Comparison Between Calculated, Simulated and Actual Plant Data of Multiple Effect Evaporators to Concentrate Sugarcane Juice

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ABSTRACT

Multiple effect evaporators systems operating at steady state can be described by a series of nonlinear algebraic equations that include total and solute mass balances, energy balances, heat transfer rate equations, and the composition and temperature dependence of related thermodynamic properties such as vapor pressures and enthalpies. The main objective is to compare between the manual calculations, simulation and real data collected from Asalaya plant for validation the best design of multiple effect evaporators system in forward feed used in Asalaya Sugar Factory. In this design a short tube vertical evaporator, Calandria type has been used. The models include overall equations of materials balance, equations of energy balance and equations of heat transfer rate for measurement area for all the effects. These equations were solved using manual calculations methods and MATLAB coded program. The results of the present investigations have been compared with the data obtained from the Asalaya Sugar Factory with five evaporators. The results showed that the concentration of sugar cane juice at the final stage is equal to 60 Brix for the manual calculations, simulation and actual plant data with zero error. The temperature of solution in the pre- effect evaporator was found to be about (114.94, 114.94, 115)**ºC**, with a relative error equal to 0.05% and the steam temperature in the pre effect was found about (120)**ºC** for the manual calculations, simulation and actual plant data, with zero error. The area and number of tubes in the (pre, second, third and fourth) effect, are in a good agreement, with the standard value (Er=3.26%). The above results show great similarity with the real behavior of evaporator unit. This can be used as a reliable tool\for the simulation of different operating conditions.

Key words: Multiple Effect Evaporators, Sugarcane Juice, Simulation, Calculation, Comparison.

1. INTRODUCTION:

Evaporation is a typical technique used in a unit operation to extract solvent as a vapor. (Kemal et al., 2017). Essentially, an evaporator is a heat exchanger that uses vapor to boil a liquid and create vapor. As a result, it can be utilized as a low-pressure boiler, producing steam that is then employed in an evaporator or as a heat source for an industrial process. (Castro., 2022). This procedure is used to concentrate a solution. Evaporators can produce a single effect or a variety of effects (MEE).The evaporation process involves removing a portion of the solvent from a solution in order to enhance its concentration. (HA Elhesain, at al., 2021). In the industries that produce sugar, fruit juices, dairy products, edible oils, tomato paste, and coffee, evaporators are among the most crucial pieces of machinery. They must use as little energy as possible because they require a lot of steam from the boiler. (Díaz-Ovalle, 2023). Since evaporation consumes a significant amount of energy in the dairy, food, and chemical industries, it is crucial to address evaporation from the perspectives of both efficient process operation and cost-effective energy use. It is only possible if the equipment provider is in a position to offer a wide selection of evaporation technologies and systems created to meet the needs of particular specialists. The required concentration % as well as local energy prices. A chemical is concentrated during the evaporation process by boiling out a solvent, often water. The finished product recovered will have a solids content that is optimal for the intended product quality and operating efficiency. (Tawanda and Charles, 2015). Evaporators can be operated on a forward, backward, or mixed feed and have a variety of effects. It is referred to as forward if the feed is fed to the effect successively and in the same sequence as the steam flows. (Faizan, and Naseem, 2013). Multiple effect evaporator systems operating in a steady state can be defined as a set of nonlinear algebraic equations that include total and solute mass balances, energy balances, heat transfer rate equations, and the composition and temperature dependence of relevant thermodynamic properties such as vapor pressures and enthalpies. Historically, using these equations for design objectives has (e.g. evaluating the heat transfer area needed for a given evaporation duty) or rating purposes (e.g. predicting the exit composition from an existing evaporator train) follows one of two approaches: (1) Trial-and-error approach based strongly on thumb-of-thumb engineering principles (Brown, 1950; Foust et al., 1980). (2) Multivariable search routines for a machine solution (Holland, 1981). In organizational study, simulation has been a common technique for modeling complicated structures. (Robinson, 2004). Simulation is one of the most important resources available to decision-makers in charge of developing and running complex systems and processes. It allows conditions to be researched, evaluated and measured that would not otherwise be possible. Simulation has become an essential problem-solving technique for developers, designers and managers in an increasingly competitive environment (Robert 1998).

2. MATERIALS AND METHODS

This paper was conducted to construct of calculations and a simulation system for multiple-effect evaporators systems with Concentrate Sugarcane Juice. The work was done by measuring the mass and energy balance at different effects to determine the total amount of vaporization, heat, area and number of tubes to solve this equation using the manual calculation and make a simulation model with forward feed Sugarcane Juice for multiple effect evaporators systems. The model will be built using MATLAB 6.1 software based on mass and energy balance at various effects, data will be collected from Asalaya Sugar Factory to better understand the evaporator dynamics and validate the simulation model.

2.1 Study Steps:

The study was carried out by calculating the results obtained from the mathematical equations performed in the current work.

Modeling processes using MATLAB 6.1 software followed by sequence steps for the simulation model creation. The study was conducted according to the following phases:

- Make a balance of the overall materials to determine the sugar cane juice concentration for each effect.
- Calculating the values of heat transfer, boiling point rise of sugar solution, area and number of tubes required in each effect.
- Making a program using MATLAB 6.1 software.
- View simulation results and compare these results with our manual calculations.
- Validation of the model built against actual data concerning plants.

Make a balance of the overall materials to determine the sugar cane juice concentration for each effect.

$F \times X_f = L_P \times X_P$--(1)

$L_P \times X_p = L_1 \times X_1$--(2)

$L_1 \times X_1 = L_2 \times X_2$--(3)

$L_2 \times X_2 = L_3 \times X_3$ --(4)

$L_3 \times X_3 = L_4 \times X_4$--(5)

Calculate sugar solution's heat capacity:

The sugar solution's heat capacity in each effect is determined from equation:

$Cp = 4.19 - 2.35 \times X$ (kJ/kg°k) (Christie, 1997)---(6)

Calculate boiling point rise in each effect:

The boiling point rise of sugar solution in each effect is calculated using the fallowing equation:

$BPR = 1.78X_i + 6.22X_i^2$ (°C) (Christie, 1997)---(7)

Calculate saturated temperature of steam in each effect:

$t_i = T_is - \Delta t_i$--(8)

Calculating area for each effect:

$Q_i = S \times \lambda_is$ (Christie, 1997)-- (9)

$A_i = Q_i / (U_i \times \Delta t_i)$--(10)

Calculating number of tubes required for each effect:

$Nt_i = A_i / a_i$---(11)

3. RESULTS AND DISCUSSION

Table (1) Comparison between calculation and simulation of heat capacity of sugar solution

Concentration (kg solid/kg sugar)	Calculation	Simulation	actual plant data
	Heat capacity (kJ/kg°k)	Heat capacity (kJ/kg°k)	Heat capacity (kJ/kg°k)
0.15	3.8375	3.8375	3.8375
0.1765	3.7752	3.7753	3.7804
0.2143	3.6864	3.6864	3.5428
0.2727	3.5492	3.5491	3.3003
0.3750	3.3088	3.3088	3.1036
0.60	2.78	2.78	2.78

Table (1) shows the decrease in heat capacity of sugar solution. With the increase of it is concentration. These results give a significant effect on concentration of sugar cane juice, indicating that the decrease of heat capacity increase the concentration of sugar cane juice. This result is in a good agreement with Afamia, 2004 in his study of Potentials for Energy Saving in Cane Sugar Industry.

Table (2) Comparison between calculations, simulation and actual plant data of boiling point Rise of sugar solution

Concentration (kg solid/kg sugar)	Calculation	Simulation	actual plant data
	Boiling Point Rise (ºC)	Boiling Point Rise (ºC)	Boiling Point Rise (ºC)
0.15	0.41	0.40695	0.41
0.1765	0.51	0.50782	0.50
0.2143	0.67	0.66704	0.96
0.2727	0.95	0.9481	1.57
0.3750	1.54	1.5422	2.15
0.60	3.31	3.3072	3.31

As show in Table (2) the increment of the boiling point Rise of sugar solution depends on the increase of the concentration. This result is in a good agreement with Afamia, 2004 in his study of Potentials for Energy Saving in Cane Sugar Industry.

Table (3) Comparison between calculation, simulation and actual plant data for temperature of solution and steam

	Calculation			Simulation			actual plant data		
	Temperature of solution(ºC)	Temperature of steam(ºC)	Δt (ºC)	Temperature of solution(ºC)	Temperature of steam(ºC)	Δt (ºC)	Temperature of solution(ºC)	Temperature of steam(ºC)	Δt (ºC)
Pre Effect	114.94	120.00	5.06	114.9383	120	5.0617	115	120	5
I Effect	107.7	114.43	6.73	107.6984	114.43	6.7321	105	115	10
II Effect	98.62	107.03	8.41	98.6163	107.03	8.4151	95	105	10
III Effect	85.05	97.67	12.62	85.0456	97.668	12.623	85	100	15
IV Effe	63.32	83.51	20.19	63.3072	83.503	20.196	55	85	30

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Table (4) Comparison between calculations, simulation and actual plant data for area, number of tube and concentration

	Calculation			Simulation			actual plant data		
	Area (m^2)	No. of tubes	Concentration (kg solid/kg sugar)	Area (m^2)	No. of tubes	Concentration (kg solid/kg sugar)	Area (m^2)	No. of tubes	Concentration (kg solid/kg sugar)
Pre Effect	1548.85	5418	0.1765	1526.2	5338	0.17647	1500	5080	0.1743
I Effect	1660.23	5807	0.2143	1634.5	5718	0.21429	2400	9380	0.2754
II Effect	1770.66	6193	0.2727	1746.9	6111	0.27273	1900	7440	0.3786
III Effect	1880.34	6801	0.375	1860.9	6731	0.375	1700	6780	0.4623
IV Effect	1860.74	6655	0.6	1956.7	6998	0.6	1600	6780	0.6

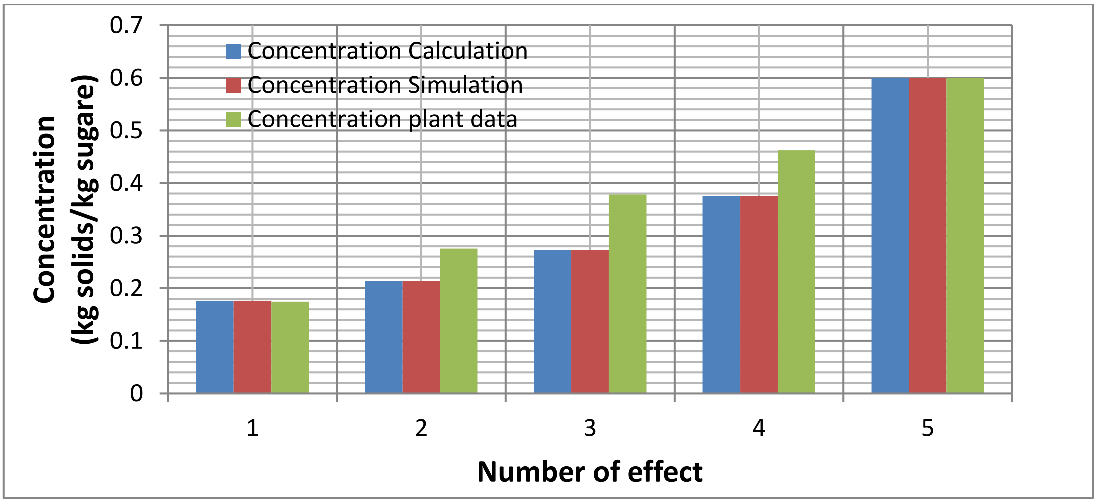

Fig. 1 The relationship between numbers of effect and Concentration of calculations, simulation and actual plant data

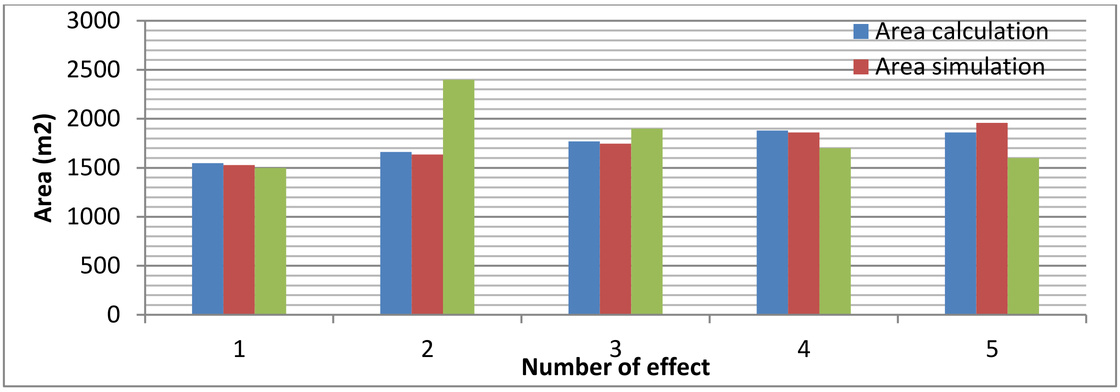

Fig. 2 The relationship between numbers of effect and area of calculations, simulation and actual plant data

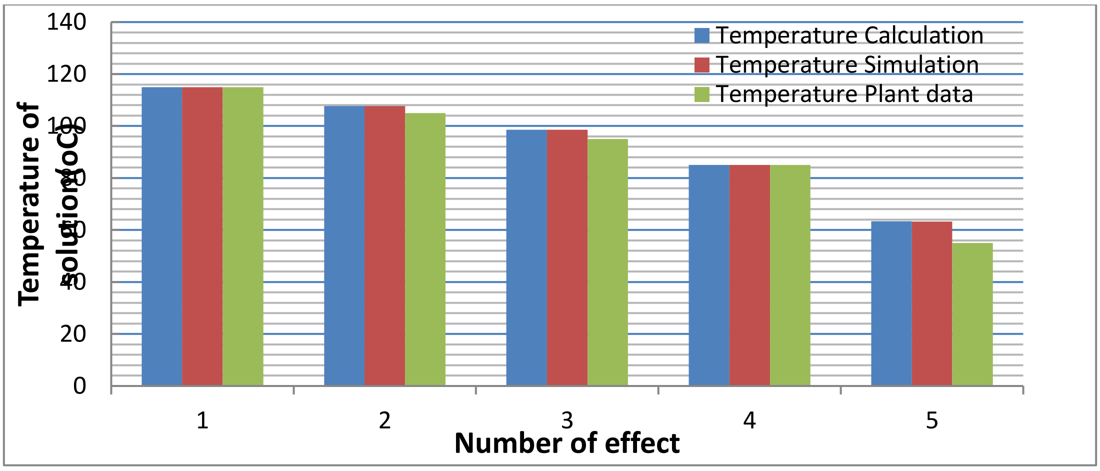

Fig. 3 The relationship between numbers of effect and temperature of calculations, simulation and actual plant data

Figure (1), (2) and (3) shows the relation between numbers of effects and concentration, area and the temperature generated by calculations results, simulation results, and actual plant data. Number of effect increases the concentration of sugar cane juice and decreases the temperature. Table (3) Table (4) shows the output results produced by calculations results, simulation results, and actual plant data. They include the fraction of solids, the temperature of sugarcane juice and steam, area and number of tubes in each effect. When we compare between calculation and simulation and actual plant data, we observed the following:

The comparison of the exit concentration data (kg of solid/kg of sugar) of each effect. For simulation, analytical and actual. Is in a good agreement.

Also we observe that, there is a good agreement in the temperature of solution and steam. The discrepancy between the simulation results, calculations results, and actual plant data for the area and number of tubes in the first effect will be attributed to that the fluid in the evaporator contains impurities and salts and over time a layer of calcification or sediment on the surface of the tubes reduces the efficiency of heat exchange, such as the formation of a crust of salts and this leads to the reduction of the exchange area and increase of resistance to heat flow, so must be improved the characteristics of juice and overall heat transfer coefficients. Process control devices were manually adjusted, which allowed fluctuations in the flow rate and vacuum level, resulting in reduced accuracy. It is therefore recommended the use of an automated control system for the vacuum level, flow rate and overall heat transfer coefficients.

4 CONCLUSION:

In this paper the results show that, for comparison of sugarcane Juice brix, temperature of solution and steam for each effect between manual calculation of equations, simulation results and actual plant data of Asalaya sugar cane industry the results was found in a good agreement. Material and energy balances, would help to assess performance of equipment, this technique also demonstrates that results obtained for the steam economy approach can be extended to every other concentrate technique of sugar cane juice to achieve the same results.

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