EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER IN SLIT-TYPE DUCTS WITH HIGH HEAT-TRANSFER RATES

Yu. P. Shlykov

Translated from Atomnaya Energiya, Vol. 8, No. 2, pp. 144-145
February, 1960
Original article submitted May 21, 1959

Heat-exchange equipment with narrow slit-type ducts (plane or annular) enjoy wide application in the various branches of technology. Among such types of equipment are found, for example, water-water reactors with plate- or tube-type heat-withdrawal elements. The abundance of experimental and theoretical papers on heat transfer in plane ducts is well known. The majority of these are devoted to studying heat exchange in relatively broad channels with small heat-transfer rates.

In nuclear reactors and reaction technology the heat-transfer rates can attain a value of $5 \times 10^6$ kcal/m$^2$·hr and higher. Calculation of high-energy reactor equipment with narrow ducts according to the familiar equations for convective heat exchange in round tubes, using the equivalent diameter $d_e$ as dimensional criterion, without appropriate experimental verification does not yield any convincing results.

The problem of dimensional criterion, i.e., the possibility of applying the indicated equations to narrow ducts, has been discussed in any variety of ways, but still stands unresolved. In a number of experimental papers on heat transfer in narrow annular ducts [1-4], containing generalizations with the application of $d_e$ equations were obtained, which differed from the equations for round tubes. In this light a reduction was noted in the heat transfer in an annular gap as compared with the heat transfer in a round tube. With the generalization of the experimental data on heat exchange in plane ducts a contradiction was also found in the choice of a dimensional criterion. Taken together, these facts encouraged the work of the present paper, the purpose of which was to verify the applicability of the usual equations for convective heat exchange to the analysis of plane narrow ducts with high heat-transfer rates and to more precisely define the problem of a dimensional criterion.

The procedure of the investigation was based on application of direct heating with a low-voltage current of the working section of the duct (1Kh18N9T steel), which is water-cooled. The principal arrangement of the experiment is shown schematically in Fig. 1, the structure of the experimental assembly in Fig. 2. The tests were carried out on narrow ducts made from flattened tubes. A series of tests were performed on the apparatus whose cross section is shown in Fig. 2.

---

**Fig. 1. Diagram of experimental setup:**

1) working section; 2) heat exchanger; 3) circulation pump; 4) feed pump; 5) volume compensator; 6) deaerator; 7) flow valve; 8) discharge metering disk; 9) step-up transformer; 10) control transformer; 11) hot junctions of thermocouples; 12) potentiometer.
The experimental conditions were varied by changing the water flow rate in the duct and the heat-transfer rate. The flow velocity of the water was varied from 5 to 12 m/sec, the heat-transfer rates from 3.6 to $5.7 \cdot 10^6$ kcal/m²·hr. The water temperature at the inlet to the duct was varied within the limits 45–80°C. A pressure of 50 atm was maintained in the loop.

A total of 65 tests were made on the heat-transfer to nonboiling water, from which 35 of the tests were performed on a duct with a gap width of 1 mm, the rest on a duct with gap width of 1.5 mm, with a constant duct width of 23 mm. The length of the working section of the duct was 200 mm. In view of the completely identical nature of the results of the measurements under the same or nearly identical working conditions, the results of 17 tests were processed.

The following formulas were used:

\[
N_u = 0.027 R_e^{0.8} P_r^{0.33} \left( \frac{H_1}{H_{st}} \right)^{0.14},
\]

Zider and Tate formula for a round tube;

\[
N_u = 0.023 R_e^{0.8} P_r^{0.43} \left( \frac{H_1}{H_{st}} \right)^{0.25},
\]

Mc Adams formula for a round tube;

\[
N_u = 0.023 R_e^{0.8} P_r^{0.43} \left( \frac{H_1}{H_{st}} \right)^{0.11},
\]


The averaged (over duct length) heat-transfer coefficients, processed according to the dimensionless criteria from the various formulas in the form of dependencies

\[
k_i = \frac{N_u}{A_i} = f (R_e),
\]

where \(A_i\) represents the right-hand sides of Eqs. (1)-(5) without the factor \(R_e^{0.8}\), are shown in Figs. 3 and 4.

In every case the equivalent diameter \(d_e = 4F/\pi\) was taken as the dimensional criterion (\(F\) is the cross section of the duct, \(\pi\) the perimeter wetted).

---

**Fig. 2.** Experimental assembly and cross section of the working section: 1) working section; 2) thermoelectric insulator inserts; 3) pressure relief plates; 4) electrical insulator inserts; 8) current-conducting busses; 9) contact sockets; 10) current-conducting sleeves; 11) inlet and outlet chambers; 12) mixer; 13) calibration plates; 14) steel foil; 15) displacer.

---

**Fig. 3.** Dependence \(k = f(R_e)\). According to the formulas: \(-1\); \(-\); \(-\).

**Fig. 4.** Dependence \(k = f(R_e)\). \(-\) and \(-\) according to the formula (4) for ducts with 1- and 1.5-mm gaps, respectively; \(-\) according to (5).