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

Adel M Salih[1], **Miqdam T Chaichan**[2], **Aedah MJ Mahdy**[3]

[1, 2] Mechanical Eng. Dept., UOT, Baghdad, Iraq
[3]The Technical Collage, the Middle Technical University, Baghdad, Iraq
E. mail: Miqdam_tc@uotechnology.edu.iq

ABSTRACT: - Laminar burning velocities were obtained for three specific equivalence ratios of propane –air mixtures (Ø= 0.8, 1.0 & 1.3). The effect of elevated pressures at variable initial temperatures was also analyzed. It was found that the laminar burning velocity is reduced with the increase of pressure at constant temperature. At mixture high initial temperatures (350 K) the effect of pressure on laminar burning velocity was limited. 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

Ever since prehistoric times, combustion has always been the major energy production process. The high level of development reached over the last century is mostly due to impressive technological improvements that result from massive utilization, transformation and control of the main energy resource: fossil oil. However, fossil energy combustion leads to high levels of pollutant emissions, such as carbon monoxide, greenhouse gases and particles. Current ecological and political contexts encourage scientists and engineers to improve combustion systems in order to limit consumption and curb toxic emissions. This objective cannot be reached nowadays only by empirical methods that would consist in improving macro-structure combustion installations [1].

The laminar burning velocity is one key parameter for the characterization of fuels, and it also serves as an important quantity to validate chemical kinetic models. Dependent only on the mixture composition, temperature, and pressure, it serves as a fundamental property of a fuel. This makes the laminar burning velocity an important global kinetic parameter for assessing fuel reactivity and for validating chemical kinetic mechanisms [2].

Propane is highly flammable fuel source when in the presence of oxygen. Flammability limits of flammable compounds in order for proper storage and handling. Propane is used in many processes and applications as a source of heating. Understand its equivalence ratio and flammability limits can help design an efficient system that is also safe for all personnel and equipment in the area. The stoichiometric equivalence ratio of air-fuel for propane in air is 15.6. At this ratio, propane achieves complete combustion resulting in little to no unwanted byproducts which can result in a buildup of soot that can lead to increasing inefficiencies and maintenance [3].

Many experiments have been proposed to predict the accurate magnitudes of the laminar burning velocity of premixed propane−air mixtures, including the combustion bomb method [4, 5 & 6], counter jet or stagnation plane method [7, 8 & 9] and heat flux method[10 & 11]. In these

methods, the experimental data were extrapolated to either zero heat loss or zero strain rate conditions to obtain the accurate magnitude. Recently, Kim and Kim[12] used an annular diverging tube to predict the laminar burning velocity of fuel− air mixtures at ambient conditions. The measured burning velocities of fuel−air mixtures match well with the existing results. However, they have not considered the effect of heat loss and thermal regeneration between flame and walls in such small channels. Most of the available experiments provide the burning velocity data at ambient temperature and pressure only. Therefore, accurate burning velocity data for various pure and diluted fuel−air mixtures at high pressures will be helpful in the design of various practical devices, such as internal combustion (IC) engines and gas turbines [12].

As we know, laminar burning velocity is a strongly dependent parameter of mixture features, e.g. initial temperature, pressure and mixture equivalence ratio. And generally, this fundamental parameter is determined at standard condition, for example, atmospheric pressure and initial temperature of 298 K, or relatively low temperature and pressure, primarily owing to some difficulties in experimental setups and measurements. However, in most practical applications, initial pressure and temperature of the mixture are often higher than the standard values. Therefore, it is very important to quantify the effects of pressure and temperature on these fundamental parameters [13 & 14].

The experimental method used herein was take advantages from using thermocouples probes as sensors. Which have been well-established to deduce flame speed, as well as laminar burning velocity from the recorded history of flame kernel development. The major objective of this paper, therefore, was to provide some improved expressions for laminar propane-air flames, as well as to study their pressure dependencies.

EXPEREMINTAL 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 [8], it is also used to obtain the laminar burning velocity of (propane-air) mixture.

$$S_u = S_f N \frac{T_u}{T_b} I \qquad \text{...... (1)}$$

Where

$$N = \frac{\sum n_r}{\sum n_b} \qquad \text{...... (2)}$$

$\sum n_r$ =Number of mole of reactants
$\sum n_b$ =Number of mole of products
And

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

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 [9].

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

To validate our results a 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 [9], Hamid [10], Yu [11], Arkan [4], Lovachev[12] and Zhou [13] is shown in Fig. 3. The comparison conducted between Ø=0.6 and Ø=1.5, which represent the working range of equivalence ratios for the tested fuel.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 Ø=1.1.

Fig. 4 represents the effect of elevated pressure on laminar burning velocity of lean propane-air mixture (Ø=0.8) with variable temperatures. It is clear that increasing pressure reduces laminar burning velocity of the mixture especially at low temperatures. Laminar burning velocities at high pressure and low temperature are low as the figure indicated. At p=1.5 bar and 300 K the measured laminar burning velocity was 18 cm/sec.

Fig. 5 illustrates the effect of elevated pressure on laminar burning velocity of stoichiometric propane-air mixture (Ø=1.0) with variable temperatures. The same effect for pressure is indicated here, but at high temperatures (350 K) this effect is relatively limited. The opposite effects of pressure and temperature cause the resultant laminar burning velocity.

Fig. 6 declares the effect of elevated pressure on laminar burning velocity of rich propane-air mixture (Ø=1.3) with variable temperatures. Pressure effect here is clearer than the former figures where the reduction in laminar burning velocities is large for 300 and 325 K mixtures. For mixtures at 350 K pressure effect was limited.

CONCLUSSIONS

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 decreases with increasing pressure depending on initial gas mixture temperature variation.
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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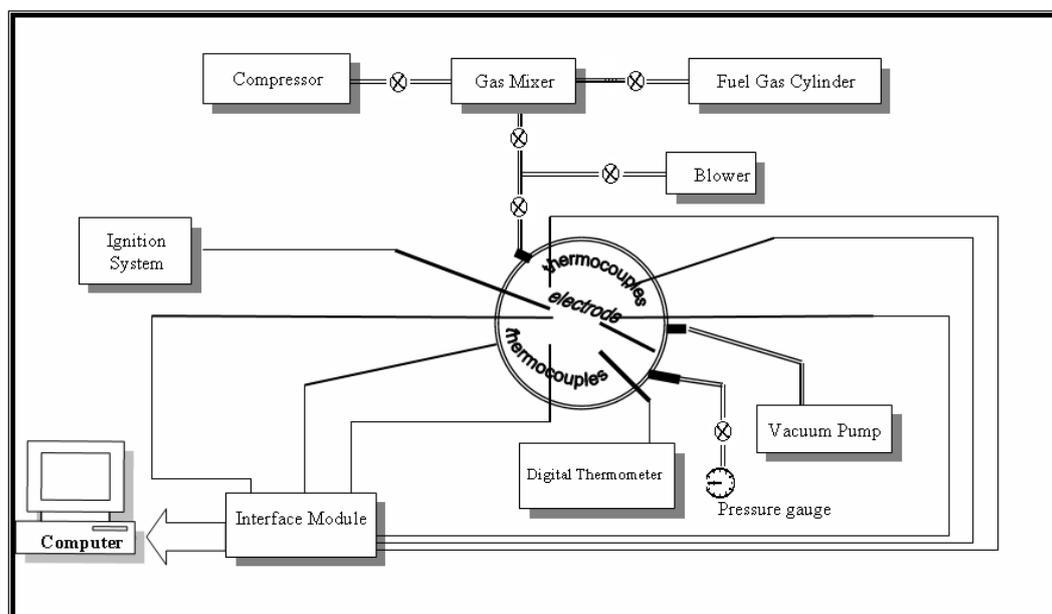
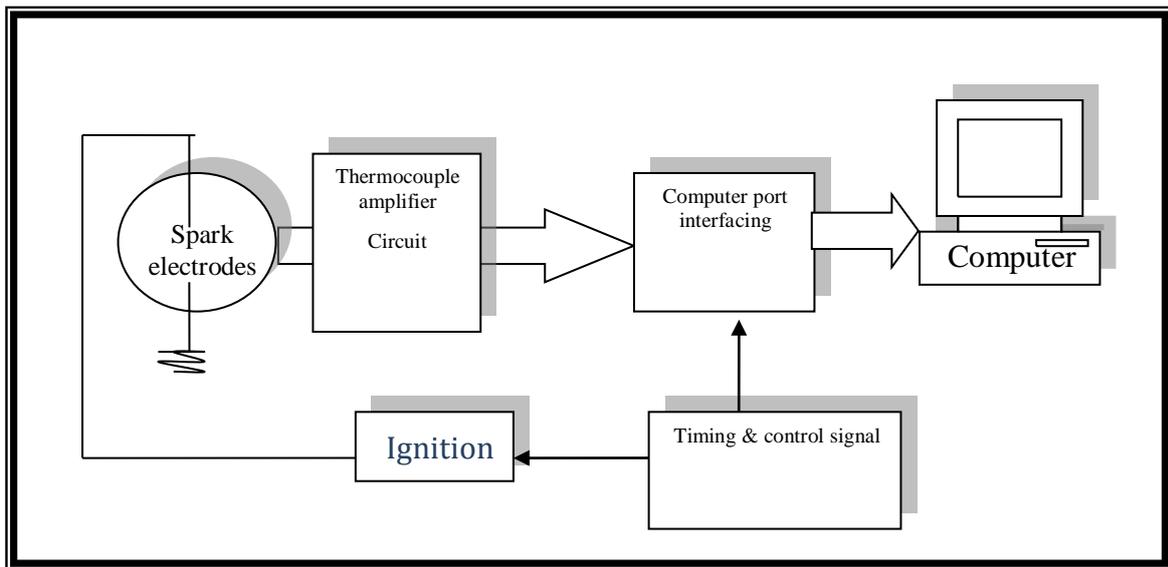Fig. 1, Block diagram of experimental apparatus

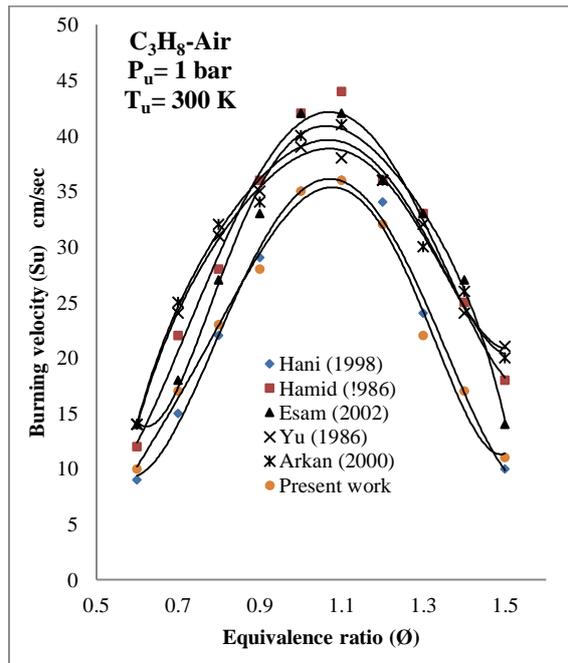Fig (2) Block Diagram of Interfacing Circuit

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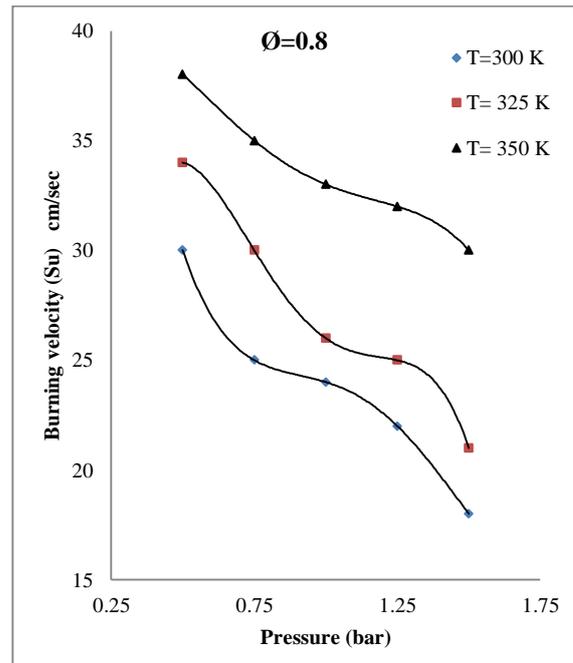

Fig. 4, pressure effect on laminar burning velocity for mixture equivalence ratio= 0.8 and variable temperatures
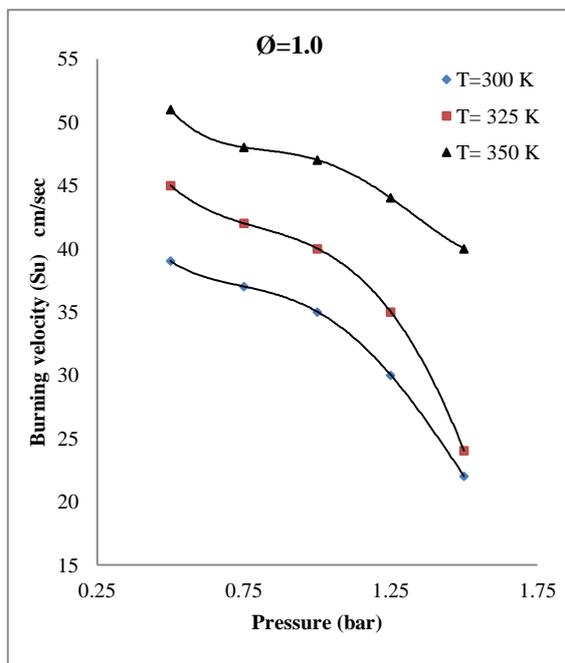

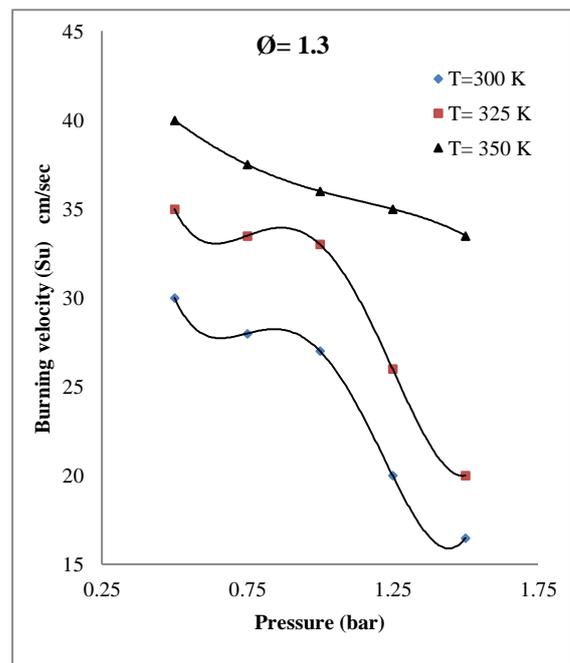Fig. 5, pressure effect on laminar burning velocity for mixture equivalence ratio= 1.0 and variable temperatures

Fig. 6, pressure effect on laminar burning velocity for mixture equivalence ratio= 1.3 and variable temperatures

دراسة تأثير الضغوط المتصاعدة على سرعة انتشار اللهب الطباقية لخلائط بروبان-هواء

عادل محمود صالح[1]، مقدام طارق جيجان[2] ، عائدة محمد جواد مهدي[3]

[1,2]قسم الهندسة الميكانيكية- الجامعة التكنولوجية- بغداد – العراق

[3]الكلية التقنية- جامعة الوسط التقنية- بغداد- العراق

الخلاصة:

تم الحصول على سرع انتشار اللهب الطباقية لنسب مكافئة محددة (Ø= 0.8، 1.0 و 1.3) لخلائط البروبان-هواء. وتم دراسة تأثير الضغوط المتصاعدة عند درجات حرارة مختلفة، ووجد ان سرعة انتشار اللهب الطباقية تقل بزيادة الضغط عند ثبوت درجة الحرارة، وعند درجات حرارة عالية للخليط (350 K) كان تأثير الضغط محدود نسبيا على سرعة انتشار اللهب الطباقي. 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