S. J. Tkachenko, Dr. Sc. (Eng.), Professor; N. V. Rezident, Cand. Sc. (Eng.), Assistant Professor; D. I. Denesiak

EXPERIMENTAL STUDY OF THE NONSTATIONARY HEAT EXCHANGE IN THE MIXTURE

Experimental studies of the heat transfer process from the vertical cylindrical wall to the organic mixture with limited information of thermal physical processes have been carried out. The portable experimental stand, main part of which consists of two coaxial cylinders, thermocouples, device for information collection from the thermocouples and its transfer to the computer. Heat transfer coefficients from the wall are determined by means of two methods: method for stationary heat exchange processes and method of the regular thermal mode in the system «cylindrical volume filled with water – metal wall – mixture», on the condition of mixture location in the external annular channel. It was revealed that at the investigated interval the ratio for the excess temperature ln(ϑ) = f(τ) is maintained, it is typical for the regular thermal mode in the solid bodies of different forms. It was established that the discrepancy of heat transfer coefficients, determined by the method of the regular thermal mode and determined by the methods of the stationary mode does not exceed 20%. The difference is explained by the fact that the experimental studies were carried out on conditions of non-stationary heat exchange and the processing of the experimental data for the determination of the heat-transfer coefficients was performed, applying the technique, used for stationary heat exchange modes. The data, obtained as a result of the studies, prove the possibility of applying the method of regular thermal mode for the study of heat transfer intensity to viscous liquids and organic mixtures. The proposed laboratory installation and the technique of the results processing enable to assess heat transfer coefficients to the viscous liquids and mixtures with the limited information about their thermal physical properties and suggested methods of intensification of the convective heat exchange.

Key words: *non-stationary heat exchange, regular thermal mode, heat exchange in organic mixtures, cooling rate, excessive temperature.*

Introduction

Experimental calculation method, applied for the determination of heat exchange intensity in the complex mixtures [1 – 3], requires further improvement as the heat transfer coefficients determined at the basic portable experimental stand, where heat exchange mode is nonstationary, were obtained as a result of application of the method of experiments processing for stationary (quasistationary) conditions of the heat exchange. Besides, experimentally determined values of the convective heat transfer coefficients in nonstationary conditions of heat exchange are used for the forecasting of heat exchange intensity in real heat-exchangers, operating in quasistationary conditions of the heat exchange.

Cooling and heating of bodies – these are nonstationary processes, which are widely spread in the nature and engineering, they are studied in the theory of heat conduction (regular steady-state thermal mode) and heat transfer. Theory of steady-state mode for nonstationary processes was developed in the studies of G. M. Kondratiev, G. N. Dulnev and other researchers. It is widely used in various calculations and for carrying out various experimental research.

Steady-state mode of the first kind, second and third are distinguished. Depending on whether t_m = const or t_m = var. Academician O. V. Lykov introduces general feature of the regularization of the bodies heating kinetics for all three kinds of steady-state modes. This characteristic is the cooling rate value, which is determined according to an average volumetric temperature of the body:

$$m = -\frac{d\bar{t}}{\left(t_m - \bar{t}\right)d\tau} = const$$

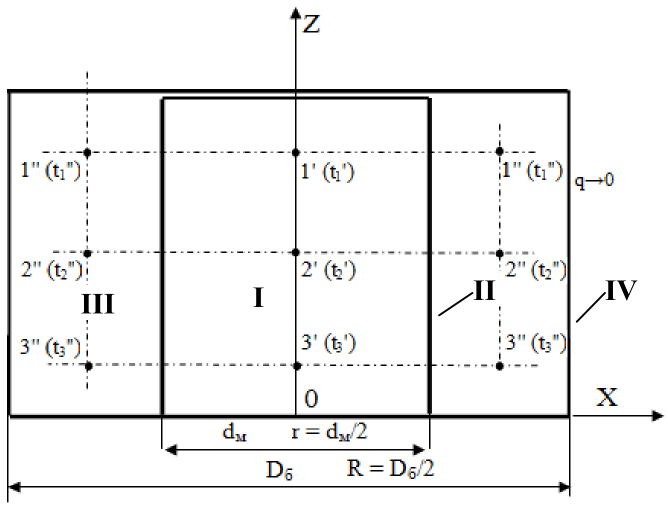
where t_m – is the ambient temperature, and τ – is time.

From this point of view there is no need to distinguish steady-state modes of the first, second and third kinds.

The given research is aimed at application of the method of steady-state thermal mode to forecast the intensity of heat exchange between the metal wall and the mixture with the limited information regarding heat-transfer characteristics in the system «cylindrical volume filled with water – metal cylindrical wall – mixture in the coaxial volume».

Main part

Diagrams of the research facilities are shown in [1 – 3]. These facilities contain the following components: cylindrical vessel with hot heat transfer fluid – water of the height of h_m = 116 mm, diameter d_m = 96 mm, wall thickness δ_{wall} = 0.5 mm and internal insulated cylindrical vessel with cold heat-transfer fluid – mixture, that forms with the internal vessel the annular volume of Δ = 52 mm of the thickness. Thin-wall shell has small heat-transfer resistance $R_{wall} = 1.1 \cdot 10^{-5}$ (m^2·K)/W. Temperatures of heat-transfer fluids were measured by means of the thermocouples in three points on the height of the cylindrical volume and annular channel, and by means of the laboratory mercury thermometer (division value 0.1 C) in the center of the volume and channel. To reveal the character of temperatures distribution in the water and in the mixture during the experiments the thermocouples were moved along the cross-section of the annular channel and cylindrical volume. Fig. 1. shows the installation, scheme of the thermocouples location (a) and their coordinates (b). The internal cylindrical volume I is filled with the hot water, the annular volume III – with the investigated mixture. Information regarding heat-transfer properties is limited. Natural non-stationary process occurs. The heat from the water to the mixture is transferred across the thin metal cylindrical surface II. Annular volume III is formed by the cylindrical wall II and externally insulated cylindrical wall IV.



	|X|	|Z|
1'	0	100
2'	0	58
3'	0	16
1"	74	100
2"	74	58
3"	74	16

Fig. 1. Basic element of the experimental installation

Cold heat transfer fluid – organic mixture, where the heat exchange intensity was studied, was poured in the annular volume. Cattle substrates of the relative humidity W = 86%, 90% and 94% were used as the studied mixtures. Temperature range of the hot heat transfer fluid is t_2'= 72…50 °C, cold heat transfer fluid temperature range is – t_2''= 20…40 C. Ambient temperature beyond the system t_{amb} = 20…22 °C. Temperatures t_2', t_2'', temperature drop $\Delta t = t_2' - t_2''$ changed with the time t_2', t_2'', $\Delta t = f(\tau)$. Thermal flow from the cylindrical volume to the mixture $Q = f(\tau)$ changed in time. On conditions of total temperature drop of less than 5 °C, the experiments were over, because the processing of such results is inexpedient due to a considerable error.

Temperature of the wall was determined from the equation $t_{wall} = t_2' - \bar{q} / \bar{\alpha}_{1Nu}$, applying the method of successive approximations, where $\bar{q}, \bar{\alpha}_{1Nu}$ – are correspondingly the moments of time τ_2 and τ_1, average thermal flow across the metal cylindrical wall and the coefficient of the convective heat transfer from the water to the wall, it is determined by the known criterial equation for a large volume on the conditions of stationary mode [4].

Specific thermal flow

$$\bar{q} = \frac{M_w \cdot C_{pw} \cdot \left[t'_{2(\tau_2)} - t'_{2(\tau_1)} \right]}{F(\tau_2 - \tau_1)}, \tag{1}$$

where M_w – is the mass of the water in the cylindrical volume, kg; C_{pw} – mass specific heat for average temperature, kJ/(kg·K); $t'_{2(\tau_1)}$, $t'_{2(\tau_2)}$ – temperatures of the water at the initial and final moment of time, ^oC, at the periods of time τ_1 and τ_2, F – area of the heat exchange, m^2.

Heat transfer coefficients from the wall to the organic mixture α_2 were determined by two methods: method of the stationary heat exchange processes and method of the regular thermal mode in the system «cylindrical volume filled with water – metal wall – mixture», on conditions of the mixture location in the external annular channel.

Among the advantages of the regular thermal mode is its versatility. It enables to carry out the experimental studies of various physical parameters: temperature conductivity coefficient, heat-conductivity coefficient, specific heat capacity, heat-transfer resistance, heat exchange coefficient, shape factors of different bodiesю. All the methods of the regular mode are self controllable.

Methods of the regular mode are distinguished by the simplicity of the measuring equipment and experimentation. On conditions of their usage, basic measuring value is the cooling rate. For this purpose it is sufficient to install one thermocouple in the random location of the studied body. The disadvantages of the regular mode include the necessity of the careful realization of the theoretical preconditions regarding the stability of the ambient temperature and heat-transfer coefficient to the external environment α during the experiment.

By the results of the experiment the distribution of excessive temperatures in the studied system is built in the form of the dependence $ln\,(t_2' - t_2'') = f(\tau)$ for W = const (Fig. 2), i. e.

$$ln(\vartheta) = ln\,(t_2' - t_2'') = f(\tau), \tag{2}$$

where $ln(\vartheta)$ – is natural algorithm of the excessive temperature of the organic mixture, °C; τ – current time of the experiment, c.

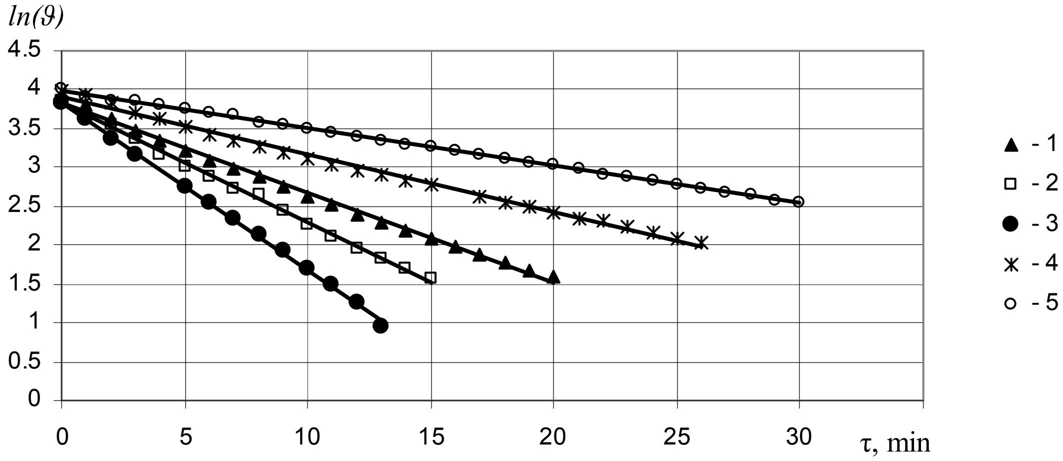


Fig. 2. Distribution of the excessive temperatures in the time:
Pig substrate, the humidity 1 – 86%, 2 – 90%, 3 – 94%, cattle substrate 4 – 94%, 5 – 90%

Proceeding from the Fig. 2 it was revealed that the dependence *ln(ϑ) = f(τ)* for the cooling of the system «cylindrical volume, filled with water – metal wall» has qualitatively identical character with the regular thermal mode, which is observed in the solid bodies of various forms [5, 6].

The rate of regular cooling of the system *m* is determined from the equation, °C/sec

$$m = \frac{ln\,\vartheta_1 - ln\,\vartheta_2}{\tau_1 - \tau_2}, \tag{3}$$

where ϑ_1, ϑ_2 – are excessive local temperatures of the body at initial τ_1 and final τ_2 moment of time, correspondingly, $\vartheta = t_2' - t_{wall}$, where t_2', t_{wall} are determined for two moments of time τ_1 and τ_2.

Taking into account the experimental results, obtained from (2) and (3) we determine convective heat transfer coefficient from the equation [5, 6]:

$$\alpha_{2m} = \frac{m \cdot C_p}{F \cdot \psi}, \tag{4}$$

where C_p –is the complete heat of the body, kJ/K, F – is the area of the cylindrical volume surface, m^2.

The irregularity ratio of temperature distribution in the body

$$\psi = \frac{\vartheta_f}{\vartheta_v} = \frac{m \cdot Cv}{\alpha_{2m} \cdot F}, \tag{5}$$

where ϑ_v – is the excessive temperature of the hot heat transfer fluid $\vartheta_v = t_2' - t_2''$, ^{o}C; ϑ_f, – is the excessive temperature of the hot heat transfer fluid relatively the average temperature of the wall $\vartheta_f = \left| t_2' - t_w \right|$.

$$\text{or } \psi = \frac{(t_2' - t_w)}{(t_2' - t_2'')}, \tag{6}$$

We will determine the convective heat transfer coefficient to the substrates from the relation

$$\alpha_{2k} = \left(\frac{1}{k_{exp}} - \frac{1}{\alpha_{1Nu}} \right)^{-1}, \tag{7}$$

where $k_{exp} = q_{exp}/\Delta t_{exp}$, W/(m^2·K) – is the experimental coefficient of the convective heat exchange, which is determined as the ratio of the specific thermal flow q_{exp} to the temperature drop $\Delta t_{exp} = t_2' - t_2''$.

Applying the above-mentioned techniques the study and calculations of the intensity of the convective heat transfer to the substrates of pigs and cattle on condition of free convection near the vertical cylindrical wall was carried out. By the results of the calculations, the dependences, shown in Fig. 3 and Fig. 4, are constructed, indices «m» and «k» denote values for various methods of α_2 determination.

Fig. 3 shows the dependence of the convective heat transfer coefficient on the cooling rate $\alpha_{2m} = f(m)$.

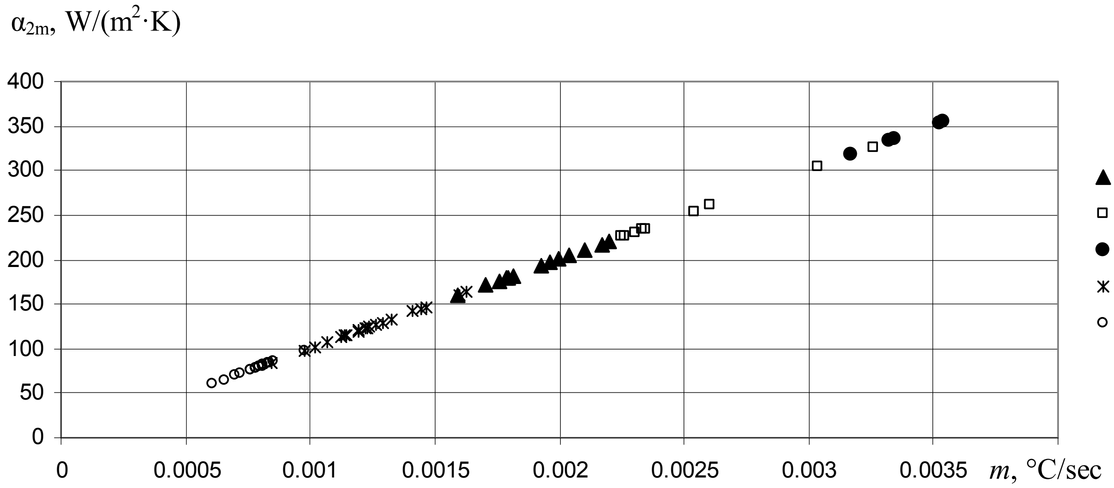


Fig. 3. Dependence of the convective heat transfer coefficient to the substrates on the rate of cooling: pig substrate, humidity 1 – 86%, 2 – 90%, 3 – 94%, cattle substrate4 – 94%, 5 – 90%

The obtained results enable to see that the location of the experimental points corresponds to qualitative curve, described in [6, 7] for solid bodies.

Nonstationary methods enable to avoid measurement of the thermal fluxes (in certain cases it is complicated) and limit by temperatures measurements in two or several points. They provide wider possibilities regarding the selection of heat sources than stationary ones, hey are, as a rule, transient in time, do not require much time for the preliminary holding of the samples at the determined temperature.

The method of nonstationary thermal conductivity allows in some cases to perform measurements on conditions of the continuous changes of temperature to its desired value. This enables to obtain, simultaneously, the corresponding continuous curve of the measured thermal parameter change in the preset temperatures interval. At the same time, in all the stationary methods, such curves are constructed by several studied points, which correspond to different stationary thermal modes, number of which is limited. The nonstationary methods have the advantages on the conditions of studying the thermal processes in complex mixtures [7, 8].

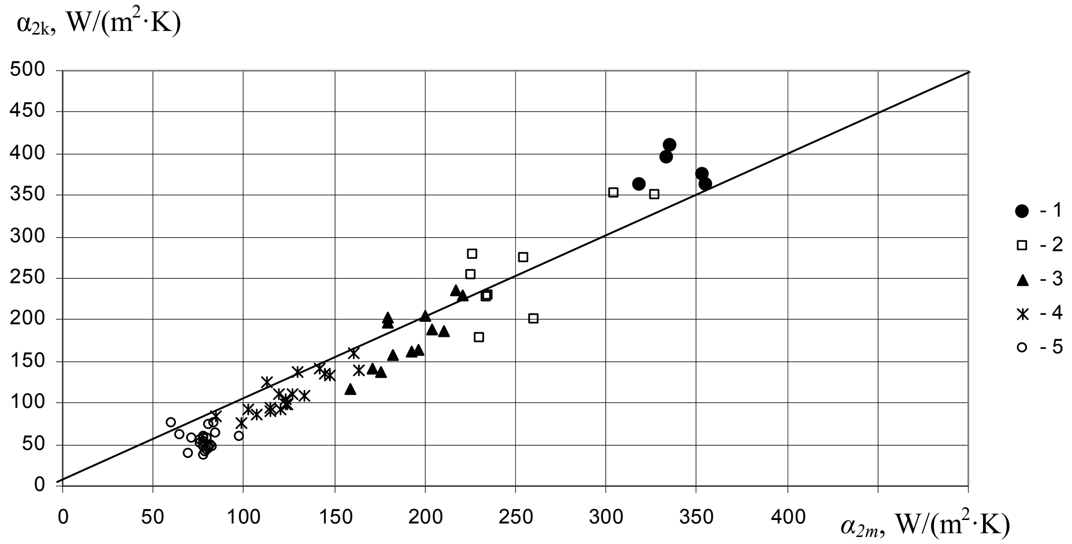


Fig. 4. Comparison of the convective heat transfer coefficients to the substrates, determined by the cooling rate α_{2m} and by the heat transfer coefficient α_{2k}: pig substrate of the humidity 1 – 86%, 2 – 90%, 3 – 94%, cattle substrate 4 – 94%, 5 – 90%

The comparison of the experimental results (Fig. 4) enables to evaluate that the divergence of the convective heat transfer coefficients is ± 20%. It is explained by the fact, that the convective heat transfer coefficients α_{2k} are determined by the conventional technique, when the studies are carried out at the steady – state mode, and α_{2m} – by the technique, applied for non-stationary processes.

The experiments, aimed at the revealing of the regular thermal mode, are carried out at the installation similar to the installation (Fig. 1), but the geometrical dimensions of heat-exchanging surface were different: height h_m = 88 mm, diameter d_m = 72 mm, wall thickness δ_w = 0.5 mm, annular channel thickness Δ = 52 mm; the dimensions of the external isolated cylindrical vessel $H_б$ = 120 mm, $D_б$ = 200 mm. It is determined that the features of the regular thermal mode are also manifested in the installation with such geometrical parameters.

The suggested laboratory installation and the technique of the experiments processing enable to evaluate the coefficients of the convective heat transfer to viscous fluids and mixtures with the limited information about their thermal physical properties and propose the methods, aimed for the intensification of the processes of the convective heat exchange.

Conclusions

By the results of the research it is determined that at the investigated interval of the parameters the relation for the redundant temperature $ln(\vartheta) = f(\tau)$ for cooling of the system «cylindrical volume filled with water – metal wall», characteristic for the regular thermal mode in solid bodies of different form is maintained.

Dependences of the cooling rate $m = f(\alpha_2)$, obtained experimentally, are described by the curve, similar by its structure to the curve, described in the literature for the solid body.

The obtained experimental data confirm the possibility of using the method of the regular thermal mode for study the intensity of the convective heat transfer to the viscous liquids and organic mixtures, fermented in the reactor of the biogas installation. Application of the methods of the regular thermal mode is a promising direction of studying the processes of the heat exchange in the viscous fluids with the known thermal physical properties and organic mixtures with limited information about thermal physical properties.

The discrepancy of the convective heat transfer coefficients, determined by the method of regular thermal mode and those, determined by the methods, used for stationary mode does not exceed 20%.

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Tkachenko Stanislav – Dr. Sc. (Eng.), Professor with the Department of Heat and Power Engineering, e-mail: stahit6937@gmail.com.

Rezydent Nataliya – Cand. Sc. (Eng.), Assistant Professor with the Department of Heat and Power Engineering, e-mail: rezidentnv1@ukr.net.

Denesyak Dmitriy – Post-graduate Student with the Department of Heat Power Engineering, e-mail: doc13energee@gmail.com.
Vinnytsia National Technical University.