HEAT TRANSFER BETWEEN A HORIZONTAL CYLINDER AND A FLUIDIZED BED WITH SMALL PACKING

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Measurements were made of heat transfer between horizontal cylinders (of 20, 30, and 50 mm diameter) and fluidized beds (of sand silica gel) with packings of spirals of wire of 10, 20 and 55 mm diameter. The data obtained were correlated and analytical relationships are presented.

Fluidized beds with some form of small packing will be used in future in various chemical processes [1, 2]. The removal of heat from such fluidized reactors is often done through cylinders. Heat transfer in these conditions is however still inadequately understood. There is some knowledge of transfer to vertical cylinders in fluidized beds [3] but no useful data for horizontal cylinders. Results are given here of an experimental investigation of heat transfer under these latter conditions.

The experiments were made in a column of 300 mm diameter described in detail in [4]. The height of the static bed was 300 mm. Air at room temperature was used to fluidize the bed. Measurements were made with silica gel ($d = 0.19$ mm) and sand ($d = 0.23$ mm) and small fixed wire spirals of 55, 20 and 10 mm diameter and lengths equal to their diameters [3].

At a height of 19 cm above the air distributing mesh in the column a horizontal cylindrical probe was placed [3]. This consisted of a copper cylinder with an electrical heater along its axis and an insulated thermocouple. Measurements were made of the electrical power released by the heater and of the temperature difference between the cylinder surface and the fluidized bed. From these the total coefficient for heat transfer from the cylinder was determined for cylinders of 50, 30 and 20 mm diameter.

Further, to measure the local coefficient over the cylinder surface another probe of 50 mm diameter was made with an electrical heating element of 65×12.5 mm. This heater was formed from a flat spiral of wire attached to the thermally insulated probe lining and covered with a copper plate. The temperature of this plate was measured by a thermocouple attached to it. The cylindrical probe could be rotated about its own axis and clamped to the column wall in any position with the position of the heater indicated outside the column.

In the first series of tests the local heat transfer coefficients were measured at various points along the perimeter of the horizontal probe in a free bed and a bed with the packing. Figure 1 shows some results of these experiments in the form of local heat transfer coefficients plotted for various gas velocities. For improved presentation values of α_{loc} are plotted for free fluidized conditions (on the left) anol boiling conditions (on the right). In the fluidized bed with low gas velocities, the lowest heat transfer was observed on the up and down stream areas. As the velocity increases the transfer in these areas improves and becomes more uniform for all circumferential positions changing even to a maximum in the down stream position. Similar results have been found previously for fluidized beds [6, 7, 9, 10].

In the fluidized condition with packings this behavior is substantially changed. Lower heat transfer is maintained even at high gas velocities in both the up- and downstream areas, particularly in the latter where the values of the coefficient are independent of the velocity. It remains constant and approximately

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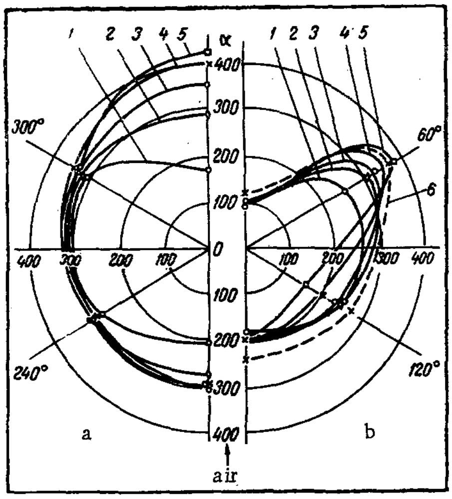

Fig. 1. Plot of α_{loc} versus interstitial velocity of air. Disperse material — sand d = 0.23 mm. a) Free bed; b) bed with packing. 1-5) Velocities 8.5; 16; 28; 50; and 70 cm /sec, respectively. Dashed line, packing 55 mm, interstitial velocity 50 cm/sec.

equal to the coefficient for the static bed, over an area bounded by the angle at which a pyramid of the bed material would repose. This observation supports the thesis that in the downstream area the bed material forms a static region.

In the fluidized condition the size and rate of bubble formation increases with the gas velocity and stationary particles are progressively drawn into the fluidized region. This is accompanied by a tendency of the bubbles to collapse in the vicinity of the static packing which leads to appreciable expansion [4] and increased voidage [3] in the boiling region. In this situation there is insufficient energy in the smaller bubbles to transfer particles to and from the region downstream of the cylinder.

As shown [5] in the region upstream of the cylinder a fluctuating air pocket is formed. As the gas velocity increases, the air pocket is repeatedly removed and reformed and improves the heat transfer. The transfer coefficient then gradually approaches the value for the sides of the cylinder.

In the region with packings the transfer coefficient for the upstream area of the cylinder remained lower than that for the downstream area for all gas velocities investigated. This confirms the thesis that density in the boiling region is higher than that with the packings. This static packing tends to reduce the motion of the particles and thereby reduces the heat transfer.

This effect of the packing is also evident from the observation that the downstream area of the cylinder is "capped" with stationary particle. Naturally therefore increase in the diameter of the horizontal cylinder increases the size of the stationary region and reduces the total heat transfer coefficient. The data in Fig. 2 illustrates the behavior graphically by showing the relationship between the total coefficients for cylinders of three different diameters to the air velocity. When the cylinder diameter was increased the transfer in the bed decreased for other constant conditions. For comparison this figure also

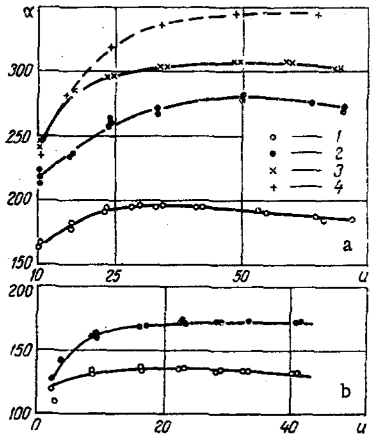

Fig. 2

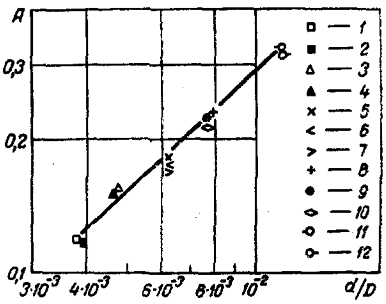

Fig. 3

Fig. 2. Mean heat transfer coefficient versus air interstitial velocity. Disperse material — sand d = 0.23 mm (a, bed with packing Ø 55 mm; b, with packing Ø 20 mm). 1, 2, 3, Probe diameters; 4, vertical position of probe Ø 30 mm.

Fig. 3. Correlational plot: 1, 2, silica gel, packings Ø 55 and 20 mm, probe Ø 50 mm; 3, 4, sand, packings Ø 55 and 20 mm, probe Ø 50 mm; 5, 6, 7, silica gel, packings Ø 55, 10 and 20 mm, probe Ø 30 mm; 8, 9, 10, sand, packings Ø 55, 10 and 20 mm, probe Ø 30 mm; 11, 12, sand, packings Ø 55 and 20 mm, probe Ø 20 mm.

shows the coefficient for transfer between a vertical surface and a boiling bed. It can be seen that the transfer coefficient of the horizontal cylinder is less than that for the vertical one.

It should also be noted that for a wide range of gas velocities, the transfer coefficient remains nearly constant at about its maximum value. It should also be noted that the transfer to the horizontal probe depends on the size of the packing elements. The experimental data for packings used here (i.e. wire spirals) are higher for the 55 mm size than for the 20 mm size. Accordingly ratios of d/l_p, d/D were used as criteria for characterizing their geometry. These take account of the probe diameter D and the hydraulic radius l_p of the packing. The latter is taken to be the radius of a layer of surface area equal to that of the packing.

The results of correlating all the data are given in Fig. 3. These data approximate to the equation

$$Nu_{max} = 19\,Ar^{0,25}\left(\frac{l_p}{d}\right)^{0,13}\left(\frac{d}{D}\right)^{0,91}. \quad (1)$$

This was obtained for ($250 \le Ar \le 1100$; $3.8\cdot 10^{-3} \le d/D \le 1.2\cdot 10^{-2}$; $5 \le l_p/d \le 160$). The maximum scatter of the points from this line does not exceed ±7%. Taking into account that the maximum error in measuring the transfer coefficient is ±3% such scatter is not excessive. In equation (1) the index of the ratio (d/D) approaches unity and consequently the transfer coefficient varies inversely with the cylinder diameter. It is not therefore advisable to use coefficients from large diameter cylinders in fluidized beds with small packings. It is also of interest to note that the index of the ratio d/l_p is much smaller. This proves that the behavior of the fixed packing has a much lesser influence on the heat transfer than the cylinder diameter.

As mentioned above, for a wide range of gas velocities the transfer coefficient is nearly constant and equal to α_{max}. From the experimental data on the Re—Ar graphs the limits within which the coefficient differs by no more than ±5% from the maximum are shown. The upper and lower limits are given by

$$Re_p = 0.064\,Ar^{0,42},$$

$$Re_в = 0.43\,Ar^{0,483}. \quad (2)$$

These equations apply for ($250 \le Ar \le 1100$). The maximum deviation of the points does not exceed ±5%.

Hence for estimating the heat transfer coefficients between the boiling bed and horizontal cylinders Eq. (1) is recommended. This equation is accurate for a fairly wide range of gas velocities within the limits defined by Eqs. (2).

NOTATION

d	is the mean diameter of particles;
l_p	is the characteristic size of packing;
D	is the probe diameter;
u	is the velocity of gas;
α, α_{loc}, α_{max}	are the mean, local and maximum heat transfer coefficients.

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