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Research Article

Effects of Oxygen Enrichment on Gasoline-Methanol blend Combustion Characteristics

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Abstract

Oxygen enhanced combustion and alternative fuels produced form renewable sources, such as methanol and ethanol consider two important techniques used to minimize the emissions and improve efficiency of the engine. In the experimental part of this study, a measurement system was designed to investigate the effect of methanol addition to gasoline with using oxygen enrichment on the laminar flame propagation. Both optical and tube methods were used to measure the speed of the laminar flame for five blends of methanol/gasoline 0% (M0), 5% (M5), 10% (M10), 15% (M15) and 20% (M20) methanol by volume. The position of flame front was placed utilizing photodiodes. The speed of laminar flame was measured at the laboratory circumstances (at 298 K and 1 atm. initial temperature and pressure, respectively) with three ratios (21, 23 and 25) % by volume of molar oxygen enrichment and for a range of equivalence ratio (ϕ) from 0.7 to 1.4. The tests were conducted at the pre-pressure period. In the theoretical part, the combustion reaction formula for methanol –gasoline blend with oxygen enrichment was presented as a function of blending ratio for stoichiometric, rich and lean mixtures. The flame temperature of all the fuel blends was calculated by making use of the HPFLAME software. Also, this part includes the calculation of laminar burning velocity by using density ratio method. Using oxygen enhanced combustion with methanol/gasoline blending increases the laminar burning velocity, flame speed and adiabatic flame temperature for each blend. Gasoline has the higher values of laminar burning velocity, flame speed and adiabatic flame temperature compared with the other blends. The laminar burning velocity values computed in the present work were found well compatible with the previous reported results for the air, combustion of gasoline, and methanol/gasoline (10% and 20%) by volume methanol.

Keywords: *Oxygen-enhanced, Methanol, laminar burning velocity, tube method, flame thickness*

1. Introduction

Variation of climate is too important global matter. It has negative influences on the economy of the world, ecosystem and living circumstances. Climate change is caused largely by using fossil fuels as principal origin to generate energy. Future climate variations importance is almost connected with the universal nitrogen oxides (NOx) and carbon dioxide (CO2) emissions into the earth's atmosphere (UNFCCC, 1997). For instance, an approximate 3000 liters of oil are equivalent about 7500 kg of CO2 released into air every year (ISOVER, 2008).

Fossil fuels consider the primary energy source for most of the combustion processes especially gasoline and diesel. Increasing pollution of environmental, increase consumption and unstable rates of end prices of fuel consider the major problems of using fossil fuels.

Energy utilization and consequently gas emissions of greenhouse require decreasing greatly in the next years. To provide a feasible solution, several techniques are explored to minimize the emissions, improve efficiency and to exploit new energy resources. Two important techniques in this field under development and studying, the first is using substituted fuels, such as hydrogen, ethanol, propane, methanol and natural gas, while the other is using oxygen – enhanced combustion (Sara McAllister *et al*, 2011).

Gulder O. L., 1983 measured laminar burning velocities for methanol/isooctane and isooctane/methanol with two types of blends (10% and 20%) methanol by volume. The measurements were conducted during the period of constant pressure combustion, and density ratio was used to calculate the burning velocities for different mixtures. It is found that the burning velocities of isooctane/methanol blend are slower than methanol and isooctane combustion alone in the air. The results were calculated for a range of equivalence ratio (0.7-1.4) and

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initial temperature of mixture Tu (300 - 600) K at a pressure of 100 kPa.

Hassan, 2010, studied experimentally the effect of using the methanol addition for gasoline blends on the engine performance. Three types of blends (10%, 20% and 30%) were used for a range of speed (850 - 2250) rpm and compression ratios (5, 7 and 9). The results indicated that the maximum power output occurred at compression ratio (7) at (10% methanol), the emissions of CO2 increased and the emissions of both CO and HC decreased.

Hajir H. L., 2016, investigated the influence of adding methanol to gasoline on the SI engine single-cylinder, four-stroke performance (brake thermal efficiency, brake specific fuel consumption, volumetric efficiency and brake power) as well as the emissions of hydrocarbons (HC) and carbon monoxide (CO). Engine vibration was also measured. Tests were conducted at a fixed throttle variable speed state, which operates with a standard and advanced spark timing (10° and 11° BTDC, respectively) over a range of speeds (1500-2250) rpm and compression ratios (8) and (9) utilizing different methanol/gasoline mixtures (0% (M0), 5% (M5), 10% (M10), 15% (M15) and 20% (M20)) methanol by volume. The experimental results depicted that for the standard spark timing, the peak power was determined at M20 and CR=9 by a rise of (18.29%) from the M0. Whereas for the advanced spark timing, the peak power was determined at M20 and CR=9 by a rise of (18.27%) from the gasoline. The advanced spark timing caused power increase by (13.4%) from the standard spark timing. Also, (0%) of CO was obtained, while the amount of HC emissions was (67 ppm). In general, M5 blend revealed the lowest values of acceleration for both lower and higher speeds (1500-2250 rpm) of engine. The fuel blend (M15) manifested maximum levels of acceleration (40.4 m/s2), compared to other fuel blends.

Shaymaa Y. Ibrahim, 2016, studied the effect of oxygen enrichment on the laminar burning velocity and flammability ranges for [(butane, Iraqi LPG, methanol and ethanol)–O2–N2] premixed blends. The speed of laminar flame was measured at the laboratory environments (the initial pressure and temperature are 1 atm. and 298 K, respectively) with 3 molar O2 enrichment ratios (21, 23 and 25) volume % and for a range of equivalence ratio (0.7 – 1.4). It was found that the laminar burning velocity and the upper flammability limits increased with the oxygen enrichment, while the lower flammability limits were constant. The burning velocity peak value occurred at the equivalence ratio of (1.1) at all oxygen levels, while, the maximum increasing percentage in the laminar burning velocity took place at the equivalence ratio of (0.7) by (60.5% and 87.7%) for methanol and ethanol, respectively. An empirical relation was performed to conjugate the effect of oxygen enrichment, mixture strength and type of alcohols on the burning velocity.

2. Experimental Apparatus and Construction

The study of flame propagation subject needs technically modern systems because of the short period available for measurement, which is not longer of a few milli seconds, it is a big problem in the present study.

In the present work, both tube and photodiode methods are employed for measuring the speed of a laminar flame.

The experimental investigation variables include the change of oxygen levels (21%, 23% and 25%) by volume, methanol/ gasoline blends (0%,5%, 10%, 15% and 20%) methanol by volume, and a wide range of equivalence ratio (0.7–1.4). All experiments were conducted under pre-pressure period.

This chapter demonstrates and explains the specifications of the test rig and peripheral devices and measuring procedures.Figure (1) shows the equipment schematic diagram

2.1 Unit of Combustion Tube

The current research used a copper tube having a length of (2000 mm), with an internal diameter of (63 mm) and a thickness of (2 mm).

The utilized material to manufacture the combustion tube appears to have little or no effect, but copper tubing was selected for the present tests for ease of fabrication and connection of the other parts to the tube by welding to have closed system for getting a nearly complete vacuum. Copper high thermal conductivity is beneficial for heating the blend to a specific temperature to meet the other requirements for new researches at a higher initial temperature, and copper is subjected to the pressure range, under which the flame can spread.

The apparatus was designed and constructed to study the combustion of different types of gaseous, liquid fuels and alcohols under different conditions.

2.2 Mixture Preparation

The process of blend preparation has a significant role in the burning velocity measurement. The performed process is relied on the partial pressure of blend components and in accordance to Gibbs-Dalton Law as in the following equations:

$$\frac{P_i}{P_{mix}} = \frac{n_i}{n_{mix}} \tag{1}$$

$$P_{mix} = \sum P_i \tag{2}$$

$$n_{mix} = \sum n_i \tag{3}$$

Where, P_i and n_i are respectively the partial pressure and no. of moles of components (N_2, O_2 and fuel), which are determine calculated by the following combustion equation:

$$C_{n_c}H_{n_H}O_{n_O} + \frac{a_{sto.}}{\emptyset}\left[O_2 + \left(\frac{1-\Omega_{O_2}}{\Omega_{O_2}}\right)N_2\right] \rightarrow \sum \text{Products} \tag{4}$$

Where,

$$a_{sto.} = n_c + \frac{n_H}{4} - \frac{n_O}{2} \quad (5)$$

$\emptyset$ is the equivalence ratio defined as:

$$\emptyset = \frac{(A/F)_{sto.}}{(A/F)_{act.}} \quad (6)$$

The preparation of the mixtures was done in two stages; the first mixture consists of oxygen and nitrogen which were prepared within a blending box designed for such aim. While, the second mixture (fuel – oxygen – nitrogen) occurs inside the tube of combustion, as explained in the following stages:-

(a) Prior to prepare the blend, the blending vessel and tube of combustion were enough cleaning from the last blend and evacuated adequately to a vacuum pressure of (0.001 bar) via a vacuum pump.
(b) In order to prepare a mixture of gases (N_2) and (O_2) in the blending chamber, a limited quantity of (O_2) gas was first charged in accordance to its fraction of partial pressure with respect to the whole pressure of (3 bar), and then (N_2) gas was charged to obtain the whole pressure of (3 bar) absolute. Both gases were then mixed for five (5 min) to obtain a uniform blend.
(c) A limited amount of liquid fuel (gasoline or methanol/ gasoline) was introduced into the tube of combustion via an injection valve. The injected quantity of fuel was calculated in accordance to its partial pressure at every level of oxygen enrichment and equivalence ratio. This injected fuel can be evaporated quickly at a pressure near to vacuum.
(d) Then, the blend of (N_2) and (O_2) gases is charged into the tube of combustion till reaching a pressure of (1) atmosphere.
(e) Eventually, the final blend in the tube of combustion was left to be mixed thoroughly for a period of (5-10 min) to get a uniform blend.

The density ratio method introduced by Andrews and Bradley was used to calculate the laminar burning velocity from measured flame speed as the following equations.

$$S_L = S_F . N . \frac{T_u}{T_b} . I \quad (7)$$

where

$$S_F = \frac{\Delta L}{\Delta t} \quad (8)$$

The magnitudes of mole ratio and flame thickness factor have been calculated according to the relations of the researches Andrews and Bradley, where:

$$N = \frac{\sum n_{rect.}}{\sum n_{prod.}} \quad (9)$$

$$I = \frac{1.04}{r_b^3}\left[(r_b - \delta)^3 + \frac{3T_b r_b^2 \delta}{(T_{ad} - T_u)} \ln\left|\frac{T_{ad}}{T_u}\right|\right] \quad (10)$$

Where (Nr and Np) calculated from the balance of combustion equation as in the below:

$$C_{n_c}H_{n_H}O_{n_O} + \frac{a_{sto.}}{\emptyset}\left[O_2 + \left(\frac{1-\Omega_{O_2}}{\Omega_{O_2}}\right)N_2\right] \rightarrow \sum \text{Products} \quad (11)$$

The adiabatic flame temperature and equilibrium composition with oxygen enrichment was calculated by using a computer program of Olikara & Borman after suitable modifications. The modifications include the change in mole ratio of nitrogen to oxygen. This program considers the dissociation for eleven species (O, N, H2, O2, N2, OH, CO, NO, H2O and CO2) in the products of combustion.

Flame thickness, could be defined that distance in which the first temperature rise occur until reach the maximum value (Tb) . Blint's correlation was used for calculation flame thickness.

$$\delta = \frac{2\lambda}{\rho_u . C_p . S_L}\left(\frac{T_{ad}}{T_u}\right)^{0.7} \quad (12)$$

Thermo-physical properties are constant values at specific temperature and evaluated at mean temperature

$$Tm = (Tu + Tb) /2 \quad (13)$$

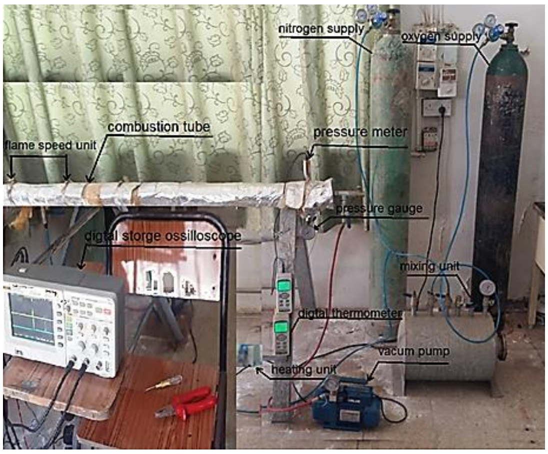

Fig.1 Experimental apparatus with all units

3. Results and discussions

Figure (2 and 3) shows the variation of adiabatic flame temperatures of the oxygen enrichment content (Gasoline (M0), and M20) flames with equivalence ratios at three oxygen enrichment levels. It can be observed that the flame temperature increases with the increment of the equivalence ratio on the weak side of the mixture till it reaches the maximum value at (Φ=1.05). Afterwards it starts to decrease on the rich side of the mixture with increment of equivalence ratio. This is due to the relation between the heat of combustion and the heat capacity of the products, where both of these decline when the equivalence ratio exceeds unity, but the heat capacity decreases slightly faster than heat of combustion between Φ=1 and the peak rich mixture . Moreover the increasing of oxygen in the mixture produces an increment in the flame temperature by increasing the heat capacity of the mixture.

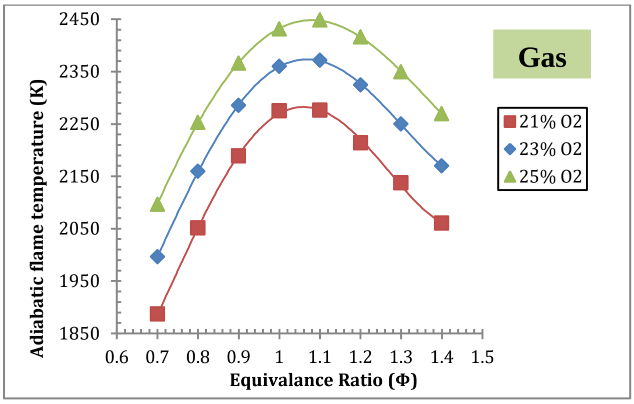

Fig.2: Adiabatic flame temperature (T_{ad}) vs. equivalence ratio (Φ) for (Gasoline – O_2 – N_2) mixture at different oxygen enrichments

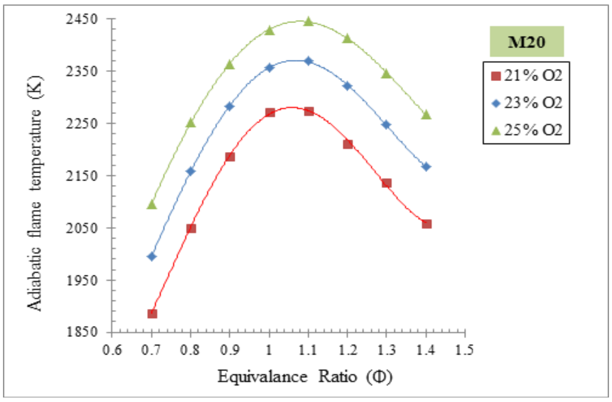

Fig.3: Adiabatic flame temperature (T_{ad}) vs. equivalence ratio (Φ) for

The measured flame speed at different equivalence ratio and oxygen enrichment of (Gsoline (M0),M20) mixtures was shown in figure (4,5). The variation of flame speed had the same trend of adiabatic flame temperature with equivalence ratios and oxygen enrichment levels. Increment the oxygen as the oxidizer will lead to increase the flame temperature and consequently the reaction rate, thus increasing the flame speed.

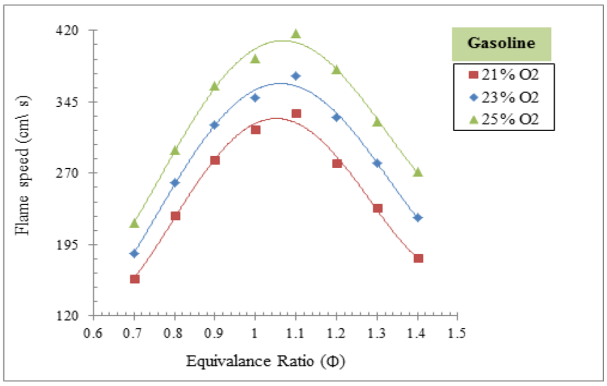

Fig.4: Flame Speed (S_F) vs. equivalence ratio (Φ) for (Gasoline– O_2 – N_2) mixtures

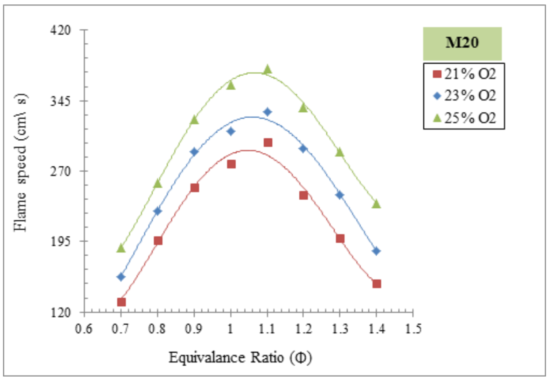

Fig.5: Flame Speed (S_F) vs. equivalence ratio (Φ) for (M20– O_2 – N_2) mixtures

Figure (6,7) illustrates the variations in mole ratio (N) at different equivalence ratios (Φ) and at different oxygen enrichment levels. It can be observed from this figure that the mole ratio decreases with increase the equivalence ratio. The trend of variation in (N) with (Φ) is similar to the three oxygen enrichment levels. Increase oxygen enrichment level and equivalence ratio will decrease the number of moles of reactants and increase the number of moles of products; therefore mole ratio decreases.

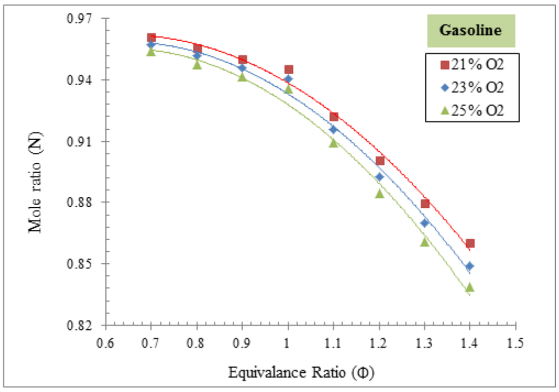

Fig.6: Mole ratio (N) vs. equivalence ratio (Φ) for (Gasoline – O_2 – N_2) mixtures

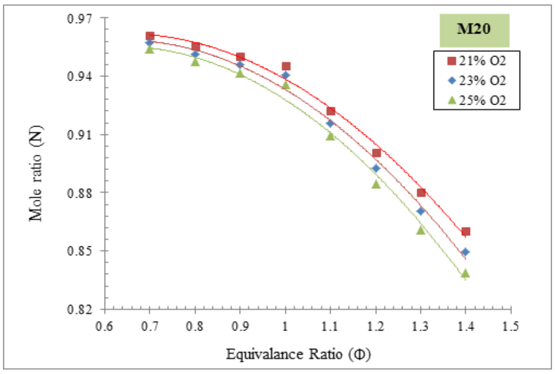

Fig.7: Mole ratio (N) vs. equivalence ratio (Φ) for (M20 – O2 – N2) mixtures

The results of laminar burning velocity estimated according to equation (7) are shown in figure (8,9).

The laminar burning velocity increases with increment oxygen levels as a result in reaction rate which is due to increase adiabatic flame temperature. The experimental results show that the maximum value for laminar burning velocity occur at equivalence ratio = 1.05.

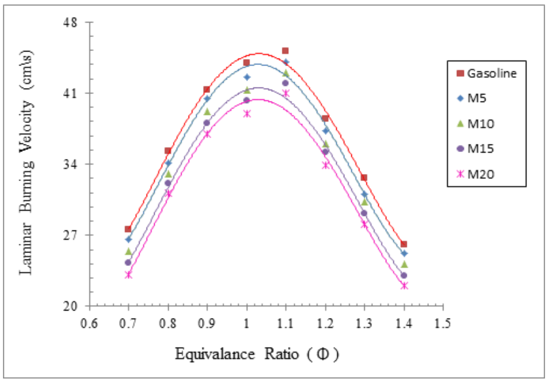

Fig.8: Laminar burning velocity (S_L) vs. equivalence ratio (Φ) for (gasoline/methanol blends – air) mixtures

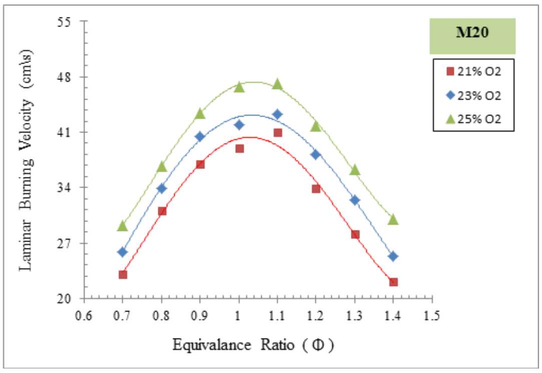

Fig.9: Laminar burning velocity (S_L) vs. equivalence ratio (Φ) for (M20 – O_2 – N_2) mixtures

Figure (10) shows the comparison of the results of present work for case (Gasoline) mixture with the published results which gives a good agreement between them. The slight differences in the values of burning velocity associated with the different techniques.

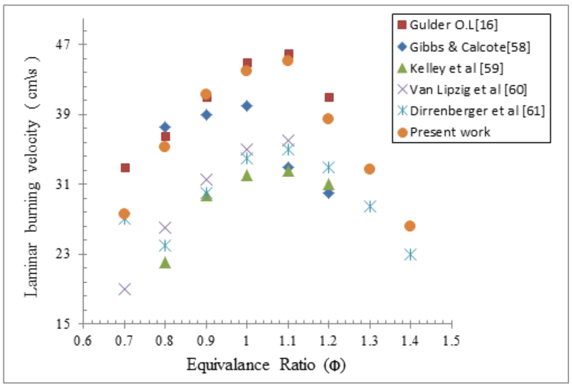

Fig.10: Compared experimental results with published data for (Gasoline – air) mixtures at T_u=298 K

Conclusions

1-The laminar flame speed and the burning velocity increase with the amount of oxygen increasing in the combustion mixture

2-The comparison of the present results of laminar burning velocity with other published results give a good agreement for case of air.

Nomenclature

Cp Specific heat at constant pressure (kJ/ kg.K)
Tm Mean temperature (K)
E/Ru Activation temperature (K) Tu Unburned gas temperature (K)
I Flame thickness factor
Ze Zel'dovich number
N Mole ratio : the ratio of number ofmoles of reactants to that of products
δ Flame thickness (mm)
Np, Nr Number of moles for product &reactant respectively
λ Thermal conductivity (J/m.s.K)
γ Exponent of the number of carbon atoms
Pu Initial pressure of mixture (atm.) ρb Burned gas density (kg / m3)
Rb Flame radius (mm) ρu Unburned gas density (kg / m3)
Ru Universal gas constant (kJ / kmol.K)
Φ Equivalence ratio
SF Laminar flame speed (cm / sec) Volume fraction of oxygen
SL Laminar burning velocity (cm / sec)
ΔL Distance between two photodiodes (cm)
SLo Laminar burning velocity at the laboratory conditions
Δt Measured time between two photodiodes (sec)
Tb Burned (or adiabatic) gas temperature (K)

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