

THE EFFECT OF INITIAL TEMPERATURE ON BURNING VELOCITY OF METHANE, PROPANE, LPG AND ISO BUTANE – AIR MIXTURES

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ABSTRACT

In present work, the burning velocity of a fuel – air mixtures varies with equivalence ratio, temperature and number of carbon atoms. Laminar flame speed have been measured experimentally inside a tube using the optical technique. The experimental work was carried out in a pre-pressure period in order to use density ratio method for calculation of laminar burning velocity. Mixture strength, unburned mixture temperature and number of carbon atoms dependence of burning velocity is represented by empirical functions over the ranges of $\phi = 0.6 - 1.5$, $T_u = 298 - 348$ °K and $n_c = 1 - 4$ atoms, all at pressure of (1 atm). In overlapping ranges, the results agree well with those previously published.

NOMENCLATURE

- S_u : Laminar burning velocity (cm/s)
 S_f : Laminar flame speed (cm/s)
 ρ_u : Unburned gases density (kg/m^3)
 ρ_b : Burned gases density (kg/m^3)
 T_u : Unburned gas temperature (°K)
 T_b : Burned gas temperature (°K)
 T_f : Flame temperature (*measured*) (°K)
N: Mole ratio = moles of unburned gases in
Equilibrium per moles of burned gases
 δ : Flame thickness (mm)
I: Flame thickness factor
 $\bar{\lambda}$: Mean thermal conductivity of flame region
(W/m °C)
 \bar{C}_p : Mean specific heat of flame region (J/mol °K)

1. INTRODUCTION

Several investigators have measured burning velocity of various hydrocarbon fuels in order to shed some light on the mechanism of flame Propagation [1], and to test and validate thermokinetic models and reaction mechanisms of hydrocarbon combustion.

Burning velocity is a physicochemical constant for a given combustible mixture. Unfortunately, although its theoretical definition is simple, the same cannot be said of its practical measurement. Linnett (1952)* has carried out a critical review of the methods of measuring burning velocity and concluded that burner methods are difficult to use accurately, but that some of the nonstationary flame methods might be satisfactory. Laffitte (1961)* and Combourieu (1961)* have discussed experimental details and theoretical relationships for the burner, soap bubble, and explosion vessel and tube methods. They concluded by favoring the vertical tube method and present a compilation of experimental values of burning velocity for various gases [2].

There is no agreement on a standardized method of measurement and conflicting values of burning velocity continue to be published.

The present work uses a more advanced technique. The optical technique has been used in measuring the laminar burning velocity for (Methane, Propane, LPG and ISO-Butane) – Air mixtures, for a wide range of equivalence ratio.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The present work used a copper tube of 1920 mm length, 100 mm inner diameter and 6 mm thickness. The high thermal conductivity of copper was used to heat the mixture to a certain temperature, as shown in Fig. (1).

Preparing operation plays an important role in amelioration of the combustion phenomenon. This operation was made depending on the partial pressures of the constituents according to Gibbs–Dalton law. The preparing operation was made in a closed vessel which was designed for this purpose to increase the total pressure of hydrocarbon–Air mixtures, consequently increasing the partial pressure of gaseous fuel. Heating tape was located around the tube for heating the mixture to a certain initial temperature. This temperature was measured by a thermocouple, which was located

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in the center of the tube.

After preparing mixture and measuring the initial temperature, the flame kernel was produced by the ignition unit. The flame speed (S_f) of the gases mixture under consideration was measured experimentally using the photocell technique. Four photocells were fixed at certain points along the tube. The distance between them was 25cm. The distance between the first photocell and spark plug was 20 cm, this configuration was made to ensure that all measurements occur at fully developed flame front. Two dual channel digital storage oscilloscopes were used to record the signals from the photocells in order to measure the flame speed and flame temperature.

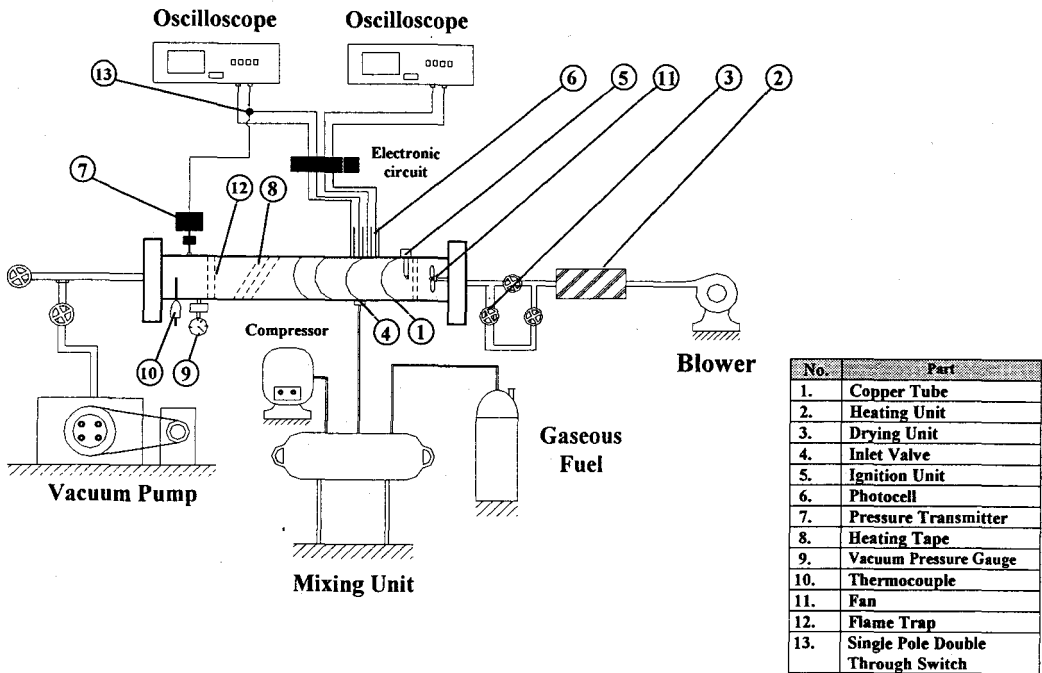


Fig. 1. Schematic diagram of the experimental apparatus.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure (2) shows the measured mean flame speed of different mixtures. In order to calculate the burning velocity from measured flame speed, the density ratio method introduced by Andrews & Bradley [2] has been used, as the following equations: -

$$Su = \frac{\rho_b}{\rho_u} \cdot S_f \quad (1)$$

$$\frac{\rho_b}{\rho_u} = \frac{T_u}{T_b} \cdot N \cdot I \quad (2)$$

The magnitudes of (I) and (N) have been calculated depending on the relations of the research of Andrews and Bradley [3].

Figures (3) and (4) show the variation of (N) and (I) with the mixture strength (ϕ). (T_f) was measured by the photocells where the generated voltage recorded from the photocell depends on the subjected light intensity produced from the flame front depending on the temperature of the zone (flame front). The flame temperature has been measured using the following equations:

$$E = \varepsilon \cdot \sigma \cdot T^4 \quad (3)$$

$$T = \left(\frac{E}{\varepsilon \cdot \sigma} \right)^{1/4} \quad (4)$$

and for black body [4]:

$$T = \left(\frac{E}{\sigma} \right)^{1/4} \quad (5)$$

Figure (5) shows the mean flame front temperature which has been measured for different gases.

The burning velocity has been calculated from:

$$Su = \frac{T_u}{T_b} \cdot N \cdot I \cdot S_f \quad (6)$$

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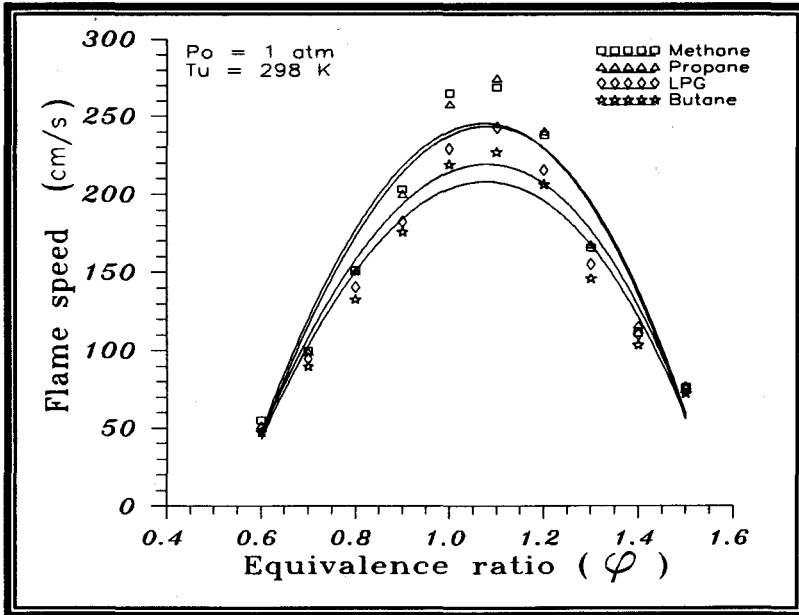


Fig. 2. Mean flame speed as a function of equivalence ratio for different mixtures.

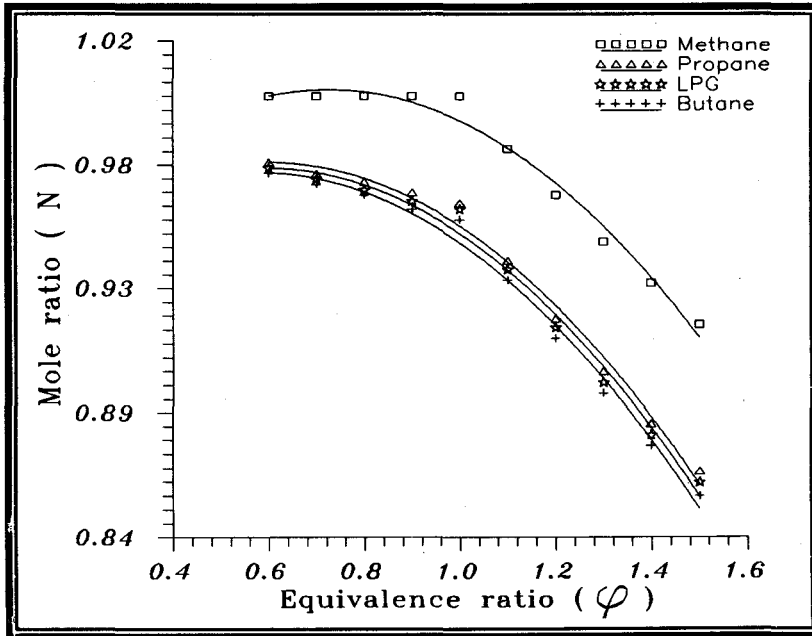


Fig. 3. Variation of mole ratio with equivalence ratio.

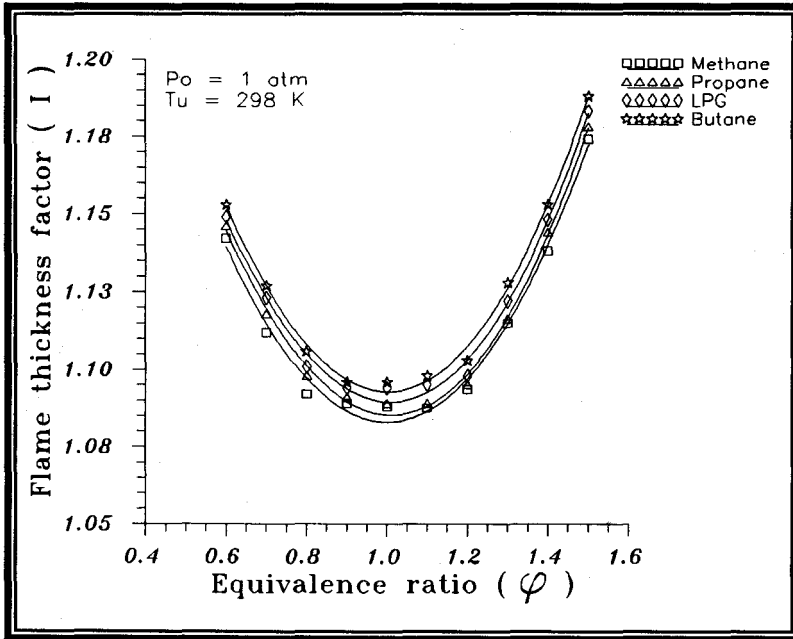


Fig. 4. Variation of flame thickness factor with equivalence ratio.

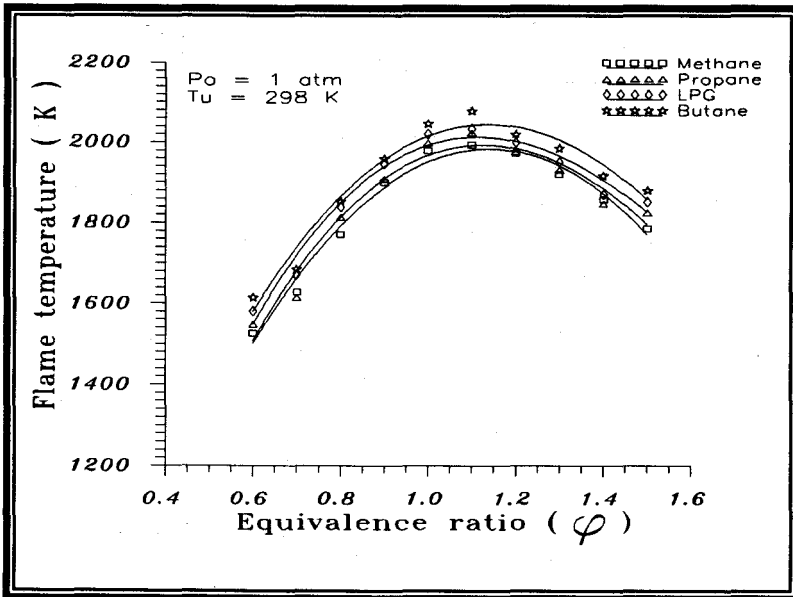


Fig. 5. Mean flame temperature as a function of equivalence ratio.

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And the flame thickness was calculated according to [5] as the following equation:

$$\delta = \frac{2\bar{\lambda}}{Su \cdot \bar{C}_p \cdot \rho_u} \quad (7)$$

And as shown in figure(6).

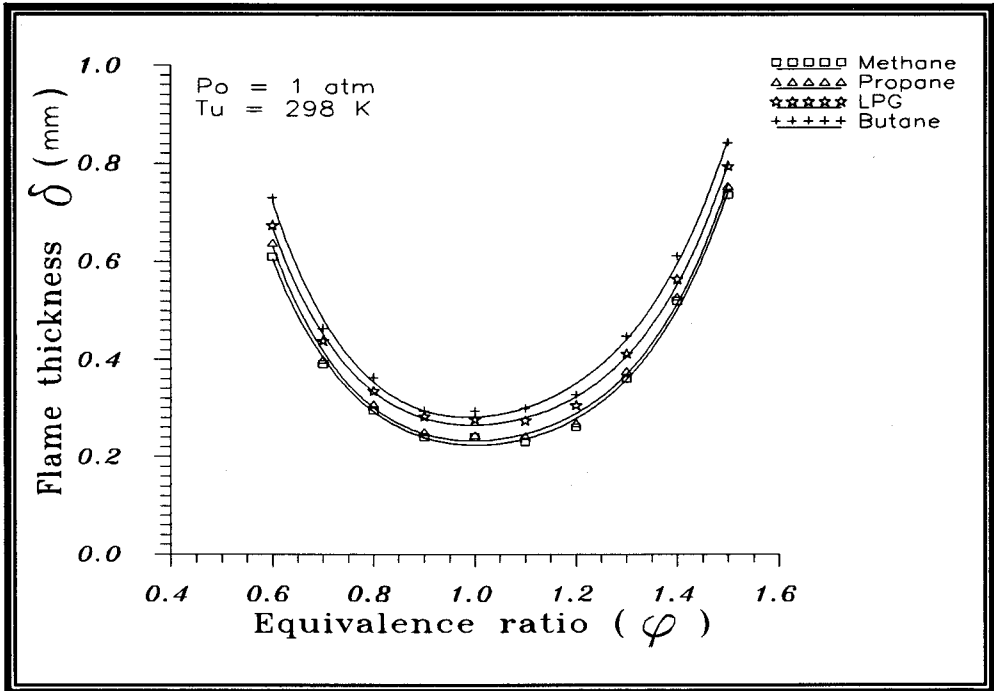


Fig. 6. Flame thickness as a function of equivalence ratio.

Burning Velocities at Atmospheric Conditions

The first set of experiments was conducted with Methane, Propane, LPG and ISO-Butane in air at a pressure (1 atm) and temperature (298 °K).

The variation of burning velocities of the different gases with the mixture strength (ϕ) is shown in figure (7). The data points represent the mean values of more than ten repetitive experiments.

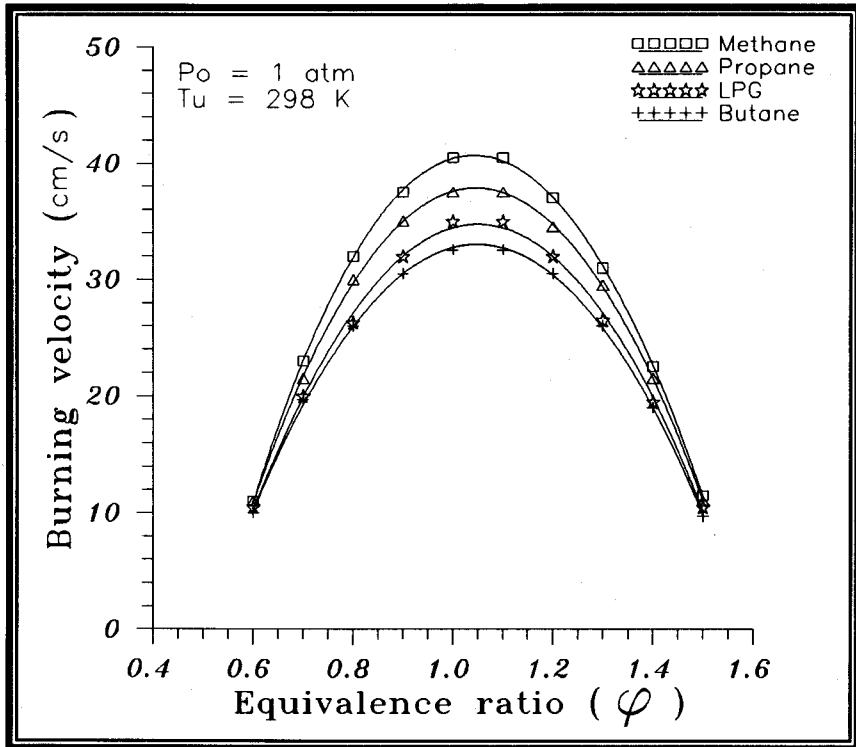


Fig. 7. Burning velocity as a function of equivalence ratio.

All the four fuels show maximum burning velocities approximately at the same equivalence ratio.

The results of experiments of Methane, Propane, LPG and ISO-Butane with air mixtures compared with the available experimental and computational data from various published sources are shown in Figures (8), (9), (10) and (11) respectively. The low measured burning velocities are most probably due to the wall quenching effect of the combustion tube wall. Wall quenching effect and correction methods are discussed in details in references [2,3]. The results exhibited a good agreement with the published data.

The hydrocarbon fuels exhibit a maximum burning velocity on the rich side near to ($\phi \cong 1.1$) under atmospheric conditions.

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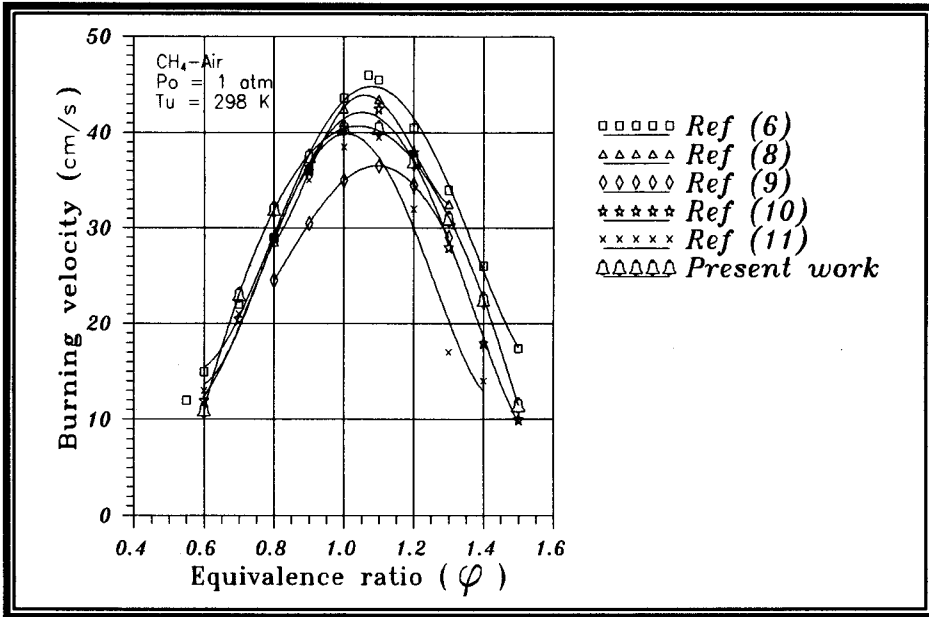


Fig. 8. Comparison of present results with the published results of methane-air mixture.

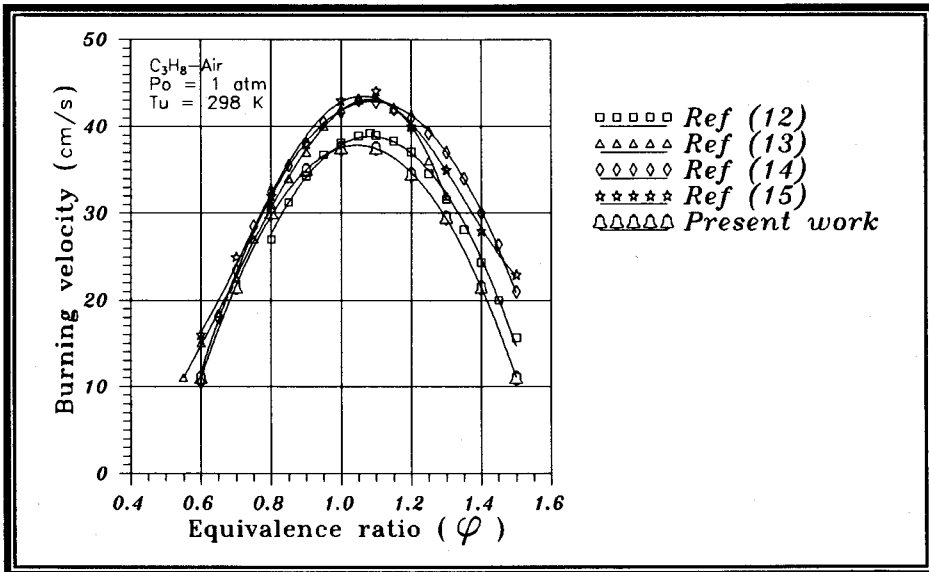


Fig. 9. Comparison of present results with the published results of propane-air mixture.

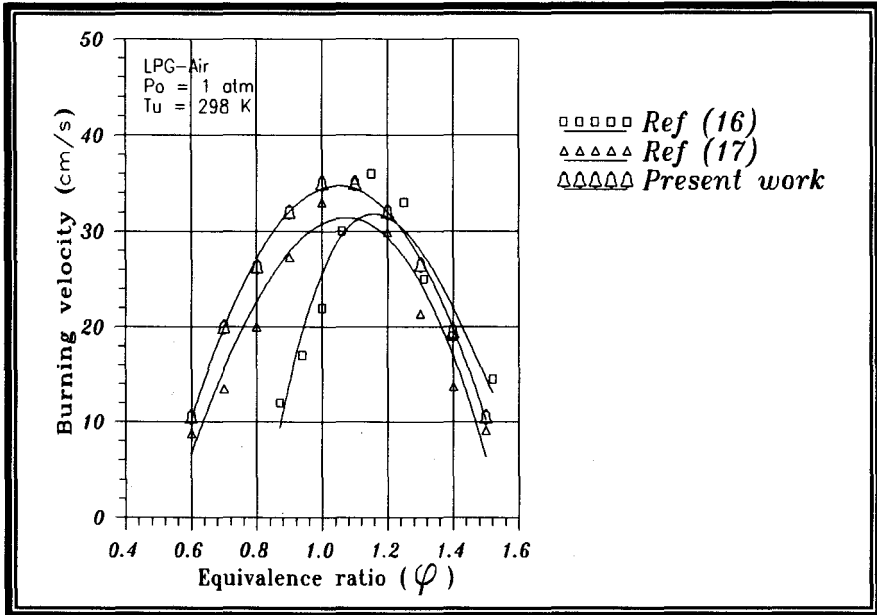


Fig. 10. Comparison of present results with the published results of LPG-air mixture.

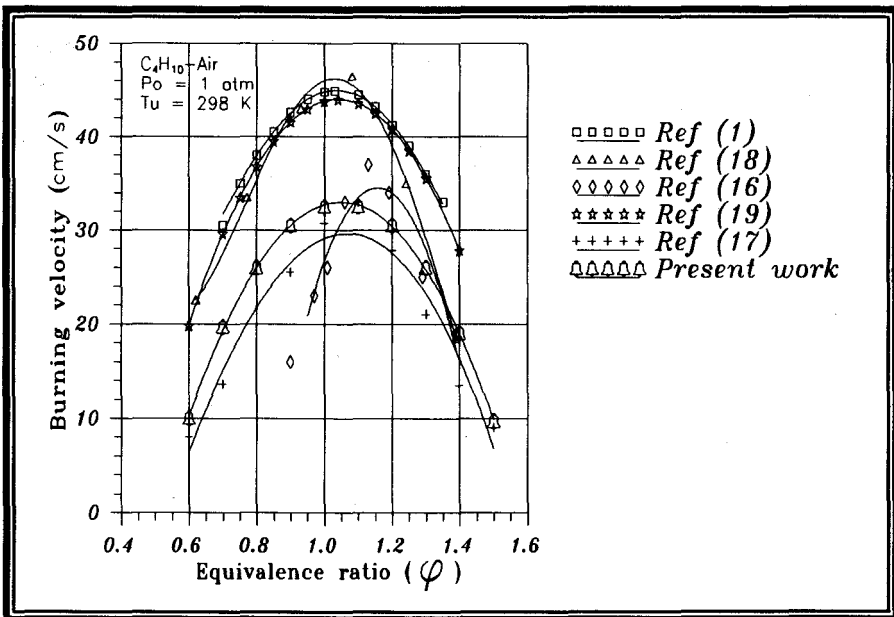


Fig. 11. Comparison of present results with the published results of butane-air mixture.

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Initial Temperature Dependence of Burning Velocity

Temperature dependence of the burning velocities of Methane, Propane, LPG and ISO-Butane is illustrated in Figure (12-a,b) at (1 atm) pressure and different equivalence ratios. These figures show temperature dependence in the following form:

$$Su = Su_o (Tu/To)^\beta \quad (8)$$

The exponent (β) varying with equivalence ratio (ϕ) for each gas fuel according to the molecular structure. Andrews and Bradley [2], for methane-air flames reported a quadratic dependence on temperature.

Here, the exponent (β) has been introduced by fitting the data using least squares method. The results are as follows:

$$\beta = A + B \phi + C \phi^2 \quad (9)$$

Where A, B and C are constants varying with the number of carbon atoms.

$$\begin{aligned} A &= -5.8098 + 4.4433 (n_c) - 0.65992 (n_c)^2 \\ B &= 16.0312 - 9.5990 (n_c) + 1.4328 (n_c)^2 \\ C &= -7.6854 + 4.8306 (n_c) - 0.7415 (n_c)^2 \end{aligned} \quad (10)$$

Number of carbon atoms dependence of Burning velocity

The effect of molecular structure on burning velocity is presented in Figure (13). Burning velocity in (cm/s) on the ordinate, and the abscissa indicates structural changes or number of carbon atoms in molecule. As indicated the burning velocity decreases with chain lengthening at different equivalence ratios. Gibbs and Calcote [1] showed the effect of molecular structure on burning velocity in their investigation. They concluded that chain lengthening and branching decrease the burning velocity, but structural alterations become less effective as the chain length is increased for hydrocarbon fuels.

A form of burning velocity variation with number of carbon atoms can be concluded as:

$$Su_o = \alpha \cdot (n_c)^\gamma \quad (11)$$

Where (Su_o) represents the burning velocity at laboratory conditions in the previous equation (eq.8) (α) and (γ) vary with mixture strength as follows:

$$\begin{aligned} \alpha &= -117.119 + 296.0025 \phi - 134.5163 \phi^2 - 4.0872 \phi^3 \\ \gamma &= 0.2962 - 0.8653 \phi + 0.4105 \phi^2 \end{aligned} \quad (12)$$

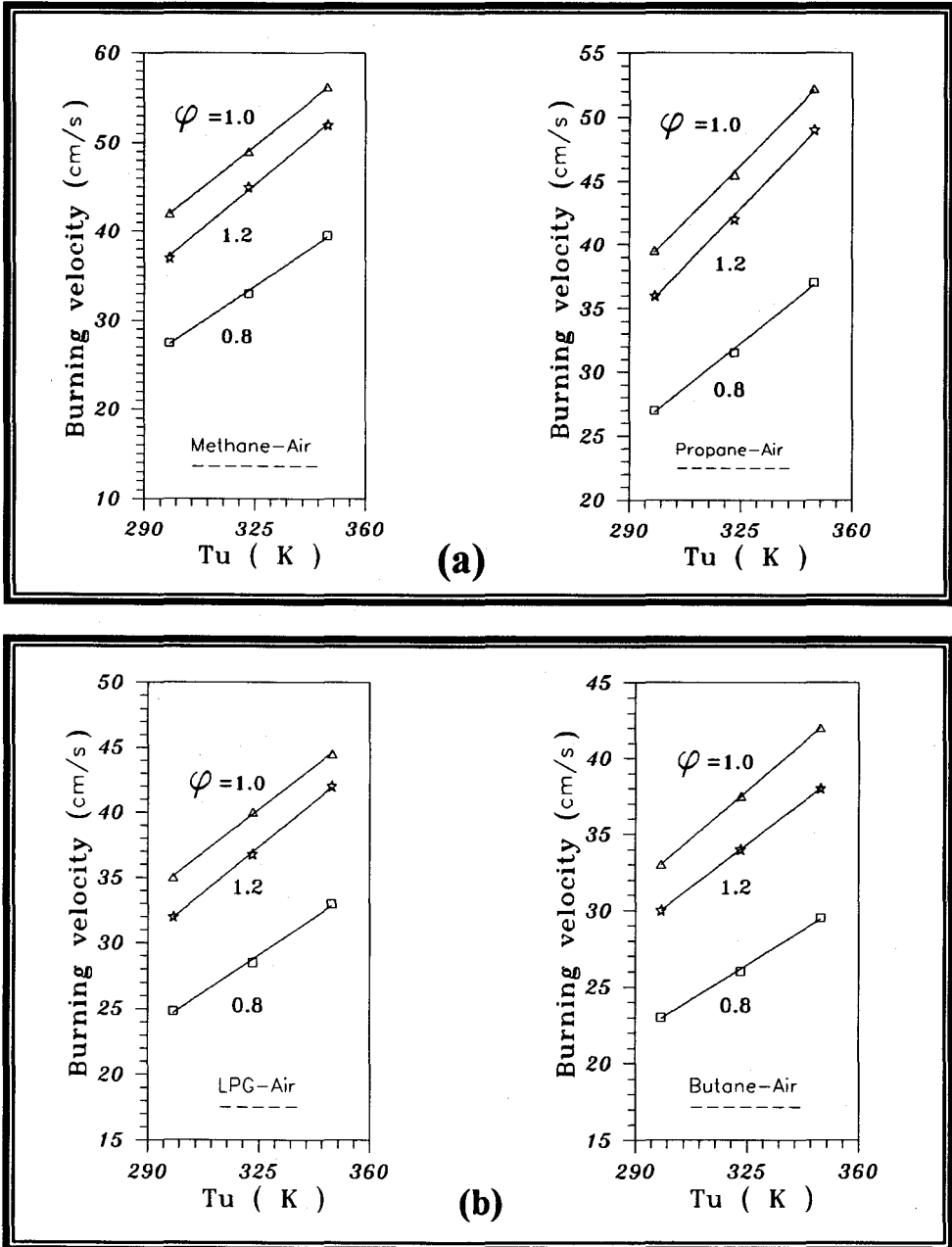


Fig. 12. Variation of burning velocity with mixture initial temperature.
 (a) Methane, propane-air mixture.
 (b) LPG, butane-air mixture.

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From Figure (13), a polynomial dependence on the number of carbon atoms can be deduced. So, we can represent the variation of burning velocity with the temperature and number of carbon atoms in three-dimensional for stoichiometric mixtures ($\phi = 1.0$) as indicated in Figure (14).

4. CONCLUSIONS

The variation of burning velocities of methane, propane, Iraqi LPG and ISO-Butane in air, as a function of mixture strength and unburned mixture temperature has been determined using tube method and advanced optical technique which is a modern technique in this field. The density ratio method that was introduced by Andrews and Bradley [2] has been used for this determination.

The temperature and number of carbon atoms dependence of burning velocity can be represented by the following empirical relation:

$$Su_{(\phi, Tu, n_c)} = Su_{o(\phi, Tu, n_c)} \cdot (Tu/To)^\beta$$

where:

$$Su_{o(\phi, Tu, n_c)} = \alpha \cdot (n_c)^\gamma$$

and;

$$\alpha = -117.119 + 296.0025 \phi - 134.5163 \phi^2 - 4.0872 \phi^3$$

$$\gamma = 0.2962 - 0.8653 \phi + 0.4105 \phi^2$$

and:

$$\beta = A + B \phi + C \phi^2$$

where:

$$A = -5.8098 + 4.4433 (n_c) - 0.65992 (n_c)^2$$

$$B = 16.0312 - 9.5990 (n_c) + 1.4328 (n_c)^2$$

$$C = -7.6854 + 4.8306 (n_c) - 0.7415 (n_c)^2$$

Which can be used with an error $\pm 5\%$, for the following conditions ($Tu = 298-348$ °K), ($\phi = 0.6-1.5$) and ($n_c = 1-4$) with $Po = 1$ atm and $°K = 298K$.

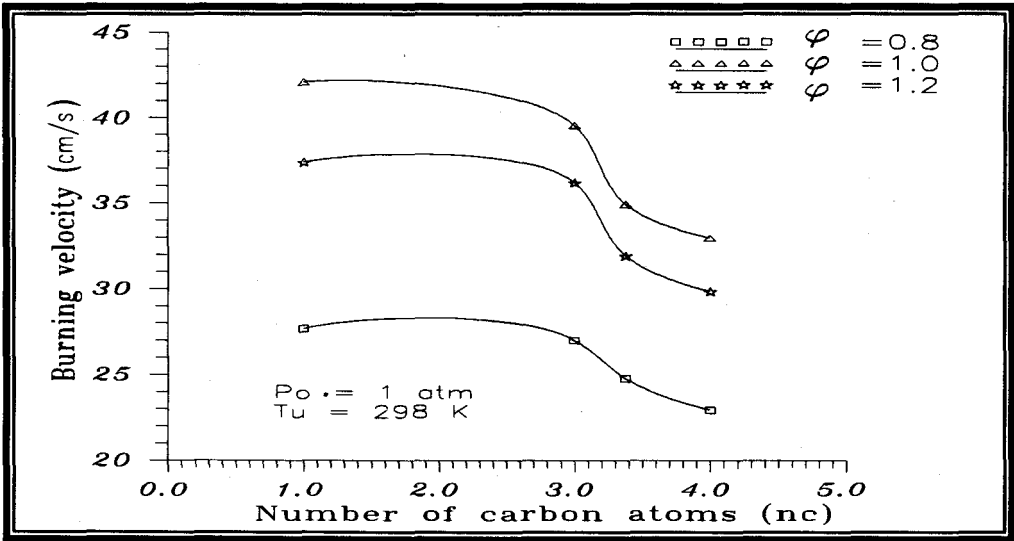


Fig. 13. Variation of burning velocity with number of carbon atoms @ ($T_u = 298 \text{ K}$) & ($P_o = 1 \text{ atm}$).

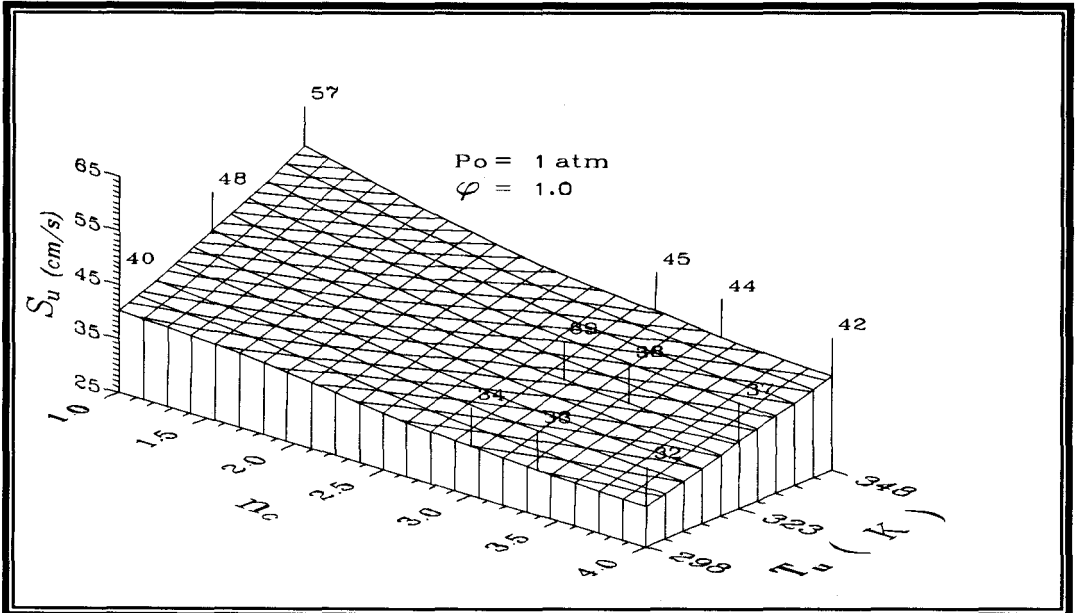


Fig. 14. Three-dimensional representation of burning velocity dependence on number of carbon atoms and initial temperature for stoichiometric mixture strength ($\phi = 1.0$).

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