Modeling of Vegetable Oil Miscellaneous Drive Process in Final Distiller Spray Zone

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Abstract: This work discusses the kinetics of the separation process of a solution consisting of vegetable oil and a low-boiling hydrocarbon solvent in a distillation process. The efficiency of the distiller is affected by capital costs, energy costs, and quality characteristics of the resulting oil. The mass transfer rate depends on the nature of the phase equilibrium, mass transfer coefficient, and contact area between the phases. The issues of mathematical modeling of heat and substance exchange processes going in the spraying zone of the final distillation device of vegetable oil are presented. The influence of various factors such as initial temperature and concentration of the feed liquid, vacuum pressure, and particle diameter on the distillation process is also discussed. The process of scattering liquid in a channel sprayer is given to two zones A and B, that is, mathematical and computer models of the processes of heat and substance exchange, which are carried out by turning the liquid into a drop, and the results of the computer model are analysed.

1 INTRODUCTION

The kinetics of the separation process of a solution consisting of vegetable oil and a low-boiling hydrocarbon solvent depends on the mass transfer between the solution and the mixture of water and heated vapors of the solvent Distillers of various designs are used in oil extraction enterprises. Important indicators of distiller efficiency are capital costs, energy costs, especially costs associated with providing superheated steam to the final distiller for contact processing of mistella, and the quality characteristics of the resulting oil [1-3,17].

Capital costs in distillation equipment are roughly proportional to size and inversely proportional to throughput. The mass transfer rate depends on the nature of the phase equilibrium, is proportional to the mass transfer coefficient and the contact area between the phases. The increase in mass transfer occurs in conditions of high turbulence of one or both phases and at high speeds of their movement relative to each other [4-6, 10,11].

When a steam nozzle is used to spray the mistella in the final still, the phase contact surface is large and very high droplet flow velocities are obtained by co-flowing the superheated water vapor near the nozzle mouth. The intensity of interphase transfer can be adjusted by changing the temperature and flow rate of the water vapor supplied to the nozzle, while the flow rate of the spray liquid remains constant. Heating the oil in the still for a long time has a negative effect on its quality, but to evaporate the solvent from the surface of the droplet, it must be heated to some degree relative to the temperature corresponding to the conditions of phase equilibrium. It depends on the pressure in the evaporation zone and the concentration of the solution on the droplet surface [7,12].

The driving force of the transfer of substances from the droplet to the external vapor environment is the difference in the partial vapor pressures of the volatile component on the droplet surface and the one expelled from it. The larger the partial vapor pressure of the volatile component in the outer stream of vapor mixtures, the smaller the diffusion flux of the mass of the vaporizing component on the droplet surface. The higher the temperature and concentration of the evaporating component on the surface of the droplet, the greater its pressure near this surface. It is necessary to choose a distiller taking into account the

above factors for the technological flow of steam mixtures [8-9,16].

2 METHODS AND MATERIALS

We will consider the process of substance exchange under study conditionally divided into A and B zones.

Modeling the heat substance exchange process in zone A. Under the conditions under consideration, we accept the following system of equations to calculate the concentration process in the drop formation zone based on equation [13] and the mathematical expression characterizing the balance (1):

$$\begin{cases} G_{\mathrm{p}} = k_a F\left(a_{\mathrm{p}} - a\right) = G_0\left(1 - \dfrac{a_0}{a}\right) \\ \dfrac{G\frac{a_0}{a}\left(1-\frac{a_0}{a}\right)}{G_{\mathrm{r}}} = \dfrac{M_{\mathrm{p}}}{M_{\mathrm{r}}}\dfrac{P_{\mathrm{p}}}{P_{\text{ym}}-P_{\mathrm{p}}} \\ P_{\mathrm{p}} = f(t,a) \\ cadt + (i - ct)da - \dfrac{\alpha_V a}{G}(t_{\mathrm{r}} - t) = 0 \end{cases} \quad (1)$$

where a - solvent concentration at a given time, %; a_{p} - solvent equilibrium concentration, %; k_a - volume coefficient of heat transfer.

Results ($Q_k < \varepsilon$) of the analysis, $\alpha_V \approx 0$ it can be considered. The value of the volume coefficient of heat transfer $\left(k_{a},\mathrm{c}^{-1}\right)$ determines the efficiency of this zone.

According to the information obtained by Beloborodov V.V., the volume coefficient of heat transfer during the final distillation by spraying liquid for vegetable oil-extractive gasoline solution is 0.02 c^{-1}. Based on this, it is convenient to express the mass transfer equation through the volumes of the light volatile component that passes into the liquid and vapor phase. In this case, the drop formation zone is considered as an object with accumulated indicators (2):

$$V_{\mathrm{p}} = k_V V \frac{(a_{\mathrm{p}}-a)\tau_{\mathrm{k}}}{100}, \quad (2)$$

where V_{p} - the volume of the solvent passing into the V - vapor phase, is the total volume of the liquid phase, and τ_{k} - the time of droplet formation.

We can characterize volumes by mass costs and write:

$$\frac{G_{\mathrm{p}}}{\rho_{\text{э}}} = k_V \frac{G_0\frac{a_0}{a}(a_{\mathrm{p}}-a)\tau_{\mathrm{k}}}{\rho}\frac{}{100}, \quad (3)$$

$\rho, \rho_{\text{э}}$ - light volatile component and solution density, respectively.

According to (3) for light volatile component and mistletoe costs

$$\frac{G\left(1-\frac{a_0}{a}\right)}{\rho_{\mathrm{p}}} = k_V \frac{G_0\frac{a_0}{a}}{\rho}\frac{(a_{\mathrm{p}}-a)\tau_{\mathrm{k}}}{100}. \quad (4)$$

After some mathematical transformations, we write the (5) that characterizes the concentration of the mistletoe at the exit of the droplet formation zone:

$$a^* = \frac{100a_0 + k\frac{\rho_{\mathrm{p}}}{\rho}a_{\mathrm{p}}a_{\mathrm{k}}\tau_{\mathrm{k}}}{100 + k\frac{\rho_{\mathrm{p}}}{\rho}a_0\tau_{\mathrm{k}}}. \quad (5)$$

When calculating the currents in this zone, the values of the following indicators were obtained: according to the data of [14], the time of droplet formation is a few microseconds, so we take it to be equal to 0.03 s;

The ratio of extraction gasoline to 95% mistella density is about 7:9; multiplying it by the average time of droplet formation, we get a value of 0.023; we accept the volumetric coefficient of mass transfer in the range of 1-10. Here, only the liquid phase is assumed, not the full size of the droplet formation zone.

The studies carried out in the K model show that the intensity of the mistella concentration process by spraying in the A zone is significantly affected by the volumetric coefficient of substance delivery. In our example, the coefficient of mass transfer is 4 times larger than in [15]. The influence of temperature on the studied process is not very significant, but it affects the coefficient of mass transfer, and as such, it should also affect the studied process.

Zone B. The droplets formed in zone A fall down and concentrate by evaporating the solvent. In accordance with its hierarchical structure, the following events affect the mistella concentration process: evaporation of the solvent from the droplet; cooling of the drop due to evaporation; heating of the droplet with the vapor phase; molecular-diffusion transfer of the solvent in the droplet; enrichment of the vapor phase with solvent vapors; vapor phase temperature change.

The mathematical model of the process in this zone can be written in the form of the following system of (6):

$$\begin{cases} a_j = a_{j-1} + \left(a_{\mathrm{p}j-1} - a_{j-1}\right)\dfrac{\pi D}{4R^2}\Delta\tau \\ \dfrac{G_0}{G_{\mathrm{r}}}\left(\dfrac{a_0}{a_j} - \dfrac{a_0}{a_{\mathrm{k}}}\right) = \dfrac{M_{\mathrm{p}}}{M_{\mathrm{r}}}\dfrac{P_{\mathrm{p}}}{P_{\text{ym}}-P_{\mathrm{p}}} \\ P = (b_{11}t_{\text{м}} - b_{10})(100 - a_{\mathrm{p}}) \\ cadt + (i - ct)da = 0 \end{cases} \quad (6)$$

a_{j-1}, a_j - mistella j concentration at the entrance and exit of the site, respectively; b_{10}, b_{11} - constant coefficients for the seed-gasoline mist (at a temperature of 80-100°C and a concentration of 90-100% $b_{10} = 3,470\ kPa/°C$, $b_{11} = 0,064\ kPa/°C$,%); R - drop radius, m; D - liquid diffusion coefficient, m²/s; τ-concentration time, s.

Calculations are carried out in the following sequence:

1) Finding distribution of mistletoe concentration in different diameters of the drop depending on the time of the drop;
2) Determination of spray mistletoe concentration versus time at different initial liquid temperatures
3) Calculation of mistletoe change over time at different initial liquid concentrations
4) Determination of the effect on the ratio of open water vapor and mistletoe consumption during spray concentration for different initial liquid concentrations
5) Show the change in mistletoe concentration over time at different values of pressure (40 and 100 kPa).

The results of the research conducted in the mathematical model for different diameters of the drop are presented in the form of graphs (1-2), which indicate that the concentration efficiency decreases when the diameter of the drop increases. So when the particle diameter is 10 µm, distillation actually takes place in one tenth of a hundredth of a second. In production, distillation takes place in a few seconds when the particle diameter obtained by spraying is 80 µm in the final distillation equipment.

3 RESULTS AND DISCUSSION

The average residence time of a particle in the spray zone of the distiller is approximately 1-2.5 s. The distillation process suddenly deteriorates when the particle diameter is 0.1 mm. Curve 4 in Figure 1 corresponds to the concentration of a droplet composed of a mixture of particles larger than the indicated diameter in a uniform mass distribution. It can be seen that at the beginning of the distillation process, the relationship is characterized by a relatively large curvature, which deteriorates significantly in the later stages of the process. For the situation under consideration, it can be assumed that there are no conditions for obtaining oil of standard requirements in a typical device. This indicates that it is necessary to pay serious attention to the problem of obtaining a finely dispersed phase with a maximum diameter of the sprayed particle not exceeding 100 µm . That's why we channel the spray nozzle and we have proposed a new effective construction.

The calculation results of the influence of the initial temperature of the liquid sprayed on the distillation process are presented in Figure 2. Calculations show that with a decrease in temperature, the intensity of the distillation process also decreases, but to bring the mistella concentration to the standard requirements, the initial temperature of the feed liquid is considered to be 90 °C.
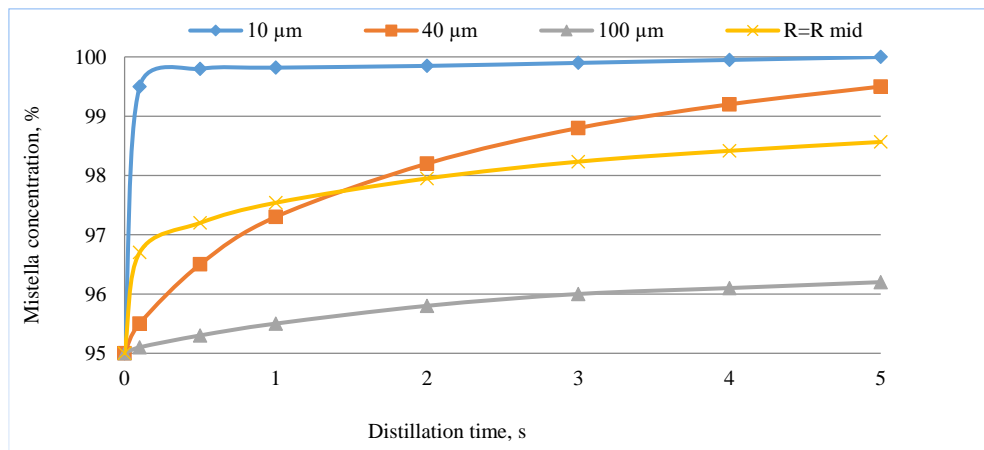

Figure 1: Variation of the mistletoe concentration depending on the drop time at different diameters of the droplet.
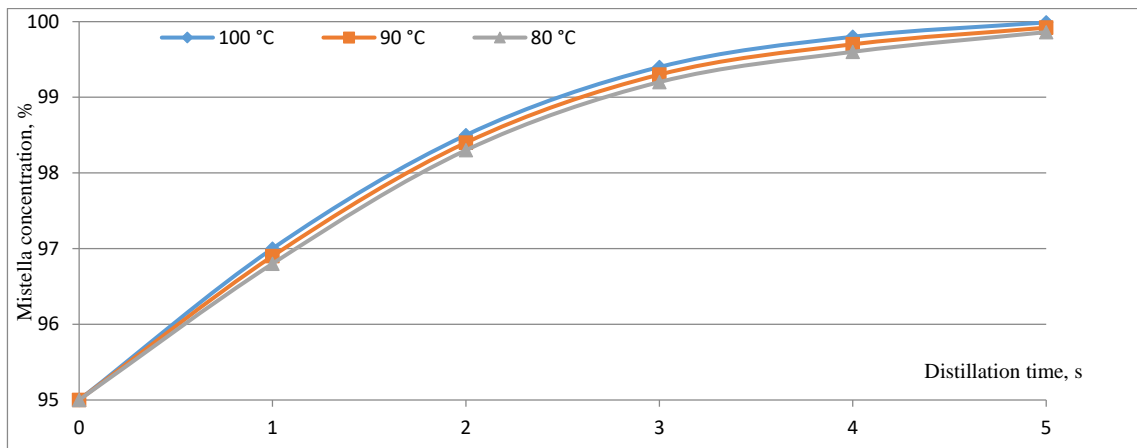
Figure 2: Changes in the concentration of micelles depending on the time of descent at different initial temperatures of the liquid.
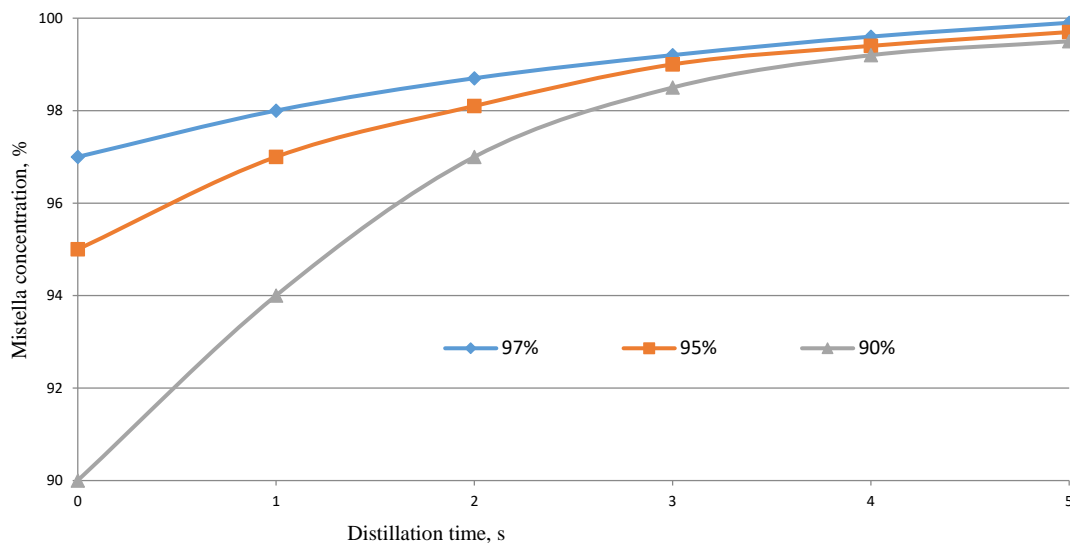

Figure 3: Changes in the concentration of mistella as a function of the time of deposition at different initial concentrations of the liquid.

Depending on the ratio of water vapor and mistletoe costs, the theoretical distribution of concentration will have its critical cost ratio for a certain value of concentration. It will be impossible to get standard oil . In practice, the consumption of water vapor should be much higher due to the uneven distribution of phases in the conditions of a complex hydrodynamic structure.

The influence of the initial concentration of the feed liquid on the distillation process is illustrated in Figure 3. It can be seen that at the end of the process,

the curves become much closer to each other, but do not merge. The difference is very noticeable, due to the slight increase in concentration at the back of the curve due to more time in the vapor phase than the liquid. This fact confirms that as the concentration of mistella in the oil increases, it becomes more difficult to drive the solvent.

When look at the Figure 4 using a vacuum of 40 kPa in the device, compared to atmospheric pressure, the process is significantly intensified.
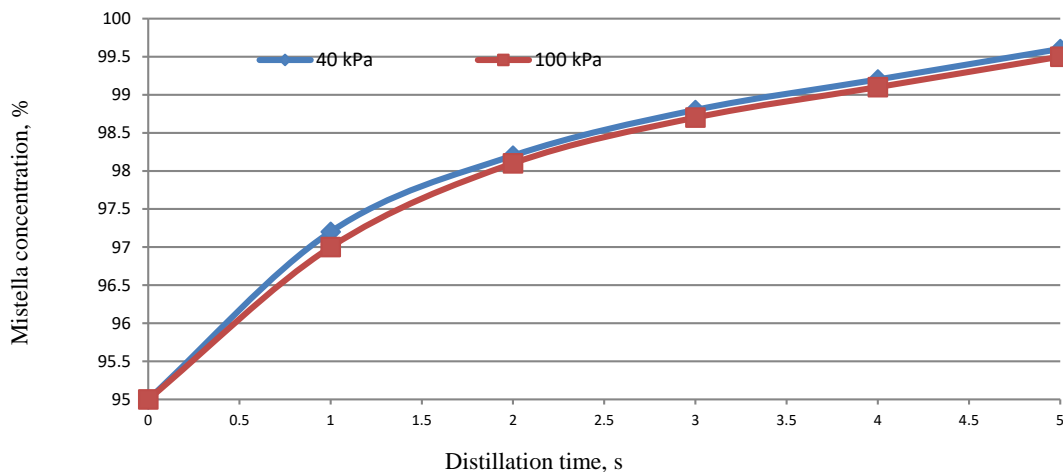
Figure 4: Using a vacuum of 40 kPa in the device.

4 CONCLUSION

A complete mathematical model of the heat substance exchange process in the spray zone of the still. Shown in the image above. The upper block represents the solution concentration zone during droplet formation. Here, a mistletoe with initial parameters is G_0, a_0, t_0 concentrated to a state with intermediate parameters . G_0^*, a_0^*, t_0^* As mentioned above, the appropriateness of the mathematical model of this zone depends on the initial temperature of the liquid. This zone is considered as an object of an ideal mixing model from the point of view of the hydrodynamic structure of a concentric flow.

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