



Design Calculations of Multiple Effect Evaporators in Sugar Industry using Visual Basic

Hamza M. A. Abaker¹, Magdi A. O. Mohammed¹ and Yousif E. E. Ahmed²

1. Dept. of Food Engineering and Technology, University of Gezira, Sudan,

2. Dept. of Computer Engineering, University of Gezira, Sudan

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ABSTRACT

Sugar juice evaporators design is challenging regarding its calculations, complexity, higher energy consumption and much heat exchange equipment used. This paper proposes design calculations software for sugar multiple effect evaporators using Visual Basic. The computer software system was developed via analyzing the evaporators design process, creating the algorithm, designing the user interface, writing program codes and supplying the components to perform calculations as required. The proposed program was experimentally used to conduct the complex design calculations of multiple effect evaporators. The experimental results for important design variables including the concentration of the syrup, the diameter of tubes, the mass of evaporated water, the quantity of the heat required and the number of the tubes were found to be: 64.02%; 110.4 kg, 0.16844 m, 118175.855 KJ and 10 respectively. The conducted results were compared to the manually obtained findings and the conducted statistical "T-test" to insure the systems accuracy.

KEYWORDS

Evaporators, Calculations Software, Algorithm Designing, Computer Aided Design

1. INTRODUCTION

Sugar is the most common food product necessary for human life, the main component of which is sucrose and other impurities [1].

The most striking advance in the sugar manufacture was no doubt the development of multiple-effect evaporation. Most of the energy consumed is in the evaporator section and the main contributor to this is the complexity in its control [2].

Multiple effect evaporator control is a challenging regarding that has been face in the sugar industries. Evaporators are the largest heat users and major contributors to losses in sugar factories. These factors make effective evaporator control crucial to overall factory efficiency. Evaporation as one of the most energy intensive processes used in the sugar industry ,it is essential that evaporation be approached from the viewpoint of economical energy utilization as well as process effectiveness.

This can be done only if the equipment manufacturer is able to offer a full selection of evaporation technology, Thus, also the sugar industry was developed with new machines as well as with improved computer technology. One of challenges in sugar fabrication is without doubt the reduction of energy consumption [3].

a. The Evaporator Vessel

An evaporator is a device that absorbs the heat surrounding it to cause the liquid refrigerant inside it to boil until the refrigerant leaves as a superheated (saturated) gas [4].

The standard multiple-effect evaporator consists of a vertical cylinder, built onto the tubular calandria across which the heat exchange takes

place. This cylindrical body terminates at the top in a "save-all", the object of which is to separate the liquid droplets which may be entrained with the vapour from the juice. Previously the evaporator bodies were always fabricated in cast iron. More recently, fabrication in steel plate is becoming more and more common. This permits of evaporator bodies which are less brittle, lighter and less expensive (Figure 1).

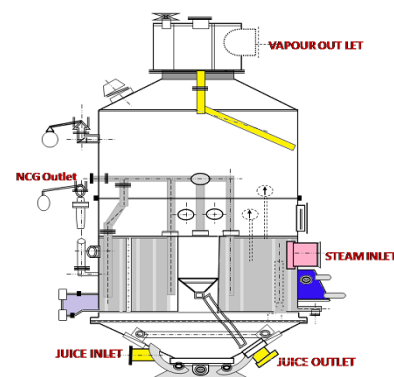


Figure 1 Evaporator Vessel

The principle utilized in the evaporator is a high pressure and temperature of steam, which acts as the heat supplier that is fed into the evaporator. The heat from the steam will increase the temperature of the evaporator, and at a specific high temperature, water in the liquid

Design Calculations of Multiple Effect Evaporators in Sugar Industry using Visual Basic

will start to vaporize, and a more concentrated product will be produced from the evaporator. The evaporation process is used in various industries, such as pharmaceuticals, food, and beverages, chemicals, and more [5].

b. Evaporation system

The developed evaporation system model uses Robert type five-effect evaporators, which operate with a vacuum at the last effect, producing the difference of temperature between each effect. Some restrictions are imposed for the optimization. Juice enters at 15% of solid content and leaves at 65% Figure (2) [6].

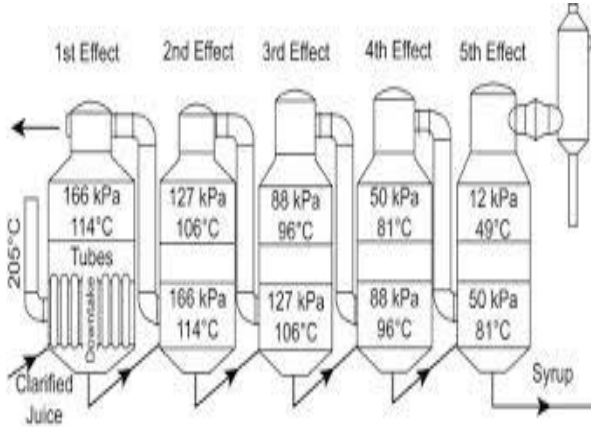


Figure (2): Multiple-effect evaporator

c. The Computer Programming

Program is simply giving directions to the computer for completing a task. In order to create a computer program, we must use a programming language such as Visual Basic. VB.NET is one of the best and most successful programming languages. It's one of the popular languages in the world. It's popular with business and in education. It's object-oriented and can do almost anything. VB.NET takes the directions you write and turns it into a program. It translates your directions into a series of steps for the computer. A computer program is only as good as its instructions. Therefore, programming should be about how to write the directions in the first place, and how to write directions that won't cause problems. And, of course, the person writing the program is a programmer [7].

2. MATERIALS AND METHODS

The methods of this research include engineering equation for calculations design of evaporators units, the data used to evaluate the computer program by Visual Basic Studio, as showing in Figure 3.

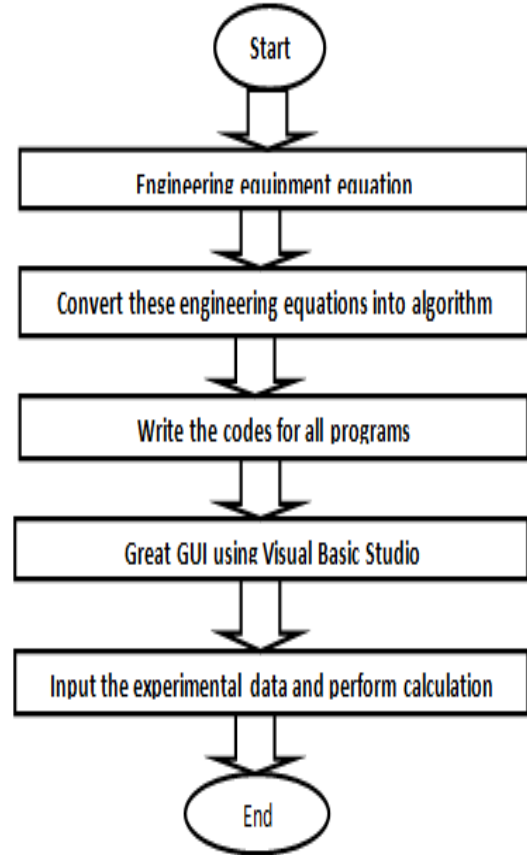


Figure (3): Flow chart of research methodology

a. Materials

Data for calculations of the evaporation system in this paper obtained from [8] as shown in Table 1 and Table 2.

Table 1 Basic parameters for design calculations

Parameter	Value	Unit
Sugar factory production G,	34.7	Kg/s
Mass of juice MJ,	138	Kg
Concentration of dry substance in the juice Cdsj,	13%	-
Concentration of dry substance in the syrup after evaporation Cdss,	65%	-
Length of boiler tube L,	2.5	m

Table 2 Basic parameters value for design calculations of multiple-effect evaporation (four evaporators and condenser).

Parameter	Body of Evaporation Station				Condenser
	I	II	III	IV	
Temperature of hot steam , t, °C ,	132	124.5	115	101	84
Pressure of hot steam, P _{h,s} , Mpa,	0.292	0.233	0.172	0.107	0.057
Clamping difference of temperature Δt, °C	6	7.5	10.5	12	15.6
Bolting temperature of juice , t°C	126	117	104.5	89	68.4
Temperature of depression Δθ, °C,	0.5	1.0	2.5	4.0	8.4
Temperature of juice steam θ, °C,	125.5	116	102	84	65
Pressure of juice steam ,P _{J,s} ,Mpa,	0.241	0.178	0.111	0.059	0.0255
Temperature loss of the steam tube Δl, °C,	1	1	1	1	1
The condensate temperature t _c , °C,	130	122.5	113	99	82
The deduction enthalpy of steam i kj/kg,	2720	2713	2570	2679	2633

b. Methods

The Engineering Equations of design calculation of multiple effect evaporation were collected from [8] [9] and represented as below:

1- Mass of syrup after evaporation bass on material balance for dry substance, kg.

$$M_{syr} = \frac{M_j \cdot C_{dsj}}{C_{dss}} \dots\dots\dots (1)$$

2- Mass of water evaporated in the condenser, kg.

$$X = \frac{M_{syr} \cdot C_{syr}(t_4 - t_{cons})}{(i_4 - i) - C_{syr}(t_4 - t_{cons})} \dots\dots\dots (2)$$

Where:

C_{syr} ≡ specific internal temperature of the syrup with 65% dry substances.

= 2. KJ/ (Kg .K).

t₄ ,t_{cons} ≡ the temperature of the boiling of the syrup in the 4th body and condenser respectively.

i₄ , i ≡ specific enthalpy of juice steam and water boiling under pressure in the in the 4th body and condenser respectively , KJ/ Kg (Table 2) .

Specific enthalpy of the water and condensate identify using the following

relishing ship. i = C_w . t_{cons} .

C_w = 4.186 KJ/Kg.°C Specific internal temperature of water.

3- The concentration of the syrup after the 4th body of the system %

$$C_{syr}^d = \frac{M_j \cdot C_{dsj}}{M_{syr} + X} \dots\dots\dots (3)$$

4- The mass of water evaporated in the 4th body of the system, Kg.

$$W = M_j \cdot (1 - \frac{C_{dsj}}{C_{dss}}) \dots\dots\dots (4)$$

The distribution of the extra steam in the bodies (Table 3)

Table (3) Distribution of the extra steam in the bodies

E ₁	E ₂	E ₃	E ₄	E ₅
20.07	14.22	18.27	2.67	0.71

The quantity of the steam obtained in the result of salve evaporation given the condensate in every evaporator (in% from beet mass)

e₁ = 0.60 % ,e₂ = 1.65 % , e₃ = 1.60 % , e₄ = 2.2 %

The real obtain extra steam in the station % .

$$E^l_1 = E_1 - e_1 , E^l_3 = E_3 - e_3 \dots\dots\dots (5)$$

$$E^l_2 = E_2 - e_2 , E^l_4 = E_4 - e_4$$

Identification of the mass of water evaporated in the all bodies % from the mass of the beet.

I. Body W₁ = W₁

II. Body W₂ = W₁ - E^l₁;

III. Body W₃ = W₁ - E^l₁ - E^l₂;

IV. Body W₄ = W₁ - E^l₁ - E^l₂ - E^l₃;

Total W = 4W₁ - 3E^l₁ - 2E^l₂ - E^l₃

From here W₁ = (W + 3E^l₁ + 2E^l₂ + E^l₃)..... (6)

We can take the quantity of the heat steam D equal to the quantity of water evaporated in the given body. From here D_i = W_i, where i, the number of the body.

5- The quantity of the heat required for the evaporation process in every body, kj.

$$Q_i = W_i (i_{ni} - i_{ci}) \dots\dots\dots (7)$$

Where:

i_{ni} ≡ the specific enthalpy of the steam, heating the named body KJ/Kg (table 3-2)

i_{ci} ≡ the specific enthalpy of the condensate , getting out of the seam body.

$$i_{ci} = C_w \cdot t_{ci} \dots\dots\dots (8)$$

t_{ci} ≡ the temperature of the condensate in (i) body °C (see table 3-2)

6- The concentration of the syrup exiting from everybody; %.

Design Calculations of Multiple Effect Evaporators in Sugar Industry using Visual Basic

$$C^I = \frac{Cdsj \cdot Mj}{Mj - W1} \dots\dots\dots (9)$$

$$C^{II} = \frac{Cdsj \cdot Mj}{Mj - W1 - W2} \dots\dots\dots (10)$$

$$C^{III} = \frac{Cdsj \cdot Mj}{Mj - W1 - W2 - W3} \dots\dots\dots (11)$$

$$C^{IV} = \frac{Cdsj \cdot Mj}{Mj - W1 - W2 - W3 - W4} \dots\dots\dots (12)$$

7- The average value of the juice concentration in everybody %.

$$C_1 = (C_{dsj} + C^I)/2 \dots\dots\dots (13)$$

$$C_2 = (C^I + C^{II})/2 ; C_3 = (C^{II} + C^{III})/2$$

$$C_4 = (C^{III} + C^{IV})/2 \dots\dots\dots (14)$$

Considering the length of the heating tubes and juice concentration we can identify the heat transfer coefficient in everybody $K, w/m^2 \cdot ^\circ C$ (Table 4).

Table (4) the heat transfer coefficient in everybody

K_1	K_2	K_3	K_4
2595	1709	1670	886

8- The surface area of the heat transfer in every body, m2.

$$F_i = \frac{1.03 \cdot Qi \cdot G}{100 \cdot Ki \cdot \Delta ti} \dots\dots\dots (15)$$

9- The effort of the surface area in everybody ;(Kg/m2.s).

$$U_i = \frac{Wi \cdot G}{100 Fi} \dots\dots\dots (16)$$

10- The value of the steam space in the i body in the evaporation system; m3.

$$V_i = \frac{Wi \cdot V}{Rv} \dots\dots\dots (17)$$

Where:

$W = W_i$ the mass water evaporated in the body.

$V \equiv$ the specific volume of the second steam at $125^\circ C \cdot V = 0.76 m^3/Kg$.

$R_v \equiv$ the volume effort of the steam space.

$$R_v = 0.75 m^3/(m^3 \cdot s).$$

Identification of the dimensions of the heating rooms using the heat surface area (diameter and the length of the tube). We take the diameter = 33 mm and the thickness of the tube = 1.5 mm (Standard).

11- The area of the tube ; m2.

$$f_i = \pi \cdot dcp \cdot L \dots\dots\dots (18)$$

Where:

$d_{cp} \equiv d_{av}$ the average of the diameters of the tube .

12- The quantity of the tubes in every body.

$$N_i = \frac{Fi}{f_i} \dots\dots\dots (19)$$

13- Determination of the steps of the distribution of the tubes in the bodies.

$$t = d_n (1.23 \dots 1.28).$$

14- Determination of the surface using by single tube , m2 ($\alpha = 60^\circ$)

$$F_{tub} = t^2 \cdot \sin \alpha \dots\dots\dots (20)$$

15- Determination of the area using by the all tubes ,m2.

$$S_i = \frac{F_{tub} \cdot ni}{Kv} \dots\dots\dots (21)$$

Where:

$Kv \equiv (0.7 \dots 0.9)$. the coefficient of the using tube calinderia.

16- Determination of the diameter of the calinderia , m .

$$D_i = \sqrt{\frac{4Si}{\pi}} \dots\dots\dots (22)$$

Flowchart

The following, Figure (4), shows the flowchart (Algorithm) of evaporator system design calculations.

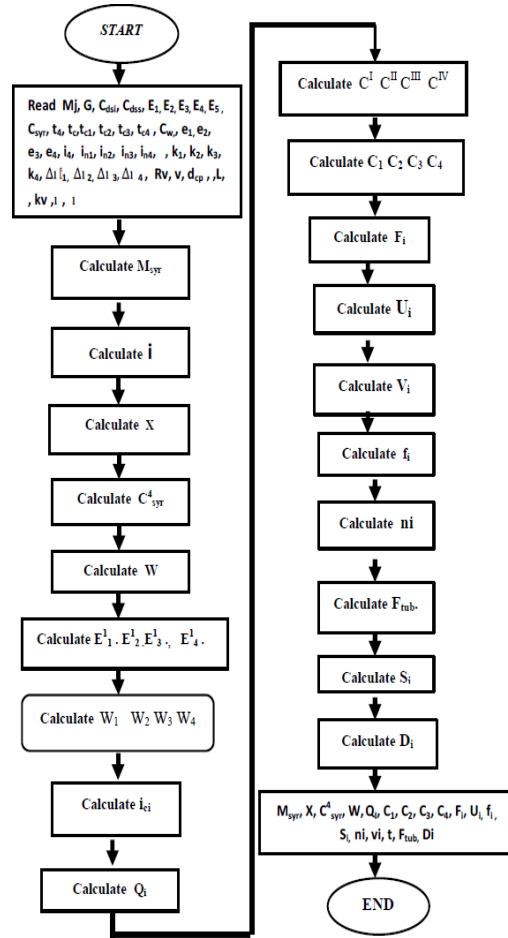


Figure (4) The Algorithm flowchart

C) Computer Program

In Visual Basic.NET, a program could be created by developing a project. The project is stored in a folder and contains files and other folders [10].

The program was created according to the following steps:

Define the Problem

Define the Problem involves numerous steps such as declare all the variables, get the user input, make the calculation, and display the output.

Define Inputs

The input is the data for the program which need to know for solve the problem. Every program requires input of some kind. Without input from the user, the computer would return the same answer every time.

Determine Processing

The processing is the calculations may involve numerous steps. It is critical that these steps be performed in the correct order. The processing is the largest and most-complicated part of a program.

Define Outputs

The output is the answer for the programs, there may be many lines of calculations for one line of output. Often it's easiest to define the output first.

Determine Variables

This is often the hardest part for beginning programmers. In general, it need a variable for nearly every number in a calculation. Think of a variable as a storage location for numbers and text. This is where the data are stored during runtime. Decide on the variables which need before to start the code. It must to be declare before write any other code.

Design Form

The form can be of almost any design as long as it accomplishes its task. There are guidelines for it and much of it is common sense. The objects on the form can be arranged in any manner the developer wants. For all program, use TextBox to enter the number of credits. and Label to display the output. also some other Labels use to identify what's on the screen, and Buttons to make the program do the calculation and another to end the program [10].

accordingly, the proposed system was developed experimentally implemented and verified as in the next section.

3. RESULTS AND DISCUSSION

This section illustrates the experiments conducted using the developed computation system considering the Visual Basic based system, numerical example and results statistical evolution.

a. The Results of Evaporation Design System Calculations Using Visual Basic

Evaporation design system calculations divided into two forms, inputs as in Figure (4) and outputs as in Figures (5) respectively.

Figure (5) Evaporation design system calculation input.

The form in Figure (4) provides the capability to the designer to the required design parameters as an input and run the calculations. Thus the conducted output as in Figure (6).

Figures (6) design system outputs

The form in Figure (5) provides the capability to the designer to present the calculations outcome according to the entered parameters as an output.

b. Numerical Example Results

The evaporation design system calculations form when selected example1 as in Figure (7).

Design Calculations of Multiple Effect Evaporators in Sugar Industry using Visual Basic

Figure (7) The calculations form when load example1 data

The results of design system form when selected example1load as in Figure (8).

Figure (8) load example1 data

When example 1 button was selected, the related design data and the result as in Figure (9).

Figure (9) Results of example1 and Run

The system provided three design examples could be loaded and calculated, in addition to free designer inputs.

c. Evaluation of the Results of Design Calculations Programming

The following Table (5) shows the comparison of the results between tow design calculation methods of evaporation system.

Table (5) the statically comparison

Parameter, Unit	Manual Calculations	Visual Basic Calculations	T-test value (Sig)
M_{syr} . kg	27.6000	27.6000	-
X .kg	0.4840	0.4280	0.500
C_{syr}^4 , %	63.9000	64.0200	0.500
W. kg	110.4000	110.4000	-
C_1 , %	21.4000	21.4370	0.452
C_2 , %	36.3000	36.2882	0.500
C_3 , %	61.0400	61.0375	0.500
C_4 , %	65.0000	65.0000	-
f_1	0.2590	0.2590	-
T	0.0413	0.4125	0.504
F_{tube}	0.0015	0.0017	0.500
Q_1 . kj	118177.50	118175.90	0.500
Q_2 . kj	75357.19	75355.71	0.500
Q_3 . kj	42036.06	42035.58	0.500
Q_4 . kj	4053.62	4057.57	0.500
F_1 .m ²	2.7000	2.7127	0.500
F_2 .m ²	2.1000	2.1013	0.500
F_3 .m ²	0.8600	0.8568	0.500
F_4 .m ²	0.1360	0.1364	.500
U_1 .kg/m ² .s	6.9800	6.9475	0.500
U_2 .kg/m ² .s	5.5900	5.6558	0.500
U_3 .kg/m ² .s	8.0880	8.1185	0.500
U_4 .kg/m ² .s	4.5600	4.5580	0.500
V_1 .m ²	55.0380	55.0370	0.500
V_2 .m ²	34.7100	34.7060	0.500
V_3 .m ²	20.3130	20.3130	-
V_4 .m ²	1.8130	1.8150	0.500
N_1	10.4000	10.4720	0.500
N_2	8.1100	8.1110	0.500
N_3	3.3200	3.3070	0.500
N_4	0.5200	0.5260	0.500
S_1 .m ²	0.0197	0.0222	0.500
S_2 .m ²	0.0152	0.0172	0.500
S_3 .m ²	0.0062	0.0070	0.500
S_4 .m ²	0.0001	0.0011	0.500
D_1 .m	0.1584	0.1684	0.500
D_2 .m	0.1392	0.1482	0.500
D_3 .m	0.0889	0.0946	0.500
D_4 .m	0.0352	0.0378	0.500

Because the Sig value is more than our alpha of .05 ($p > .05$), so conclude that there is no significant difference between the two methods of calculations.

d. Discussion

The main purpose of this paper is to use computer software such as Visual Basic program which made engineering calculation design simple and more accurate. Visual Basic has been used for conducting the complex design calculations of multiple effect evaporators in sugar industry to control the use of energy and concentration of syrup. First

the manual method calculations were carried out using data and engineering equations which collected from specific literature for reliable results, and then proposed program was used to carried out the same calculations. The Visual Basic calculation results shown there is almost no significant difference between manual and computer software methods. So various design tools and computer software could be used to optimize food equipment processes for more accurate results.

4. Conclusions

The paper investigated the possibly to implement the interactive computer environment for efficient and accurate design aids. It would suggest that the developed user-friendly interfaces and the utilized software approaches make the food processing equipment design easy and adaptable. The Visual Basic and other software is a valuable to find the improvements in different objective functions for different food engineering processing calculations.

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