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SIMILARITY OF TEMPERATURE AND CONCENTRATION FIELDS IN FILTRATION COMBUSTION OF GASES

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Abstract. The paper presents a mathematical model of a stationary wave of filtration combustion of gases, taking into account heat transfer to the surrounding space and diffusion coefficients of the components of the mixture of gases. As a result of the study, relations for the wave velocity in adiabatic and non-adiabatic modes of combustion are obtained, which contain the Lewis numbers of the mixture components, along with other physical and chemical constants of the mixture and porous medium. In the case of absence of heat loss into the surrounding space and intensive interfacial heat exchange, the similarity criteria of temperature and concentration fields are established. Linear dependences of the relative concentration of the mixture components on the dimensionless temperature are obtained. Calculated characteristics of the stationary wave of filtration combustion of hydrogen- and methane-air mixtures at heat loss and its absence have been analysed. The critical velocities of blowing at which the standing wave of combustion and the change of the direction of the wave motion are realised are established. It is argued that at further increase of heat transfer coefficient into the surrounding space the critical velocities will coincide and the change of the wave motion direction will not occur, since the curves of wave velocity dependence on the blow-in velocity have a parabolic form.

1. Introduction

In the theory of combustion of gases it is known that at equality of diffusion and diffusivity coefficients there is a similarity of temperature and concentration fields [1], i.e. there is a relationship between concentration and temperature [2]. This, in turn, means constancy of total enthalpy in the stationary mode of propagation of the combustion front, which consists of thermal and chemical energy. A decrease in one of them led to an increase in the other. In the study of filtration combustion of gases (FCG), the diffusion coefficient of the missing component of the gas mixture [3,4] was used in the form of the Lewis number (representing the ratio of the diffusion coefficient to the diffusivity). Its effects were understood as the effects of the Lewis number compiled for a mixture of gases without porous medium, and the effects of the flame front curvature in the case of FCGD [5]. In [5], the difference between the FCG wave parameters and their theoretical values was experimentally

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shown, which could manifest themselves in the regions of mixture compositions where Lewis number effects are detected in conventional flame conditions. Because of this, the authors of [5] assumed the existence of a connection between the FCG anomalies (underestimation of the temperature in the combustion wave and the shift of the maximum of the wave velocity toward poor mixtures) and the Lewis number effects. In this connection, we set a task to find out the influence of the Lewis numbers of mixture components on the combustion process.

2. Mathematical model

To solve the task at hand, we consider a mathematical model of FCG, which includes the equations of heat transfer in porous medium and gas mixture, the equations of conservation of mass of gas components and the equation of state

$$\begin{aligned}
&\rho_1 c_p \frac{\partial T_1}{\partial \tau} + \rho_1 c_p v_1 \frac{\partial T_1}{\partial \xi} = \frac{\partial}{\partial \xi}\left(\alpha_1 \lambda_1 \frac{\partial T_1}{\partial \xi}\right) - \alpha_c S_c (T_1 - T_2) + \rho_1 J Q,\\
&\rho_2 c_2 \frac{\partial T_2}{\partial \tau} = \frac{\partial}{\partial \xi}\left(\alpha_2 \lambda_2 \frac{\partial T_2}{\partial \xi}\right) + \alpha_c S_c (T_1 - T_2) + \alpha_0 (T_0 - T_2),\\
&\rho_1 \frac{\partial \eta_{1(i)}}{\partial \tau} + \rho_1 v_1 \frac{\partial \eta_{(i)}}{\partial \xi} = \frac{\partial}{\partial \xi}\left(\rho_1 D_{1i} \frac{\partial \eta_{1(i)}}{\partial \xi}\right) + \rho_1 \zeta_{1(i)} J, \quad i = 1, 2, ..., k,\\
&\frac{\partial \rho_1}{\partial \tau} + \frac{\partial \rho_1 v_1}{\partial \xi} = 0, \quad \rho_1 T_1 = \rho_{10} T_{10}, \quad J = \eta_{1(k_*)} k_0 \exp(-E/RT_1),\\
&\alpha_c = \frac{Nu \lambda}{d_{eff}},\ Nu = 0,395 Re^{0.64} Pr^{1/3},\ Re = \frac{|v_1| d_{eff} \rho_1}{\mu_1 \alpha_1}, Pr = \frac{c_p \mu_1}{\lambda_1},\\
&d_{eff} = \frac{2\alpha_1 d_3}{3\alpha_2},\ S_c = \frac{6\alpha_2}{d_3},\ \zeta_{1(i)} = -\frac{g_{1(i)}(\nu''_{1(i)} - \nu'_{1(i)})}{g_{1(k_*)}(\nu''_{1(k_*)} - \nu'_{1(k_*)})}.
\end{aligned} \tag{2.1}$$

Here $\nu'_{1(i)}$, $\nu''_{1(i)}$ - are initial and final stoichiometric coefficients of the substances, respectively; $g_{1(i)}$ - molecular weights of components; index; k_* in the concentration designation means the missing gas component, k - the number of gas phase components, Nu, Re, Pr, - Nuselt numbers, Reynolds numbers, Prandtl accordingly; μ_1 - viscosity coefficient; d_{eff} - the represented diameter of the channels; T_0 - ambient temperature; ρ_{10} - is the reduced density of the initial mixture, α_0 - is the volumetric heat transfer coefficient to the surrounding space.

In model (2.1) the number of equations is larger than in the previous models of filtration combustion of gases. This is the peculiarity of the model under consideration. In this model, the mass conservation equations of each component of the gas mixture are used. Involvement of these equations in the mathematical model is due to the fact that the influence of diffusion coefficients of components on the wave velocity is taken into account.

To investigate the mathematical model (2.1), we transfer to the moving coordinate system by means of the formula $x = \xi + Ut$ and consider the steady-state mode of the FCG wave. The steady-state mode corresponds to the case when the structure of the wave does not depend on time. i.e., with an unlimited increase of time ($t \to \infty$) profiles of gas and porous medium temperatures, concentration of gas mixture components, gas mixture density and filtration rate do not change ($T_1 = T_1(x)$, $T_2 = T_2(x)$, $\eta_{1(i)} = \eta_{1(i)}(x)$, $\rho_1 = \rho_1(x)$, $v_1 = v_1(x)$). In this case the system (2.1) will take the form

$$\begin{aligned}
&\rho_1 c_1 (v_1 + U)\frac{dT_1}{dx} = \frac{d}{dx}\left(\alpha_1\lambda_1\frac{dT_1}{dx}\right) - \alpha_c S_c (T_1 - T_2) + \rho_1 Q J,\\
&\rho_2 c_2 U\frac{dT_2}{dx} = \frac{d}{dx}\left(\alpha_2\lambda_2\frac{dT_2}{dx}\right) + \alpha_c S_c (T_1 - T_2) + \alpha_0 (T_0 - T_2),\\
&\rho_1 (v_1 + U)\frac{d\eta_{1(i)}}{dx} = \frac{d}{dx}\left(\rho_1 D_{1(i)}\frac{d\eta_{1(i)}}{dx}\right) + \rho_1\zeta_{1(i)} J, \quad i = 1, 2, ..., k,\\
&\rho_1 (v_1 + U) = \rho_{10}(v_{10} + U),\ \rho_1 T_1 = \rho_{10} T_0,\ J = \eta_{1(k_*)} k_0 \exp(-E/RT_1).
\end{aligned} \tag{2.2}$$

In case of instantaneous interfacial heat exchange ($\alpha_c S_c = \infty$) when the phase temperatures are approximately the same ($T_1 \approx T_2 = T$) from system (2.2) by summation of the first and second equation we obtain

$$\begin{aligned}
&(\rho_{10} c_p (v_{10} + U) + \rho_2 c_2 U)\frac{dT}{dx} = (\alpha_1\lambda_1 + \alpha_2\lambda_2)\frac{d^2T}{dx^2} + \rho_1 Q J + \alpha_0 (T_0 - T),\\
&\rho_{10} c_p (v_{10} + U)\frac{d\eta_{1(i)}}{dx} = \rho_1 D_{1(i)}\frac{d^2\eta_{1(i)}}{dx^2} + \rho_1\zeta_{1(i)} J,\ i = 1, 2, ..., k,\\
&J = \eta_{1(k_*)} k_0 \exp(-E/RT),\ \rho_1 T_1 = \rho_{10} T_0.
\end{aligned} \tag{2.3}$$

Further, we assume that heat release due to chemical reaction occurs in a narrow spatial interval - the combustion zone. The mixture of gases coming to the combustion zone is heated as a result of heat exchange with a porous medium that recovers heat from the combustion products zone (relaxation zone). Since in this region adjacent to the combustion zone, the chemical reaction rate and temperature changes are insignificant, we assume negligibly small terms containing the chemical reaction rate (J) in comparison with other terms of equations (2.3) and constant thermal conductivity coefficients (λ_1, λ_2). Hence, the system (2.3) without these terms has the form

Let us write the system (2.3) in the following form

$$\begin{aligned}
&(\rho_{10} c_p (v_{10} + U) + \rho_2 c_2 U)\frac{d(T - T_0)}{dx} =\\
&= (\alpha_1\lambda_1 + \alpha_2\lambda_2)\frac{d^2(T - T_0)}{dx^2} + \rho_1 Q J + \alpha_0 (T_0 - T),\\
&\rho_{10} c_p (v_{10} + U)\frac{d\eta_{1(i)}}{dx} = \rho_1 D_{1(i)}\frac{d^2\eta_{1(i)}}{dx^2} + \rho_1\zeta_{1(i)} J,\ i = 1, 2, ..., k,\\
&J = \eta_{1(k_*)} k_0 \exp(-E/RT),\ \rho_1 T_1 = \rho_{10} T_0.
\end{aligned} \tag{2.4}$$

The characteristic equations of the system (2.4) are the following equations:

$$k^2 - a_1 k - a_3 = 0, \quad p^2 = a_{2(i)} p = 0,$$

where

$$a_1 = \frac{\rho_{10} c_p (v_{10} + U) + \rho_2 c_2 U}{\alpha_1\lambda_1 + \alpha_2\lambda_2},\ a_3 = \frac{\alpha_0}{\alpha_1\lambda_1 + \alpha_2\lambda_2},\ a_{2(i)} = \frac{\rho_{10}(v_{10} + U)}{\rho_{1e} D_{1(i)e}}.$$

The solutions of the system (2.4) in the regions before the combustion zone (heating zone, $x < 0$) and after the combustion zone (relaxation zone, $x > 0$) have the following form

$$x < 0: \quad T - T_0 = (T_e - T_0)e^{k_2 x},\ \eta_{1(i)} = \eta_{1(i)0},$$

$$x > 0: \quad T - T_0 = (T_e - T_0)e^{k_1 x},\ \eta_{1(i)} = \eta_{1(i)0} = (\eta_{1(i)e} - \eta_{1(i)0})e^{a_{2(i)x}},$$

where

$$k_1 = \frac{a_1 - \sqrt{a_1^2 + 4a_3}}{2}, \quad k_2 = \frac{a_1 + \sqrt{a_1^2 + 4a_3}}{2}.$$

3. Relationships for the velocity of the stationary combustion wave

In combustion theory, the ratio for the steady-state wave velocity is obtained by integrating the energy equation within the combustion zone, since all thermal energy is released in a narrow temperature and space zone. In the stationary case, the integral from the heat release source is equal to the total heat influx into the system [4]. When integrating, the following approximations are used

$$T - T_0 = (T_e - T_0)e^{kx} \approx (T_e - T_0)(1 + kx),\ x << 1,$$

$$\exp\left(-\frac{E}{RT}\right) \approx \exp\left(-\frac{1}{\beta}\right) \cdot \exp\left(-\frac{E(T - T_e)}{RT_e^2}\right),$$

and to the heat source $(\rho_1 QJ)$ is multiplied by the sum of the concentration of the components, which is identically equal to one: $\sum\limits_{i=1}^{k} \eta_{1(i)} \equiv 1$.

As a result of integration we have a relation for the FCG wave velocity

$$\begin{gathered}
(v_{10} + U)^2 = \frac{k_0 \exp(-1/\beta)\gamma\lambda_1\Lambda\sqrt{1 + 4\Delta/(1 - u_0/(1 + \phi))^2}}{\rho_{10}^0 c_p u_\varphi a_4 \eta_{1(k_*)}} \cdot \frac{T_0}{T_e} \times \\
\times \left[\eta_{1(k_*)0} + \frac{\eta_{1(k_*)e} - \eta_{1(k_*)0}}{\dfrac{\gamma}{Le_{eff} a_4} + 1} + \eta_{1(k_*)0} \sum_{i=1}^{k} \frac{\eta_{1(k_*)e} - \eta_{1(k_*)0}}{\dfrac{\gamma}{Le_{eff} u_\varphi a_4} + 1} + \right. \\
\left. + \left(\eta_{1(k_*)e} - \eta_{1(k_*)0}\right) \sum_{i=1}^{k} \frac{\eta_{1(k_*)e} - \eta_{1(k_*)0}}{\dfrac{\gamma}{Le_{eff} u_\varphi a_4} + \dfrac{\gamma}{Le_{eff} u_\varphi a_4} + 1}\right] - \\
- \frac{(v_{10} - U)\alpha_0 (T_e - T_0)(k_1 - k_2)\sqrt{1 + 4\Delta/(1 - u_0/(1 + \varphi))^2}}{Q\eta_{1(k_*)}\rho_{10} k_1 k_2}.
\end{gathered} \tag{3.1}$$

Here

$$\gamma = \frac{RT_e^2}{E(T_e - T_0)},\ \Lambda = 1 + \frac{\alpha_1\lambda_1}{\alpha_2\lambda_2},\ \Delta = \frac{\alpha_0(\alpha_1\lambda_1 + \alpha_2\lambda_2)}{U^2(\rho_{10}c_p + \rho_2 c_2)^2},\ u_0 = \frac{v_{10}}{U},$$

$$T_e - T_0 = \frac{Q\eta_{1(k_*)}}{c_p u_\varphi \sqrt{1 + 4\Delta/(1 - u_0/(1 + \varphi))^2}},\ u_\varphi = 1 + \frac{\varphi}{1 - u_0},\ \varphi = \frac{\rho_2 c_2}{\rho_{10} c_p},$$

$$a_4 = \frac{1}{2}\left[1 + \sqrt{1 + \frac{4\alpha_0(\alpha_1\lambda_1 + \alpha_2\lambda_2)}{\rho_{10}c_p(v_{10}+U) + \rho_2 c_2 U}}\right]$$

Ratio (3.1) is an expression for determining the stationary wave velocity in the nonadiabatic regime. This relation, along with other parameters of the system, includes the diffusion coefficients of all components of the gas mixture in the form of Lewis numbers.

In the case of $\alpha_0 \to 0$ that is, at neglecting heat losses into the surrounding space, from (3.1) we obtain the relation for the wave velocity in the adiabatic regime

$$\begin{aligned}
(v_{10}+U)^2 = {} & k_0 \exp\left(-\frac{1}{\beta}\right) \frac{\gamma\lambda_1\Lambda}{\rho_{10}^0 c_p u_\varphi \eta_{1(k_*)0}} \cdot \frac{T_0}{T_e} \times \\
& \times \Bigg[\eta_{1(k_*)0} + \frac{\eta_{1(k_*)e} - \eta_{1(k_*)0}}{1 + \dfrac{\gamma}{Le_{eff_{(2)}} u_\varphi}} + (\eta_{1(k_*)e} - \eta_{1(k_*)0}) \times \\
& \times \sum_{i=1}^{k} \frac{\eta_{1(k_*)e} - \eta_{1(k_*)0}}{\dfrac{\gamma}{1 + Le_{eff_{(2)}} u_\varphi} + \dfrac{\gamma}{Le_{eff_{(i)}} u_\varphi}} + \eta_{1(k_*)0} \sum_{i=1}^{k} \frac{\eta_{1(k_*)e} - \eta_{1(k_*)0}}{1 + \dfrac{\gamma}{Le_{eff_{(i)}} u_\varphi}} \Bigg].
\end{aligned} \tag{3.2}$$

4. Similarity criteria for the fields of medium temperature and concentration of gas mixture components

Consider the system (2.3) at $\alpha_0 = 0$ i.e. in the case of neglecting heat losses into the surrounding space:

$$\begin{aligned}
& (\rho_{10}c_p(v_{10}+U) + \rho_2 c_2 U)\frac{dT}{dx} = (\alpha_1\lambda_1 + \alpha_2\lambda_2)\frac{d^2T}{dx^2} + \rho_1 Q J, \\
& \rho_{10}c_p(v_{10}+U)\frac{d\eta_{1(i)}}{dx} = \rho_1 D_{1(i)}\frac{d^2\eta_{1(i)}}{dx^2} + \rho_1\zeta_{1(i)}J,\ i = 1, 2, ..., k, \\
& J = \eta_{1(k_*)} k_0 \exp(-E/RT).
\end{aligned} \tag{4.1}$$

Let's carry out the operation of unmeasuring of variables and parameters of the system (4.1) by means of relations:

$$x = x'L,\ T = T_0 + \theta(T_e - T_0),\ \eta_{1(i)} = n_{1(i)}\zeta_{1(i)}\eta_{1(k_*)} + \eta_{1(i)},\ T_e = T_0 + \frac{\eta_{1(i)0}Q}{c_p u_\varphi},$$

$$u_\varphi = 1 + \frac{\varphi}{1+u_0},\ \varphi = \frac{\rho_2 c_2}{\rho_{10}c_p},\ u_0 = \frac{v_{10}}{U},\ L = \frac{\kappa\Lambda}{(v_{10}+U)u_\varphi}, \kappa = \frac{\lambda_1}{\rho_{10}^0 c_p},$$

$$\Lambda = 1 + \frac{\alpha_2\lambda_2}{\alpha_1\lambda_1},\ Le_{eff_{(i)}} = \frac{Le_{(i)}}{\Lambda},\ Le_{(i)} = \frac{D_{(1(i))}}{\kappa}$$

The mass concentrations of the components were unmeasured taking into account the first integrals of the continuity equations of the components. As a result, from system (4.1) we have

$$\begin{aligned}
&\frac{d\theta}{dx'} = \frac{d^2\theta}{dx'^2} + a\bar{J},\\
&\frac{dn_{1(i)}}{dx'} = Le_{eff_{(i)}} u_\varphi \frac{dn_{1(i)}}{dx'^2} + a\bar{J},\\
&\rho_1(T_0 + \theta(T_e - T_0)) = \rho_{10}T_0,\\
&\bar{J} = n_{1(k_*)} \exp(-E/(R(T_0 + \theta(T_e - T_0))),\\
&a = \frac{\rho_1 k_0 L}{\rho_{10}(v_{10} + U)}.
\end{aligned} \tag{4.2}$$

Provided $Le_{eff_{(i)}} u_\varphi = 1$ system (4.2) admits linear dependence of function variables

$$n_{1(i)} = \theta(i \neq k_*), \quad n_{1(k_*)} = 1 - \theta.$$

Hence, the condition $Le_{eff_{(i)}} u_\varphi = 1$ is a criterion of similarity of temperature and concentration profiles of components.

The relations for the wave velocity (3.1) and (3.2) at the similarity criterion will respectively take the form

$$\begin{aligned}
(v_{10} + U)^2 = {} & \frac{k_0 \exp(-1/\beta)\gamma\lambda_1\Lambda\sqrt{1 + 4\Delta/(1 - u_0/(1 + \varphi))^2}}{\rho_{10}^0 c_p u_\varphi a_4} \times\\
& \times \frac{T_0}{T_e} \cdot \left(1 - \frac{a_4}{\gamma + a_4}\right) -\\
& - \frac{(v_{10} + U)\alpha_0(T_e - T_0)(k_1 - k_2)\sqrt{1 + 4\Delta/(1 - u_0/(1 + \varphi))^2}}{Q\eta_{1(k_*)}\rho_{10}k_1k_2}.
\end{aligned} \tag{4.3}$$

$$(v_{10} + U)^2 = k_0 \exp(-1/\beta) \frac{\gamma^2\lambda_1\Lambda}{\rho_{10}^0 c_p u_\varphi(1 + \gamma)} \cdot \left(\frac{T_0}{T_e}\right)^2. \tag{4.4}$$

5. Analysis of the main characteristics of the stationary wave of filtration combustion of gases

On the basis of relations (4.3) and (4.4) the main characteristics of the filtration combustion wave of hydrogen- and methane-air mixtures were calculated.The calculations were performed for different concentrations of hydrogen and methane in the mixture at varying the fresh mixture injection rate.Calculations of the steady-state wave velocity at heat losses were performed for different wall heat transfer coefficients α_W tubes of radius R_W which are related to the volumetric heat transfer coefficient to the surrounding space by the relation:

$$\alpha_0 = \frac{2\alpha_W}{R_W}.$$

Calculations using the relation (4.3) revealed that the curves of wave velocity dependence on the blowing velocity at heat losses for hydrogen- and methane-air mixtures have a U-shaped form (Fig.1) and the orders of velocity change within $10^{-6} - 10^{-4}$m/s, which agrees with the experimental data [8,9]. In Fig.1a we observe that up to the values of heat transfer coefficient to the surrounding space $100W/(m^2 \cdot K)$ the change of propagation direction is not observed within the limits of change of the mixture blowing velocity, and for methane-air mixture (Fig.1b) the critical heat transfer coefficient to the surrounding space is equal to $50W/(m^2 \cdot K)$. As the heat transfer coefficient to the surrounding space increases, the U-shaped curve of the wave velocity dependence on the inlet velocity is shifted and the change of the wave motion direction will occur at two values of the inlet velocity. Since at critical values of the inlet velocity a standing wave of combustion is carried out, it should be assumed that with the increase of the heat transfer coefficient into the surrounding space the critical velocities coincide and the change of directions will not occur. In this case, the maximum wave velocity in the direction of the fresh mixture flow decreases and corresponds to relatively small values of the inlet velocity.

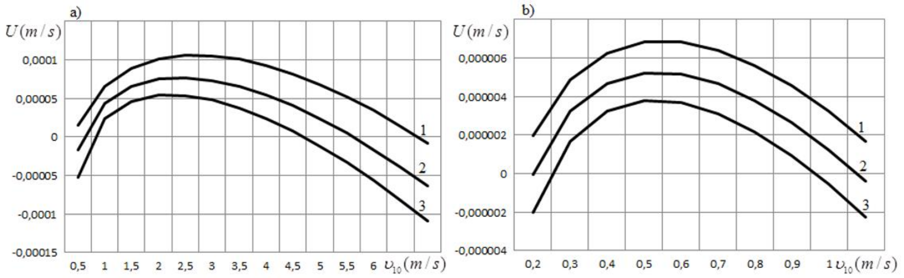

Figure 1. Wave velocity versus blowing velocity curves at 65% hydrogen (a) and 7.5% methane (b) in the mixture and different heat transfer coefficients to the surrounding space: a)$1-100$, $2-140$, $3-180W/(m^2 \cdot K)$; b) $1-40$, $2-50$, $3-60W/(m^2 \cdot K)$

The curves of dependence of the wave velocity on the inlet velocity for hydrogen- and methane-air mixtures in the adiabatic regime ($\alpha_0 = 0$) are shown in Fig.2. At a relatively small percentage of hydrogen in the mixture (33%), the wave velocity increases with increasing blow-in velocity (Fig.2a). Increasing the hydrogen concentration in the mixture (up to 65%), we observe that the wave velocity curves acquire a maximum. At the same time, the maximum of the wave velocity falls on relatively small values of the blowing velocity, and at high blowing velocities ($65\% H_2$) a change of the mode of combustion wave propagation from counter to downward is observed. In the case of methane-air mixture combustion, the wave velocity curves from the blow-in velocity have maxima at all considered mixture compositions (Fig.2b). At the same time, a change in the direction of wave propagation from counterflow to downflow is observed. With decreasing methane concentration in the mixture, the maximum of the wave velocity on the curves and the point of change of directions shift toward small values of the blow-in velocity.

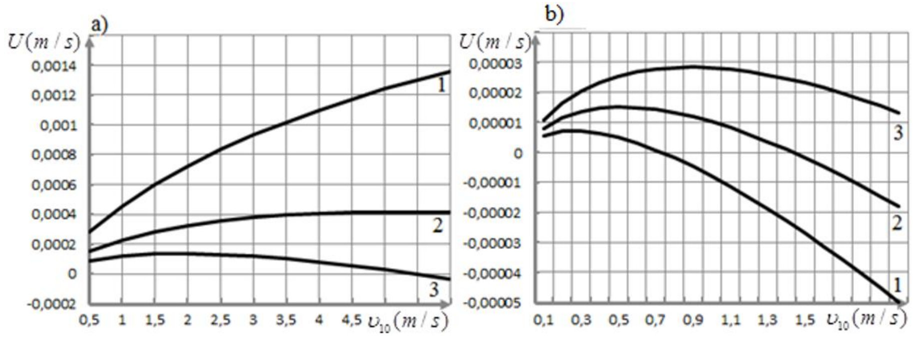

Figure 2. Wave velocity vs. blowing velocity curves at different concentrations of hydrogen (a) and methane (b) in the mixture: a)$1-33\%$, $2-55\%$, $3-65\% H_2$; b) $1-7.5\%$, $2-8.5\%$, $3-9.5\% CH_4$

Note that the function values at the first points of all curves shown in Figs.3-5 are calculated at an injection velocity of $0.1 m/s$, and the subsequent values are calculated at increasing injection velocity in steps of $0.1 m/s$. Note that the larger the hydrogen concentration in the mixture, the wider the interval of variation of the Lewis number (Fig.3a). This means that relatively large concentrations of hydrogen in the mixture correspond to relatively large diffusion coefficients. In the case of a methane-air mixture, the interval of variation of the Lewis number relative to hydrogen is small and practically does not change when varying the percentage of methane in the mixture (Fig.3b).

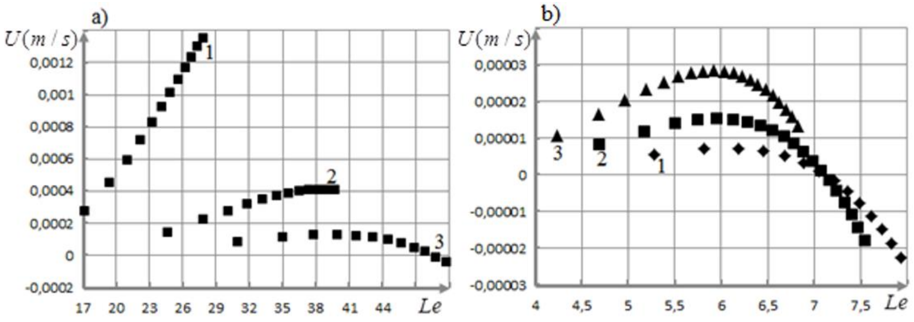

Figure 3. Wave velocity dependence curves on Lewis number at different concentrations of hydrogen (a) and methane (b) in the mixture: a) $1-33\%$, $2-55\%$, $3-65\% H_2$; b) $1-7.5\%$, $2-8.5\%$, $3-9.5\% CH_4$

If the diffusion coefficients of the components are equal, the following formula is obtained for the equilibrium temperature

$$T_e = T_0 + \frac{LeQ\eta_{1(k_*)}}{c_p\Lambda}, \tag{5.1}$$

Since $u_\varphi = \Lambda/Le$ Formula (5.1) shows that the equilibrium temperature is directly proportional to the diffusion coefficient (Fig.4a,b). From Fig.4 shows that varying the concentration of hydrogen and methane in the mixture practically does not change the value of the equilibrium temperature. The equilibrium temperature increases for hydrogen- and methane-air mixtures with increasing Lewis number, i.e., with increasing diffusion coefficient. At the same time, the equilibrium temperature of methane-air mixture is much larger than the equilibrium temperature of hydrogen-air mixture for all considered compositions.

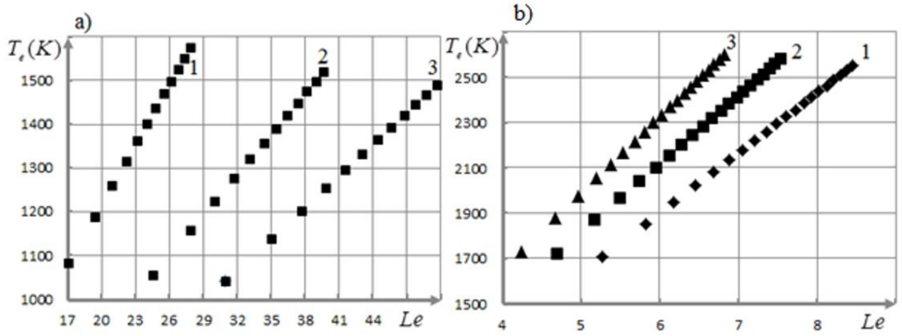

Figure 4. Curves of dependence of equilibrium temperature on Lewis number at different concentrations of hydrogen (a) and methane (b) in the mixture: a) $1-33\%$, $2-55\%$, $3-65\%H_2$; b) $1-7.5\%$, $2-8.5\%$, $3-9.5\%CH_4$

Blow-in velocity dependence curves on the generalized Zel'dovich number $\gamma = RT_e^2/(E(T_e-T_0))$ are given in Fig.5. The generalized Zel'dovich number characterizes the dimensionless activation energy. From Fig.5a shows that an increase in the generalized Zel'dovich number leads to an increase in the wave velocity for a relatively small percentage of hydrogen in the mixture (33%), and with increasing concentration ($65\%H_2$), the appearance of a velocity maximum as the velocity increases is observed γ. In the case of a methane-air mixture, the increase γ contributes to the change of the propagation mode from satellite to counter propagation. In this case, the lower the concentration, the lower the values of γ at which the mode change occurs (Fig.5b).

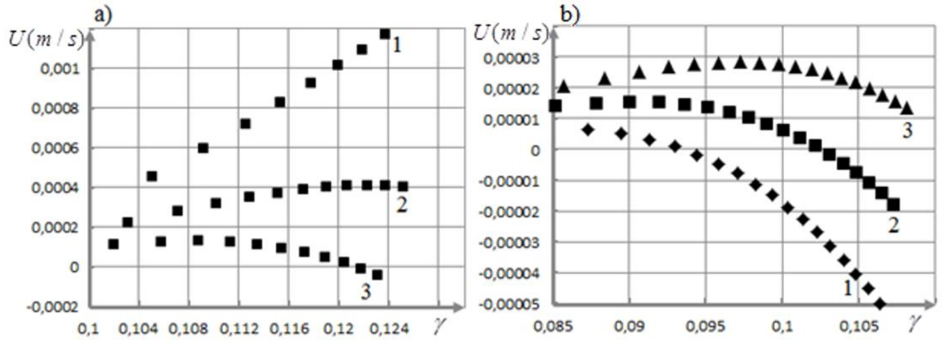

Figure 5. Wave velocity dependence curves on the generalized Zel'dovich number at different concentrations of hydrogen (a) and methane (b) in the mixture: a) $1-33\%$, $2-55\%$, $3-65\%H_2$; b) $1-7.5\%$, $2-8.5\%$, $3-9.5\%CH_4$

6. Conclusions

The condition of similarity of profiles of medium temperature and concentration of gas components in the case of filtration combustion of gases is obtained.

The dependence of the wave velocity and equilibrium temperature on the Lewis number of the components is established, which allows us to find the diffusion coefficients of the mixture components. The greater the concentration of hydrogen in the mixture, the wider the interval of the Lewis number variation. In the case of methane-air mixture, the interval of Lewis number variation with respect to hydrogen is small and practically does not change when varying the percentage of methane in the mixture. For hydrogen and methane-air mixtures, relatively large Lewis numbers correspond to relatively large equilibrium temperatures.

The curves of dependence of the wave velocity on the blowing velocity at heat loss for hydrogen- and methane-air mixtures have a U-shaped form. The maximum of the wave velocity occurs at relatively small values of the inlet velocity.

Both in the case of combustion of hydrogen-air mixture and in the case of methane-air mixture, an increase in the heat transfer coefficient of the wall leads to an increase in the wave velocity.

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