DETERMINATION OF HEAT TRANSFER COEFFICIENTS USING DYNAMIC CHARACTERISTICS

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A description is given of a method for determining the heat transfer coefficients from the heating-cooling temperature curves of both heat transfer agents in an intermittent heat exchanger.

The method of determining the heat transfer coefficients from the dynamic characteristics simplifies the investigation of heat transfer in intermittent heat-exchange apparatus and gives more reliable results [1].

The basis of this method is the static equation

$$T\dot{t} + t = \theta. \tag{1}$$

This is used to determine the time constant in accordance with the experimental data, after which the heat transfer coefficients are calculated.

Thus, for the case of heating by a single-phase heat transfer agent the joint solution of the cooling equation of one of the agents, the heating equation of the other and the basic heat transfer equation leads to the equation

$$T = \frac{Mc}{W\left[1 - \exp\left(-\frac{kF}{W}\right)\right]}, \tag{2}$$

from which the heat transfer coefficient is determined.

Equation (2) is obtained in this form only if the flow rate and temperature of the heating agent at the exchanger inlet are constant and in the absence of heat losses to the ambient medium from either agent. This limits the usefulness of the method.

Discarding the latter of the above-mentioned assumptions considerably complicates the calculations, since Eq. (2) takes the form

$$T = \frac{Mc}{W\eta\left[1 - \exp\left(-\frac{kF}{W\eta}\right)\right]}, \tag{2a}$$

where η is a coefficient by means of which we take the heat losses into account [2].

At the same time, an analysis of all three temperature curves $t = f_1(\tau)$, $t'_{\mathrm{T}} = f_2(\tau)$; $t''_{\mathrm{T}} = f_3(\tau)$ makes it possible to solve this problem with less severe assumptions, since the dynamic characteristics of the exchanger are considered jointly.

Thus, for the specific case of heating by a single-phase heat transfer agent through a jacket the condition of zero heat losses to the ambient medium from both agents is replaced by a milder condition applying to the heated agent only.

Moreover, it is no longer necessary to maintain constant values of the flow rate and temperature of the heating agent at the exchanger inlet.

Equating the quantity of heat absorbed by the heated agent to the quantity of heat transferred, which is determined from the basic heat transfer equation, we have

$$Mcdt = kF\,\frac{(t'_{\mathrm{T}} - t) - (t''_{\mathrm{T}} - t)}{\ln\frac{t'_{\mathrm{T}} - t}{t''_{\mathrm{T}} - t}}\,d\tau.$$

In our case, when the water equivalent of the agent filling the apparatus exceeds by approximately an order the water equivalent of the agent filling the jacket, we are justified in expressing the temperature difference as the logarithmic mean.

Going over to finite differences, we obtain the formula

$$k = \frac{Mc}{F\,\Delta\tau}\int\limits_{(t'_{\mathrm{T}},\, t''_{\mathrm{T}},\, t)_{\tau}}^{(t'_{\mathrm{T}},\, t''_{\mathrm{T}},\, t)_{\tau+\Delta\tau}} \frac{\ln\frac{t'_{\mathrm{T}} - t}{t''_{\mathrm{T}} - t}}{t'_{\mathrm{T}} - t''_{\mathrm{T}}}\,dt. \tag{3}$$

Where necessary it is possible to take the temperature dependence of the specific heat into account.

The table presents the results of a typical calculation based on Eq. (3): 3 kg of water is heated in a laboratory apparatus with a mixer and a water jacket; the area of the heating surface is 0.05 m^2.

Table

Calculation of Heat Transfer Coefficient from the Experimental Data

τ	$\Delta\tau$	t	t'_{T}	t''_{T}	Δt	$\frac{Mc}{F\Delta\tau}$	k
300	—	36.0	95.0	58.0	—	838	—
600	300	59.0	93.0	72.0	23.0	838	650
900	300	73.5	91.0	80.0	14.5	838	738
1200	300	81.5	90.0	86.0	8.0	838	772
1500	300	85.9	90.0	88.0	4.4	838	795

The calculation employs the arithmetic means of the temperatures on the time interval considered.

If the experimental temperature curves are represented in the form of power series, instead of integration in finite differences or graphical integration, the calculations can be performed on a computer.

NOTATION

t is the temperature of the heated substance, °C; M is the mass of the heated substance, kg; c is the specific heat of the heated substance, J/kg · deg; θ is the temperature effect due to the heat transfer agent, °C; t'_T is the inlet temperature of the single-phase (liquid) heat transfer agent, °C; t''_T is the outlet temperature of the single-phase (liquid) heat transfer agent, °C; F is the heat transfer surface, m^2; k is the heat transfer coefficient, $W/m^2 \cdot deg$; $\dot{t}$ is the derivative with respect to time, deg/sec; T is the time constant of the heat exchanger, sec; W is the water equivalent of the heat transfer agent, W/deg.

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