FTD-MT-24-188-67

AD 668159

FOREIGN TECHNOLOGY DIVISION

UNSTABLE CONVECTION HEAT EXCHANGE AND HYDRODYNAMICS IN CHANNELS (SURVEY OF LITERATURE ON SINGLE-PHASE HEAT TRANSFER AGENTS)

by

E. K. Kalinin

50 YEARS
1917 1967
GOLDEN ANNIVERSARY
FOREIGN TECHNOLOGY DIVISION

28

This document is a machine translation of Russian text which has been processed by the AN/GSQ-16(XW-2) Machine Translator, owned and operated by the United States Air Force. The machine output has been post-edited to correct for major ambiguities of meaning, words missing from the machine's dictionary, and words out of the context of meaning. The sentence word order has been partially rearranged for readability. The content of this translation does not indicate editorial accuracy, nor does it indicate USAF approval or disapproval of the material translated.

FTD-MT-24-188-67

EDITED MACHINE TRANSLATION

UNSTABLE CONVECTION HEAT EXCHANGE AND HYDRODYNAMICS IN CHANNELS (SURVEY OF LITERATURE ON SINGLE-PHASE HEAT TRANSFER AGENTS)

By: E. K. Kalinin

English pages: 23

SOURCE: AN BSSR. Vestsi. Seryya Fizika-Tekhnichnykh Navuk (Belorussian, Russian). (Academy of Sciences of the Belorussian SSR. News. Series in the Physical and Technical Sciences). No. 4, 1966, pp. 1-22.

UR/0201-66-000-004 TP7501296

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

FTD-MT- 24-188-67 Date 31 Aug. 1967

ITIS INDEX CONTROL FORM

01 Acc Nr	68 Translation Nr	65 X Ref Acc Nr	76 Reel/Frame Nr
TP7501296	FTD-MT-24-188-67		1881 0485

97 Header Clas	63 Clas	64 Control Markings	94 Expansion	40 Ctry Info
UNCL	UNCL, 0	0		UR

02 Ctry	03 Ref	04 Yr	05 Vol	06 Iss	07 B. Pg.	45 E. Pg.	10 Date
UR	0201	66	000	004	0001	0022	NONE

Transliterated Title NESTATSIONARNYY KONVEKTIVNYY TEPLOOBMEN I GIDRODINAMIKA V KANALAKH (OBZOR LITERATURY PO ODNOFAZNYM TEPLONOSITELYAM)

09 English Title UNSTABLE CONVECTION HEAT EXCHANGE AND HYDRODYNAMICS IN CHANNELS (SURVEY OF LITERATURE ON SINGLE-PHASE HEAT TRANSFER AGENTS)

43 Source
AN BSSR. VESTSI. SERYYA FIZIKA-TEKHNICHNYKH NAVUK(RUSSIAN)

42 Author	98 Document Location
KALININ, E. K.	
16 Co-Author	**47 Subject Codes**
NONE	20, 01
16 Co-Author	**39 Topic Tags:**
NONE	hydraulics, gas flow, drag coefficient, heat transfer, aerodynamic theory, differential equation
16 Co-Author	
NONE	
16 Co-Author	
NONE	

ABSTRACT: In this continuation of a survey of the published works of theoretical and experimental studies of unstable heat exchange and hydrodynamics in channels, the author reviews several preliminary mathematical formulas and criteria of the profiles of temperature and heat exchange, and attention is drawn to the relative paucity of theoretical and experimental studies in this area, both in the USSR and abroad. English Translation: 23 pages.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	А а	A, a	Р р	Р р	R, r
Б б	Б б	B, b	С с	С с	S, s
В в	В в	V, v	Т т	Т т	T, t
Г г	Г г	G, g	У у	У у	U, u
Д д	Д д	D, d	Ф ф	Ф ф	F, f
Е е	Е е	Ye, ye; E, e*	Х х	Х х	Kh, kh
Ж ж	Ж ж	Zh, zh	Ц ц	Ц ц	Ts, ts
З з	З з	Z, z	Ч ч	Ч ч	Ch, ch
И и	И и	I, i	Ш ш	Ш ш	Sh, sh
Й й	Й й	Y, y	Щ щ	Щ щ	Shch, shch
К к	К к	K, k	Ъ ъ	Ъ ъ	"
Л л	Л л	L, l	Ы ы	Ы ы	Y, y
М м	М м	M, m	Ь ь	Ь ь	'
Н н	Н н	N, n	Э э	Э э	E, e
О о	О о	O, o	Ю ю	Ю ю	Yu, yu
П п	П п	P, p	Я я	Я я	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

UNSTABLE CONVECTION HEAT EXCHANGE AND HYDRODYNAMICS IN CHANNELS (SURVEY OF LITERATURE ON SINGLE-PHASE HEAT TRANSFER AGENTS)

E. K. Kalinin

Continuation[1]

In Part I of the survey it was shown that methodically the determination by experiments of the coefficients of heat radiation α and flow friction ξ in unstable conditions do not encounter fundamental difficulties, as also the use of these values for engineering calculations by a one-dimensional method.

In the second part of survey there are examined the theoretical and experimental research in unstable heat exchange and hydrodynamics in channels covered in literature.

---

[1]For the beginning of the article, Part I, see "Izvestia of Academy of Sciences of the Belorussian SSR" No. 4, 1966. Series of physical and technical sciences.

PART II

1. Unstable Hydrodynamics

It is obvious that unstable convection heat exchange to a considerable degree is determined by unstable hydrodynamics. Consequently, study of the latter, apart from its independent value, is necessary for the understanding and development of methods of calculation of unstable heat exchange. In the beginning it is expedient to examine the qualitative picture of unstable flow in a channel. During turbulent isothermal flow of an incompressible liquid in a pipe the equation of motion has the form:

$$\rho \frac{\partial W_x}{\partial t} + \rho W_r \frac{\partial W_x}{\partial r} = -\frac{\partial P}{\partial x} + \frac{1}{r}\tau + \frac{\partial \tau}{\partial r} \quad ; \qquad (1)$$

where $\tau = (\mu + \mu_T)\frac{\partial W_x}{\partial r}$. (2)

Permitting (1) and (2) with respect to the gradient of speed:

$$-\frac{\partial W_x}{\partial r} = \frac{r}{\mu + \mu_T - r\rho W_r}\left(-\frac{\partial P}{\partial x} - \rho\frac{\partial W_x}{\partial t} + \frac{\partial \tau}{\partial r}\right) \qquad (3)$$

If the profile of speed in a flow with acceleration were quasi-stable (i.e., it would correspond in every given moment of time to the stationary for a given instantaneous flow rate), then value of the bracket in (3) would not depend on the radius. In reality this is impossible, since $\frac{\partial P}{\partial x} = Const$ by radius, but $\frac{\partial W_x}{\partial t}$ is changed from zero on the wall to a maximum on the axis of the pipe.

In the quasi-stable case $\frac{\partial \tau}{\partial r} = \frac{\tau_{w_K}}{r_w} = Const$. Taking this as the first approximation and considering (2) and (3) will come to the conclusion that in an accelerated flow $\frac{\partial \tau}{\partial r} \neq Const$ grows from the axis to the wall (in absolute value) when $\frac{\partial W_x}{\partial t} > 0$ and decreases when $\frac{\partial W_x}{\partial t} < 0$. A comparison of the quasi-stable profile of speed with the nonstable is expedient when the quasi-stable pressure gradient $\left(\frac{\partial P}{\partial x}\right)_K$ equals

$$-\left(\frac{\partial P}{\partial x}\right)_K = -\frac{\partial P}{\partial x} - \rho\frac{\partial W}{\partial t}$$

where $\frac{\partial W}{\partial t}$ is the average flow rate acceleration. Qualitatively such a comparison is represented in Fig. 1.

During acceleration of the flow $\left(\frac{\partial W}{\partial t} > 0\right)$ the profile of speed becomes more filled; there appears a radial component of speed $W_r > 0$, $\tau_w > \tau_{w_K}$ and, consequently,

$$\xi > \xi_K, \text{ since } \xi = 8\frac{\tau_w}{\rho W^2}$$

In turbulent flow an increase of $\frac{\partial W_x}{\partial r}$ at the wall leads to increase of the output of turbulence $\rho\overline{W_x' W_r'}\frac{\partial W_x}{\partial r}$, which in comparison with the quasi-stable turns out to be higher at the wall and lower in the flow core.

Heat flow on the radius of the pipe

$$q = -(\lambda + \lambda_T)\frac{\partial T}{\partial r} \qquad (4)$$

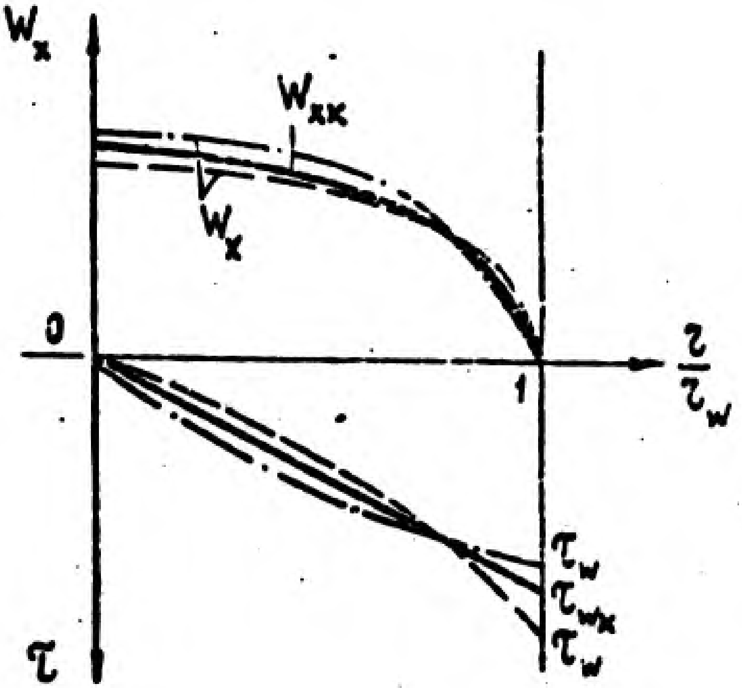

Fig. 1. Distribution of tangential stresses and profile of speed in an accelerated flow. —·—·— is delayed flow $\frac{\partial W}{\partial t} < 0$; ———— is quasi-stable flow; — — — — is accelerated flow $\frac{\partial W}{\partial t} > 0$.

decreases from a maximum at the wall to zero on the axis. Consequently, for assigned temperature head an increase of λ_T near the wall will lead to a growth of the coefficient of heat radiation in comparison with its quasi-stable value. During deceleration of the flow the picture is the reverse. In the case of laminar flow the character of the nonstable change of the profile of speed and the tangential stress will be qualitatively analogous to that depicted on Fig. 1, but less noticeable, since $\mu_T = 0$ in (3).

The considerations expounded show that the hypothesis of quasi-stability does not correspond to reality. Therefore the quasi-stable method of calculation of hydraulic losses founded on it is very approximate. Although unknown, whatever in that or another case of calculation is allowed. A series of works is dedicated to a theoretical analysis and experiments in nonstable hydrodynamics in channels. Let us consider them briefly. Carstens and Roller [1] obtained an expression for the ratio of the nonstable coefficient of friction ξ to the quasi-stable ξ. They originated from the following assumptions:

1) the profile of speed in the core of a turbulent flow obeys the usual root law;

2) mean-integral acceleration on the radius equals the average expenditure;

3) gradient of tangential pressure on the axis of the channel is equal to the quasi-steady-state value, i.e.,

$$\left.\frac{\partial T}{\partial z}\right|_{z=0} = \left(\frac{\partial \tau}{\partial z}\right)_{K}\bigg|_{z=0} = \frac{\tau_{w_K}}{z_w} \tag{5}$$

Then

$$\frac{\xi}{\xi_K} = 1 + \frac{4F_3(1)d}{\xi_K W^2} \cdot \frac{\partial W}{\partial t} \tag{6}$$

Here $F_3\left(\frac{z}{z_w}\right)$ is a function which depends on radius and wall index n in the expression for profile of speed. When $n = 7$, $F_3 = 0.1123$. Let us note that assumption 3 is illogical since the authors in their own computations operate with average-expenditure acceleration, but not acceleration on the axis of the channel. This is clear from Fig. 1 and leads to the oversized values given in formula (6). Dependence (6) and the experimental data obtained

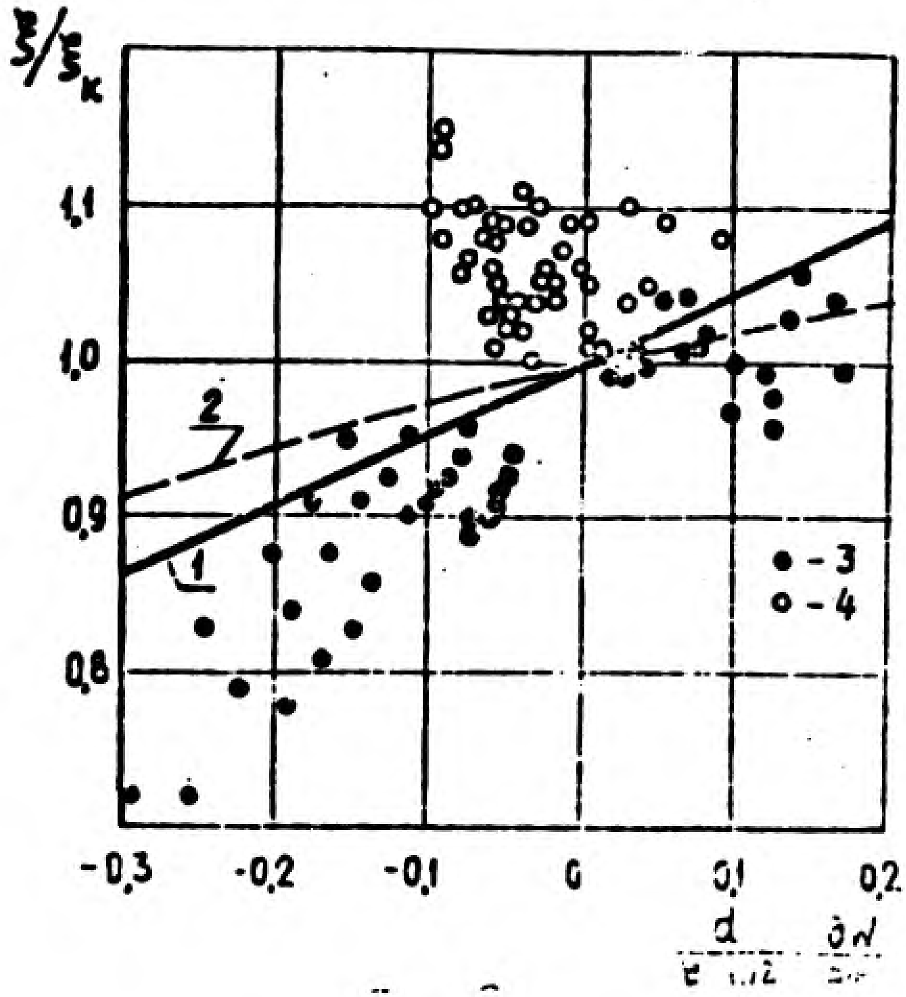

Fig. 2. Experimental determination of the coefficient of friction for nonstable turbulent flow in a pipe. 1 — Equation (6); 2 — Equation (6) taking into account error allowed by authors [1] in the distribution of tangential stresses; 3 — Experimental points [2]; 4 — Experimental points [1].

by [1] and [2] are represented on Fig. 2. The authors of [2] recommend the formula for calculation:

$$\frac{\bar{\xi}}{\bar{\xi}_K} = 1 + C\,\frac{2d}{\xi_K W^2}\cdot\frac{\partial W}{\partial t} \qquad (7)$$

where C is the experimental coefficient.

During acceleration it is equal to 0.01, and during deceleration 0.62.

These experiments were conducted on water in a vertical smooth pipe with a length of 27 calibre with Reynolds numbers to $5 \cdot 10^5$ and $-0.3 < \frac{4\tau_w}{\xi_\kappa W^2} \cdot \frac{\partial W}{\partial t} < 0.3$. In [1] the experiments also were conducted on water, but in a horizontal pipe with a length of 500 calibre. The experiment started from a zero flow rate. At first there was established streamline conditions, then, according to growth of speed in the entrance sections there appeared turbulent flow which spread to the outlet and attained it at $t\sqrt{\frac{gh_0}{L}} \geqslant 1.38$, where h_0 is the piezometric pressure in the tank, and L is the length of the pipe. Experimental points in [1] and [2] deviate from the results of quasi-stable calculation by not more than 20-30%. During nonstable flow hydraulic losses in friction are only a part of total losses, even including inertial hydraulic losses. This permits the authors [1] to make a conclusion concerning the acceptability, for engineering goals, of the use of the quasi-stable method of calculation. The influence of instability of the flow of gas on the coefficient of flow friction was investigated by V. A. Tsetserin [3]. In the method of the experiment by V. A. Tsetserin there are made such rough assumptions (actually the inertial component in equation of motion is not considered) that results obtained in [3] cannot be taken into account.

N. A. Panchurin [4]-[7] solved, in the form of an infinite series, the equation of Navier-Stokes for laminar flow during an exponential change of the pressure gradient. The same equation, but in averaged values, is solved by him for turbulent flow. Here ε_τ was accepted as depending on speed, but constant by section. With such a simplification the solution for turbulent flow presents practical interest. In the case of laminar flow it was shown that for accelerated flow the profile of speed is more filled, and for delayed it is less filled than for quasi-stable, however the example did not get as far as a comparison of ξ and ξ_κ. Experiments by N. A. Panchurin were carried out on water, which oscillated in a U shaped pipe with a length of 7 m (d = 147 mm) during $Re \leq 10^5$ and $\frac{dW}{dt} \leq 1.4$ m/s^2. Oscillations of the column of water were compared with the computed values obtained from the solution of the equation of oscillation with friction.

In equation there was put $\xi_\kappa = 0.019$ which corresponds to the self-simulating region of flow at $Re \geq 6 \cdot 10^5$. From experiments it turned out that $\xi > \xi_\kappa$ both during acceleration and during deceleration of flow. This is quite natural since in the method of calculation there were not considered losses on formation of the profile of speed, changeability ξ_κ, eddy formation during oscillation of the flow in the U shaped pipe, etc.

The experiments of I. S. Kochenov and Yu. I. Kuznetsov [8] with turbulent flow of water gave a very great influence of instability on ξ, as also their theoretical analysis for laminar flow. During acceleration of flow they obtained $\xi > \xi_\kappa$, and during deceleration $\xi < \xi_\kappa$ up to $\xi < C$.

Perimutter and Siegel [9] obtained a solution of the equation of motion for laminar flow of an incompressible liquid in a flat channel during a jump-shaped change of the pressure gradient.

Considerable interest is presented by works dedicated to the theoretical research of a nonstable boundary layer [10], [11]. In these works it is shown that during acceleration of flow the profile of speed is more filled, the coefficient of friction increases and separation of flow is hampered. During deceleration, conversely. Also, the determining factor, as in channels, is the relative acceleration $\frac{1}{W} \cdot \frac{\partial W}{\partial t}$. During acceleration of the cylinder the point of breakaway shifts back, therefore the width of wake flow and the coefficient of profile resistance is lowered. During deceleration, conversely. This is well confirmed by experiment [12]. The same will be true for other blunt bodies having separation of flow.

In channels, in places where there are vortexes (local resistances) it is possible to expect that the coefficient of local resistance during acceleration of flow will also be less than quasi-stable, and during deceleration, more so. Experiments [2] and [4] on diaphragms in pipes confirm this. It was determined that the less the ratio of the diameter of the hole of the diaphragm to the diameter of the pipe, the bigger this effect will be.

2. Unstable Heat Radiation

a. Laminar flow. We know of only theoretical works dedicated to investigation of heat exchange during nonstable laminar flow of heat-transfer agents in pipes and flat channels. The solution of equations of energy and motion in these works is looked for under the following general assumptions;

1. physical properties are constant,
2. the liquid is incompressible,
3. heat supply due to dissipation of energy is absent,
4. thermal conduction along the axis of the channel is equal to zero.

5. $W_r = 0$ ($W_y = 0$).

Under these assumptions (for a pipe) the problem reduces to a separate solution of the equation of motion:

$$\frac{\partial W_x'}{\partial t} + W_x' \frac{\partial W_x'}{\partial x} = -\frac{1}{\rho}\cdot\frac{\partial P}{\partial x} + \nu \frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\frac{\partial W_x}{\partial r}\right) \qquad (8)$$

and the equation of energy:

$$\frac{\partial T}{\partial t} + W_x \frac{\partial T}{\partial x} = \frac{\lambda}{\rho C_p}\cdot\frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) \qquad (9)$$

The equation of energy (9), as a rule, is solved approximately either by the method of the "rod" model, or by the integral method. The method of the "rod" model consists of the fact that speed in (9) is regarded constant on the section and equal to the average flow rate, i.e., $W_x = W$. Further, the solution is sought in the form of a series, analogous to the steady-state solution, but in which every member is multiplied by function $F_n(x,t)$. Substitution of this expression in (9) gives a partial differential equation of the first order relative to $F_n(x,t)$. Solving it by the method of characteristics or another way, we find $F_n(x,t)$ and the solution of the nonstable problem.

The integral method differs from the preceding only by the fact that in (9) distribution W_x' is considered on the section of the channel, but function $F_n(x,t)$ is the permutation of the sought solution not in (9) but in the equation obtained after integration of (9) over the radius of the pipe. Both methods do not permit estimating deflection from the exact solution without a direct comparison with the last one. But they permit one qualitatively and correctly to describe the basic peculiarities of nonstable heat exchange.

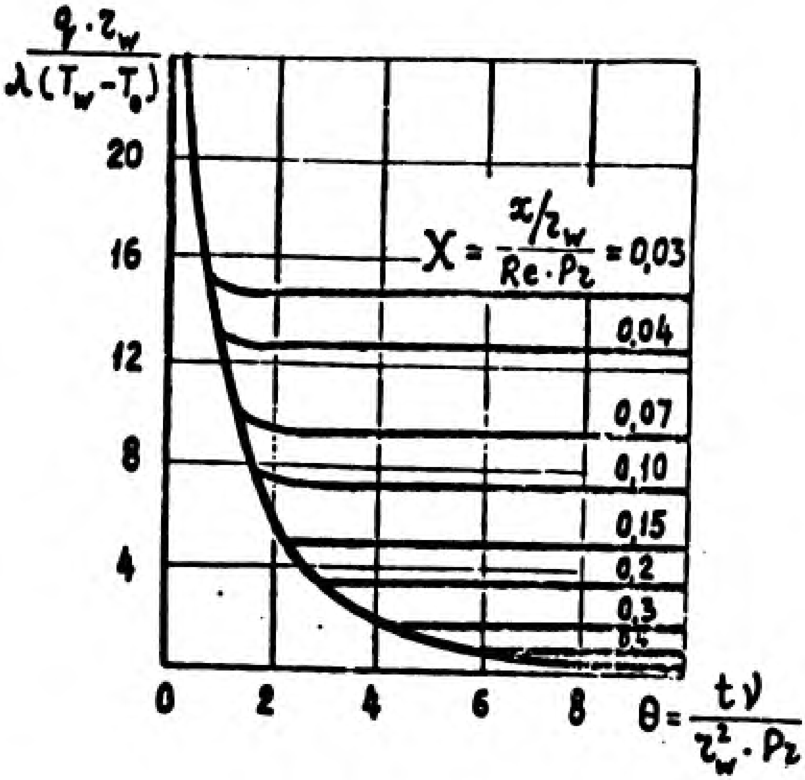

Fig. 3. Nonstable change of heat flow during an abrupt change of the temperature of the wall of a cylindrical pipe.

On Fig. 3 according to the data of R. Siegel [13] there is represented the change in time of heat flow after a jump of wall temperature. A curve of the hyperbolic type describes the change of heat flow in sections ($X > \theta$), to which the heat-transfer agent, located at the initial moment outside the limits of the heating section still did not reach. In these sections there occurs a nonstable heating of the heat-transfer agent due to thermal conduction only. This curve coincides well with the solution of the nonstable heat-conduction equation for a rod of heat-transfer agent.

The straight lines parallel to the abcissa are the steady-state solution for sections $X < \theta$, which for the given section passes to a nonstable solution.

Sparrow and Siegel [14], [15], [16] using the "rod" model conduct an analytic investigation of the simplest cases of nonstable heat exchange, when the speed of the heat-transfer agent is constant.

Perimutter and Siegel [9] also using the "rod" model analyze nonstable heat exchange in a flat channel, already taking into account the jump-like change of the pressure gradient.

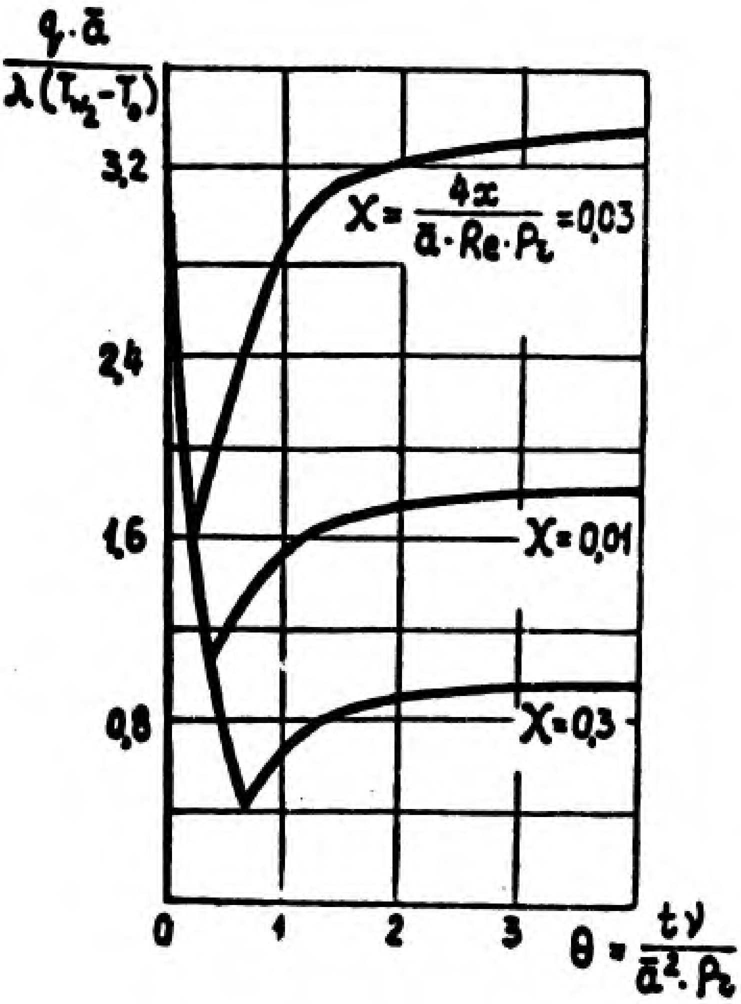

Fig. 4. Change of heat flow during an abrupt change of the gradient of pressure and temperature of the walls (P_r = 0.7).

Initial moment: $W = W_1 = 0$; $T = T_w = T_0$

Final moment: $W = W_2$; $T_w = T_{w_2}$

On Fig. 4 there are represented the results of their calculation for a simultaneous stepwise change of wall temperature and pressure gradient. When $X > \partial$ nonstable thermal conduction takes place heat flow drops. When $X < \theta$, there is convection heat exchange with variable flow speed. Heat flow in this case grows, since with a growth of speed the temperature head grows. In a later work [17] these authors examine analogous problems, applying the integral method. The qualitative results coincide. In work [18] using a "rod" model they study heat exchange in a flat channel with an arbitrary time and length change of heat flow.

Millsaps and Pohlausen [19] by the integral method investigated heat exchange at nonstable flow of a liquid metal in a pipe taking into account axial thermal conductor.

b. Turbulent flow. A theoretical analysis of nonstable heat exchange in a turbulent flow, even examined by methods of approximation is much more difficult than in laminar flow. For nonstationary flow, analysis in general is now impossible, since there are no data about the distribution on a section of a channel of the turbulent exchange coefficients momentum, and heat. Therefore in theoretical works there are studied only thermal instability during a constant profile of speed and stationary distribution of turbulent parameters on the section of flow.

Sparrow and Siegel [20] examine heat exchange during an abrupt change of wall temperature using the integral method. Applying the method of superposition they widen the found solution to the case of a linear change in time of wall temperature. The data of this analysis are compared with results of the quasi-stable calculation when $\alpha = Const$. It is shown that divergence with the quasi-stable calculation is even greater as the contribution of nonstationary thermal conduction is greater. Also applying the integral method Jill [21] analyzes heat exchange during an abrupt change of the temperature of the heat-transfer agent at the entrance to the heating section.

Of experimental investigations at present there are published only the works of the colleagues of the Moscow Aviation Institute [22], [23], [24]. The experiments described in these works were conducted on a smooth round pipe of stainless steel with a diameter of 5.39 mm, thickness 0.3 mm and length 223 calibre. The working substance is air. The coefficient of heat radiation was determined by the method expounded in the first part of the survey.

There were investigated two types of instability:

1) abrupt rise and drop of thermal load (electroheating of the tube) during a constant flow rate of air;

2) rise and drop of the flow rate of air during constant heat emission in the walls of the tube. During the rise flow rate was rapidly (0.1-0.3 s) increased, then smoothly (2-5 s) decreased to a new steady-state value, which was 2-3.7 times larger than the initial value.

During a drop of the flow rate the picture is reversed — at first a sharp fall, then a smooth growth of the flow rate. In the work it is shown that $K = f(K_T, K_G)$. Criterion K_T, and consequently $\frac{\partial(T_w - T_f)}{\partial t}$ (or $\frac{\partial T_w}{\partial t}$) considers the influence on K of the nonstationary change of profile of temperature. In other words, K_T considers the contribution in heat radiation of nonstationary thermal conduction. Criterion K_G and the parameter $\frac{\partial G}{\partial t}$ corresponding to it consider the influence of a nonstationary change of the profile of speed on heat radiation.

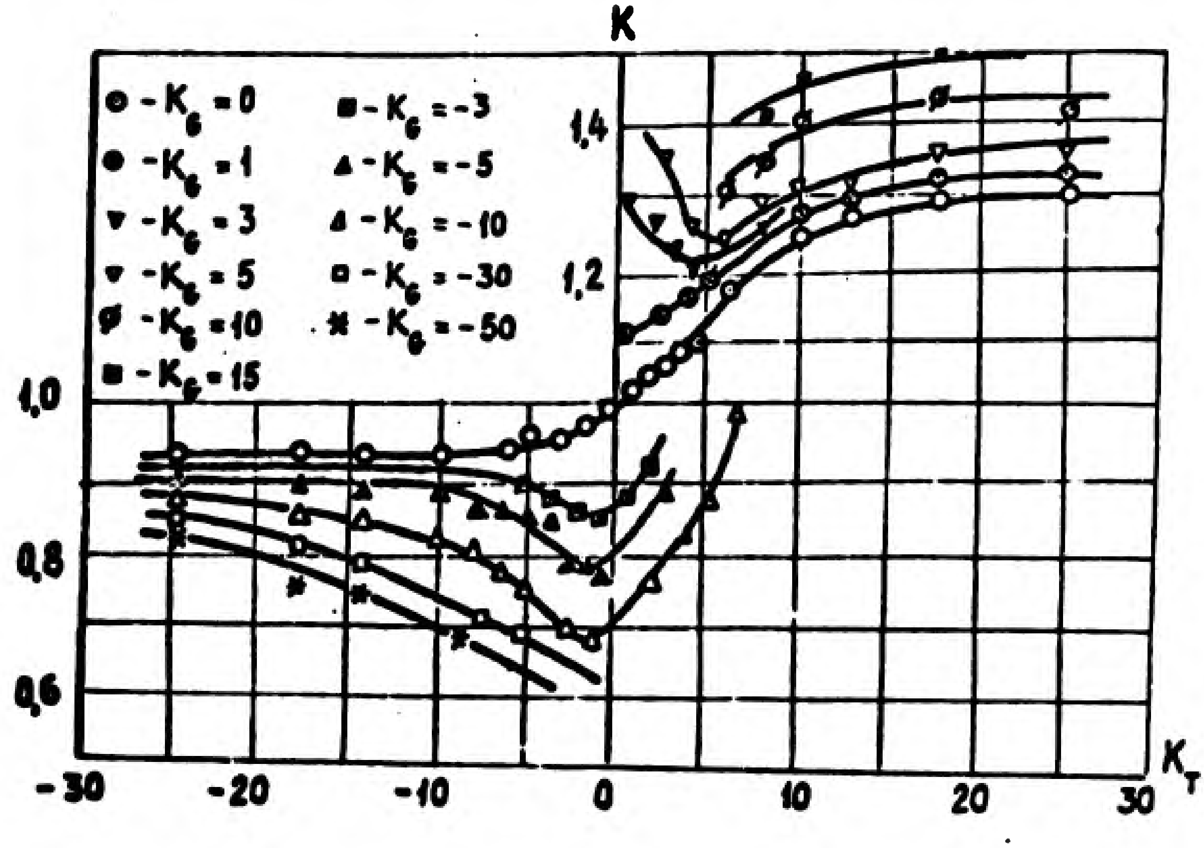

Fig. 5. Dependence of K on K_T and K_G during a rise and drop of the flow rate.

In the experiments K was changed from 0.5 to 1.7. On Fig. 5 there is represented dependence $K=f(K_T, K_G)$, obtained during a drop and rise of the flow rate. In the work it is noted that the influence of the temperature factor in transient conditions is stronger on heat radiation and flow friction than in stable. This is explained by the fact that with identical values of the temperature factor, deviation of the density of the gas at the wall from the mean value of density in the section is greater in transient conditions (when $\frac{\partial T_w}{\partial t} \neq 0$). Consequently, the influence of the temperature factor on the development of turbulence $\rho \overline{w_x' w_r'} \frac{\partial w}{\partial r}$ in transient conditions is greater than in stable.

3. Conjugate Problems of Unstable Heat Exchange

Perimutter and Siegel [17] considered the influence of heat capacity of the wall on heat exchange in a flat channel during an abrupt change of the pressure gradient and external temperature of the wall, and Siegel [25] jointly investigated the process of heat exchange between rod laminar flow in a flat channel and the wall with final heat capacity and constant temperature by thickness. The solution was numerical during a constant flow rate. He also obtained conditions: when $x > Wt$, unstable thermal conduction; when $x < Wt$, unstable convection heat exchange, which for the given case is the superposition of nonstable thermal conduction on stable convection heat exchange.

A. V. Lykov and T. L. Perel'man [26] considered a change of temperature by thickness of the wall. They tried to examine heat exchange between a small rod, located flush with the wall of a right angled channel, and laminar flow: the rod was assumed to be heat-insulated from the wall of the channel, and the liquid incompressible with constant physical properties.

However, after a series of mathematical simplifications, they essentially brought the problem to an analysis of nonstable thermal conduction between an infinite plate of finite thickness and a rod flow of infinite thickness. Also it is assumed that the plate has a finite heat capacity and one heat-insulated side, and in the flow there is heat emission proportional to the temperature of the flow.

Namely this (and not the initial) problem is solved in [26] without corresponding reservations, which leads the authors to physically doubtful conclusions in the interpretation of the obtained results.

An experimental investigation of conjugate problems was carried out by Ye. V. Kudryavtsev, K. N. Chakalev, and N. V. Shumakov [27]. They investigated heat exchange between the end of a rod and a flow of hot water in a thermostat or in a right angled channel. The rod was raised flush with the wall and was heat-insulated from it.

The whole method of treatment of the experiment is built on the assumption about a one-dimensional change of temperature in rods (only lengthwise along its axis). In reality the coefficient of heat radiation on the surface of the end of the rod is strongly changed. Consequently, the temperature field in the rod essentially is not one-dimensional.

The authors [27] did not consider this and came to inexplicable conclusions from the point of view of contemporary hydrodynamics on the dependence of the nonstable coefficient of heat radiation on the physical properties of rods and their dimensions.

4. Other Problems of Nonstable Heat Exchange

In literature there are published interesting works devoted to different aspects of nonstable heat exchange. For example, in [28]-[32] there is theoretically examined nonstable heat exchange under conditions of free convection.

In [11], [33]-[36] there is examined nonstable heat exchange with external circulation, etc.

Conclusions on the Second Part of the Survey

1. The structure of flow during nonstable broken and continuous flow in channels is different than quasi-stable. This can lead to substantial deviations of heat radiation and flow friction from the data of the quasi-stable calculation.

2. During stable hydrodynamics and thermal instability heat radiation also can differ noticeably from the quasi-stable due to the superposition of nonstable thermal conduction.

3. Theoretical research of nonstable heat radiation published in literature even for laminar flow in virtue of the great complexity of the problems are approximate and have a qualitative character. Theoretical research of conjugate problems is connected with still greater mathematical difficulties.

4. Experimental investigation of nonstable hydrodynamics and heat radiation in channels is in the initial stage.

Conclusion.

The necessity of a deep and manifold investigation of nonstable hydrodynamics and heat radiation is sharply confirmed by the requirements of practice. The attempt to account for the contemporary state of this problem is caused by a desire to attract to its study a large circle of researchers.

LITERATURE

1. M. K. Carstens; T. E. Roller. J. of the Hydraulics Proceedings of the Amer. Society of Civil Engineering. February 1959.

2. J.W. Daily, W.L. Hankey, K.W. Olive, J.M. Jordan. Trans. ASME vol. 78. N5 1956.

3. V. A. Tsetserin, *Vliyaniye nestatsionarnosti techeniya gaza na koeffitsiyent soprotivleniya magistral'nykh gazoprovodov* (Influence of the instability of flow of a gas on the drag coefficient of main gas conduits). Author's abstract of dissertation in competition for the academic degree Candidate of Technical Science, Minsk, 1961.

4. N. A. Panchurin, *Nekotoryye voprosy teoreticheskogo i eksperimental'nogo issledovaniya neustanovivshegosya dvizheniya zhidkosti v trubakh* (Certain questions of the theoretical and experimental investigation of unstable motion of a liquid in pipes). Author's abstract of dissertation in competition for the academic degree Doctor of Technical Science. Leningradskiy institut vodnogo transporta, 1964.

5. N. A. Panchurin, *Trudy LIVT*, vyp. XIII, 1961.

6. N. A. Panchurin, *Trudy LIVT*, vyp. X, 1963.

7. N. A. Panchurin, *Trudy LIVT*, vyp. XIX, 1963.

8. I. S. Kechenov, Yu. I. Kuznetsov, *Sb. Teplo- i massoperenos* (Coll. Heat and mass transfer), t. 1, Izd. *"Nauka i tekhnika"*, Minsk, 1965.

9. Perimutter, Siegel, Trans. ASME "*Teploperedacha*"("Heat transfer"), ser. S, No. 4, 1961.

10. V. V. Struminskiy, Sb. teoreticheskikh rabot po aepodinamike (Collection of theoretical works on aerodynamics), Oborongiz, 1957.

11. Yu. L. Rozenshtok, Sb. "Teplo- i massoperenos" ("Heat and mass exchange), t. 1, Izd. "Nauka i tekhnika", Minsk, 1965.

12. A. D. Yung, "Sovremennoye sostoyaniye aerodinamiki bol'shikh skopostey" ("Contemporary state of the aerodynamics of high speeds"), t. 1, gl. X, Izd. IL, Moskva 1955.

13. R. Siegel. Trans. ASME. J. of Applied Mechanics ser. E vol. 72. N2. 1960.

14. E.M. Sparrow, R. Siegel. Proceedings of II US National Congress Applied Mechanics. 1958.

15. E.M. Sparrow, R. Siegel. Trans ASME. J. of Heat Transfer. ser. C. vol 81. pp. 29-36. 1959.

16. R. Siegel. Trans. ASME. J. of Applied Mechanics. ser. E. vol. 81. pp. 140-142 1959.

17. M. Perlmutter, R. Siegel. Int. J. Heat Mass Transfer v. 3. pp. 94-107. 1961

18. Siegel and Perlmutter. Trans. ASME, Series C, "Heat transfer" Vol. 85, No. 4, 19.

19. K. Millsaps, K. Pohlausen. Proceedings Conference on Differential Equations. University of Maryland. March 1955.

20. E.M. Sparrow, R. Siegel. Trans. ASME. J. Heat Transfer, ser. C. v. 82 N3. 1960

21. W.N. Gill. A.I.Ch.E. Journal vol. 8. N2. 1962.

22. V.K. Koshkin, Y.I. Danilov, E.K. Kalinin, G.A. Dreitser, B.M. Galitsevsky, V.G. Isosimov. Unsteady Heat Transfer in Tubes Resulting Changs in Heat Flow Gas Mass Flow Rate and Acoustic Resonance". Proceedings Third International Heat Transfer Conference". August 1966. Chicago

23. B. M. Galitseyskiy, G. A. Dreytser, V. G. Izosimov, E. K. Kalinin, V. K. Koshkin. "Eksperinental'noye issledovaniye nestatsionarnogo teploobmena v trube pri izmenenii teplovogo potoka"("Experimental investigation of nonstable heat exchange in a pipe during a change of heat flow"). Izv. AN BSSR. Seriya fiziko-tekhn. nauk.

24. B. M. Galitseyskiy, G. A. Dreytser, V. G. Izosimov, E. K. Kalinin, V. K. Koshkin. "Eksperimental'noye issledo'aniye nestatsionarnogo teploobmena v trube pri izmenenii paskhoda raza" ("Experimental investigation of nonstable heat exchange in a pipe during change of the flow rate of a gas"). Izv. AN BSSR, Seriya fiziko-tekhn. nauk.

25. R. Siegel. Int. J. Heat and Mass Transfer Vol 6, pp. 607-620, 1963.

26. A. V. Lykov, T. L. Perel'man, Sb. "Teplo- i massoobmen tel s okruzhayushchey gazovoy sredoy" ("Heat and mass exchange of bodies with a surrounding gaseous environment"). Izd. Nauka i tekhnika, Minsk, 1965.

27. Ye. V. Kudryavtsev, K. N. Chakalev, N. V. Shumakov, "Nestatsionarnyy teploobmen" ("Nonstable heat exchange"). Izd. AN SSSR 1961.

28. Gebkhart, Trans. ASME. Ser. C, "Heat Exchange", Vol. 84, No. 4, 1962.

29. Chang, Anderson, Trans. ASME. Ser. C. "Heat Exchange", Vol. 83, No. 4, 1961.

30. Shetts, Eykhgorn, Trans. ASME. Ser. C "Heat Exchange", Vol 84, No. 4, 1962.

31. Zayberg, Myulzher, Trans. ASME. Ser. C. "Heat Exchange", Vol. 84, No. 2, 1962.

32. Gebkhart, Trans. ASME. Ser. C. "Heat Exchange", Vol. 85, No. 1, 1963.

33. Gudmen, Trans. ASME. Ser. C. "Heat Exchange", No. 3, 1961.

34. Sess, Trans. ASME. Ser. C. "Heat Exchange", No. 3, 1961.

35. Adams, Gebkhart, Trans. ASME. Ser. C. "Heat Exchange", No. 2, 1964.

36. E. M. Sparrow, J. L. Cress. NASA, TN4311 June, 1958.

APPENDIX: DESIGNATIONS AND INDICES

Designations

G - mass flow rate of heat-transfer agent,

ρ - density,

W - average-expenditure speed,

W'_x , W_r — projection of speed on the x-axis and on radius,

t - time,

x - coordinate along the axis of the channel,

T - temperature,

T_b - mean-calorimetric temperature of the heat-transfer agent,

P - static pressure,

τ - tangential stress

μ - coefficient of dynamic viscosity,

μ_T - coefficient of turbulent viscosity,

λ - coefficient of thermal conduction,

λ_T - coefficient of eddy conductivity,

ν - coefficient of kinematic viscosity,

$\varepsilon_\tau = \frac{\mu \cdot \tau_r}{\rho}$ — turbulent coefficient momentum transfer,

ε_q — turbulent coefficient of heat transfer,

a - coefficient of temperature transfer,

C_p - specific heat capacity at constant pressure,

ξ - coefficient of flow friction,

$\bar{\xi}$ - average length coefficient of flow friction

d - diameter of pipe

$\bar{a}$ - half the height of a flat channel,

L - length,

g - acceleration due to gravity,

h - piezometric pressure,

Nu, Re, Pr — criterion of Nusselt, Reynolds, Prandtl,

$K = \frac{Nu'}{Nu_K}$ — ratio of nonstable heat radiation and quasi-stationary,

$K_T = \frac{\partial (T_w - T_6)}{\partial t} \cdot \frac{d^2}{(T_w - T_6)a}$ — criterion of temperature instability,

$K_G = \frac{\partial G}{\partial t} \cdot \frac{d^2}{G \cdot \nu}$ — criterion of hydrodynamic instability.

Indices

K - quasi-steady-state magnitude of a value,

W - magnitude value on the wall

C - magnitude value on the axis,

1;2 - initial and final steady state.