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EFFECT OF INITIAL TEMPERATURE ON BURNING VELOCITY OF METHANOL AND ETHANOL - AIR MIXTURES

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ABSTRACT

The optical technique has been used to determine the effect of initial temperature on laminar flame speed of Methanol, Ethanol - Air premixed mixtures experimentally inside a tube. The flame front position had been located by a photocell. The laminar flame speed measured at a laboratory conditions for a wide range of equivalence ratios. All experimental work was carried out at constant pressure (Pre-Pressure period), in order to use density ratio method for the calculation of laminar burning velocity. The flame temperature has been calculated theoretically. Mixture strength and unburned mixture temperature dependence of burning velocity is represented by empirical function over the ranges ϕ = 0.7-1.4, Tu = 300 K-373 K at pressure of (1 atm). In overlapping ranges, the results agree well with those previously published.

Keywords: methanol, ethanol, laminar burning velocity, premixed flame.

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)
N	Mole ratio = moles of unburned gases in equilibrium per moles of burned gases
I	Flame thickness factor

1. INTRODUCTION

In recent years, computer simulation models of spark ignition engine cycles have been extensively utilized as tools to understand the effects of various engine variables on exhaust emissions and fuel economy. Some of these simulations use turbulent burning models, which require knowledge of laminar burning velocity of the fuel - air mixture as a function of pressure, temperature and mixture strength. Growing concern about alcohol fuel utilization has also necessitated burning velocity data for studies related to engines fueled with alcohol.

Although the combustion rates in engines cannot be fully explained by laminar burning velocities alone, the laminar burning velocity data are needed to approach the problem [1].

The aim of the present work is to measure the effect of unburned mixture temperature on the laminar burning velocities of methanol and ethanol burning in air, and their dependence on mixture strength using a tube with the optical technique.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The present investigation used a copper tube of (1920mm) length, (100mm) inner diameter and (6mm) thickness. Availing the high thermal conductivity of copper was used to heat the mixture to a certain temperature. Heating tapes were located around the tube for heating the mixture to a certain initial temperature. This temperature was measured by a thermocouple, which was located at the center of the tube. Figure-1 shows the details of the rig used in the research.

After preparing mixture and measuring the initial temperature, the flame kernel was produced by ignition unit. This kernel grown to became flame front, which moves through the unburned mixture at speed, which represents the flame speed (S_f).

The flame speed of the fuels under consideration was measured experimentally using the optical technique. Four photocells were fixed at a certain points along the tube. The distance between them was (25cm). The distance between the first photocell and spark ignition plug was (20cm). This configuration was made to ensure that all measurements occur at fully developed flame front.

Two photocells were attached to the first digital storage oscilloscope, and the other two photocells in parallel with the pressure transmitter were attached to the second oscilloscope. The electrical signal was generated when the flame front moved in front of the photocells. This signal sent to the electronic circuit, amplified, then sent to the oscilloscopes. Consequently the exact time difference between two photocell signals was measured at a certain distance (25cm), therefore; present work measures flame speed. The obvious cause for choosing along tube was to measure the flame speed at a pre-

pressure period for each concentration for different mixtures.

3. EXPERIMENT RESULTS AND DISCUSSIONS

Figures (2) and (3) show the measured mean flame speed of different equivalence ratio of methanol-air and ethanol-air mixtures.

In order to calculate the burning velocity from measured flame speed, the density ratio method introduced by Andrews and Bradley [2], has been used as the following equations:

$$S_u = \frac{\rho_b}{\rho_u} \cdot S_f \tag{1}$$

$$\frac{\rho_b}{\rho_u} = \frac{T_u}{T_b} \cdot N \cdot I \tag{2}$$

The magnitudes of (I) and (N) have been calculated depending on the relations of the research of Andrews and Bradley [3]. Figures (4), (5) and (6) shows the variation of (I) and (N) with the mixture strength (ϕ). Adiabatic flame temperature was calculated using the equation of Al-Ani [4].

The burning velocity has been calculated from:

$$S_u = \frac{T_u}{T_b} \cdot N \cdot I \cdot S_f \tag{3}$$

The variation of burning velocities of methanol-air and ethanol-air mixtures is shown in Figures 7(a) and 7(b). The data points represent the mean value of more than ten repetitive experiments. The maximum burning velocities for both fuels are approximately at equivalence ratio of (1.05).

4. BURNING VELOCITY AT ATMOSPHERIC CONDITIONS

The experiments of methanol and ethanol was conducted in air at P = 1 atm and initial temperature Tu = 333K-373K. The results compared with the available experimental data from published sources are shown in Figures (8) and (9), respectively. The high measured burning velocities are most probably due to the initial temperature difference [1].

5. INITIAL TEMPERATURE DEPENDENCE OF BURNING VELOCITY

Temperature dependence of the burning velocities of Methanol and Ethanol is illustrated in Figures 10(a), (b) at (1atm) pressure and different equivalence ratios. The figure shows temperature dependence in the following form.

$$S_u = S_{uo}(T_u / T_{uo})^{\alpha} \tag{4}$$

The exponent (α) varying with mixture strength (ϕ) for each fuel according to the molecular structure. Gulder [1] reported a power equation with constant temperature exponent.

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

$$\alpha = A + B.\phi + C.\phi^2 \tag{5}$$

Where A, B, and C are constants varying with number of carbon atoms (n_c):

$$\left.\begin{aligned} A &= 7.915 - 1.2576\ (n_c) \\ B &= -10.19 + 2.438\ (n_c) \\ C &= 3.8117 - 0.9183\ (n_c) \end{aligned}\right\} \tag{6}$$

6. NUMBER OF CARBON ATOMS DEPENDENCE OF BURNING VELOCITY

The effect of molecular structure on burning velocity is presented in Figure-11. 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 [6] 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 alcohol fuels.

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

$$S_{uo} = \psi.(n_c)^{\gamma} \tag{7}$$

Where (S_{uo}) represents the burning velocity at laboratory conditions in the previous equation (4), (ψ) and (γ) vary with mixture strength as follows:

$$\begin{aligned} \psi &= -164.21 + 401.75.\phi - 185.54.\phi^2 \\ \gamma &= -1.146 + 2.006.\phi - 0.905.\phi^2 \end{aligned} \tag{8}$$

7. CONCLUSIONS

The variation of burning velocities of methanol and Ethanol 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 [3] 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:

$$S_{u(\phi,Tu,n_c)} = S_{uo(\phi,Tu,n_c)} \cdot (T_u / T_{uo})^{\alpha}$$

Where

$$S_{uo(\phi,Tu,n_c)} = \psi \cdot (n_c)^{\gamma}$$

And

$$\psi = -164.21 + 401.75.\phi - 185.54.\phi^2$$

$$\gamma = -1.146 + 2.006.\phi - 0.905.\phi^2$$

And

$$\alpha = A + B.\phi + C.\phi^2$$

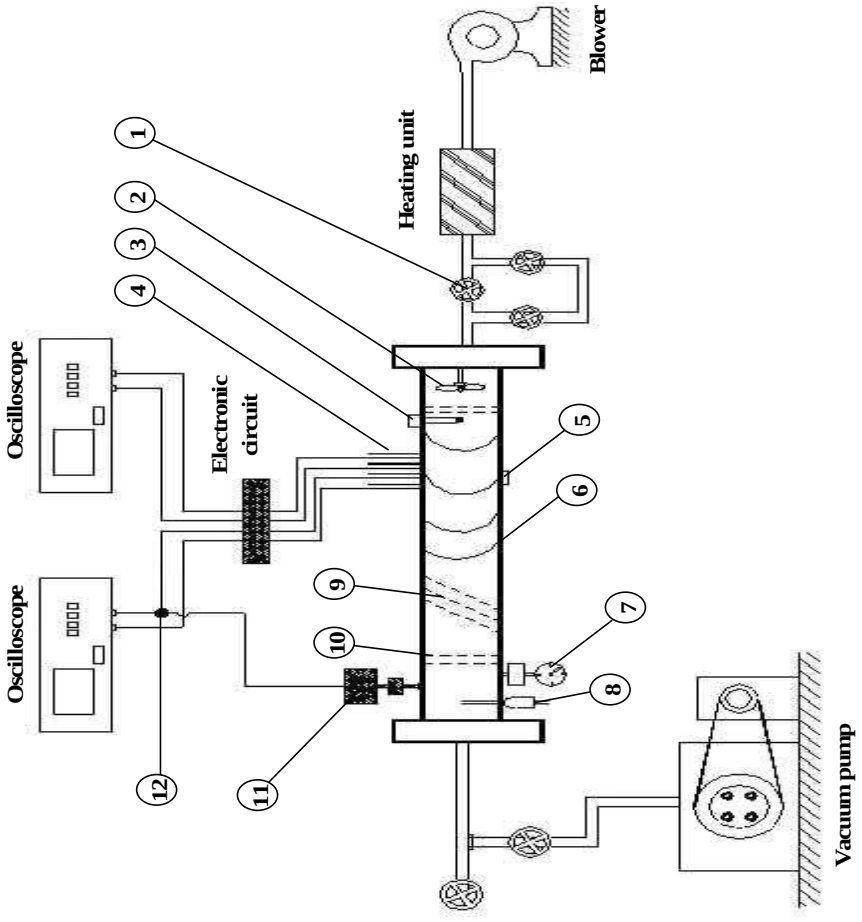
Where

$$A = 7.915 - 1.2576\ (n_c)$$

$$B = -10.19 + 2.438\ (n_c)$$

$$C = 3.8117 - 0.9183\ (n_c)$$

Which can be used with an error (± 5%), for the following conditions (Tu = 300K-373K), (ϕ = 0.7-1.4) and (n_c = 1, 2) with Po = 1 atm and T_{uo}= 333 K.



No.	Part	No.	Part
1	Drying unit	7	Vacuum pressure gauge
2	Fan	8	Thermocouple
3	Ignition unit	9	Heating tape
4	Photocell	10	Flame trap
5	Fuel injection valve	11	Pressure transmitter
6	Copper tube	12	Single pole double through switch

Figure-1. Schematic diagram of the experimental rig.

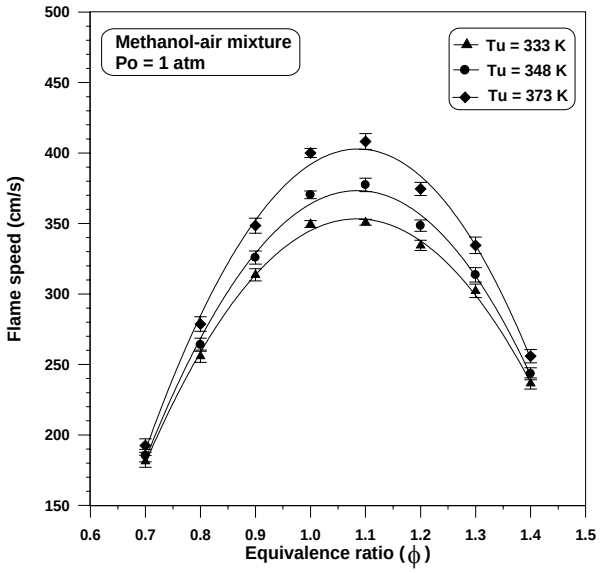


Figure-2. Flame speed as a function of equivalence ratio for Methanol-air mixture.

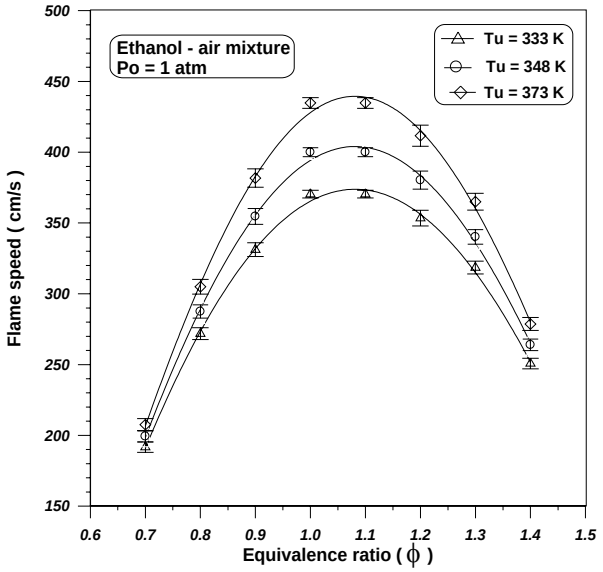


Figure-3. Flame speed as a function of equivalence ratio for Ethanol-air mixture.

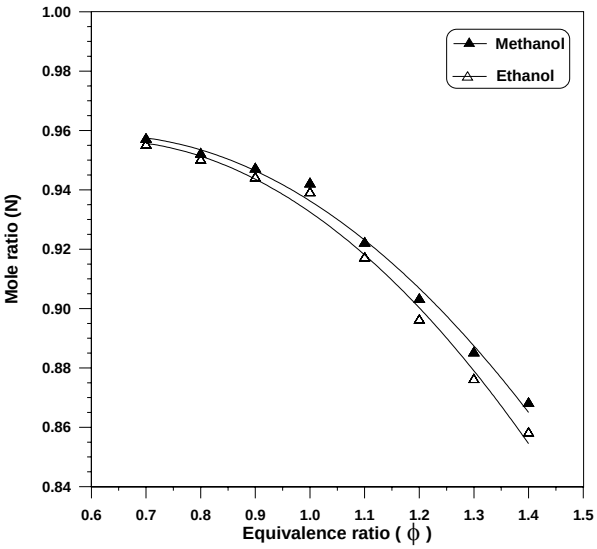


Figure-4. Mole fraction variation with equivalence ratio for methanol and Ethanol-air mixtures.

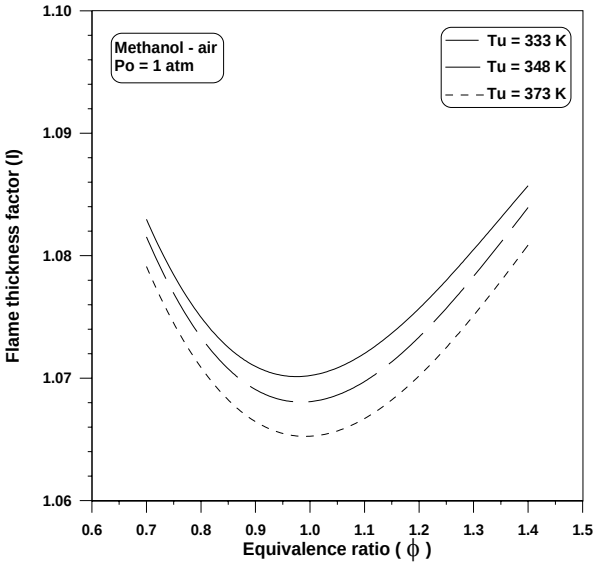


Figure-5. Flame thickness factor variation with equivalence ratio for Methanol-air mixture.

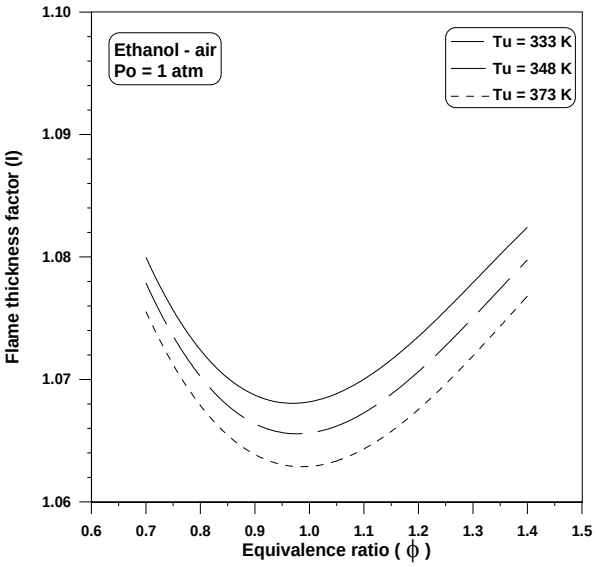


Figure-6. Flame thickness factor variation with equivalence ratio for Ethanol-air mixture.

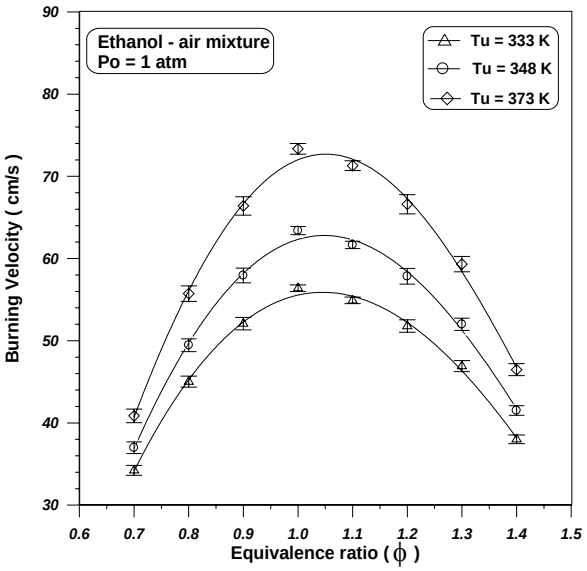


Figure-7(b). Burning velocity variation with equivalence ratio for Ethanol-air mixture.

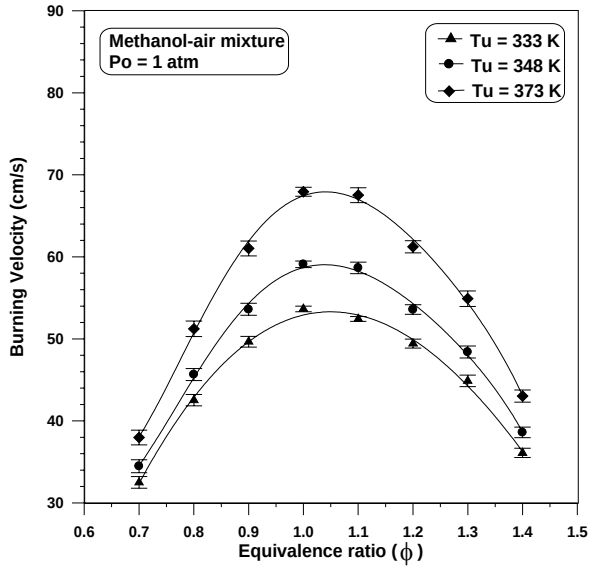


Figure-7(a). Burning velocity variation with equivalence ratio for methanol-air mixture.

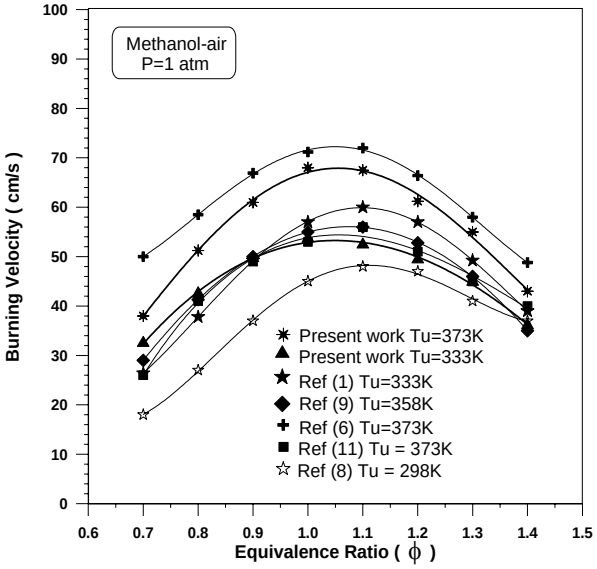


Figure-8. Comparison of burning velocity of methanol-air mixture with the published data.

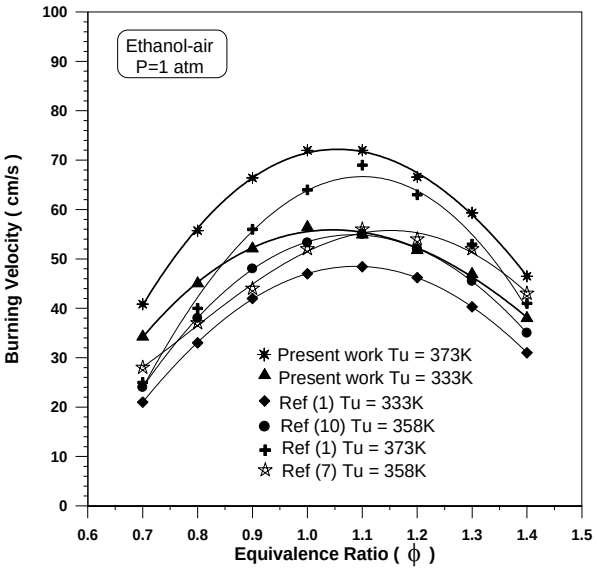
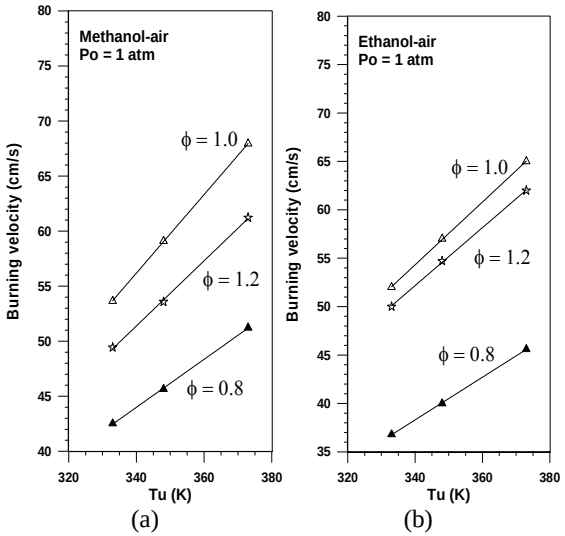


Figure-9. Comparison of burning velocity of ethanol-air mixture with the published data.



(a) (b)

Figure-10(a)-(b). Variation of burning velocity with unburned mixture initial temperature.

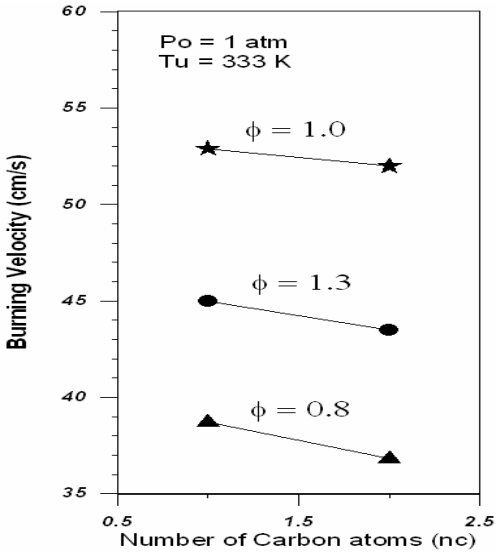


Figure-11. Variation of burning velocity with number of carbon atoms at different mixture strength.

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