Table 1 gives the results.

The dynamic viscosity was calculated from the measured data by means of the P—V—T data we have obtained [3] for binary mixtures.

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INFLUENCE OF ULTRASOUND ON HEAT TRANSFER UNDER THE CONDITIONS OF FORCED FLOW OF A HIGH-TEMPERATURE MELT

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The influence of elastic oscillations at a frequency of 20 kHz on the heat transfer associated with the forced flow of a high-temperature melt in a tube is investigated experimentally. It is shown that the heat-transfer coefficient can be as much as doubled.

Resonant acoustic oscillations in tubes are known to be capable of eliciting significant variations in the local values of the heat-transfer coefficients in laminar and turbulent forced flows [1-3]. However, the literature is practically devoid of quantitative data on the influence of elastic oscillations at ultrasonic frequencies on the magnitude of heat transfer toward the wall of a tube in the forced flow of high-temperature melts, even though it is clear from the practical point of view that a major increase in the heat-transfer coefficient offers a basis for the intensification of heat- and mass-transfer processes in industrial equipment.

We have carried out an experimental study of the influence of elastic oscillations on the heat transfer from a flow of molten steel to the wall of a water-cooled tube. The experimental apparatus contained a water-cooled tube of dimensions $l/d \approx 3$, $l \approx 0.1$ m with magnetostrictive ring transducers fitted onto it; the transducers were driven at a frequency of 20 kHz. Axisymmetrical radial oscillations were excited in the wall of the tube to establish conditions of uniform influence of the applied field on the heat-transfer along the axis of the duct.

The experiments were carried out for various values of the bulk velocity of the flowing metal, for various hydrodynamic parameters of the molten metal, and with variation of the electrical power supplied to the transducers. Ultrasound was also generated and turned off intermittently during pouring of the metal. The temperature of the metal as it was poured into the tube was equal to 1520 ± 10°C.

The experimental measurements were carried out according to the arrangement shown schematically in Fig. 1. The magnetostrictive transducers were driven by an oscillator with an independent excitation circuit consisting of the master stage 1, the buffer amplifier 2, and the final amplifier 3. The amplitude of the oscillations was measured by means of the transducer 5, whose electrical output signal was sent to the voltmeter 6.

The active electrical power W_e supplied to the transducers 4 was measured with the thermal wattmeter 7 and was recorded on the KSP-4 automatic potentiometer 8, and the electric

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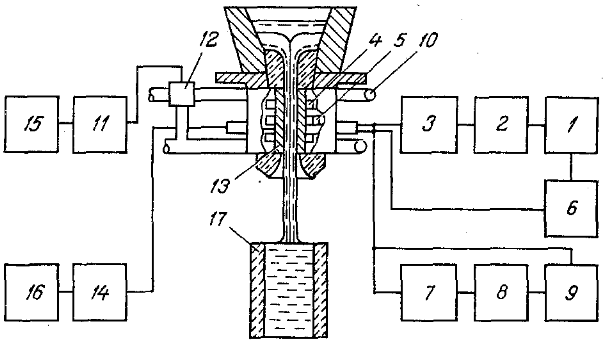

Fig. 1. Block diagram of the experimental arrangement.

TABLE 1. Comparison of Heat-Transfer Coefficients of a Liquid Metal with Variation of the Ultrasonic Power (v = 1.28 m/sec, Re = 70,000)

W_e, watts	$W_a \cdot 10^{-4}$, W/m²	$Q^* \cdot 10^{-6}$, W/m²	$\alpha^* \cdot 10^{-4}$, W/m²·K
900	0,9	2,08	0,69
1200	1,2	2,27	0,76
1300	1,3	2,88	0,96

driving frequency was monitored by the Ch3-35 digital frequency meter 9. The temperature of the water coolant in the inflow and outflow conduits 10 was measured by means of the thermopile 12, which was made of Chromel–Alumel wire of diameter 0.3 mm. The total sensitivity of the thermopile junctions was 1 mV/°C. The temperature rise of the water-cooled container 13 was measured by means of caulked thermocouples made of copper–Constantan wire of diameter 0.2 mm. The thermocouples were calibrated according to the melting point of pure metals: indium (of extreme purity) and tin (high-purity). The total measurement error was ±1°C. The wire diameter chosen for the thermocouples permitted the measurements to be performed within the indicated error limits at temperature rates of change up to 150°C/sec. The thermocouple emf was measured with the F-30 digital millivoltmeters 11 and 14 and was recorded by the respective automatic potentiometers 15 and 16. The temperature of the molten metal was determined by means of a thermocouple and a Positerm instrument manufactured by Electro-Nite n. v. The error was equal to 0.1% of the measured value.

The metal flowed from the tube into the crystallizer 17. Measurements were conducted both during the admission of the first batches of liquid metal into the tube in the transient thermal and unstabilized hydrodynamic state and also in the steady state under conditions of relative stabilization of the thermal and hydrodynamic flow parameters. It was also deemed important to determine the amount of heat transfer directly in one experiment at a constant bulk velocity under conditions with and without the application of oscillations.

The results of the experiments are shown in Fig. 2 and Table 1.

Figure 2 shows the time variation of the heat flux. The ultrasound is turned off at time τ_1. This is observed to cause a reduction in the heat flux by about one half. At time τ_2 the ultrasound is turned on impulsively, causing the heat flux to increase. The removal of ultrasonic oscillations at time τ_3 causes the heat transfer to drop once again until the time τ_4, at which relative stabilization of the heat flux sets in without the application of ultrasound.

Table 1 gives the results of a similar experiment with the specific acoustic power varied within $(0.9-1.3) \cdot 10^4$ W/m². The results show that the heat-transfer coefficient increases 1.50-fold with a 1.45-fold increase in the specific power. This indicates a considerable influence of elastic oscillations of the tube wall on the steady-state heat transfer.

In the case of transient thermal and hydrodynamic states during the initial pouring of the molten metal under the action of ultrasound, a substantial increase in the heat-transfer

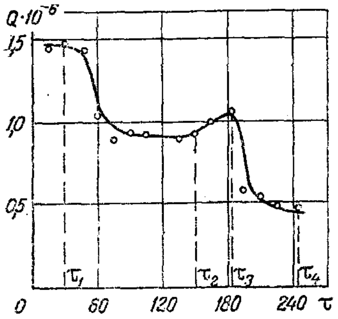

Fig. 2. Heat flux $Q \cdot 10^{-6}$, W/m^2, vs time τ, sec, with and without the application of ultrasonic oscillations, $v = 0.6$ m/sec, $W_a = 0.2 \cdot 10^4$ W/m^2.

coefficient and heat flux is observed in comparison with similar pouring conditions without the application of ultrasound. For example, in measurements performed 4 sec after the start of pouring, the value of the specific heat flux without ultrasound was $0.55 \cdot 10^6$ W/m^2, and with ultrasound it was $0.86 \cdot 10^6$ W/m^2; the corresponding values of the heat-transfer coefficient were $\alpha = 0.19 \cdot 10^4$ and $\alpha^* = 0.28 \cdot 10^4$ W/m^2·K. Thus, the heat-transfer increases by a factor of 0.54. These results show that the application of ultrasound either in the steady-flow regime or in the transient pouring state produces roughly the same increase in the heat-transfer coefficient within the measurement error limits. As pouring is continued (after 4 sec) without the application of ultrasound, the metal is observed to congeal rapidly at the tube walls, causing the bulk velocity and effective duct diameter to change appreciably. Under these conditions, therefore, it is impossible to compare the values of the heat-transfer coefficient with and without ultrasound.

NOTATION

l, length of the cooled tube; d, diameter of the tube; v, bulk flow velocity; τ, time; Q, heat flux; Q*, heat flux under the action of ultrasonic oscillations; α, heat-transfer coefficient; α^*, heat-transfer coefficient under the action of ultrasonic oscillations; W_e, active electrical power demand of the transducers; W_a, specific acoustic power; $Re = vd/\nu$, Reynolds number.

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