The Influence of Baffles in Packed Beds on Radial Transport

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The experiments reported herein show that simple types of lateral baffles placed in a packed bed can double the rate of heat transport to the wall, while causing only a slight increase in bed pressure drop. This result suggests that the customary use of granular materials in packed beds may not represent the best geometric arrangement in terms of the lateral transport obtained and the price paid for it in pressure loss and capital construction cost. Experiments with baffled beds may stimulate the exploration of new geometric arrangements which will balance the objectives of simplicity and high performance better than present packings do.

Lateral transport in packed beds has been described by a number of authors in terms of a random walk dispersion process (*1, 3, 4*). The random walk makes inefficient use of the energy consumed in flow and mixing because the lateral steps taken are short in distance and randomly directed. It should be possible, by altering the bed geometry, to exchange some of the short side-to-side movements for longer bulk flow traverses which will assist lateral transport without greatly increasing the fluid path length and pressure drop.

The hypothesis was tested with various baffle arrangements in an experimental packed tube equipped to heat flowing air by means of an electrical resistance wire wound on the wall (*2*). Two types of baffles were used: disks and doughnuts, consisting of disks concentric with the tube, alternating with annuli whose outer perimeters touched the wall; and circular partitions in the tube, whose flow openings were made by cutting the circles along a chord, and which were placed with the openings of adjacent baffles on opposite sides of the tube. The heat transfer and bed pressure drop were measured for baffles of different dimensions.

In this exploratory study a simple measure of heat transfer was employed to evaluate the baffles. An effective wall film coefficient h_e was calculated from the heat gained by the fluid, the wall area, and the logarithmic mean of the inlet and outlet temperature differences between wall and fluid. While the calculation of h_e was not in correspondence with the mechanism of this type of heat transfer, it did allow for an easy comparison among the various baffle arrangements and permitted the use of an apparatus requiring only four thermocouples.

APPARATUS AND PROCEDURE

The apparatus consisted of a Pyrex tube having a packed section 3.6-in. I.D. by 15 in. length, packed with 0.3 in. alumina spheres and various cardboard baffle arrangements. The tube was wound with electrical resistance wire and heated to warm flowing air from room temperature to about 180°F. Four thermocouples were placed to measure the air and wall temperatures at the inlet and at the outlet. The air temperatures were measured at the center line with thermocouples placed just before an inlet distributor plate and at the end of the packing at the outlet. For wall temperature measurement the tube wall was drilled through at positions 0.25 in. downstream from the inlet distributor plate and 0.25 in. upstream from the outlet end of the packing. Thermocouples were cemented in the holes with their junctions just beneath the inside wall surface. The wall temperatures thus measured coincided under flow conditions with those of a thermocouple probe placed with its junction against the inside wall surface. The maximum error in the temperatures was estimated to be 2°F. A mercury manometer was used to measure the pressure drop across the test section, and by alternate connections to adjust the air flow rate with an orifice meter. The packed tube was oriented vertically with upward air flow.

The procedure consisted of hand packing the tube with alumina spheres and the chosen baffle arrangement, starting the air flow and heat, waiting for steady terminal temperatures to be attained, and recording the four terminal temperatures and the pressure drop across the test section. The air mass flow rate for all runs was approximately constant at 230 lb./(hr.) (sq. ft.), based on the empty tube. The electrical heating rate was approximately the same for all runs.

The effective wall film coefficient was calculated from the equations

$$h_e = \frac{q}{A\,\Delta t_m}$$

where the total heat transferred was found from

$$q = W\,C_p\,(t_{\text{outlet}} - t_{\text{inlet}})$$

and the logarithmic mean temperature difference was given by

$$\Delta t_m = \frac{\Delta t_{\text{inlet}} - \Delta t_{\text{outlet}}}{\ln \dfrac{\Delta t_{\text{inlet}}}{\Delta t_{\text{outlet}}}}$$

RESULTS

The experiments covered the examination of different baffle dimensions for two types of baffles. The first type comprised alternate disks and annuli, equally spaced axially and arranged in radial planes concentric with the tube. The dimensions of this system were completely specified by the baffle-to-baffle spacing, the diameter of the disks, and the inner diameter of the annuli. The outer diameter of the annuli was always the tube inside diameter of 3.6 in. The second type of baffle was made from 3.6-in. diameter disks cut off along a chord and arranged in radial planes with alternate openings on opposite sides of the tube. The dimensions of this system were specified by the baffle-to-baffle spacing and the maximum perpendicular distance from the chord to the opposite edge.

Experimental results on terminal temperatures, the wall film coefficient, and bed pressure drop are summarized in the accompanying table.

It can be seen that trials 6, 7, and 12, representing highly baffled beds, gave better than twice the wall coefficient of the unbaffled bed, with only about 20% more bed pressure drop.

DISCUSSION

The values of h_e in baffled beds were compared with the unbaffled bed value of 8.4 B.t.u./(hr.) (sq. ft.) (°F.), obtained in trial 1. For disks and doughnuts the effect of baffle-to-baffle spacing was shown in trials 4 and 6, where h_e increased from 15.0 to 19.2 when the spacing was reduced from 2 to 1 in. A sharp improvement in heat transfer with decreased baffle spacing was apparent in trials 8, 9, and 12, where partition baffles gave coefficients of 7.8, 10.3, and 21.3 for spacings of 3, 2, and 1 in. A strong center-to-side or side-to-side traversing bulk flow was required for the best heat transfer.

The effect of disk diameter was shown in trials 2, 3, and 4. The analogous effect of chord to opposite edge distance for partition baffles was shown in trials 10, 11, and 12. These two sequences indicated the value of decreasing the flow cross section near the wall. The pinch at the wall apparently gave a high value to the true wall film coefficient, which had a beneficial effect on the over-all heat

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Process fluid: Air
Tube dimensions: 3.6-in. I. D. by 15 in. length
Packing: 0.3-in. alumina spheres
Mass flow rate: 230 lb./(hr.)(sq. ft.), based on empty tube
Linear velocity: 1.0 ft./sec., based on empty tube

Trial no.	Baffle dimensions, in.: Baffle to baffle spacing	Diam. of disks	Inner diam. of annuli	Chord to opposite edge	Temperature, °F.: Wall at inlet	Inlet air	Wall at exit	Exit air	h_e, B.t.u./(hr.) (sq. ft.) (°F.)	Bed pressure drop, in. Hg
1	Unbaffled bed				136	77	201	177	8.4	7.0
	Disk and doughnut baffles									
2	2.0	1.75	2.5		132	76	210	178	7.8	7.0
3	2.0	2.5	2.5		133	77	197	175	8.9	7.5
4	2.0	3.25	2.5		121	77	201	189	15.0	
5	1.0	3.25	No Annuli		123	77	201	182	11.3	
6	1.0	3.25	2.5		125	77	201	195	19.2	8.4
7	1.0	3.25	1.0		108	77	200	193	23.7	
	Staggered horizontal partitions									
8	3.0			3.0	111	77	192	158	7.8	
9	2.0			3.0	137	77	204	186	10.3	
10	1.0			2.0	132	76	203	183	10.1	7.5
11	1.0			2.5	121	76	193	174	10.8	8.0
12	1.0			3.0	109	77	197	189	21.3	8.0

transfer measured by the effective wall film coefficient.

The effect of annulus inner diameter was shown in trials 5, 6, and 7. The value of a traversing bulk flow from center-to-wall was again apparent. Neither large disk baffles nor large annular baffles were anywhere near as effective alone as was their combination in trials 6 and 7.

The small rise in bed pressure drop associated with baffling suggested that the actual fluid path length and flow cross section were little affected by the presence of the baffles. The flow pattern was altered to favor lateral transport without increasing the dissipation of mechanical energy. This finding was modified however by the increase in bed void fraction which undoubtedly accompanied increased baffling.

CONCLUSIONS

Exploratory studies have shown that transverse baffles placed in a packed bed can double the effective lateral transport of heat, and presumably of mass also, while increasing the bed pressure loss by about 20%. The baffles should impress a traversing lateral bulk flow on the normal flow regime. To improve heat transfer to the surroundings the baffles should pinch the fluid flow at the wall.

NOTATION

A = inside wall area of packed bed, sq. ft.
C_p = mass heat capacity, B.t.u./(lb.) (°F.)
h_e = effective wall film coefficient, B.t.u./(hr.) (sq. ft.) (°F.)
q = total heat transfer rate, B.t.u./hr.
t = temperature, °F.
Δt = temperature difference between wall and bulk fluid, °F.
Δt_m = logarithmic mean temperature difference, °F.
W = flow rate through apparatus, lb./hr.

LITERATURE CITED

1. Baron, Thomas, *Chem. Eng. Progr.*, **48**, 118 (1952).
2. Hoffman, Paul, S.M. thesis, Mass. Inst. Technol., Cambridge, Massachusetts (1960).
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Dear Editor:

In a recent Communication to the Editor Holm (*1*) treated the effect of nonuniform vapor distribution on distillation plate efficiency and showed that when vapor rate increases along the direction of flow of the liquid phase, Murphree plate efficiencies are in general greater than those for uniform vapor distribution as given by Lewis (*2*).

There appears to be an error in the author's derivation which renders his results invalid.

In arriving at the expression for E_{mv}/E [the author's Equation (4)] the author used the following expression for the average vapor concentration above the tray:

$$\bar{y} = \int_0^1 y\,dw$$

Correctly, $\bar{y}$ is the mass average concentration and should be given by

$$\bar{y} = \int_0^1 y \frac{g}{\bar{G}} dw \qquad (1)$$

Using this we arrive at

$$\frac{E_{mv}}{E} = \int_0^1 \frac{g}{\bar{G}} e^{E\lambda\left(1 - \int_0^w \frac{g}{\bar{G}} dw\right)} dw \qquad (2)$$

Since $g/\bar{G}$ is a function of w, we may write

$$\int_0^w \frac{g}{\bar{G}} dw = \phi(w) \text{ and}$$
$$\frac{g}{\bar{G}} = \frac{d\phi}{dw} = \phi'(w) \qquad (3)$$

and Equation (2) now becomes

$$\frac{E_{mv}}{E} = e^{E\lambda} \int_0^1 \phi'(w)\, e^{-E\lambda\phi(w)}\, dw$$
$$= \frac{e^{E\lambda}}{E\lambda} \left[e^{-E\lambda\phi(w)}\right]_1^0 \qquad (4)$$

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