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**ORIGINAL RESEARCH PAPER**

# KINETICS OF EDIBLE OILS PHYSICAL REFINING

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**Abstract:** Physical refining of edible oils is a valuable industrial processing which removes the minor compounds without chemical reagents involvement, based on the selective distillation process of the volatile compounds with high pressure steam at temperatures below 200 °C. Efficient removal of the minor compounds, which are considered as impurities in refined edible oils, is realized in the industrial practice both with the distillation and adsorption operation in the physical refining process.
The paper presents the kinetics equation involved in a new optimization algorithm used to estimate the time-temperature dependency in the selective distillation process and adsorption kinetics equation.

**Keywords:** *edible oils, physical refining, distillation, adsorption*

## INTRODUCTION

The oils refining objective is to remove completely all the minor compounds which are present in the crude oil: free fatty acids, peroxides, phospholipides, pigments, water, heavy metals and all the insoluble impurities which affect both the commercial quality and the shelf life [1]. The fractionating distillation and the complex adsorption of the minor compounds are the two main principles of oils purifying in the physical refining industrial processing [2]. The bleaching with activated earth agent removes the trace metals, peroxides, pigments and the secondary products of oxidation [3].
The mass transfer equation of adsorbed compounds to the surface of the adsorbing agent described the dynamics of the process until the equilibrium isotherm is reached [4].
An optimized algorithm for the modeling of the heat transfer process in the fractionating distillation taking into account the resistance to heat transfer in order to calculate the heat transfer coefficients is proposed for the industrial processing.

## ANALYTICAL MODEL CONSTRUCTION

In the model system, we consider the oil mass as a conglomeration of spherical oil particles and the fact that the injection of the high-pressure steam is realized into the atomized oil [5, 6].
The Incropera equation describes the heat diffusion for spherical particle:

$$\frac{1}{\alpha}\cdot\frac{\partial T}{\partial t}=\frac{2}{r}\cdot\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial r^2} \tag{1}$$

where:
α - thermal diffusion coefficient ($m^2 \cdot s^{-1}$);
$T$ - spherical particle temperature (K);
$t$ - duration of the heat transfer (s);
$r$ - spherical particle radial position (m).
The resistance to heat transfer is described by equation (2):

$$\frac{T-T_\infty}{T_0-T_\infty}=\sum_{i=1}^{\infty}C_i\exp(-\zeta_i^2\cdot \mathrm{Fo})\frac{1}{\zeta_i r^n}\sin\zeta_i r^n \tag{2}$$

where:
$T_\infty$ - mass oil temperature (K);
$T_0$ - initial atomized oil temperature (K);
$C_i$ - coefficient of heat transfer equation (dimensionless);
$\zeta_i$ - coefficient of Biot equation: $\mathrm{Bi}=\bar{h}\frac{R}{\lambda}$ (dimensionless);
$\lambda$ - thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$);
R - atomized particle radius (m);
$\bar{h}$ - heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$);
Fo - Fourier Number: $\mathrm{Fo}=\frac{\alpha t}{R^2}$ (dimensionless);
$r^n$ - atomized particle radius at the $n$ distance (m).

In the optimized algorithm for the determination of heat transfer coefficients $\bar{h}$ we can model the time-temperature distillation curves in the physical refining process.
In the oils purification with adsorbents (bleaching) the kinetics of the pigments diffusion from oil mass into the active surface of bleaching agent is described by a Kadirvelu linear regression equation (3):

$$-\ln\frac{C}{C_i} = k\frac{\tau}{V} \tag{3}$$

where:
$C$ - concentration of vegetal absorbable compounds (pigments) in oil, at time $\tau$ (μmol·mL$^{-1}$);
$C_i$ - initial concentration of vegetal absorbable compounds (pigments) in oil (μmol·mL$^{-1}$);
$k$ - total diffusion mass transfer coefficient (mL·min$^{-1}$);
$\tau$ - bleaching time (min);
$V$ - volume of the oil batch (mL).
The bleaching capacity of the adsorbent agent characterizes the purifying industrial performance of activated earth:

$$CA = \left(C_i - C_\tau\right)\cdot\frac{V}{A} \tag{4}$$

where:
$CA$ - adsorption capacity of bleaching agent (μmol·g$^{-1}$);
$C_\tau$ - the oil pigments concentration at the $\tau$ moment (μmol·mL$^{-1}$);
$A$ - adsorbent dose (g).
The purifying capacity is active until the saturation or inactivation of the active earth surface occurs, when the bleaching effect is stopped and the separation of the phases is imposed.
In the particular case of the intramolecular diffusion, the Kadirvelu linear regression equation is described by the equation (5):

$$\frac{A}{V}\cdot CA = k_i\tau^{0.5} \tag{5}$$

where:
$CA$ - adsorption capacity at time $\tau$ (μmol·g$^{-1}$);
$k_i$ - the intramolecular diffusion coefficient (μmol·mL$^{-1}$·min$^{-0.5}$).

## NUMERICAL MODEL

The energy balance model for simulating the heat transfer from high pressure steam to atomized vegetable oil is described in the equation (6), which permits the construction of the numerical algorithm for the time-temperature description of the physical refining.

$$T_{i+1} = T_i + K\cdot F\cdot\left(T_S - T_i\right)\cdot\varphi_P\cdot\frac{\Delta\tau}{M_O\cdot c_O + M_D\cdot c_D} \tag{6}$$

where:

$T_i$ and $T_{i+1}$ - oil temperature at the beginning and at the end of each numerical modeling time step (K);
$K$ - overall coefficient of heat transfer from the heating steam to the processed oil ($W \cdot m^{-2} \cdot K^{-1}$);
$F$ - heat transfer surface ($m^2$);
$T_s$ - steam temperature (K);
$\varphi_P$ - external heat losses coefficient (dimensionless);
$\Delta\tau$ - discrete interval of time used as a computing time step (s);
$M_O, M_D$ - oil mass and deodorization apparatus mass, respectively (kg);
$c_O, c_D$ - specific thermal capacity of the oil processed and of the apparatus material, respectively ($J \cdot kg^{-1} \cdot K^{-1}$).

The modified equation of Bailey (7) permits the calculation of the necessary steam-stripping agent:

$$S = \frac{41}{\mu} \cdot \frac{M_O}{\psi} \cdot \frac{p_a}{p_s} \cdot \lg \frac{a_i}{a_f} \tag{7}$$

where:
$S$ - mass consumption of direct stripping steam (kg);
$\mu$ - average molecular mass of oil triglycerides (Da);
$\psi$ - vaporization efficiency: $\psi = 0.5,\ldots,0.8$ (dimensionless);
$p_a$ - absolute process pressure in the apparatus (Pa);
$p_s$ - vapor pressure of $i$ component (Pa);
$a_i$, $a_f$ - initial and final mass concentration of the volatile component at the beginning and at the end of the distillation, respectively (%).

The ratio between $a_i$ and $a_f$ is the deodorization efficiency, named $E$ ratio (%):

$$E = \frac{a_i}{a_f} \tag{8}$$

The $E$ ratio imposed the time of the distillation process, until 99.98% of the volatile undesirable compounds from oil are removed:

$$\tau = \frac{41 M_O \cdot p_a \cdot \lg E}{\mu \cdot \psi \cdot p_s(T) \cdot \varphi_D} \tag{9}$$

where:
$\varphi_D$ - mass flow of direct stripping steam (kg/s).

## CONCLUSION

The $E$ ratio is an engineering tool for evaluating the efficacy of distillation process in the physical refining. The numerical model constructed for conducting the industrial plants of vegetable oils refining automatically select the optimized values of process parameters, such as process duration, temperature conditions, process pressure, and mass flow of stripping steam and heating surface of deodorizators.

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