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THE STUDY OF HEAT EXCHANGE DYNAMICS OF VENTILATION EMISSIONS ON HEAT UTILIZATION WITH CONSIDERATION FOR WATER VAPOUR CONDENSATION

Problem statement. Known corrosion-resistant air heaters made from glass tubes have not received wide acceptance because of some defects (low mechanical strength, temperature deformation, complexity and unreliability of assemblies, etc.), whereas the structure of insulated glazing heat exchange devices has some advantages. The aim of present paper is to study heat exchange dynamics of ventilation emissions in insulated glazing air heater on heat utilization with consideration for water vapor condensation.

Results and conclusions. The study of heat exchange in channel insulated glazing heat exchanger at heat utilization of corrosion-active ventilation emissions is carried out with consideration for water vapour condensation on heat-exchange surfaces. It is shown that the rate of heat exchange under longitudinal flow of vertical glass surfaces air heated and steam-and-air cooled is 15—20 % lower than the rate of heat exchange at air cooling.

Keywords: insulated glazing air heater, heat of condensation, water vapours, utilization, ventilation, emissions, heat exchange.

Introduction. In the present time, particular emphasis is placed on the problems of energy saving in all fields of fuel-energy complex related to generation, transfer, and consumption of heat energy. Ventilation emissions are reserves of secondary energy sources. In industry enterprises, ventilation emission heat is utilized with the use of various heat exchangers which must fulfill high requirements on corrosion stability.

Among existing structures of heat exchangers, deserves much consideration recuperative multimedia devices with uniform heat exchange elements which separate rectangular channels or channels of circular section from each other.

Known corrosion-resistant air heaters made from glass tubes [1, 2] have not received wide acceptance because of some defects (low mechanical strength, temperature deformation, complexity and unreliability of assemblies, etc.).

The structure of insulated glazing heat exchange devices has some advantages: temperature deformation resistance, high mechanical strength, simplicity of assembly replacement. Convection heat exchange in heat exchange glass block devices for utilization of heat of ventilation emissions at developed turbulent motion was investigated in [3]. In this work, however, the problem of the effect of water vapor condensate on heat exchange dynamics was not elucidated.

In this connection, the aim of present paper is to study heat exchange dynamics of ventilation emissions in insulated glazing air heater on heat utilization with consideration for water vapor condensation. Experimental setup was developed to study heat exchange through plane corrosion-resistant heat exchange glass surfaces for new design of air heater (insulated glazing). This name arose from the fact that the heater is of glass blocks arranged in a certain order with the use of elastic seals.

In experimental setup, right-angled air and gas channels were formed by corrosion-resistant glass heat exchange surfaces made of 5 mm thick low-alkali sheet glass.

The experimental setup to study heat exchange dynamics of ventilation emissions in insulated glazing air heater on heat utilization with consideration for water vapor condensation is shown in Fig. 1.

Air provided by ventilator 4 is divided by air tap 7 in two air flows. One of the flows (heating medium) is directed along air duct 13 with corrugated inserts 9, 10 to air heater 2, where the flow is heated to the required temperature, mixed with vapor from vapor generator 3 in reducer 6, forming vapor-gas mix, and is supplied to the central gas channel of air heater 1 through separating box 15. The flow is removed from the channel through separating box 14 and outlet branch 16. The other flow (heated medium) is directed to air heater 1 along corrugated air tap through outlet branch 5 and separating box 14, passes through the channels of air heater for heated air located on two sides from the central channel, mixed in separating box 15 with the total flow of heated air, which is removed from the setup through branch 17.

The study of heat exchange was carried out at turbulent conditions. Hot air mixed with water vapor was used as heating medium, and outside air was used as heated medium. Average values of the coefficients of heat emission from medium to wall and from wall to medium were obtained. Quantitative assessment of heat exchange intensity dependence on geometric characteristics of the structure and roughness of inner streamline surface is hampered because in most cases experimental data on heat exchange in certain conditions are unavailable [4, 5].

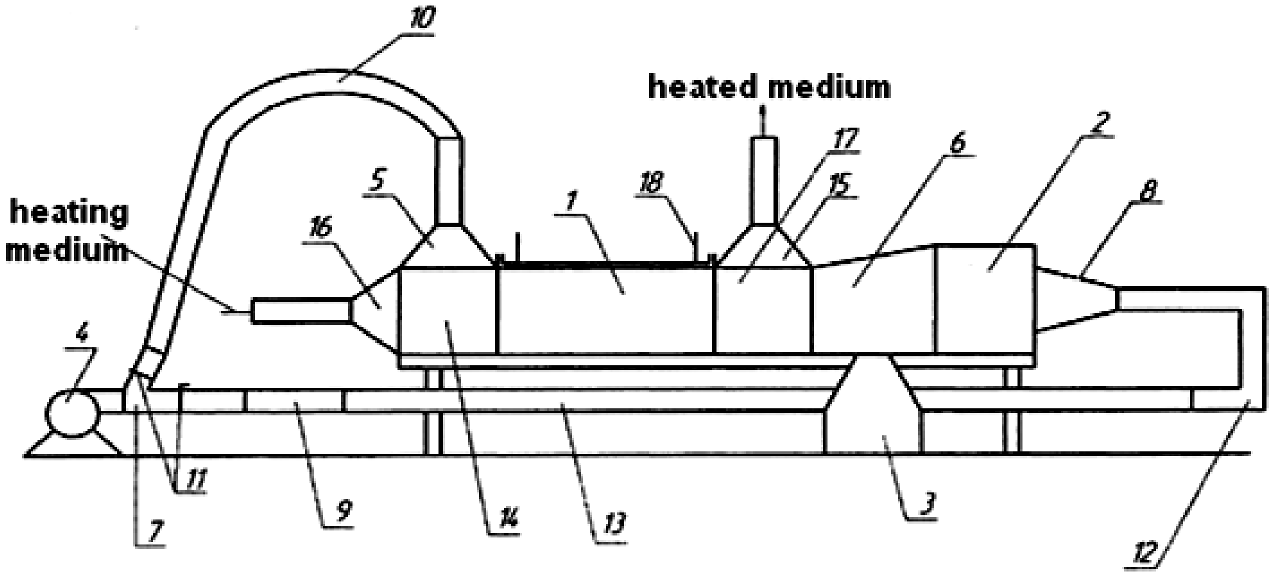

Fig. 1. Insulated glazing air heater

In the general case, in the problem on heat exchange at vapor condensation from gas-vapor mixture heat emission coefficient depends on two thermal resistances — diffusion resistance and resistance of the condensate film.

Experiments on heat exchange study in heat exchanger with corrosion-resistant heat exchange surfaces were conducted at counterflow for fixed air rates from 5 to 10.5 m/sec at relations adopted for plate air heaters [4], air, and air-vapor mixture:

$$w_{НС} = (1.4 \div 1.6) w_{ГС}, \tag{1}$$

where $w_{НС}$, $w_{ГС}$ are rates of heated and heating medium, respectively.

Total heat absorption of heated air flow, W, was determined from heat balance equation

$$Q^{|} = \overline{c}\overline{V}_{кан}(t^{|}_{вх} - t^{|}_{вых}) \cdot 10^3, \tag{2}$$

where $\overline{c}$ is the volume heat capacity at average temperature of air flow, kilojoule / (m^3·K); $\overline{V}_{кан}$ is the heated air flow discharge in channel, m^3/sec; $t^{|}_{вх}$, $t^{|}_{вых}$ are temperatures of heated air flow at the inlet and at the outlet of channel, respectively, ^{o}C.

To determine heat transfer coefficient, we applied steady state heat flow method which involves the use of Newton-Rikhman law,

$$dQ^{|} = \alpha F_{cm}(t'_{в.cm} - t')dF_{cm}\,, \tag{3}$$

where $t^{|}_{в.cm}$ is the average temperature of glass heat exchange surface on the side of heated air flow, ^{o}C; $t^{|}$ is the average temperature of heated air flow in channel, ^{o}C; α is heat transfer coefficient of heat transferring surface, W/(m^2 · К); F_{cm} is the calculation surface of heat transfer of glass heat exchange surface (wall), m^2.

Average coefficient of heat transfer from heat transferring surface are determined for each experiment:

$$\alpha' = \frac{Q^{|}}{F_{\text{ст.}}(t^{|}_{\text{в.ст}} - t^{|})}\,, \tag{4}$$

where *L* is the length of channel; *q* is the specific heat flow; *x* is the coordinate over channel length.

Calculation parameters required to obtain criterion equation at longitudinal flow of heated air medium inside right-angled channel were determined in experiment at direct measurement.

The values of volume air heat capacity, heat conductivity coefficient, kinematic viscosity, and Prandtl number were calculated at average temperature of air flow [6].

According to [8], at turbulent liquid motion, calculation of heat transfer in rectangular channels at longitudinal sweeping can be performed with the use of equivalent diameter,

$$a/b = 1{:}40,$$

where *a*, *b* are height and width of the channel cross-section, respectively.

In this case,

$$a/b = 6.$$

In evaluating error in measurement of glass plate surface, it was established that its maximum value does not exceed 7.5 %.

To estimate heat outflow through the walls of the setup, we used basic heat transfer equation

$$Q = \sum k_i F_i \Delta t_i\,, \tag{5}$$

where k_i is the coefficient of heat transfer through i^{th} heat exchange surface, W/(m^2 · K); F_i is the calculation surface of i^{th} heat exchange surface determined by geometrical sizes, m^2; Δt_i is the average temperature head, ^{o}C.

In estimating heat outflow, it was found that it is about 6 % of the total heat flow.

Average temperature heads were used to define average values of heat transfer coefficient for each experiment:

$$\bar{k} = \frac{Q^{|}}{F_{cm}\Delta\bar{t}}, \tag{6}$$

where $\Delta\bar{t}$ is the average temperature head defined at

$$\Delta t_{б} / \Delta t_{м} \leq 1.7$$

with sufficient accuracy:

$$\Delta\bar{t} = \frac{\Delta t_{б} + \Delta t_{м}}{2}, \tag{7}$$

where $\Delta t_{б}$, $\Delta t_{м}$ are difference in temperatures of mediums on the other end of heating surface, ^{o}C.

The surface temperature of glass plate on the side of heating («vapor-gas» flow) and heated («air» flow) mediums was measured by chromel-copel thermocouples of diameter 0.5 mm. Error in measurement of surface temperature of glass plate as a result of temperature field distortion by thermocouples was calculated by the formula [11]

$$\delta t = t - t_n = \frac{\Lambda_к - \Lambda_n}{\Lambda_o + \Lambda_к}(t_n - t_c), \tag{8}$$

where t is the temperature measured by thermocouple; t_n is the surface temperature; t_c is the ambient temperature; $\Lambda_K, \Lambda_O, \Lambda_П$ are total heat conductivity between contact area and environment между interiors of the body and contact area $F_к$, between free surface of the object and environment in terms of area $F_к$, respectively.

In plate heat exchangers with smooth slit-like channels, at forced flow of working medium regularities of the processes of local and average heat transfer for slit-like channels remain the same as for tubes and expressed at turbulent air motion by dependence [12]

$$Nu = f(\mathrm{Re}). \tag{9}$$

With consideration for moderate length of the channel in insulated glazing air heater (the ratio of the length of the channel to its equivalent diameter is $L/d_Э = 7.2$), heat transfer at longitudinal internal sweeping of channels by heated air is described by Nusselt equation [8, 9]

$$\overline{Nu} = c_{ПР} \operatorname{Re}^{0.8} \operatorname{Pr}^{0.43} \varepsilon_L , \tag{10}$$

where c_{np} is the coefficient of proportionality; Re is Reynolds number; Pr is Prandtl number; ε_L is the correction factor for the coefficient of heat transfer at initial heat-treating site.

The values of Prandtl number and Reynolds number are determined at average temperature of the medium moving in the channel.

Correction factor ε_L at channel length-diameter ratio

$$L/d \leq 15$$

and turbulent motion was calculated by the formula [10]

$$\varepsilon_L = 1.38 \left(\frac{x}{d} \right)^{-0.12} . \tag{11}$$

In studying heat exchange in channels of rectangular glass block air heater, we calculated coefficient of proportionality for each n experiment:

$$c_{ПРn} = \frac{\overline{Nu}}{\operatorname{Re}^{0.8} \operatorname{Pr}^{0.43} \varepsilon_L} . \tag{12}$$

Viscosity coefficient of the mixture are calculated by the equation

$$\mu_{CM} = \frac{(1 - \varepsilon_{ГО}) \mu_П + 1.6 \varepsilon_{ГО} \mu_Г}{1 + 1.6 \varepsilon_{ГО}} . \tag{13}$$

Fig. 2 shows graphs

$$\overline{Nu} = f(\operatorname{Re})$$

constructed by experimental data obtained in study of heat exchange (curves 1, 2, 3) through the wall of heat exchange surfaces made of glass, wire glass and glass with artificial roughness (equal to 0.03 mm) on heat exchange surface.

The roughness was developed in order to compare with heat exchange through metal heat exchange surfaces in plate heat exchangers characterized by average value of absolute roughness equal to 0.03 mm.

Furthermore, data of other authors on glass block air heater [3] are shown on Fig. 2 to compare heat transfer in insulated glazing air heater.

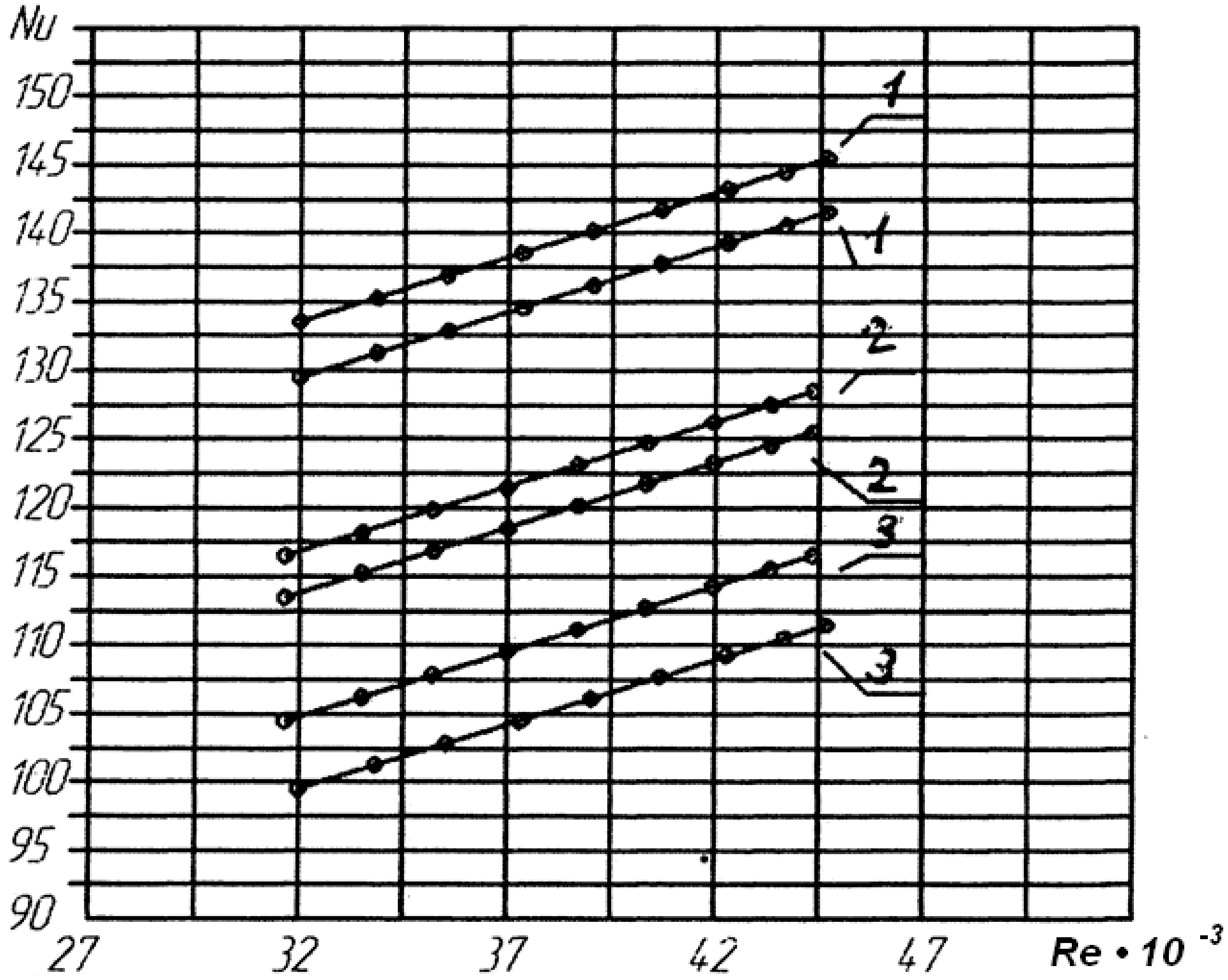

Fig. 2. Heat transfer at longitudinal internal sweeping of surface heated by air and cooled by air and air-vapor:
1, 1' — reinforced glass smooth heat exchange surfaces;
2, 2' — glass rough heat exchange surface;
3,3' — glass smooth heat exchange surfaces;
• — heat transfer at longitudinal internal sweeping of surface heated and cooled by air [3];
Δ — heat transfer at longitudinal internal sweeping of surface heated by air and cooled by air-vapor

Conclusions

1. The comparison of results of heat exchange at longitudinal sweeping of vertical glass surfaces heated by air and cooled by air and air-vapor shows that the value of

heat criterion *Nu* at air-vapor cooling is 15—20 % lower than the value of *Nu* at air cooling.

2. The reduction in efficiency of heat exchange at air-vapor cooling compared to air cooling is attributable to the condensate film on heat exchange surface forming at condensation of water vapors, which produces additional thermal resistance.

3. The new design of insulated glazing air heater provides considerable increase in efficiency and reliability.

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