HEAT EXCHANGE IN A THIN CHANNEL

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Abstract: În lucrare este propusă metoda de calcul al procesului de transfer de căldura ce are loc în spaţiul dintre condensator şi peretele dulapului frigiderului casnic.
Key words: household refrigerator, heat exchange, thin channel

Acceleration of heat exchange in industrial processes, devices, electrical appliances etc. is only possible when deep knowledge of the process is available. We will examine the heat exchange process in the condenser of a household refrigerator. We assume that the system consisting of the condenser and the refrigerator's housing represents a thin channel, with a heat source on one side (condenser), and a heat sink on the other side (refrigerator's wall). On the bottom there is another source of heat - the refrigerator's compressor (Fig. 1). We will study the laminar gas flow in a thin channel whose thickness is considerably smaller than its length and height.

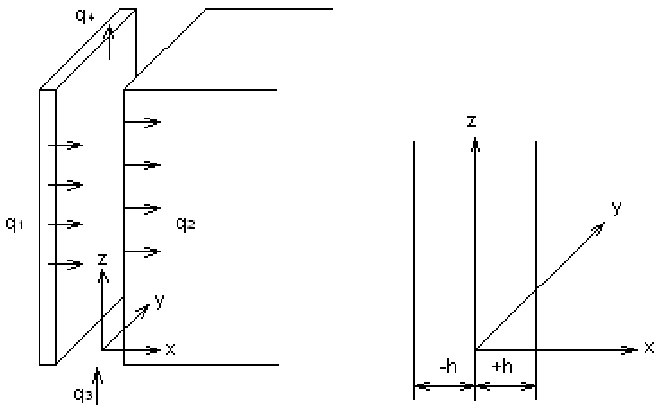

Fig. 1. T*he heat source dislocation*

We will consider the quasi-stationary state of the compressor's functioning, which essentially determines the efficiency of the device.

$$w_x \frac{\partial T}{\partial x} + w_z \frac{\partial T}{\partial z} = \frac{\lambda}{c \cdot \rho}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2}\right) \qquad (1)$$

$$\left.\frac{dT}{dx}\right|_{x=-h} = -\frac{\alpha_1}{\lambda_1}\left(T_{cd} - T_a\right) \quad (2)$$

$$\left.\frac{dT}{dx}\right|_{x=h} = -\frac{\alpha_2}{\lambda_2}\left(T_a - T_{cd}\right) \quad (3)$$

$$\left.\frac{dT}{dz}\right|_{x=0} = -\frac{q_3}{\lambda_3} \quad (4)$$

The flow equations read:

$$w_x \frac{\partial w_x}{\partial x} + w_z \frac{\partial w_x}{\partial z} = \nu\left(\frac{\partial^2 w_x}{\partial x^2} + \frac{\partial^2 w_x}{\partial z^2}\right) \quad (5)$$

$$w_x \frac{\partial w_z}{\partial x} + w_z \frac{\partial w_z}{\partial z} = \nu\left(\frac{\partial^2 w_z}{\partial x^2} + \frac{\partial^2 w_z}{\partial z^2}\right) + g\beta\Delta T \quad (6)$$

Continuity equation:

$$\frac{\partial w_x}{\partial x} + \frac{\partial w_z}{\partial z} = 0 \quad (7)$$

The last equation implies that in the space wall-condenser the mass is conserved. The solution of Equation (1) for a non-stationary state when the compressor is turned on is given by:

$$T = \frac{z}{2\pi\sqrt{a}} \int_0^t \frac{d\tau}{(t-\tau)^{3/2}} \int_{-\infty}^{\infty} e^{-\frac{(x-3)^2+z^2}{4a(t-\tau)}} T d\xi \quad (8)$$

In our case expression (8) can be simplified. We follow Kondratiev and consider the heat exchange in a regular state. In the boundary layer near the refrigerator's wall the air flow has an opposite direction with respect to the flow of hot air moving upwards being warmed by the compressor and condenser. The air is injected not only at the bottom near the compressor but also at the top close to the refrigerator's body (Fig. 2). Therefore, the z-component of the velocity vector changes its sign along the x-axis.

Equation (1) together with the boundary conditions (2-4) has the following solution:

$$T = \frac{\left(T_{cm} - T\right)w_z}{z w_x}\left(x - h\right) + T_{cond} + \frac{\alpha_2}{\lambda_2}\frac{\left(T_b - T_x\right)w_x z}{\left(T_{cm} - T\right)w_z}\left[e^{-\frac{\alpha w_x}{a}h} - e^{\frac{w_x}{a}(x-h)}\right] \quad (9)$$

Equation (9) is used to determine the temperature, while Equation (8) gives the temperature distribution in the thin channel.

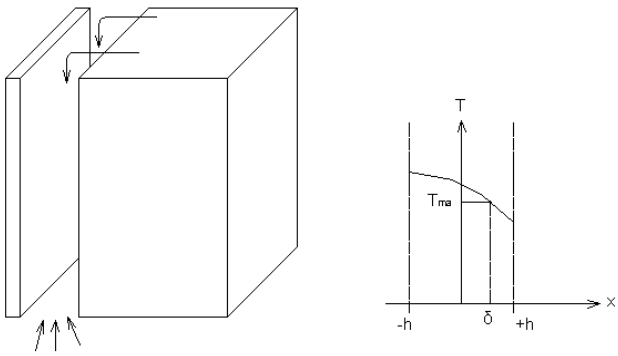

Fig. 2. The air's flow and the temperature distribution in the thin channel

In order to determine the airflow field, Equations (5-7) have to be solved. The influence of temperature on the flow is determined by the air's density variation as function of temperature. The change of velocity vector's direction will be observed in the region where the air's temperature is equal to the temperature of the surrounding environment. The thickness of the boundary layer with an opposite flow direction is determined by the ratio of heat fluxes q_1 and q_3 on one side, and q_2 on the other side. The value of q_2 indicates the quality of isolation of the refrigerator's body. The w_x velocity component is negligibly small with respect to the w_z component, that is the flow lines are not deformed along the z axis. The inflection point can be found from Equation (9) by the substitution $T=T_{ma}$.

In the calculations, the viscosity variation with temperature is ignored.

In the interval [-h,δ] the air temperature is higher than the temperature of the environment; in this region we observe a flux of hot air moving upwards. In the interval [δ,h] the air temperature is lower than the temperature of the environment and the air is moving downwards. The layer of cold air is being pushed by the warm air coming from the compressor located at the bottom. The exact flow picture of this process is reasonably complicated and not required for our analysis. We accept that the air flux consists of several layers and the velocity vector is changing its direction in the plane x=δ. In the x direction heat exchange takes place only by conduction. Therefore, we will examine Equation (6). It's solution, given the discussed simplifications, is (10) where T is computed from (9).

$$\frac{w_z^2}{2} = g\beta \int_0^L T dz \,, \tag{10}$$

The above relation can be used to determine the velocities of the upward moving air in the interval [-h, δ] and the downward moving air in the interval [δ,h]. As further simplification, the average temperatures in each interval may be used.

Given the air velocity, we can determine the true values of the convection coefficients. Consequently, the refrigerator's efficiency can be improved by increasing the heat exchange.

Nomenclature:

T, T_{cm}, T_{cond}, T_a - current temperature, compressor temp., condenser temp., air temp., K;

w_x, w_z - x and z components of velocity, m/s;

λ - thermal conduction coefficient, W/(mK);

c - specific heat capacity, kJ/(kgK);

ρ - air density, kg/m^3;

α_1, α_2 - thermal convection coefficient for condenser and refrigerator wall, W/(m^{2}K);

ν - kinematic viscosity, m^2/s;

β - thermal expansion coefficient of air, 1/K;

g - gravitational acceleration, m^2/s;

$2h$ - thickness of the thin channel, m;

δ - coordinate of the plane where the air temperature equals the environment temperature, m.

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