

STUDY OF THE EFFECT OF ELEVATED TEMPERATURES ON THE LAMINAR BURNING VELOCITY OF PROPANE-AIR MIXTURES

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ABSTRACT: - Laminar burning velocities were obtained at wide equivalence ratios of propane –air mixtures. The effect of elevated temperatures was also analyzed. It was found that the laminar burning velocity is increased with the increase of temperature at constant pressure. For equivalence ratio= 1.1 the laminar burning velocity was always the maximum. The laminar flame speed results were compared with other researches and it was found a good agreement.

Keywords: Laminar burning velocity; Constant-volume bomb, Propane, preparation unit, thermocouples.

INTRODUCTION

One of the distinguished features of laminar premixed flames is that they have a characteristic propagation rate, commonly called the burning velocity, the burning velocity, S_u , is more precisely defined as the velocity at which unburned gases move through the combustion wave in the direction normal to the wave surface. Laminar burning velocities are greater significance, since they are used in many areas of combustion science such as in designing burners and predicting explosions. They play essential roles in determining several important aspects of the combustion in spark ignition engines. Among these are the ignition delay (which in turn affects the range of equivalence ratios over which an engine can be operated and cycle to cycle variations) ⁽¹⁾.

Data of laminar burning velocities are still needed as inputs to many turbulent combustion models. Also, in internal combustion engines the initial combustion is laminar, so again there is need for the laminar burning velocity.

There are several computing methods for determining a laminar burning velocity. These methods are divided into two classes: stationary and non-stationary flame methods. The two methods discussed (the counter flow- burner method and the constant volume method) are considered to be the most prominent.

The counter flow-burner technique is principally associated with Law's group, who has studied a very wide range of fuels. The method is convenient for both liquid and gaseous fuels, with a good control of mixture composition. This technique is best suited to pressures and temperatures close to ambient, and it is necessary to correct for the effects on the burning velocity of strain in the complex fluid flow; this correction procedure is still a subject of debate ⁽²⁾.

The constant-volume bomb method uses a spherical or cylindrical vessel with central ignition and relies on measurements taken after the early stages of flame propagation, during which there is an insignificant pressure rise. The advantage of measuring the burning velocity using the closed vessel over other methods is that, from a single test, burning velocities can be calculated over a wide range of temperatures and pressures.

The laminar burning velocity is a function of not only the fuel/oxidant ratio, but also the temperature and pressure of the system and the presence of any diluents in the mixture ⁽³⁾. Previous work ⁽⁴⁾ has shown that if the initial temperature (unburnt gases temperature) increased the laminar burning velocity increased and reference ^(5 & 6) has shown that if initial pressure of unburnt gases increases the laminar burning velocity decreased. So, the main aim of this study is to investigate the effect of initial pressure upon laminar burning velocity for wide range of equivalence ratios.

EXPERIMENTAL APPARATUS

Figure (1) shows the apparatus used in this study. It consists of the following: combustion vessel and heating, ignition circuit, mixture preparing unit and data acquisitions system. The cylindrical test vessel with (305mm) diameter; (305mm) length and (11.5mm) thickness is provided with central ignition electrodes. An initial temperature can be achieved and maintained using the heating system and the temperatures which are measured by using digital thermometer instead of the space inside the cylinder to give precise measurements of temperature. Borden pressure gauge is made to measure the initial pressure inside the cylinder. After combustion a thermocouples sensors was used to check the flame propagation, and to measure the flame speed. The computer control system is used to read the flame speed of the flame propagation inside the cylinder. Six thermocouples were used; they are fixed inside the cylinder.

These thermocouples are connected to a computer in order to collect process and display the data are obtained from the thermocouples. So an electrical interface circuit (control system hardware) was designed and implements to process the signals arriving from the thermocouples after feeding them to the parallel port of the computer.

A computer program (control system software) is used to activate the port and process the data controlled. Below is a determination for the hardware and software of the control system used to connect the thermocouples to a computer as shown in figure (2). The control system was designed with the cooperation of Computer Engineering and Information Technology Dept., University of Technology.

Burning velocity calculation

The present work has derived the burning velocities from flame speed measurements in explosions by using density ratio method that takes into account the temperature distribution through flame front ⁽⁷⁾, it is also used to obtain the laminar burning velocity of (propane-air) mixture.

$$S_u = S_f N \frac{T_u}{T_b} I \quad \dots\dots\dots (1)$$

Where

$$N = \frac{\sum n_r}{\sum n_b} \quad \dots\dots\dots (2)$$

$\sum n_r$ =Number of mole of reactants

$\sum n_b$ =Number of mole of products

and

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

The burning velocity reported in present work are based on ($r_b = 2.5$ cm) because the cut-off pressure rise corresponding to this radius is very small and in most cases of interest its effect on burning velocity is negligible ⁽⁸⁾.

Materials

Propane (C_3H_8) produced by Al-Dora Refinery was in this investigation. This gas was selected because it is the main part of the liquefied petroleum gas (LPG) used in Iraq. LPG high content of propane makes most of their combustion properties similar. Also, this fuel results in abundance during lubricants productions that make it an important studying issue.

RESULTS and DISCUSSIONS

Fig. 3 shows the comparison of the laminar burning velocities for propane- air mixture at $T_u= 300$ K and $P_u= 1$ bar obtained from the present work with those of the most recently reported data of Hani ⁽⁷⁾, Hamid ⁽⁸⁾, Yu ⁽⁹⁾, Arkan ⁽³⁾, Lovachev ⁽¹⁰⁾ and Al-Salman ⁽¹²⁾. The figure shows a very good agreement with data of Hani for all equivalence ratios. The differences in burning velocities obtained on the present work and in the data of Hamdi are very low. The maximum velocity obtained from the present study is 35.1 cm/sec at $\phi=1.1$.

Fig. 4 shows the variation of the burning velocities as a function of unburned gas temperature with fixed pressure ($P_u= 1$ bar) for wide range of equivalence ratios from $\phi=0.5$ to 1.5. The comparison conducted between $\phi=0.6$ and $\phi=1.5$, which represent the working range of equivalence ratios for the tested fuel. It can be seen from the figure that at a fixed pressure the burning velocities for propane-air mixtures increase with temperature. The tests conducted for three temperatures gradient 300, 325 and 350 K that represent the initial working temperatures in practical operations.

Fig. 5 shows the variation of burning velocity as a function of equivalence ratio and temperature at fixed pressure at 0.5 bar. It can be seen from the figure that the burning velocity increases with the increase in initial temperature (300, 325 and 350 K). The maximum burning velocity achieved in the present work was at $\phi=1.1$ and $T_u=350$ K.

Fig. 6 represents the effect of equivalence ratio on laminar burning velocity of propane-air mixture at fixed pressure of 1.5 bar. It can be seen from the figure that the burning velocity increases with the increase in initial temperature (300, 325 and 350 K). The maximum burning velocity achieved in the present work was at $\phi=1.1$ and $T_u=350$ K as the preceding figures.

CONCLUSIONS

1. The laminar burning velocity for propane-mixture has been compared with the earlier reported data. The values obtained from the present work give very good agreement with the recently reported data.
2. The laminar burning velocity for propane –air mixture increases with initial gas mixture temperature increases.
3. A new technique that uses a computer in the measurement system to get the best results has been employed for the measurement of laminar flame speed.

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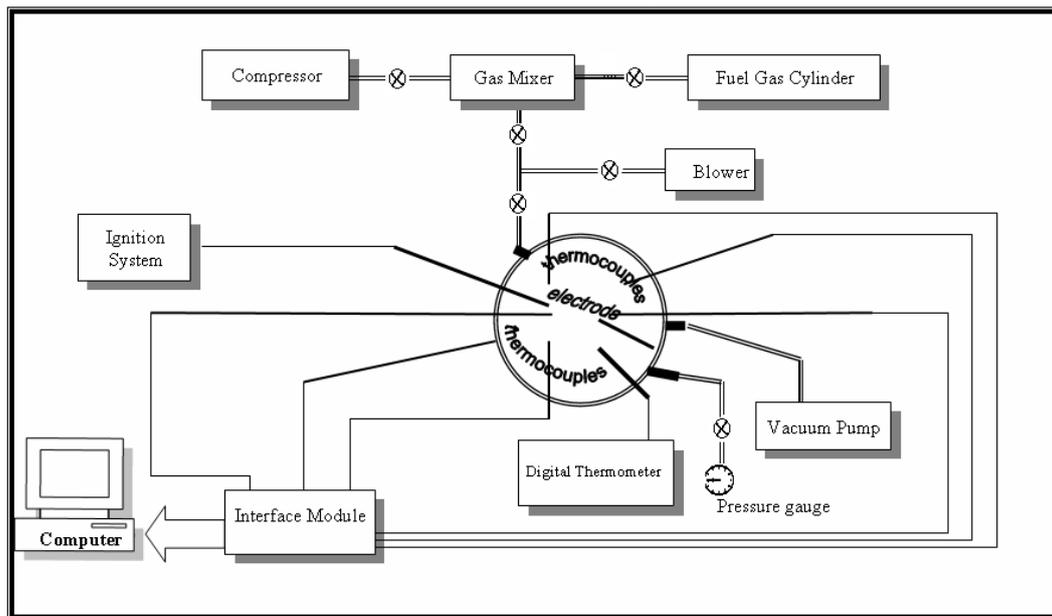


Fig. 1, Block diagram of experimental apparatus

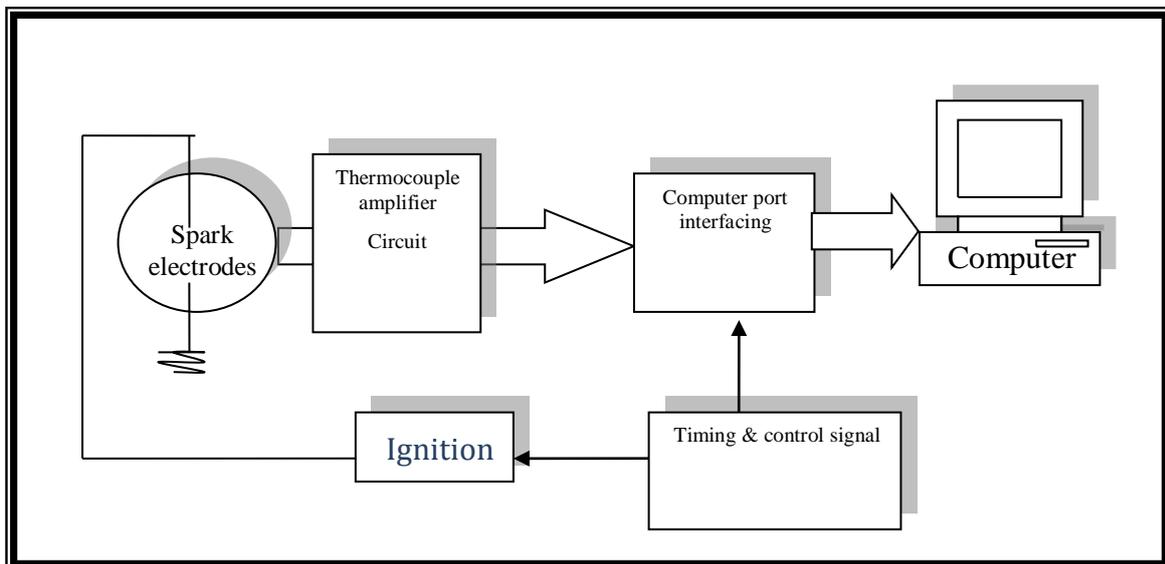


Fig (2) Block Diagram of Interfacing Circuit

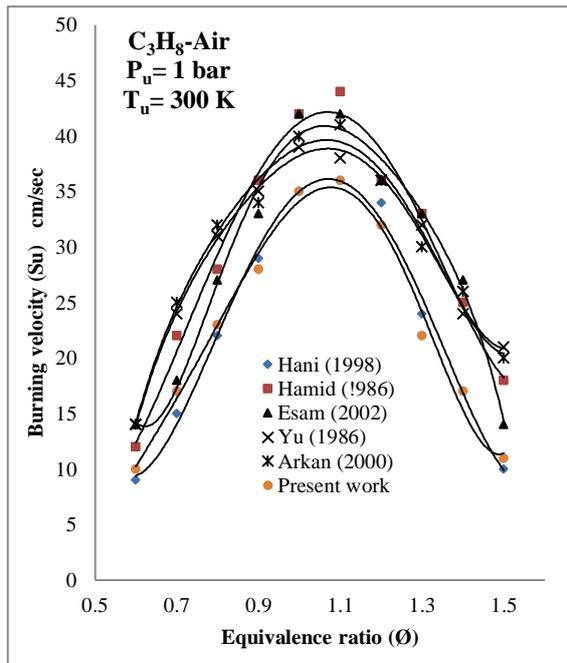


Fig. 3, comparison of present results with the published results of propane-air mixtures

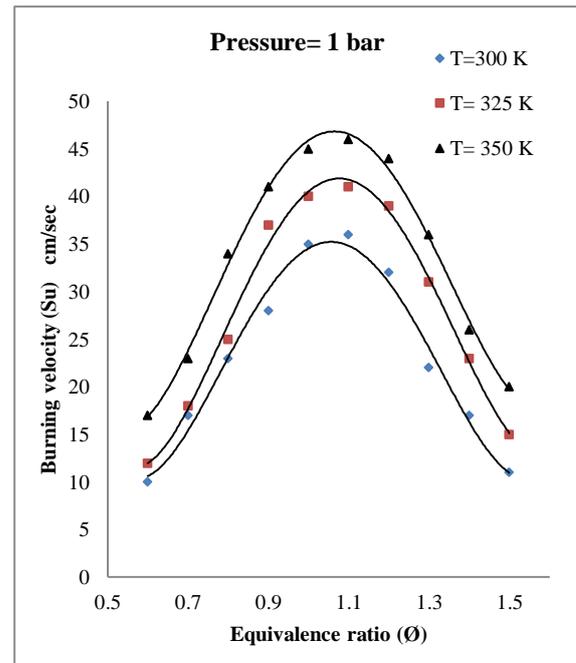


Fig. 4, temperature effect on laminar burning velocity for wide range of equivalence ratios at fixed P=1 bar

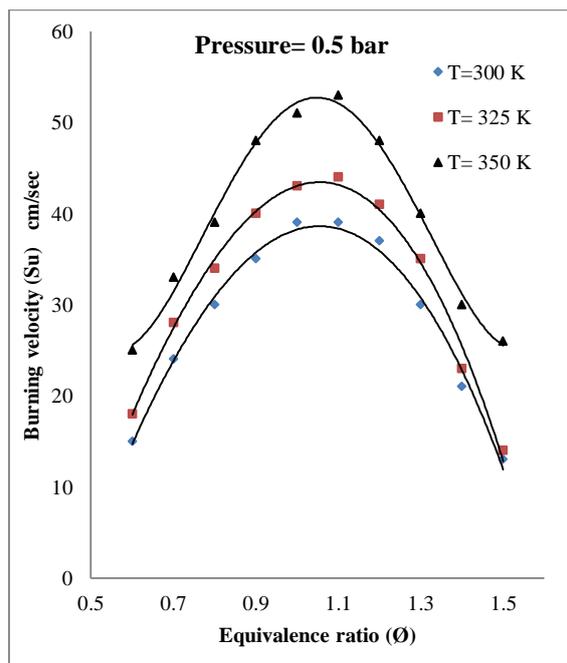


Fig. 5, temperature effect on laminar burning velocity for wide range of equivalence ratios at fixed P=0.5 bar

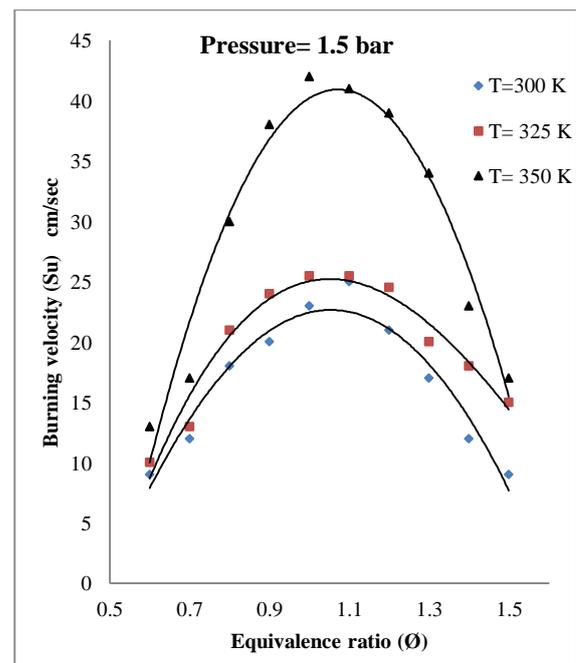


Fig. 6, temperature effect on laminar burning velocity for wide range of equivalence ratios at fixed P=1.5 bar

دراسة تأثير درجات الحرارة المتصاعدة على سرعة الأحتراق انتشار اللهب لخلائط بروبان-هواء

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الخلاصة:

تم الحصول على سرع الأحتراق الطباقية لمدى واسع من النسب المكافئة لخلائط البروبان-هواء. وتم دراسة تأثير درجات الحرارة المتصاعدة، ووجد ان سرعة انتشار اللهب الطباقية تزداد بزيادة درجات الحرارة عند ثبوت الضغط، وكانت اعلى سرعة احتراق طباقية دائما عند نسب مكافئة تساوي 1.1. تمت مقارنة سرعة الأحتراق الطباقية مع بحوث اخرى ووجد توافق جيد في النتائج.

الكلمات المفتاحية: سرعة الأحتراق الطباقية، وعاء ذو حجم ثابت، البروبان، وحدة التحضير، المزدوجات الحرارية