Journal of Food Engineering 91 (2009) 29–33

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Modelling and evaluating the batch deodorization of sunflower oil

S. Akterian *

University of Food Technologies, Division Vegetable Oils, 26 Maritza Boulevard, BG-4002 Plovdiv, Bulgaria

ARTICLE INFO

Article history:
Received 12 December 2007
Received in revised form 10 June 2008
Accepted 1 August 2008
Available online 9 August 2008

Keywords:
Batch deodorization
Oleic acid
Steam distillation
Sunflower oil
Vacuum

ABSTRACT

An engineering approach for evaluating the oil temperature during the batch deodorization is proposed. This approach employs a quasi-steady model including equations of steady-state heat transfer for consecutive time steps of computation. A new index – De-value – for assessing the efficacy of batch deodorization is proposed. The De-value represents the reduction of a key volatile component. It was established that the oleic acid is better to be used as a key component for assessing the deodorization of high oleic sunflower oil conducted at low temperature conditions – below 200 °C. The deodorization process of sunflower oil may be accepted as efficient if the De-value reaches a value 2 ± 0.2. The engineering approach proposed for evaluating De-value can be used as a tools for: (i) estimating the efficacy of process conditions applied at present; (ii) specifying eligible values of process parameters when a new process design will be established.

1. Introduction

Deodorization is a crucial refining stage with an important effect on the quality of oil refined. Principally, it is a steam distillation under vacuum. The purpose of this process is the removal of undesired volatile odoriferous components in vegetable oils, namely aldehydes, ketones, carbohydrates, and free fatty acids. Among them the heavier free fatty acids have the lowest vapor pressure and therefore they are the least volatile components (Bockisch, 1998). The saturated stearic acid $C_{18:0}$ with a molecular mass of 284.5 Da, the saturated palmitic acid $C_{16:0}$ with a molecular mass of 256.4 Da, the unsaturated oleic acid $C_{18:1}$ with a molecular mass of 282.4 Da and linoleic acid $C_{18:2}$ with a molecular mass of 280.4 Da are of the biggest interest because their concentrations in crude sunflower oil and in the oils before deodorization are the highest (Vasileva, 2003) and their vapor pressures are the lowest. The deodorized oils can be considered as a binary mixture including triglycerides (non-volatile in practice) and a key component – a volatile free fatty acid (Bockisch, 1998). The free stearic acid is used as a key component in the cases when the deodorization process is carried out at temperatures exceeding 200 °C (Vasileva, 2003). It is not found any criterion or an index cited in the specialized literature for assessing the reduction of undesired volatile components of the oil when the deodorization is carried out under variable temperature conditions.

At present, three types of deodorizers – batch, semi-continuous and continuous – are used in the practice. Semi-continuous and continuous deodorizers are best suited for large plants. These deodorizers enable the residence time of oil and the consumption of stripping steam to be reduced (Brekke, 1980). They can gain a heat recovery up to 50% and 85%, respectively (Carson, 1988). The batch deodorizers are more suitable for small plants because of their flexibility and very low instatement costs (Bockisch, 1998). A large part of Bulgarian refineries are small and medium enterprises and for that reason the batch deodorizers are widespread. The temperature of the oil in these batch deodorizers is variable throughout the process and it is low due to the technical background of these small refineries. Two stages can be specified during the batch deodorization: (i) indirect heating up to temperatures 145–160 °C, and (ii) indirect heating up to temperatures 175–210 °C under high vacuum conditions (with a residual pressure 0,3...1...15 kPa) and a simultaneous injection of stripping superheated steam.

The deodorization is a complex heat and mass transfer process. During deodorization some degradation reactions such as hydrolysis of triglycerides and *cis–trans* isomerization reactions of free fatty acids (Ceriani et al., 2008; Kemeny et al., 2001; Tasan and Demirci, 2003) take place as well. The equation of Bailey (1941) for the requirement of stripping steam is recognized all over the world (Bockisch, 1998; Brekke, 1980; Gavin, 1978; Leniger and Beverloo, 1975; Molchanov, 1965). The vaporization efficiency included in this equation can be determined more accurately if the approach presented by Ceriani and Meirelles (2005), Decap et al. (2004) and MacFarland et al. (1972) is taken into consideration. Dijksra (1999) showed that Bailey's equation is eligible for batch and crow-flow deodorizing systems but it is not suitable for evaluation of the stripping requirement of countercurrent continuous

* Tel.: +359 32 603822; fax: +359 32 644102.
E-mail addresses: akterian@abv.bg, dr.akterian@gmail.com

0260-8774/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2008.08.001

Nomenclature

a	mass concentration of the key volatile component – a free fatty acid (%)
a_I, a_F	Initial and final mass concentration of the key volatile component at the beginning and at the end of the process (%)
c, c_M	specific thermal capacity of the oil processed and the metal body of apparatuses, respectively (J kg^{-1} °C^{-1})
D	mass consumption of direct stripping steam (kg)
$\dot{D}$	mass flow of direct stripping steam (kg/s)
De	deodorization value (1)
De$_1$, De$_2$, De$_3$	deodorization values when the key component is stearic, oleic or palmitic acid, respectively (1)
Di	average absolute relative deviation between the temperatures of oil determined theoretically and experimentally (%)
F	heating surface of the apparatus (m^2)
k	overall coefficient of heat transfer (W m^{-2} °C^{-1})
m	number of the experimentally measured temperatures during the process
M, M_M	mass of the oil processed and the metal body of apparatuses, respectively (kg)
n	the total number of consecutive computing time steps (1)
p_A	absolute working/process pressure in the apparatus during the second stage (Pa)
p_S	the vapor pressure of a key component (Pa)
p_{S1}, p_{S2}, p_{S3}	the vapor pressure of stearic, oleic and palmitic acids, respectively (Pa)
T	temperature of oil processed (°C)
T_S	temperature of the heating medium – dry saturated steam (°C)
Δt	a short discrete interval of time used as a computing time step (s)
η	coefficient accounting the external heat losses (1)
μ	average molecular mass of triglycerides in sunflower oil (Da): $\mu = 880$ Da
ψ	vaporization efficiency (1): ψ = 0.5,. . .,0.8

Subscripts

E, T	experimental and theoretical
i, i+1	related to the beginning and the end of a computing time step, respectively
1,2	related to the first and the second stage of deodorization process, respectively

deodorizing systems. He advanced a new equation for determining the stripping requirement of countercurrent deodorizers as the number of mass transfer units were taken into consideration. The mass transfer during batch and continuous deodorizers were simulated by Ceriani and Meirelles (2004b,c). They applied a differential distillation model as vapor–liquid equilibria of fat system (triacylglycerides, diacylglycerols, monoacylglycerols, free fatty acids, etc.) were described by group contribution equations for vapor pressures and activity coefficients. These excellent contributions applied a sophisticated set of equations with a large number (over 10) of empirical coefficients. So, these approaches are more suitable for scientific investigations and the process design of continuous deodorization processes.

The heat transfer during deodorization is also complicated and it is difficult to be modelled by more sophisticated techniques due to the following reasons: First, there are not sufficient and detailed investigations on the heat transfer in viscous liquids, such as oils, by means of a free convection in apparatuses without mechanical stirring. Second, there is a heat transfer in two-phase system including liquid oil and steam superheated during the second stage of the process.

The objectives of the present paper were to propose (i) a simplified engineering approach for predicting the oil temperature during batch deodorization; (ii) a dimensionless index for assessing the reduction of undesired components in vegetable oils; and (iii) an engineering approach for evaluating this index as the temperature history of the oil, the process pressure and the mass flow of stripping steam are taken into consideration.

2. Model of heat transfer

A quasi-steady energy balance model for simulating the heat transfer in vegetable oil was employed. The unsteady heat transfer was described by a sequence of short regular time intervals Δt (of the order of seconds). The heat transfer during each time interval was considered as steady. Moreover, the temperature field of the oil throughout apparatus' volume was assumed as uniform for each time interval.

The history of oil temperature was determined by means of a sequence of computing time steps which duration is equal to the time interval Δt. The oil temperature T_{i+1} at the end of each computing time step can be calculated by the following equation:

$$T_{i+1} = T_i + k \cdot F \cdot (T_S - T_i) \cdot \eta \cdot \Delta t / (M \cdot c + M_M \cdot c_M). \quad (1)$$

This equation was derived from the differential energy balance of the apparatus related to the beginning and the end of the computing step. It was assumed that the temperature T_S of the heating medium throughout the process is stationary. The temperature of the entire metal body with the steam coil/jacket was assumed to be equal to the temperature T_S of the heating medium for each computing step. It was taken into consideration that the intensity of heat transfer at steam condensation is high and the thermal conductivity of the metal body is high as well. The intensity of heat transfer was evaluated by the overall coefficient of heat transfer from the heating steam to the oil processed. Two values k_1 and k_2 of this coefficient for the first and the second stages, respectively, were adopted. The stripping steam used during the second stage leads to a reduction of heat transfer intensity. The lower value of the coefficient k_2 reflects this circumstance.

3. De-value

3.1. Definition

The De-value for evaluating the reduction degree of undesired odoriferous components in vegetable oils deodorized is defined by means of the following relation taking into account the reduction of a free fatty acid adopted as a key component

$$\mathrm{De} = \frac{a_I}{a_F}. \quad (2)$$

3.2. Evaluation

The mass consumption D of stripping steam for a deodorization process conducted at a constant temperature T is determined by the following modified equation of Bailey (1941):