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Effect of Vertical Alignment on the Performance of Bubble and Foam Fractionation Columns

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In the course of recent research on bubble and foam fractionation (Valdes-Krieg et al., 1973, 1975), we have observed that the flow conditions and separations obtained in a countercurrent bubble fractionation column are sensitive to slight departures from true vertical alignment of the column. This phenomenon was observed to occur in a number of runs in which an anionic surfactant and copper ions were removed from a high-ionic-strength solution, which simulated a three-fold concentrated seawater brine. Surfactant removals were especially affected by column misalignment. We conducted a few experiments which would measure the effect of a controlled tilt in the column and compare its performance under aligned and misaligned conditions.

EXPERIMENT

A 6.95-cm diameter plexiglas column with a total length of 190.5 cm (foam and liquid pool combined) was used to conduct the experiments. Foam collapse was accomplished by means of a rotating perforated sleeve at the top of the column. The bottom of the column was provided with a fused-silica diffuser plate through which prehumidified air was sparged. Liquid entered the column 164 cm above the sparger plate through perforations in an annular distributor fed through a two-line manifold. The interface between aerated liquid (bubble regime) and foam was held 10 cm above the feed level. A similar device was used to withdraw the liquid effluent at the sparger level. The use of these distributors minimized liquid maldistribution at the inlet and outlet points, as well as bubble entrainment in the effluent. Axial liquid-phase concentration

Table 1. Effect of Vertical Alignment on Column Performance

Liquid flow rate = 800 cm³/min

Air flow rate = 1500 cm³/min

	Set 1**		Set 2		Set 3		Set 4	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Column misalignment, degrees	0	*	0	*	0	1	0	1
Surfactant concentration in feed, ppm	19.6	19.6	31.0	31.0	37.2	37.2	39.6	39.6
Surfactant concentration within column at liquid entry point, ppm	10.4	10.0	16.0	13.6	20.9	20.3	25.3	24.4
Surfactant concentration in liquid effluent, ppm	0.40	0.80	2.8	3.95	5.0	7.5	4.0	7.5
Surfactant concentration in collapsed foam, ppm	202	241	93	122	140	154	145	165

* Uncontrolled tilt, less than 1 degree.

** Obtained using concentrated NaCl solution (10.5% w/v).

profiles were measured during the runs by inserting glass-teflon needle valves at several locations along the column height. These valves had their inlet 0.5 cm from the column wall to avoid sampling of a boundary layer. A traveling probe was located 92.5 cm from the column bottom to permit sampling of the liquid phase along the radius of the column. Vertical alignment was accomplished by adjusting nuts on threaded rods which supported the column at the two extremes. True internal vertical alignment was obtained by means of plumb bobs, and controlled tilts were measured with adjustable levels, having vernier radial calibrations, attached to the column.

The anionic surfactant used was Neodol 25-3A (Shell Chemical Co.), which had been proven effective for increasing heat-transfer rates in seawater desalination in vertical-tube evaporators (Sephton, 1973). Surfactant solutions in a model solution (sodium, magnesium and calcium chlorides, and sulfates) simulating a threefold concentrated seawater brine were used for the experiments. Surfactant analysis was carried out spectrophotometrically (Moore and Kobleson, 1956); the maximum error in this determination was found to be 10%, as determined by duplicate and triplicate analyses.

RESULTS AND DISCUSSION

Typical performance characteristics of the column for vertically aligned and misaligned conditions are given in Table 1. Comparison of removals for a given set of runs under both conditions reveals a pronounced effect of slight misalignment (one degree) on column performance. This was accompanied by the formation of an overhead foam with a lower liquid fraction and a slight reduction in air holdup. Bubble swarms exhibited a net velocity of ascent which appeared to be radially uniform under aligned conditions. Back-circulation of bubbles on the side toward which the column was tilted was observed under misaligned conditions. The scale of this circulation was about 90 cm, being localized in the intermediate levels of the column of liquid. Released pulses of $KMnO_4$ solution in the liquid feed line evidenced liquid-phase channeling under these conditions, and the absence of such channeling when the column had true vertical alignment.

Axial concentration profiles within the liquid phase of the contactor can be used to evaluate longitudinal dispersion and mass transfer rates for solute transport to the interface. Figure 1 depicts such concentration profiles for samples withdrawn through the column wall on the side opposite to the direction of tilt for one set of runs. One feature of such curves is a sudden drop in concentration in the liquid as it enters the column. This phenomenon is often called a *concentration jump* and is the result of dilution of the feed by less concentrated liquid through longitudinal dispersion. The decrease in solute concentration with distance along the column reflects the combined effects of countercurrent contact with the air bubbles, longitudinal dispersion, the surface-equilibrium relationship and the mass-transfer rate of surfactant to the air-liquid interface. Comparison of the profiles under aligned and misaligned conditions reveals only a minor change in the amount of concentration drop between the feed and the liquid phase within the column at the liquid-introduction point. This was evident for all sets of runs, as given in Table 1. The curve in Figure 1 obtained under misaligned conditions corresponds to sampling in the region of lower net velocity of ascent of the bubble swarm. Independent measurements of radial concentration profiles demonstrated that surfactant concentrations were higher on this side of a misaligned column. The axial profile for misaligned conditions shows a much less steep axial concentration gradient, crossing the curve corresponding to aligned conditions and ultimately reaching an effluent concentration much higher than that in the aligned case. As shown in Table 1, this feature was observed in all runs.

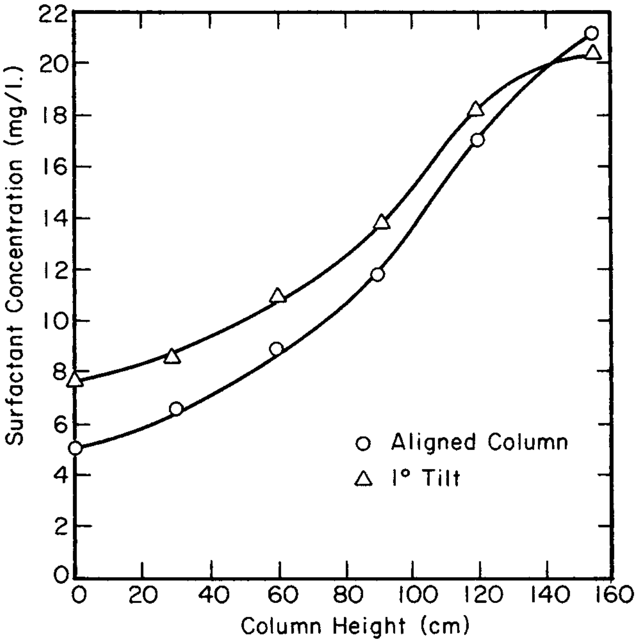

Fig. 1. Axial concentration profiles under aligned and misaligned conditions (Run set no. 3).

The less steep gradient could come from greater backmixing of the liquid or from channeling (radial velocity variations). The absence of any large effect of misalignment on the concentration drop at the feed inlet suggests that channeling in lower regions is the greater effect. This corresponds to the visual observations of channeling when $KMnO_4$ solution was added.

CONCLUSIONS

Vertical misalignment of foam and bubble fractionation columns can strongly affect their performance, even for slight departures from the true vertical. The sensitivity to misalignment is probably affected by flow rates, bubble diameters, and length-to-diameter ratio of the column. These factors were not investigated explicitly. It would appear that a number of cases of nonreproducibility of bubble-column performances can be explained by slight departures from true vertical alignment of the contactor.

Deckwer et al. (1973) reported experimentally derived backmixing coefficients for bubble columns, which varied abruptly at a certain point in the column. It may be that this phenomenon is also associated with effects of slight departures of the column from the vertical.

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Remarks on the Rate of Formation of Bisulfite Ions in Aqueous Solution

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In 1964 a paper by Wang and Himmelblau was published in the *AIChE Journal* on the rate of formation of bisulfite ions in aqueous solution. The results of this work based on radioactive tracer techniques have been widely used in fields of both engineering and science. Apparently unknown to them at that time another work, one based on relaxation methods and conflicting drastically with theirs, had already been published by Eigen et al. (1961). It is the purpose of this note to point out this discrepancy and to shed new light on the rate at which physically dissolved SO_2 dissociates into HSO_3^- in aqueous solutions.

Both of the earlier studies made use of the same reaction for the formation of the bisulfite ion:

$$SO_2 + H_2O \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} H^+ + HSO_3^- \qquad (1)$$

For comparison purposes, the values of the forward rate constant k_1 and of the reverse rate constant k_{-1} are presented from the respective works in Table 1. As is readily apparent, we are not concerned about small deviations of possibly experimental origin, but rather about very large discrepancies of over 8 orders of magnitude which could have arisen only through false assumptions or fundamental differences in definition in one or the other of the two works. Whether the values of Wang and Himmelblau or those of Eigen et al. are used could therefore completely alter the interpretations of other experimental results. One example of this occurred recently in the interpretation of recent laboratory experiments by Beilke et al. (1975).

Since a decision as to which set of measurements one should accept, if either, requires an independent basis, some simple measurements were made in our own laboratory. The experimental setup is shown in Figure 1. A mixture of triply purified N_2 and traces of SO_2 were bubbled continuously through the two bubble columns connected in series. The first bubble column contained 40 or 70 ml of doubly distilled water, the second, the same volume of highly diluted H_2O_2 to oxidize and fix any SO_2 not absorbed in the first column. Measurements were made continuously of pH in the first column and specific conductivity in the second. The concentration of SO_2 in the source chamber was measured by having the gas mixture sucked through a conductivity cell (Hartmann and Braun), calibrated against the standard procedure of West and Gaeke (1956).

As the gas mixture contained no oxygen, the formation of $SO_4^=$ was excluded, leaving HSO_3^- and $SO_3^=$ as the

Table 1. Comparison of Measured Rate Constants, Appropriate to 20°C

Rate constant	Wang and Himmelblau (1964)	Eigen et al. (1961)	Units
k	$(2.2) \cdot 10^{-2}$	$(3.4) \cdot 10^{6}$	s^{-1}
k_{-1}	1.6	$(2.0) \cdot 10^{8}$	$l\,mole^{-1}\,s^{-1}$

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