The American Journal of Applied Sciences
ISSN 2689-0992 Volume 08 - 2026

Simulation of Cotton Micella Evaporation in Tubular Apparatus With An Rising Film Of Liquid

Muzaffar Khamdamov
Teacher, Gulistan State University, Republic of Uzbekistan, Gulistan, Uzbekistan

Abdukarim Khudayberdiev
Doctor of Philosophy in Engineering Sciences (PhD), Associate Professor, Namangan State Technical University, Republic of Uzbekistan, Namangan, Uzbekistan

Absalom Xudayberdiyev
Doctor of Technological Sciences, Professor of Namangan Institute of Engineering and Technology, Republic of Uzbekistan, Namangan, Uzbekistan

Anvar Khamdamov
Doctor of Engineering Sciences, Professor, Namangan State Technical University, Republic of Uzbekistan, Namangan, Uzbekistan

Received: 04 Apr 2026 | Received Revised Version: 28 Apr 2026 | Accepted: 20 May 2026 | Published: 15 June 2026

Volume 08 Issue 06 2026 | Crossref DOI: 10.37547/tajas/Volume08Issue06-02

Abstract

A mathematical model of the statics of the preliminary distillation of cottonseed oil miscella in tubular apparatuses with an ascending liquid film is proposed. It facilitates the design of apparatuses with an optimal heating surface and the identification of their effective operating modes based on an analysis of the temperature and miscella concentration distribution along the height of the tube bundle. Selected results of a study of the statics of cottonseed oil miscella evaporation in a tubular evaporator of the Extraction Technician extraction unit of Gulistan Extract-Yog JSC are presented. It was found that, at a miscella flow rate of Go = 3,31 t/h, to achieve the required outlet concentration aex ≥ 95 % at temperatures tex ≤ 110-115 ℃, 76÷84 m2 of the active heat-transfer surface of the apparatus is required. To increase the efficiency of the device, it is recommended to increase the miscella consumption by 13÷24 % in accordance with the identified heating surface reserve (24 m2).

Keywords: Oil, miscella, distillation, evaporation, distiller, heating surface, tube, modeling.

Cite This Article: Muzaffar Khamdamov, Abdukarim Khudayberdiev, Absalom Xudayberdiyev, & Anvar Khamdamov. (2026). Simulation of Cotton Micella Evaporation in Tubular Apparatus With An Rising Film Of Liquid. The American Journal of Applied Sciences, 8(06), 239–247. https://doi.org/10.37547/tajas/Volume08Issue06-02

1. Introduction

Preliminary distillation of vegetable oil miscella [1-3] is a single-pass evaporation of a two-component mixture of oil in a solvent, during which the transition of the low-boiling component from the liquid phase to the vapor phase occurs in full accordance with its relative volatility or boiling point. The phenomenon of self-evaporation ensures the removal of the solvent from the miscella during its boiling due to the heat of superheating of the mixture. This technological process is carried out in tubular single-pass evaporators (distillers), operating with an ascending or falling liquid film [4-6].

The efficiency of the preliminary miscella distillation stage determines the required quality characteristics of commercial vegetable oil. Therefore, research aimed at identifying optimal process conditions for this process, which can reduce process costs and design equipment with an optimal heat transfer surface, is of scientific and practical value.

2. Methods

This study analyzes the efficiency of cottonseed miscella evaporation using a process statics model in a tubular film evaporator at the Gulistan Oil Extraction Plant [7] and determines the optimal heating surface area for the apparatus.

To calculate the optimal heating surface area for the evaporator, it is of great interest to study the patterns, temperature distribution, and concentration of the evaporated miscella along the height of its tube bundle, which is accomplished through mathematical modeling of the statics of this process [8,9].

When developing a mathematical model for the statics of miscella preliminary distillation in a vertical tubular evaporator (evaporator), the process occurring within the heat-transfer tubes is crucial [8,10-12].

To study the process of miscella evaporation in vertical tubes, the latter are divided into several elementary sections ("quasi-tubes") with a height of Δh, having initial j-1 and final j section boundaries (see Fig. 1), where the liquid temperature at the inlet of the section is t_{j-1} and at the outlet is t_j [8,12].

The basis for the mathematical description of the miscella evaporation process in a tubular apparatus is the equations for the material and heat balance of the process in an elementary section of the tubes.

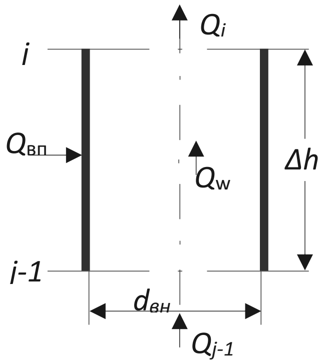


Fig. 1. Heat balance diagram for the miscella distillation process

The generalized heat balance equation for the miscella evaporation process in a vertical heat-transfer tube bundle of the apparatus is:

$$Q_{j-1} + Q_{w\,j-1} + Q_{ss} = Q_j + Q_{w.j} + Q_{kn} + Q_{los}, \tag{1}$$

where $Q_{j-1} = G_{j-1}c_{\,j-1}t_{j-1}$ is the heat supplied to the apparatus tube bundle by the miscella flow;

$Q_{wj-1} = W_{j-1}i_{j-1}$ is the heat introduced by the secondary vapors of the solvent; $Q_{ss} = Di_{wv}$ is the heat of the heating water vapor; $Q_j = G_jc_jt_j$ is the heat carried away by the flow of miscella evaporated in the tubes; $Q_{wj} = W_ji_j$ is the heat loss with solvent vapor; $Q_{kn} = Di_{kn}$ is the heat loss with water vapor condensate; Q_{los} is the heat loss to the environment; G is the mass flow rate of miscella in the tubes, kg/s; D is the flow rate of heating water vapor for the process, kg/s; W is the flow rate of secondary solvent vapor, kg/s; t is the boiling point of the miscella in the tubes, °C; c is the heat capacity of the miscella at temperature t, J/(kg °C); i is the enthalpy of solvent vapor, J/(kg °C); i_{wv} and i_{kn} are the enthalpy of water vapor and its condensate, J/(kg °C).

It is known that under static conditions, the heat loss Q_{los} from the apparatus to the environment is constant, and therefore its influence on the heat balance of the process can be ignored.

Given this assumption, the expanded form of the heat balance equation for the miscella evaporation process in an elementary section of vertical pipes (1) is as follows:

$$G_{j-1}c_{j-1}t_{j-1} + W_{j-1}i_{j-1} + Di_{\text{wv}} = G_jc_jt_j + W_ji_j + Di_{\text{kn}}, \qquad (2)$$

or

$$G_{j-1}c_{j-1}t_{j-1} + W_{j-1}i_{j-1} + D(i_{\text{wv}} - i_{\text{kn}}) = G_jc_jt_j + W_ji_j, \qquad (3)$$

According to the heat transfer mechanism [13, 14], the heat of water vapor $Q_{\text{wv}}=D(i_{\text{wv}}-i_{\text{wv}})$, expended on evaporating the liquid in the tubes, consists of the following three components:

- heat transferred from water vapor to the tube wall

$$Q_{\text{pw1}} = \alpha_1\Delta F_{\text{ext}}\,(t_{\text{kn}} - t_{\text{pw1}}), \qquad (4)$$

- heat passing through the tube walls by conduction

$$Q_{\text{pw2}} = (\lambda_{\text{pw}}/\delta_{\text{pw}})\,\Delta F_{\text{ave}}\,(t_{\text{pw1}} - t_{\text{pw2}}), \qquad (5)$$

- heat transferred from the hot tube wall to the liquid

$$Q_{\text{li}} = \alpha_2\Delta F_{\text{int}}\,(t_{\text{pw2}} - t_{j-1}) \qquad (6)$$

where α_1 and α_2 are, respectively, the heat transfer coefficients from water vapor to the pipe wall and from the pipe walls to the liquid, W/(m^2 °C); λ_{pw} is the thermal conductivity coefficient of the pipe material, W/(m °C); t_{kn} is the condensation temperature of water vapor, °C; t_{pw1} and t_{pw2} are, respectively, the temperature of the outer and inner surfaces of the pipe walls, °C; δ_{pw} is the pipe wall thickness, m; F_{ext}, F_{int} and F_{ave} are, respectively, the heat transfer surface (m^2) of the tube bundle of the apparatus by the diameter of the heat transfer pipes (m): outer d_{ext}, inner d_{int} and average $d_{\text{ave}} = 0{,}5(d_{\text{int}}+d_{\text{ext}})$, $F_{\text{ext}} = \pi d_{\text{ext}}n\Delta h$; $F_{\text{int}} = \pi d_{\text{int}}n\Delta h$ и $F_{\text{ave}} = \pi d_{\text{ave}}n\Delta h$; n is the number of tubes in the apparatus, pcs. Therefore, adding equations (4), (5), and (6)

$$+\begin{cases} Q_{\text{int}} = \alpha_1\Delta F_{\text{ext}}\,(t_{\text{kn}} - t_{\text{pw1}}), \\ Q_{\text{pw}} = (\lambda_{\text{pw}}/\delta_{\text{pw}})\,\Delta F_{\text{ave}}(t_{\text{pw1}} - t_{\text{pw2}}), \\ Q_{\text{liq}} = \alpha_2\Delta F_{\text{int}}\,(t_{\text{pw2}} - t_{j-1}), \end{cases}$$

and after a series of transformations [13], we obtain

$$Q(1/\alpha_1 + \lambda_{\text{pw}}/\delta_{\text{pw}} + 1/\alpha_2) = \Delta F_{\text{ave}}(t_{\text{kn}} - t_{j-1}). \qquad (7)$$

Hence

$$Q = (1/\alpha_1+\lambda_{\text{wт}}/\delta_{\text{pw}}+1/\alpha_2)^{-1}\Delta F_{\text{ave}}(t_{\text{kn}} - t_{j-1}), \qquad (8)$$

where $(1/\alpha_1+\lambda_{\text{pw}}/\delta_{\text{pw}}+1/\alpha_2)^{-1} = K$ is a well-known expression for the heat transfer coefficient in the apparatus [13-15].

Consequently, the amount of heat transferred to the micelle flow by water vapor through heat transfer in the apparatus is expressed as

$$Q_{\text{int}} = K\,\Delta F_{\text{cp}}(t_{\text{kn}}-t_{j-1}) = K\pi d_{\text{cp}}n\Delta h\,(t_{\text{kn}}-t_{j-1}). \qquad (9)$$

Taking into account (9), the heat balance equation for evaporation of miscella (3) in an elementary section of vertical pipes with a height of Δh can be written as follows:

$$G_{j-1}c_{j-1}t_{j-1} + W_{j-1}i_{j-1} + K\Delta F(t_{\text{kn}} - t_{j-1}) = G_jc_jt_j + W_ji_j, \qquad (10)$$

or

$$G_{j-1}c_{j-1}t_{j-1} + W_{j-1}i_{j-1} - G_jc_jt_j - W_ji_j = -K\Delta F(t_{\text{kn}} - t_{j-1}). \qquad (11)$$

Taking into account the current flow rates of the concentrated miscella

$$G = G_o(a_o/a) \qquad (12)$$

and the released solvent vapors

$$W = G_o(1 - a_o/a), \qquad (13)$$

Determined from the process material balance equation [4-6,9], expression (11) can be written as

$$G_o(a_o/a_{j-1})c_{j-1}t_{j-1}+G_o(1 - a_o/a_{j-1})i_{j-1}-G_o(a_o/a_j)c_jt_j - G_o(1 - a_o/a_j)i_j = -K\Delta F(t_{\text{kn}} - t_{j-1}); \qquad (14)$$

or

$$G_o(a_o/a_{j-1})c_{j-1}t_{j-1}+G_oi_{j-1}-G_o(a_o/a_{j-1})i_{j-1}-G_o(a_o/a_j)c_jt_j-G_oi_j+G_o(a_o/a_j)i_j=-K\Delta F(t_{kn}-t_{j-1})$$

where G_o is the flow rate of the initial miscella, kg/s; a_o is the initial concentration of the miscella, % (mass).

Taking the constant process parameters G_o and a_o out of the brackets, we obtain

$$G_oa_o[c_{j-1}t_{j-1}/a_{j-1}+i_{j-1}/a_o-i_{j-1}/a_{j-1}-c_jt_j/a_j-i_j/a_o+i_j/a_j]=-K\Delta F(t_{kn}-t_{j-1}). \qquad (15)$$

By rearranging the terms (15) and taking into account the expressions for the heating surface $\Delta F = \pi d_{cp}n\Delta h$, we obtain

$$G_oa_o[(i_j/a_j-c_jt_j/a_j)-(i_{j-1}/a_{j-1}-c_{j-1}t_{j-1}/a_{j-1})-(i_j/a_o-i_{j-1}/a_o)]=-K\pi d_{ave}n\Delta h\,(t_{kn}-t_{j-1}).$$

$$G_oa_o[(i_j-c_jt_j)/a_j-(i_{j-1}-c_{j-1}t_{j-1})/a_{j-1}-(i_j-i_{j-1})/a_o]=-K\pi d_{ave}n\Delta h\,(t_{kn}-t_{j-1}). \qquad (16)$$

Dividing both sides of (16) by Δh we get

$$G_oa_o/\Delta h[(i_j-c_jt_j)/a_j-(i_{j-1}-c_{j-1}t_{j-1})/a_{j-1}-(i_j-i_{j-1})/a_o]=-K\pi d_{ave}n(t_{kn}-t_{j-1}). \qquad (17)$$

Keeping in mind that $a_j = a_{j-1}+\Delta a$ и $i_j-i_{j-1} = \Delta i$, expression (17) can be written as

$$(G_oa_o/\Delta h)[\Delta(i-ct)/\Delta a-\Delta i/a_o]=-K\pi d_{ave}n(t_{kn}-t_{j-1}). \qquad (18)$$

or

$$(G_oa_o\,\Delta/\Delta h)[(i-ct)/a-i/a_o]=-K\pi d_{ave}n(t_{kn}-t_{j-1}), \qquad (19)$$

where Δa and Δi are the increment of concentration and enthalpy.

Moving from the increment to the differential, we obtain

$$(G_oa_o)d/dh[(i-ct)/a-i/a_o]=-K\pi d_{ave}n(t_{kn}-t_{j-1}). \qquad (20)$$

Equation (20) characterizes the changes in the parameters of the miscella concentration process (a and t) along the height of the vertical tubes h in preliminary distillers with known process (G_o, a_o, P, $P_{кн}$) and design parameters (d, n, h).

Analysis of the equations for calculating the parameters included in (20) is as follows.

The boiling point of the miscella t depends on its concentration a and the absolute pressure in the apparatus P. To calculate the boiling point of cotton miscella at P = 20÷200 kPa, the following mathematical relationship is recommended [16] with an error of less than 2%:

$$t = c_o + c_1P + c_2a + c_3P^2 + c_4a^2 + c_5P^3 + c_6a^3 + c_7aP + c_8aP^2 + c_9a^2P, \qquad (21)$$

where $c_o \div c_9$ are constant coefficients of the equation.

For strong miscella ($a \geq 64\%$), the curve of change in boiling point of which with respect to its concentration is a steep line, the numerical values of the coefficients (21) are equal to: $c_o = -1082{,}85$; $c_1 = 1{,}809431$; $c_2 = 44{,}79217$; $c_3 = -0{,}55451\ 10^{-2}$; $c_4 = -0{,}618587$; $c_5 = 0{,}107\cdot10^{-4}$; $c_6 = 0{,}2908\cdot10^{-2}$; $c_7 = 0{,}204719\cdot10^{-1}$; $c_8 = 0{,}49\cdot10^{-5}$; $c_9 = 0{,}1379\cdot10^{-3}$.

The heat capacity of cottonseed miscella c (kJ/kg °C) depends on its concentration a and temperature t [9]:

$$C_{mis} = 0{,}01[229{,}2 - 0{,}624a + (0{,}588 - 0{,}00158a)\,t]. \qquad (22)$$

According to the classification of evaporators by the enthalpy of secondary vapor [9], preliminary distillers with an ascending liquid flow are classified as devices of the first group. The enthalpy of the solvent vapor i (kJ/kg) leaving these devices is determined by the boiling point of the miscella at the outlet of the tubes [9]:

$$i_w = 372 + 1{,}78\,t. \qquad (23)$$

The condensation temperature of water vapor $t_к$ is determined from reference literature [15], depending on its pressure P_{wv} in the heating chamber of the device. The heat transfer coefficient K in the apparatus is calculated using known criteria equations [13-15], using calculated and experimental data.

By combining the above equations (20), (21), (22), and (23) into a system, we obtain the following mathematical model of the statics of the preliminary distillation process of cottonseed oil miscella in a vertical tubular apparatus operating with an ascending liquid film:

$$\begin{cases} (G_o a_o) d/dh[(i - ct)/a - i/a_o] = -K\pi d_{ave} n(t_{kn} - t_{j-1}), & (20) \\ t = c_o + c_1 P + c_2 a + c_3 P^2 + c_4 a^2 + c_5 P^3 + c_6 a^3 + c_7 aP + c_8 aP^2 + c_9 a^2 P, & (21) \\ c_{mic} = 0{,}01[229{,}2 - 0{,}624a + (0{,}588 - 0{,}00158a)t], & (22) \\ i = 372 + 1{,}78\, t, & (23) \\ a_j \le a_{zad} \text{ at } t_j \le t_{ogp}. & (24) \end{cases}$$

This statics model of the process under study makes it possible to study and analyze the nature of the distribution of temperature and miscella concentration along the height of the boiling tubes of distillers and, on this basis, to design new devices with an optimal heating surface or to identify the degree of operating efficiency of existing designs of pre-distillers, for example, ND-1250, TDA-8, “Extraktionstecnik”, etc., used in oil and fat industry enterprises [4-6].

The above proposed model of the statics of the process of preliminary distillation of miscella (20-24) is implemented according to the following algorithm.

1. The numerical values of the design and technological parameters of the apparatus are set: the diameter of the boiling pipes d, their total number n in the apparatus, the miscella flow rate (the productivity of the apparatus) G_o, its initial concentration a_o, the operating pressure in the apparatus P and the water vapor pressure P_{wv} in its inter-tube space (or its condensation temperature $t_{кн}$).

2. Substituting the values of miscella concentration a and pressure P into (21), determine its boiling point t.

3. Based on the values of concentration a and temperature t, the heat capacity of the miscella c is calculated according to (22).

4. Substituting the values of the boiling point t of the miscella into (23) determine the enthalpy of the solvent vapor i_w at this temperature.

5. Using experimental data, the value of the heat transfer coefficient in the apparatus K is set, or its value can be calculated depending on the hydrodynamic regime of the miscella flow in the tubes [15], taking into account the continuous change in the properties of the miscella and solvent depending on the process temperature.

6. Substituting the values of G_o, a_o, a, t, t_{kn} and K into (20), the corresponding height of the section of heat transfer tubes Δh_j,is determined, where $j = 1,2,3, \ldots, N$, and $\Sigma\Delta h_j = h_{gen}$.

7. The value of the miscella concentration increment is set $\Delta a = a_j - a_{j-1}$.

8. Taking into account the increase in concentration $a_j = a_{j-1} + \Delta a$, checking compliance with the conditions of limitation on the temperature of the miscella at the outlet of the apparatus $t_j < t_{гres}$ (24) a repeated calculation is made from point 2 to point 8.

9. At given values of the operating pressure in the apparatus P, the calculation is carried out until the regulated value of the miscella concentration $a_j \le a_{zad}$ back is reached.

This technique is based on taking into account the continuous temperature change in the properties of cotton miscella and solvent in the vapor and liquid phases. This refinement of process parameters contributes to the development of an energetically optimal heat transfer surface for tubular distillers.

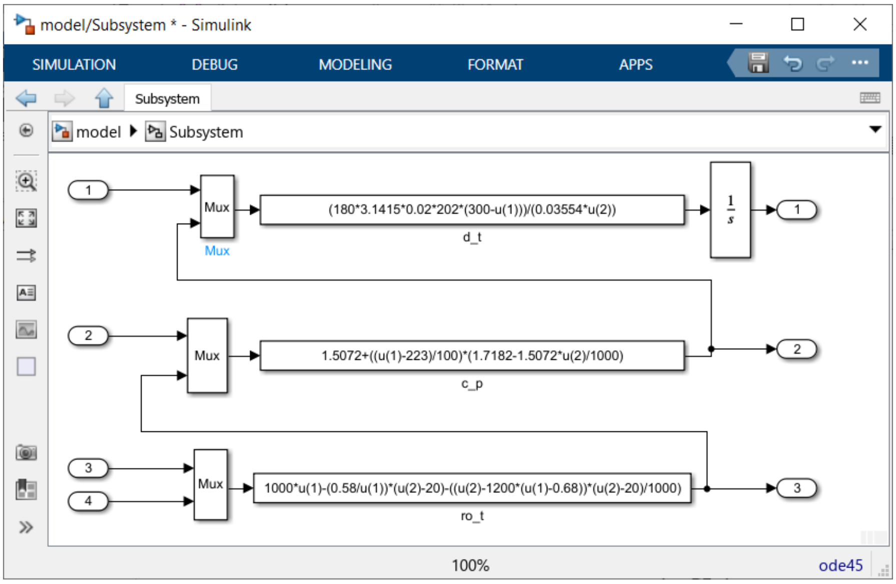
When designing an energetically optimal design of a tubular distiller, taking into account the limitations on productivity G_o and the temperature of the evaporated miscella t_j, its minimum heat transfer surface F_{min} is selected as an optimality criterion [10]:

$R_{opt} \rightarrow \min F\,(d, n, h)$, (25)

with known values of diameter din, number of pipes n and height of pipes h in the apparatus.

Since the optimal heating surface of the apparatus is expressed as $F_{\text{опт}} = \pi d_{\text{int}} n h_{\text{ opt}}$, then when h_{opt} is reached, the equivalent optimal height of the tubes hopt is established, corresponding to the specified values of the design ($d_{\text{int,}}\, n$) and technological parameters (G_o, a_o, P, a_{opt}, t_{opt}) of the process.

To study the statics of preliminary distillation of cottonseed oil miscella in tubular apparatuses, a computer model of the process was compiled on the MATLAB/Simulink platform using its mathematical model (see Fig. 2).



```
(180*3.1415*0.02*202*(300-u(1)))/(0.03554*u(2))
1.5072+((u(1)-223)/100)*(1.7182-1.5072*u(2)/1000)
1000*u(1)-(0.58/u(1))*(u(2)-20)-((u(2)-1200*(u(1)-0.68))*(u(2)-20)/1000)
```

Fig. 2. Computer model of the statics of cottonseed oil miscella evaporation in a tubular apparatus using the MatLab Simulink platform.

3. Results and Discussion

A computer model was used to study the statics of the cottonseed oil miscella concentration process in a tubular film evaporator of the third distillation stage of the Extraction Stecnik extraction unit at Gulistan Extract-Yog JSC [7].

The industrial apparatus primarily consists of a vertical cylindrical body with a bundle of heat transfer tubes mounted within it, a chamber for distributing the initial miscella among the tubes, and a built-in upper cylindrical separator for separating the resulting vapor-liquid mixture under gravity [4-7]. Saturated steam is supplied to the intertube space (heating chamber) of the apparatus.

According to the technological regulations for the production of products in the unit [7], the apparatus has the following design parameters: $F = 100$ m^2; $d_{\text{int}} = 0.03$ m, $n = 224$ pcs and $h = 4.6$ m. $F = 100$ m^2; $d_{\text{int}} = 0{,}03$ m, $n = 224$ pcs and $h = 4.6$ m.

The miscella distillation process in this apparatus was studied using the following regulated process parameters [7]: the flow rate of miscella entering the apparatus $G_o =$ 3,31 t/h (0.92 kg/s), its concentration a_o = 60÷65% (mass) and temperature $t_o = 60\div70$ ^{0}C; the miscella in the apparatus is concentrated to $a_{ex} \geq 95\%$ at a temperature $t_{ex} = 100\div115$ °C; the operating pressure in the apparatus is $P = 50$ kPa, and the saturated water vapor pressure in the intertube space of the apparatus is $P_{wv} = 0{,}5$ MPa. The average calculated value of the heat transfer coefficient in the apparatus is $K = 300$ W/(m^2 °C).

Based on the results of the process study, the concentration a (%, mass) and temperature t (°C) distribution curves of cottonseed miscella were constructed across the height of the tube bundle h of the pre-distiller-evaporator under the above-mentioned process conditions, with the process temperature limits $a_o = 60$–65 %, $t_o = 60$–70 °C, and $t_{ex} \leq 100$–115 °C (see Figs. 3 and 4).

Fig. 3 shows the concentration *a* and temperature *t* distribution curves of cottonseed miscella across the height of the tube bundle *h* of the evaporator at $G_o = 0.92$ kg/s, $a_o = 60$ %, and $t_o = 60$ °C, with the process temperature limit $t_{ex} \leq 110$ °C.

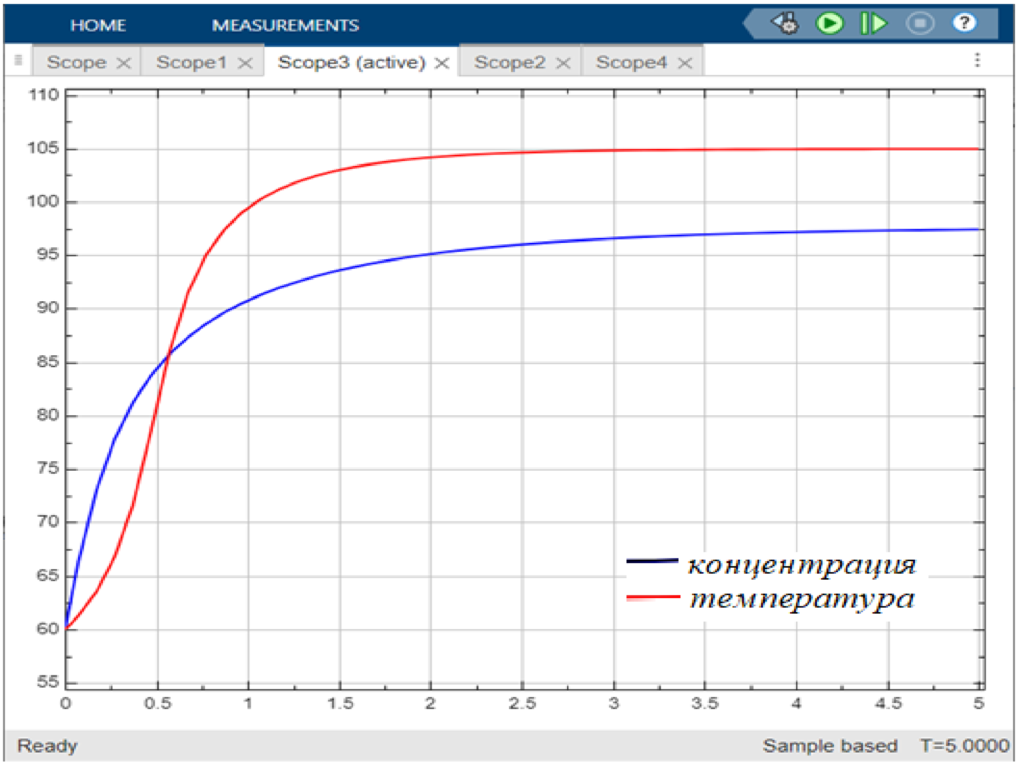


Fig. 3. Distribution of the concentration *a* and temperature *t* of cottonseed miscella across the height of the evaporator tube bundle *h* at $G_o = 0.92$ kg/s, $a_o = 60\%$, $t_o = 60$ °C, *P* = 50 kPa, tкн = 151 °C, and K = 300 W/(m^2 °C)

Figure 3 shows that when the initial miscella enters the heat exchange tubes, it is heated to its boiling point. The temperature of the miscella evaporated in the tubes increases parabolically, reaching up to 105 °C in a section of the tube bundle with a height $h \leq 2.5$ m. The rate of miscella temperature rise in the pipe sections is 39°C/m in sections with a height of up to $h \leq 1$ m, and 4–5°C/m in sections with a height of 1–2 m. Subsequently, as the miscella temperature approaches the condensation temperature of the heating water vapor, the concentration and temperature changes at the end sections of the pipes decrease, achieving a constant temperature difference of 46 °C between the coolants. Under these conditions, the miscella concentration gradually increases from 60 % to 97.5 % along the apparatus's tubes. In this case, the rate of increase in the concentration of miscella in the sections of the tube bundle is, respectively, 31 %/m in the section of tubes with a height of up to $h \leq 1$ m, 4 ÷ 5 %/m at a height of tubes from 1 to 2 m, 2 %/m at a height of 2 to 3 m, and less than 1 %/m from 3 m and above.

Figure 3 also shows that for concentrating cotton miscella to $a_{ex} = 97.5\%$ at a temperature of tout = 105 °C, a section of the tube bundle with an active height of $h_{act} = 3.5 \div 4$ m is sufficient, which is 76 ÷ 87 % of the total height of the bundle of boiling tubes in the apparatus. As we can see, the primary miscella evaporation process occurs in a section of the tube bundle with a height $h \leq 4$ m (or $F_{min} = 85$ m^2), while the remaining section (0.6–1.1 m) operates idle at a given mixture flow rate and essentially serves as a reserve for further increasing the unit's performance.

Figure 4 shows the distribution curves for the miscella concentration a and temperature t over the height of the evaporator tube bundle *h* at $G_o = 0.92$ kg/s, $a_o = 65$ %, and $t_o = 70$ °C, with a process temperature limit of tout $t_{ex} \leq 115$ °C.

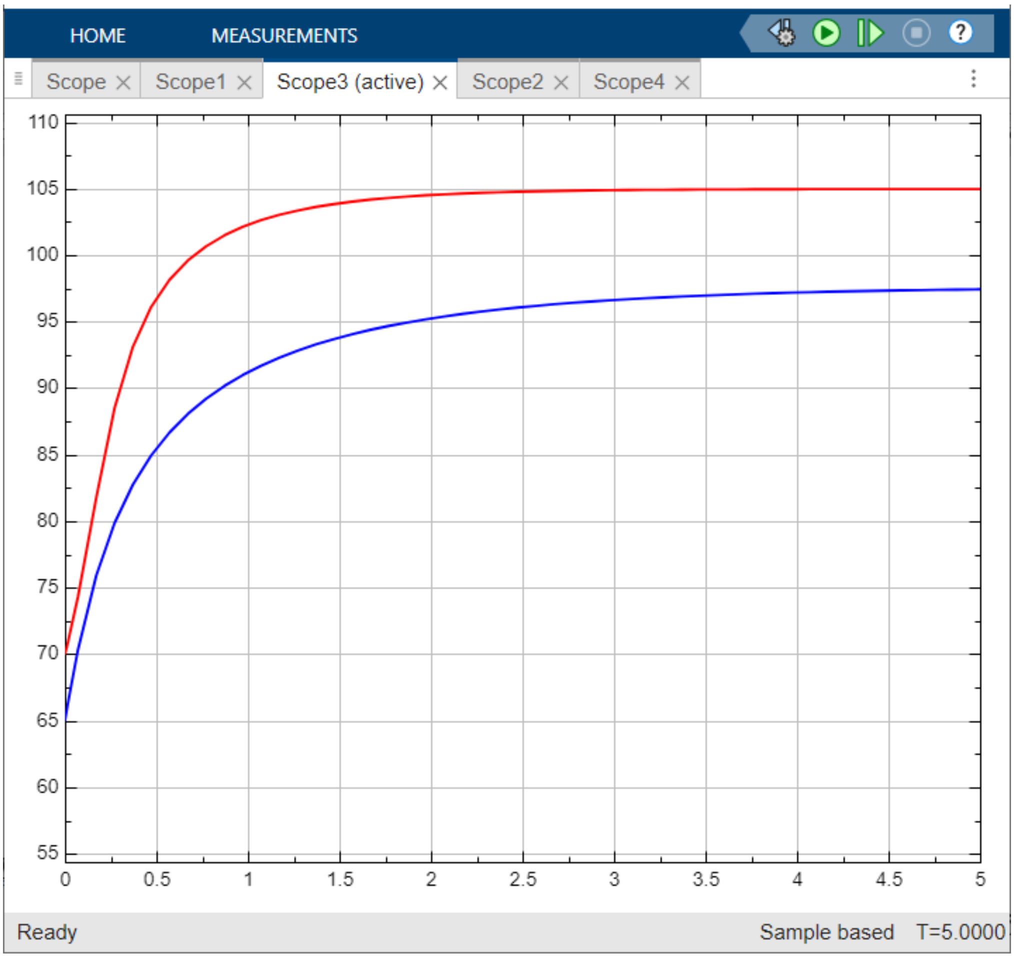


Fig. 4. Distribution of the concentration a and the boiling point t of cotton miscella by the height of the evaporator tube bundle h at $G_o = 0.92$ kg/s, $a_o = 65\%$, $t_o = 70$ °C, P = 50 kPa, tкн = 151 °C, and K = 300 W/(m^2 °C)

Figure 4 shows that the boiling point of the miscella in the evaporator tubes gradually increases from 70 °C to 105 °C with increasing speed and in a section of the tube bundle with a height $h = 2.5$ m, which is 54.3% of its total height. The rate of miscella temperature increase in the tubes is, respectively, 32 °C/m in the section with a height of up to $h \leq 1$ m, 2 °C/m in the section with a height of 1 to 2 m, and less than 1°C/m closer to the temperature equilibrium point ($h \geq 2$ m). Subsequently, as a constant temperature difference between the coolants is achieved, the rate of miscella temperature change in the remaining section of the tubes (from 2.5 to 4.6 m) decreases and becomes constant.

As we can see, the main process of miscella concentration from 65 to 97.5 % occurs in the section of the tube with a height of $h \leq 3.5$ m, while the rest of the tubes operate idle, indicating insufficient utilization of the evaporator's thermal capacity. It follows that, for a given evaporator throughput of G_o = 3310 kg/h, the required heat transfer surface is $F_{pac} = 76$ m^2.

It should also be noted that the identical nature of the miscella parameter distribution curves in both study variants indicates a high intensity of solvent distillation when organizing evaporation in a rising film.

A comparison of the results in both study variants of the cottonseed miscella preliminary distillation showed that for evaporation of $G_o = 3.31$ t/h of miscella to $a_{ex} \geq 97.5\%$ at $a_{ex} \leq 110$-115 °C, the required height of the evaporator tube bundle is h_{act} = = 3.5 ÷ 4.0 m (76 ÷ 87% of its total height - 4.6 m). In this regard, to improve the efficiency of the apparatus, we recommend increasing the miscella flow rate by 13 ÷ 24%, in accordance with the identified reserve heating surface (24 m^2), which helps to stretch the active zone of evaporation of the mixture over the entire height of the tube bundle.

4. Conclusion

Thus, the results of a study of the statics of evaporation of cottonseed oil miscella in a tubular evaporator with an ascending film of liquid showed that at a given miscella flow rate G_o = 3.31 t/h, to achieve the required concentration at the outlet $a_{ext} \geq 95\%$ at temperatures $t_{ex} \leq 110$-115 ℃, 76÷84 m^2 of the active heat transfer surface of the apparatus will be required. It was revealed that an increase in the initial temperature by 5 ℃ and the miscella concentration by 5 % leads to a reduction in the heating surface of the apparatus by 24 %. This circumstance indicates the need for additional research to improve the technological efficiency of operating distillers, identify a reserve for increasing their specific productivity and design devices with a compact heat transfer surface based on the use of design and technological methods for intensifying heat transfer with an ascending liquid film.

References

1. Beloborodov V.V. Basic Processes of Vegetable Oil Production. Moscow: Food Industry, 1966. 478 p.
2. Industry Technology (Vegetable Oil Production): Textbook / L.A. Mkhitaryants, E.P. Kornena, E.V. Martovshchuk, S.K. Mustafayev; edited by E.P. Kornena. - St. Petersburg: GIORD, 2009. 352 p.
3. Vegetable Oil Production Technology / V.M. Kopeykovsky, S.I. Danilchuk, G.I. Garbuzova, et al.; edited by V.M. Kopeykovsky. Moscow: Light and Food Industry, 1982. 416 p.
4. Koshevoy E.P. Technological Equipment for Vegetable Oil Production: Textbook. Manual for Universities / E.P. Koshevoy. - 2nd ed., revised and expanded. - Moscow: Yurait, 2017. - 365 p.
5. Gavrilenko I.V. Equipment for the Production of Vegetable Oils. - 2nd ed., revised and expanded. - Moscow: Food Industry, 1972. - 312 p.
6. Maslikov V.A. Technological Equipment for the Production of Vegetable Oils. - 2nd ed., revised and expanded. - Moscow: Food Industry, 1974. - 439 p.
7. Production process regulations for the production of cottonseed oil and meal using the "pre-pressing-extraction" scheme at the "Ekstrakttechnik" extraction plant with a capacity of 900 tons/day for processing cotton seeds at JSC "Guliston ekstrakt yog`". Vol. 1. TR 16472899-001:2016.
8. Khudayberdiev A.A., Khamdamov M.B. On the principles of modeling the process of distillation of cottonseed oil miscella in a tubular apparatus //Collection of materials of the international scientific and industrial complex. Part 2. - Namangan: NaMITI, November 18-19, 2022 g. - pp. 257-258.
9. Artikov A.A. Processes and apparatus of food production. Mathematical modeling. Heat transfer processes. Evaporation. - Tashkent, Okituvchi, 1983. - 121 p.
10. Khudaiberdiev A.A. Intensification of the heating process of petroleum feedstock. Monograph. - Tashkent: Navroz, 2019. - 213 p.
11. Artikov A. Computer methods of analysis and synthesis of chemical-engineering systems. - Tashkent: TKTI, 2017. - 35 p.
12. Artikov A. Computer methods of analysis and synthesis of chemical-engineering systems: textbook for master's students of technological specialties. - Tashkent: Voris-nashriyot, 2012. - 160 p.
13. Kasatkin A.G. Basic processes and apparatuses of chemical engineering: Textbook for universities. - 10th ed., stereotyped, revised. Reprinted from the 1973 ed. - Moscow: OOO TID "AlyanS", 2004. - 783 p.
14. General course processes and apparatuses of chemical engineering: Textbook. In 2 books /V.G. Einstein, M.K. Zakharov, G.A. Nosov et al.; Ed. V.G. Einstein. - Moscow: Logos, 2002. - 1758 p. Book 1. - 888 p.
15. Pavlov K.F., Romankov P.G., Noskov A.A. Examples and problems in the course of processes and apparatuses of chemical engineering. Textbook for universities / Ed. P.G. Romankov. - 10th ed., revised and enlarged. - Leningrad: Chemistry, 1987. - 576 p.
16. Yusupbekov N.R., Meidman L.S., Artikov A.A. Boiling point of cottonseed oil miscella // Oil and fat industry, 1979. - No. 6. - pp. 19-21.