STUDY CONCERNING THE HEAT TRANSFER BETWEEN A DISPERSE MATERIAL AND A SOLID HEAT CARRIER

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Results are shown of an experimental study concerning the heat transfer between two disperse media in a compact bed mixed in a revolving drum.

The advantages of heat exchangers with an intermediate solid heat carrier become most obvious during high-temperature treatment of fine-disperse material. The use of a solid heat carrier makes it simple to design a thermally stable heat transfer surface and to eliminate the erosion of disperse material by hot gases.

The energy lost on transporting a solid heat carrier is minimum and the concentration of a disperse material in the heat exchanger is maximum with the heat treated material in a compact bed.

The problem of heat transfer in a stationary bed of disperse material and with uniformly distributed heat sources was considered in [1].

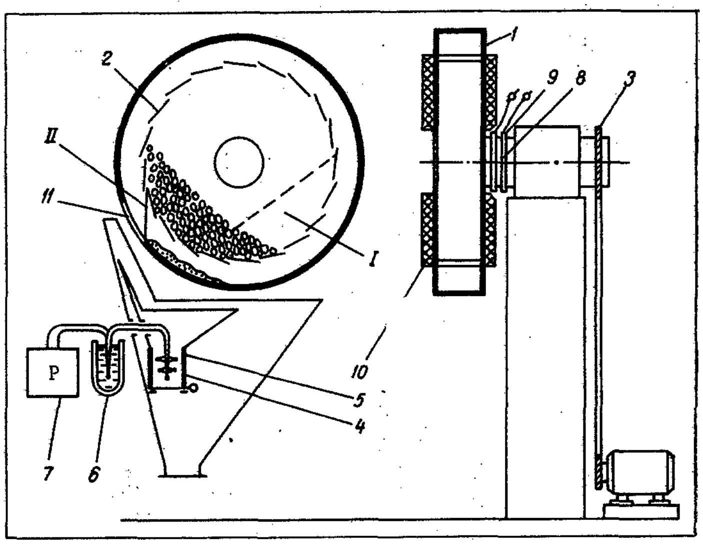

Fig. 1. Schematic diagram of the apparatus for studying the heat transfer in a mixture of disperse materials: 1) drum, 2) shutter grid, 3) drum drive, 4) disperse-material collector, 5), 6) hot and cold thermocouple junctions, 7) potentiometer, 8) slip rings, 9) sliding contacts, 10) electric heater for the end surface, 11) hatch door for removing the disperse material, I) position of material in the drum during mixing, II) position of material in the drum during separating.

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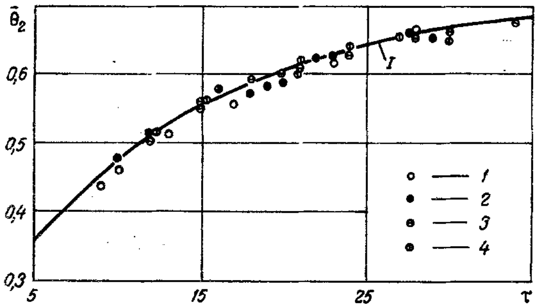

Fig. 2

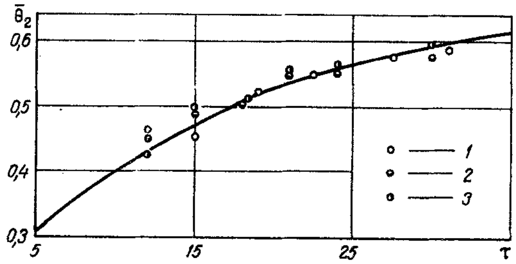

Fig. 3

Fig. 2. Temperature variation with time (τ sec) in the fine-disperse 90-114 μm sand fraction (β_2/ε = 1.046) heated with porcelain balls (R_1 = 10 mm): drum speed 10 rpm (1), 15 rpm (2), 20 rpm (3), 25 rpm (4), according to formula (1) (I).

Fig. 3. Temperature variation with time (τ sec) in fine-disperse kaolin (β_2/ε = 1.169) heated with porcelain balls (R_1 = 10 mm): drum speed 15 rpm (1), 20 rpm (2), 25 rpm (3), according to formula (1) (I).

Accounting for the distribution characteristics of solid components in a mixture with d_1/d_2 > 25 has made it possible to reduce the solution in [1] to the following form:

$$\bar{\theta}_2 = \left[\frac{1-\beta_1^{1/3}-\beta_1^{2/3}+\beta_1}{2\beta_2(\lambda_2/\lambda_1+\beta_1^{-1/3}-1)} - \frac{W_1}{W_1+W_2}\right] \times \exp\left\{-\frac{8a_1\tau}{R_1^2[1+\lambda_1/\lambda_2(\beta_1^{-1/3}-1)]}\left(1+\frac{W_1}{W_2}\right)\right\} + \frac{W_1}{W_1+W_2} \quad (1)$$

for $\beta_2 > \varepsilon$;

$$\bar{\theta}_2 = \left[\frac{1-\beta_1^{1/3}-\beta_1^{2/3}+\beta_1}{2\beta_2(\lambda_2/\lambda_1+\beta_1^{-1/3}-1)} - \frac{W_1}{W_1+W_2}\right] \times \exp\left[-\frac{8a_2(1-\varepsilon)\tau}{R_1^2\varepsilon(\lambda_2/\lambda_1+\beta_1^{-1/3}-1)}\left(1+\frac{W_2}{W_1}\right)\right] + \frac{W_1}{W_1+W_2} \quad (2)$$

for $\beta_2 < \varepsilon$.

If the temperature difference b between the solid components of the process is given, then the time necessary for such a temperature change to occur can be determined according to the formula:

$$\tau_b = -\ln b \cdot \frac{R_1^2[1+\lambda_1/\lambda_2(\beta_1^{-1/3}-1)]}{8a_1(1+W_1/W_2)} \quad (3)$$

for $\beta_2 > \varepsilon$

and

$$\tau_b = -\ln b \cdot \frac{R_1^2\varepsilon(\lambda_2/\lambda_1+\beta_1^{-1/3}-1)}{8a_2(1-\varepsilon)\left(1+\frac{W_2}{W_1}\right)} \quad (4)$$

for $\beta_2 < \varepsilon$.

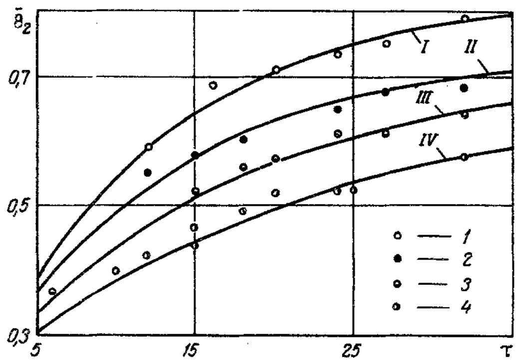

Fig. 4. Temperature variation with time (τ sec) in the fine-disperse 114-315 μm fraction of sand heated with porcelain balls (R_1 = 10 mm) at a drum speed n = 20 rpm; relative volume concentration of the disperse material β_2/ε = 0.678 (1), 0.891 (2), 1.095 (3), 1.180 (4), according to formulas (1) and (2) (I-IV).

In the general case of mixing as in a drum, for example, the solid components of the mixture are distributed nonuniformly. The motion of a mixture may also, under various conditions, cause the temperature gradients to decrease and the bed porosity to increase.

In order to study the heat transfer between a moving mixture of a disperse material and a granular heat carrier, the authors performed experiments on an apparatus shown schematically in Fig. 1. This apparatus consisted of a cantilever mounted drum 750 mm in diameter with a cylindrical grid of shutters 600 mm in diameter inside it.

Into the inner cavity of the drum was poured a granular heat carrier and the disperse material. During counterclockwise rotation the shutters closed into a barrier inside which both components mixed. The components could be separated by reversing the drum rotation and thus opening the shutters into a cylindrical sieve. Such a drum design eliminated losses of time on various auxiliary operations during change-over from mixing to separating, it also yielded a more accurate determination of the true contact time with the heat carrier.

In each series of tests we measured the temperature of the disperse material after heating by the carrier for various lengths of mixing time. The solid heater material had been heated before that to 230-350°C in an electric oven.

The drum was equipped with a thermal compensation system at the end surfaces and with a regulator-drive. As the granular heat carrier we used porcelain balls with a radius $R_1 = 10$ mm and grade G-70 fireclay balls with a radius $R_1 = 3$ mm.

The loose disperse material were 90-114 μm, 114-315 μm, 315-500 μm, 500-700 μm, and 700-1000 μm fractions of quartz sand, the cohesive disperse material was dresses kaolin from the Prosyansk deposits. The drum speed was varied within the 10-25 rpm range; the drum was 25-30% full, with the relative volume concentration of the disperse medium varying within $\beta_2/\varepsilon = 0.678-1.18$.

In the evaluation of test data, proper consideration was given to the heating of the disperse material by the drum walls. The test results are compared here with calculations according to formulas (1) and (2).

The thermophysical properties of quartz sand had been determined experimentally, those of kaolin, porcelain, and G-70 fireclay had been taken from the published literature.

The tests have revealed no effect of the drum speed on the heat transfer between the disperse material and the solid heat carrier. An explanation for this is that particles of loose material circulate mainly along closed trajectories inside the drum and that the velocity of their principal motion is very low.

It is to be noted that in all cases the conditions inside the revolving drum corresponded to "rolling" motion. The results of heating quartz sand of the 90-114 μm fraction and kaolin with porcelain balls ($R_1 = 10$ mm) at various drum speeds are shown in Figs. 2 and 3.

When the concentration of the fine-disperse material in the mixture changes, as long as $\beta_2 < \varepsilon$, one notes some decrease in the rate of heat transfer between the mixture components. An explanation for this is that, at a lower than "saturation" concentration of the disperse component ($\beta_2 = \varepsilon$), this heat treated material occupies the interstices between the balls of the heat carrier but very nonuniformly: more densely in the bottom part of the layer, where it has filled the interstices prior to "saturation." When $\beta_2 < \varepsilon$, therefore, the heat transfer surface between both components becomes smaller.

Dating on heating the 114-315 μm fraction of sand with porcelain balls at various concentrations β_2 are shown in Fig. 4.

A comparison between test data and calculations according to formulas (1) and (2) indicates that within the ranges $\beta_1 > 0.25$, $d_1/d_2 > 33$, $\tau = 0.05 c_2 \rho_2 d_2^2/\lambda_G$ there is agreement within a probable error of ±6.8%.

For $d_1/d_2 < 33$ the bed of fine-disperse particles in the intergranular interstices of the heat carrier has a higher porosity and, therefore, the calculated values of $\overline{\theta}_2$ differ from the test values.

At time $\tau < 0.05 c_2 \rho_2 d_2^2/\lambda_G$ the bed of fine-disperse material cannot be considered quasihomogeneous [2], as has been assumed for the derivation of Eqs. (1) and (2).

NOTATION

- $\lambda_1, \lambda_2, \lambda_G$ are the thermal conductivity of the solid heat carrier material, of the disperse material, and of the gas respectively;
- β_1, β_2 are the volume concentration of the solid heat carrier and of the disperse material, respectively: $\beta_1 = V_1/(V_1 + V_2)$, $\beta_2 = 1 - \beta_1$;
- V_1 is the true volume flow rate of the solid heat carrier;
- V_2 is the effective volume flow rate of the disperse material;
- W_1, W_2 are the water equivalent of the solid heat carrier and of the disperse material respectively;
- a_1, a_2 are the thermal diffusivity of the solid heat carrier material and of the disperse material respectively;

ε is the porosity of the bed of solid heat carrier particles;

τ is the time, sec;

$\overline{\theta}_2 = (\overline{t}_2 - t_2')/(t_1' - t_2')$;

$\overline{t}_2$ is the mean instantaneous temperature of the heated medium;

t_1', t_2' are the initial temperature of the heating medium and of the heated medium respectively;

d_1, d_2 are the diameter of heat carrier particles and of disperse material particles respectively;

c_2 is the specific heat of disperse solid material;

ρ_2 is the density of disperse solid material.

LITERATURE CITED

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