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ZERO-DIMENSIONAL MODELLING OF PULSED JET COMBUSTION IN A CONSTANT VOLUME CHAMBER

The zero-dimensional thermochemical model for the two-step combustion in the Pulsed Jet Combustion (PJC) in a constant volume chamber is proposed. At first, a rich air-fuel mixture is burned in the prechamber. The combustion products have equilibrium composition and thermo-chemical parameters calculated with the STANJAN code. Then, a high-speed turbulent plume of combustion products is isentropically injected into the main chamber. The plume is composed of multiple vortices of different sizes which provide multiple ignition sites. Composition and temperature are assumed as uniform in each vortex while pressure is assumed as uniform in the whole chamber. Combustion is sustained in the vortices due to mixing of the high-temperature combustion products with the cold fresh air-fuel mixture. Vortices grow in size due to engulfing new portions of fresh mixture and due to thermal expansion caused by chemical reaction of one-step Arrhenius type. The combustion terminates when the entire mixture is burned or when the rate of entrainment of cold mixture by the vortices is so high that the combustion cannot be sustained. As an example, a combustion of stoichiometric methane-air mixture is considered in the paper. The effects of velocity associated with the mass flow rate of entrainment of the fresh mixture, number of vortices, heat loss, mass and velocity distribution on pressure history in the chamber are presented in diagrams.

NOMENCLATURE

A – area of a surface
B – universal gas constant
c_p, c_v – specific heats at constant pressure and volume, $\kappa = c_p/c_v$
C, D – quantities defined in Eq. (7) and Eq. (16)
d – vortex diameter
H, h – enthalpy, specific enthalpy
k_A – Arrhenius constant

L – mean beam length for thermal radiation
m – mass, $m_1 = m_x^o + m_o^o$ – total mass of gas in the main chamber
M – molecular mass
n – polytropic exponent
N – number of moles
NC – number of vortices
NS – number of species
p – pressure
Q – heat loss
R – individual gas constant
T – temperature
u – the mean velocity of entrainment
V – volume
x – mass fraction
y – molar fraction
α – heat transfer coefficient
ε – vortex emissivity
λ – excess air factor
ρ – density
σ_e – extinction coefficient

SUBSCRIPTS

j – number of the vortex
k – type of the species
o – unburnt mixture
p – prechamber
x – burnt mixture

SUPERSCRIPT

o – initial value

INTRODUCTION

The concept of Pulsed Jet Combustion (PJC), proposed by Oppenheim [1,2] for implementation in the design of internal combustion engines, refines the open chamber – direct injection – stratified charge concept. The concept is based on an assumption that the combustion process starts in a prechamber and is followed by efflux of hot combustion products through an orifice into the cylinder head space. Due to shear stresses encountered at the exit from the orifice the high-speed jet of the combustion products forms a turbulent plume. The plume consists of many vortex nodules, distinguished by their recirculation pattern. The vortices, due to high temperature, provide a multiple ignition sites. They behave as whirpools and continuously entrain fresh, unburned mixture from the surrounding. The stream of fresh gas when mixed with the hot combustibles allows the combustion process to be sustained in the vortices. The process of mixing of the fresh mixture with gas in the vortices proceeds very quickly due to high turbulence of gas in the vortices and due to specific vortex structure [1]. The vortices act then, in effect, as well-stirred reactor systems. Therefore, the combustion process begins to proceed in many sites instead of propagating in the mode of a turbulent diffusion flame.

In the PJC concept the process may thus be divided in two steps:

- the combustion in the prechamber providing a high-speed turbulent jet of combustion products rich in active radicals,
- formation of vortices followed by reignition and combustion inside them.

Preliminary experimental studies indicate that the PJC concept is particularly suited for the execution of the combustion process in engines burning lean mixtures [1,3]. It is capable to initiate and execute the exothermic process of combustion at values of the equivalence ratio far below LML (Low Misfire Limit). Moreover, a little higher maximum pressures attained in shorter time were observed in the combustion chamber during realization of the process. A preliminary approach to 3-D modelling of pulsed jet injection was presented in [4].

The paper describes an idealized, zero-dimensional thermochemical model for the two-step combustion in the PJC system. At first the simplifying assumptions are discussed followed by the derivation of governing equations. Then, an example of combustion of methane-air is given which allows to study some features of the model as well as to estimate influence of selected parameters on the combustion process.

1. MATHEMATICAL MODEL OF PJC COMBUSTION

1.1. Assumptions

It is assumed that the combustion system consists of the main constant-volume chamber of volume V_o and the prechamber of the volume V_p. Before ignition, the former one is filled with the homogeneous fuel-air mixture with specified mass fractions x_{ok} of constituents, while the latter one is filled with homogeneous mixture of different composition with molar fractions y_{pk}. Initial temperature and pressure in the system are $T_p^o = T_x^o$ and p^o.

After ignition of the mixture in the prechamber, a turbulent plume is formed in the main chamber by the jet of combustion products. The turbulent plume is composed of a number NC of vortices which in general may have a certain mass distribution and thus different sizes. The selected j -th vortex of mass m_j is assumed to be spherical with diameter d_j, to have uniform temperature T_{xj} and uniform composition given by molar fraction y_{xkj}. The vortices engulf the cold fuel-air mixture with the mass rate dm_{xj}/dt and heat it up by mixing with the high-temperature combustion products. The combustion process in the vortices is thus reinstated and speeded up and generates heat to warm up new portions of the cold mixture. During the process the vortices grow in size both by entraining the cold mixture and by thermal expansion caused by chemical reaction proceeding inside them. The remaining fresh mixture in the main chamber is compressed during the process of combustion that goes on in the vortices. The combustion process comes to an end when either the entire fuel-air mixture is burned or when combustion is supressed in the vortices.

Additional assumptions are adopted to supplement the previous ones:

- in prechamber gas is burned adiabatically under constant volume conditions,
- combustion products in the prechamber have a thermodynamical equilibrium composition,
- expansion of combustion products from the prechamber into the main chamber is isentropic;
- vortices, once appeared, do not disappear or multiply,
- only fresh mixture is entrained by each vortex,
- mixing and reacting of fresh mixture with combustion products in any vortex proceed simultaneously,
- chemical reaction inside vortices is a one-step Arrhenius type,
- any interaction between vortices is absent;
- the cold mixture is compressed isentropically when pressure is varying in the main chamber,
- no chemical reaction occurs in the cold mixture;
- fuel-air mixture and combustion products obey the ideal gas laws,
- specific heat of each species is only temperature dependent,
- pressure is uniform throughout the system.

1.2. GOVERNING EQUATIONS

1.2.1. INJECTION OF THE HOT GAS FROM THE PRECHAMBER INTO THE MAIN CHAMBER

The fuel-air mixture of known composition characterized by air excess ratio λ_p and of known m_p is burned in the prechamber under constant volume, constant internal energy conditions. The final equilibrium composition y^o_{pk}, temperature T^o_p, pressure p_p and mean molar mass M_p are calculated by using the

STANJAN code [5]. The combustion products are then injected into the main chamber in the form of a plume and expand isentropically to the volume V_x^o according to the formula

$$V_x^o = V_p\left[\left(p_p/p_o\right)^{1/\kappa} - 1\right]$$

where κ is the ratio of specific heats at constant pressure c_p and volume c_v, respectively. The initial density ρ_x^o, mass m_x^o, temperature T_x^o and number of moles N_x^o of the injected gas in the main chamber can be obtained from the formulae

$$\begin{aligned}\rho_x^o &= m_p/\left(V_p + V_x^o\right)\\ m_x^o &= V_x^o\,\rho_x^o\\ N_x^o &= m_x^o/M_p\\ T_x^o &= p_o M_p/\left(\rho_x^o B\right)\end{aligned}$$

The plume of hot gas of mass m_x^o is broken into a number of NC vortices. The j-th vortex has initial mass m_{xj}^o, diameter d_j^o, volume V_{xj}^o, temperature $T_{xj}^o = T_x^o$, composition described by molar fraction $y_{xkj}^o = y_{pk}^o$ and contains N_{xj}^o number of moles.

1.2.2. RATE OF CHANGE OF MASS OF *j*-th VORTEX

Each vortex, due to exothermic reaction, expands pushing out the boundary of the turbulent jet plume in which it resides. The unburnt mixture of the surrounding is then forced to penetrate into the vortex. The rate of change of mass of j-th vortex, caused by the entrainment of the fresh mixture, can be expressed as

$$\frac{dm_{xj}}{dt} = A_{xj}u_j\rho_o \tag{1}$$

where: A_{xj} – external surface of the spherical vortex, $A_{xj} = \pi d_j^2$,
ρ_o – density of the fresh mixture, $\rho_o = pM_o/BT_o$,
u_j – the mean velocity of flow of the fresh mixture into the vortex (velocity of entrainment).

The mean velocity of entrainment can vary during the process of combustion in the main chamber. It was assumed in the form

$$u_j = \chi_o u_j^o \tag{2}$$

where u_j^o is the constant upper limit to the mean velocity of entraiment and the coefficient χ_o is introduced to account for the change of the mean velocity due to the change of vortex rotation and a process of engulfing of burned gas from neighbouring vortices.

1.2.3. RATE OF CHANGE OF VOLUME AND TEMPERATURE OF *j*-th VORTEX AND PRESSURE IN THE CHAMBER

In order to derive expressions for pressure in the chamber, the energy equation for *j*-th vortex (in formulation using enthalpy) was used

$$\frac{dH_{xj}}{dt} = \frac{dQ_{xj}}{dt} + V_{xj}\frac{dp}{dt} + h_o\frac{dm_{xj}}{dt} \tag{3}$$

The enthalpy of *j*-th vortex H_{ij} can be expressed as

$$H_{xj} = \sum_{k=1}^{NS} N_{xj} y_{xkj} M_k h_k\left(T_{xj}\right) \tag{4}$$

and the specific enthalpy of the fresh mixture being entrained by the vortex as

$$h_o = \sum_{k=1}^{NS} x_{ok} h_k\left(T_o\right)$$

where NS is the number of different species involved in the process.

The specific enthalpy of *k*-th species is temperature dependent and was calculated from formula

$$h_k(T) = h_k^{298} + \int_{298}^{T} c_p(T)\,dT$$

where h_k^{298} is the standard enthalpy of formation and c_{pk} is the specific heat of *k*-th species that was obtained from formulae of the type

$$c_{pk} = a_{1k} + a_{2k}T + a_{3k}/T^2 + a_{4k}T^2 + a_{5k}T^3$$

where constants a_{ik} for each species were taken from [6].

Formula (4) was then introduced into the energy equation, Eq.(3), and the differential form of the ideal gas law for *j*-th vortex

$$\frac{dT_{xj}}{dt} = \left(V_{xj}\frac{dp}{dt} + p\frac{dV_{xj}}{dt}\right) / \left(BN_{xj}\right) - T_{xj}\frac{dN_{xj}}{dt} / N_{xj} \tag{5}$$

utilized to eliminate dT_{xj}/dt and to obtain expression for the rate of change of volume of *j*-th vortex

$$\frac{dV_{xj}}{dt} = \left[\frac{dQ_{xj}}{dt} + h_o\left(T_o\right)\frac{dm_{xj}}{dt} - \sum_{k=1}^{NS} M_k\left(N_{xj} h_k\left(T_{xj}\right)\frac{dy_{xkj}}{dt} + \right.\right.$$

$$+ \left(h_k\left(T_{xj}\right) - c_{pk}\left(T_{xj}\right)T_{xj}\right)y_{xkj}\frac{dN_{xj}}{dt} + \tag{6}$$

$$\left.\left. + y_{xkj}c_{pk}\left(t_{xj}\right)/B - 1\right)V_{xj}\frac{dp}{dt}\right] \Big/ C_j$$

where

$$C_j = p \sum_{k=1}^{NS} M_k y_{xkj} c_{pk}(T_{xj}) / B \tag{7}$$

Heat loss from each vortex is assumed to occur both by radiation and convection. Thermal radiation loss is mainly due to high content of carbon dioxide and water vapour in the products of combustion. Convection loss is a result of partial contact of a vortex with the wall of the chamber. Heat loss is thus calculated from the following expression

$$-\frac{dQ_{xj}}{dt} = A_{xj}\, \sigma \left(\varepsilon_j T_{xj}^4 - a_j T_w^4\right) + \chi_j A_w\, \alpha_j \left(T_{xj} - T_w\right) \tag{8}$$

where: σ – black body constant,

T_w – wall temperature of the combustion chamber,

A_w – wall surface,

α_j – heat transfer coefficient,

ε_j – emissivity of the vortex, $\varepsilon_j = 1 - \exp\left[-\sigma_e(T_{xj}) L_j\right]$,

a_j – absorptivity of the vortex, $a_j = 1 - \exp\left[-\sigma_e(T_w) L_j\right]$,

σ_e – radiation extinction coefficient,

L_j – mean beam length for thermal radiation, $L_j = 3.6 V_{xj} / A_{xj}$.

Coefficient χ_j accounts for the partial contact of the vortex with the wall of the combustion chamber.

1.2.4. RATE OF CHANGE OF TEMPERATURE AND VOLUME OF THE UNBURNT GAS IN THE COMBUSTION CHAMBER

The rate of change of volume of the unburnt mixture dV_o can be derived independently by considering differential form of the ideal gas equation for the unburnt mixture and eliminating the rate of change of temperature T_o by the expression

$$\frac{dT_o}{dt} = (n-1)\, T_o \frac{dp}{dt} / (np) \tag{9}$$

derived from the differentiation of equation for polytropic process. This leads to the following formula

$$\frac{dV_o}{dt} = -\frac{R_o T_o}{p} \sum_{j=1}^{NC} \frac{dm_{xj}}{dt} - \frac{m_o R_o T_o}{np^2} \frac{dp}{dt} \tag{10}$$

The polytropic exponent n is calculated from the formula

$$n = \frac{\kappa}{\left[1 + \dfrac{\alpha_o \chi_o A_w (T_o - T_w) p}{m_o c_{vo} T_o \, dp/dt}\right]} \tag{11}$$

and was derived by matching heat loss rate for the polytropic process

$$\frac{dQ_o}{dt} = m_o c_{vo} \frac{(n-\kappa)}{(n-1)} \frac{dT_o}{dt} \tag{12}$$

with the heat flowing to the wall of the chamber

$$\frac{dQ_o}{dt} = \alpha_o \chi_o A_w (T_o - T_w) \tag{13}$$

In the above expressions κ stands for the isotropic exponent, c_{vo} is the specific heat of the unburnt gas at constant volume and $\chi_o = 1 - \sum_{j=1}^{NC} \chi_j$.

1.2.5. RATE OF CHANGE OF PRESSURE IN THE CHAMBER

As total volume of the chamber is constant, then the following relation is valid

$$\frac{dV_o}{dt} + \sum_{j=1}^{NC} \frac{dV_{xj}}{dt} = 0 \tag{14}$$

Substitution of Eqs (6) and (10) into the above relation allowed to obtain the final equation for the rate of change of pressure in the system

$$\frac{dp}{dt} = \left[\sum_{j=1}^{NC} \left[\left(R_o T_o / p - \sum_{k=1}^{NS} x_{ok} h_k(T_o)\right) \frac{dm_{xj}}{dt} + \sum_{k=1}^{NS} M_k \left(N_{xj} h_k(T_{xj}) \frac{dy_{xkj}}{dt} + \right.\right.\right.$$
$$\left.\left.\left. + \left(h_k(T_{xj}) - c_{pk}(T_{xj}) T_{xj}\right) y_{xkj} \frac{dN_{xj}}{dt}\right) - \frac{dQ_{xj}}{dt}\right] \Big/ C_j\right] \Big/ D \tag{15}$$

where

$$D = (n-1) m_o R_o T_o / (\kappa p^2) - \sum_{j=1}^{NC} \left(\sum_{k=1}^{NS} M_k y_{xkj} c_{pk}(T_{xj}) / B - 1\right) V_{xj} / C_j \tag{16}$$

and m_o, R_o are the mass and the gas constants of the unburnt mixture, respectively.

Inspection of Eq. (15) leads to the conclusion that the rate of change of pressure is dependent not only on the change in mass of the vortex but also upon the variation of its composition and the total number of moles contained in each vortex. These two latter factors depend on the number of species involved in the process and on chemical reactions between the species and thus need further specification.

2. EXAMPLE: COMBUSTION OF A STOICHIOMETRIC METHANE--AIR MIXTURE

As an example, combustion of a stoichiometric ($\lambda_o = 1$) air-hydrocarbon mixture was considered. It was assumed that five species: fuel C_nH_m – (1), oxygen – (2), nitrogen – (3), carbon dioxide – (4) and water vapour – (5) are present in the system. Only one bulk kinetic reaction for combustion of hydrocarbon to CO_2 and H_2O was assumed

$$\frac{dy_{x1j}}{dt} = -k_A(p, T_{xj})\sqrt{N_{xj}/V_{xj}}\; y_{x1j}\,y_{x2j}^{1/2} \tag{17}$$

The rate constant for this equation was assumed in the form proposed by Edelman [7,8]

$$k_A = 6\cdot 10^4 \gamma\, T_{xj}(0.9869\cdot 10^{-5}p)^{0.2}\exp\left(-12200/T_{xj}\right) \tag{18}$$

with $\gamma = 80$ chosen for the stirred flow.

Equations for the rate of change of molar fractions of these species were obtained from balances of mass of fuel and elements such as O_2, N_2, C and H_2 in each vortex. These balances took into account both feeding from neighbourhood of the vortex and disappearance of fuel due to chemical reaction. In the final form these equations can be presented as

$$\frac{dy_{xkj}}{dt} = a_{kj}\frac{dm_{xj}}{dt}\Big/N_{xj} + b_{kj}\,k_A\,y_{x1j}\,y_{x2j}^{0.5} \tag{19}$$

$$\frac{dN_{xj}}{dt} = A_1\frac{dm_{xj}}{dt} + A_2\sqrt{N_{xj}/V_{xj}}\;k_A\,N_{xj}\,y_{x1j}\,y_{x2j}^{0.5} \tag{20}$$

where

$$a_{kj} = x_{ok}/M_k - y_{xkj}A_1,$$

$$b_{kj} = \left(e_k - y_{xkj}A_2\right)\sqrt{N_{xj}/V_{xj}},$$

$$e_1 = -1, \quad e_2 = -(m/4+n), \quad e_3 = 0,$$

$$e_4 = n \quad e_5 = m/2,$$

$$A_1 = \sum_{k=1}^{5} x_{ok}/M_k,$$

$$A_2 = (m/4 - 1)$$

where $m = 4$ and $n = 1$ for methane and M_k is the molar mass of each species.

The set of differential nonlinear equations (1), (5), (6), (9), (15), (19) and (20) was solved using the standard Runge-Kutta method. In the example the following values of additional parameters were assumed:

- in the prechamber:

$$V_p = 2 \cdot 10^{-6}\ \mathrm{m}^3, \quad T_p^o = 65°\mathrm{C}, \quad p^o = 0.1\ \mathrm{MPa}$$

excess air factor $\lambda_p = 0.8$

- in the main chamber:

$$V_o = 251.3 \cdot 10^{-6}\ \mathrm{m}^3, \quad T_o^o = 65°\mathrm{C}, \quad p^o = 0.1\ \mathrm{MPa}$$

excess air factor $\lambda_o = 1$

The extinction coefficient, appearing in expressions for vortex emissivity and absorptivity was calculated from the formula [9]

$$\sigma_e(T) = (p/10^5)(y_{x4} + y_{x5})(1 - 3.7 \cdot 10^{-4} T)\left[\frac{0.78 + 1.6 y_{x5}}{(p/10^5)(y_{x4} + y_{x5}) L} - 1\right]$$

The heat transfer coefficient, both for vortices and the unburnt gas, was obtained from Van Tyen expression [7]

$$\alpha = 5.41 \cdot 10^{-3}(3.22 + 0.864 u^o)\left[(p/10^6)^2 T\right]^{1/3}$$

in which u^o for the unburnt mixture was taken to be the mean of u_j^o. The formula

$$\chi_j = m_{xj}/m_t$$

where $m_t = m_o + \sum_{j=1}^{NC} m_{xj}$, was assumed in most calculations. Their results are presented in Fig.1-6 for absence of heat loss to the wall of the combustion chamber and in Fig.7 for presence and absence of heat loss.

CONCLUSIONS

A zero-dimensional thermochemical model of PJC system has been proposed that gives a realistic estimate of time for pressure rise (several ms). The model yields the rate of pressure rise depending on many factors related to the type of fuel, parameters of fuel combustion in the prechamber, parameters describing the turbulent jet plume injected into the main chamber and parameters of fuel combustion in the main chamber. Other quantities such as the rate of temperature rise in the vortices and the unburnt mixture, as well as a variation in the composition of each vortex can be easily calculated.

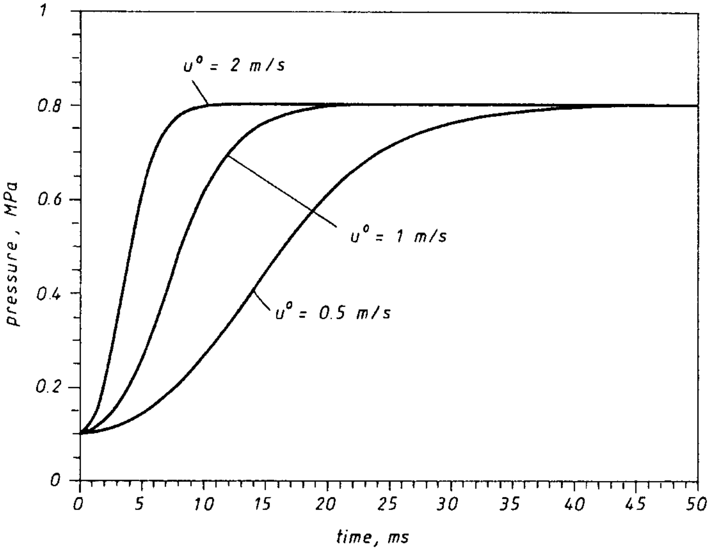

Fig. 1. Pressure versus time for low values of entrainment velocity $u = \chi_o u^o$ (number of vortices $NC = 1$, $\chi_o = (m_t - m_x)/m_t$)

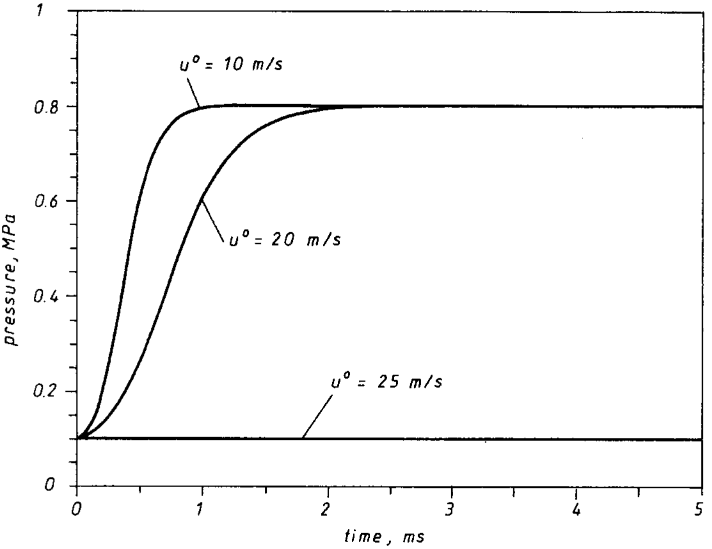

Fig. 2. Pressure versus time for high values of entrainment velocity $u = \chi_o u^o$ (number of vortices $NC = 1$, $\chi_o = (m_t - m_x)/m_t$)

The form of pressure versus time function greatly depends on the entrainment velocity (velocity of flow of the fresh air-fuel mixture into each vortex) – Figs.1,2. If the velocity is doubled, then the time of the process is approximately decreased twofold. It has been found that there exists a critical velocity u^*_{oj} (approximately equal to u^*_{oj} = 22.5 m/s in the presented example) such that for $u^*_{oj} > u_{oj}$ combustion is not sustained in a vortex (due to prevailing cooling effect).

Variation of the entrainment velocity $u(t) = \chi(t)u_0$ with time is also of great importance and can change pressure versus time behaviour of the system significantly. In Fig.3 three forms of function $\chi(t)$ have been used. The value of $\chi = 1$ gives the most rapid increase of pressure in the system while the expression $\chi = \left(m^o_{xj} d^o_j\right) / \left(m_{xj} d_j\right)$, derived from equation of conservation of angular momentum of the vortex, gives the slowest increase.

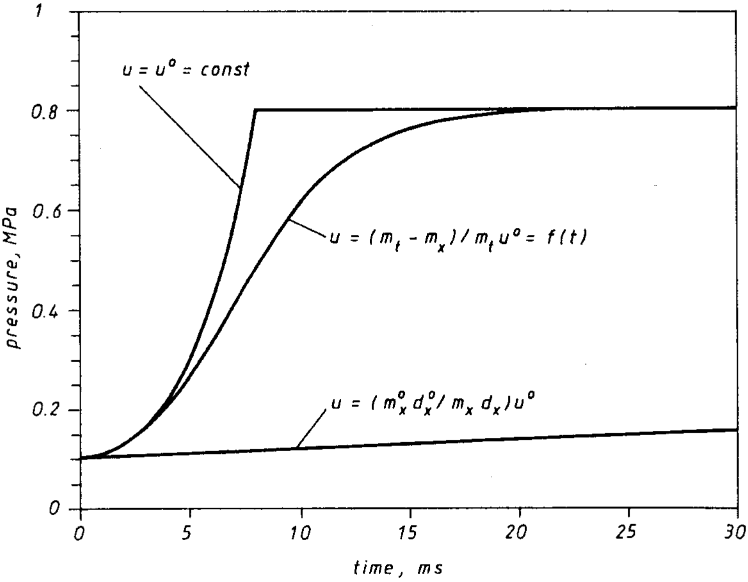

Fig. 3. Pressure versus time for different time variation of entrainment velocity u (number of vortices $NC = 1$)

Increase of number of vortices in the plume formed in the main chamber after injection of the hot, turbulent jet increases the rate of pressure rise in the system – Fig.4. This seems to be due to the increased external surface of the total number of vortices and its influence is similar to the increase in the velocity of entrainment.

Mass m_{xj} and velocity u_j distributions for vortices may play an important role in pressure versus time response of the system – Figs.5,6. Mass distribution of vortices seems to have greater influence on the pressure rise in the system than velocity distribution.

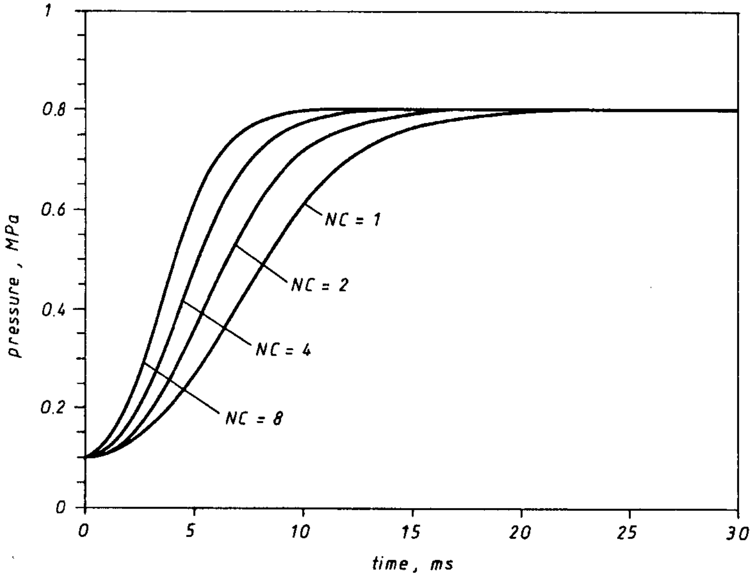

Fig. 4. Pressure versus time for different number of vortices NC ($u = \chi_o u^o$, $\chi_o = (m_t - m_x)/m_t$, u^o = 1 m/s)

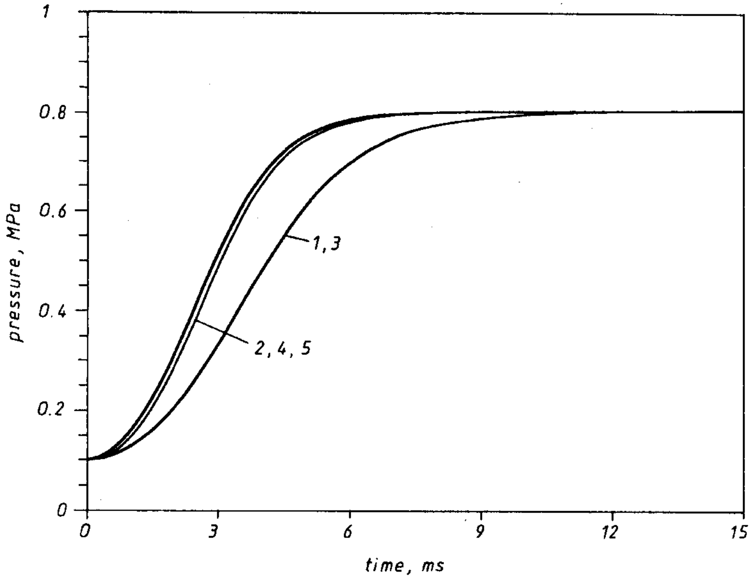

Fig. 5. Pressure versus time for different mass distributions m_{xj} of vortices and distributions of entrainment velocity $u = \chi_o u^o$, $\chi_o = (m_t - m_x)/m_t$; number of vortices $NC = 8$: 1 – uniform distribution of m_{xj} and u^o, u^o = 1 m/s; 2 – uniform distribution of m_{xj}, linear increase of u^o from 0.5 to 2 m/s; 3 – linear decrease of m_{xj} and uniform distribution of u^o, u^o = 1 m/s; 4 – linear decrease of m_{xj} and linear increase of u^o from 0.5 to 2 m/s; 5 – linear decrease of m_{xj} and linear decrease of u^o from 2 to 0.5 m/s

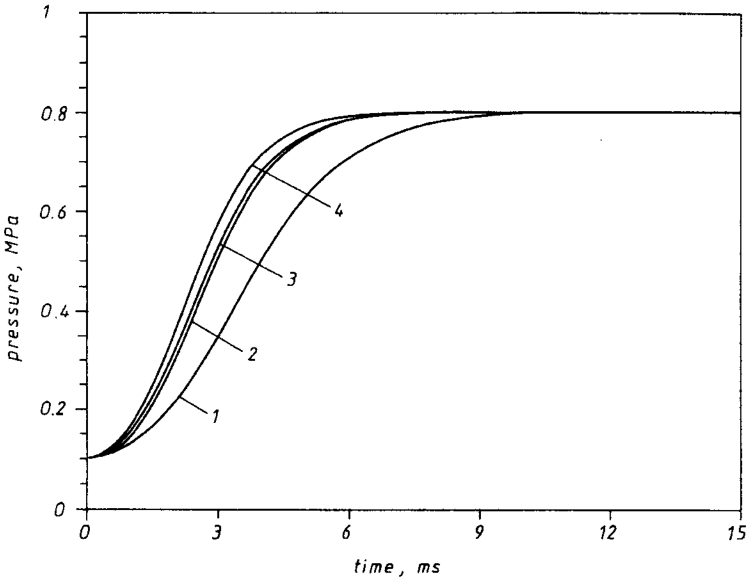

Fig. 6. Pressure versus time for a certain mass distribution m_{xj} of vortices (number of vortices of definite mass varying in a triangular way with m_{xj}) and different distributions of entrainment velocity $u = \chi_o u^o$, $\chi_o = (m_t - m_x)/m_t$; number of vortices $NC = 9$: 1 – uniform distribution of u^o, $u^o = 1$ m/s; 2 – linear increase of u^o from 0.5 to 2 m/s with vortex mass; 3 – linear decrease of u^o from 2 to 0.5 with vortex mass; 4 – velocity u^o varying in a triangular way with vortex mass

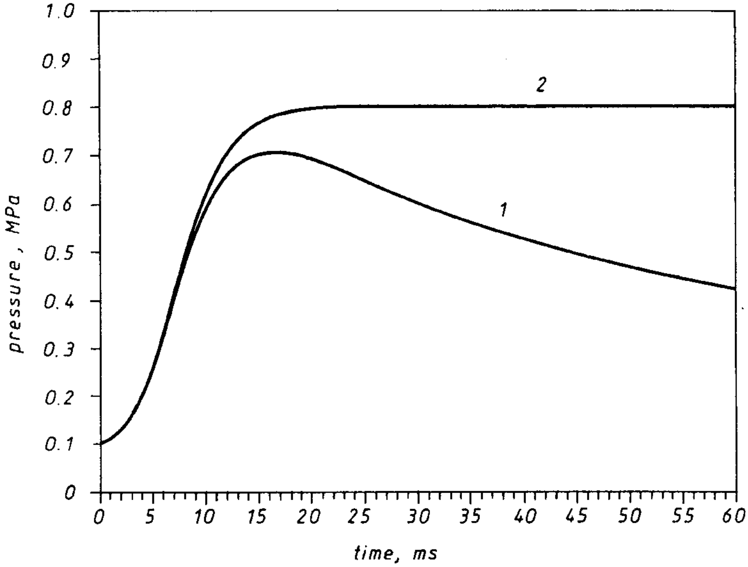

Fig. 7. Pressure versus time for presence (1) and absence (2) of heat loss ($NC = 8$, $u = \chi_o u^o$, $\chi_o = (m_t - m_x)/m_t$, $u^o = 0.5$ m/s

Heat loss to the wall of the combustion chamber significantly modifies pressure versus time diagram of the system, Fig.7, and makes it to resemble the experimental results [1]. Heat loss causes a certain decrease in the maximum pressure in the chamber, but its greatest influence on pressure fall occurs when the rate of heat release, due to combustion process in vortices, is decreasing.

The paper may be treated as a preliminary study of the model. Further improvement of the model that would account for vortex interaction with each other are required for better representing realistic conditions.

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ZEROWYMIAROWY MODEL SPALANIA TYPU PJC W KOMORZE O STAŁEJ OBJĘTOŚCI

Streszczenie

Zaproponowano zerowymiarowy, termochemiczny model dwustopniowego spalania typu PJC (Pulsed Jet Combustion) w komorze o stałej objętości. W początkowym stadium bogata mieszanka paliwowo-powietrzna jest spalana we wstępnej komorze spalania. Produkty spalania mają skład równowagowy o parametrach termochemicznych wyznaczonych za pomocą programu STANJAN. W drugim stadium procesu silnie turbulentna struga produktów spalania zostaje izentropowo wtryśnięta do głównej komory spalania, gdzie, na skutek aerodynamicznego oddziaływania ze świeżym ładunkiem, ulega rozbiciu na wiele (różniących się wielkością) wirów, które stanowią miejsca zapłonu i spalania kolejnych porcji świeżej mieszanki. Założono jednorodność koncentracji reagentów i temperatury w każdym z wirów. Przyjęto, że ciśnienie jest stałe w całej objętości komory spalania. Spalanie jest podtrzymywane wewnątrz wirów na skutek mieszania wysokotemperaturowych produktów spalania z zimną mieszanką paliwowo-powietrzną. Wymiary wirów rosną na skutek dopływu z zewnątrz świeżych porcji mieszanki oraz na skutek termicznego rozszerzania się spowodowanego chemiczną reakcją pierwszego stopnia zachodzącą wewnątrz wirów. Proces spalania w komorze zostaje zakończony, gdy cała mieszanka zostanie spalona lub gdy dopływ mieszanki do wirów jest na tyle intensywny, że spalanie nie może być podtrzymane. Jako przykład rozważono proces spalania stechiometrycznej mieszanki powietrze-metan. Na wykresach przedstawiono zmianę ciśnienia w komorze spalania w funkcji czasu dla wielu czynników, takich jak: liczba wirów, prędkość zasysania świeżej mieszanki przez wiry, straty ciepła do otoczenia, rozkłady masowe wirów oraz prędkości zasysania świeżej mieszanki.

НУЛЬРАЗМЕРНАЯ МОДЕЛЬ СЖИГАНИЯ ТИПА PJC В КАМЕРЕ ИМЕЮЩЕЙ ПОСТИЯННЫЙ ОБЪЕМ

Краткое содержание

В работе предложена нульразмерная, термохимическая модель двухступенчатого сжигания типа PJC (Pulsed Jet Combustion) в камере имеющей постоянный объем. В начальной стадии богатая топливно-воздушная сместь сжигается в аванкамере сжигания. Продукты сгорания имеют равновесный состав с термохимическими параметрами, опереденными с помощю програма STANJAN. Во второй стадии процесса сильно турбулизированная струя продуктов сгорания изентропичецко впрыскивается в главную камеру сжигания, где – в результате аэродинамического воздействия со свежим зарядом – подвергается распаду на много (отличающихся величиной) вихрей, которые являются местом воспламенения и температуры в каждом из вихрей. Принято, что давление постоянно во всем объеме камеры сжигания. Сгорание поддерживается внутри вихрей в результате смешивания высокотемпературных продуктов сгорания с холодной топливовоздушной смесью. Размеры вихрей увеличиваются в результате притока извне свежих доз смеси, а также в результате термического расширения, вызванного химической реакцией первой степени, происходящей внутри вихрей. Процесс сгопяния в камере заканчивается, когда вся смесь уже сожжена или когда приток смеси в вихри настолько интенсивный, что сгорание не может поддерживаться. Для примера представлен процесс сграния стехиометрической смеси воздух-метан. На диаграммах представлено изменение давления в камере сжигания в функции времени для многих факторов, таких как: число вихпей, скорость засасывания свежей смеси вихрами, потеря тепла в окружающую спеду, массовая разноска вихрей и скорость засасывания свежей смеси.