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NON-STATIONARY HEAT TRANSFER DURING CONVECTIVE HEAT TRANSFER

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Abstract. This article discusses the control over some of the technological processes in the chemical, oil, and thermal power industries.

It is always necessary to take into account the fact that the thermophysical parameters of a liquid have in hydraulics and hydrodynamics, especially in thermal physics, and under the action of physical fields, the physical parameters of the liquid first of all change.

It is also emphasized that the use of the values of the physical properties of the liquid, which is valid for the case of stationary physical fields in the case of non-stationary physical fields, can lead to a significant plug. This is a very important point that is always important to keep in mind.

The absence of a method for studying the coefficient of non-stationary heat transfer during convective heat transfer is due to the mathematical complexity that arose when solving the inverse problem for the differential equation of heat conduction with variable coefficients. This is one of the main points in this topic.

In any case, this problem we have disclosed does not claim to be highly accurate, since it was obtained on the basis of an approximate solution of an approximate mathematical model.

But these conclusions are as close as possible to a clear solution to the problem.

For the control of some technological processes in the chemical, oil industry, as well as thermal power, the most promising are the effects on these processes by physical fields.

As a parameter controlling the technological process, one can take the thermophysical parameters of the liquid, which have a significant effect in this case, since the physical parameters of the liquid change primarily under the action of physical fields.

In this regard, in recent years, a huge number of works have been published in periodicals devoted to the theoretical and experimental study of the physical properties of liquids.

Based on these studies, various devices have been developed to determine the physical properties of a liquid.

The developed methods and devices were mainly created for cases of stationary physical fields (fields of pressures, temperatures and velocities) [1].

It should be noted that the methods developed for determining the physical properties of a liquid for stationary physical fields are valid only for these fields.

The use of the values of the physical properties of the liquid, which is valid for the case of stationary physical fields in the case of non-stationary physical fields, can lead to a significant blockage.

All real technological processes of the chemical and oil industries, as well as thermal power engineering associated with convective heat transfer, are not essentially stationary.

In this case, all the thermophysical parameters of the liquid are relaxed, and the relaxation time is different for different parameters. In this regard, at present, there are methods for studying non-stationary thermophysical parameters of a liquid [2].

The absence of a method for studying the coefficient of non-stationary heat transfer during convective heat transfer is due to the mathematical complexity that arose when solving the inverse problem for the differential equation of heat conduction with variable coefficients.

In the periodicals, various attempts were made to take into account the influence of the inertia of the temperature field on the value of the non-stationary heat transfer coefficient.

Taking into account that the thermophysical parameters of a liquid are very sensitive to the methods of their determination, in our opinion, the influence of the inertia of the temperature field on the value of the non-stationary heat transfer coefficient should be taken into account in the differential equation of thermal conductivity [3].

Let us first consider the steady-state temperature regime during convective heat transfer. We assume that the process of convective heat transfer in the laminar regime is described by the differential equation:

$$C_p\ \rho V\frac{dT}{dx} = -\frac{2\alpha_\infty}{R}(T - T_0) \tag{1}$$

where ρ is the density of liquid,

T - temperature

V – the volume of liquid

C – heat capacity

R – pipe radius

In this case, for simplicity of change, it is assumed that the heat transferred due to the convention is much greater than the heat transferred due to diffusion, i.e.:

$$C_p\rho\ V\frac{dT}{dx}\ \gg \lambda\frac{d^2}{dx^2}T \tag{2}$$

where λ – wavelength;

The solution of equation (2) under the condition $T_{(0)} = T_1$, T $(\ell) = T_2$ allows us to find the stationary coefficient of convective heat transfer α_∞according to the following formula:

$$\alpha_\infty = \frac{C_p\rho VR}{2\ell} \times \ln\frac{T_1 - T_0}{T_2 - T_0} \tag{3}$$

The convective heat transfer coefficient under non-stationary temperature conditions is determined from the solution of the inverse problem for the heat conduction equation, which in the one-dimensional case under condition (2) has the form:

$$C_p\rho\left(\frac{dT}{dt} + V\frac{dT}{dx}\right) = -\frac{2\alpha}{R}(T - T_0) \tag{4}$$

The problem is solved under the following boundary and initial conditions:

$$T(0,t) = F(t);\ T(\ell,t) = \varphi(t);\ T=(x,0)= T_0 \tag{5}$$

The solution to the problem is constructed by averaging inertia over the entire length of the pipe, i.e.

$$\varphi(t) = \frac{1}{\ell}\int_0^\ell \frac{dT}{dt}\,dx \tag{6}$$

where is φ (t) - heat transfer coefficient

ℓ - pipe length

$dT -$ temperature differential

In this case, the differential equation (4) is reduced to the form:

$$\frac{dT}{dt} + \frac{2\alpha T}{C_p\rho uR} = \frac{\ell\alpha T_0}{C_p\rho uR} - \frac{\varphi(t)}{\upsilon} \tag{7}$$

The solution to this equation under boundary conditions (5) has the form:

$$T(x,t) = F(t)\, e^{\frac{-2\alpha x}{C_p\rho u R}} + \left(T_0 - \frac{C_p\rho u\varphi}{2\alpha}\right)\left(1 - e^{\frac{-2\alpha x}{C_p\rho u R}}\right) \quad (8)$$

Considering that

$$\frac{dT}{dt} = F'(t)\, e^{\frac{-2\alpha x}{C_p\rho u R}} - \frac{C_p\rho R\,\varphi(t)}{2\alpha}\left(1 - e^{\frac{-2\alpha x}{C_p\rho u R}}\right) \quad (9)$$

where F - friction force

To determine φ (t) from (6) we have the equation:

$$\varphi(t) = \frac{F'(t)}{2\alpha} C_p\rho UR \left(1 - e^{\frac{-2\alpha x}{C_p\rho u R}}\right) - \frac{C_p\rho R\,\varphi'(t)}{2\alpha}\left[1 + \frac{C_p\rho UR}{2\alpha\ell}\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right)\right] \quad (10)$$

Reducing the notation

$$\frac{C_p\rho UR}{2\alpha\ell}\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right) = A; \quad \frac{C_p\rho UR}{2\alpha\ell}\left(1 - \frac{A}{\ell}\right) = B \quad (11)$$

Equation (10) is reduced to the form:

$$\varphi(t) = F'(t)\,A - B\,\varphi' \quad (12)$$

The solution to this equation is:

$$\varphi(t) = e^{\frac{-t}{B}} \int_0^t \frac{A}{B} e^{\frac{t}{B}}\, p'(t)\, dt \quad (13)$$

Using the second boundary condition (5) to determine the coefficient of unsteady heat transfer during convective heat transfer, we obtain the equation:

$$\varphi(t) = F'(t)\, e^{\frac{-2\alpha\ell}{C_p\rho u R}} + T_0\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right) - \frac{C_p\rho R}{2\alpha}\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right) e^{-\frac{t}{\ell}} \int_0^t \frac{A}{B} F'(t)\, e^{\frac{t}{B}}\, dt \quad (14)$$

Equation (11) can be written in the form:

$$\left[\varphi(t) - F(t)\, e^{\frac{-2\alpha\ell}{C_p\rho u R}} - T_0\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right)\right] e^{\frac{t}{B}} = \frac{C_p\rho R}{2\alpha}\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right) \int_0^t \frac{A}{B} F'(t)\, e^{\frac{t}{B}}\, dt \quad (15)$$

Differentiating equation (15) with respect to time t, we bring it to the following form for (φ (t)-F(t)

$$e^{\frac{-2\alpha\ell}{C_p\rho u R}})\, e^{\frac{t}{B}} + \frac{\ell^{\frac{t}{B}}}{B}\left[\varphi - F e^{\frac{-2\alpha\ell}{C_p\rho u R}} - T_0\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right)\right] = \frac{C_p\rho R}{2\alpha}\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right) \frac{A}{B}\, F'(t)\, e^{\frac{t}{B}} \quad (16)$$

Reducing the left and right sides of equations (16) by exp $\left(\frac{t}{B}\right)$ we get:

$$\varphi'(t) - F(t)\, e^{\frac{-2\alpha\ell}{C_p\rho u R}} + \frac{1}{B}\left[\varphi'(t) - F(t)\, e^{\frac{-2\alpha\ell}{C_p\rho u R}} - T_0\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right)\right] = \frac{C_p\rho R}{2\alpha}\left(1 - e^{\frac{-2\alpha\ell}{C_p\rho u R}}\right) \frac{A}{B}\, F'(t) \quad (17)$$

Equation (17) is a transcendental equation, the exact solution of which is possible by determining the non-stationary heat transfer coefficient. Bearing in mind that in a laminar mode of fluid movement in a pipe with unsteady heat exchange, the following takes place:

$$\frac{2\alpha\ell}{C_p\rho uR} < 1 \text{ и } \exp\left(-\frac{-2\alpha\ell}{C_p\rho uR}\right) \approx 1 - \frac{2\alpha\ell}{C_p\rho uR} - .... \quad (18)$$

Thus, it is possible to construct an approximate solution to equation (17) by determining the coefficient of unsteady heat transfer in convective heat transfer

$$\boldsymbol{\alpha} = \frac{C_p\rho R\,(\varphi'(t) - F'(t))}{\varphi(t) - F(t)} \quad (19)$$

Comparing (3) and (19), we have

$$\frac{\alpha}{\alpha_\infty} = \frac{2\ell}{V}\,\frac{(\varphi'(t) - F'(t))}{\varphi(t) - F(t)}\quad \left[\ln\frac{T_1 - T_0}{T_2 - T_0}\right]^{-1} \quad (20)$$

Formula (17) establishes the relationship between stationary and non-stationary heat transfer during convective heat transfer. It does not pretend to be highly accurate, since it was obtained on the basis of an approximate solution to an approximate mathematical model.

The exact analytical solution of the inverse problem for determining the non-stationary heat transfer coefficient is associated with mathematical complexity [4].

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KONVEKTİV İSTİLİK ÖTÜRÜLMƏSİ ZAMANI QEYRİ-STASİONAR MÜBADİLƏSİ

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Xülasə. Məqalə kimya, neft və istilik-energetika sənayelərində bəzi texnoloji proseslərin idarə edilməsindən bəhs edir. Həmişə nəzərə almaq lazımdır ki, mayenin termofiziki parametrləri hidravlikada və hidrodinamikada, xüsusən də istilik fizikasında olur və fiziki sahələrin təsiri altında ilk növbədə mayenin fiziki parametrləri dəyişir.

Həmçinin vurğulanır ki, mayenin fiziki xassələrinin qeyri-stasionar fiziki sahələr vəziyyətində stasionar fiziki sahələr üçün etibarlı olan dəyərlərindən istifadə əhəmiyyətli bir fişə səbəb ola bilər. Bu, həmişə xatırlanması vacib olan çox vacib bir məqamdır.

Konvektiv istilik ötürülməsində qeyri-sabit istilik ötürmə əmsalının öyrənilməsi metodunun olmaması dəyişən əmsallı diferensial istilik ötürmə tənliyi üçün tərs məsələnin həllində yaranan riyazi mürəkkəbliklə bağlıdır.

Bu, mövzunun diqqət çəkən məqamlarından biridir.

Hər halda, həll etdiyimiz məsələ təxmini riyazi modelin təxmini həlli əsasında əldə edildiyi üçün yüksək dəqiqliyə iddia etmir.

Lakin bu nəticələr problemin birmənalı həllinə mümkün qədər yaxındır.

***Açar sözlər**: konvektiv istilik ötürülməsi, stasionar və qeyri-stasionar istilik mübadiləsi, boruda mayenin hərəkəti, istilik keçiriciliyi tənlikləri.*

НЕСТАЦИОНАРНАЯ ТЕПЛООТДАЧА ПРИ КОНВЕКТИВНОМ ТЕПЛООБМЕНЕ

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Резюме. В статье рассматривается управление некоторыми технологическими процессами в химической, нефтяной и теплоэнергетической отраслях. Всегда необходимо учитывать тот факт, что теплофизические параметры жидкости имеют в гидравлике и гидродинамике, особенно в теплофизике, и под действием физических полей в первую очередь изменяются физические параметры жидкости. Также подчеркивается, что использование значений физических свойств жидкости, которые справедливы для случая стационарных физических полей в случае нестационарных физических полей, может привести к значительной пробке. Это очень важный момент, о котором всегда важно помнить.

Отсутствие метода исследования коэффициента нестационарной теплоотдачи при конвективном теплообмене связано с математической сложностью, возникшей при решении обратной задачи для дифференциального уравнения теплопроводности с переменными коэффициентами. Это один из основных моментов в этой теме.

В любом случае раскрытая нами задача не претендует на высокую точность, так как получена на основе приближенного решения приближенной математической модели.

Но эти выводы максимально приближены к однозначному решению проблемы.

Ключевые слова*: конвективный теплообмен, стационарный и нестационарный теплообмен, движение жидкости в трубе, уравнения теплопроводности.*

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