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HEAT EXCHANGE BETWEEN THREE STREAMS IN PIPES OF VARIABLE CROSS SECTION

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A method of calculating the thermal characteristics in the interaction of three streams in pipes of variable cross section in the presence of heat exchange with the ambient medium is discussed.

A method of calculating the temperature and heat-flux profiles during heat exchange between three media moving in pipes of constant cross section in the absence of heat exchange with the ambient medium was discussed in [1]. In [2] the analytical apparatus of this problem was simplified, and the problem of calculating the thermal characteristics in the interaction of three streams in pipes of constant cross section with allowance for heat exchange with the ambient medium was also considered.

The problem of heat exchange between three streams in pipes of constant cross section without allowance for the ambient medium was also discussed earlier in [3-6], although the solutions obtained then did not make it possible to extend them directly to more complicated cases: the interaction of a larger number of media, variable stream cross sections, or both factors together.

The latter problem is solved rather simply on the basis of the approach used in [2]. For determinacy, let us consider heat exchange during the direct-flow–counterflow motion of three streams in pipes of variable cross section with allowance for the thermal interaction with the ambient medium (Fig. 1).

Streams enter a system of three coaxially arranged pipelines of length l_e from different ends. Water with an assigned temperature $t_{1,e}$ enters the central pipe and air with an assigned temperature $t_{3,e}$ enters the outer annular channel from the end with the coordinate l_e. A stream (combustion products) with an assigned temperature $t_{2,0}$ enters the intermediate annular channel in the initial cross section $l = 0$. The temperature of the ambient medium is taken as constant and equal to t^*. We neglect the thermal resistance of the pipe walls, the radial temperature gradient of the streams, and the temperature dependence of the thermophysical properties.

The geometry of the pipelines changes in the cross section with the coordinate l^*. The pipeline system can thereby be divided into two sections (I and II), in each of which the cross sections remain constant and the equations obtained in [2] for determining the lengthwise variation of the stream temperatures remain valid:

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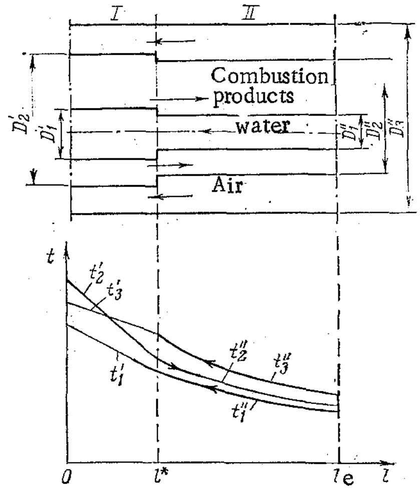

Fig. 1. Diagram of the system of pipelines and the axial distributions of stream temperatures.

$$t_1 = t^* + \sum_1^3 m_i C_i \exp(\lambda_i l), \tag{1}$$

$$t_2 = t^* + \sum_1^3 n_i C_i \exp(\lambda_i l), \tag{2}$$

$$t_3 = t^* + \sum_1^3 C_i \exp(\lambda_i l). \tag{3}$$

Equations (1)-(3) were found by solving a system of first-order, linear, homogeneous, differential equations,

$$dx/dl + a_1 x + b_1 y = 0,\ dy/dl + a_2 x + b_2 y + d_2 z = 0,$$
$$dz/dl + b_3 y + d_3 z = 0, \tag{4}$$

obtained from a detailed analysis of heat exchange between the media.

In Eqs. (1)-(3) and in the system (4) we use the notation

$$x = t_2 - t_1,\ y = t_2 - t_3,\ z = t_3 - t^*,\ a_1 = \frac{k_1 \pi D_1}{c_1 G_1} + \frac{k_1 \pi D_1}{c_2 G_2},$$

$$b_1 = \frac{k_2 \pi D_2}{c_2 G_2},\ a_2 = \frac{k_1 \pi D_1}{c_2 G_2},\ b_2 = \frac{k_2 \pi D_2}{c_2 G_2} + \frac{k_2 \pi D_2}{c_3 G_3},$$

$$d_2 = -\frac{k_3 \pi D_3}{c_3 G_3},\ b_3 = -\frac{k_2 \pi D_2}{c_3 G_3},\ d_3 = \frac{k_3 \pi D_3}{c_3 G_3},$$

$$m_i = 1 - \frac{d_3 + \lambda_i}{b_3} - \frac{b_1 (d_3 + \lambda_i)}{b_3 (a_1 + \lambda_i)},\ n_i = 1 - \frac{d_3 + \lambda_i}{b_3},$$

where λ_i are roots of the characteristic equation of the system (4). The constants C_i are determined from the solution of the system of equations (1)-(3) using the boundary conditions.

In the further analysis of the problem we designate quantities pertaining to section I by the index ' and those pertaining to section II by the index ". Using the boundary conditions, as well as the condition that $t_1' = t_1''$, $t_2' = t_2''$, and $t_3' = t_3''$ at $l = l^*$, and analyzing the system of equations (1)-(3) for sections I and II, one can find the constants C_i and then obtain the final expressions for the longitudinal temperature distributions.

With allowance for this notation, the assigned conditions at the boundaries are $t''_{1,e}$, $t'_{2,0}$, and $t''_{3,e}$, and on the basis of Eqs. (1)-(3) one can obtain a system of six algebraic equations in canonical form:

$$
\begin{gathered}
\sum_1^3 n_i' C_i' = t'_{2,0} - t^*,\\
\sum_1^3 m_i'' C_i'' \exp(\lambda_i'' l_e) = t''_{1,e} - t^*,\\
\sum_1^3 C_i'' \exp(\lambda_i'' l_e) = t''_{3,e} - t^*,\\
\sum_1^3 m_i' C_i' \exp(\lambda_i' l^*) - \sum_1^3 m_i'' C_i'' \exp(\lambda_i'' l^*) = 0,\\
\sum_1^3 n_i' C_i' \exp(\lambda_i' l^*) - \sum_1^3 n_i'' C_i'' \exp(\lambda_i'' l^*) = 0,\\
\sum_1^3 C_i' \exp(\lambda_i' l^*) - \sum_1^3 C_i'' \exp(\lambda_i'' l^*) = 0.
\end{gathered} \tag{5}
$$

By solving the system (5) by the standard method, one can find the constants C_i' and C_i'' and finally determine the longitudinal temperature profiles in sections I and II using Eqs. (1)-(3).

It is quite obvious that the method under consideration also allows one to solve the problem easily for cases when the pipeline cross sections change not at one but at several points along the length and for a larger number of interacting media. By varying the pipeline diameters, one can obtain temperature profiles assigned in advance when necessary.

NOTATION

t_1, t_2, t_3, t^*, temperatures of water, combustion products, air, and ambient medium, respectively; D_1, D_2, D_3, diameters of the inner, middle, and outer pipes of the pipeline system; G_1, G_2, and G_3, mass flow rates of water, combustion products, and air; c_1, c_2, c_3, specific heat capacities of water, combustion products, and air; k_1, k_2, coefficients of heat transfer from combustion products to water and air; k_3, coefficient of heat transfer from air to the ambient medium.

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