Performance of Thermal Separation Column with Vertical Barriers

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(Received August 6, 1976)

The relative performance of a new type thermal separation column has been reinvestigated. It was concluded that a column having a couple of vertical barriers is superior to an ordinary open column working under the same temperature gradient.

In previous papers[1,2] reports were given on the performance of a new type thermal separation column in which a couple of vertical screens are installed as flow barriers. The discussion given therewith was found to contain some defects.[3] The column consisted of a couple of cylindrical screens suspended coaxially between double cylinders each of which served as a hot and cold plate. Two different views can be considered in evaluating the performance of this type of column.

(1) The screens are merely inserted in a column space of width $2w$.

(2) Two additional spaces are produced outside the pair of screens.

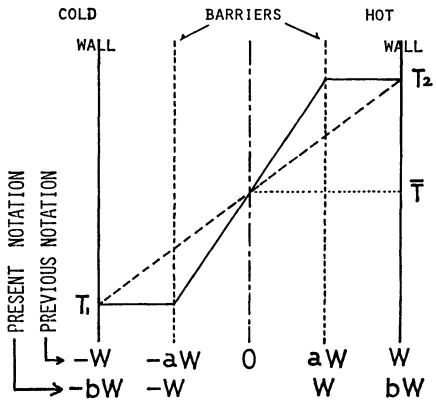

Fig. 1. Basic model of the column with vertical barriers. T_1; Temperature at cold wall, T_2; temperature at hot wall, $\bar{T}$; mean temperature.

The reason for the confusing concept is closely related to the assumption as regards mathematical treatment, the underlying assumption being that the temperature gradient is located only over the space between the two screens and the spaces outside the screens are isothermal (Fig. 1). If the mathematical model is realized in an actual column, a larger temperature gradient will be obtained (solid line, Fig. 1) in the space between the two screens as compared with the case in which the same temperature difference is applied over the whole apparatus (dotted line). This will lead to an enhanced separation. The question arises: Is the better performance observed with the barrier-column simply caused by the enhanced temperature gradient? Comparison should be made under the same temperature gradient but not the temperature difference.

If the temperature gradient developed in the column is not much influenced by the installation of vertical barriers view (1) should be adopted. We thus need to use two reference columns for discussing the relative performance of the barrier-column. In order to fulfill the requirement of the same temperature gradient, one of the references should be an open column having two walls located at positions where screens are located in the barrier-column (narrower reference column). The other is an open column having the same geometry as that of the barrier-column (wider reference column). The previous discussion was developed only with the latter reference for the reason that the actual temperature gradient in the barrier-column might differ from that of the mathematical model, and that the externally applied temperature difference might be divided over each sub-column. It is also difficult to compare the performance when we take the narrower reference column with a different geometry as a standard.

Experimental

In order to confirm the reliability of the theory we have constructed an open column (narrower reference). Dimensions and characteristic constants of the two reference columns together with those for the barrier-columns are given in Table 1, and a schematic diagram of the reference columns in Fig. 2. The structure of the barrier-column and details of the experiments were reported.[2]

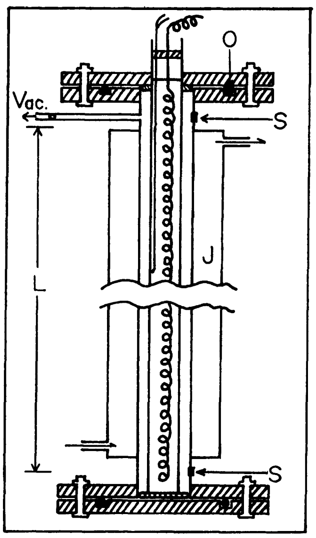

Fig. 2. Schematic view of double cylinder type thermal separation column.
S; Sampling port, O; O-ring, J; water jacket.

Table 1. Geometry and characteristics of columns

(A) Geometry of columns.

Column	Outer tube i.d. r_1 (cm)	Inner tube o.d. r_2 (cm)	r_1/r_2	Half width w (cm)	Mean circumference B (cm)
A (wider reference)	5.27	2.17	2.43	0.775	11.68
B (narrower reference)	4.50	2.95	1.53	0.388	11.70
C (barriered column)	5.27	2.17	2.43	0.775	11.68

(B) Temperature difference applied and characteristic constants.

Column	T (°C)	H (g/s)	K_c (g cm/s)	K_d (g cm/s)	$(2AL)$[a] calcd	$(2AL)$ exptl	t_r (exptl)[b] (min)
A	78	3.49×10^{-3}	13.69	6.88×10^{-3}	0.0305	0.033	0.35
B	78	4.23×10^{-4}	0.104	3.45×10^{-3}	0.500	0.394	3.53
C	78	1.27×10^{-3}	1.77	6.90×10^{-3}	0.086	0.0955	0.78

a) Corrected for cylindricity. b) Relaxation time.

Results and Discussion

If we take view (2) the narrower reference column should be taken as the standard. A slight modification of the theory is advantageous. It is convenient to use the reciprocal $b(=1/a)$ of design parameter a, which indicates the relative location of barriers against the hot and cold walls.

The basic coefficients of transport are then expressed as follows in terms of b:

$$H' = \{2(b-1)^3+1\}H \tag{1}$$

$$K_c' = \{4(b+1)(b-1)^6+4(b-1)^3+1\}K_c \tag{2}$$

$$K_d' = b\cdot K_d \tag{3}$$

where symbols with primes are for the barriered column and those without ones are for the reference column. The quality factor (Eq. 24, Ref. 1) thus becomes

$$\frac{A'}{A} = \frac{H'/2K_c'}{H/2K_c} = \frac{2(b-1)^3+1}{4(b+1)(b-1)^6+4(b-1)^3+1}. \tag{4}$$

A(or A') defined, respectively, by

$$A = H/2(K_c+K_d) \tag{5}$$

is a parameter appearing in the definition of equilibrium separation factor

$$q_e = e^{2AL}. \tag{6}$$

In the derivation of Eq. 4, the contribution of K_d (and K_d') was ignored. Equation 4 is graphically represented in Fig. 3 against parameter b. Experimental value of A'/A referred to the narrower reference was found to be 0.242, *ca.* 40% greater than the theoretical one, 0.175, at b=2.0 (*i.e.*, a=1/2). A 40% deviation is acceptable if local inhomogeneity in both the column structure and temperature distribution is taken into consideration. The result is in line with the theory. We see that the quality factor A'/A decreases with increasing b. This was expected, since gases in the additional spaces will have a diluting effect to reduce the separation.

Monotonous decrease in A'/A with increasing b (Fig. 3) does not mean that the performance of the barrier-column is inferior. The performance of a given column should be evaluated by taking into account the factors such as product yield per unit time, per unit volume of

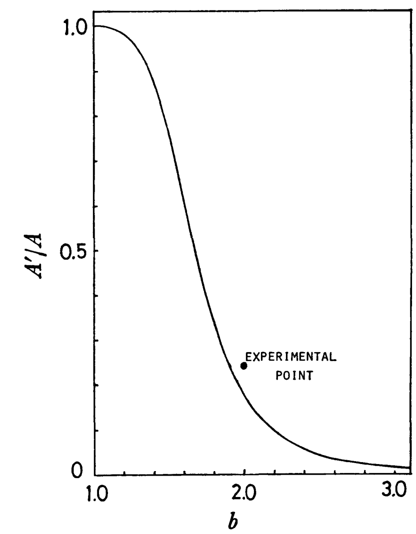

Fig. 3. Change in quality factor A'/A with b according to Eq. 4.
Experimental point is the ratio of columns C and B.

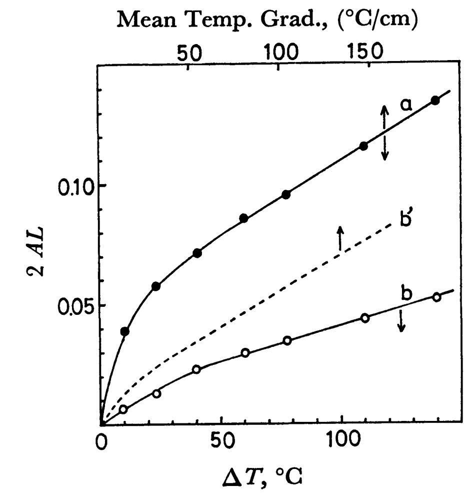

Fig. 4. Comparison of performance of barriered column (curve a) with that of the wider reference (b and b′). Curves b and b′ are drawn on the base of applied temperature difference and temperature gradient, respectively.[3] Curve a can refer to both the two scales at upper and lower marginals.

apparatus, per unit energy consumed, *etc.* besides the degree of equilibrium separation. A comparison of any given two columns is complicated. We have no reliable means to compare the overall performances of two columns of different size. If, however, we take the wider reference as the standard, both total capacity of the column and energy consumed per unit time can be assumed almost to be common. This is clearly an advantage.

There still remains a question concerning the temperature gradient, which should be higher in the barrier-column than in the wider reference under the same temperature difference applied. The barrier-column was constructed to fulfill the design parameter a to be 0.5 ($b=2$). Thus the temperature gradient should be twice as high as the wider reference if applied temperature difference is equal. The performance for the barrier-column observed at a given ΔT should be compared with that for the wider reference column observed at a twice greater value of the given ΔT.

In Fig. 4, a part of which was reproduced from Ref. 2, the scale of abscissa is expressed as applied temperature difference and also as mean temperature gradient. Curve a, which stands for the barrier-column, refers to both the two scales, while b is drawn on the base of applied ΔT. Curve b′ was drawn by shifting[4] curve b in order to compare the performances at the same temperature gradient. It is clearly indicated that the performance of the barrier-column is much better than that of the wider reference column operating under a twice greater temperature difference.

References

1) K. Sasaki, T. Yoshitomi, and N. Miura, *Bull. Chem. Soc. Jpn.*, **49**, 363 (1976).

2) K. Sasaki, N. Miura, and T. Yoshitomi, *Bull. Chem. Soc. Jpn.*, **49**, 367 (1976).

3) *Cf.* Ref. 1, footnote 17.

4) This is equivalent to reducing the temperature scale to one-half for curve b.