Results are given on the heat transfer between the gas and the granular material in a multistage apparatus, and comparison is made with calculations.

In the present work we compare experimental measurements on heat transfer with calculated values obtained from the formulas of [2], and determine the change in the temperature gradients in various parts of a multistage as used in heat engineering and in the performance of various technical processes [1].

The tests were made on a particular type of multistage apparatus consisting of a combination of direct-flow parts with countercurrent flow of the heat carrier as a whole over the apparatus (Fig. 1a). In Fig. 1a four stages in the apparatus are shown; each stage is part of the pneumatic tube 3, 7, 11, or 15 (height 0.5 m and internal diameter 0.027 m) and a separator 4, 8, 12, or 16 of inertial collision type [3].

The heat-carrying gas comes from the oven 22, moves upwards from the bottom, passes in sequence through sections 15, 11, 7, and 3 of the apparatus, and is extracted by the fan 21. The amount of gas passing through the apparatus during the run was recorded by the RS-100 gas counter 20.

The polydisperse material is supplied by the hopper 1 and inlet 2 to the lower part of the upper stage 3 of the apparatus, and it is carried by the gas to the separator 4 where it leaves the flow and passes via the outlet 5 to stage 7, etc.

The material is collected in bunker 23 when it has passed through all stages of the apparatus. The small particles carried off by the gas flow are deposited in the cyclone 19. A suitable hydrodynamic ceiling is provided to organize the gas flow in the required direction in the transfer sleeves 5, 9, 13, and 17 (dtn = 0.008 m), each of which has two baffles 6, 10, 14, and 18. The design of the baffle is shown in Fig. 1b. This disposition of the baffles facilitates production of the moving close-packed layer in the couplings, in which the temperature was monitored. Of course, the height of the moving close-packed layer should be arranged for each stage to avoid gas leak along the walls.

on the basis of the characteristics of the material and the hydraulic resistance of the apparatus.

The two baffle valves in each transfer section provide for continuous transfer of the material as a whole through the apparatus.

The temperatures of the gas and the material were monitored by nine Chromel–Alumel thermocouples placed as shown in Fig. 1. These were read by the electronic potentiometer type EPP-09 shown at 24. The hot junctions recorded the gas temperature and were protected by thin copper grids to avoid contact with particles of the material.

As we have previously described [3] detailed measurements on the separator and the method of calculating the efficiency of particle removal, we do not consider these topics here.

The throughput was determined by weighing the material supplied to the hopper. The measurements were made with quartz sand with various mean particle diameters: \( d_M = 0.3 \cdot 10^{-3} \text{ M} \), \( d_M = 0.5 \cdot 10^{-3} \text{ M} \), \( d_M = 0.75 \cdot 10^{-3} \text{ M} \).

The material flow concentration \( \mu_C \) was varied within limits 0.2–0.5 kg/kg; the initial gas temperature was varied between 473 and 673 °K in steps of 50–100 °K.

Hydrodynamic calculations are involved in complete characterization of such an apparatus; the resistance of the heat-transfer apparatus is the sum of the resistances of the parts consisting of tubes and separators; each of these aspects was examined separately and had been adequately discussed in the literature.

We measured the hydrodynamic resistance of the apparatus as a whole for systems with 2, 4, and 6 stages, the pressure being monitored by manometer 25. For initial gas speeds varying between 12 and 25 m/sec, the resistance of the 2-stage apparatus was 60–65 mm of water, that of the 4-stage apparatus 90–100 mm, and that of the 6-stage apparatus 110–120 mm.

The heat-transfer experiments were conducted on an apparatus consisting of 2, 4, or 6 sections; the results were compared with calculated ones by deriving the latter as follows. The dimensionless temperature of the material is

\[
\theta_M = \frac{1}{1 + R} \left[ 1 - \exp \left( - \frac{\alpha F_t}{W_M} (1 + R) \right) \right].
\]

The dimensionless gas temperature is

\[
\theta_g = 1 - R \theta_M,
\]

where

\[
\theta_M = \frac{\theta - \theta_1}{t_1 - \theta_1}, \quad \theta_g = \frac{t - \theta_1}{t_1 - \theta_1}, \quad R = \frac{W_M}{W_g}.
\]

The true surface of the heat-transfer material in each part of the apparatus \( F_t \), was determined via the following equation [4]:

\[
F_t = k F_c \left[ 1 + \exp (-c \theta) \right],
\]

where \( F_c = |\mu V_{tu}\gamma_{g,av}\sigma|, \quad k = 1.8 + 6 \gamma_M d_M, \quad c = 0.92 - 0.6 \gamma_M d_M. \)

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**Fig. 2.** Temperatures, °K, of material (a) and gas (b) in parts of the apparatus with initial temperatures \( t_1, °K; 1) 673; 2) 573; 3) 473. The broken lines are from experiment, and the continuous lines are from calculation.