THE EFFECT OF INTRACHAMBER NONSTATIONARITIES ON THE FORMATION OF ELECTROPHYSICAL PRESENTATION OF LRE OPERATING PROCESS

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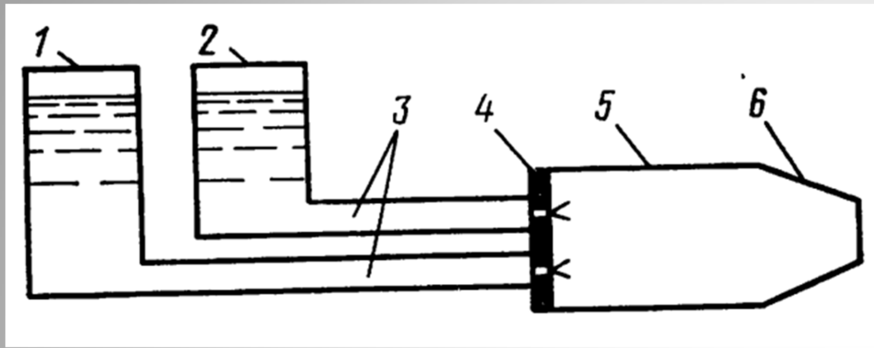

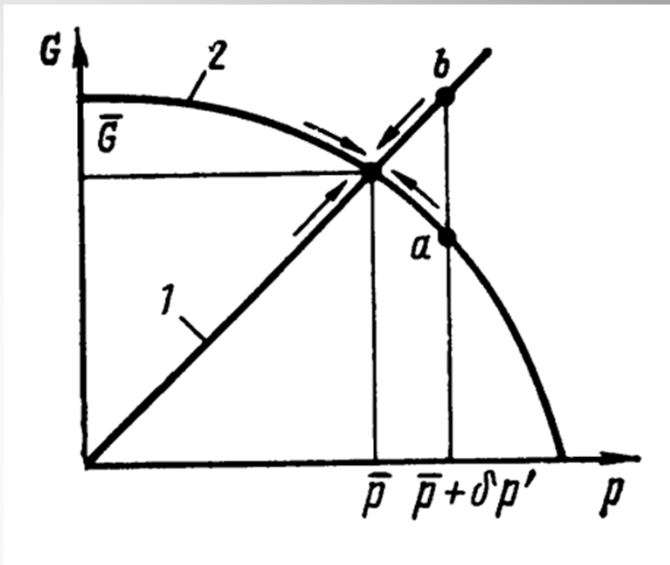

Simple jet engine:
1 - fuel at pressure
2 - oxidizer at pressure
3 - system of delivery
4 - injectors
5 - combustion chamber
6 - outlet nozzle

Static stability of system:
1 – flow rate throw nozzle
2 - flow rate throw injectors
G - flow rate
p – pressure at combustion chamber

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In combustion chambers of engines due to temporal nonstationarities of performance characteristics, the phenomenon of instability in the volume distribution of electric charge having macroscopic nature is progressing.

$\tau_f \sim 1 \div 10^{-4} s$ - fluctuations period:

- natural frequency of fuel-oxidizer delivery system
- fluctuation and non-stationarity of fuel and oxidizer parameters
- natural frequency of combustion chamber
- etc

Set of frequencies may lead to the resonance phenomenon.

The development of instabilities is effected, in terms of energy, by the transfer of acoustic component of the energy of the medium into the electric field energy.

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$\tau_e \sim 10^{-11} s$ - period of plasma oscillations

$\tau_i \sim 10^{-5} s$ - restoration of the ionization equilibrium time (after fluctuations influence)

$\tau_r \sim 10^{-3} s$ - combustion chamber residence time

$\tau_f \sim 1 \div 10^{-4} s$ - fluctuations period

Thus, in each produced, existing and destroyed volume of medium with excess electric charge inside the combastion chamber, as well as their combination, at any given time can be considered in a quasi-stationary ionization equilibrium state.

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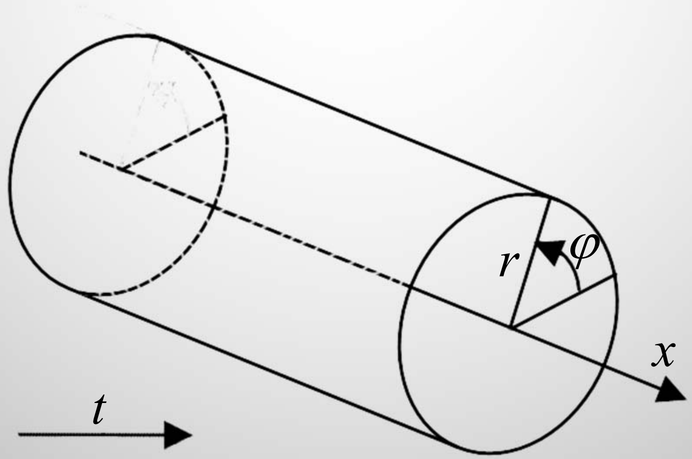
Levels of model presentation for combustion chamber:

- 3-D non-stationary model: t, x, r, φ
- 2-D non-stationary model (axial symmetry): t, x, r
- 1-D non-stationary model ("without wall off combustor"): t, x



Combustion yield plasma is low-temperature plasma, presented as quasi-equilibrium three-liquid physical model:

- neutral one type atoms
- ion with positive charge
- electrons with negative charge

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Description of physical model by mathematical model (set of equations):

$$n_e m_e \left(\frac{\partial}{\partial t} + U_e \nabla \right) U_e + \frac{e n_e}{\mu_e} (U_e - U_a) + \nabla p_e - e n_e E = 0$$

$$n_i m_i \left(\frac{\partial}{\partial t} + U_i \nabla \right) U_i + \frac{e n_i}{\mu_i} (U_i - U_a) + \nabla p_i + e n_i E = 0$$

motion of electron and ion plasma components

$$\frac{\partial}{\partial t} \rho_\Sigma + \nabla (\rho_\Sigma U_\Sigma) = 0$$

flow continuity low

$$\frac{\partial}{\partial t} q + \Delta \vartheta_k = 0$$

charge conservation law

$$\Delta E - \frac{1}{\varepsilon_0} q = 0$$

Poisson equation

$$\frac{\alpha \eta}{(1-\alpha)(1+\eta)} = 6.666798 \cdot 10^{-2} \frac{T^{\frac{3}{2}}}{P_\Sigma} e^{-\frac{V}{kT}}$$

ionization equilibrium of medium in Saha form

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Aggregate form of acoustic oscillation is considered:

$$P_{\Sigma} = p_0 \left[1 + c\cos\left(\frac{2\pi n_1 f_0}{a_0} x\right) \sin(2\pi n_1 f_0 t) \right]$$ - total pressure

$$T = T_0 \left[1 + c\cos\left(\frac{2\pi n_1 f_0}{a_0} x\right) \sin(2\pi n_1 f_0 t) \right]$$ - absolute temperature

Simplifying of the mathematical model:

$$a \ll 1 \Rightarrow 1 - a \approx 1$$

$$\eta \ll 1 \Rightarrow 1 - \eta \approx 1$$

$$U_e \gg U_i \Rightarrow U_i \pm U_e \approx \pm U_e$$

$$U_e \gg U_a \Rightarrow U_a \pm U_e \approx \pm U_e$$

η - relative electron concentration

α - ionization degree

U_e - electron component velocity of medium

U_i - ion component velocity of medium

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Simplified mathematical model (2 equations):

$$\frac{\partial\varphi}{\partial\tau}+\frac{u_e}{1+\frac{\alpha_0^2 e^{2\varphi}}{s}}\frac{\partial\varphi}{\partial x}=\frac{1}{1+\frac{\alpha_0^2 e^{2\varphi}}{s}}\left\{\frac{\partial u_e}{\partial x}+k_6\left[\cos(2\pi t)\cos(2\pi x)-u_e\sin(2\pi t)\sin(2\pi x)\right]\right\}$$

$$\frac{\partial u_e}{\partial\tau}+u_e\frac{\partial u_e}{\partial x}+k_1\sqrt{g}u_e-k_3 g\frac{\partial\varphi}{\partial x}-k_4\sin(2\pi\tau)\sin(2\pi x)-k_2\int_0^x(\alpha+\alpha s-\frac{s}{\alpha})dx=0$$

Time and space variables are replaced by dimensionless analogues

$$x=Xf_0/\sqrt{\gamma R_{gas}T_0},\quad \tau=tf_0$$

$u_e=\frac{U_e}{a0}$ - relative electron component velocity (relatively sonic velocity)

k_i - specially computed constants

Calculating ionization degree using φ-function

$$\alpha=\alpha_0 e^{\varphi},\ (\varphi=\ln\frac{\alpha}{\alpha_0}=\ln\alpha-\ln\alpha_0,\quad \alpha_0=\alpha|_{t=0})$$

Another medium parameters calculations using simplified model:

$$j(t,x) = e\alpha(t,x)U_e(t,x)\frac{P_0}{kT_0}$$ - current density

$$\sigma(t,x) = \frac{j(t,x)}{E(t,x)}$$ - plasma conductivity

$$\mu_e(t,x) = \frac{U_e(t,x)}{E(t,x)}$$ - electron mobility

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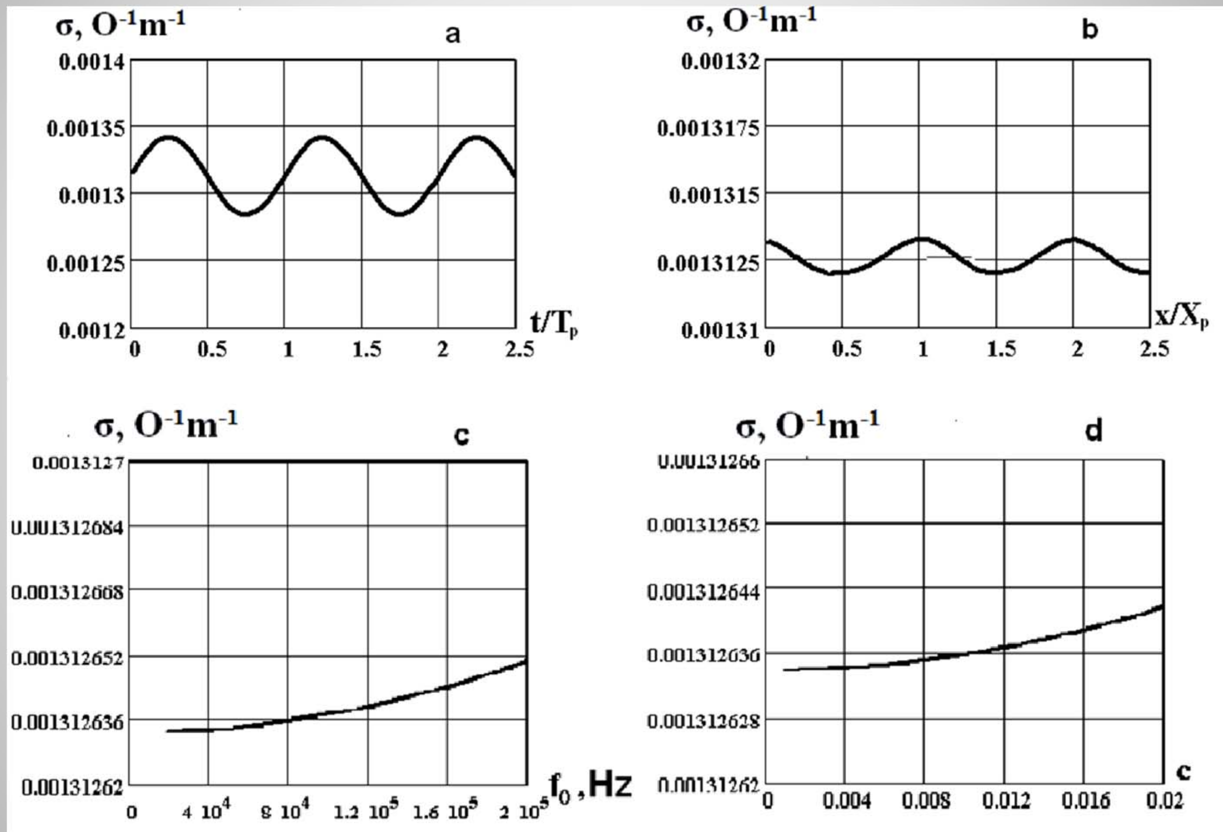
Weak dependences:



Dependence of conductivity of combustion yields plasma: on time (a), on coordinate (b), on frequency (c), on amplitude (d) of acoustic signal at 0.4 MPa, 2000 K, acoustic signal with frequency 50 kHz and amplitude of modulation 0.001

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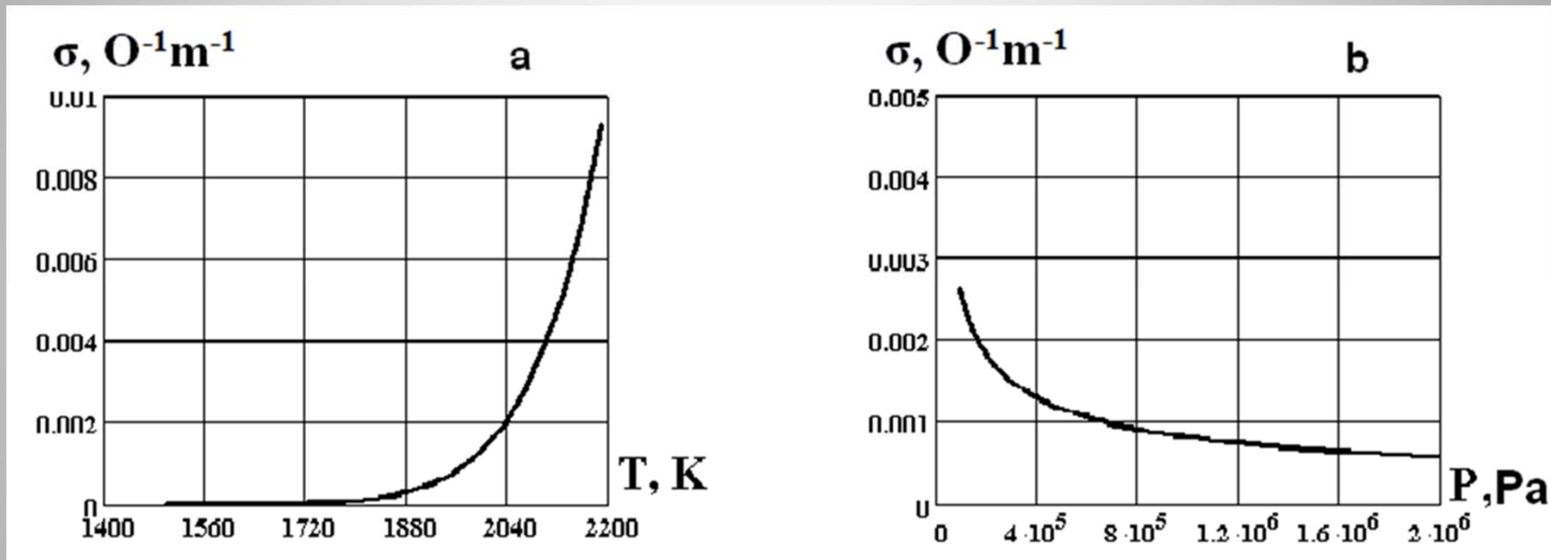
Strong dependences:



Dependence of conductivity of combustion yields plasma: on temperature (a), on pressure (b) at 0.4 MPa, 2000 К, acoustic signal with frequency 50 kHz and amplitude of modulation 0.001

Calculating temperature using measurements of conductivity:

$$\sigma_{эксп} - \sigma(T_0, P_0) = 0$$

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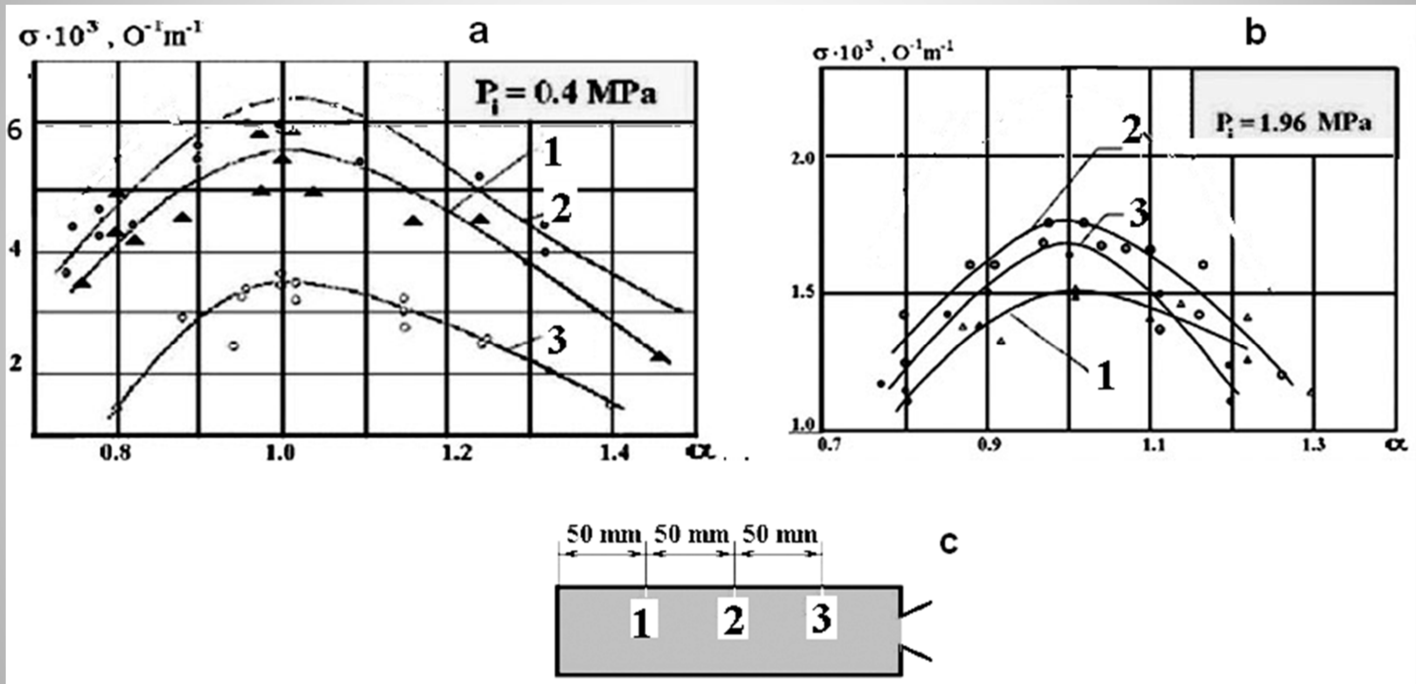
Experimental setup data:



Dependencies of conductivity of combustion yields plasma on excess-oxidizer coefficient at the pressures 0.4 MPa (a) and 1.96 MPa (b) measured at the three sections of combustion chamber (c).

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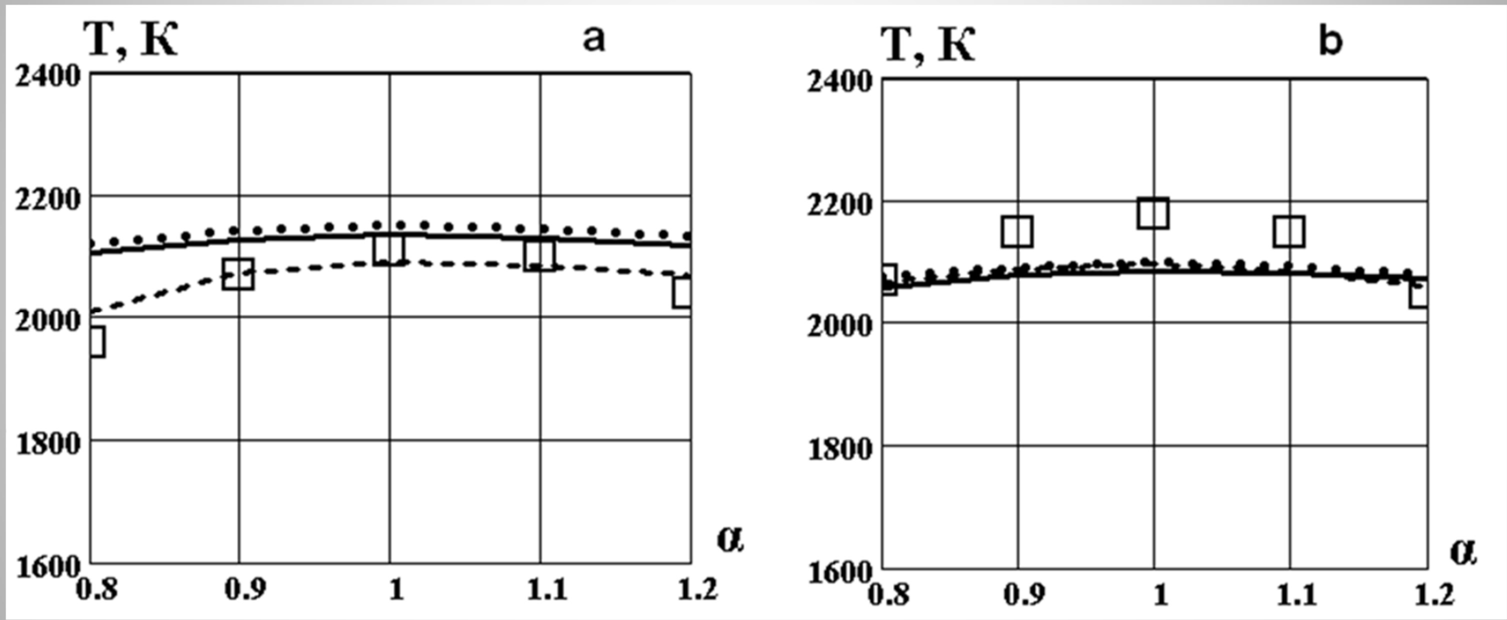
Comparison of experimental and theoretical data:



Dependence of temperature on excess-oxidizer coefficient, computed by conductivity: solid curve - section 1, dotted curve - section 2, dashed curve - section 3; points – data of another independent calculation method at 0.4 MPa (a) and 1.96 MPa (b)

The method suggested in this work can be used for determination of temperature distribution, electron mobility and other plasma parameters in various regions of combustion chamber in real time.

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Results:

- The formation mechanisms of time and volume non-stationarity is observed.
- The development of instabilities is effected, in terms of energy, by the transfer of acoustic component of the energy of the medium into the electric field energy.
-The physical model of combustion yield plasma as a tree-liquid model has been proposed.
- The mathematical model has been constructed from equations described plasma physics laws.
- The mathematical model has been simplified.
- The analytical formulas for determination of electron velocity and ionization degree has obtained.
- The experemental data and theoretical method have been compared.

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Thank you for you attention.