Features of heat transfer at increase of temperature of the working body, intensive up to 12000 K/s

Yuriy Volodin¹, Olga Marfina¹ and Alexander Kirpichnikov²

¹Kazan State University of Architecture and Engineering 420043 Green str., 1 Kazan, Russia
²Kazan National Research Technological University 420015, Karl Marx str., 68 Kazan, Russia
yu.g.volodin@mail.ru

Abstract. In work results of pilot studies of heat transfer are given in a cylindrical pipe which represents imitating model of a spherical pipe. Experiments are executed on a gasdynamic pipe of the opened type. The starting mode, at operation of gas-turbine engines (GTE), is one of the main modes in which sometimes there are refusals. The non-staff mode of heat transfer when thermal parameters of a gas stream exceed values of settlement can be the cause of refusal, there is an intensive local heating of a streamline surface of a structural element(s) of the engine. Pilot studies were conducted at various values of intensity of increase of temperature of a working body that has allowed to record the phenomenon of a laminarization of the thermal turbulent boundary layer (TBL) at the thermal stream directed from a gas stream to a wall of the channel. At emergence of the phenomenon of a laminarization of value of local coefficients heat transfer decrease by 2,5 – 3 times. Since opening of this phenomenon it was also shown in various situations at acceleration of a gas stream and even at high extents of heating of a wall of a cylindrical pipe at the stationary modes of a current. In the non-stationary mode and the specified direction of a thermal stream this phenomenon is revealed for the first time. As the parameter of a laminarization of TBL the temperature pressure or a temperature factor is offered, and border of area of a laminarization of TBL is size ΔT ≥ 700 K.

1. Introduction

At operation of GTE usually allocate four main stages from which the starting mode is distinguished, being one of the important and responsible modes. Start-up is the most responsible operation as a result of ignition of fuel for a short period temperature of a working body leading to essential change of sizes of all parameters of the engine, and, mainly, to increase in temperature of structural elements of the engine very quickly increases. And still in the starting mode of the engine there are situations when there is a premature refusal of his work with the subsequent destruction of structural elements. Local heating of separate elements, i.e. the process of a heat transfer happening outside the combustion chamber in axisymmetric spherical pipes where the heated gas stream on an entrance to the turbine is formed rotating her is the reason of such destruction of the engine. At launch of the power station during ignition temperature of a working body sharply increases and its heatphysical properties change. This process is followed by unsteady-state effects [1, 2]. When temperature of a working body reaches a constant, conditions for a laminarization of a turbulent interface are created.
Since opening of the phenomenon of a laminarization caused by acceleration of a stream due to change of geometry of a streamline body [3 - 4] it is also recorded at a gas suction from an interface [5], cooling of a streamline surface [6], joint impact of cooling of a wall and acceleration of a stream of gas [7 - 9], heating of a streamline surface [10 – 11]. Quantitative assessment was carried out “universally” in acceleration parameter \( K = -\frac{v}{w_0} \cdot \frac{\partial w_0}{\partial x} \), irrespective of the conditions which have created this phenomenon.

2. Experimental stand
The experimental studies are conducted at the gasdynamic stand of the opened type with arc heating of a working body [1]. Range of change of Reynolds number of Re constructed on speed of average flow was \( Re = 30000 – 60000 \), temperatures of a working body \( T = 293 – 1500 \) K with temperature gradient to 12000 K/ s. Mean square errors of measurement of temperature and coefficient of a thermolysis in experiences haven’t exceeded 1,6% and 9,5%.

3. Results of researches
At increase in temperature of a gas stream density decreases and the viscosity of a working body increases, the stream speed as his mass expense remains to constants as a result increases. Increase in speed in time reaches \( \frac{\partial w_0}{\partial x} = 700 \) m/s with a gradient of change of temperature on an entrance to the skilled channel \( \frac{\partial T_0}{\partial t} \) to 12000 K/ s. The temperature factor \( \psi_h = T_w/T_0 \) decreases in size from 1 to 0,25. To increase in temperature of \( T_0 \) of a gas stream there is a unsteady-state process of a heat transfer lasting about 0,1 pages. In the following time interval of \( t > 0,1 \) about heat exchange process stationary with constants in size parameters.

The size of coefficient of a heat transfer \( St \) was determined by expression

\[
St = \frac{q_w}{\rho_0 w_0 (h_0'' - h_w)}
\]

Under the terms of an experiment mass speed \( \rho_0 w_0 \) is a constant. Density of a thermal stream of \( q_w \) was determined by expression

\[
q_w = C_{pw}\rho_w\Delta_w \frac{\partial T_w}{\partial t} + \Delta q_w.
\]

In expression (2) \( q_w \) are the losses of heat caused by free convection and due to radiation ability of a surface of the skilled channel, have made less than 10% of the size \( q_w \). In expression (2) the first composed represents the work of specific heat, density of material of a wall of the channel, thickness of a wall of the channel and a temporary gradient of temperature of a wall. Rate of increase of temperature of \( T_w \) of a wall, is invariable size. From this it follows that density of a stream of \( q_w \) is size invariable. In turn \( q_w \) enters expression (1) by which coefficient heat transfer \( St \) is determine. Follows from the analysis of expression (1) that the only variable is the difference of enthalpies here. Change of this size when performing pilot studies has shown that excess by a temperature pressure of value \( \Delta T \geq 700 \) K promotes that skilled points in fig. 1 are grouped about a curve 2 in independence of the location of measuring section in length of the skilled channel and size of number Re. Increase in an experiment of operating time of a plasmatron has shown that with warming up of walls of the channel and as, the investigation, reduction of size of a temperature pressure comes the return monotonous movement of skilled points from a curve 2 for the laminar modes of a current to the turbulent mode. Duration of the period of time during which skilled points are present at the vicinity curve 2, the size of a temperature pressure defines. At the bigger size of a temperature pressure more time for warming up of walls of the channel and achievement of boundary size \( \Delta T \approx 700 \) K below which the heat transfer will begin to increase in size again will be required.
Figure 1. Dependence of size of coefficient heat transfer \( St \) on number Reynolds \( Re_h^{**} \). The «1» line – \( St = \frac{0.0128}{Re_h^{0.2} Pr^{0.75}} \), the «2» line – \( St = \frac{0.22}{Re_h^{0.75} Pr^{4/3}} \), the «3» line – approximating dependence
\[
St = St_0 \frac{1}{w_0} \begin{vmatrix} \frac{1}{Re_h^{2}} \frac{d(\Delta h)}{dt} \end{vmatrix} , \ a - X = 2.5, \ b - X = 4.5, \ b - X = 6.5
\]

At the considered thermogasdynamic situation there are two reasons accelerations of a stream – the first, acceleration at the expense of the derivative speed of a stream on longitudinal coordinate, i.e. a longitudinal gradient of pressure and, the second, acceleration at the expense of the derivative speed of a stream on time, i.e. unsteady-state.

Comparison with the results of researches of other authors published in references has shown that the correlation on character, sizes and the direction of change of Reynolds numbers \( Re_{01}, Re^{**}, Re_h^{**} \), to sizes of local coefficients of friction and a heat transfer, range of change of characteristic number of \( Re^{**} \sim \) from 1000 to 400, the size of a positive gradient of speed of \( \frac{\partial w_0}{\partial t} = 700 \) m/sec$^2$ is observed.

Taking into account influence of a factor of unsteady-state the parameter of acceleration can be determined on expression
\[
K = \frac{\nu}{w_0^2} \frac{\partial w_0}{\partial x} + \frac{\nu}{w_0} \frac{\partial w_0}{\partial t} = K_x + K_t .
\]

However the generalizing parameter of friction allows to make accounting of impact of different enrollment of the destabilizing factors on a dynamic interface and its parameters
\[
\tau_w' = \frac{\partial \tau}{\partial t} = -\frac{2\delta}{C_f} \left( \frac{1}{w_0} \frac{\partial w_0}{\partial x} + \frac{1}{w_0} \frac{\partial w_0}{\partial t} \right) = z + \lambda ,
\]

where \( z \) – the parameter of dynamic unsteady-state, \( \lambda \) – the parameter of a longitudinal gradient of pressure. The similarity of the right parts in expressions (3) and (4) attracts attention. I.e. it is possible to write down identity
\[
K = \frac{w_0}{\nu} = \tau_w' \frac{C_f}{2 \delta} \text{ илн } \text{ K} = \tau_w' \frac{\nu}{C_f} \frac{C_f}{2} = \tau_w' \frac{1}{Re_\delta} \frac{C_f}{2} ,
\]

where \( Re_\delta = \frac{\delta w_0}{\nu} \).

From this it follows that acceleration parameter \( K \) is function of the generalizing friction parameter \( \tau_w' \), number \( Re_\delta \) and coefficient of friction \( C_f \), i.e. is the characteristic of a dynamic interface. Influence of various destabilizing factors such as, for example, nestatsonarnost, longitudinal gradient of pressure, having blown or a suction, two-staging, etc., it is considered by the generalizing friction parameter. Besides, influence of the generalizing friction parameter on sizes of coefficients of transfer and other characteristics of dynamic and thermal interfaces are widely presented in literature.

If to pass from acceleration parameter \( K \) to the generalizing parameter \( \tau_w' \) that, we will receive
\[
\tau_w' = \frac{K Re_\delta}{C_f/2} .
\]

By substitution of critical size of parameter of acceleration \( K \) in expression (5) we will receive TPS laminarization border on a surface.
\[ \Psi = \frac{C_f}{C_{f0}} = f(\tilde{\nu}_w, Re_0). \]

In the situation of a condition of heat exchange considered by authors defines a temperature pressure and, therefore, the statement is correct to recognize him as the parameter of a laminarization of thermal TBL, and to determine borders of a laminarization of TBL by the size of a temperature pressure or temperature factor.

4. Conclusion
The effect of a laminarization of thermal TBL is gained at sharp increase in temperature of a working body. The temperature pressure which defines borders of a transitional zone and border of area of a laminarization of TBL (\( \Delta T \geq 700 \, K \)) is the reason of a laminarization of TBL in the considered situation.

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