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HEAT EXCHANGE IN ANNULAR CHANNEL WITH INTERMEDIATE HEAT CARRIER

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The article explains the results of the experimental investigation of heat exchange in an annular channel with an intermediate heat carrier. A comparison is presented with coaxial cylinders rotating in the same direction. The experimental devices are described.

A characteristic feature of all structures for drying sheet material on drums is the possibility of heat transfer from a primary heat carrier with elevated pressure and temperature to the material through intermediate heat carriers making it possible, without greatly raising the pressure in the drum cavity, substantially to increase the temperature of the drum surface, and thus to intensify the drying process. As intermediate heat carriers various high-temperature (organic and inorganic) liquids are suggested which have low vapor pressure at high temperature. At the Kaliningrad Branch of the Central Research, Project, and Design Institute for Planning Equipment of the Pulp and Paper Industry (TsNIIbummash) also a number of designs were suggested where heat transfer is effected from an inner (moving or fixed) cylindrical jacket, consisting of annular pipes and being heated by highly superheated steam, to the outer shell of the drying drum through an intermediate heat carrier that fills the closed annular space (channel) between the tubular jacket and the outer drum shell.

Inside the drying drum, heat exchange using an intermediate heat carrier proceeds similarly to heat exchange in the annular channels of coaxial cylinders where the gap between them is filled with a heat carrier that does not move axially, and the heat is transferred from the inner cylinder to the outer cooling cylinder by a heat carrier filling the space between them [1-18].

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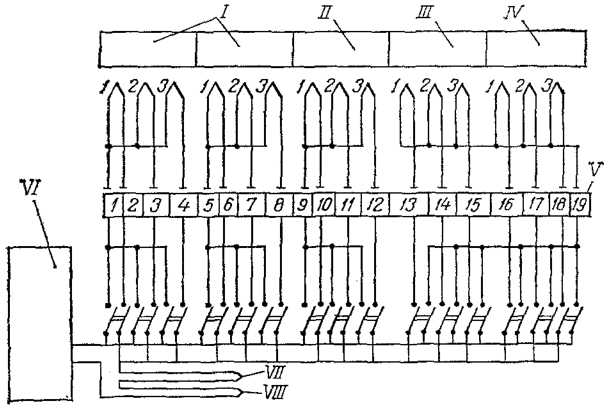

Fig. 1. Schematic diagram for measuring thermo-emf at control points of the drum: I, II, III, IV) controlled temperature points (cylinder wall, heater, steam, intermediate heat carrier, respectively); V) measuring collector with sliding contacts; VI) dc potentiometer type PP-63; VII) hot junction; VIII) cold junction (1-19; contact numbers).

Investigation of heat exchange inside a drying drum with intermediate heat carrier filling an annular channel closed at the end faces was carried out on two experimental installations.

The experiments were carried out on an available prototype of a drying drum with 209 mm diameter, 482 mm long, with intermediate heat carrier. The drum was driven by a dc motor with speed controllable from 0 to 1500 rpm. Inside the drum were mounted (through flanged joint) electric heaters with small radial gap over the entire length; this gap was filled with diphenyl mixture which transferred the heat from the electric heaters to the drum walls. The surface of the drying drum was cooled by an endless cloth belt moistened by a stabilizing liquid dispenser. The wrapping angle of the cloth belt on the drum was $\varphi = 0.555$.

The temperature of the surfaces was measured with copper – constantan thermocouples connected to rings of the measuring collector with sliding contacts and potentiometer which rotated together with the drum.

A schematic diagram of measurements at the control points of the drum is shown in Fig. 1. The investigations were carried out on a drying drum with intermediate heat carrier under conditions of industrial operation. The heat carrier was a widely used industrial oil (IS-20, IS-45) which is thermally stable in the temperature range 150-250°C.

The procedure of heat exchange inside the experimental drying drum was heat transfer from the tubular heater, heated by steam ($P > 10$ kgf/cm^2, $t > 150$°C), through a moving layer of industrial oil (intermediate heat carrier) to the outer shell of the drying drum cooled by the strip of paper pulp to be dried. The wiring for measurements of the control points of the heater, of the layer of industrial oil, of the inner and outer walls over the entire width of the drying drum was arranged analogously to the laboratory tests. At both stages of the experimental investigations, like in [19], a method was used which is based on determining the specific heat flux through the wall of the drying drum in steady-state thermal regime according to the temperature gradients over the entire width of the drum.

For the experimental investigation of heat exchange inside the drum we selected the procedure of separately determining the heat-transfer coefficients from the heater to the intermediate heat carrier and to the outer drum wall in different variations of thermal loads and rotational speeds of the drying drum. The heat-transfer coefficients were determined from the specific heat fluxes and the measured temperatures of the intermediate heat carrier, the walls and heaters of the drum.

The total heat flux was determined by two mutually independent methods. In the laboratory investigations it was determined from the difference in temperatures and power of the electric heaters; in the industrial tests it was determined from the balance of heat expended on drying the strip of paper pulp, supplied to the heater by the steam, and the heat being released with the condensate, taking into account the heat loss to the environment.

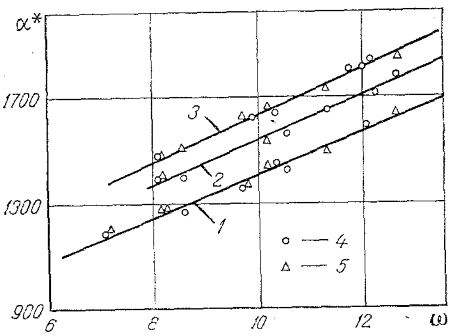

Fig. 2

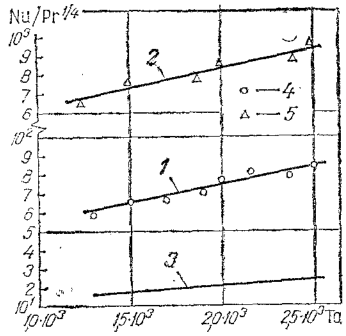

Fig. 3

Fig. 2. Dependence of the heat-transfer coefficient α^* on the rotational speed of the drum: 1, 2, 3) temperature of the intermediate heat carrier equal to 150, 200, 250°C, respectively; 4) industrial oil IS-20; industrial oil IS-45. α^*, W/m^2·deg; ω, rad/sec.

Fig. 3. Generalization of the experimental data on heat exchange in a closed annular channel of a rotating drying drum: 1) laboratory tests; 2) industrial tests; 3) coaxial cylinders rotating in the same direction [18]; 4) diphenyl mixture; 5) industrial oil IS-20.

In the criterial generalization of the results of the experimental investigation, we took as the characteristic linear dimension the thickness of the layer of intermediate heat carrier, and as the characteristic temperature the mean temperature and the hot thermocouple junctions in the drum wall, on the surface of the heater, and in the layer of intermediate heat carrier.

It was most convenient to evaluate the intensity of heat transfer by the arithmetic mean of the heat-transfer coefficients.

The heat-transfer coefficients experimentally obtained under laboratory and industrial conditions were higher (2-3 times) than the values attained in fixed surface heat exchangers [20, 21]. In dependence on the operating conditions (throughput of steam, temperature of the heated steam, rotational speed of the drum, and correspondingly in dependence on the thermal and hydrodynamic situation inside the drum, the heat-transfer coefficients changed within the limits 900-3000 kcal/m^2·h·deg (1046-3490 W/m^2·deg). The heat-transfer coefficients increase with increasing rotational speed of the drum in all thermal regimes under experimental conditions. The nature of the dependence of the heat-transfer coefficients on the rotational speed of the drum is always the same, regardless of the temperature of the intermediate heat carrier. With the same rotational speed of the drum, the heat-transfer coefficients have the larger numerical values, the higher the temperature of the intermediate heat carrier is (Fig. 2).

The intensity and nature of the heat exchange in the annular gap inside the drum are affected by the rotary motion of the drying drum and by the hydrodynamic interaction between the layer of intermediate heat carrier and the heater and outer shell of the drying drum bounding it. In addition to that, since the temperature of the heating surface of the heater is higher than the temperature of the intermediate heat carrier washing it, phase transformations or partial decomposition of the heat carrier may occur, and this causes turbulization of its near-wall layer.

Generalization of the experimental data on heat transfer in an annular channel of the drying drum in a series of laboratory tests using diphenyl mixture as intermediate heat carrier (Fig. 3) made it possible to obtain the criterial equation $Nu = 1.67(Ta^2Pr)^{1/4}$. In a series of experiments with an industrial installation, where the intermediate heat carrier was industrial oil IS-20, the equation $Nu = 19(Ta^2Pr)^{1/4}$ was obtained.

Thus, it can be seen from Fig. 3 that the same regularities characterize heat exchange in the annular channel of a drying drum filled with intermediate heat carrier, and heat exchange in the annular channel of coaxial cylinders rotating in the same direction without axial flow of the liquid [18].

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