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Optimum Blowing Steam Rate in Deodorization and Steam Distillation[1]

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THE optimum blowing steam rate in commercial deodorization has long been a subject for conjecture. The best solution thus far has been a compromise between the economic aspects which dictate the lowest possible sparging rate and the quality considerations which heretofore have indicated that the higher the blowing rate, the greater the degree of deodorization. Thus the total blowing steam used in commercial practice has been estimated (1, 3) to vary from 3% (for some continuous installations) to over 100% (in older batch systems) of the weight of the stock deodorized. In most instances these blowing steam rates are based solely on rule of thumb or arbitrarily accepted practice.

Some time ago, as the result of conflicting recommendations, concentrated attention to the subject resulted in the following hypothesis: at some point the benefit of increased blowing steam must be more than offset by the resultant loss in vacuum due to pressure drop through the system and overloading of the vacuum equipment.

This paper proposes to show that, technologically, there is an optimum blowing steam rate characteristic of each individual system and that rates above this optimum actually lessen the degree of deodorization.

For well-designed installations with high capacity vacuum systems, this technically optimum rate may be higher than is economically practical. Other systems however with high pressure drop and low capacity jets may well be found to be operating at disadvantageously high blowing steam rates, a reduction of which would result in better deodorization and lower costs.

Theoretical

The integrated form of Bailey's (1) equation for batch deodorization is

$$S = PO/EP_v(\ln V_1/V_2) \tag{1}$$

where S = total blowing steam per batch (mols)
P = absolute pressure in deodorizer (ins. Hg)
O = batch size (mols)
E = vaporization efficiency (dimensionless)
P_v = vapor pressure of volatile component(s) (ins. Hg)
V_1 = initial concentration of volatile components (%)
V_2 = final concentration of volatile components (%)

The total mols of steam (S) may also be expressed as

$$S = Rt \tag{2}$$

where R = blowing steam rate (mols per hour)
t = deodorization time (hours)

Equations (1) and (2) may be combined and rewritten as

$$\ln(V_1/V_2) = (EP_vRt)/(PO) \tag{3}$$

Under practical conditions in commercial equipment it is desirable to operate the vacuum system under design conditions calculated to maintain the lowest possible absolute pressure at all times (1). The vacuum attained in the kettle is dependent upon the absolute pressure at the vacuum source (fixed by jet design and load) and the pressure drop through the system (a function of kettle design and blowing steam rate). Thus the total absolute pressure (P) is seen to be a variable, characteristic of the system and empirically dependent upon the load or blowing steam rate (R) (see Figure 1).

Under normal conditions of production, besides the initial content of volatile odoriferous materials (V_1), such factors as deodorization cycle time (t), batch size (O), deodorization efficiency (E), and deodorization temperature and the corresponding vapor pres-

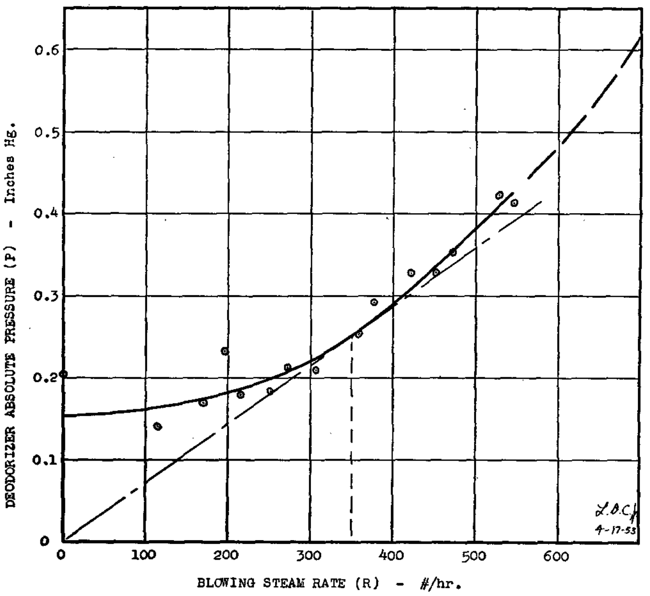

FIG. 1. Operating curve: Deodorizer pressure vs. blowing steam rate. Deodorizer B-118.

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sure of volatiles (P_v) are relatively uniform and can be lumped into a constant, k, to give

(4) $\ln(V_1/V_2) = k(R/P)$

This relates those factors of interest in the present study, namely, blowing steam rate (R), the corresponding pressure in the deodorizer (P), and the resulting degree of deodorization or residual volatiles (V_2). V, R, and P may be expressed in any consistent and convenient absolute units with corresponding values of k.

From equation (4) it is evident that the smallest possible value of V_2 corresponds to the highest possible value of the ratio (R/P). Figure 1 is a typical pressure-drop or load curve, from which it can readily be seen that as the sparging rate is gradually increased from zero through the lower values, the absolute pressure remains low hence the ratio of (R/P) increases rapidly. As the blowing rate is further increased, the vacuum begins falling off at an increasingly greater rate, until at the high end of the curve a moderate increase in steam flow results in a large increase in absolute pressure with the result that the ratio (R/P) is reduced, to the detriment of the deodorization operation. Hence the independent variable, blowing rate (R), should be increased or decreased (depending on whether the rate is below or above the optimum, respectively) as long as the change results in an increase in the ratio (R/P), or as long as

(5) $(R \pm \Delta R)/(P \pm \Delta P) > R/P.$

Before the above inequality can be reversed, some point must be passed (the optimum; R_o, P_o) at which a differential change in blowing steam rate (dR) does not affect the ratio (R/P), or

(6) $(R_o \pm dR)/(P_o \pm dP) = R_o/P_o,$

at which point,

(7) $dR/dP = R_o/P_o.$

Since, in Figure 1, P is plotted as the dependent variable against R as the independent variable, (7) is more conveniently written

(8) $dP/dR = P_o/R_o$

from which we see that the slope of the curve must equal the ratio of the coordinate values at the optimum blowing steam rate (R_o).

Thus, according to the hypothesis presented here, optimum removal of odoriferous materials in a normal deodorization cycle should occur when:

a) R/P is a maximum (or P/R is a minimum)

b) $dR/dP = R/P$ (or $dP/dR = P/R$)

Conditions a) and b) should both be satisfied at the same value of R (*i.e.*, R_o).

Under these optimum conditions not only should the total materials (volatile and neutral oil) distilled off be at a maximum, but entrainment should be disproportionately high, as seen through a study of Bailey's (1) modification of the equation of Souders and Brown, which gives the critical velocity of a vapor required to carry droplets of a given size as

(9) $v_c = K'(D^{1/2}/d_2^{1/2})$

where v_c = critical linear velocity of the vapor
K' = a constant
D = diameter of the droplet
d_2 = vapor density.

The linear velocity of an ideal vapor through any system is proportional to the mass rate (R) and inversely proportional to its density (d_2), which in turn is directly proportional to the absolute pressure of the system (P), so that in a given system,

(10) $v = c(R/P)$

where c is a constant and v is the linear velocity. From this it is apparent that maximum linear velocity coincides with optimum conditions (maximum R/P) and that further increasing the blowing steam rate actually results in a decrease in linear velocity due to the compression of vapors. It is also evident from (9) however that this increase in absolute pressure, and hence in vapor density, results in a decrease in the critical vapor velocity required to carry droplets of a given size. Thus it appears that entrainment increases rapidly with increasing linear velocity and gas density up to the point of optimum deodorizing conditions, after which decreasing velocity compensates to a degree (depending on operating curve characteristics) for the increasing vapor density, resulting in disproportionately high values of entrainment at the optimum blowing steam rate (R_o). This does not conflict with Bailey's data on entrainment, obtained in equipment in which blowing steam and vacuum could evidently be controlled independently (5), thus eliminating the effect of vapor compression.

Experimental

Data were collected at random over a period of five months from a commercial batch deodorizer operating on a 7-hour cycle handling 15,500 lb. of hydrogenated soybean oil per batch at 400-430°F. Blowing steam rate was varied from 0 to 550 lb./hr., with sustained operation at various settings between 200 to 550 lb./hr. Operations were carried out with due precautions (including organoleptic evaluations) such as to insure no damage to the resulting deodorized oils. Data about each setting were grouped and averaged to minimize effects of other variables. These averaged data were then plotted to give the operating curve shown in Figure 1.

Values of absolute pressure (P) and blowing steam rate (R) were taken from the smoothed curve, and P/R ratios calculated. From Figure 1 the slope (dP/dR) of the operating curve was determined at various blowing steam rates. Calculated values are given in Table I and are plotted against R in Figure 2, from which the optimum blowing rate (R_o) for this system was found to be about 350 lb./hr.

Hotwell scrap and catch oil, representing distilled and entrained materials, were collected and weighed

TABLE I

Values of Operating Variables Taken from Smoothed Curve (Fig. 1), with Corresponding Values of P/R, dP/dR, and and Catch and Hotwell Oil

Blowing Rate R (lb./hr.)	Pressure P (ins. Hg)	P/R	dP/dR	Catch and Hotwell Oil (Avg. lb./batch)
0	0.155	*a*	....	....
50	0.157	0.003140	0.000074	....
100	0.161	0.001610	0.000131	....
150	0.169	0.001127	0.000194	....
200	0.181	0.000905	0.000281	111.7
250	0.197	0.000788	0.000379	....
300	0.220	0.000733	0.000546	131.3
350	0.253	0.000723	0.000736	....
400	0.291	0.000728	0.000789	....
450	0.333	0.000740	0.000917	....
500	0.380	0.000760	0.000968	....
550	0.429	0.000780	0.001030	94.2
600	0.485	0.000808	0.001147	....

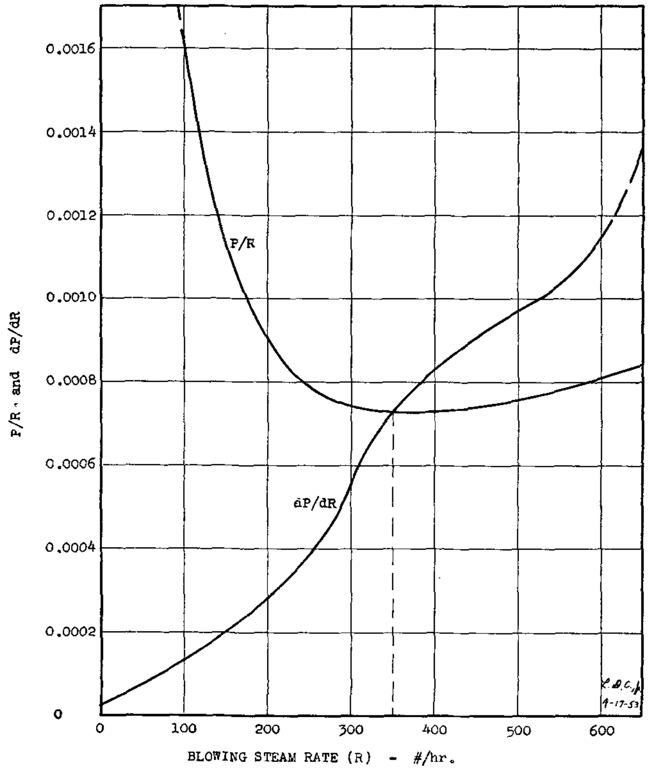

FIG. 2. P/R ratio and dP/dR vs. blowing steam rate.

from a total of 21 batches at three blowing steam rates (200, 300, and 550 lb./hr.). These data also are given in Table 1.

Discussion

It is evident that correct results depend on reliable instruments which give reasonably accurate absolute values and that sufficient data must be taken to eliminate the effects of extraneous variables (*e.g.*, pressure of steam to jets, condenser water temperature, etc.) through averaging and smoothing data. Pressure readings should not be taken very early in the cycle because of the high values resulting from deaeration and initial high velocity removal of copious volatile materials. Of primary interest are conditions near the end of the run as V_2 is approached.

The assumption that E, the vaporization efficiency, is constant is based on Bailey's (1) experience, which indicates that this term varies but little in a given system, and is practically independent of pressure variations in the normal range of deodorization. E indicates the degree of approach to equilibrium distribution of volatiles between the oil and the steam leaving the oil surface, and is expressed as

$$\text{(11)} \qquad E = p'_v/p_v$$

where p'_v = the actual partial pressure of the volatile component in the vapor phase

p_v = the equilibrium pressure of the volatile component in the oil.

Bailey cites estimates of E ranging from 0.7 to 0.99 for various systems.

The term K, developed by Wolf and Rushton (4), is a rate constant affected by nearly all the variables in the system and as such includes E, but can not be compared to it. Wolf and Rushton postulate that K is inversely proportional to the absolute pressure (P) and also find that a near-linear relationship exists between K and the mass steam rate (R). Thus K, a measure of the rate of removal of volatiles, would appear to approach a maximum as the ratio R/P approaches a maximum, under otherwise fixed conditions. This agrees with the theoretically optimum conditions for deodorization developed here from Bailey's equation.

It is of interest to note that the limited data on entrained and distilled materials indicate that extreme conditions remove less material than does operation near the optimum. From theoretical and practical considerations the materials removed at 550 lb./hr. blowing steam rate should be greater than those removed at 200 lb./hr., for two reasons: a) distillation should be greater because of the higher ratio of R/P (or lower ratio of P/R; see Table I): b) entrainment should be greater because of the concordantly higher linear velocity and greater gas density. Failure of data to confirm expectations may possibly be ascribed to the limited accuracy under the conditions of experimentation, which nevertheless satisfactorily illustrate the principles involved.

In view of the very sharp increase of the P/R ratio as the blowing steam rate is reduced below optimum in this case (see Figure 2), it would be advisable to operate at or slightly above the indicated optimum (*i.e.*, between 350-400 lb./hr. of blowing steam). This optimum rate may or may not be critical, depending on the characteristics of the individual system.

From the nature of the operating curve it is evident that the point of tangency of a straight line through the origin corresponds to optimum conditions (see Figure 1), since at that point P/R = dP/dR. Also it is the lowest possible value of P/R common to the curve and the tangent through the origin, which has a slope of m = (P-O)/R-O), or P/R.

The principles outlined here would appear to apply equally well to deodorization, solvent stripping, or any other form of steam distillation, continuous or batch, on any scale from bench to plant.

The optimum blowing steam rate for a given system can be determined easily by the following steps:

a) Collect and average enough reliable operating data at various blowing steam rates to insure a smooth and reasonably accurate operating curve;
b) Plot averaged values of absolute pressure (P) vs. blowing steam rate (R), in any convenient units;
c) Draw a straight line through the origin tangent to the smoothed operating curve. The point of tangency defines optimum operating conditions for the system.

Taste panel methods similar to those of the Northern Regional Research Laboratory (2) failed to detect any difference in either initial flavor or flavor stability between oils deodorized at optimum or sub-optimum conditions. Organoleptic tests can not be expected to detect flavor differences of the magnitude which occur in normally deodorized good quality oils, especially in view of the precautions commonly taken to guard against under-deodorization.

Summary

On the basis of Bailey's equation for deodorization it is proposed that there is an optimum sparging rate,

characteristic of each individual system, for steam distillation and its specialized forms, such as deodorization and stripping. It is suggested that the principles involved are applicable to continuous or batch systems of any size.

A simple method of determining this optimum rate is described and illustrated with data from a commercial batch deodorizer.

It is proposed that, under optimum conditions:

a) the ratio of absolute pressure (P) to the blowing steam rate (R) is at a minimum;
b) total distillation is at a maximum;
c) the linear velocity of the vapor is at a maximum; and
d) entrainment is disproportionately high.

It is recognized that this technically optimum blowing steam rate may not coincide with the most economical conditions of operation, depending on the characteristics of the system.

It is concluded that operation at rates appreciably above the optimum can in no way be justified.

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A New Source of Carotene: Palm Fiber Oil From Elaeis Guineensis

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FOR several years our laboratories have been very much interested in the study of extraction methods and the physical and chemical properties of carotene from palm oils which are produced in the French Overseas Territories, such as the Ivory Coast, Dahomey, and the Cameroons. Carotene is the ideal coloring agent for margarine. It is indeed the natural pigment of butter and moreover plays a specific role in the animal organism as provitamin A. Thus its superiority over coloring agents without vitaminic power is obvious (1). Carotene was discovered more than a century ago in carrots which still are, besides alfalfa, an important raw material for the industrial preparation of carotene. However carrots and alfalfa, are very poor sources of carotene as compared to African palm oil.

Furthermore a difference must be made among palm oils according to their origins. Oils produced in the Far East and most of the oils from the Belgian Congo contain about 0.05-0.06% of carotene,[1] while palm oils from the Ivory Coast, especially from Dahomey, contain as much as 0.1-0.16%.

Palm oil consumers prefer the lightest colored oils for soap and margarine manufacture in order to avoid the expensive and difficult bleaching treatment. Oil palm growers have thus been brought to select palm trees capable of producing high yields of light-colored oil. In French Africa palm oil is produced exclusively from natural wild palms, which are likely to produce highly colored oils. Especially in Dahomey climatic conditions are very favorable for the development of pigment. The oil yield per acre, in this last case, amounts to only one-third or one-fourth of the yields obtained on the estate plantations of Malaya, but this oil, strongly colored is an excellent material for the industrial production of carotene.

During our investigations we have been led to study the constitution of the oil which remains in the cakes of the fruit fibers. These fibrous oil cakes generally contain about 10% of glycerides. Because of their high cellulose and lignin content and their low percentage of protein, they have no food value for animal feeding. In Africa they are used for fuel. Thus they are an almost valueless by-product. When the oil is extracted by means of a suitable solvent, such as petroleum ether or chlorinated solvents, it is very highly colored.

TABLE I

Average Total Carotene Contents

Source	Mg./pound (estimated as beta-carotene)	
	Fresh	Dry
Carrots (4)	12	110
Sweet Potatoes (5)	14	64
Alfalfa (5)	28	118
Barley (5)	21	140
Clover (5)	....	153
Rye (5)	38	203
Sweet Clover (5)	15	89
Wheat (5)	20	118
Estate palm oil (Belgian Congo, Far East)	225	
Wild Palm Oil (Ivory Coast, Dahomey)	450- 800	
Estate Palm "fiber oil"	650-1,100	
Wild Palm "fiber oil"	1,300-2,200	

After numerous tests we have found that the carotene content of "fiber oil" from either wild or cultivated trees is much higher (about three to four times more) than it is in the corresponding "expression oil." For instance, from palm fruits from the Ivory Coast the expression oil has 0.1-0.14% of carotene while the corresponding "cake oil" or fiber oil generally shows a carotene content of 0.3-0.4% and sometimes even more. While the expression oils obtained from fruits from estates of the Belgian Congo or Malaya contain approximately 0.06% of carotene, the fiber oil shows a content of 0.15-0.25% (2).

By assay on young rats the biological value of the carotene containing concentrates from expression palm oil corresponds with the carotene content found by spectrophotometry (3). The absorption spectra of

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[1] Total content of all isomers.