EXPERIMENTAL STUDY OF CONVECTION IN A NONHERMETIC INTERLAYER

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The results are presented on a study of the thermal regime of a plane vertical interlayer under conditions of through and not-through slot filtration of air with boundary conditions of the third kind at the outer walls of the interlayer.

Vertical air interlayers are a component part of many building structures, primarily of transparent structures. Despite the very wide distribution of two-pane barriers (windows, showcases, stained glass), however, their thermal regime has so far been inadequately studied. Data on the effect of air filtration on the height distribution of temperature in barriers and on the thermal resistance of the interlayer are absent in particular.

We have attempted to obtain experimental data on the effect of air filtration through natural and artificial (ventilation) slots in wall interlayers on the temperature fields of these walls and on the intensity of heat exchange through the interlayer.

The temperatures t_+ and t_- of the air on each side of the interlayer, the heat-exchange coefficients α_+ and α_- at the respective outer walls, and the weight flow rate G of air penetrating into the interlayer by not-through (Fig. 1a) or through (Fig. 1b) filtration are taken as assigned quantities.

The quantities sought are the local temperatures $t_i(y)$ $(i = 1, 2)$ of the walls of the interlayer and the averages (over the height of the interlayer) of the convective heat fluxes q_i.

The study was performed in a climate chamber which provides stability of the temperature regimes. The walls of the interlayer were made of Plexiglas, which made it possible to create a larger (and, consequently, more accurately computable) temperature drop in the walls.

The realization of the schemes of slot filtration illustrated in Fig. 1 was accomplished as follows. In scheme a cold air penetrated into the lower openings of the interlayer under the effect of hydrostatic forces and, having been heated, emerged through the upper openings. In scheme b the air movement through the interlayer occurred due to an artificially created pressure drop between the cold and hot media.

The values of t_+ were close to 20°C, while those of t_- were varied in the region of negative temperatures (down to −30°C). The values of α_+ and α_- were determined by the mode of free convection at the outer walls of the interlayer and comprised $\alpha_+ \simeq \alpha_- \simeq 8.7\ \mathrm{W/m^2 \cdot deg}$ (including both convective and radiative components).

The Biot number of the walls, which affects the process relatively little, was 0.4, while the variation in the Grashof number, accomplished mainly by variation in the width L of the interlayer, covered (together with measurements made earlier [1]) almost the entire useful range – from $\mathrm{Gr}_L = 3.5 \cdot 10^3$ to $\mathrm{Gr}_L = 2 \cdot 10^9$.

Heat exchange in the absence of filtration was studied in the first stage. It was established that the onset of the self-similar mode of free convection occurs at $\mathrm{Gr}_L = 1 \cdot 10^7$.

For $\mathrm{Gr}_L > 1 \cdot 10^7$ the best agreement with our experimental data is given by the Dropkin–Somerscales formula [2]

$$\mathrm{Nu} = 0.0426\, \mathrm{Gr}_L^{1/3}. \tag{1}$$

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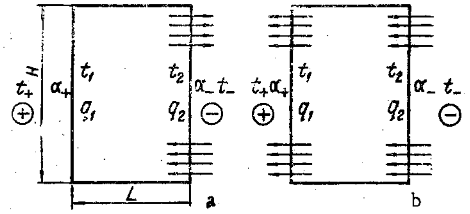

Fig. 1

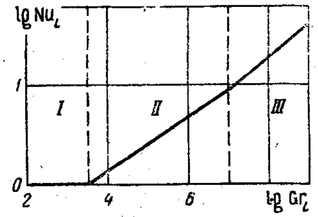

Fig. 2

Fig. 1. Types of slot filtration: a) not-through; b) through.

Fig. 2. Regions of heat exchange in a hermetic vertical interlayer: I) conductive transport, $Nu_L = 1$; II) transitional, $Nu_L = 0.118 Gr_L^{0.27}$; III) region of self-similar mode of convection, $Nu_L = 0.0426 Gr_L^{1/3}$.

On the other hand, as is known, when $Gr_L < 3 \cdot 10^3$ a mode of conductive heat transfer occurs for which

$$Nu_L = 1. \tag{2}$$

Therefore, as a natural adjunct to Eqs. (1) and (2) we propose the interpolative dependence (Fig. 2)

$$Nu_L = 0.118\, Gr_L^{0.27}. \tag{3}$$

This formula agrees well with the experimental data [1] already available for $3.5 \cdot 10^3 < Gr_L < 1 \cdot 10^7$.

We note that Eqs. (1) and (3) do not contain the geometrical parameter H/L, since its influence (at least in the region H/L > 5 which we studied) is very slight. In particular, in [2] its influence in the region 4.4 < H/L < 16.6 could not be detected at all.

In analyzing the results of the second stage of the experiment (nonhermetic interlayers) it was found that the quantitative relations for through and not-through infiltration are rather close. Therefore, the functions presented in Fig. 3 for q_1 and q_2 are averaged and are applicable to either scheme of slot filtration. Here the values of q_1 and q_2 in Fig. 3 are normalized to q_0 – the convective heat flux with the same boundary conditions through the same interlayer in the absence of infiltration, determined from Eq. (3) or (1).

The Reynolds number

$$Re = \frac{Gl}{\nu\rho} \tag{4}$$

represented in Fig. 3 includes 1 lin. m of surface as the geometrical dimension l, while the values ν and ρ correspond to the kinematic viscosity and air density under the conditions of the average temperature $t_{in} = \frac{1}{2}(t_1 + t_2)$ in the interlayer.

As follows from Fig. 3, for Re ≃ 200 the convective flux q_2 is reduced to zero, while for Re > 200 this flux changes sign, since the average air temperature in the interlayer becomes lower than the temperature of the "cold" wall.

In the case of a change in the direction of filtration, i.e., in the case of penetration of air into the interlayer not from the cold, but from the hot medium, the functions found remain in force and only the subscripts are changed: the upper branch in Fig. 3 will correspond to q_2/q_0, while the lower branch will correspond to q_1/q_0.

The study performed showed that under natural conditions of development of the process of heat exchange the variations in α_+ and α_- over the height of the interlayer can be neglected (self-similar mode of free convection), while the variation in wall temperatures t_1 and t_2 can be taken as linear.

According to our data,

$$t_i = t_{im} - n_i (t_+ - t_-) Gr_H^{0.05} (1 - 5 \cdot 10^{-4} Re) \left(\frac{H}{2} - y \right), \tag{5}$$

where i = 1, 2; $n_1 = 0.024$ (1/m) and $n_2 = 0.024(1 - 5 \cdot 10^{-4} Re)$ 1/m.

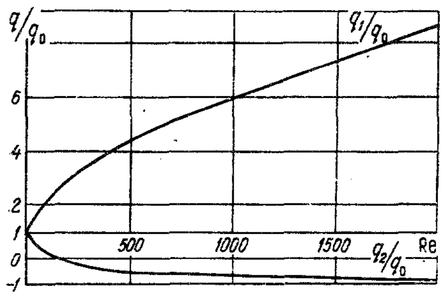

Fig. 3

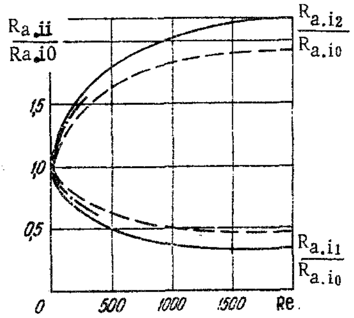

Fig. 4

Fig. 3. Variation in average convective heat fluxes in interlayer as a function of the intensity of slot filtration.

Fig. 4. Effect of filtration on thermal resistance of interlayer: solid curves: experiment (showcases, $Bi_1 = 0.4$); dashed lines: electrical analog [3] (window); dashed-dot line: experiment [1] (window, $Bi_1 = \frac{1}{2} Bi_2 = 0.04$).

The same linear nature of variation with distance from the lower edge of the wall of the interlayer is also observed for the local heat fluxes

$$q_1 = \alpha_+ [t_+ - t_1(y)], \tag{6}$$

$$q_2 = \alpha_- [t_2(y) - t_-]. \tag{7}$$

The values of the temperatures t_{im} averaged over the height which enter into Eq. (5) are easily determined from the one-dimensional transfer equations with allowance for the dependences of q_1 and q_2 on the slot filtration, which are presented in Fig. 3.

Instead of convective heat fluxes, for practical calculations it is usually more convenient to operate with the thermal resistance $R_{a.i}$ of the air interlayer, which also includes the radiant component.

The dependences for $R_{a.i\,1}$ and $R_{a.i\,2}$ corresponding to the calculation of the temperature at the first and second walls of ordinary transparent-wall interlayers are presented in Fig. 4. A comparison of our experimental data (solid lines) with the data of other authors is presented in the same figure.

NOTATION

$Nu_L = qL/\lambda(t_1 - t_2)$, Nusselt number; $Gr_L = gL^3\beta(t_1 - t_2)/\nu^2$, $Gr_H = gH^3\beta(t_1 - t_2)/\nu^2$, Grashof numbers; $Re = Gl/\nu\rho$, Reynolds number; t_+, t_-, air temperatures outside interlayer; t_1, t_2, wall temperatures of interlayer; α_+, α_-, coefficients of heat exchange at outer walls of interlayer; q, convective heat flux.

LITERATURE CITED

1. K. P. Kopylov, Scientific Proceedings of Moscow Scientific-Research Institute of the Glavmosstroy [in Russian], Part 6, Moscow (1969).
2. D. Dropkin and E. Somerscales, Trans. Amer. Soc. Mech. Eng., J. Heat Transfer, 87, No. 1, 77 (1965).
3. V. N. Bogoslovskii, Structural Heat Physics [in Russian], Vysshaya Shkola, Moscow (1970).