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HEAT AND MASS EXCHANGE WITH VAPORIZATION AND COMBUSTION IN A  
LAMINAR BOUNDARY LAYER OF n-HEXANE AND ETHYL ALCOHOL

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Results of an experimental investigation of the combustion of n-hexane and ethyl alcohol in a boundary layer as well as the dependency criteria for calculating the process being examined are presented.

There are only individual works [1-3], many conclusions of which require further refinement, concerning the investigation of heat- and mass-exchange processes under conditions involving combustion of liquid hydrocarbons and alcohols, that have practical and scientific value for chemical technology, physicochemical hydrodynamics, and other areas. Thus, in [1-3], the influence of the transverse flow rate of matter and the depth of the evaporation surface of the injectant, filtered through a porous wall and combusted in an airflow, has not been studied. These problems are examined in the present work.

The combustion of n-hexane and ethyl alcohol was studied experimentally in a low velocity wind tunnel with 0.28×0.34 m rectangular transverse cross section in the working part of the tunnel. The velocity, temperature of the air flow, and the dimensionless parameter of the air blowing in were varied over the following range:  $u_{\infty} = 2-15$  m/sec,  $T_{\infty} = 290-470^{\circ}\text{K}$ ,  $F = (1.24-8.30) \cdot 10^{-3}$  for ethyl alcohol and  $F = (3.39-12.75) \cdot 10^{-3}$  for n-hexane. The local values of the Reynolds numbers varied over the range  $Re_{\Delta x} = 10^3-10^6$ .

The investigation of the combustion of n-hexane and ethyl alcohol was carried out on a porous metallic plate with dimensions 0.196×0.060×0.003 m, separated into four sections. Metallo-ceramic porous plates with a thickness of 0.003 m were pressed out of spherical powder of chrome-plated low-carbon steel with a fraction diameter of 0.063 and 0.1 mm. Their average porosity was about 30%. Copper-constantan thermocouples, whose electrodes had a diameter of 0.1 mm, were affixed to the surface of the porous wall and along its thickness. Each section of the test body was water cooled and was supplied by liquid injectant [1-3]. The temperature in the boundary layer was measured by a Chromel-Alumel thermocouple with a junction diameter of 0.1 mm. The concentrations of the gas components were measured by sampling with the help of a stainless-steel tube with an external diameter of 0.7 mm and a wall thickness of 0.1 mm followed by analysis using a KhL-3 chromatograph. The body was flush mounted to the bottom wall of the working part of the wind tunnel. The experimental setup and the technique used in carrying out the investigations are examined in greater detail in [3].

Typical profiles showing the variation in temperature and concentration along the height of the boundary layer with combustion of n-hexane and ethyl alcohol are shown in Fig. 1. The maximum temperatures  $T_{*}$  in the combustion zone for n-hexane and ethyl alcohol vary in the range 1100-1320 and 1130-1470°K, respectively. The value of  $T_{*}$  is less than the corresponding adiabatic theoretical combustion temperature  $T_{ad}$ , equal to 2397°K for n-hexane and 2350°K for ethyl alcohol. The inequality  $T_{*} < T_{ad}$  stems from losses of heat with exiting gases and chemically incomplete combustion in the maximum temperature zone, occurring with excess air coefficients of  $\alpha = 0.65-0.75$ , as well as some decrease (up to 4%) in the measured temperatures  $T_{*}$  due to convective and radiative heat exchange at the thermocouple junction, respectively,

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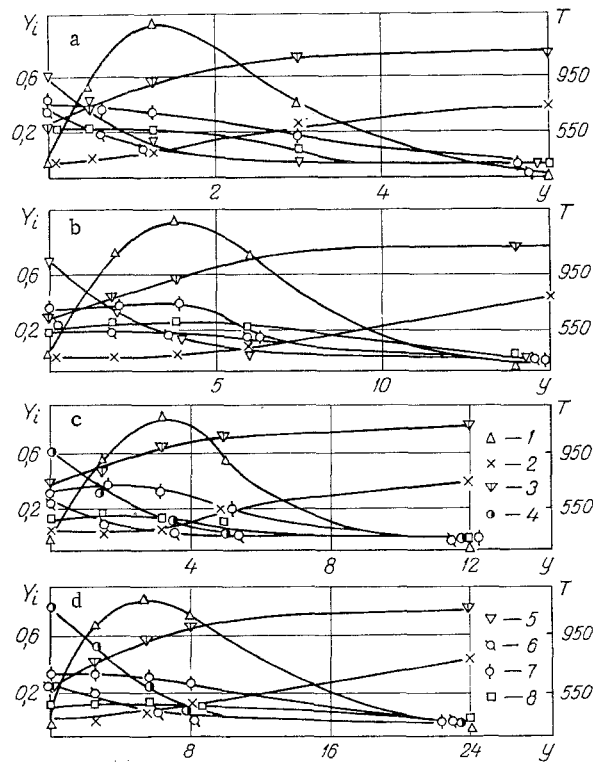


Fig. 1. Temperature and concentration distribution along the height of a laminar boundary layer with combustion of ethyl alcohol (a, b) and n-hexane (c, d) in the boundary layer: a)  $Re_{\Delta x} = 4.1 \cdot 10^3$ ,  $F = 4.93 \cdot 10^{-3}$ ; b)  $Re_{\Delta x} = 18.7 \cdot 10^3$ ,  $F = 23.3 \cdot 10^{-3}$ ; c)  $Re_{\Delta x} = 8.7 \cdot 10^3$ ,  $F = 4.99 \cdot 10^{-3}$ ; d)  $Re_{\Delta x} = 24.6 \cdot 10^3$ ,  $F = 3.84 \cdot 10^{-3}$  (1-T; 2- $Y_{O_2}$ ; 3- $Y_{N_2}$ ; 4- $2Y_{C_6H_{14}}$ ; 5- $2Y_{C_2H_5OH}$ ; 6- $2Y_{CO}$ ; 7- $2Y_{H_2O}$ ; 8- $2Y_{CO_2}$ ). T, K; y, mm.

with the surrounding medium and the surfaces of the working section or the test body itself. Certain errors in the measurements of  $T_*$  arise due to averaging of the temperature over the thickness of the thermocouple junction.

As is well known, the saturated vapor pressure of liquid at its boiling temperature equals atmospheric pressure, and the value of the weight  $C_{iW}$  or mole  $Y_{iW}$  concentration must equal unity, i.e.,  $C_{iW} = Y_{iW} = 1$ . In the case being examined, the concentration of n-hexane and ethyl alcohol on the surface of the porous body varies in the range of 0.2-0.4 (see Fig. 1a-d), i.e.,  $Y_{iW} < 1$ . The latter inequality stems from the fact that the liquid injectant was vaporized from the geometric surface of the test body and, therefore, the vaporization surface area approximately equalled the porosity of the body. In a number of experiments, the value of  $Y_{iW}$  is less than the porosity  $\Pi$ , which probably stems from the depth of the vaporization front. For  $Y_{iW} > \Pi$ , the area of the vaporization surface is greater than the porosity, i.e., it may be assumed that in this case local liquid films are formed. However, it should be noted that the quantities  $Y_{iW}$  and  $\Pi$  under the conditions of the experiment being examined differ insignificantly.

The experimental data on the vaporization of n-hexane and ethyl alcohol were analyzed using the following similarity criteria

$$St = St(Re_{\Delta x}, Pr, B), \quad St_m = St_m(Re_{\Delta x}, Sc, B_m) \quad (1)$$

with the functional relation between them established. Here  $St$  and  $St_m$  are the thermal and diffusion Stanton numbers;  $Pr$  and  $Sc$ , respectively, Prandtl's and Schmidt's numbers;  $B$  and  $B_m$ , blow-in parameters. The analytical expression for the parameters entering into (1) has the following form:

$$St = q_w/(\rho u)_\infty (H_* - H_w), \quad St_m = (m_\infty/m_i) F \ln(1 - Y_{iw})^{-1},$$

$$B = 1 - 0.485 (m_\infty/m_i)^{0.33} (\tilde{\mu}\tilde{\rho})_c^{-0.5} b,$$

$$B_m = 1 - 0.485 (m_\infty/m_i)^{0.33} (\tilde{\mu}\tilde{\rho})_c^{-0.5} b_m, \quad (2)$$

where

$$F = (\rho v)_w/(\rho u)_\infty; \quad b = F/St_0; \quad b_m = F/St_{m0};$$

$$St_0 = 0.332 Re_{\Delta x}^{-0.5} Pr^{-0.67}; \quad St_{m0} = 0.332 Re_{\Delta x}^{-0.5} Sc^{-0.67}. \quad (3)$$

As a result of analyzing the experimental data using the relations (1), the following dependency criteria were obtained for calculating the heat and mass exchange under conditions of porous blow-in and combustion of n-hexane and ethyl alcohol:

$$St/St_0 = 1.473B, \quad St_m/St_{m0} = 1.579B_m,$$

or

$$St = 0.489 Re_{\Delta x}^{-0.5} Pr^{-0.67} B, \quad St_m = 0.491 Re_{\Delta x}^{-0.5} Sc^{-0.67} B_m, \quad (4)$$

where  $St_0$  and  $St_{m0}$  are determined by the relations (3) and the other numbers are determined by relations (2).

In relations (4), all parameters are referred to the temperature of the surrounding medium.

The spread in the experimental points when they are described by the empirical relations (4) does not exceed  $\pm 18\%$ .

#### NOTATION

$c_i = \rho_i/\rho$ , mass concentration of the  $i$ -th component;  $Y_i$ , mole fraction of the  $i$ -th component;  $\rho$ , mass density;  $\tilde{\rho} = \rho/\tilde{\rho}$ ;  $H$ , total enthalpy;  $T$ , temperature;  $x$ , coordinate along the flow;  $y$ , coordinate transverse to the flow;  $u$ , velocity along  $x$ ;  $v$ , velocity along  $y$ ;  $\mu$ , dynamic viscosity;  $\tilde{\mu} = \mu/\mu_\infty$ ;  $C_p$ , specific heat capacity at constant pressure;  $x_0$ , length of the superposed thermally insulated section;  $D$ , coefficient of diffusion;  $q$ , heat flux;  $m$ , molecular weight;  $Re_{\Delta x} = (x - x_0)(\rho u/\mu)_\infty$ ;  $Pr = \mu C_p/\lambda$ ;  $Sc = \mu/\rho D_e$ ;  $F = (\rho v)_w/(\rho u)_\infty$ . The indices are as follows: 0, standard conditions;  $w$ , conditions at the wall;  $e$ , effective value;  $\infty$ , main flow;  $*$ , combustion front;  $c$ , quantities referred to the temperature  $T_c:0.5 (T_w + T_\infty)$ ;  $i$ , filtered liquid injectant.

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