THE INFLUENCE OF EQUIVALENCE RATIO ON BURNING VELOCITY OF AVIATION FUEL RT

T.L. Chelyshev, Researcher, All-Russian Research Institute for Fire Protection, Moscow region, Balashikha-3, 143900 Russia

V.V. Molkov, Head of the Department, Ph. D., All-Russian Research Institute for Fire Protection, Moscow region, Balashikha-3, 143900 Russia

Burning velocity of fuel RT - air mixture have been determined using the constant volume bomb method for equivalence ratios 0.69-1.62. The results can be presented as burning velocity dependence on equivalence ratio by formula $S_{ui} = 0.720 \cdot \phi^3 - 3.222 \cdot \phi^2 + 4.525 \cdot \phi - 1.547$. Measurements of the maximum explosion pressure have also been made for equivalence ratios 0.69-2.32. The dependence of maximum explosion pressure on mixture composition can be described by formula $\pi_e = -2.993 \cdot \phi^2 + 8.154 \cdot \phi + 2.188$

Keywords: burning velocity, equivalence ratio, inverse problem method, explosion pressure

INTRODUCTION

It is well known that burning velocity depends on mixture composition, pressure and temperature. The method used in our study is a dimentionlessly simple and accurate for determination of burning velocity from the pressure record in closed spherical bomb. Many researchers have presented correlations showing the pressure and temperature dependence for burning velocity. However the most investigations have been made for mixtures with one combustible component. Babkin et al. have explored methane-air [1, 2] and propane-air [3] mixtures in a wide range of pressures and temperatures. Iijima and Takeno [4] have obtained a combined empirical relations for methane-air mixture for a wide range of pressure and temperature. Bose et al. [5] have proposed empirical relations for methane-air mixture as function of temperature, pressure and equivalence ratio. The number of investigations of burning velocity for the multicomponent fuels is considerably less. Metghalchi and Keck [6] have explored blended fuel indolene (RMFD303). The measurements were carried out in a heated spherical bomb with emphasis on the high temperature and pressure range. They have obtained relations for burning velocity as function of temperature inside the range 300-700 K, and pressure inside the range 0.4-50 atm, and equivalence ratios 0.8-1.4. The present study is connected to equivalence ratio dependence of burning velocity for wide concentration range of fuel RT (analogous to western aviation fuels Jet A, Jp-5, Avcat) in air. The properties and composition of the fuel RT are given in Table. 1.

Table 1

Properties and blend composition of the aviation fuel RT

Stoichiometric concentration, % vol.	1.33
Average molecular formula	$C_{10.5}H_{20.5}$
Blend component, weight percents:	
Paraffin	57.8
Aromatic	16.5
Naphthenic	25.7

METHOD

The burning velocity was determined by processing of the measured pressure-time record in the spherical constant volume bomb. The pressure-time diagram for determination of the burning velocity have been used earlier by Babkin et. al.[1, 2, 7], Garforth [8], Metghalchi and Keck [6, 9], Iijima and Takeno [4]. They have used pressure-time diagram to calculate the flame radius and laminar burning velocity. The comparison of experimentally determined flame radius with calculated one was used for the assessment of the method validity. The calculated pressure-time curve in the vessel is obtained by an integration of the differential equation of the mathematical model [7]

$$\frac{d\pi}{dt}=\frac{3\cdot\pi^{1+1/\gamma_u}\cdot(1-n_u\cdot\pi^{-1/\gamma_u})^{2/3}\cdot G}{a\cdot(\pi^{1/\gamma_u}-(\gamma_u-\gamma_b)/\gamma_u\cdot n_u)}\cdot S_u, \tag{1}$$

in which

$$n_u=1-\frac{\pi^{1/\gamma_u}+\frac{\gamma_b-1}{\gamma_u-1}\cdot(1-\pi^{1/\gamma_u-1})-1}{G}, \tag{2}$$

$$G=\gamma_b\cdot[1+\frac{\pi_e-1}{\gamma_b}-\frac{\gamma_u\cdot(\gamma_b-1)}{\gamma_b\cdot(\gamma_u-1)}]\cdot\pi^{1/\gamma_u-1}+\frac{\gamma_b-\gamma_u}{\gamma_u-1}. \tag{3}$$

Taking as an approximation the adiabatic mixture compression, the burning velocity changes with growth of dimentionless pressure is described by an expression

$$S_u=S_{ui}\cdot\pi^{\varepsilon} \tag{4}$$

The γ_u, γ_b parameters appearing in the design formula are determined by a thermodynamic analysis. The π_e is obtained from experiments. The form of theoretical curve $\pi=f(t)$ is determined by two unknown parameters - initial burning velocity S_{ui} and thermokinetic index ε. The calculated dependence of pressure variation inside vessel is optimized according to the experimental one by means of the minimization of function $\Phi(\overline{\Theta})$

$$\Phi(\overline{\Theta})=\sum_{k=1}^{N}[\pi_k^e(t_k)-\pi^c(t_k,\overline{\Theta})]^2 \tag{5}$$

Theoretical dimensionless pressure $\pi^c(t_k,\overline{\Theta})$ at time moment t_k was obtained by numerical integration of the equation (1).

To determine two mentioned above unknown parameters S_{ui} and ε the inverse problem method [10, 11] was used with standard non-linear evaluation procedure [12]. This method is applicable when influence of convection on spherical shape of the flame can be neglected. The criterion was used according to which we can neglect influence of convection if $Fr \geq 0.11$, where Freud number

$$Fr=\frac{S_s^2}{g\cdot 2\cdot r_b}. \tag{6}$$

The flame radius can be determined by known formula

$$r_b=(1-n_u\cdot\pi^{-1/\gamma_u})^{1/3}\cdot a, \tag{7}$$

and calculated visual flame velocity is obtained by a differentiation of equation (7)

$$S_s = \frac{dr_b}{dt}. \tag{8}$$

The mathematical model used in the work assumes flame sphericity, neglects of flame front thickness and heat losses, and do not take into account effects of pressure waves and spark energy. The neglect of the flame front thickness leads to some reduce of estimated laminar burning velocity, however the error of estimation composes about 5 % [13]. In the studies [6, 7] have been shown that effects associated with heat losses to vessel wall, electrodes, radiation losses and gradient of temperature in burning products is insignificant. It was shown also that the spark energy up to approximately 100 mJ doesn't influence on the flame propagation nature [6].

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The constant volume bomb is designed for experiments with maximum pressure up to 600 atm and maximum initial temperature 150 °C.

The bomb represents spherical chamber with an inside diameter of 270 mm. Two stainless steel electrodes are hermetically introduced into the bomb with spark gap at the center. The gap size can be varied up to 3.0 mm. The bomb has two opposite situated windows with inside diameter of 100 mm. The bomb is located inside the special thermostat. On external surface of the bomb there were mounted three thermocouples to supervise the uniformity of heating. The ignition system stores the energy in the capacitors and releases it between electrodes. It was shown also that the energy in the spark can be varied from 100 mJ to 80 J.

The partial pressure of components during mixture preparation were measured by tenzoelectric transducer of absolute pressure range 0...6 kPa with the accuracy 0.5 %. Dynamic pressure was measured by tenzoelectric pressure transducer with accuracy 0.5 %. The heating of the bomb was executed by power heaters and fan, located inside the thermostat.

The dynamic pressure was recorded to a 8-bit oscillograph with accuracy 2.4 %. The maximum number of digitized points per channel is 4096 and the time increment between two points is 0.2 msec.

The evaporator was filled by fuel up to 80 % volume. The fuel was poured at room temperature and heated then to 60-65 °C. Evaporation temperature was selected to provide fuel pressure for any experiment. To make a measurement without vapor condensation inside the bomb the last one was heated to the temperature 92-94 °C and then was filled with desired fuel-air mixture. Initial temperature of the bomb was selected to prevent a condensation of fuel vapor inside the bomb. Gaseous fuel and air were introduced into the bomb through a heated pipe with a prescribed proportion. A length of pipe was 1.5 m. A waiting time of 5 minutes was then allowed to permit the fuel and air to mix completely and become quiescent. Then the mixture was ignited and pressure-time diagram was recorded by the oscillograph.

RESULTS AND DISCUSSION

In this study investigations has been made with aviation fuel RT - air mixture having initial pressure 1 atm, temperature 92-94 ^{o}C and equivalence ratios from 0.69 to 2.32. In present investigations maximum explosion pressure was determined for range of equivalence ratios 0.69-2.32. Large quantity of experimental data give complete picture of maximum pressure change for exploring range of equivalence ratios (Fig. 1). The peak of maximum pressure curve is correspond to equivalence ratio 1.28. The dependence of maximum pressure on mixture composition can be described by an equation of form

$$\pi_e = -2.993 \cdot \phi^2 + 8.154 \cdot \phi + 2.188. \qquad (9)$$

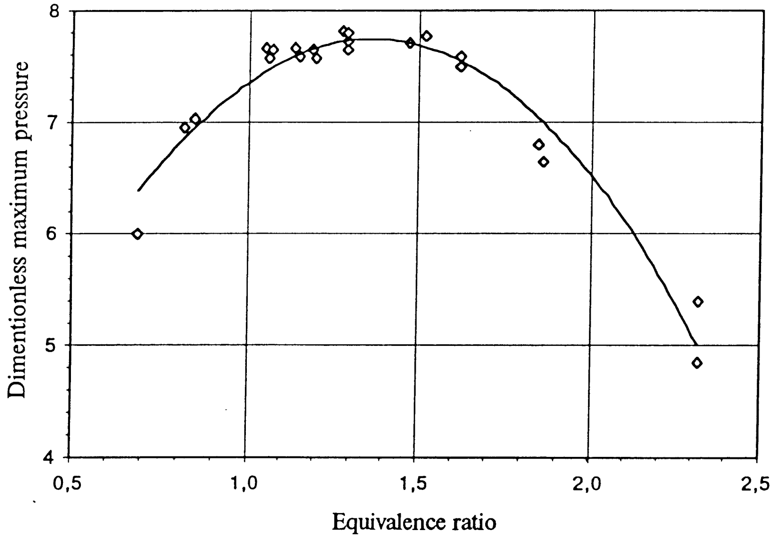

Fig. 1. Dependence of dimentionless maximum explosion pressure on equivalence ratio

Burning velocities were computed with use of experimental pressures corresponding to dimentionless pressure π from 1.01 to 6.0 to exclude influence of ignition source and heat losses on explosion dynamics (pressure-time diagram) for a near stoichiometric mixtures (ϕ=0.9-1.4) and for others from 1.01 to 4.5. Burning velocity was computed for the range of equivalence ratios from 0.69 to 1.62. Fig. 2 shows a burning velocity as a function of an equivalence ratio. The maximum burning velocity accord to equivalence ratio 1.13. The error in the measurement of maximum pressure is about 5 % and in the calculation of burning velocity using equation (1) is about 10 %. According to results of other researches [6] the position of the maximum burning velocity appears to shift right from stoichiometric to fuel-rich mixture. The dependence of burning velocity on mixture composition can be represented by an equation of the form

$$S_{ui} = 0.720 \cdot \phi^3 - 3.222 \cdot \phi^2 + 4.525 \cdot \phi - 1.547. \tag{10}$$

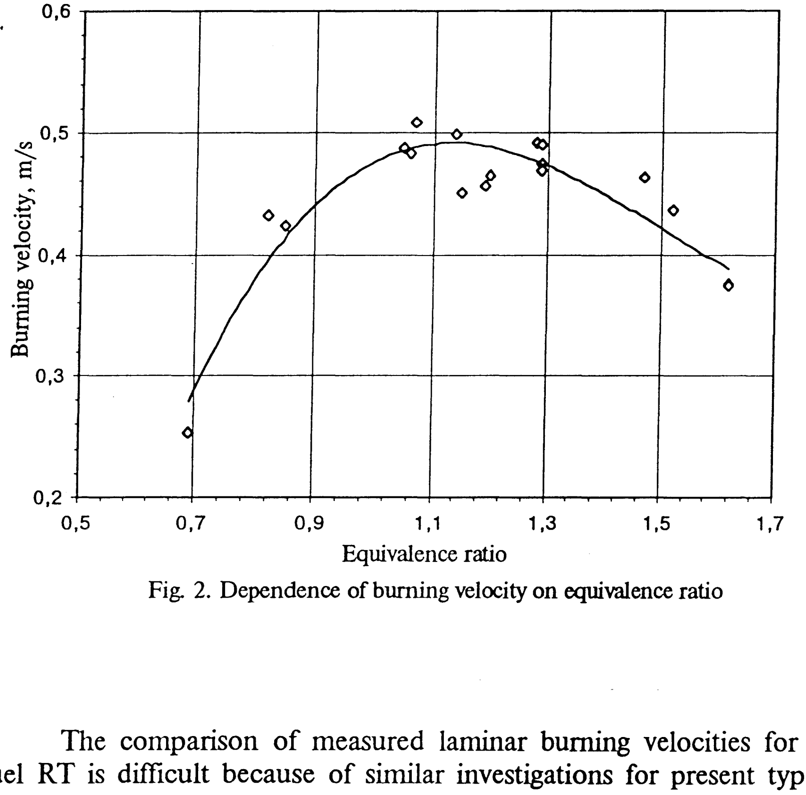

Fig. 2. Dependence of burning velocity on equivalence ratio

The comparison of measured laminar burning velocities for blends such as fuel RT is difficult because of similar investigations for present type of blends are absent. It's possible to mark the study of Metghalchi and Keck [5], where data for similar blend such as RMFD303 have been given. In this study burning velocity for RMFD303-air mixture have been determined for equivalence ratios 0.85-1.55. The maximum burning velocity accord in this work to equivalence ratio 1.15. The dependence of burning velocity from equivalence ratio of fuel RMDF303 in air mixture is similar for fuel RT - air mixture that has the form of parabola with negative second derivative.

CONCLUSIONS

Measurement of the maximum explosion pressure in a wide range of equivalence ratios 0.69-2.32 for aviation fuel RT - air mixture at initial temperature 92-94 ^{o}C and pressure 1 atm have been made. The results of this study are given by an equation of the form (9).

Determination of the burning velocity for equivalence ratios 0.69-1.62 have been made. The results of this study are given by an equation of the form (9).

NOMENCLATURE

a - radius of the experimental bomb, m;
Fr - Freud number;
g - gravitational acceleration, m/s^2 (9.81 m/s^2);
m_u, m_i - current and initial value of burning mixture mass, kg;
N - number of experiment points according to which the optimization is performed;
$n_u = m_u/m_i$ - dimentionless mass of burning mixture in vessel;
p - current calculated pressure in vessel, atm;
$p(t_k)$ - experimental pressure in time moment t_k, atm;
p_e - maximum explosion pressure in a vessel, atm;
p_i - initial pressure in a vessel, atm;
r_b - flame radius, m;
S_s - visible flame velocity, m/s;
S_u - current burning velocity, m/s;
S_{ui} - initial burning velocity, m/s;
t - time, s;
t_k - time of experimental point k, s;
$\Phi(\overline{\Theta})$ - minimization function;

$\phi = \dfrac{\text{current fuel} - \text{air ratio}}{\text{stoichiometric fuel} - \text{air ratio}}$ - equivalence ratio;
ε - thermokinetic index;
γ_u, γ_b - adiabatic exponents of unburned mixture and burned products accordingly;
$\pi = p/p_i$ - dimentionless pressure;
$\pi_e = p_e / p_i$ - dimentionless maximum explosion pressure in a vessel;
$\pi^c(t_k, \overline{\Theta})$ - theoretical dimentionless pressure in time moment t_k;
$\pi^e_k(t_k) = p(t_k) / p_i$ - experimental dimentionless pressure in time moment t_k;

$\Theta = \begin{Vmatrix} S_{ui} \\ \varepsilon \end{Vmatrix}$ - column vector of unknown parameters.

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