Energy Conservation in Solvent Extraction Plants

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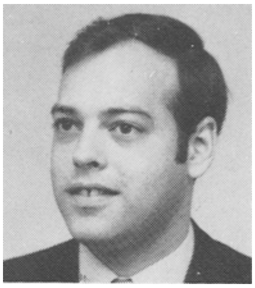

ABSTRACT

Solvent extraction plants have been designed for a long time at low capital cost, often at the expense of higher operating costs. Due to rising energy prices, the processing cost structure is changing to such an extent that the designs should be reconsidered. Conservation of steam, on the liquid side (distillation and condensation) and on the solid side (desolventizing, toasting, drying, and cooling), is discussed for existing plant designs.

Solvent extraction plants have been designed at low capital cost, which often results in higher operating costs. However, because energy prices are continuously rising, the processing cost structure is changing to such an extent that reconsideration of plant designs is feasible. In 1976, energy costs will amount to ca. 1/3 of the total production costs of soybean solvent extraction, so it seems worthwhile to study the possibilities of minimizing energy consumption in the extraction plant. Consequently, our attention must be focused on savings in steam consumption because steam demands the greater part (ca. 2/3) of the total energy costs for extraction.

In an extraction plant, steam is applied where heat is required (distillation, toasting, drying) and to desolventize the oil and meal. If we start with soybeans at 15 C (containing 20% oil and 12% water) and obtain oil at 80 C and meal at 20 C (containing 1% residual oil and 12% water), a total steam consumption of 350 kg per ton beans (i.e., 2.5 MJ/kg) is found, taking heat losses and some recoverable heat flows into account. Table I gives the steam consumption spread over the various process steps. The amounts of steam have been converted to "normal" conditions, i.e., 100 C and 1.01 x 10^5 Pa, and expressed per ton of soybeans.

These data result from heat and mass balances over the various process steps, based on the process conditions and material analyses of an existing 1,600 t/d soybean solvent extraction plant. Evidently, desolventizing/toasting and drying/cooling of the meal are the major steam consumers, and also conditioning uses a considerable amount of steam. It may not be concluded from Table I that distillation is one of the minor steam consumers because the reuse of the greater part of the heat from the desolventizer-toaster vapors has already been accounted for. If not so, distillation would demand ca. 3 times as much steam.

Because much steam is required to desolventize the meal, a reduction of the hexane content of the meal leaving the extractor is an attractive energy-saving alternative. This reduction can be achieved by pressing the extracted hexane-containing meal before desolventizing. Another means is a longer drainage time in the last section of the extractor. In drainage experiments in a pilot-plant extraction column, the fraction of miscella adhering to the meal was measured as a function of the drainage time for various flake thicknesses and bed heights. Figure 1 represents an example of such a drainage curve.

TABLE I

Steam Consumption of Various Process Steps in Soybean Solvent Extraction

Process	Steam consumption (kg/t)
Conditioning	60
Extraction	20
Distillation	40
Desolventizing/Toasting	150
Drying/Cooling	80
Total	350

If the drainage time is doubled or even tripled, the amount of hexane adhering to the meal will be reduced by ca. 5%. This implies a reduction in heating and evaporation of ca. 55 kg solvent per ton beans, resulting in a reduced steam consumption of ca. 15 kg/t. Due to the reduced amount of steam, less condensation will occur in the toaster, and meal with less moisture will be obtained. Consequently, less water has to be evaporated, which reduces steam consumption further by ca. 10 kg/t. Unfortunately, these drainage conditions cannot be adapted easily in existing extractors without increasing the residual oil content of the meal. In new designs, however, the last draining zone can easily be extended. In addition, pressing the extracted hexane-containing meal will reduce even further the amount of adhering miscella and, as a result, the steam costs.

Other steam-saving alternatives can be sought in the desolventizing operation itself. All required heat that is not supplied by direct stripping steam will not lead to condensation on the meal. Less condensation in the meal results in a lower energy consumption in the drying/cooling process. A few ways of achieving this are predesolventizing by means of tubular dryers with indirect steam heating on the wall; predesolventizing by means of superheated hexane gases (as designed by Blaw Knox and EMI); and predesolventizing by means of vacuum applied to the hot extracted meal.

A drawback of all these alternatives is that less heat from desolventizer-toaster vapors is available for reuse in the distillation operation. To arrive at the optimum steam-saving effect of these modifications, it might well be necessary to reconsider the distillation design. In this respect,

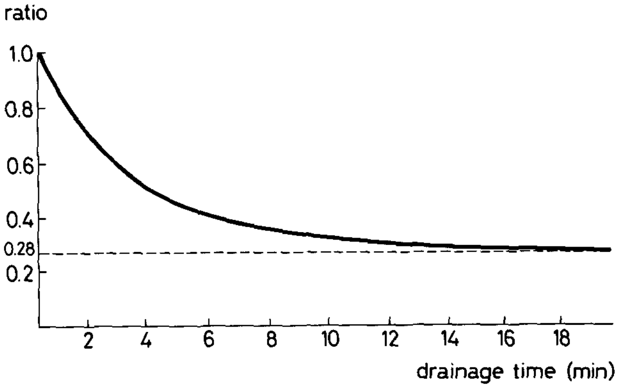

FIG. 1. Ratio of amount of adhering miscella to that of defatted flakes (kg/kg) as a function of drainage time.

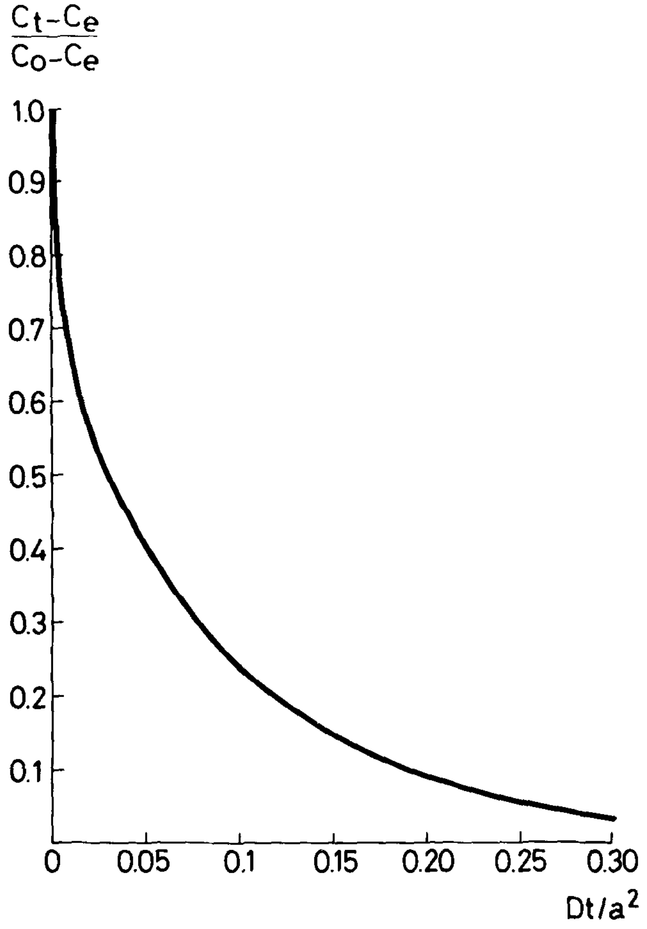

FIG. 2. "Drying rate" vs. Fourier number (according to Newman).

multiple-effect distillation, where the heat from condensing hexane vapors is reused in the foregoing evaporator stage, opens interesting opportunities.

A considerable amount of steam is also used for drying the meal to the desired moisture level. The required heat of vaporization is usually supplied by heated air. When the meal is dried in rotating drums, some steam can be saved because the heat is directly supplied by steam onto the wall and through pipes (Vetter). In case of a vacuum drying/cooling operation (as proposed by De Smet), the desired drying effect can partly be achieved by using the heat content of meal leaving the toaster. This alternative is only feasible when both the heat and mass transfer phenomena have a similar time constant, which we will now discuss.

The cooling of a spherical meal particle from 75 to 25 C in an air flow ($v = 0.5\ ms^{-1}$) at a temperature of 20 C without any moisture evaporating can be described by

$$\alpha_o \pi d^2 (\bar{T} - T_l) = -1/6\ \pi d^3 \rho_i (C_p)_i\ d\bar{T}/dt \qquad \text{(I)}$$

where

α_o = overall heat transfer coefficient = W/(m$^2\cdot{}^o$C)
$1/\alpha_o = 1/\alpha_i + 1/\alpha_e$
$\alpha_i = 160$ W/(m$^2\cdot{}^o$C); $\alpha_e = 42$ W/(m$^2\cdot{}^o$C)
d = meal particle diameter = m
T_l = air temperature = ^{o}C
$\bar{T}$ = mean temperature of meal particle at time t = ^{o}C
ρ_i = mass density of meal = kgm^{-3}
$(C_p)_i$ = specific heat of meal = Jkg^{-1}
i = subscript referring to interior of meal particle
e = subscript referring to surface of meal particle

Integration of Eq. I at the boundary condition $\bar{T} = T_o$ at t=0 gives

$$\log [(\bar{T} - T_l)/(T_o - T_l)] = -6\ \alpha_o\ t(2.3\ \rho_i (C_p)_i d) = -0.005t \qquad \text{(II)}$$

For $\bar{T}$ = 25 C it follows that t = 200 s.

The amount of heat becoming available from this cooling step can supply the heat of vaporization for reduction of the moisture content of the meal from 20 to 16%, i.e., from 25 to 19% based on a dry matter. Because the resistance to mass transfer inside the particle is ca. 20 times higher than that outside the particle, the drying rate is determined by water diffusion.

The "drying rate" equals $(C_t-C_e)/(C_o-C_e) = 19/25 = 0.76$ (assuming $C_e \simeq 0$), where C_o = initial moisture concentration in the meal particle, C_t = mean moisture concentration in the meal particle at time t, and C_e = moisture concentration at the particle surface.

From Newman (Fig. 2) it follows that $D\ t/a^2 = 0.004$, where D = diffusivity of water = $8 \cdot 10^{-11}\ m^2/s$ at 25 C and a = particle radius = $2.5 \cdot 10^{-3}$ m, so t = 300 s.

Thus the heat transfer is somewhat faster than the mass transfer but is of the same order of magnitude. The heat content of the meal from the toaster, however, is usually less than that required to obtain the desired drying effect. Therefore, some extra heat has to be added. Moreover, steam is required for raising vacuum in case of rather high vacuum operation. Compared to air drying/cooling, a potential steam saving of ca. 50 kg/t can be achieved in this way.

We have offered only a few of the many ways in which energy can be saved in solvent extraction. A further investigation into these and other alternative ways of processing will undoubtedly reveal potentially available heat flows, such as condensate, vapors, and air, which might be profitably reused.