CALCULUS OUTLINES FOR THE FALLING-FILM EVAPORATOR USED IN THE SUGAR INDUSTRY

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Abstract: The concentration (the vaporization) is the technological operation by Concentration is the technological operation by which the amount of dry substance is increased by partial elimination of a water from the diffusion juice and their transformation in the concentrated syrup by providing the necessary thermal energy (of the boiling heat of the vaporization) [4]. In other words, the vaporization is a thermal transfer operation by which a liquid reach the vaporous state, elimination and the concentration of the making steams [4].

Key words: evaporator, calculus, sugar, industry.

1. INTRODUCTION

The used equipments for making this technological operation are called evaporator or concentrator. In figure 1 is presented the principle scheme of an evaporator with film concentration, it used in the sugar industry for the concentration of the diffusion juice.

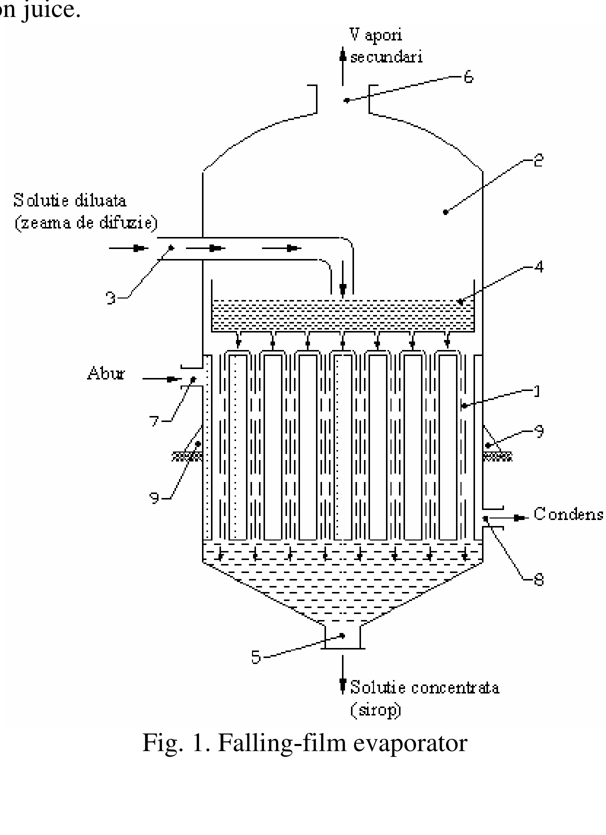


Fig. 1. Falling-film evaporator

Such evaporator consist in principle of: 1 –multi-tubular heating (evaporation) zone (with boiling pipes); 2 – vaporization space (room); 3 –supply pipe with diffusion juice; 4 –tub with homogenous supply orifices with solution for making film in the interior of boiling pipes; 5 –exhaust connection of the concentrate solution; 6 – exhaust stove pipe of the secondary steam; 7 –supply connection with steam for boiling; 8 –exhaust connection of the condensed steam; 9 –supports for the concentrated fastening.

This constructive type is of the concentrator is defining by a heat transfer coefficient very good in analogy with another constructive type and also, by a contact duration between the product under the concentration and the warm area which alternate between 1-5 s, depending by the viscosity of the weak solution, this duration is minimum in analogy with all another evaporator types. In table 1 is the principal constructive and functional specific features for the concentrators with the downward film resulted by free flow.

The constructive and functional parameters. Table 1. [4]

Parameter	Value
The pipe diameter, [mm]	50-60 (max. 100)
The pipe length, [mm]	3000-7000
The film thickness, [mm]	2-3
The entire coefficient of the thermic transfer , [W/m^{2}K]	1000-2500
The stationary time in concentrator, [s]	37-70
The speed of the downward flow, [m/s]	0,08-0,1
The area of the thermic transfer , [m^2]	1500
The concentrator diameter, [m]	2,2
The construction height, [m]	19
The entire volume, [m^3]	5,3

2. CALCULUS OUTLINES

• ***The mass flow capacity of the solution*** which flow in the shape of the film on the internal surface of a pipe is calculated with:

$$Q_1 = \frac{dm}{d\tau} = \frac{\rho \cdot dV}{d\tau} = = \frac{\rho \cdot \pi \cdot d_1 \cdot \delta \cdot dz}{d\tau} = \rho \cdot \pi \cdot d_1 \cdot \delta \cdot w \quad \text{[kg/s]} \qquad (1)$$

where: ρ –us the diffusion juice density, [kg/m^3];
d_1 –the internal diameter of a pipe, [m];
δ –the film thickness, [m];
w –the downward flow speed of the diffusion juice in film, [m/s];
dm –the mass of a infinitesimal element of a film , [kg];
$d\tau$ –the time measure, [s];
dV –the volume of a infinitesimal element of a film, [m^3];
dz –the height of a infinitesimal element of a film, [m].

• ***The mass flow capacity of the vaporized water:***

$$Q_{av} = \frac{\pi \cdot d_1 \cdot L_1 \cdot k \cdot \Delta t}{c_v} \quad \text{[kg/s]} \qquad (2)$$

where: L_l –is the length of a pipe, [m];
k –the entire coefficient of the heat transfer [W/m^2·K];
c_v – boiling heat of the water vaporization, [J/kg];
Δt –the average difference by temperature, [°C].

• ***The equation of the balance sheet of the materials*** for the entire concentrator can be:

$$Q_i = Q_c + Q_a \qquad \text{[kg/s]} \tag{3}$$

where: Q_i –is the flow capacity of the initial weak solution, [kg/s];
Q_c – the flow capacity of the concentrated weak solution, [kg/s];
Q_a – the dissolved flow capacity of water vaporized (don't include solvate), [kg/s]

and:

$$Q_i \cdot su_i = Q_c \cdot su_c \tag{4}$$

where: su_i –is the content by dry substance, respectively the concentration by saccharose of the initial weak solution, [%];
su_c – the content by dry substance or the concentration by saccharose of the final weak solution , [%].

• ***The equation of the heat transfer*** for entire concentrator can be:

$$Q_a = \alpha \cdot Q_0 + \beta \cdot Q_i \qquad \text{[kg/s]} \tag{5}$$

where: Q_0 –is the flow capacity by heat carrier (elementary steam) used by heating, [kg/s];
α –the vaporization coefficient, [kg vaporized water /1 kg by elementary steam];
β – the auto vaporization coefficient, [kg vaporized water /1 kg solution];

and their expression are:

$$\alpha = \frac{h_{ap} - h_c}{h_{as} - c_c \cdot t_c} \tag{6}$$

$$\beta = \frac{c_i \cdot t_i - c_c \cdot t_c}{h_{as} - c_c \cdot t_c} \tag{7}$$

where: h_{ap} –is the mass enthalpy of the elementary steam, [J/kg];
h_{as} – the mass enthalpy of the secondary steam, [J/kg];
h_c – the mass enthalpy of the result of the result condensing from elementary steam, [J/kg];
c_i –the heat average mass capacity of the initial solution, [J/kgK];
c_c – the heat average mass capacity of the concentrated solution, [J/kgK];
t_i –the temperature of the initial solution from entrance in concentrator, [°C];
t_c – the temperature of the initial solution at emergency from concentrator, [°C].

• ***The transmission equation of the thermic flux*** *from the heat carrier (steam) to the solution (the diffusion juice):*

$$\Phi = k \cdot A \cdot \Delta t \qquad \text{[W]} \tag{8}$$

where: k –the entire coefficient of the thermic transfer, [W/m^{2}K];
A –the area of the thermic transfer, [m^2];

Δt –the average temperature difference, [°C];

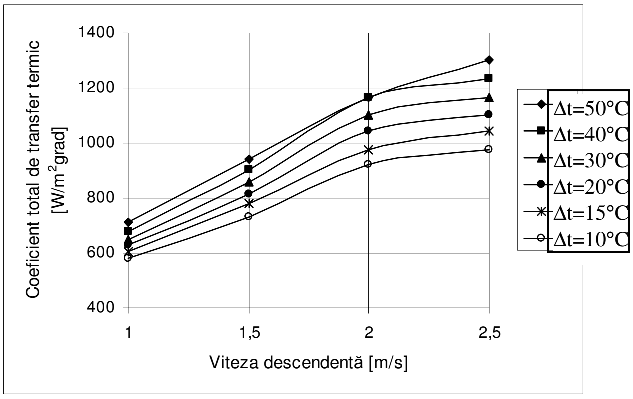
$$\Delta t = t_{ca} - t_{fs} \qquad [°C] \tag{9}$$

where: t_{ca} –the concentration temperature of the steam, [°C];
t_{fs} –the average boiling temperature of the solution on the average pressure from concentrator, [°C].

In the figure 2 is presented the variation of the heat transfer depending on the difference of the temperature between the heat carrier and the solution and depending on downward speed of the solution and the dependence on the constructive and functional parameters for the evaporator, but on the physics properties of the solution who which was concentrated, can be calculated with:

$$k = 8{,}83 \cdot 10^4 \cdot \frac{d^{0,57} \cdot w}{\eta^{0,25} \cdot \Delta t^{0,1}} \cdot \left(1 + \frac{2{,}5}{L}\right) \qquad [W/m^2K] \tag{10}$$

where: d –is a pipe diameter, [m];
w –the flow speed of the solution, [m/s];
L –the pipe length, [m];
η –the dynamic viscosity of the solution [Pa·s];
Δt –the used average temperature difference, [°C].



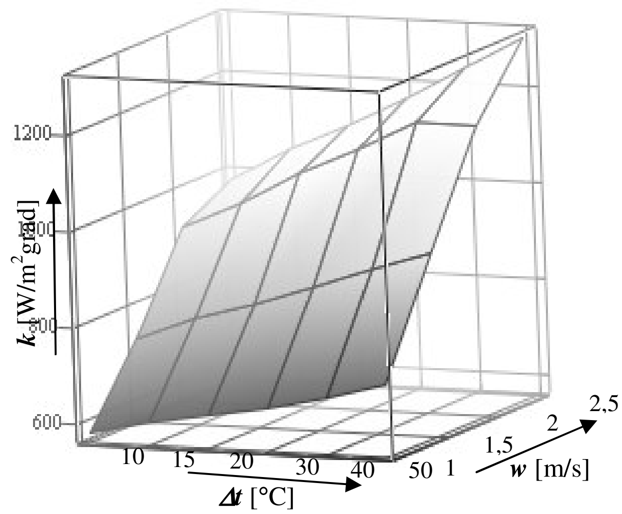


Fig. 2. The variation of the entire coefficient of the heat transfer depending on the temperature difference and the downward speed of the diffusion juice

• ***The final concentration of the solution*** can be calculated using the equations (3) and (4):

$$\begin{cases} Q_i = Q_c + Q_a \\ Q_i \cdot su_i = Q_c \cdot su_c \end{cases} \tag{11}$$

From where resulted:

$$su_c = \frac{Q_i \cdot su_i}{Q_c} = \frac{Q_i \cdot su_i}{Q_i - Q_a} \quad [\%] \tag{12}$$

• ***The pipe length*** (necessary to the concentration of the solution from s_{ui} at s_{uc}) can be calculated with:

$$L = \frac{\delta \cdot w \cdot \rho \cdot c_v \cdot (su_c - su_i)}{su_c \cdot k \cdot \Delta t} \quad [\text{m}] \tag{13}$$

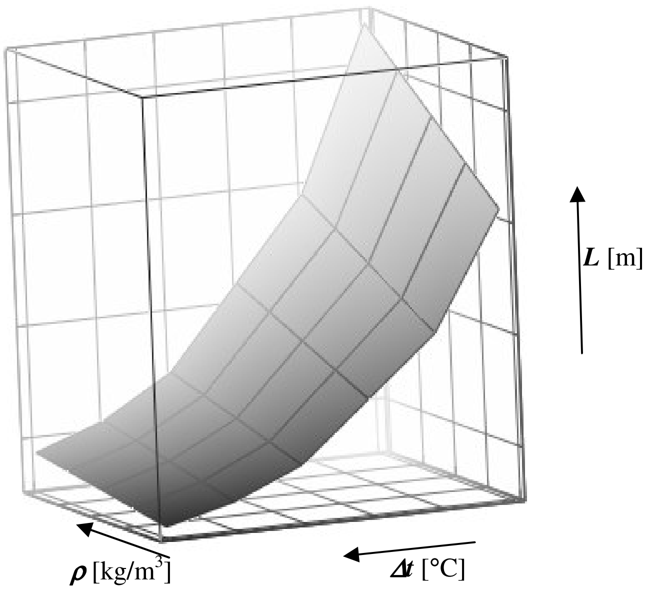


Fig. 3. The length pipe variation depending on the temperature difference and the density of the diffusion juice from different stage of the concentration.

• ***The downward film thickness*** is dependent by the physics properties of the solution, and it can be calculated with

$$\delta = \sqrt[3]{\frac{3 \cdot \eta \cdot m}{\rho^2}} \quad [\text{m}] \tag{14}$$

where m is a parameter which, for the downward flow in working condition that don't outrun Re=1600, it can be calculated with:

$$m = \frac{\text{Re} \cdot \eta}{4} \tag{15}$$

• ***The maximum speed at the downward flow*** can be calculated with:

$$w_{\max} = \frac{\rho \cdot \delta^2}{2 \cdot \eta} \qquad \text{[m/s]} \qquad (16)$$

• ***The critical film thickness*** (which coresponde of the maximum value $w_{\max}$):

$$\delta_{\max} = 10{,}6 \cdot \sqrt[3]{\frac{\eta}{\rho^2}} \qquad \text{[m]} \qquad (17)$$

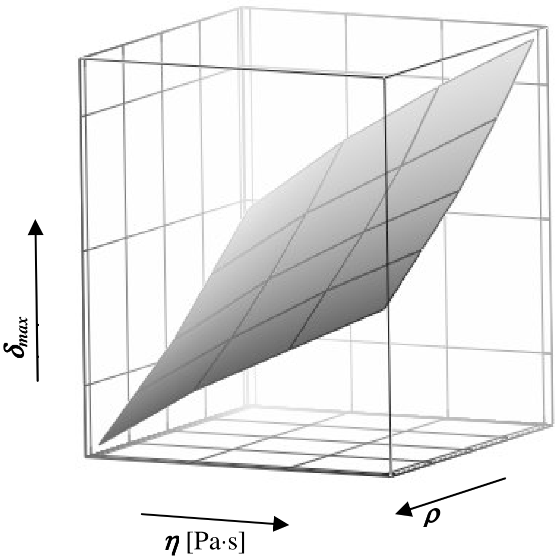


Fig. 4. The variation of the maximum thickness of the film depending on the dynamic viscosity and the density of the diffusion juice from different stage of the concentration.

3. CONCLUSIONS

From the theoretical study result that the value of the entire coefficient of the thermal transfer, in the case of the evaporator type, grow up proportional with the growing up of the flow downward speed of the solution from the boiling pipes and with the growing up of the temperature difference between the heat carrier and the diffusion juice. The necessary length of a pipe (boiling pipes) is correlated with the temperature difference between heat carrier and diffusion juice. The length should be longer when the temperature difference is smaller. The same length is direct proportional with the solution density, also. The critical film thickness (that value mustn't be exceeded) depends on the dynamic viscosity of the solution; it is increasing when the value of dynamic viscosity is increasing. Than the density of the diffusion juice is bigger also the critical film thickness must be smaller.

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