Effect of Surface Active Agents on a Sieve Plate Distillation Column

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Surface active agents have been shown to significantly affect the efficiency of packed distillation columns. Francis and Berg (1967) found that increases in efficiency of as great as 100% could be achieved by the addition of small amounts of such materials. Such improvements were observed only for surface tension negative systems as defined by Zuiderweg and Harmens (1958). In these systems, the reflux liquid decreases in surface tension down the column causing channeling due to incomplete wetting of the packing. On the other hand, positive systems increase surface tension down the column and exhibit better wetting characteristics, hence greater interfacial area and higher efficiency. Neutral systems, that is, those for which no significant surface tension gradients are developed, show wetting and efficiency characteristics similar to positive systems in supported area equipment. In the cases examined by Francis and Berg, surface active agents were found to stabilize the liquid films in the negative systems against breakup and channeling in both organic and aqueous test mixtures resulting in the restoration of efficiencies to values comparable to those of positive and neutral systems.

The distillation studies of Francis and Berg were carried out in supported area equipment, that is, a packed column. Zuiderweg and Harmens show, however, that in the absence of surfactants, the behavior of such systems may be quite different from that in which the interfacial area is unsupported. Although positive systems again exhibit the greater efficiency, the efficiency is attributed to the tendency of these systems to froth, increasing transfer area. Negative and neutral systems are incapable of developing a stable froth.* In the organic mixtures of Zuiderweg and Harmens, efficiency differences of as much as 100% were found. The effect of surfactant addition in distillations carried out in unsupported area equipment has not been investigated although Bozhov and Elenkov (1967) report results for the desorption of oxygen from water in a sieve plate column. They found marked improvements in efficiency using small amounts of dissolved soap, but larger concentrations resulted in the flooding of the column with a stable foam.

In this study, the effect of surface active agents on the relative efficiencies of positive and negative distillations is examined using unsupported area equipment (a sieve plate column). The formic acid-water system is used as the test mixture because of the convenient azeotrope existing near the center of the concentration range. Below the azeotrope point, the system is surface tension positive and above it, surface tension negative. Also, the relatively high level of surface tension of the mixture leads to a maximum effect of a surface active agent. Finally, it was this system for which the most dramatic results were

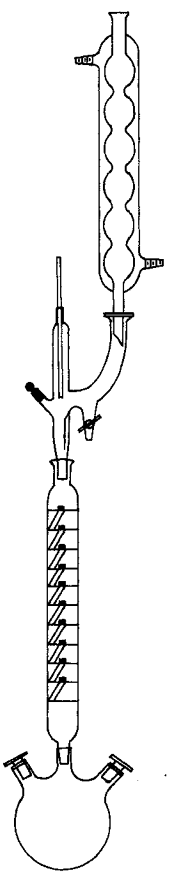

Fig. 1. Schematic diagram of sieve plate distillation apparatus.

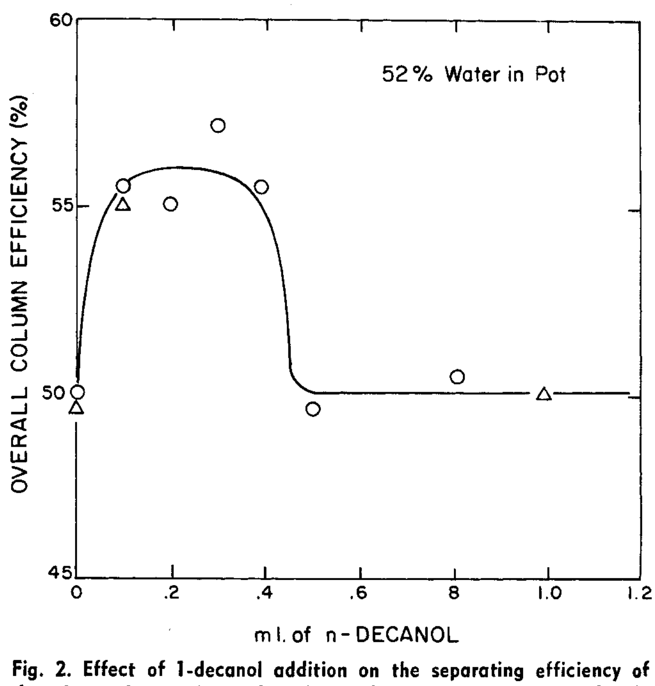

Fig. 2. Effect of 1-decanol addition on the separating efficiency of the sieve plate column for the surface tension negative formic acid-water system.

* At high vapor rates, however, negative systems may develop a stable spraying action increasing area under such conditions (Fane and Sawistowski 1968).

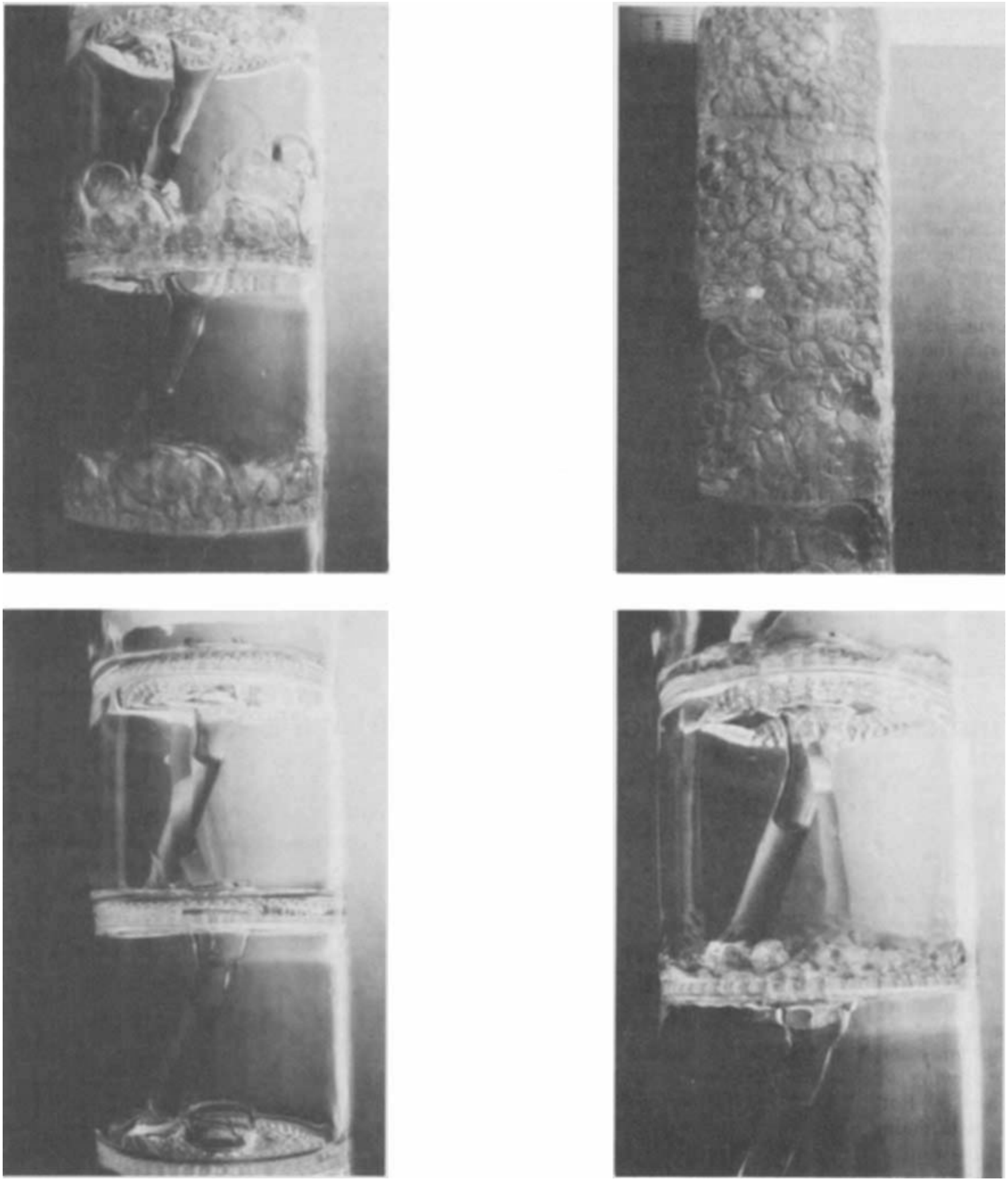

Fig. 3. Frothing behavior on sieve plates: (a) positive system, no decanol present; (b) positive system, 0.5 ml of decanol added; (c) negative system, no decanol present; (d) negative system, 0.2 ml decanol added.

found by Francis and Berg for supported area equipment. As in the latter study, 1-decanol is used as the surfactant. Its immiscibility and volatility are such that appreciable amounts of it are present throughout the column during operation.

EXPERIMENT

Distillations were carried out using a nine tray glass Oldershaw sieve plate column with downcomers, as shown in Figure 1. Inside column diameter was 3.8 cm and tray spacing 3.5 cm. The still head was fitted with a thermometer and a sample port which drained a condensate well containing approximately one ml of liquid. The pot was a one-liter flask heated by a Glas-Col electric heating mantle with power supply controlled by a variac. 400 ml of water-formic acid test mixture were added to the pot; the surface tension positive mixture was 47.2 and the negative mixture 59.5 mol % formic acid. Decanol was added to the pot in amounts varying from 0 to 0.5 ml at the beginning of each run. The column was operated for at least two hours to achieve steady state prior to sampling, and a minimum of 30 min. elapsed between successive samplings. Top and bottom samples were analyzed with a refractometer and by titration against a NaOH standard. Runs were made at two power settings, one corresponding to a low boil-up rate and the other just below the flood point in the absence of surfactant.

RESULTS AND DISCUSSION

The surface tension positive system (the formic acid rich distillation) had an overall column efficiency of 65% at both the high and low vapor rates. The addition of small amounts of 1-decanol caused no change in column operation or efficiency at the low vapor rate, but induced flooding at the higher vapor rate due to the production of a stable foam. Column behavior for the positive systems is shown in Figures 3a and 3b.

The surface tension negative system, on the other hand, exhibited an overall column efficiency of 50%. Efficiency was increased to 56% with the addition of 0.1 to 0.4 ml of 1-decanol as shown in Figure 2. With 0.5 ml or more of surfactant, the column efficiency returned to its original value of 50%. Changing the vapor rate in the negative distillation had negligible effect on column operation and efficiency in either the presence or absence of surfactant.

Although the difference in efficiency between positive and negative systems in this study was not of the magnitude reported for the nonaqueous systems of Zuiderweg and Harmens, the difference between them was reduced by 30% with the addition of very small amounts of surfactant. The low concentrations of surfactant in the negative system increased the stability of vapor bubbles on the surface of the plates, as shown in Figures 3c and 3d and thus enhanced the interfacial area available for mass transfer. The surfactant thus caused the behavior of negative system in the sieve plate column to resemble that of the positive system, a result similar to that found in studies of supported area equipment.

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LITERATURE CITED

Bozhov, I., and D. Elenkov, "The Influence of Surfactants on Mass Transfer Determined by the Liquid Boundary Layer on Plates without Downcomers," *Intern. Chem. Eng.*, **7**, 316 (1967).

Fane, A., and H. Sawistowski, "Surface Tension Effects in Sieve Plate Distillation," *Chem. Eng. Sci.*, **23**, 943 (1968).

Francis, R. C., and J. C. Berg, "The Effect of Surfactants on a Packed Distillation Column," *ibid.*, **22**, 685 (1967).

Zuiderweg, F. J., and A. Harmens, "The Influence of Surface Phenomena on the Performance of Distillation Columns," *ibid.*, **9**, 89 (1958).

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Axisymmetric Stagnation Flow Towards a Moving Plate

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In some forced convection cooling processes a coolant is impinged on a continuously moving plate. This note discusses the fluid mechanics and the heat transfer near the stagnation region.

The two-dimensional stagnation flow towards an infinite plate moving with constant velocity in its own plane was obtained by Rott (1956) and Glauert (1956). The possibility of extending the flow to three dimensions was mentioned by Rott, although this has never been done. In what follows we shall present the most important case, namely, the axisymmetric stagnation flow towards a moving plate.

AXISYMMETRIC CASE

Let the Cartesian velocity components at infinity be $u = ax$, $v = ay$, $w = -2az$ which represents a potential axisymmetric stagnation flow. Let the plate be at $z = 0$, moving with constant velocity U in the x direction.

We substitute

$$u = U\chi(\eta) + xa\varphi'(\eta) \tag{1}$$

$$v = ya\varphi'(\eta) \tag{2}$$

$$w = -2\sqrt{a\nu}\,\varphi(\eta) \tag{3}$$

$$p = -\frac{\rho}{2}\left[a^2(x^2 + y^2) + w^2 - 2\nu w_z\right] \tag{4}$$

$$\eta = \sqrt{a/\nu}\,z \tag{5}$$

into the Navier-Stokes equations and obtain

$$\varphi''' + 2\varphi\varphi'' - (\varphi')^2 + 1 = 0 \tag{6}$$

$$\varphi(0) = \varphi'(0) = 0,\ \varphi'(\infty) = 1 \tag{7}$$

$$\chi'' + 2\varphi\chi' - \chi\varphi' = 0 \tag{8}$$

$$\chi(0) = 1,\ \chi(\infty) = 0 \tag{9}$$

Equations (6) and (7) describe the well-known Homann's axisymmetric flow towards a fixed plate (1936). However Equation (8) cannot be obtained from Equation (6) through simple substitution as in the two-dimensional case. Numerical integration of the system Equations (6) to (9) is necessary. Using the Runge-Kutta method, the numerical values of χ and χ', together with more accurate values of φ and φ', are tabulated in Table 1. Figure 1 shows how χ and χ' decay with increasing distance from the plate.

The shear stress on the plate in the x direction is

$$\tau = \mu\sqrt{\frac{a}{\nu}}\,U\left[\chi'(0) + \frac{xa}{U}\varphi''(0)\right] = \mu\sqrt{\frac{a}{\nu}}\,U\left(-0.938732 + 1.311937\frac{xa}{U}\right). \tag{10}$$

It is zero at $x = 0.715531\ U/a$.

HEAT TRANSFER

Suppose the temperature of the fluid at infinity is T_∞ and the temperature of the plate is T_0. Ignoring viscous dissipation, the energy equation is