Modeling the film zone of the continuous deodorator

S G Marchenkova, I V Krotova, A S Shchitnikov, O Ya Kolman, G V Ivanova and S A Khudonogov
Siberian Federal University, Svobodny prospect, 79, Krasnoyarsk, 660041, Russia

E-mail: mart293@inbox.ru

Abstract. The article proposes a model of the film zone of a vegetable oil deodorizer. General expressions are obtained for the analysis and calculation of deodorization and distillation neutralization of oils in the film. The relations obtained in this work can be applied to multicomponent systems. The model can be used in particular to improve the energy efficiency of deodorization plants.

1. Introduction
Deodorization is the final stage of the refining process, the purpose of which is to remove various impurities from crude oils. Impurities include substances that are formed in oilseeds during their ripening and as a result of technological operations preceding refining. Impurities can be both undesirable (harmful) and useful in terms of the quality of the final product. Thus, the task of refining in general and deodorization in particular is to achieve the maximum possible degree of elimination of harmful impurities from the processed product and the maximum preservation of useful substances in the final product [1, 2].

In the processing of oils used in the production of canned food and the production of margarine products, a prerequisite is to obtain unallocated, that is, without taste and odor, transparent, light-colored oils [3]. In particular, increased requirements for the feedstock are presented in the production of mayonnaise [4]. The decisive role in achieving this goal belongs to the deodorization process [5].

The desire to reduce technological operations associated with the influence of temperature, oxygen, chemicals and other factors on the glyceride portion of fats indicates the advisability of combining the deodorization process with the removal of free fatty acids (distillation neutralization). The technology of alkali-free removal of free fatty acids (alkali-free refining) is very promising, as it eliminates the use of alkaline solutions, reduces fat loss, allows to save fatty acids in their native form, and reduces the pollution of wastewater [6].

The most important technological parameters that determine the efficiency of the process and the quality of the finished product are: deodorization temperature (distillation neutralization); residual pressure in the deodorizer; temperature and quantity of hot steam supplied to the deodorizer; process time. The conditions of contact of hot steam with deodorized fat are essential [7].

Substances distilled off during deodorization (distillation neutralization) are very diverse in their content in fat and composition of saturated and unsaturated fatty acids, hydrocarbons, glycerides of low molecular weight fatty acids, di- and monoglycerides, ketone aldehydes, alcohols, etc.) [6].

Along with purely physical phenomena (distillation of volatile components; condensation of distilled substances on the walls of the deodorizer; entrainment of neutral fat in the form of droplets with steam;...
distillation of triglycerides with at temperatures above 523 K) during deodorization and distillation neutralization, various chemical reactions can also occur that affect the quality of the finished product.

The intensity of the physical and chemical phenomenon during deodorization (distillation neutralization) depends on the initial state of fat, technological modes and process parameters, its organization and equipment design [8].

In addition to the quality indicators of the finished product, the effectiveness of deodorization (distillation neutralization) is largely determined by the level of neutral fat loss during the process, energy costs, equipment performance.

The temperature factor, in addition to a significant effect on the quality of the product, largely determines other characteristics of the effectiveness of deodorization plants. [9, 10].

The aim of this work is to solve the problem of optimizing deodorization (distillation neutralization) in the film zone of the apparatus, taking into account the variability of the equilibrium concentration of the distilled component in the liquid phase along the height of the film zone.

2. Materials and research methods

Under these conditions, it seems relevant to build mathematical models of deodorization (distillation neutralization) that are quite general in terms of applicability to various types of the initial product, reflecting the design features of the most common types of deodorizers, which allow varying various technological parameters of the process during the computational experiment. It is a question of both continuous apparatuses and periodic apparatuses that have not lost their significance. Also, the relevance of constructing a mathematical model of the dependences of optimized parameters on selected factors for viscous environment is noted in [5].

The temperature factor is one of the contributors to the intensification of the distillation process, which in turn can help reduce the duration of the thermal effect on the fat in the deodorizer and increase the performance of distillation plants.

The aim of this work is to solve the problem of optimizing deodorization (distillation neutralization) in the film zone of the apparatus, taking into account the variability of the equilibrium concentration of the distilled component in the liquid phase along the height of the film zone. The benefits of deodorization in the film are largely due to the short duration of fat in it, that is, the minimum time for thermal exposure to the product. The rationality of the combination of film and cube zones in the deodorizer is noted in [6-8].

At the same time, the kinetic laws of deodorization (distillation neutralization) in the film zone are not well understood. In particular, earlier deodorization models were based on the assumption that the equilibrium concentration of the distilled component in the liquid phase is constant over the height of the film zone, which significantly reduces the accuracy of the process description.

When formulating the problem, the following initial relations were adopted.

The equation of material balance for the distilled component.

\[ y = \frac{G}{L} \cdot x + \frac{L \cdot y_k - G \cdot x_n}{L} \]  \hspace{1cm} (1)

Equations of phase equilibrium:

\[ y_p = P_{AP} \cdot \frac{x}{P_p} \]  \hspace{1cm} (2)

\[ x_p = P_p \cdot \frac{y}{P_{AP}} \]  \hspace{1cm} (3)

Kinetic equation of distillation:

\[ \frac{dx}{d\tau} = -\beta_{XP} \cdot (x - x_p) \]  \hspace{1cm} (4)

Here: \( G, L \) – molar flow rates of the liquid and vapor phases; \( y, x_p, x_n \) – molar concentration of the distilled-off component in the vapor phase (current, equilibrium, final); \( P_{AP} \) – molar concentration of the distilled component in the liquid phase (current, equilibrium, initial); \( P_{AP} \) – pressure of the pure distilled
off component at the deodorization temperature; \( P_P \) – is the total pressure in the film zone; \( \tau \) – time; \( \beta_{XP} \) – coefficient of the kinetic equation of distillation.

The solution of system (1)-(4) was obtained in the following dimensionless form:

\[
\bar{x} = \exp\left(\frac{K_{AP}}{K_\mu} \cdot K_{TP}\right) \times \left(1 - \frac{K_{AP}}{K_\mu} \exp\left(\frac{K_{AP} - 1}{K_\mu} \cdot K_{TP}\right)\right)^{-1} + \frac{K_{AP}}{K_\mu} \exp\left(\frac{K_{AP} - 1}{K_\mu} \cdot K_{TP}\right)
\]

The entered dimensionless quantities are decrypted as follows:

\[
\bar{x} = \frac{x}{x_n}
\]

\[
K_{AP} = \frac{P_P}{P_{AP}}
\]

\[
K_\mu = \frac{L}{G}
\]

\[
H_P = \frac{z}{H_P}
\]

\[
K_{TP} = \frac{\beta_{XP} \cdot \rho \cdot H_P}{G}
\]

\[
K_{XY} = \frac{y_n}{x_n}
\]

where: \( \rho \) – is the density of the liquid phase (fat); \( H_P \) – the height of the film zone; \( y_n \) – is the initial concentration of the distilled off component in the vapor phase; \( z \) – is the coordinate of the point under consideration along the height of the film zone (the origin corresponds to the upper point of the film zone); \( G \) – is the mass flow rate of the liquid phase (oil) per unit length of the wetted perimeter; \( \delta \) – is the thickness of the liquid film (oil).

The film thickness of the flowing liquid (oil) in accordance with the recommendations [5] can be calculated by the following formulas:

for laminar mode

\[
\delta = \sqrt{\frac{3 \mu G}{\rho^2 g}}
\]

for wave mode

\[
\delta = 0.93 \cdot \sqrt{\frac{3 \mu G}{\rho^2 g}}
\]

To calculate the final concentration of the component to be distilled off in the liquid phase (at the end of the film zone), it is sufficient to take \( H_P \) equal to unity in the ratio (9). The expression for the final concentration will take the form:

\[
\bar{x}_k = \frac{\frac{K_{AP}}{K_\mu} \cdot K_{AP} \cdot K_{XY} \left(1 - \exp\left(\frac{1 - \frac{K_{AP}}{K_\mu} \cdot K_{TP}}{K_{AP} \cdot K_{XY}}\right)^{-1}\right) - \frac{K_{AP}}{K_\mu} \exp\left(\frac{1 - \frac{K_{AP}}{K_\mu} \cdot K_{TP}}{K_{AP} \cdot K_{XY}}\right)^{-1}}{\frac{K_{AP}}{K_\mu} \cdot \exp\left(\frac{1 - \frac{K_{AP}}{K_\mu} \cdot K_{TP}}{K_{AP} \cdot K_{XY}}\right)^{-1}}
\]

As it follows from [2], the most effective from the point of view of intensification is the wave mode of film motion. At zero concentration of the distilled component in the vapor phase, the dimensionless final content of the component in the liquid in accordance with (14) will be.
\[ \bar{x}_k = \frac{\frac{K_{AP}}{K_{\mu}} - 1}{\frac{K_{AP}}{K_{\mu}} \exp\left(\frac{1}{1 - \frac{K_{AP}}{K_{\mu}}} K_{tP}\right)} \]  

For \( \frac{K_{AP}}{K_{\mu}} = 1 \) expression (15) is indefinite and the quantity \( \bar{x}_k \) cannot be found in this case. In this regard, a separate solution to the system (1)-(4) was obtained for \( \frac{K_{AP}}{K_{\mu}} = 1 \). When searching for a solution, it was taken into account that in this case the angles of inclination of the equilibrium line and the working line to the abscissa axis are the same, and, therefore, the driving force of mass transfer along the film zone does not change. Thus, the change in the zone is linear. The solution for this case is as follows:

\[ \bar{x} = \frac{(K_{AP} K_{XY} - 1) K_{lP}}{K_{lP} + 1} \bar{H}_P + 1 \]  

Expression (16) allows you to calculate the concentration of the distilled component in the liquid in the film zone \( \frac{K_{AP}}{K_{\mu}} = 1 \).

For the final concentration of the distilled component in the film zone, from (16) we easily obtain:

\[ \bar{x}_k = \frac{K_{AP} K_{XY}}{K_{lP} + 1} \]  

Finally, at zero initial concentration of the distilled component in the vapor phase, we have

\[ \bar{x}_k = \frac{1}{K_{lP} + 1} \]  

The obtained solution of the problem (14) and the initial relations (1)-(4) allow us to find the expression for the saturation coefficient of the vapor phase by the distilled component:

\[ \bar{y}_k = \bar{y}_r = \frac{K_{AP}}{K_{\mu}} \left(1 - \bar{x}_k\right) + K_{AP} K_{XY} \]  

3. The discussion of the results

It should be noted that most of the existing models and methods for calculating deodorization (distillation neutralization) are focused on the process that takes place at constant technological parameters (temperature, residual pressure, consumption of hot steam). At the same time, studying the process with variable technological parameters is catching attention. Variation in process parameters may be useful to improve process efficiency and quality of finished product.

The resulting relations: (5), (14)-(19) can serve as the basis for the analysis and calculation of deodorization and distillation neutralization of oils in the film. Expressions (5), (14), (16), (17), (19) can also be used to calculate the film zone of a combined continuous deodorizer, including film and cube zones. In the latter case, the listed expressions should be an integral part of the general model of the combined apparatus.

4. Conclusion

The relations obtained in this work can also be applied to multicomponent systems if the concentration of the components to be distilled off in the liquid phase and vapor phase is low. In this case, expressions of the type (5), (14)-(19) can be written for each component of a multicomponent system. The combination of these expressions forms a mathematical model of the distillation of a multicomponent system.

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