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Characterization and Effects of Scale Formation on Heat Transfer System of Multiple-Effect Evaporator Units in Cane Sugar Industry

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Abstract

"Characterization and Effects of Scale formation on Heat transfer system of Multiple-effect evaporator units in Cane sugar industry" is the title of my thesis work, the study has been conducted characterization of scale formation by collected scale samples from Wonji-Shoa Sugar Factory and characterized chemically to determine its composition and the scale was resulted 2604.70 mg/l composed of $CaSO_4$ in the fourth body evaporator and 2860.66 mg/l in the fifth effect evaporators and minor amounts have been recorded in the other three effects. Additionally, process water has been characterized for their composition and pH which shows that process water is within a normal hardness and pH range. But the juice was abnormally high when compared to world average of 1.5% CaO % in juice. Therefore, the main cause of heat transferring units scaling in the plant was the $CaSO_4$ content of the juice. To overcome this problem, Selecting of the best quality of calcium compound and treating the juice with H_2SO_4 and heat is the best technology. Energy and material balance for a five-effect evaporator was performed in the multiple effect evaporators; Temperature, vapor flow rate, Liquid flow rate, pressure bleeding, composition and other process variables have been determined by developed a set of non-linear equations derived from the mass and energy balance relations. These equations are then solved using the Newton-Raphson method by developing a mat lab code.

Keywords: Characterization; Evaporator units; Fouling; Heat transfer rate; Material and energy balance; Process variables; Process water analysis

Introduction

Fouling is generally defined as the accumulation and formation of unwanted materials on the surfaces of processing equipment, which can seriously deteriorate the capacity of the surface to transfer heat under the temperature difference conditions for which it was designed. Fouling of heat transfer surfaces is one of the most important problems in heat transfer equipment. Fouling is an extremely complex phenomenon [1]. Evaporation falls into the concentration stage of downstream processing and is widely used to concentrate sugar juice. If a single evaporator is used for the concentration of any solution, it is called a single effect evaporator system and if more than one evaporator is used in series for the concentration of any solution, it is called a multiple effect evaporator system. Adding one evaporator to the single effect decreases the energy consumption to 50% of the original amount. Adding another effect reduces it to 33% and so on. The number of effects in a multiple-effect evaporator is usually restricted from four to seven because after that, the equipment cost starts catching up to the money saved from the energy requirement drop [2]. Almost all sugar plants experience scaling of pre-heaters, distilleries and evaporators; but the extent of scaling varies from plant to plant. These encrustations are formed from the combined effects of several processes involving inorganic and organic molecules or ions. The possible causes of the scaling are impurities in sugar juice or process water [3]. Scale facilitates the corrosion of surfaces, restricts fluid flow and, because it has low thermal conductivity, its accumulation on metal surfaces hinder heat transfer across the tubes wall. The type of the scale being formed depends on a number of variables such as quality of input materials and intermediate products, flow properties of the fluid, rate of evaporation, and process conditions of the system [4,5].

Materials and Methods

Materials and chemicals

Materials used in the chemical characterization experiment are, scrapper, sample scale collector, 500 ml Erlenmeyer flask, 100 ml burette, 500 ml beaker, 100 ml beaker, 100 ml volumetric flask, digital weighing balance (precision, ± 0.0001 gram), measuring cylinder, funnels, pH meter, glass stirrer, 500 ml Erlenmeyer flask and Chemical reagents used in this study are; ammonia buffer solution, eriochrome black T indicator solution, ethylene diamine tetra acetic acid (EDTA), pH buffer solutions 4.00 and 9.00. Scale consists of many components and its composition can best determined using Flame atomic photometer atomic absorption spectrophotometer and ICP-Spectroscopy ULTIMA-2 in our laboratory in chemical engineering department at post graduates research lab.

Determination of process water pH

First, the pH meter calibrated using the 4.00 and 9.00 pH buffer solutions while stirring at a constant rate. Calibrations have been done at the beginning of experimental work using fresh buffer solutions. Then, the sample is allowed to cool to room temperature. Finally, the pH of the sample has been measured while stirring at a constant rate, allowing at least one minute for the reading to stabilize. This test has been done for one day every hours and the average pH reading of the test has been recorded.

Determination of total hardness

The method is based on the chelating of EDTA, i.e., the reaction between EDTA and calcium and magnesium ions in the water. The

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result is expressed as the total calcium and magnesium concentration in ppm $CaCO_3$. The sample water first filtered and 50 ml of the filtered water sample pipette into a 250 ml Erlenmeyer flask. After adding about 2 ml of buffer solution, 3-4 drop of eriochrome black T indicator solution added. After the appearance of wine red color, the solution is titrated with 0.05 M EDTA from the burette until a blue end point is reached by the disappearance of the last purple coloration.

Total hardness calculation

$$\text{Calcium determination } (\text{Ca}) = titre \times \frac{250cm^3}{50g \times 10cm^3} \times \frac{calcium(mg)}{1000ml} \times 100g$$

Total hardness (as ppm $CaCO_3$)=Titration volume (ml) × 20. From the following procedures, the calculation for titration method of water sample collected from the Wonji-Shoa sugar Plant has been calculated as follows:

Calculation for morality of EDTA: M.V ($MgSO_4$)=M'.V' (EDTA)

Cations and anions of process water experimental analysis

Flame photometry: A traditional and simple method for determining cations and anions in water analysis involves the technique of emission flame photometry. This relies on the principle that sample water was drawn into a non-luminous flame will ionize, absorb energy from the flame and then emit light of a characteristic wavelength as the excited atoms decay to the unexcited ground state and the detector has been read out the result.

Composition of syrup samples analysis collected from clarification unit

Sample aliquots (5 ml) were taken from stock sample solutions prepared at concentrations representing 0.25 g/ml syrup in 1% nitric acid (HNO_3). The aliquots were placed in 50 mL Erlenmeyer flasks. Samples were then spiked with the metals of interest from a multi element standard. Digestion was performed at 90°C on hot plate. Oxidizing agents were added in a stepwise fashion to avoid vigorous reactions and minimize analyze loss. Specifically, 1.0 ml of 16 M HNO_3 was added and allowed to react until all evidence of digestion (gas evolution) had ceased. On average, this required 20 min. Next, 4 ml of 30% (wt/v) H_20_2 was added and allowed to react for approximately 30 min. This was then followed by an additional 5 ml of 30% (wt/v) H_20_2. After digestion ceased, the hot-plate temperature was increased to 120°C and the samples were evaporated to near dryness (volume <0.5 ml), cooled, and transferred to a final volume of 10 ml using 1% HNO_3. During sample evaporation, samples should be periodically checked to avoid losses due to spattering. Collect subsamples for analyses. The samples of clarified juice were analyzed for impurities by inductively coupled plasma mass spectrometry (ICP-MS) at Bahirdar university chemical engineering department post graduates research laboratory.

Characterization of scale in evaporator units

Scale characterization chemically by ICP-MS instrumental analysis was performed. And the samples are further classified for chemical characterizations, as 1st, 2nd, 3rd, 4th and 5th effects for five effect evaporator units. In this experiment, the deposit sample characterized for 1st, 2nd, 3rd, 4th, and 5th effect evaporators at Bahirdar University in chemical engineering department at post graduate research laboratory using Inductively Coupled Plasma Atomic Emission Spectrophotometer (ICP-AES). Samples dried in Furnas for 520°C till become finely powder and the samples made more powder by grinder then digested by inorganic acid (1M of HCl) by taking 5 g of scale sample from each effect in order to become pure and clear solution and heated for 45°C for 15 minutes for further digestion to made pure solution and safe for ICP-MS analysis mechanism. Finally, filtered by watman filter paper and prepared 100 ml sample of the pure solution and analyzing by ICP-MS with aided of computer software and Aragon gas element.

Material and energy balance calculations in multiple effect evaporators

Material and Energy balance was used and various operating parameters of different effects are related by the mass and enthalpy balance relations, the heat transfer rates and the phase equilibrium relationships for the liquid and vapor rates. This results in a set of non-linear equations. The number of variables and equations depends on the operating strategy of the evaporator system. This system of non-linear equations is then solved, iteratively and by developing a code for the Newton Rapson method. A five-effect system is using the mass and energy balance relations. A total of 15 equations are obtained from the flow sheet of evaporation plant for the process variables V_0, T_1, T_2, T_3, T_4, T_5, L_1, L_2, L_3, L_4, L_5, U_1, U_2, U_3, U_4, U_5, and other parameters were determined.

Determination of physical parameters in multiple effect evaporators

The accumulation of unwanted deposits on the surfaces of heat exchangers is usually referred to as fouling. For all fouling modes, the amount of material deposited per unit area, m_f is related to the fouling resistance (R_f), the density of the foulant (ρ_f), the thermal conductivity (λ_f) and the thickness of the deposit (*xf*) by the following equation: $m_f = \rho_f xf = \rho_f \lambda_f R_f$, Whereas, the resistance to heat flow across an evaporator surface tube is given by: $R_f = \frac{X_f}{\lambda_f}$, And the thickness ($x_f$) of the deposit also determined and λ_f is thermal conductivity of particular foulant taken heat transfer datum. Here the foulant's thermal conductivity of is 0.74 W/mK [6] and The thickness of each effect is now determined as $X_f = \frac{m_f}{\rho_f} = \lambda_f R_f$.

Results

Analysis of process water

The input water quality analysis of Wonji-Shoa sugar plant was investigated. Water quality parameters including total hardness, TDS, COD, BOD and EC were measured. The result obtained was presented in Table 1. It can be seen that the result obtained is in good agreement with process water quality standards. It can be seen some parameters in Table 1.

This analysis result shown that the total hardness of process water is below the lower limit for scale formation in the heat transfer media. And pH results also in the range of raw water used for the boiler in the evaporation process i.e., not sever for scale formation for the plant. But if the level of total hardness limitation in process water analysis, is above

Parameters	Experimental result	Process water standards
TH	210 mg /Lt	0-300 mg/Lt
pH	8.09	6.5-8.5
TDS	20 ppm	18.2-45.4 ppm
COD	24.375 mg/l	26 - 90 mg/L
BOD	9.750 mg/l	40-120mg/L
EC	19 μs/cm	1-120 μs/cm

Table 1: Test of process water quality parameters.

300 mg $CaCO_3$/lt can result in scale deposition and higher pH also caused to mere basicity and to stack the juice in the evaporator vessel and led to scale deposition, particularly on heating transfer surfaces. And as presented on South African water quality guidelines for process water analysis, water with total hardness of 0-300 mg $CaCO_3$/lt will not cause scaling in the heat exchangers [7].

Similarly for Ethiopia, as reported to WHO as country report in 2004-2005, the permissible level of total hardness for process water ranges from 0-300 mg CaCO3/lt [8]. For the level of pH, both WHO guideline and Ethiopian guideline recommended the range of 6.5 to 8.5 pH. As it can be seen from the test results compared with the recommended results of different findings and compared with investigation thesis work values in Table 1, there is no problem of water quality as process water in sugar plant of Wonji-Shoa sugar factory.

Similarly, experiments were conducted on analysis of chemical oxygen demand (COD), biological oxygen demand (BOD), electrical conductivity (EC) and total dissolved solids (TDS). This analysis predicted that scale formation as biofilm or bio-fouling formation in the evaporation plant at the heat transfer tubes in the evaporator unit and the investigated result would have shown as in Table 1.

As shown in the Table 1 the amount of dissolved oxygen in the process water is indicated to industrial scale formation, in process water analysis and also chemical oxygen demand (COD) is a measure of the amount of chemicals (usually organics) that may cause scale formation in evaporator plants in sugar factory. Normally, total dissolved solid (TDS) values were recommended up to 180.2-445.4 ppm in process water [9]. Chemical oxygen demand values also ranged from 26-90 mg/L, BOD values also varying from 40-120 mg/L in process water and Electrical Conductivity (EC) values also from 1-120 μmhos/cm in waste water [10]. If higher results were obtained other the ranged values, because of input of higher concentration of organic matter in the process water investigation, scale would have been deposited in the heat transfer surfaces [11]. But as obtained in present investigation (Table 1), the process water taken from the plant does not show any significant for scale deposition even not nearby to the values of standard values to be caused to scale in all parameters determined above. So that this indicated that the factory has used more purified process water that could not lead to bio-fouling of heat exchangers/scale deposition due to these parameters.

Cations and anions analysis of process water

This experiment also explored the quality of process water used in the sugar plant. Then it is detected by Flame photometer analyzer instrument. Some cations and anions analysis have been detected by taken process water sample from Wonji-Shoa sugar plant evaporation unit. In order to know what extent of quality process water is safe as boiling purpose for evaporation process. And experiments were conducted at Amhara Design and Supervision works Enterprise laboratory and the following results were presented.

The principal risks to scale deposition associated with process water supplies are cations and anions impurities. And it has been shown that, process water analysis test aided to establish the safety of process water supplied to boilers in the evaporator plant. Some agencies refer to this strategy as "minimum monitoring", while others use the term "critical-parameter testing" [11]. The results of the cations and anions impurities analysis are presented in the Table 2. The samples/tests have not been found any effect in the sugar factory and the standard values for cations and anions in general is listed in Table 2. While the finding results in the plant was under these values. Hence, cations and anions impurities have not been found any effect of the process water samples to form scale deposition. The values determined experimentally ranged for cations and anions are below the standard values for causing scale deposition i.e., under the values of 75-26.79% [12]. The highest value of parameter is 2% that is far from the lower values of 25% which was not affected for the quality of process water in Wonji sugar factory. From this experiment we conclude that the impurities of cations and anions have not any influences for scale/bio-fouling conditions in the evaporation plant.

Composition of syrup samples analysis collected from clarification unit

Syrup composition analysis was conducted in Bahirdar University, chemical engineering department post graduates research laboratory by ICP-Spectroscopy ULTIMA-2 and Atomic absorption spectra photometer. And the syrup samples taken from clarification units before it sent to evaporation units. This composition analysis mainly concerned to known the constituents of juice composition impurities that affects the heat transfer rate in the evaporation process, because after the juice is clarified it directly sent to evaporation units. In addition, by sampled eleven experiments and taken 5 ml for each experiment Table 3 results were obtained. Syrup analysis shows that the constituent compounds of the syrup in which impurities arose for causing scale formation in the evaporation plant. During harvesting with soil types and carried their content to the clarification unit and continued to the evaporation plant. Hence this analysis concerned at performing of syrup sample to know the elemental composition of syrup before it gone to evaporation process. This exactly answered that, where is the source of the scale former materials and which compound is responsible for the scale deposition in the evaporation plant. Therefore, the main component that caused to scale formation was calcium oxide impurities that account higher values of compositions in the syrup analysis as shown from Table 3.

The next major component of the scale is loss on ignition (LOI), which is with 294.9 mg/l are, mostly organic compounds which can be damaged by ignition and moisture content, Silicon dioxide also 292.19 mg/l is the third rank from the analysis investigation that had highest values may be come from the soil content during harvesting of the cane sugar. Whereas, other constituents are relatively too low and not numerically significant for affecting the study of scale deposition. Generally, it can be seen that the concentration so formed is CaO which shows that the main component responsible for the scaling deposition in the plant.

Characterization of scale in multiple effects evaporator units

Scale characterization was conducted by ICP-MS and atomic absorption spectra photometer analysis by taken five samples from five effect evaporators of Wonji-Shoa sugar factory. And the

Impurities parameters	Amount (mg/L)	SV (mg/L) [10]
Chlorides	1.648	0.3-5.87
Nitrates	1.370	0.12-2.83
Nitrides	1.499	0.0045-1.67
Iron	2.300	0.34-3.5
Fluorides	1.500	0.65-1.72
Sodium	12.00	22.5-128
Potassium	0.05	0.2-5.3
Sulphates	1.814	0.0083-2.1
Phosphates	1.433	0.8-2.56

Table 2: Cations and anions of process water results.

Constituents	Conc (mg/L)	SV (mg/L)
Silicon dioxide (SiO2)	292.190	78-315
Aluminum oxide (Al2O3)	24.180	1.5-27
Iron oxide (Fe2O3)	59.440	0.3-62
Calcium oxide (CaO)	3189.570	20-150
Magnesium oxide (MgO)	19.450	3-24.71
Sodium oxide (Na2O)	17.060	3-19.34
Potassium oxide (K2O)	15.330	2.59-20.7
Titanium dioxide (TiO2)	2.015	0-3.15
Manganese oxide (MnO)	1.260	0.15-2.16
Phosphors pentoxide (P2O5)	24.127	2.7- 30
Loss on ignition (LOI)	294.900	≤ 80.97

Table 3: Syrup sample analysis in Wonji-Shoa sugar plant.

characterization was performed for each effect.

The composition of sample scale characterized using inductively coupled plasma atomic emission spectrophotometer (ICP-AES) and atomic absorption spectra photometer at Bahirdar University, in chemical engineering post graduate research laboratory and the analysis result has been summarized as in Table 4.

From chemical analysis result, the deposit is clearly a scale which is formed due to Calcium compound which has higher content in the juice than iron and magnesium, in the last effect which is critical point for heat transfer declined, in which resulted in hard scale formation. This shows that the type of fouling encountered in the plant is precipitation fouling due to calcium compound deposition as listed in each effect. Similarly, from this Table we can deduced that the values at the first and second effects the amount of elemental concentration is insignificant when compared to the last effects, this means that the impurities simply float in the evaporator tube till the juice is gotten high energy demand and evaporated more water. But the third effect is the initial point for scale deposition as shown from the Table 3, about 2170.583, 158.33 and 31.819 mg/L for calcium, iron and magnesium respectively these values were the starting point for hard scale formation in evaporation plant, this over all process analysis for scale characterization for elemental profile is explained by the following plot.

In addition, other than calcium sulfate the second higher value component is iron compounds this indicated that it caused for rust in evaporator tube, but magnesium is almost none as shown in the graph. From that graph visualization clearly shown that the result on what element was caused in the multiple effect evaporators (MEE) during the chemical characterization by ICP-MS instrument. The effect of this scale is decreased the heat transfer rates in heating media and cause severely hindrance flow through piping since it forms thick scale layers in the plant. And as it can be seen from the graph scale formation is increased across the effect number of the evaporator as scale formation also proportionally increased. This was because of the water content of the juice is decreased from first effect to the fifth effect. And the juice content is become more thicken (concentrated) and the impurity components easily stacked in the wall tube of the evaporator. Therefore, scale is initiated to be formed. Generally, from this investigation work the causal component impurity for scale deposition in the plant was calcium sulfate as investigated experimentally.

Material and energy balance calculations in multiple effect evaporators

A large problem in the evaporation system is determining of parameters iteratively as shown in Tables 5 and 6. The material and energy balance developed and solved by using simulator software MATLAB code. The code has been written according to the sugar parameters and experimentally determined equations. The results have been discussed in the following section. The material and energy balance has been validated using numerical solutions of material and energy balance equations and other constant values taken from literature and Wonji-Shao sugar factory manual. Some of them are experimental data and some of them have been calculated using empirical correlations [13]. The advantage of using the heat transfer coefficient as opposed to an evaporation rate per unit area is the fact that it takes into account temperature difference so is a good basis for comparison between effects where operating conditions such as temperature and liquid flow rate may vary. The equation developed for a five-effect evaporator system with forward-feed and solved using the Newton-Raphson method is presented in Table 5.

The material and energy balance result is presented for each parameter in Table 4. As can be seen from the Table temperature decreased from first effect to fifth effect while the liquid flow rate is increased as the number of effect is increased. This shows that as the liquid flow rate is increased the juice becomes concentrated and more scale is formed in the wall of the evaporator and evaporation rate becomes fast and minimum energy or steam is required this caused to decreased the temperature in the evaporation plant. Similarly, vapor flow rate (V_r), bleeding pressure (B_{pe}) and over all heat transfer coefficient (U) decreased with respect to number of effects. This was because of evaporation takes place in, enclosed vessel, and the escaping molecules accumulate as a vapor above the liquid. Many of the molecules return to the liquid, with returning molecules becoming more frequent as they become more density and vapor flow rate become decreased.

This indicated that more energy is consumed by the evaporation process by forming scale deposition in the wall of evaporation unit. Since the molecular kinetic energy is greater at higher temperature, more molecules can escape the surface and the saturated vapor pressure is correspondingly higher but the Temperature is dropped from effect to effect correspondingly the bleeding also decreased this is again due to scale formation declined to the system during the evaporation system. Whereas, the overall heat transfer coefficient also decreased from first effect to the fifth effect as the system temperature declined this indicated that the deposition of scale formed is served for the evaporation system. Generally, this material and energy balance Table indicates that how the evaporation parameters related with scale deposition and what were their significant effect for the evaporation process relative material and energy balance calculations by chemical process simulator, hence each parameter was analyzed and discussed according to the relevance to scale deposition in the evaporation process. So in the plant there is a scale deposition and highly decline for efficiently energy use in the evaporation unit.

The overall heat transfer coefficient is calculated from the heat transfer area that taken from Wonji-Shoa sugar plant manual [14] and from the temperature of each effect that we got from the iteration

E No	Ca (mg/lt)	Fe (mg/lt)	Mg (mg/lt)
1	651.175	47.5	8.830
2	868.233	63.33	14.128
3	2170.583	158.33	31.819
4	2604.7	190.00	35.32
5	2860.66	210.11	35.84

Table 4: Elemental distribution of the scale deposition in MEE System.

calculations with a given of heat transfer rate. From this graph the fouling part of the evaporator was decline from effect to effect with corresponding increment of scale formation, as shown from the graph. This shows that scale deposition hindered the evaporation process as in which lead to instantly drop the overall heat transfer coefficient in the evaporation plant. Generally, the overall heat transfer coefficient and scale deposition were inversely proportional with respect of effect numbers. As the number of effect increased the scale deposition become more thicken because the evaporation process is highly removed more water from the juice and the juice content is more concentrated but the overall heat transfer coefficient and the temperature values were decreased linearly as shown in Figures 1-4.

Determination of physical parameters in multiple effect evaporators

Experiments were conducted for physical characterization of scale deposition that had been taken samples from five effect evaporator from Wonji-Shoa sugar plant. In the previous experimental analysis performed by ICP-MS instrument in chemical characterization section were used for initial determinations of physical parameters, such as, thickness (cm), mass of foulant (kg/m^2) and heat resistance to flow (m^{2}k/W) had been determined in this experiments in each evaporator units. For each calculations of these parameters such as density, thermal conductivity of foulant is taken from on lines [15] and from books of fouling of heat exchangers respectively and the heat surface area is taken from sugar factory manual [16] and the calculated result of the physical parameters were listed in the following Table 5.

Fouling is the accumulation of unwanted material on solid surfaces in heat exchangers (MEE). The fouling material can consist of either living organisms (bio-fouling) or a non-living substance (inorganic or organic) that causes deposit formation, deposition, scaling, scale formation, slagging, and sludge formation. Analyzing the data presented in Table 5, it can be noticed that both mass deposition (kg/m^2), thickness (cm) and resistance to heat flow (m^{2}k/W) were increased from effect 1-5 effects during the process in the evaporation plant. Furthermore, in the plant fouling resistances of evaporators did change significantly increase for R_f and is clearly appeared from $R_f = 3.793 \times 10^{-4}$ to 0.00167 m^{2}K/W.

This means that in heat exchanger Process (evaporator) the fouling resistance value of R_f affected critically for the system of heat flow, but at the first and the second ones are almost none this means the impurities simply float in the fluid i.e., insignificant which was out of from the Recommended fouling resistances for MEE 0.035-0.045 m^{2}K/W [17] and another books for Sugar solution recommended that, 17°Bx gives fouling resistance values as 1.5-2 × 10^{-4} [4]. In other case the mass deposition of the scale formation is very high as compare to international standard sugar factory recommended values of $CaSO_4$ (g/l) is 1-2.5 [18]. But the Table shown above is too high 2.861 which were out of these ranged values.

From overall characterization experiment observation, the deposit is clearly a scale which is formed due to crystallization which in most cases results in hard scale. This shows that the type of fouling encountered in the plant is precipitation fouling. In addition to these, the thickness of the scale observed is abnormally thick which has a capacity to incur extra resistance to the heat flow across the heat transferring surface. In addition, the thickness of the scale formed in MEE is high 4.111 cm which is too thick and can increase the resistance to heat flow due to their low thermal conductivity. 0.03 cm scale deposition on heat transfer surface can cause 2.5% increase in fuel consumption. Hence in this work the scale thickness was obtained 4.11 cm which increased 342.5 kg/s steam as extra steam consumption. The overall visualization is described in Figure 5.

Conclusions

Sugar plant is one of process industries where scale deposition leads to high economic penalties, since it involves a number of heat exchangers. In this study, the problem of scale deposition in evaporators in Wonji-Shoa sugar factory had been studied, the cause of the scaling problem and characterization of scale deposition, analysis of process water, syrup composition analysis and material and energy balance calculations have been conducted by MATLAB software.

Deposit samples taken from evaporator of Wonji-Shoa sugar factory and characterized both physically and chemically was performed. In addition to this, the mass of deposited samples analyzed using ICP-Spectroscopy to identify the composition of the scale and so that gave the indication to determined scale causing components of the raw material would have been analyzed.

Scale deposition sample was taken from Wonji-Shoa sugar plant cleaning evaporators unit and analyzed so as to identify the scale causing components. From samples investigated it is found that $CaSO_4$ is the main scale causing component. Further components are found in both the deposit samples and leads to the conclusion that crystallization of $CaSO_4$ is the main cause for scaling in syrup evaporators. Experiments are conducted in order to study how the various operational Parameters of scaling process affected. The focus was on the impurity characterization, process water analysis, syrup composition determination and material and energy balance calculations by used MATLAB software in order to determined process parameters like temperature, overall heat transfer coefficient, liquid flow rate, vapor flow rate and bleeding pressure were determined experimentally and by MATLAB software codes respectively.

From investigation of the cause of this scaling, process water used in the plant is with good quality, the only source of this scaling is mixed juice in the clarification units and continued causal effect to the evaporation unit. To ensure that really the cause of the scaling is juice, the raw material juice and process water characterized and the juice found with abnormally high CaO (3189.57 mg/l) content in juice. Which most probably comes from poor quality of quick lime used in the clarification but, quality of the process water used in the plant was very good which could not be the cause for the scaling.

These ensured that the main cause of the scaling in the plant is the raw juice input to the evaporation plant. This leads to the conclusion that crystallization of Ca compounds is the main cause for scaling

Figure 1: Scale sample taking from Wonji-shoa sugar factory from multiple effect evaporators.

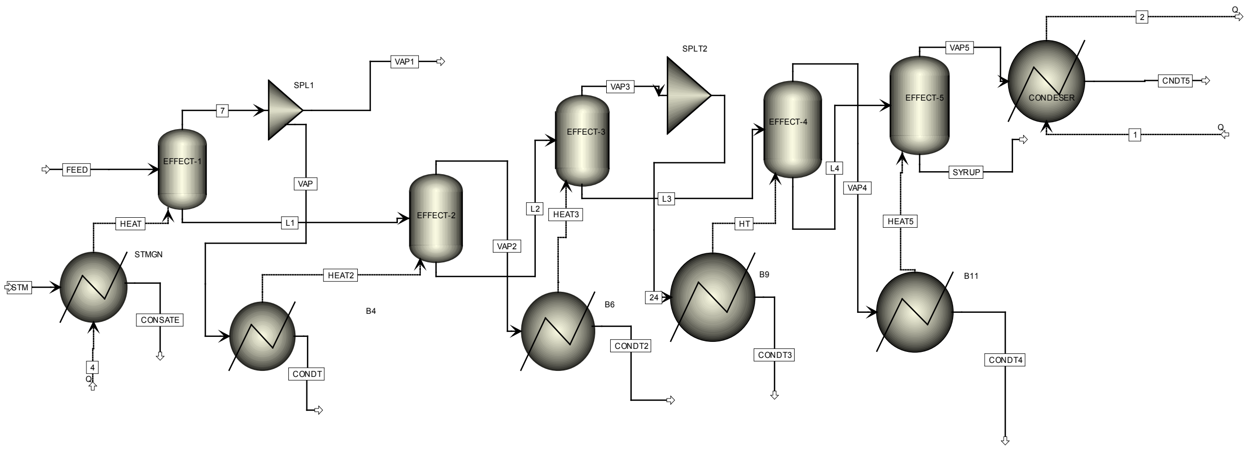

Figure 2: Process flow sheet for the sugarcane evaporation plant by Aspen plus Software.

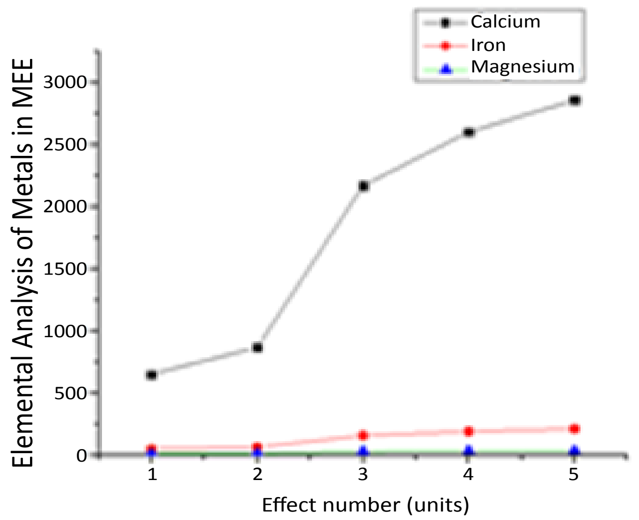

Figure 3: Elemental concentration profile on multiple effect evaporators for scale formation.

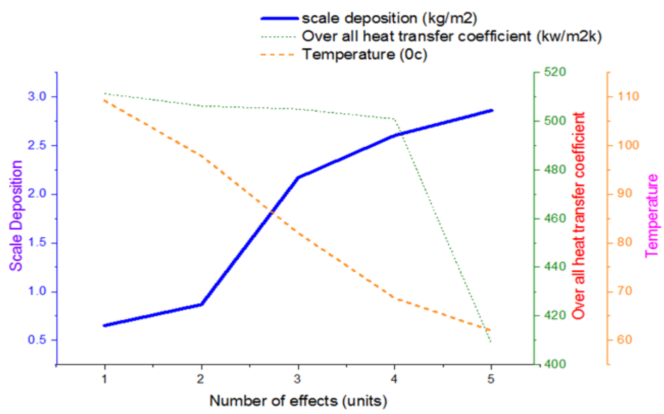

Figure 4: Over all heat transfer coefficient and temperature profile with respect to scale deposition in MEE.

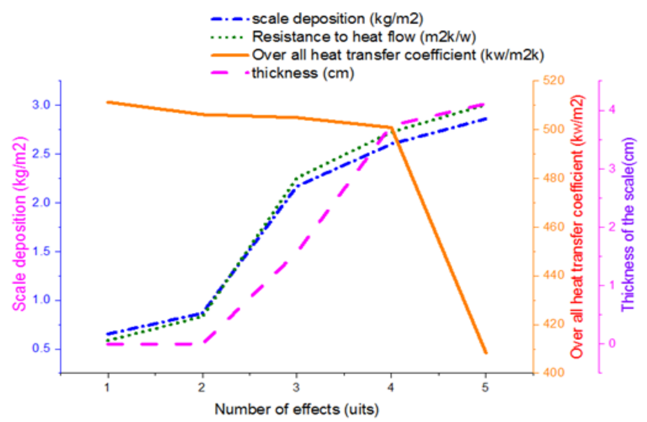

Figure 5: Profile of scale deposition, thickness and resistance to heat flow V_s evaporator units.

E No	T_i	L_i	V_r	B_{pe}	U_i
1	109.180	34.7059	3.831	0.545	511.347
2	97.862	34.2303	2.633	0.452	506.287
3	82.037	32.9455	1.285	0.404	504.998
4	68.639	30.3122	0.476	0.384	500.888
5	62.000	26.4810	0.094	0.377	408.428

Table 5: Determination of parameters in five-effect evaporator system by Matlab.

E No	m_f	A_{tube}	ρ_f	λ_f	X_f	R_f
1	0.6512	1800	2320	0.74	2.807×10^{-4}	3.793×10^{4}
2	0.868	1400	2320	0.74	3.74×10^{-4}	5.1×10^{-4}
3	2.171	600	2320	0.74	1.569	0.00127
4	2.604	300	2320	0.74	3.741	0.00152
5	2.861	300	2320	0.74	4.111	0.00167

Table 6: Determination of scale deposition, thickness and resistance to heat flow across a tube surface in MEE evaporator unit.

of heat exchangers in sugar plant. To overcome this problem, treating the juice with H_2SO_4 and heat is the best technology with appropriate conditions. Because, the reaction of CaO with 80% purity and with 98.5% H_2SO_4 concentration at higher temperature (100°C) give $CaSO_4$ which is insoluble in water and easily separated by sedimentation. Sugar Technology books explained that with varying in the clarification unit conditions like 100°C temperatures, 4 pH, and 50°C brix determined as the optimum clarification process conditions [5] these operation condition will be permanently solved the problem of scale formation in the evaporation units and it is economical solution since the reaction mechanism is not controllable reaction.

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