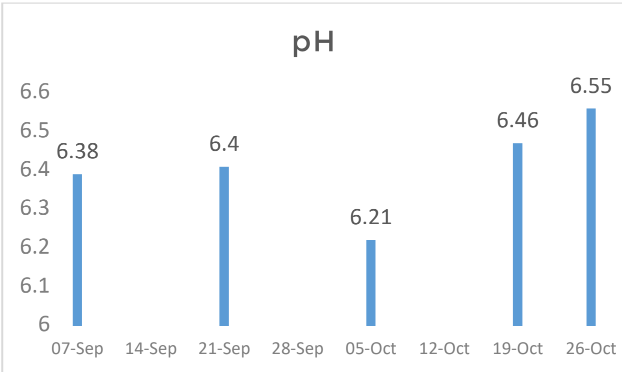

Fig 8. pH comparison to the time

The analysis of the pH calculation on the juice (clear juice) on September 7, 2021, was at 6.38 and on October 26, 2021, it was at 6.55. The pH number is directly proportional to the CaO content in the juice (clear juice), the higher the CaO content, the higher the pH of the juice (clear juice).

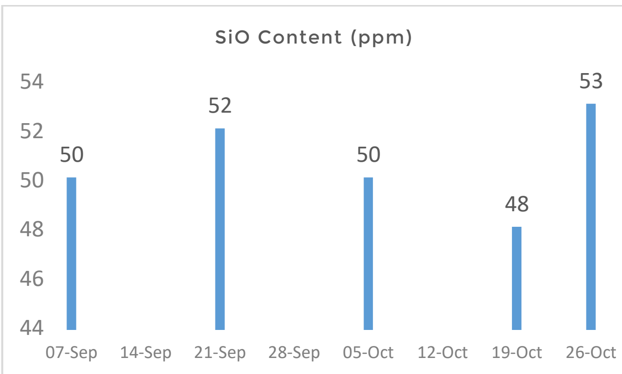

Fig 9. SiO content per time

3.5. SiO content in clear juice

The results of the calculation of silica (SiO2) content in feed water determine how much silica (SiO2) content is in it, the higher the content, the greater the potential to cause the formation of mineral crusts in the calandria evaporator tube which inhibits heat transfer.

4. CONCLUSION

The performance of the evaporator in its heat transfer decreases over time due to the increasing scale formed in the calandria evaporator, the process of evaporation of water in each evaporator container decreases due to heat transfer resulting in insufficient temperature evaporating the water contained in the juice, so that the volume of water vapor also decreases. The content of CaO and SiO in the sap can indeed over time rise and fall depending on the parameters of the milled sugarcane material, but over time the milling time, the content of CaO and SiO in the evaporated juice in the evaporator will be left behind and attached to the calandria so that it forms a mineral crust.

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