

Simulation of a Multistage Distillation Process in a Rotary Disc Device

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Annotation: The final stage of the miscella distillation process is the stage that affects the course of the next technological stages and in many respects predetermines the quality of the product. Improvement of this process is especially important in connection with the use of fundamentally new equipment for its implementation, further increase in the efficiency of the process due to the release in this process of a new secondary product - fatty acids.

The final distillation processes for cottonseed oil miscellas and the equipment used in industrial practice for their implementation have their limitations. Further improvements in the traditional way of technological equipment may not yield the expected results in practice. Achieving significant technological results in this area requires a new approach to the distillation of cottonseed oil miscellas and further development of the theoretical and practical basis of the process, the organization of the process in new, highly efficient methods, and the development and introduction of new types of intensive equipment.

Based on mathematical modeling of the distillation process and computer study of models, methods have been determined for creating compact devices with rational design and technological parameters, reducing the consumption of structural materials used in the manufacture of distillers, saving energy resources.

In order to reduce the boiling point of the miscella during the process, taking into account the insolubility of the components of the mixture in water, high-temperature water vapor is added to its composition in an open manner as an additional component. In the final stage of the distillation process, the driving component is separated according to the equilibrium state between the liquid and vapor phases.

It is known that the boiling point of a mixture depends directly on the proportions of the components in it. The boiling point of hexane is below the C_{10} boiling point of capric acid. Therefore, as the proportion of capric acid in the mixture increases, so does its boiling point.

Taking into account the technological mode of the final distillation process, the total pressure in the system was initially taken equal to $P=10$ kPa, and then its value was increased to 20, 30, 40 kPa. A t - x - y diagram was constructed, representing the equilibrium concentrations of a mixture of free fatty acids at various temperatures and pressures that dissolve certain values of the

saturated vapor pressure of the components. As the temperature of the mixture in the process increases and the pressure in the apparatus decreases, the proportion of free fatty acids in the vapor phase increases.

One of the main accelerating factors is the multiple atomizations of the liquid phase during the stripping of cottonseed oil miscellas in an open water vapor environment. When the miscellas are scattered by means of fast-rotating discs, a new dispersed phase consisting of very fine droplets is formed. The smaller the diameter of the liquid droplets formed at this time, the greater their total surface area. As a result, the value of the contact surface between the liquid and vapor phases increases, and the processes of heat and metabolism between them accelerate. Multiple re-scattering of miscellas in the apparatus results in multiple renewals of the liquid phase.

The distillation process in the apparatus was carried out in six stages. Researches on a computer model of the process studied each stage of the device - the change in the concentration of the solvent in the liquid and vapor phase overtime on each plate, as well as the change in the concentration of free fatty acids in the vapor phase.

In a multi-stage distillation process, the concentration of the lightly volatile component in the liquid phase decreases over time, from the first stage to the next. At this time, the concentration of the light volatile component in the vapor phase gradually increases.

Keywords: final distillation, free fatty acids, miscella, caprine acid, hexane, cottonseed oil, light volatile component, rotary disc device, multi-stage process, mathematical modeling, computer model, MATLAB Simulink, t-(x,y) diagram, x,y diagram, partial pressure, equilibrium concentration, drop, plate, concentration, relative volatility coefficient

Introduction: Metabolic processes play an important role in the chemical industry and food production technologies. Such processes are based on the transition of substances from one phase to another through the contact surface of the phases[1]. In industry, various devices are used to carry out metabolic processes, in particular the distillation process. In existing devices, the processing time is long, and the energy consumption is high since the contact surface of the phases is small. This leads to an increase in product quality and the cost of the process.

During the distillation process, the flow of the liquid and vapor phases must go in the opposite direction to completely displace the solvent from the oil and increase the saturation coefficient with water vapor. These requirements are met by rotating disc distillers, in which the miscella comes from the top and the harsh water vapor from the bottom. The liquid is separated from the solvent, and the water vapor is enriched with astascin solvent vapor[2].

Denial methods: In oil extraction production, vegetable oil receives extracts and oil into a solution - extraction gasoline. Then, from the resulting solution, the volatile component of gasoline is mistakenly removed in the distillation unit of the solution - distillators. Usually, after preliminary distillation, cottonseed oil is subjected to final distillation, where residual gasoline is determined from its oil under the influence of hot water vapor at a temperature that increases 100 °C. During final distillation, fatty acids in the oil often go into the vapor phase together with gasoline. With the existing technology, the existing fatty acids are condensed together with gasoline and sent to the solution tank. The collected solution is returned to production. The rectification units developed by us make it possible to capture separate fatty acid vapors from the

vapors of the final distiller. And this is the best way to organize additional profit from oil production. Formation of a mathematical model of the process of distillation of fatty acids requires the formalization of the mathematical description of the homogeneous state of the steam-flow system[3].

Results and discussion: We are considering the issue of determining the equilibrium state of extraction gasoline and fatty acid during final distillation. Fatty acids have different levels of carbon at different levels of condensation in barometric condensers. Of the fatty acid found in cottonseed oil, capric acid is the more volatile. For this, to determine the amount of capric acid in the secondary paralysis after the final distillation, we determine the homogeneity of the capric acid system and the extraction of gasoline. Extraction gasoline is mainly composed of hexane, which is why it is sometimes called technical hexane. It has the formula C_6H_{14} and capric acid has the formula $C_{10}H_{20}O_2$ [4].

$$y = \frac{\alpha x}{1 + (\alpha - 1) x} \quad (1)$$

where x and y are the molar fractions of the low-boiling component in the liquid and equilibrium vapor; $\alpha = p_1 / p_2$ - coefficient of relative volatility.

Temperature, °C	Saturated vapor pressure, mm Hg		Temperature, °C	Saturated vapor pressure, mm Hg	
	Hexane, p_1 , mmHg	Capric acid, p_2 , mm Hg		Hexane, p_1 , mmHg	Capric acid, p_2 , mm Hg
60	570	0.0174	170	8073	24.7424
70	790	0.0426	180	9561	38.6545
80	1068	0.0982	190	11231	58.8565
90	1416	0.2145	200	13099	87.4844
100	1844	0.4463	210	15157	127 1305
110	2365	0.8867	220	17430	180.8553
120	2990	1,6886	230	19922	252.1897
130	3730	3.0922	240	22639	345 0957
140	4596	5.4590	250	25589	463 9083
150	5602	9 3172	260	27021	570.0585
160	6757	15 4079			

The table shows the equilibrium states of pure vapors of hexane and acid. To calculate the value of the effective relative volatility, the equilibrium state was determined for different temperatures of distillation with an inert gas. From the equilibrium table, you can determine α , for example, at a temperature of 60 °C $\alpha = 32758$, at a temperature of 260 °C $\alpha = 47.4$.

At level (1) to determine the cost at level (1), a formalized computer model on the wall of the MATLAB Simulink program. Figure 1[5].

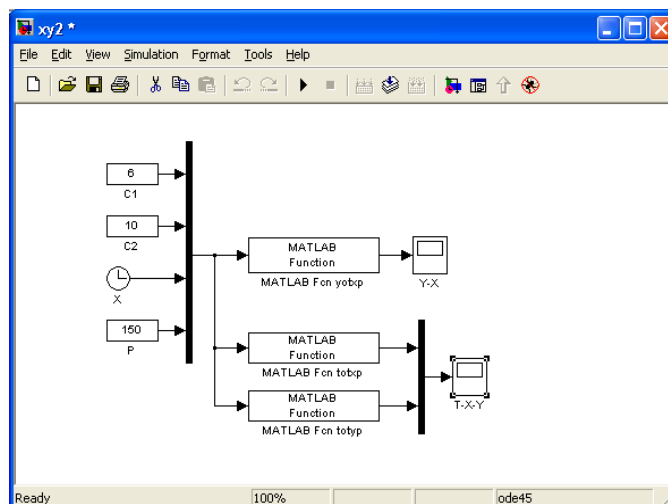


Figure: 1

In a two-component mixture at the same temperature, the each component has a different saturated vapor pressure. To construct $t(x, y)$ diagrams, the following formula is used[4]

$$x = \frac{P - p_2}{p_1 - p_2} \quad (2)$$

and

$$y = \frac{p_1 x_1}{P} \quad (3)$$

where P -the total pressure of the mixed vapor in the system; p_1 and p_2 - stability of saturated vapors of pure components a and b at a given temperature.

The final distillator is currently exported with a residual pressure in the apparatus in the limit of 20 kPa (150 mm Hg) at a temperature of 100-110°C. For this case, the diagrams shown in figure 2 were obtained on a computer model. Analysis of the diagram shows a small fraction of liquid acid in the vapor phase. Proportion of fatty acid increases with increasing vacuum depth and process temperature.

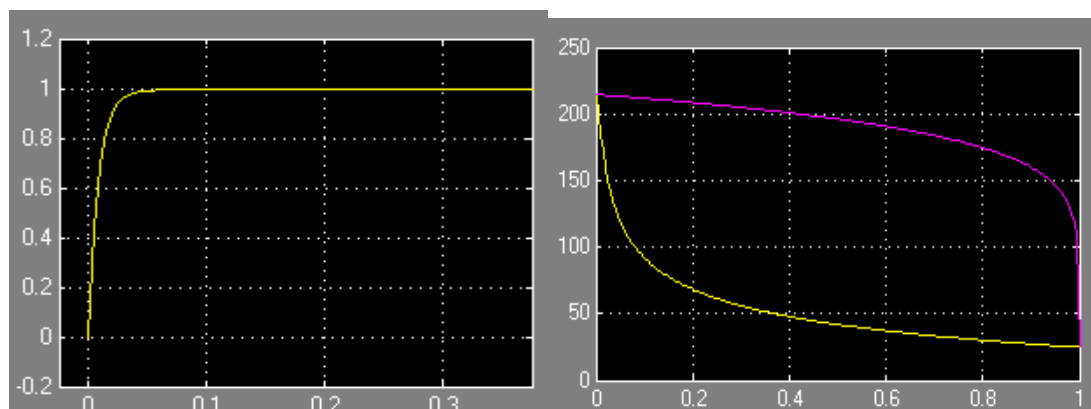
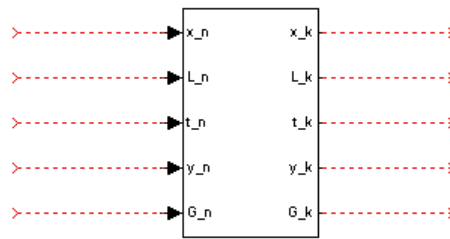


Figure: 2

To simulate the thermal and metabolic processes occurring in a multi-stage device, it is advisable to first simulate it for a one-stage process. In this case, one step is considered as an ideal mixing model. Thermal and metabolic processes occurring in one stage can be described as a

system as follows [6]:



where x_n and x_k are the initial and final concentrations of the light volatile component in the liquid phase, respectively, in kmol;

L_n and L_k - initial and final flow rate of the liquid phase, respectively, kg / s;

y_n and y_k are the initial and final concentration of the highly volatile component in the vapor phase, respectively, kmol;

G_n and G_k - initial and final consumption of the vapor phase, respectively, kg / s;

t - the temperature of the liquid phase, K.

The change in the concentration of the light volatile component in the liquid phase with time can be expressed by the following differential equation:

$$\frac{dx}{d\tau} = \frac{L_n x_n - L \cdot x - K_x F (x - x^*)}{V_L \rho_L}$$

Under the action of centrifugal force, the liquid is thrown to the edge of the device in the form of a parallel curtain of tiny droplets. The contact surface between the liquid and vapor phases is formed between water vapor and liquid droplets supplied from the bottom of the device.

The number of droplets formed when liquid is sprayed onto droplets of diameter d_m during the metabolic phase is determined by the expression

$$n = \frac{V}{V_m} \tau = \frac{6V\tau}{\pi d_m^3};$$

where V - the volumetric flow rate of the sprayed liquid, m^3/s ; V_m - drop volume, m^3 ; τ - reset time of drop, sec.

The contact surface F of the phases is equal to the surface area of the drop F_m multiplied by the number of drops n

$$F = F_m n = \frac{6V\tau}{d_m};$$

It can be assumed that the drop is trying to move relative to the edge circle of the disk. In this case, the length of the drop path to the device wall is equal to the following expression

$$l = \sqrt{R^2 - r^2}$$

where- R and r are the radii of the device body and disk, respectively, m.

For practical calculations, the droplet speed is taken equal to 80% of the rotation speed of the disk edge. Thus $\tau = \sqrt{R^2 - r^2} / (0.8u)$

$$F = 7.5 \frac{V \sqrt{R^2 - r^2}}{u d_m};$$

Equation of recovery of the liquid phase due to the evaporation of highly volatile components

$$L = L_n - \sum \Delta L$$

The amount of light volatile components evaporated from the liquid phase is:

$$\Delta L = \frac{L_n(x_n - x)}{1 - x}$$

The concentration of the light volatile component in the vapor phase is as follows:

$$y = \frac{G_n y_n + \Delta L}{G}$$

Equation of the increase in the vapor phase as a result of the addition of light volatile components of the liquid phase to the vapor phase

$$G = G_n + \sum \Delta L$$

To determine the equilibrium concentration of a light volatile component, it is necessary to determine its partial pressure. According to Dalton's law, the total vapor phase pressure is equal to the sum of the partial pressures of the components on the solution.

$$P_{full} = P_{sol} + P_{wat} + P_{oil}$$

The partial vapor pressure of cottonseed oil is low, because $P_{oil} = 0$.

The partial vapor pressure of the extraction gasoline is found from the following equation:

$$p = \frac{\frac{G \cdot y}{\sum \frac{G_i y_i}{M_i}}}{M} P_{full}$$

The equilibrium concentration can be determined from the partial pressure:

$$x^* = \frac{p}{(b_{11}t - b_{10}) \cdot 100}$$

Change in the amount of heat in the liquid phase

$$\frac{dQ_{ms}}{d\tau} = q_{ms} - q_{oil} - q_{sol} - q_{wat}$$

where q_{ms} - the amount of heat supplied with the miscella, J; q_{oil} - the amount of heat lost by the finished oil, J; q_{sol} - the amount of heat transferred to the vapor phase due to the extraction of gasoline molecules, J; q_{wat} - the amount of heat transferred from the vapor phase to the liquid, J.

The change in the amount of heat in the liquid phase is found from the following expression

$$Q_{ms} = m_{ms} c_{ms} t_{ms}$$

where m_{ms} - the amount of miscella, kg (can be calculated as a constant amount over time for a certain flow rate of live steam); c_{ms} - the specific heat of the miscella, J / (kg * K); t_{ms} - the temperature of the miscella, K.

The amount of heat that miscella gives is determined by the following expression:

$$q_{ms} = G_{ms} c_{ms} t_n$$

The amount of heat lost by the finished oil is determined from the following expression

$$q_{oil} = G_{oil} c_{oil} t_{\kappa}$$

or by calculating the material balance we obtain the following

$$q_{oil} = G_{ms} \frac{x_n}{x_k} c_{oil} t_k$$

where c_{oil} - the heat capacity of the oil, J / kg (taken equal to c_{ms}); t_k - the temperature of the finished oil, K.

The amount of heat transferred to the vapor phase by the produced gasoline

$$q_{sol} = G_{sol} i_{sol}$$

where i_{sol} - the enthalpy of gasoline vapor extraction, J/kg.

The amount of heat transferred from the vapor phase to the liquid phase

$$q_{wat} = \alpha F (t_{wat} - t_{ms})$$

where α - heat transfer coefficient, W / (m²*K); F - total surface area of drops, m²; t_{wat} - vapor phase temperature, K.

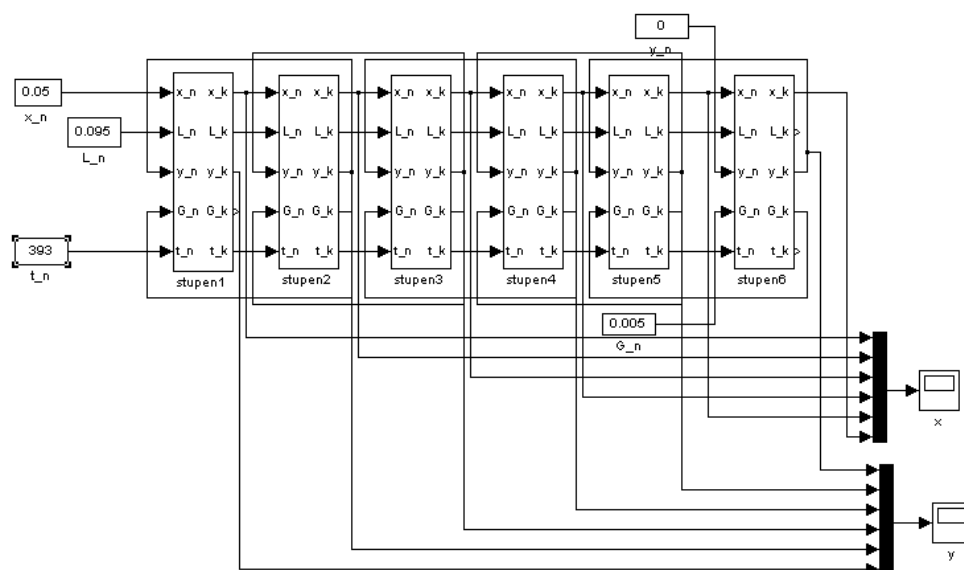
The change in the temperature of the liquid phase with time is represented by the following differential equation:

$$\frac{dt_{ms}}{d\tau} = \left(G_{ms} c_{ms} t_{ms} - G_{ms} \frac{x_{ms,n}}{x_{ms,k}} c_{ms} t_{ms} - G_{sol} i_{sol} + \alpha F (t_{sol} - t_{ms}) \right) / V_L \rho_L c_L$$

The above mathematical equations are combined into a single system and form a one-stage mathematical model:

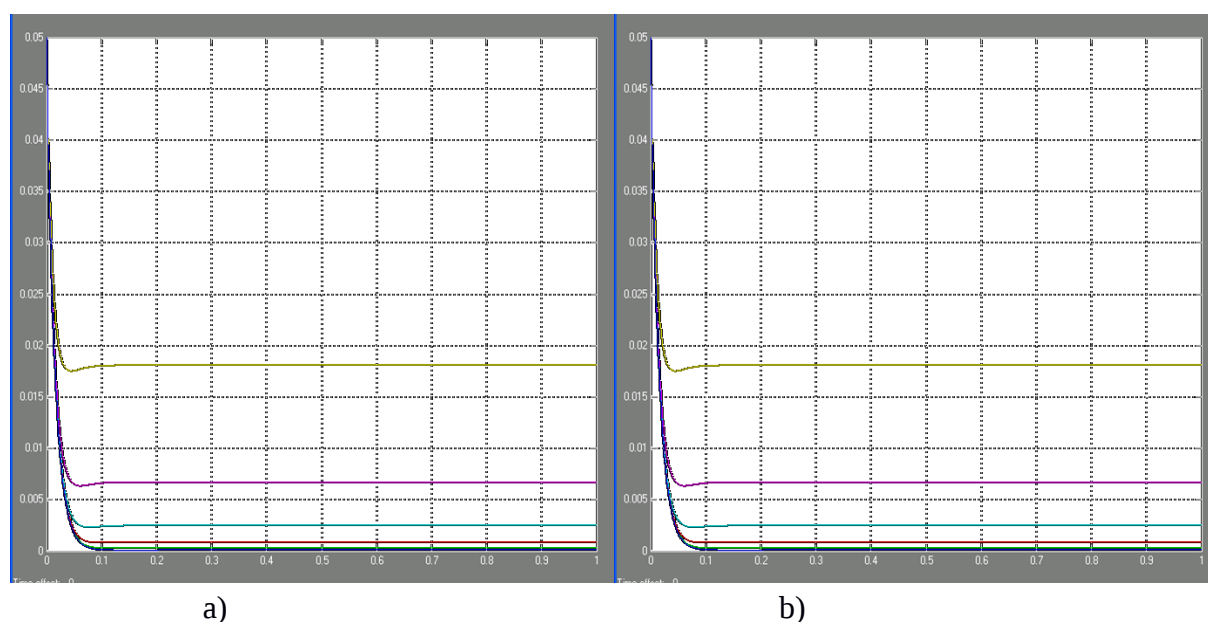
$$\left\{ \begin{array}{l} \frac{dx}{d\tau} = \frac{L_n x_n - L \cdot x - K_V V_L (x - x^*)}{V_L \rho_L} \\ L = L_n - \sum \Delta L \\ \Delta L = \frac{L_n (x_n - x)}{1 - x} \\ y = \frac{G_n y_n + \Delta L}{G} \\ G = G_n + \sum \Delta L \\ x^* = \frac{p}{(b_{11} t - b_{10}) \cdot 100} \\ p = \frac{G \cdot y}{\sum \frac{G_i y_i}{M_i}} P_{full} \\ \frac{dt_{ms}}{d\tau} = \left(G_{ms} c_{ms} t_{ms} - G_{ms} \frac{x_{ms,n}}{x_{ms,k}} c_{ms} t_{ms} - G_{sol} i_{sol} + \alpha F (t_{wat} - t_{ms}) \right) / V_L \rho_L c_L \end{array} \right.$$

A computer model of the system of equations for one stage of the distillation process has been developed. The input and output values of each phase are available, and we get the output values by entering the input values of the first phase. The outputs of the first stage are the inputs of the second stage, and the outputs of the previous stage are the inputs of the next stage. Since our device is a six-stage, the graph shows the time-varying concentrations of the liquid and vapor phases at each stage - the plate.



The figure shows the change in the concentration of the light volatile component x solvent in the liquid phase and in the vapor phase.

For calculation using a computer model of the distillation process, we will make the following designations: the initial liquid flow to the first stage of the disk rotor device - the first plate $L_n = 0.095$; $x_n = 0.05$; $G_n = 0.005$; $y_n = 0$; $t_n = 393$.



Conclusions

Analysis of the simulation results shows that distillation process ksingle stage rotorwhen all stages of disk equipment are given the same initial values of the process parameters, the concentration of the light volatile component in the liquid phase decreases as the transition from the first phase to the next. The concentration of highly volatile components in the vapor phase gradually increases. Over time, the concentration change slows down as the process approaches the steady state.

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