THE INFLUENCE OF THE RELAXATION TIME ON THE LIQUID HEAT CAPACITY

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The nonstationary method of the simultaneous definition of the relaxation time of the temperature field and the liquid heat capacity is proposed. The proposed method rests on the solution of the inverse problem for the heat conduction equation of the relaxing temperature field. The influence of the relaxation time on the heat capacity of the liquids has been estimated.

The one of the important thermophysical liquid parameters, playing the essential role at the heat transfer, is heat capacity. The different methods were elaborated for the investigation of the heat capacity. In the work [1], the temperature dependence of the several samples of the oil is experimentally investigated. It is established, that oil heat capacity increases with the temperature increase. In the work [2], the influence of the different physical fields on the thermophysical liquid properties is investigated theoretically.

The liquid is heating under the action of the acoustic waves and goes to the nonequilibrium state. All thermophysical properties, including the heat capacity, relax, i.e. they vary the depending on time. Each parameter has its own relaxation time, in the result the spectrum of the relaxation times of the thermophysical properties appears.

The investigation of the influence of the relaxation time on the liquid heat capacity presents the big interest. For the simplification of the narration let's consider, that the relaxation time is the identical and is equal to the relaxation time of the temperature field for the all thermophysical properties. The relaxing temperature field for the one-dimensional case is expressed by the differential equation (heat exchange with the environment not takes into account):

$$c\rho\left(\frac{\partial T}{\partial t}+\upsilon\frac{\partial T}{\partial x}+\tau_0\frac{\partial^2 T}{\partial t^2}\right)= \lambda\frac{\partial^2 T}{\partial x^2}+2\alpha\, I(t)\cdot e^{-2\alpha x}. \qquad (1)$$

Here τ_0 is the relaxation time, α is the absorption coefficient of the acoustic waves in the liquid; I is the radiation intensity of the acoustic waves. The rest symbols are common.

Taking into consideration, that the heat transport because of the convection is more bigger, than because of the diffusion, i.e.

$$c\rho\upsilon\frac{\partial T}{\partial x} >> \lambda\frac{\partial^2 T}{\partial x^2}$$

Equation (1) is expressed in the form:

$$c\rho\left(\frac{\partial T}{\partial t}+\upsilon\frac{\partial T}{\partial x}+\tau_0\frac{\partial^2 T}{\partial t^2}\right)=2\alpha I(t)\cdot e^{-2\alpha x}. \qquad (2)$$

The initial and boundary conditions are expressed in the following form:

$$\begin{array}{ll} T(0,x)=T_0=const; & T(0,t)=f(t); \\ \frac{\partial T}{\partial t}(0,x)=0; & T(\ell,t)=\varphi(t). \end{array} \qquad (3)$$

In the given work the task about the definition of the relaxation time τ_0 and its influence on the heat capacity of the liquids is solved theoretically. The given task mathematically leads to the solution of the differential equation (2) under the initial and boundary conditions (3).

The Laplace transformation is applied for the solution of this task. The equation (2) assumes the following form in images:

$$\frac{dT^*}{dx}+T^*\left(\frac{s}{\upsilon}+\frac{s^2\tau_0}{\upsilon}\right)= \frac{2\alpha\, e^{-2\alpha x}}{c\rho\upsilon}I^*+\frac{T_0}{\upsilon}(1+\tau_0 s) \qquad (4)$$

where

$$T^*(x,s)=\int_0^\infty T(x,t)\cdot e^{-st}dt;$$

$$I^*(s)=\int_0^\infty I(t)\cdot e^{-st}dt.$$

Solving the equation (4) at the boundary conditions (3), we obtain the following equation:

$$\varphi^*(s)=e^{-a\ell}f^*(s)+\frac{b}{a}-\frac{b}{a}\cdot e^{-a\ell}+ \frac{2\alpha I^*(s)}{c\rho\upsilon}\frac{e^{-2\alpha\ell}-e^{-a\ell}}{a-2\alpha}, \qquad (5)$$

where

$$a=\frac{s}{\upsilon}+\frac{s^2\tau_0}{\upsilon},\quad b=\frac{T_0}{\upsilon}(1+\tau_0 s)$$

$$f^*(s)=\int_0^\infty f(t)e^{-st}dt,\quad \varphi^*(s)=\int_0^\infty \varphi(t)e^{-st}dt, .$$

Taking into consideration, that a<1 and α<1, we expand $e^{-a\ell}$ and $e^{-2\alpha\ell}$ into s power series. We confine ourselves to two first members of the expansion and equation (5) assumes the following form:

$$\varphi^*(s) = (1 - a\ell) f^*(s) + b\ell + \frac{2\alpha\psi^*(s)\ell}{c\rho\upsilon}. \quad (6)$$

The method of the determinated moments is applied for the definition of the relaxation time τ_0 and heat capacity *c*. Expanding the functions $\varphi^*(s)$, $f^*(s)$ and $\psi^*(s)$ into series on the *s* power we obtain:

$$\begin{aligned} \varphi^*(s) &= \varphi_0 - s\varphi_1 + \frac{s^2}{2}\varphi_2 - \ldots \\ f^*(s) &= f_0 - sf_1 + \frac{s^2}{2} f_2 - \ldots \\ \psi^*(s) &= \psi_0 - s\psi_1 + \frac{s^2}{2}\psi_2 - \ldots \end{aligned} \quad (7)$$

where

$$\begin{aligned} \varphi_0 &= \int_0^\infty (\varphi(t) - \varphi_\infty)\, dt; \quad \varphi_1 = \int_0^\infty (\varphi(t) - \varphi_\infty)\, t\, dt; \\ f_0 &= \int_0^\infty (f(t) - f_\infty)\, dt; \quad f_1 = \int_0^\infty (f(t) - f_\infty)\, t\, dt; \\ \psi_0 &= \int_0^\infty (\psi(t) - \psi_\infty)\, dt; \quad \psi_1 = \int_0^\infty (\psi(t) - \psi_\infty)\, t\, dt; \end{aligned} \quad . (8)$$

Taking into account the expressions (7), for equation (6) we have:

$$\begin{aligned} &\varphi_0 - s\varphi_1 + \frac{s^2}{2}\varphi_2 - \ldots = \\ &= (1 - a\ell)\left(f_0 - sf_1 + \frac{s^2}{2} f_2 - \ldots \right) + b\ell + . \\ &+ \frac{2\alpha\ell}{c\rho\upsilon}\left(\psi_0 - s\psi_1 + \frac{s^2}{2}\psi_2 - \ldots \right) \end{aligned} \quad (9)$$

Equating the coefficients having the equal *s* powers we obtain the following system:

$$\begin{cases} \varphi_0 = f_0 + \dfrac{T_0\ell}{\upsilon} + \dfrac{2\alpha\ell}{c\rho\upsilon}\psi_0 \\ -\varphi_1 = -f_1 - \dfrac{\ell}{\upsilon} f_0 + \dfrac{T_0\ell}{\upsilon}\tau_0 - \dfrac{2\alpha\ell}{c\rho\upsilon}\psi_1 \end{cases} . \quad (10)$$

Solving this system we obtain the two unknown values: heat capacity *c* and relaxation time τ_0:

$$c = \frac{2\alpha\ell\psi_1}{\rho\upsilon\left(\varphi_1 - f_1 - \dfrac{\ell}{\upsilon} f_0 + \dfrac{T_0\ell}{\upsilon}\tau_0 \right)} \quad (11)$$

$$\tau_0 = \frac{\upsilon\left[\psi_1\left(\varphi_0 - f_0 - \dfrac{T_0\ell}{\upsilon} \right) - \psi_0\left(\varphi_1 - f_1 - \dfrac{\ell}{\upsilon} f_0 \right) \right]}{T_0\,\ell\,\psi_0}. \quad (12)$$

From the equation (11) it is seen, that liquid heat capacity decreases with the increase of the relaxation time.

The experiments, carried out by us, show, that liquid temperature dependences on time according to the following law:

$$\begin{aligned} f(t) &= T_0 + T_{01}\left(1 - e^{-k_1 t}\right) \\ \varphi(t) &= T_0 + T_{02}\left(1 - e^{-k_2 t}\right). \end{aligned} \quad (13)$$

Substituting the values $f(t)$ and $\varphi(t)$ in the equation (8) we obtain:

$$\begin{aligned} f_0 &= -\frac{T_{01}}{k_1}; \quad f_1 = -\frac{T_{01}}{k_1^2}; \\ \varphi_0 &= -\frac{T_{02}}{k_2}; \quad \varphi_1 = -\frac{T_{02}}{k_2^2}. \end{aligned} \quad (14)$$

If the system doesn’t relax under the rest equal conditions, i.e. τ_0=0, the equation (11) has the form:

$$c_0 = \frac{2\alpha\,\ell\,\psi_1}{\rho\upsilon\left(\varphi_1 - f_1 - \dfrac{\ell}{\upsilon} f_0 \right)}. \quad (15)$$

From the comparison of the formulae (11) and (15), we obtain:

$$\frac{c}{c_0} = \frac{1}{1 + \dfrac{T_0\ell\tau_0}{\upsilon\left(\varphi_1 - f_1 - \dfrac{\ell}{\upsilon} f_0 \right)}}. \quad (16)$$

Substituting the formula (14) in the formula (16) we obtain:

$$\frac{c}{c_0} = \frac{1}{1 + \dfrac{T_0\ell\tau_0}{\upsilon\beta}} \quad (17)$$

where

$$\beta = \frac{T_{01}}{k_1^2} - \frac{T_{02}}{k_2^2} + \frac{\ell}{\upsilon}\frac{T_{01}}{k_1}.$$

It is possible to estimate the influence of the relaxation time on the heat capacity of the liquids by the formula (17).

At τ_0=0, i.e. when relaxation absence and the system is in the equilibrium state, we have the ratio:

$$\frac{\psi_1}{\psi_0}=\frac{\varphi_1-f_1-\frac{\ell}{\upsilon}f_0}{\varphi_0-f_0-\frac{T_0\ell}{\upsilon}}. \qquad (18)$$

Taking into consideration the formula (14), the equation (18) is reduced to the following form:

$$\frac{\psi_1}{\psi_0}=\frac{T_{01}k_2^2(\upsilon+\ell k_1)-T_{02}\upsilon k_1^2}{k_1k_2(T_{01}k_2\upsilon-T_{02}\upsilon k_1-T_0\ell k_1k_2)}. \qquad (19)$$

From the condition (18) we find the liquid flow velocity at which the relaxation absence:

$$\upsilon=\frac{\ell\left(\frac{\psi_1}{\psi_0}T_0-f_0\right)}{\frac{\psi_1}{\psi_0}(\varphi_0-f_0)-\varphi_1+f_1}. \qquad (20)$$

Therefore, we can conclude that changing the liquid flow velocity it is possible to operate of the thermodynamic state of the liquid.

[1] *G.T. Gasanov, A.A. Aliyev, L.P. Guryanova.* J. «Fizika», cild 6, №1, 2000, c.41-42.
[2] Kh.G. Gasanov. Gidrodinamicheskiye issledovaniya vzaimodeystviya akusticheskikh I lazernikh izlucheniy s jidkostiyu. Baku, Izd.. «Açıq dünya», 2002, 384c. (in Russian).

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RELAKSASİYA MÜDDƏTİNİN MAYELƏRİN İSTİLİK TUTUMUNA TƏSİRİ

Akustik dalğaların təsirindən maye daxilində bütün istilik fiziki parametrlər relaksasiya edirlər. Temperatur sahəsinin relaksasiya müddətini və istilik tutumunu birgə təyin etmək üçün yeni metod işlənmişdir.

Göstərilmişdir ki, temperatur sahəsinin relaksasiya müddəti artdıqca istilik tutumu azalır. Relaksasiya müddətini tənzimləmək üçün mayenin axın sürətindən istifadə olunması təklif olunur.

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ВЛИЯНИЕ ВРЕМЕНИ РЕЛАКСАЦИИ НА ТЕПЛОЕМКОСТЬ ЖИДКОСТЕЙ

Предлагается нестационарный метод одновременного определения времени релаксации температурного поля и коэффициента теплоемкости жидкости. Предложенный метод основан на решении обратной задачи для уравнения теплопроводности релаксирующего температурного поля. Оценено влияние времени релаксации на теплоемкость жидкостей.

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