HEAT-TRANSFER CHARACTERISTICS OF A JET FLAME IMPINGING ON A HEAT-SENSING SURFACE

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Experimental data and analytical relations are given for the heat transfer from direct-jet and swirl-jet flames impinging on a heat-sensing surface.

Theoretical solutions do not exist at the present time for the problem of heat transfer between swirled gas jets and heat-sensing surfaces, despite their potential usefulness in engineering calculations. To solve the stated problem Konakov and others [1] have proposed a method based on the physical analysis of the combined radiative and convective heat-transfer effects (combination heat transfer). According to this method, the processes taking place in a combustion chamber are described by a system of equations that includes the equations of energy conservation, motion, and continuity of the jet as well as for the partial composition of the gas. The coefficients of dynamic viscosity, heat capacity, and thermal conductivity of the gases entering into this system are assumed to be known functions of the temperature

Applying the general procedure of similarity theory to the system of equations, we obtain the invariant relation

$$Nu_{co} = f(\mathrm{Re},\ \bar{h},\ \varphi/90°,\ \Omega), \quad (1)$$

in which Ω is calculated by the procedure of Akhmedov [2].

It is important to note that relation (1) is valied for a furnace chamber with constant geometrical dimensions or for a steady-state process in which the medium in a combustion chamber is highly turbulent and the molecular transfer of mass and energy is small in comparison with molar transfer.

We have carried out experimental studies on a test arrangement described in [3]. The distances from the burner orifice to the heat exchanger were as follows: 0.56; 0.75; 0.9; 1.5; 2.1; 3.0 m. The Reynolds number was varied from 1400 to 5500. Direct-jet and swirl-jet flames were investigated.

In the processing of the experimental data the diameter of the heat exchanger (d_c = 480 mm) was taken as the governing length, and the average temperature of the flame near the heat-sensing surface of the heat exchanger ($\bar{T}$) as the governing temperature.

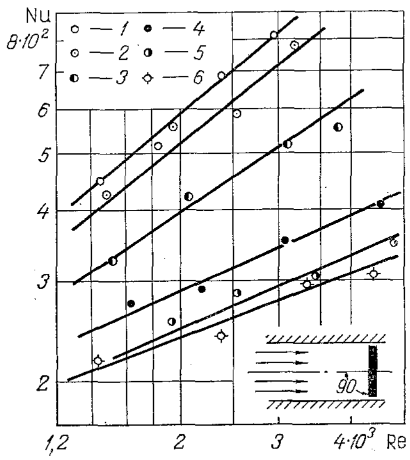

Fig. 1. Function Nu = f(Re, $\bar{h}$) for swirl-jet flames (Ω = 1.2). 1) $\bar{h}$ = 5.6; 2) 7.5; 3) 9.0; 4) 15.0; 5) 21.0; 6) 30.0.

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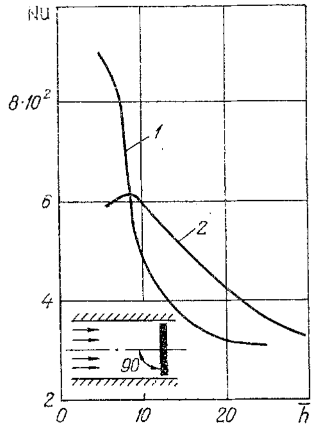

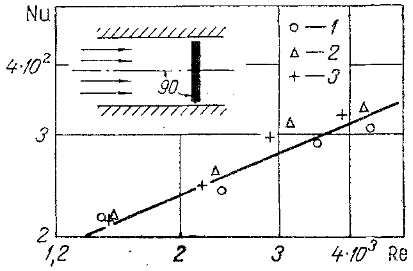

Fig. 2 Fig. 3

Fig. 2. Function $Nu = f(\bar{h}, \Omega)$ for straight and vortex burners in a gas combustion chamber ($\varphi = 90°$, Re = 3500): 1) $\Omega = 1.2$; 2) 0.

Fig. 3. Function $Nu = f(Re, \Omega)$ in a gas combustion chamber for vortex and straight burners ($\bar{h} = 30$, $\varphi = 90°$): 1) Vortex burner, $\Omega = 1.2$; 2) direct burner, $\Omega = 0$; 3) vortex burner, $\Omega = 0.3$.

The experimental data on combination heat transfer in a prismatic furnace chamber for swirl-jet flows ($\Omega = 1.2$) show (Fig. 1) that when the parameter $\bar{h}$ is increased, both the qualitative and the quantitative heat-transfer patterns change. It follows from Fig. 2 that $Nu = f(\bar{h})$ acquires (fixed Re = 3500) its maximum value for $\bar{h} = 5.6$, while for $\bar{h} = 15$ or more in the case of a swirl-jet flame ($\Omega = 1.2$) the heat transfer falls off sharply, becoming lower

TABLE 1. Evaluation of the Exponents $\bar{n}$, $\bar{m}$ and Coefficient c in Relation (2)

$\bar{h}$	5—8			8—15			15—21	
				φ=90				
Ω	1,2	0,3	0	1,2	0,3	0	0,3	0
c	2,10	0,73	0,77	20,10	7,52	3,82	41,90	39,46
$\bar{n}$	0,81	0,81	0,81	0,55	0,67	0,67	0,53	0,53
$\bar{m}$	—0,31	0,13	0,04	—0,57	—0,46	—0,2	—0,7	—0,65
				φ=60				
Ω	1,2	0,3	0	1,2	0,3	0	0,3	0
c	1,19	1,05	0,55	59,71	9,15	3,44	69,72	18,93
$\bar{n}$	0,79	0,76	0,77	0,46	0,63	0,65	0,46	0,56
$\bar{m}$	—0,35	0,09	0,35	—0,73	—0,43	—0,12	—0,7	—0,49
				φ=30				
Ω	1,2	0,3	0	1,2	0,3	0	0,3	0
c	0,76	0,56	0,35	18,16	5,44	2,19	18,27	6,02
$\bar{n}$	0,79	0,78	0,8	0,49	0,6	0,65	0,52	0,6
$\bar{m}$	—0,045	0,12	0,23	—0,45	—0,29	—0,09	—0,51	—0,32
				φ=0				
Ω	1,2	0,3	0	1,2	0,3	0	0,3	0
c	1,07	0,45	0,42	38,82	4,75	0,98	18,68	12,80
$\bar{n}$	0,8	0,77	0,76	0,41	0,63	0,73	0,44	0,6
$\bar{m}$	—0,32	0,11	0,14	—0,65	—0,46	—0,12	—0,44	—0,7

in comparison with a direct-jet flame, and for $\bar{h} = 30$ it is evident from Fig. 3 that the heat transfer equalizes for all types of flames, swirl- and direct-jet.

This nonuniformity of the heat-flux distribution along the furnace chamber is caused by the aerodynamic characteristics of swirl-jet flames. As the degree of swirling is increased the range of the flame diminishes in connection with the sharper intensification of mass transfer with the surrounding medium, as well as the vigorous degeneration of the aerodynamic structure and geometrical integrity of the flame.

The maximum heat transfer from a direct-jet flame, as we see in Fig. 2, is observed near $\bar{h} = 9$, and starting roughly with $\bar{h} = 15$ the heat transfer is higher in comparison with swirl-jet flames. However, as in the latter case, the heat transfer along the chamber decreases, and for $\bar{h} = 25$ it is 43% lower than its maximum value.

Analytical relations of the form

$$\mathrm{Nu}_{co} = c\,\mathrm{Re}^{\bar{n}}\,\bar{h}^{\bar{m}} \tag{2}$$

have been obtained for $\bar{h} = 5$-8, 8-15, 15-21 and $\varphi = 90, 60, 30, 0°$ (Table 1). The data in Table 1 can be used to calculate the heat transfer in a prismatic furnace chamber for swirl- and direct-jet flames.

A reduction of the combination heat transfer with decreasing angle of impingement of the flame on the heat-sensing surface is observed for all the investigated flames. The maximum heat transfer is observed for impingement angles close to straight-on ($\varphi = 90°$). The sharpest reduction in heat transfer occurs in the range of impingement angles 30-70°.

NOTATION

Nu, Nusselt number; Re, Reynolds number; $\bar{h} = L/d_0$, dimensionless distance from gas-burner assembly to heat-sensing surface; φ, angle of impingement of flame on heat-sensing surface; Ω, degree of swirling of flame; d_c, calorimeter diameter; $\bar{T}$, flame temperature.

Subscript: co, combination.

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