THE MATHEMATICAL MODEL OF EDIBLE OILS PHYSICAL REFINING

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Abstract : A differential vaporization model is proposed in the present research paper in order to simulate the batch physical refining and/or deodorization process used in the vegetable oil industry.
The fractionate distillation based on the differential vapor–liquid equilibrium of oil systems and the steam entrainment of distillate compounds process are mathematically designed in a differential equation for the vapor pressures and activity coefficients.

Keywords: *edible oils, physical refining, deodorization, mathematical modeling*

INTRODUCTION

Edible oils physical refining is an industrial technology which is applied in order to remove free fatty acids (FFA), odor & flavor constituents from the degummed and blanched oils. The deodorization is conducted in protective technological conditions, under deep vacuum and at high temperature (1 – 2 mm Hg, 185 – 195 °C, max. 130 minutes in the continuous process, and 1 – 6 mm Hg, 210 – 274 °C, 180 – 480 minutes in the batch process) and the separation of the distillated compounds with deaerated

steam [1]. The process is based on the large differences between the volatility of the oil basis and the majority of the minor compounds [2 - 3].
The vapor–liquid equilibrium of these oil systems are described by equations for vapor pressures [4] and activity coefficients [4 - 5]. The simulation in order to quantify and characterize the composition of the deodorization distillate is realized in correlation with the technological routine and oil quality (Table 1).

Table 1. *The quality characteristics of Soya deodorized oil [6]*

Quality characteristics	Soya oil before deodorization (blanched oil)	Soya oil deodorized
FFA, %	0.05 – 0.08	0.02 – 0.03
Peroxide value, mEq/kg	0 – 0.2	0
Cold test, h	26 – 50	26 – 50
AOM (100 mEq/kg),h	25 – 36	25 – 36
Soap, ppm	0	0
Phosphorus, ppm	0	0
Iron, ppm	0	0
Copper, ppm	0	0
Iodine value, mg/g	129 – 131	129 – 131
Gardner Color index	4 – 5	0 – 1
Water, %	0	0

Chemical interactions, vaporization effect and the separation of the distillated compounds with deaerated sparging steam are not considered in the simulation.
Commercial software (Aspen Plus®, HYSYS®, PRO/II®) is used for complex multicomponent biological systems [7]. The procedure proposed by Ceriani and Meirelles for calculating vapor pressures and VLE of multicomponent oil systems allows the simulation of different processes within the vegetable oil system.
A comparative analysis of the mathematical models, which can provide a valuable simulation of the batch-type refining and deodorization, is the main objective of the present research.

COMPARATIVE ANALYSIS AND DISCUSSIONS

The vapor pressure equation and the thermodynamic approach of Ceriani and Meirelles [4] for VLE model is described by equation (1):

$$y_i \cdot P = \gamma_i \cdot x_i \cdot P_i^{vp} \cdot \vartheta_i \tag{1}$$

with:

$$\vartheta_i = \frac{\phi_i^{sat}}{\phi_i} \exp\left[\frac{V_i^L \cdot \left(P - P_i^{vp}\right)}{RT}\right] = \frac{\phi_i^{sat}}{\phi_i} \cdot POY \tag{2}$$

where: ϑ_i is the correction factor for the vapor phase; x_i and y_i are the molar fractions of component i of the liquid / vapor oil phases, respectively; P is the total pressure; R is the gas constant, T is the absolute temperature; P_i^{vp} and ϕ_i^{sat} are, respectively, the vapor

pressure and the saturation coefficient of the pure *i* component; γ_i is the activity coefficient; ϕ_i is the saturation coefficient; V_i^L is the liquid molar volume of component *i*; *POY* is the Poynting factor.

Because of the high temperatures used in deodorizing units, the vapor pressures of some components, such as water and short-chain fatty acids - FA (6:0 to 12:0), are high enough to generate $\phi_i^{sat} \neq 1$.

In a multicomponent differential distillation process as the deodorization process, the oil composition is changing continuously, there the process is a dynamic one and the mathematical modeling must reveal the real dynamic oil state in each stage of the process.

The composition of the deodorization distillate varies during the process (90 – 130 minutes, 120 minutes in physical refining of palm oil) and in the mathematical model we consider the average of total distillate collected. The differential distillation is treated as a sequence of various and successive vaporizations, step by step, in the decreased value of the vapor tension or relative volatility degree.

Three different models for simulating deodorization are used in practice:

Model I [4] does not take into account the injection of sparge steam in the deodorized oil. The total pressure in the deodorization system is the sum of the partial pressures of all oil distillable compounds present in the initial stage.

$$f = P - \sum_{i=1}^{n} \left[\gamma_i \cdot x_i \cdot P_i^{vp} \cdot \vartheta_i \right] \tag{3}$$

where *n* is the total number of oil distilled compounds.

Model II [8] considers the injection of sparge steam in deodorization process, but considers the deaerated steam as an inert gas, which decreases the total pressure by its partial vapor pressure.

$$f = P - \sum_{i=1}^{n} \left[\gamma_i \cdot x_i \cdot P_i^{vp} \cdot \vartheta_i \right] \cdot \left[1 + \frac{\dot{m}_w}{\dot{m}_v} \cdot \frac{\sum_{i=1}^{n} y_i \cdot M_i}{18} \right] \tag{4}$$

where: $\dot{m}_w$ and $\dot{m}_v$ are the mass flow of water and volatile fatty compounds respectively, in the vapor phase in grams per second (g/s); M_i is the molar mass of each distilled component *i*; y_i is the molar fraction in vapor phase of component *i*.

Model III [9] includes the variable generated by the effect of condensed steam in cold oil which increases the volatility of the distilled compounds and decreases the deodorization temperature. The deodorization simulation process was divided in two parts:

(i) Indirect pre-heating of degassed oil at the process temperature (185 – 195 °C, 1 – 2 mm Hg, in continuous deodorization, and 210 – 274 °C, 1 – 6 mm Hg in the batch-type process), realized with economizer heat exchanger (for the

recovery of the thermal energy of deodorized oil) and with high pressure steam (30 – 40 daN/cm^2);

(ii) Fractionate distillation and vapor separation with deaerated sparge steam at constant temperature, which was allowed by the presence of water in the liquid phase. The distilled compounds are condensed, cooled and stored.

The simulation of the first part (i) is realized with **Model I**. At the deodorization temperature is initiated the stripping phenomenon and condensed water from steam is included as the (n + 1) component in the liquid phase.

$$f = P - \sum_{i=1}^{n+1} \left[\gamma_i \cdot x_i \cdot P_i^{vp} \cdot \vartheta_i \right] \tag{5}$$

Model III is the optimal simulation equation of the deodorization process in the batch technological routine.

CONCLUSIONS

The mathematical models for the simulation of the edible oil deodorization or physical refining are viable if they take into account the real technological and technical conditions, the performance of the industrial plant and the quality of oils (FA composition and profile of minor components).

The stripping/deodorization loss is restricted under 0.2 – 0.3% + 1.2 FFA% and the deodorized oil quality is standardized for the edible use (Table 1).

The stripping steam, in wt% of oil, is 5 – 15% in batch-type deodorization and decreased at 1 – 5% in the continuous and semi-continuous technologies.

The correction of the theoretical models in the real condition of the industrial plant processing is realized taking into account the following elements:

(i) The vaporization rate and efficiency factors in the dynamic equilibrium of oil system;

(ii) Thermal induced degradation (thermo-oxidation, isomerization, thermal fraction, thermal lipolyses);

(iii) Technological losses due to mechanical entrainment.

The **Model III** permits a gross estimation of deodorized distillate composition generated by oils with initial high acidity (sunflower, rapeseed, palm, olive oils) in the batch-type procedure.

The correction of the **Model III** in semi-continuous and continuous deodorization involves the following aspects:

(i) Maximum increasing of deodorizing efficiency and control, minimum loss and zero risk of air exposure (double shell packed column with thermal insulation);

(ii) Minimum entrainment (inlet flash chamber);

(iii) Integrated scrubber with minimum pressure drop;

(iv) Maximum removal of volatiles (deep packing bed);

(v) Minimum air leakage (steam sealed manways);

(vi) Maximum heat recovery before final stripping (economizer).

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