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HEAT TRANSFER IN THE THERMAL ENTRANCE REGION OF LIQUID FILM FLOW

Досліджено динаміку розвитку теплообміну на початковій термічній ділянці при переміщенні плівки рідини вздовж вертикальної поверхні сталевої трубки малого діаметра. Досліджено вплив поперечної кривизни поверхні зрошування на теплообмін на початковій термічній ділянці при ламінарному та ламінарно-хвильовому русі плівки.

Исследована динамика развития теплообмена на начальном термическом участке при движении пленки жидкости по вертикальной поверхности стальной трубы малого диаметра. Исследовано влияние поперечной кривизны поверхности орошения на теплообмен на начальном термическом участке при ламинарном и ламинарно-волновом движении пленки.

The purpose of the present research is to obtain a comprehension for the heat transfer developments in the entrance region of high viscosity liquid film flow. This study is related with the experiments in laminar transformer oil film flowing down a vertical surface of small diameter tube. The paper presents the evaluation of surface cross curvature influence on the local heat transfer in the thermal entrance region of laminar and wavy-laminar film flow.

a – thermal diffusivity;
C_{Rq} – curvature correction factor;
d – hydraulic diameter of the film;
g – acceleration of gravity;
Ga_R – Galileo number;
Nu_d – Nusselt number;
Pe – Peclet number;
Pr – Prandtl number;
q – heat flux density;
R – tube external radius;
Re – Reynolds number;
x – longitudinal coordinate;
α – heat transfer coefficient;
Γ – wetting density;
δ – film thickness on surface of vertical tube;
ε_R – relative cross curvature of the film;
ν – kinematic viscosity;
λ – thermal conductivity;
ρ – liquid density.

Subscripts:
f – film flow;
s – film surface;
stab – stabilized flow;
t – thermal boundary layer;
w – wall of tube.

The heat transfer in the entrance region was studied experimentally for boundary condition $q_w = const$. The experiments have been performed with transformer oil film flowing down a vertical surface stainless tube of 3,8 mm diameter. The research was provided in presence and absence of isothermal section on the tested tube. The considerable relative cross curvature for the laminar or wavy-laminar film flow it is possible with high viscosity liquid or with high Prandtl number. In such case the thermal entrance region is much longer than hydrodynamic one.

The local heat transfer coefficient in the entrance region for laminar film flow on vertical plane surface can be determined by the expression [1,2]

$$\mathrm{Nu}_{df} = 8{,}24\left[1 + 0{,}0011\left(\mathrm{Pe}_f d/x\right)^{4/3}\right]^{1/4}\left(\mathrm{Pr}_f/\mathrm{Pr}_w\right)^{1/4}. \quad (1)$$

For stabilized heat transfer, evaluating the cross curvature of wetted surface, Eq. (1) can be written as follows

$$\mathrm{Nu}_{df} = 8{,}24 C_{Rq}\left(\mathrm{Pr}_f/\mathrm{Pr}_w\right)^{1/4}. \quad (2)$$

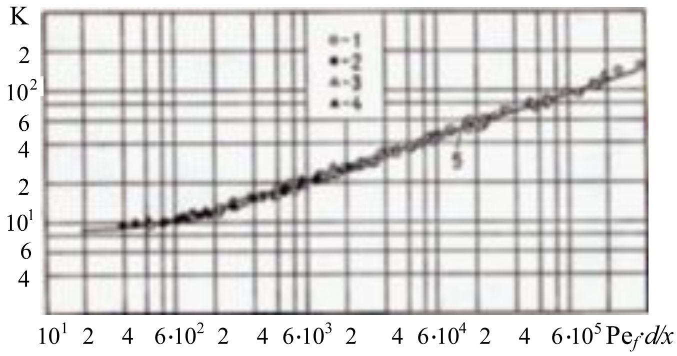

Fig. 1. Experimental results of local heat transfer: 1,2 – laminar and wavy-laminar flow in absence of the isothermal section correspondingly; 3,4 – laminar and wavy-laminar flow in presence of the isothermal section; 5 – equation (7); $K = \mathrm{Nu}_{df} C_R^{-1} (\mathrm{Pr}_w/\mathrm{Pr}_f)^{1/4}$.

In this case the thickness of thermal boundary layer is equal to the film thickness and can be determined [3] by the following equation

$$\delta = 1{,}67R\left(\sqrt{1+1{,}09\left(\mathrm{Re}/\mathrm{Ga}_R\right)^{1/3}-1}\right). \quad (3)$$

For the laminar film flow we can assume that local heat transfer coefficient is inversely proportional to the thickness of thermal boundary layer $\alpha/\alpha_{stab} = \delta/\delta_t$. Taking this precondition into account, from Eqs. (1) and (2) it follows that

$$\frac{\delta_t}{\delta} = \frac{\alpha_{stab}}{\alpha} = \left[1+0{,}0011\left(\mathrm{Pe}_f d/x\right)^{4/3}\right]^{-1/4}. \quad (4)$$

On this correlation basis, the relative cross curvature of the laminar film one can express as follows

$$\varepsilon_R = \frac{\delta}{R}\left[1+0{,}0011\left(\mathrm{Pe}_f d/x\right)^{4/3}\right]^{-1/4}. \quad (5)$$

In absence of external heat transfer ($q_s = 0$), the correction factor evaluates the film curvature

$$C_{Rq} = C_R = 1+0{,}52\varepsilon_R. \quad (6)$$

External heat transfer does not influence the heat transfer intensity in the thermal entrance region and Eq. (5) is valid. The local heat transfer coefficient in the thermal entrance region for the laminar film falling down outside surface of vertical tube can be determined by following equation

$$\mathrm{Nu}_{df} = 8{,}24\left[1+0{,}0011\left(\mathrm{Pe}_f d/x\right)^{4/3}\right]^{1/4} \times$$
$$\times C_R\left(\mathrm{Pr}_f/\mathrm{Pr}_w\right)^{1/4}. \quad (7)$$

The comparison of theoretical results obtained by Eq. (7) with experimental data is presented in Fig. 1. As we can see, the experimental results are in good agreement with Eq. (7).

REFERENCES

1. *Gimbutis G., Gimbutyte I. and Sinkunas S.* Heat Transfer in a Falling Liquid Film with Large Curvature. – Heat Transfer Research, Scripta Technika, 1993, Vol. 25, No. 2, pp. 216–219.
2. *Gimbutis G., Gimbutyte I. and Sinkunas S.* Heat Transfer of a Falling Liquid Film under Different Heat Flux Distribution in the Film. – Transport Processes in Engineering. Elsevier, 1992, Vol. 2, pp. 1177–1188.
3. *Гимбутис Г.И.* Теплообмен при гравитационном течении пленки жидкости. – Вильнюс: Мокслас, 1988. – 233с.

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