INVESTIGATION OF HEAT TRANSFER IN LONGITUDINAL AIR FLOW OVER A STAGGERED TUBE BUNDLE

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Results are presented of an investigation of heat transfer in a longitudinal flow of air over a staggered tube bundle with s/d = 1.2 and with heating and cooling in the range Re = 2 · 10^3–10^5.

Heat transfer in longitudinal flow over close-packed staggered tube bundles has been investigated in [1] and [3] with s/d = 1.2 in [2] with s/d = 1.22, and in [4] with s/d = 1.19. In most of these papers heat transfer on the bundle was determined from measurement of the temperature of one tube wall, usually the central one. At the same time, a substantial nonuniformity of wall temperature of the various tubes was observed in [5, 6] in individual transverse sections of the bundle.

The present paper is devoted to an investigation of heat transfer in longitudinal flow over staggered tube bundles with relative pitch s/d = 1.2, with heated (experimental section No. 1) and cooled (experimental section no. 2) air, the average heat transfer for all tubes of the bundle being determined in the heater.

Section no. 1 (Fig. 1) consisted of 19 tubes of diameter 11 ± 0.01 mm and wall thickness 0.65 ± ± 0.01 mm, held together in a bundle by means of two brass plates, the distance between which was 1.5 m. The distance of the outermost tubes from the hexagonal housing was 1.72 mm. Heating of the air was accomplished directly by passing alternating electric current through the tube bundle. To compensate for difference in thermal expansion of the tubes and the housing, there was provision for free movement of the tubes relative to the upper tube plate. The maximum nonuniformity of heat generation along the tubes did not exceed 1.5 to 2%.

The heat transfer coefficients were measured in a section of length l = 800 mm ($l/d_e \cong 130$), previously found to have stabilized longitudinal flow. The heater tube wall temperature was measured in all 19 tubes of the bundle, at the beginning, middle, and end of the experimental section. Thermocouples (chromel-kopel) made from wire of 0.2 mm diameter were attached directly to the tube walls by argon-arc welding. The thermoelectrodes of the thermocouples were introduced into the tubes through the ends of the heater.

The amount of heat generated in the experimental section was determined from the change in heat content of the air. This disagreed with the measured electrical power by 5–10%.

The experimental cooler (section no. 2) is of similar construction to the heater; there is counterflow of cooling water inside the tubes; the thermocouples for measuring the tube wall temperatures are positioned outside the tubes, and are led in through a joint in the housing.

To measure the temperature of the stream in the intertube space of the cooler, a moveable longitudinal thermocouple was located along the axis of

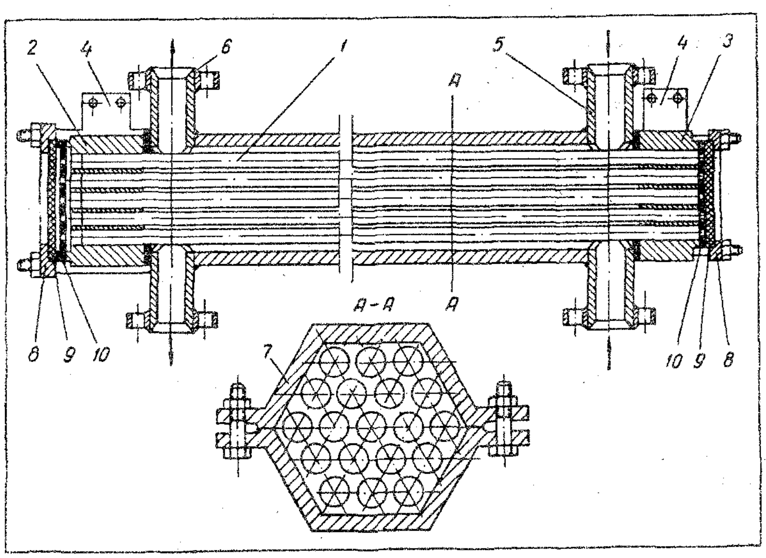

Fig. 1. Experimental heater: 1) tube; 2) upper tube plate; 3) lower tube plate; 4) current busbars; 5) inlet fitting; 6) outlet fitting; 7) housing; 8) pressure flange; 9) pressure cover; 10) glass-textolite gasket for insulating the thermocouple thermoelectrodes.

the central element; the hot thermocouple junction was produced by butt-welding the chromel and kopel wires.

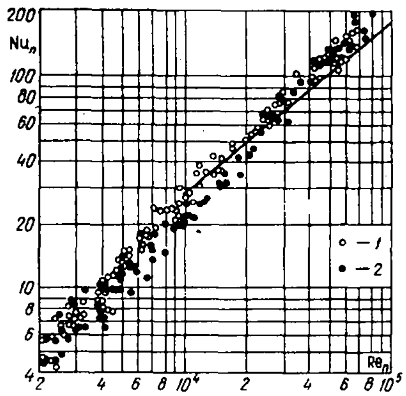

Fig. 2. Heat transfer coefficients with heated air: 1) mean heat transfer for the 19 tubes of the bundle; 2) mean heat transfer for the 7 central tubes: continuous line—from Mikheev's formula [3].

The experimental sections were arranged vertically; the air flowed upwards from below in section no. 1, and downwards from above in section no. 2, i.e., the directions of free and forced convection coincided in both cases. The equivalent diameter, determined according to total washed perimeter, was d_e = 6.15 mm for section no. 1, and 6.125 mm for no. 2.

The limits of error in determining heat transfer coefficients for both sections did not exceed ±10 to 15%. The temperature profile along the perimeter of the tubes was investigated in preliminary experiments, and no nonuniformities were observed.

Test data are shown in Fig. 2 for the average heat transfer for all 19 tubes of the heater bundle, referred to mean stream temperature and equivalent diameter d_e. These data may be correlated as follows, with maximum scatter of the order of ±15%:

$$\text{for } 2\cdot 10^4 < Re_n < 8\cdot 10^4 \quad Nu_n = 0.0202 Re_n^{0.8}; \qquad (1)$$

$$\text{for } 2\cdot 10^3 < Re_n < 2\cdot 10^4 \quad Nu_n = 0.001136 Re_n^{1.09} \cdot \qquad (2)$$

In the turbulent region the test data are, on the average, 12% above the value from Mikheev's formula for a tube [7]:

$$Nu_n = 0.018 Re_n^{0.8}. \qquad (3)$$

Processing of the test data in terms of mean temperature of the boundary layer t_f, equal to the half sum of the mean temperature of wall and stream, indicates that they are, on the average, 11% below the values from the Weisman [8] formula:

$$Nu_f = (0.026 s/d - 0.006) Re_f^{0.8} Pr_f^{1/3}, \qquad (4)$$

allowing for the dependence of heat transfer on the pitch of the staggered tube bundles.

A determination was also made of the mean heat transfer coefficient for the seven central tubes of the bundle. It is characteristic that transition to developed turbulent flow in the given case was delayed in comparison with the whole bundle, and occurred for $Re_n \cong 25 \cdot 10^4$.

As may be seen from Fig. 2, for $Re > 2.5 \cdot 10^4$, the mean heat transfer for the central tubes of the bundle agrees with that for the whole bundle. It should be noted that this agreement occurs for a ratio of the distance of the outermost tubes from the housing to the minimum distance between tubes of the order of 0.7 to 0.8, and when this ratio is changed the heat transfer at the outer tubes may differ from that at the central tubes.

It is interesting to note that in the flow transition region no fluctuations are observed in heat transfer coefficient and wall temperature, such as were observed in some experiments in tubes (e.g., [9]). This is evidently due to the fact that the turbulent plugs formed during transition from laminar to turbulent flow in longitudinal flows over tube bundles embrace only the wide parts of the intertube spaces, while laminar flow continues to exist in the narrow parts. They cannot therefore create any appreciable change of tube wall temperature (with the possible exception of part of the perimeter).

The test data for cooling at $Re_n > 3 \cdot 10^4$ may be generalized by the formula

$$Nu_n = 0.0206 Re_n^{0.8} \qquad (5)$$

and fall, on the average, 2% above the heated data, i.e., the experimental results obtained by the two different methods fall within the limits of experimental accuracy.

REFERENCES

1. E. V. Firsova, IFZh, no. 5, 1963.

2. A. Ya. Inayatov and M. A. Mikheev, Teploenergetika, no. 3, 1957.

3. D. A. Dingee and J. W. Chastain, Reactor Heat Transfer Conference of 1956. AEC Report TSD 7529, 1957.

4. J. L. Wantland, Reactor Heat Transfer Conference of 1956. AEC Report TSD 7529, 1957.

5. A. J. Friedland, O. E. Dwyer, M. W. Maresca, and D. F. Bonilla, International Developments Heat Transfer, part 3, ASME, New York, 1961.

6. A. Draycot and K. R. Lowther, International Developments Heat Transfer, part 3, ASME, New York, 1961.

7. M. A. Mikheev, Fundamentals of Heat Transfer [in Russian], GEI, 1956.

8. I. Weisman, Nuclear Science and Engineering, 6, no. 1, 1959.

9. A. D. Id, collection: Heat and Mass Transfer [in Russian], 3, GEI, 1963.

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