EXPERIMENTAL METHOD FOR CALCULATION OF LAMINAR BURNING VELOCITY OF PARAFFIN GASEOUS FUEL IN CLOSED VESSEL USING DATA ACQUISITION SYSTEM

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ABSTRACT

The burning velocity is defined as the velocity at which unburned gases move through the combustion wave in the direction normal to wave surface. It is used in many areas of combustion science such as in designing burners and predicting explosions.

In this research a data acquisition system has been designed to measure the laminar burning velocity using a modern technique, which uses thermocouples as measuring sensors connected to a an interface computer. The hardware has been designed to connect three groups of sensors to the computer. A program has been used to access the interface and to acquire the huge measured data which is filtered through reading in a suitable manner. The results made it possible to achieve an imperical equation can be used in evaluating laminar burning velocity of parraffin gaseous fuels, the expermintal investigations show acceptable computations compared with previous researches results.

طريقة عملية لقياس سرعة الاحتراق الطباقية لوقود غازي بارافيني في وعاء مغلق باستخدام نظام اكتساب البيانات

الخلاصة

تعرف سرعة الاحتراق بالسرعة التي تتحرك بها الغازات غير المحترقة خلال موجة الاحتراق في اتجاه عمودي على سطح الموجه، وتستخدم في عدة مجالات في علم الاحتراق، مثل تصميم المحارق وتوقع الأنفجارات.

في هذا البحث، تم تصميم نظام اكتساب البيانات لقياس سرعة الاحتراق الطباقية باستخدام تقنية جديدة، يتم بها استخدام المزدوجات الحرارية كمتحسسات قياس مرتبطة بحاسب آلي عن طريق جهاز توصيل، وتم استخدام برنامج لإدخال البيانات الموصلة إلى الحاسبة لغرض تصفيتها وقراءتها بطريقة مناسبة، مكنت نتائج البحث من استخلاص معادلة تجريبية يمكن استخدامها لقياس سرعة وقود غازي بارافييني طباقية، لقد أعطت النتائج العملية عمليات حسابية مقبولة مقارنة بنتائج بحوث سابقة.

INTRODUCTION

There are many applications of combustion which is occurred in either a flame or nonflame mode. Flames in turn are categorized as being either premixed flames or nonpremixed (diffusion) flames. The two classes of flames are related to the state of mixedness of the reactants (Kwon, 1992).

In premixed flame, the fuel and the oxidizer are mixed at the molecular level prior to the occurrence of any significant chemical reaction. In diffusion flame, the reactants are initially separated and reaction occurs only at the interface between the fuel and oxidizer, where mixing and reaction both tack place (Karim, 1985).

The study of laminar and turbulent flame propagation is important to the analysis of the confined flame and unconfined flame which may occur when the combustion process tacks place in an open vessel or in an unlimited size (Tseng, 1995).

One of the distinguished features of laminar premixed flames is burning velocity. It is found that a detailed knowledge of laminar premixed flames will provide insights into properties such as heat release rates, flammability limits, propagation rates, quenching, and emissions. The production of accurate measurements on laminar premixed flames plays a key role in process of understanding a large range of flames (Dugger, 1955).

There are several computing methods for determining a laminar burning velocity (LEV). They are divided to stationary and nonstationary flame methods. The counter flow burner method is convenient for both liquid and gaseous fuels, with a good control of mixture composition. 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. A wide range of temperatures and pressures can be calculated (Iijima, 1986).

The aim of this paper is to show how the LEV can be measured using thermocouples at different initial pressure. A data acquisition system is designed and used for this purpose.

Techniques of flame speed measurements

The measuring of flame speed needs a special technique for detection of flame front arrival along a certain space, therefore many investigators worked hard to find out the different techniques of measuring flame speed.

Thermocouple technique

The flame is propagated inside the flame chamber passing over many thermocouple junctions located or inserted inside the chamber. The thermocouple can be used as a sensor probe (Hameed, 1997 & Gulder, 1983).

Ionized probe

Combustion operation is a fast chemical reaction. This phenomenon happens because of the ionization of reacting atoms. At this level the chemical reaction happens using ionization probes inserted into the chamber one monitors the instantaneous flame position (Gulder 1983, Gulder 1984 and Iijima & Takeno 1986) have used this technique. This technique cannot give the real position of the flame front because of the ionization levels stay high behind the flame front.

Optical technique

Depending upon optical technique used, it is difficult to obtain an accurate of flame front because of the bounded thickness for reaction area. The flame front consists of four zones; visible zone, reaction zone, Schlieren zone and shadow zone (Chang, 1983 and Kwon et. al, 1992).

Density Ratio Method

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$$Su = S_f \frac{\rho_b}{\rho_u}$$

$$Su = S_f * N * \frac{T_u}{T_b} * I$$

The flame-speed is related to burning velocity during the pre-pressure period. This method was used by (Tseng et. al, 1995); (Hayder 1997), (Hani 1998), (Ahmed 2003) and (Esam 2002).

EXPERMINTAL SETUP

Data acquisition system

The computer control system is used to read the flame speed inside the cylinder. Six thermocouples were used fixed inside the cylinder which is distributed regularly as shown in Figure 1. They are connected to computer in order to collect, process and display the data. These collected data are getting at a very short time period. An interface circuit is built between the sensors and the computer. The thermocouple signals are reading through the parallel port. Figure 2 shows the demonstration for the hardware and software of the control system.

Hardware interface

The combustion chamber contains six thermocouples. Three of them represent start signals and the other three used as stop (end) signals. Figure 4 illustrates the thermocouple interface. A bidirectional buffer is used to control the direction of data. The computer program scans the six buffered signals and detects the start and stop signals.

The ignition circuit is used to furnish the power needed by the sparking coil, and to have the ability of precious timing of the spark start and end related to other parameters in the chamber. The timing and control circuit is needed to produce all the signals controlling the timing periods and time delays between events in the whole process from the start of ignition till the transfer of data to the computer. Figure 5 shows the timing and control circuit.

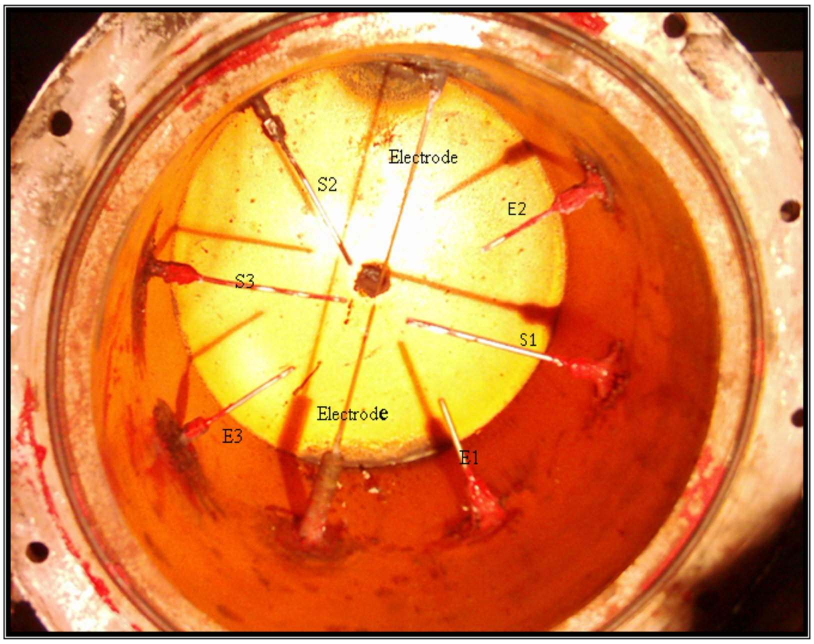

Fig. 1, the internal structure of combustion chamber

Distances between the ignition center and sensors are:

I.C – S_1 is 2 cm
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I.C is Ignition Center
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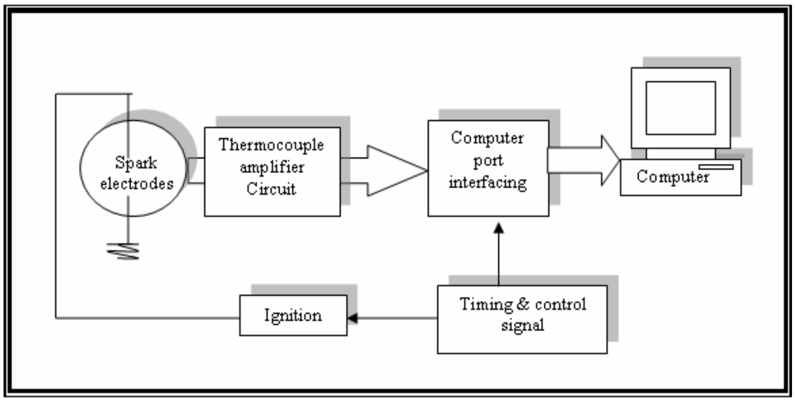

Fig. 2, Block diagram of interfacing circuit

Software system

A program is used to configure, read, filter, process and calculate the results. It acquires the data through the parallel port. Each of the start and stop signal is represented by one bit. The data is accumulated in a buffer of 50000 bytes. This buffer will be processed such that all reading data will be searched for starting bits and ending bits for each sensor. After that the program will calculated the time between each start and end bit flags.

Equivalenc ratio measurments

To prepare the mixture (fuel-air), a gas mixer has been designed and constructed for hydrocarbon compounds that have a low partial pressure like (methane, propane, LPG & butane). The main purpose of preparing the fuel-air mixture in the mixing unit rather than in the cylinder is to increase the total pressure of the mixture and consequently increase the partial pressure of hydrocarbon fuel to increase the accuracy.

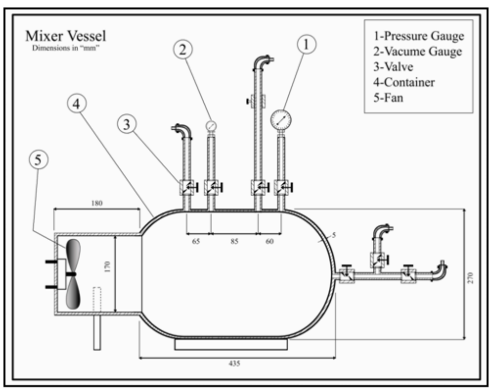

Fig. 3, Mixture preparing unit diagram

The mixer is made of (iron-steel); it has a cylindrical shape without any skirt to improve the efficiency of mixing operation. Mixer dimensions are (435mm) length, (270mm) diameter and (5 mm) thickness as shown in Fig. 3. It undergoes a pressure of more than (60 bar) and also withstands high temperatures. The mixing unit has five holes of (12.7mm) in diameter. Two holes are used to fix the pressure gauge and vacuum gauge, the third is for admitting the dry air to the mixing unit from the compressor through the filter dryer, the fourth hole is for admitting the fuel from the fuel cylinder through pressure gauge regulator and the last hole admits the homogeneous mixture to the combustion chamber.

A cover is added on one side of the mixer in order to connect the fan to a power source of (12volt) DC. Through a glass sealed electrical connections, which are sealed completely to prevent any leakage of gas to improve the mixing operation and obtain a homogenous mixture. All welding in the cylinder is done using Argon welding, and tested by increasing the internal pressure of the cylinder to avoid any leakage.

Preparation of the fuel-air mixture

The mixture preparation process has an important role in measuring the burning velocity. The process performed is based on partial pressure of mixture components and according to Gibbs-Dalton Law, to obtain an accurate equivalence ratio, because the ratio has effect on flame speed. The preparation of the mixture is done inside a mixing box, which was designed for this purpose. The partial pressure for hydrocarbons (methane, propane, butane and LPG) is low so this method is used to obtain an increasing partial pressure for the used hydrocarbon fuels. The mixture is prepared to a total pressure (5bar) for each hydrocarbon fuel according to the following steps:

1- The secondary mixing box is sufficiently purged of air or any previous mixture used in previous experiments, so that it reaches approximately (0.001 bar) pressure. The flashing process is done by admitting dry air to the box till it reaches a pressure of (1 atm). This process is repeated three times to be certain that the mixing box is completely flushed.

2- After the third flushing process, the box will be vacuumed. The gas fuel (methane, propane, LPG and butane) will be admitted to the mixing box then vacuumed. This process is repeated for one or two times such that all the components in the mixing box will be filled with gas fuel only.

3- After the vacuum process of the mixing box is performed as shown in the first two steps to prepare it for a new charge, a predetermined amount of gas fuel will be admitted to the mixing box according to the partial pressure (read from vacuum gauge) that is fixed on the box relative to one atmosphere such that the pressure valve stayes closed during the process time to ensure that it is not damaged.

4- Dry air will be admitted to the box till it reaches mixture pressure of (1 atm).

5- The vacuum pressure valve will be closed and the pressure valve will be opened, to compress the dry air using a compressor to a total pressure of (5bar) absolute for a certain equivalence ratio (lean, stoichiometric or rich).

6- To obtain a homogenous mixture a mixing fan is operated for (3-5 minutes).

7- The fan is stopped for a while in order to prepare the combustion chamber for a new experiment.

8- In this step, the cylinder is vacuumed from the previous combustion product components using a vacuum pump to a pressure of (0.001 bar) then air is admitted to the cylinder to a pressure of (1 atm) and vacuumed again, this operation is repeated for three times to ensure there is no combustion producted left from the previous experiments.

9- After the cylinder is completely vacuumed, some of the homogeneous mixture will be admitted to the cylinder and then vacuumed, this operation is done twice to ensure that only the homogenous mixture is in the cylinder.

10- After being completely vacuumed the cylinder, the homogeneous mixture will be admitted to the cylinder from the mixer at the wanted pressure and left for (5 min) before ignition to obtain a laminar flame and obtain a mixture free of turbulence and eddies, then the mixture will be ready for ignition. Meanwhile, the computer and ignition system will be prepared.

RESULTS and DISCUSSION

Laminar burning velocity is an important physicochemical parameter of a combustible mixture. It contains the basic information regarding diffusivity, exothermicity and reactivity. The extensive effort expended to accurately determine their values especially those of the conventional hydrocarbon air mixtures. Many measurements have been made in order to determine the burning velocities of different fuel-oxidant mixtures. The LEV depends on the composition, temperature and pressure of the initial mixture and the fuel molecular structure.

Figures (6-12) show the burning velocity results of methane, propane, LPG, and butane air mixtures. The density ratio method which was employed depends on the measured flame speed initial pressure and initial mixture temperature. The effects of equivalence ratio, initial pressure and number of carbon atoms on the burning velocity were taken into consideration.The following imperical equation can be derived from the practical results:

$$Su = \beta (P)^{\alpha} (nc)^{\gamma}$$

Where:

$$\beta = -107.41119 + 297.54962\phi - 162.06667\phi^2 + 11.964077\phi^3$$

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

$$\gamma = -1.20457 + 1.79413\phi - 0.797576\phi^2$$

The derived empirical equation can be used with an error about (±5.8%) calculated using the following equation

$$E_{abs} = \left| value_{\exp} - value_{theo} \right|$$

$$Error = \frac{\overline{E}_{abs}}{R_{\max}}$$

Where $\overline{E}_{abs}$ = Average absolute error $\left[\frac{1}{N} \sum_{i=1}^{N} E_{abs}(i) \right]$

R_{max}= Maximum burning velocity from experimental data.

N= number of data measured.

The equation (6.21) is used under the following conditions

$0.6 \le \Phi \le 1.5$, $1 \le nc \le 4$, $0.5 \le P \le 1.5$, Tu=300K and P_0=1 atm, T_0=298K.

From the above mensioned figures, it is seen that the studied researches didn't take any accounts of the effects of number of carbon atoms and combustion chamber geometry except the work that was done by (Arkan, 2000) and (Esam, 2002), which took in consideration the effect of number of carbon atoms upon the laminar burning velocity of paraffines family.

So; the present work represents an attempt to add a new emprical equation for laminar burning velocity of (methane, propane, LPG and butane)-air mixtures (i.e. paraffines family) that takes in consideration the effects of equivalence ratio (Φ), number of carbon atoms and the initial pressure (P), to be applicable under certain conditions, the derived equation also takes into account the effects of both equivalence ratio and initial pressure upon the laminar burning velocity under laboratory conditions (Su_0) and the exponent of the number of carbon atoms (γ). Fig (6) shows the effect of equivalence ratio (Φ) and number of carbon atoms (nc) upon the laminar burning velocity of the hydrocarbons under consideration according to the derived equation observed that the laminar burning velocity decrease with the increasing of the number of carbon atoms from (nc=1) to (nc=4); figures (7 to12) show a comparison between the results of the derived equation using a cylinder and that obtained experimentally in this research with the available published results of other investigators taking in consideration the variation of equivalence ratio, it can be observed that the agreement is acceptable and that confirms the validity of derived equation.

A comparison of the results of derived equation with that published for Ethane-air mixture is shown in Fig (13). It can be observed that they are agreed and that confirms the derived empirical equation to other types of fuel in paraffin family.

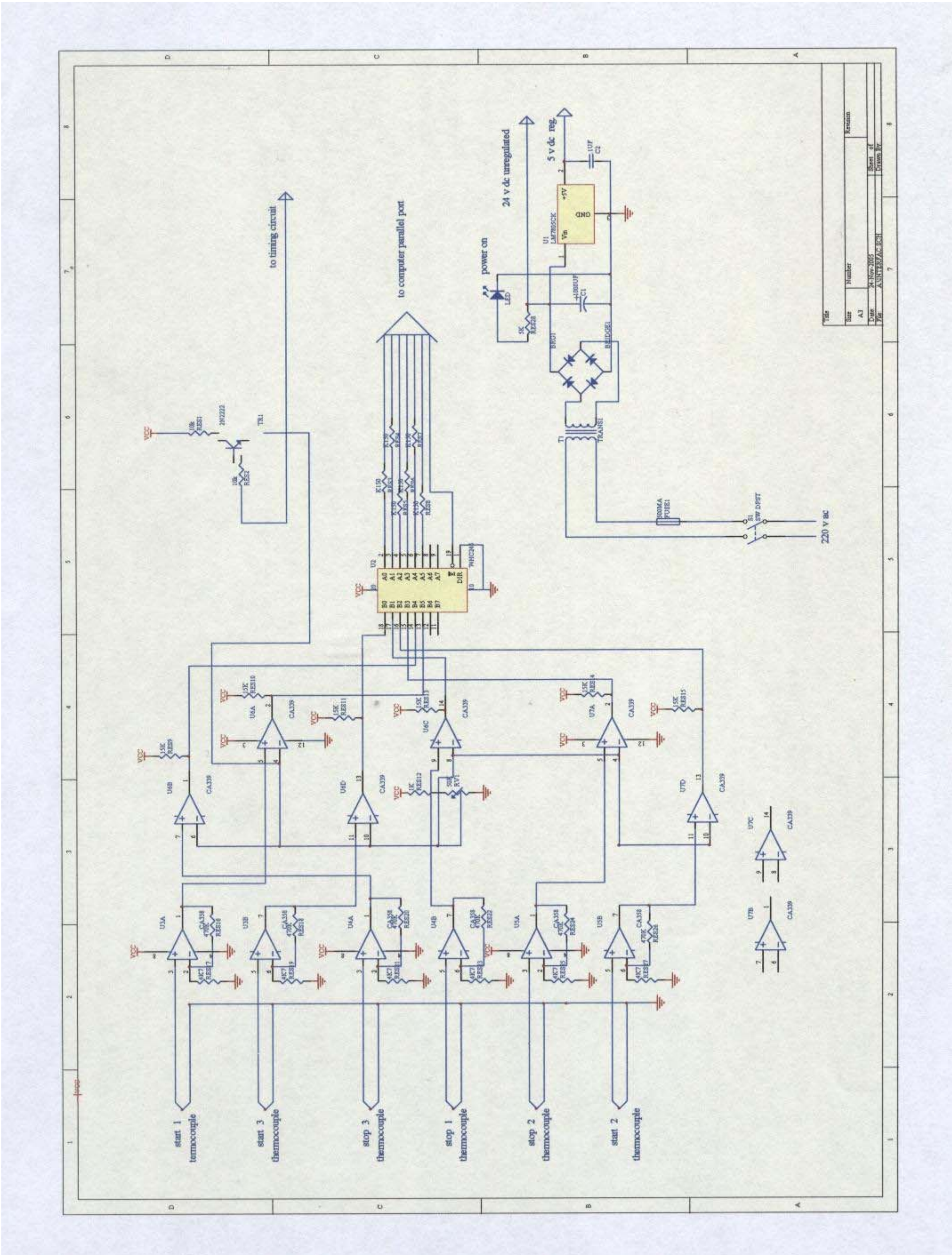

Fig. 4. Amplifier and Interfacing Circuit

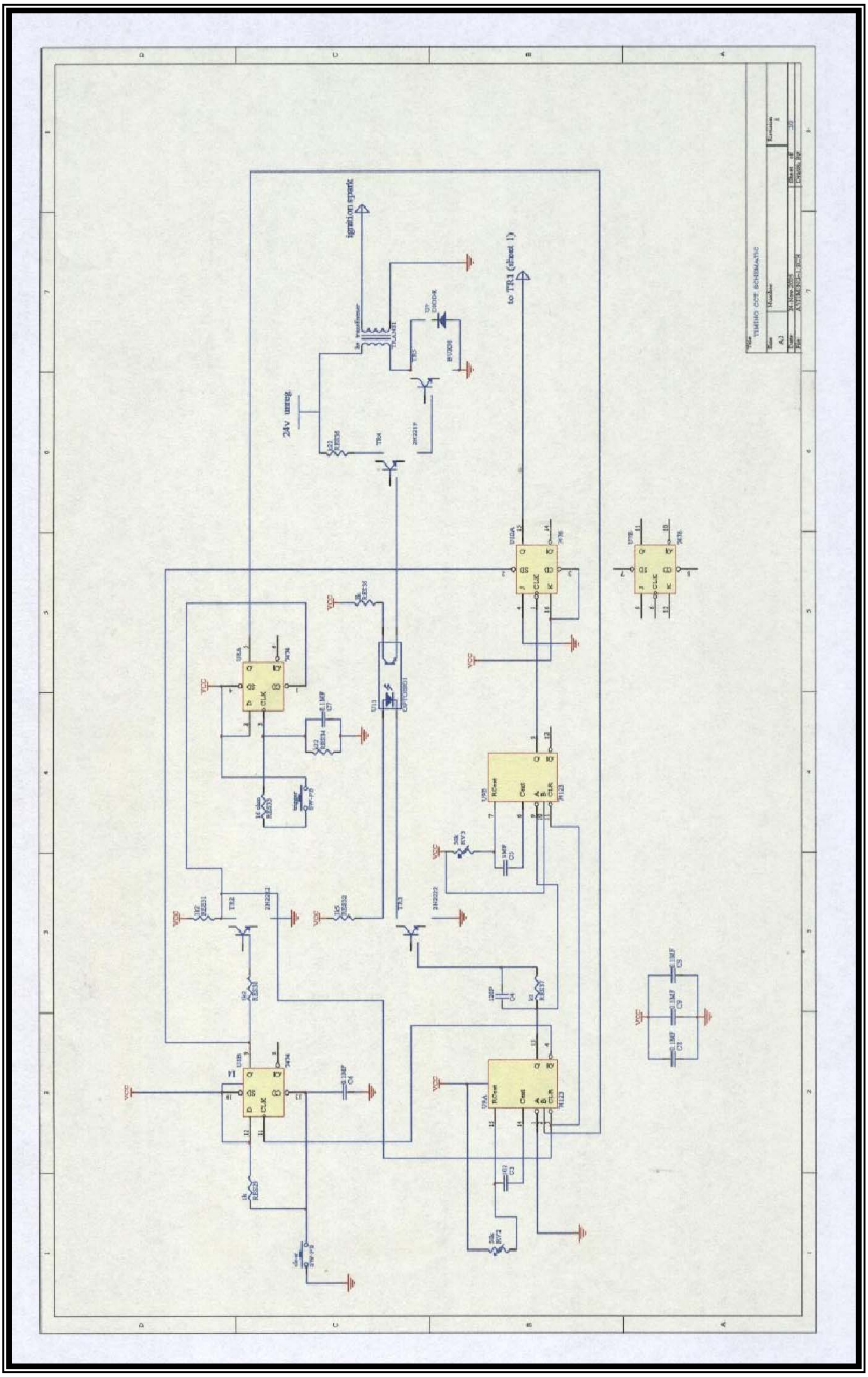

Fig. 5, Timing and Control Circuit

CONCLUSIONS

1- A modern technique that uses a computer in the measurement system to get the best results has been employed for the measurement of laminar flame speed.

2- The measurement of laminar flame speed has been obtained during the pre-pressure period of combustion using density ratio method. The laminar burning velocity and flame temperature of (methane, propane, LPG, and butane)-air mixture were taken over a wide range of equivalence ratios and at different initial pressures.

3- The laminar burning velocity increases at low initial pressure. In this work the laminar burning velocity is considered at vacuum through the pressurized environment before ($0.5 \leq P \leq 1.5$) while most published works considere either vacuum or pressureized environment, and the adiabatic flame temperature increases with the increasing of initial pressure for all types of fuel used.

4- The analysis of present work shows that as the fuel molecular weight (number of carbon atoms in fuel) increases, the laminar burning velocity decreases, and vice-versa.

5- An empirical equation has been obtained that takes into consideration the effects of equivalence ratio, initial pressure and number of carbon atoms upon the laminar burning velocity. The values of laminar burning velocity calculated from this equation show an acceptable agreement with the published work. So this equation (empirical equation) can be used to calculate the burning velocities of any gas of paraffin family with an estimated error of (±5.8 %).

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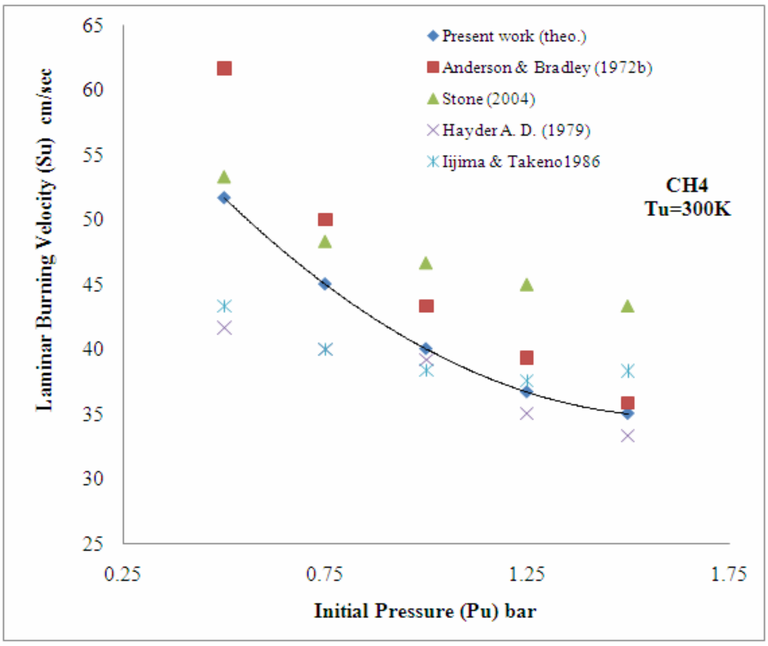


Fig. 6, Compareson between present work (emperical equation) for stoichiometric methane-air flames, with selected values from the

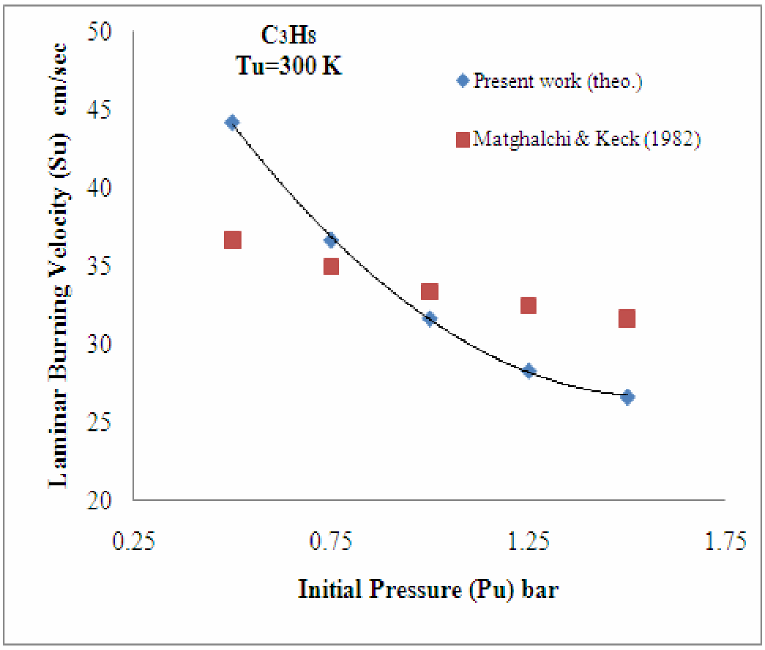


Fig. 7, Compareson between present work (emperical equation) for stoichiometric propane-air flames, with selected values from the literatures, at different pressures.

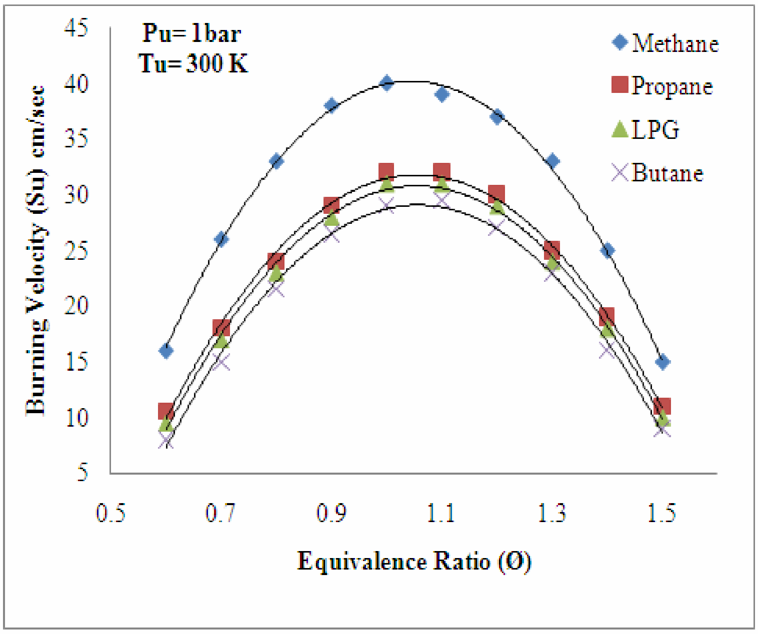


Fig. 8, Variation in burning velocity with equivalence raio for different mixtures according to the results of the emperical equation

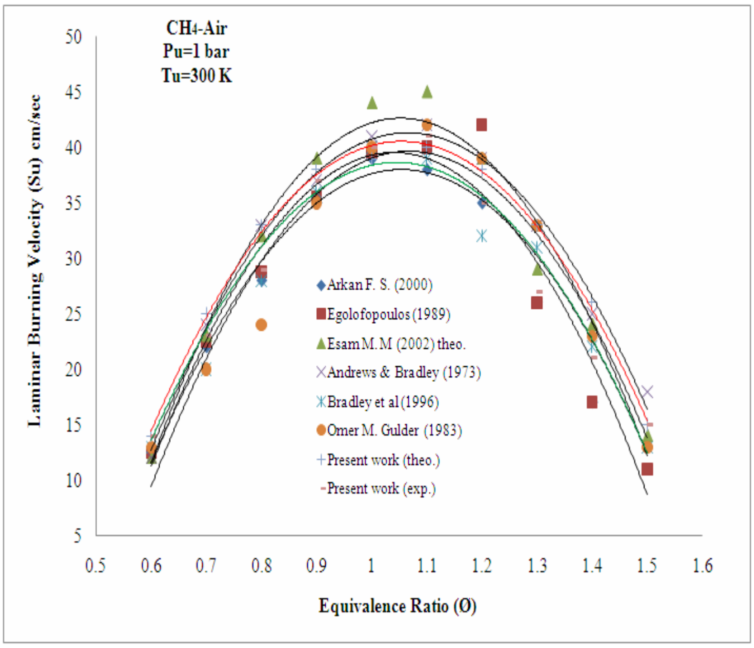


Fig. 9, Compareson of emperical equation results with the buplished results of methane – air mixtures.

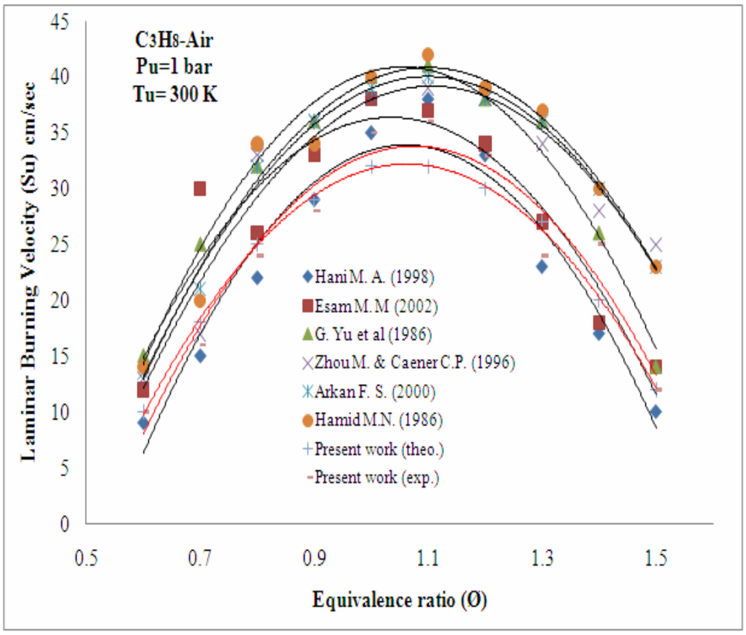


Fig. 10, Compareson of emperical equation results with the buplished results of propane – air mixtures.

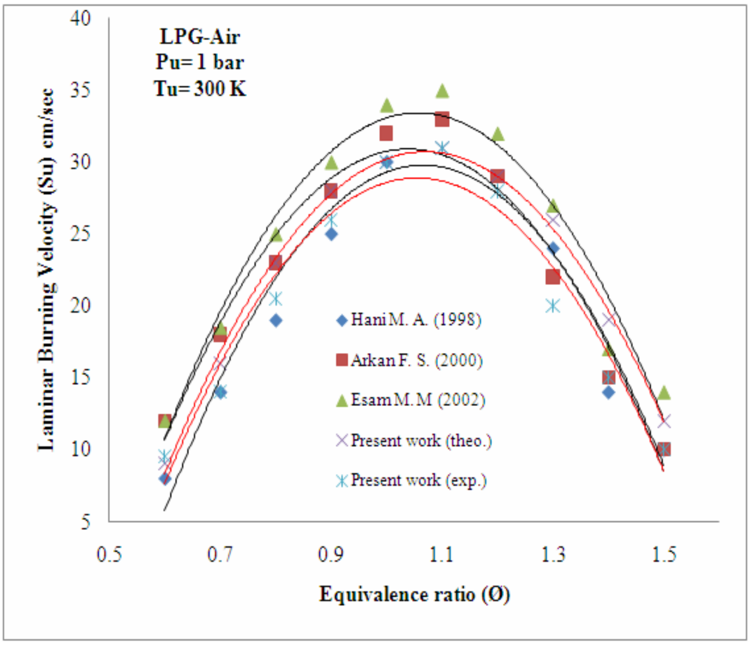


Fig. 11, Compareson of emperical equation results with the buplished results of LPG – air mixtures.

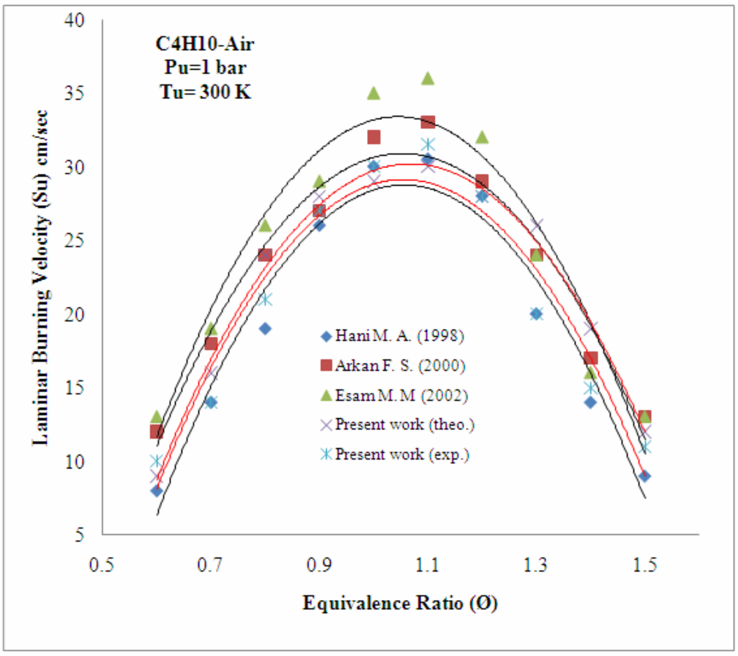
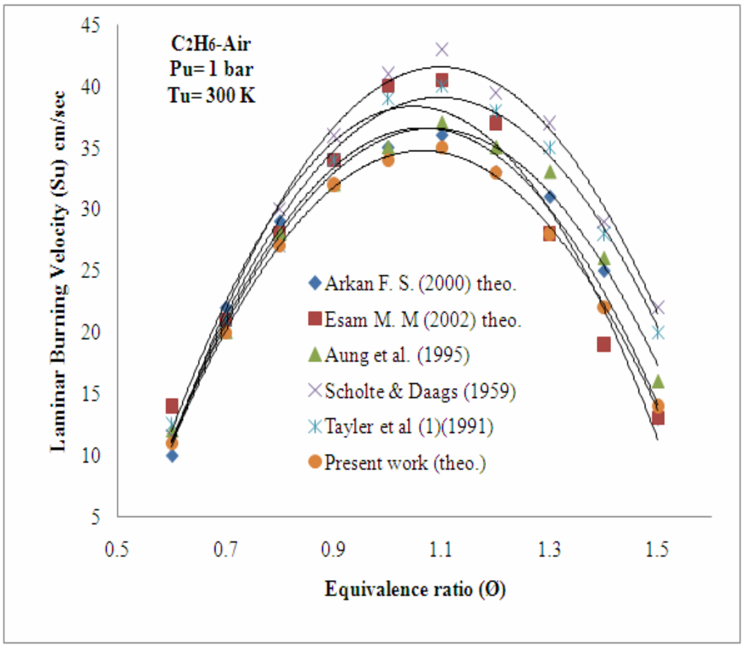


Fig. 12, Compareson of emperical equation results with the buplished results of butane – air mixtures.



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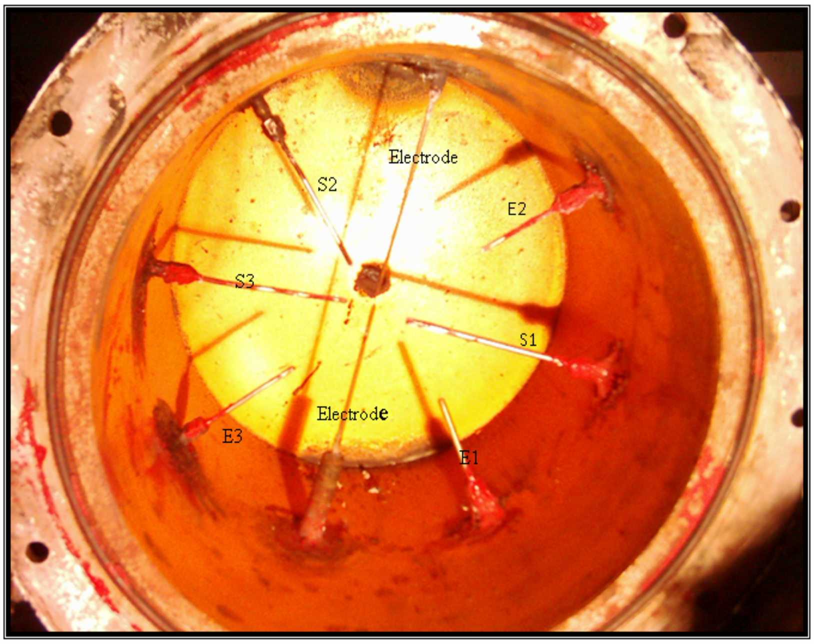

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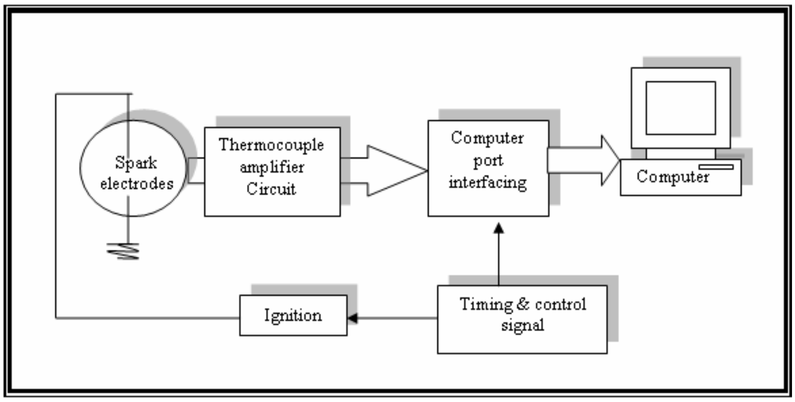

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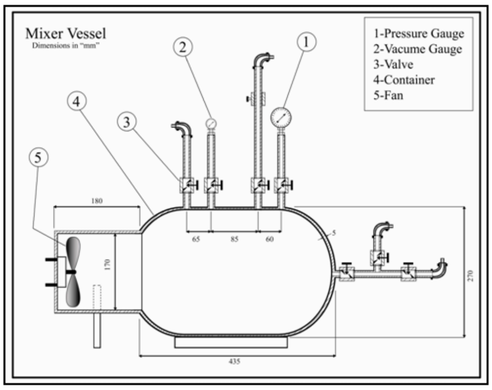

Fig. 3, Mixture preparing unit diagram

The mixer is made of (iron-steel); it has a cylindrical shape without any skirt to improve the efficiency of mixing operation. Mixer dimensions are (435mm) length, (270mm) diameter and (5 mm) thickness as shown in Fig. 3. It undergoes a pressure of more than (60 bar) and also withstands high temperatures. The mixing unit has five holes of (12.7mm) in diameter. Two holes are used to fix the pressure gauge and vacuum gauge, the third is for admitting the dry air to the mixing unit from the compressor through the filter dryer, the fourth hole is for admitting the fuel from the fuel cylinder through pressure gauge regulator and the last hole admits the homogeneous mixture to the combustion chamber.

A cover is added on one side of the mixer in order to connect the fan to a power source of (12volt) DC. Through a glass sealed electrical connections, which are sealed completely to prevent any leakage of gas to improve the mixing operation and obtain a homogenous mixture. All welding in the cylinder is done using Argon welding, and tested by increasing the internal pressure of the cylinder to avoid any leakage.

Preparation of the fuel-air mixture

The mixture preparation process has an important role in measuring the burning velocity. The process performed is based on partial pressure of mixture components and according to Gibbs-Dalton Law, to obtain an accurate equivalence ratio, because the ratio has effect on flame speed. The preparation of the mixture is done inside a mixing box, which was designed for this purpose. The partial pressure for hydrocarbons (methane, propane, butane and LPG) is low so this method is used to obtain an increasing partial pressure for the used hydrocarbon fuels. The mixture is prepared to a total pressure (5bar) for each hydrocarbon fuel according to the following steps:

1- The secondary mixing box is sufficiently purged of air or any previous mixture used in previous experiments, so that it reaches approximately (0.001 bar) pressure. The flashing process is done by admitting dry air to the box till it reaches a pressure of (1 atm). This process is repeated three times to be certain that the mixing box is completely flushed.

2- After the third flushing process, the box will be vacuumed. The gas fuel (methane, propane, LPG and butane) will be admitted to the mixing box then vacuumed. This process is repeated for one or two times such that all the components in the mixing box will be filled with gas fuel only.

3- After the vacuum process of the mixing box is performed as shown in the first two steps to prepare it for a new charge, a predetermined amount of gas fuel will be admitted to the mixing box according to the partial pressure (read from vacuum gauge) that is fixed on the box relative to one atmosphere such that the pressure valve stayes closed during the process time to ensure that it is not damaged.

4- Dry air will be admitted to the box till it reaches mixture pressure of (1 atm).

5- The vacuum pressure valve will be closed and the pressure valve will be opened, to compress the dry air using a compressor to a total pressure of (5bar) absolute for a certain equivalence ratio (lean, stoichiometric or rich).

6- To obtain a homogenous mixture a mixing fan is operated for (3-5 minutes).

7- The fan is stopped for a while in order to prepare the combustion chamber for a new experiment.

8- In this step, the cylinder is vacuumed from the previous combustion product components using a vacuum pump to a pressure of (0.001 bar) then air is admitted to the cylinder to a pressure of (1 atm) and vacuumed again, this operation is repeated for three times to ensure there is no combustion producted left from the previous experiments.

9- After the cylinder is completely vacuumed, some of the homogeneous mixture will be admitted to the cylinder and then vacuumed, this operation is done twice to ensure that only the homogenous mixture is in the cylinder.

10- After being completely vacuumed the cylinder, the homogeneous mixture will be admitted to the cylinder from the mixer at the wanted pressure and left for (5 min) before ignition to obtain a laminar flame and obtain a mixture free of turbulence and eddies, then the mixture will be ready for ignition. Meanwhile, the computer and ignition system will be prepared.

RESULTS and DISCUSSION

Laminar burning velocity is an important physicochemical parameter of a combustible mixture. It contains the basic information regarding diffusivity, exothermicity and reactivity. The extensive effort expended to accurately determine their values especially those of the conventional hydrocarbon air mixtures. Many measurements have been made in order to determine the burning velocities of different fuel-oxidant mixtures. The LEV depends on the composition, temperature and pressure of the initial mixture and the fuel molecular structure.

Figures (6-12) show the burning velocity results of methane, propane, LPG, and butane air mixtures. The density ratio method which was employed depends on the measured flame speed initial pressure and initial mixture temperature. The effects of equivalence ratio, initial pressure and number of carbon atoms on the burning velocity were taken into consideration.The following imperical equation can be derived from the practical results:

$$Su = \beta(P)^{\alpha}(nc)^{\gamma}$$

Where:

$$\beta = -107.41119 + 297.54962\phi - 162.06667\phi^2 + 11.964077\phi^3$$

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

$$\gamma = -1.20457 + 1.79413\phi - 0.797576\phi^2$$

The derived empirical equation can be used with an error about (±5.8%) calculated using the following equation

$$E_{abs} = \left|value_{\exp} - value_{theo}\right|$$

$$Error = \frac{\overline{E}_{abs}}{R_{\max}}$$

Where $\overline{E}_{abs}$ = Average absolute error $\left[\frac{1}{N}\sum_{i=1}^{N} E_{abs}(i)\right]$

R_{max}= Maximum burning velocity from experimental data.

N= number of data measured.

The equation (6.21) is used under the following conditions

$0.6 \le \Phi \le 1.5$, $1 \le nc \le 4$, $0.5 \le P \le 1.5$, Tu=300K and P_0=1 atm, T_0=298K.

From the above mensioned figures, it is seen that the studied researches didn't take any accounts of the effects of number of carbon atoms and combustion chamber geometry except the work that was done by (Arkan, 2000) and (Esam, 2002), which took in consideration the effect of number of carbon atoms upon the laminar burning velocity of paraffines family.

So; the present work represents an attempt to add a new emprical equation for laminar burning velocity of (methane, propane, LPG and butane)-air mixtures (i.e. paraffines family) that takes in consideration the effects of equivalence ratio (Φ), number of carbon atoms and the initial pressure (P), to be applicable under certain conditions, the derived equation also takes into account the effects of both equivalence ratio and initial pressure upon the laminar burning velocity under laboratory conditions (Su_0) and the exponent of the number of carbon atoms (γ). Fig (6) shows the effect of equivalence ratio (Φ) and number of carbon atoms (nc) upon the laminar burning velocity of the hydrocarbons under consideration according to the derived equation observed that the laminar burning velocity decrease with the increasing of the number of carbon atoms from (nc=1) to (nc=4); figures (7 to12) show a comparison between the results of the derived equation using a cylinder and that obtained experimentally in this research with the available published results of other investigators taking in consideration the variation of equivalence ratio, it can be observed that the agreement is acceptable and that confirms the validity of derived equation.

A comparison of the results of derived equation with that published for Ethane-air mixture is shown in Fig (13). It can be observed that they are agreed and that confirms the derived empirical equation to other types of fuel in paraffin family.

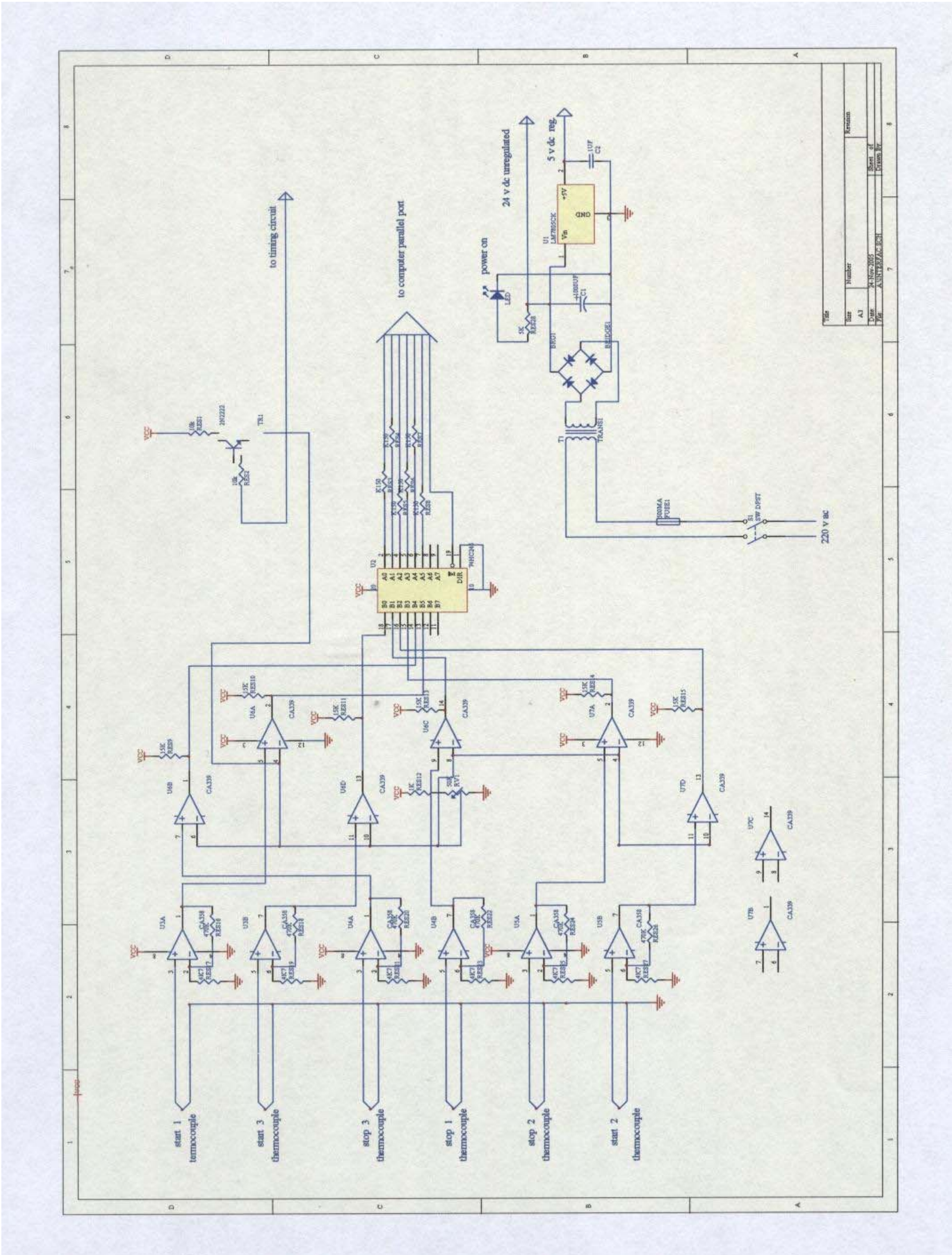

Fig. 4. Amplifier and Interfacing Circuit

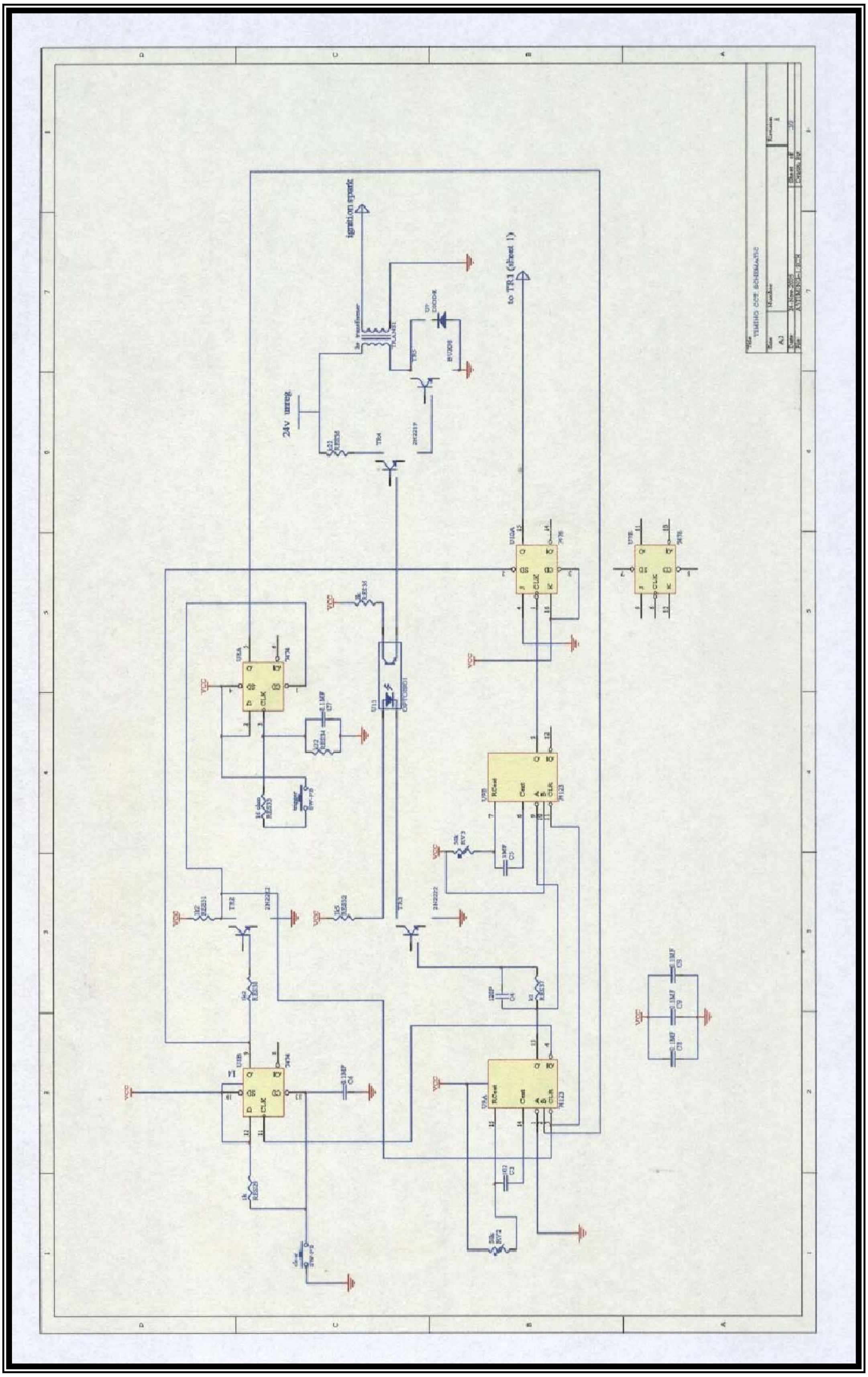

Fig. 5, Timing and Control Circuit

CONCLUSIONS

1- A modern technique that uses a computer in the measurement system to get the best results has been employed for the measurement of laminar flame speed.

2- The measurement of laminar flame speed has been obtained during the pre-pressure period of combustion using density ratio method. The laminar burning velocity and flame temperature of (methane, propane, LPG, and butane)-air mixture were taken over a wide range of equivalence ratios and at different initial pressures.

3- The laminar burning velocity increases at low initial pressure. In this work the laminar burning velocity is considered at vacuum through the pressurized environment before ($0.5 \leq P \leq 1.5$) while most published works considere either vacuum or pressureized environment, and the adiabatic flame temperature increases with the increasing of initial pressure for all types of fuel used.

4- The analysis of present work shows that as the fuel molecular weight (number of carbon atoms in fuel) increases, the laminar burning velocity decreases, and vice-versa.

5- An empirical equation has been obtained that takes into consideration the effects of equivalence ratio, initial pressure and number of carbon atoms upon the laminar burning velocity. The values of laminar burning velocity calculated from this equation show an acceptable agreement with the published work. So this equation (empirical equation) can be used to calculate the burning velocities of any gas of paraffin family with an estimated error of (±5.8 %).

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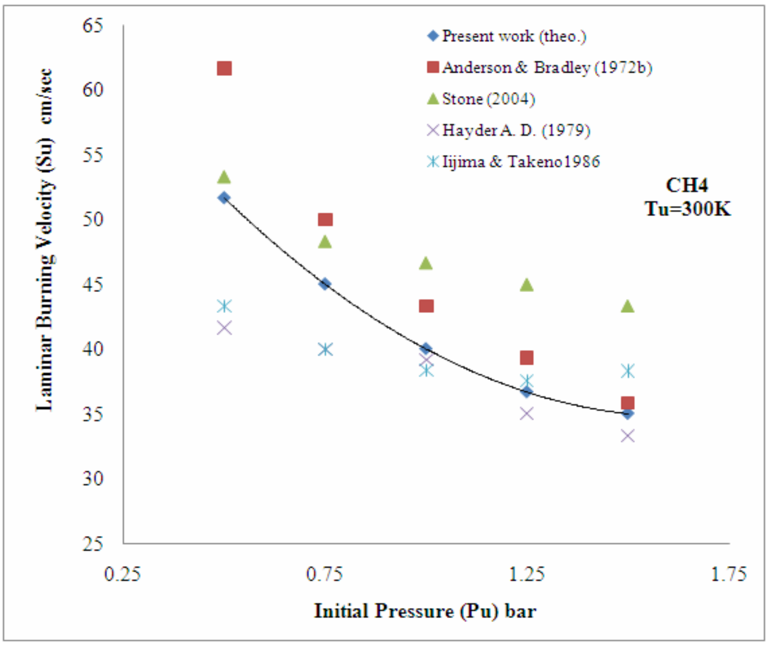

Fig. 6, Compareson between present work (emperical equation) for stoichiometric methane-air flames, with selected values from the

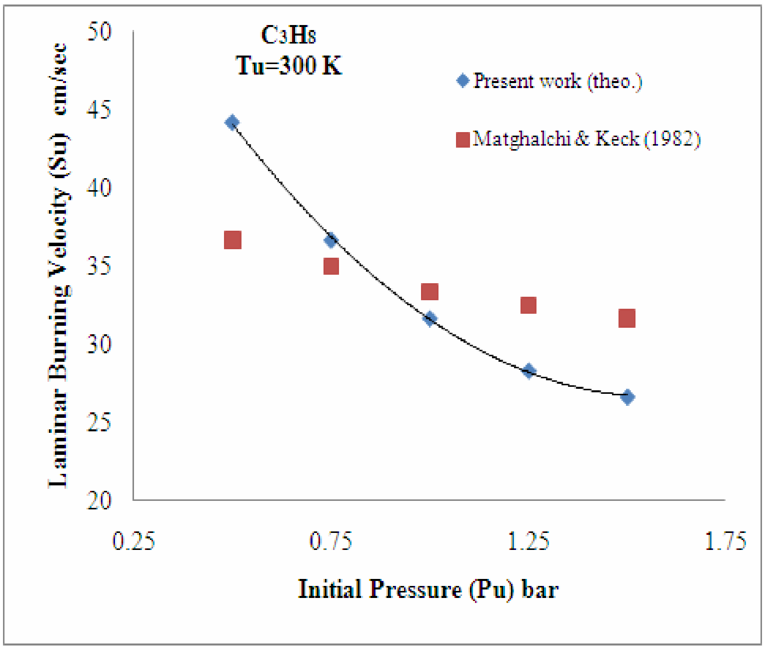

Fig. 7, Compareson between present work (emperical equation) for stoichiometric propane-air flames, with selected values from the literatures, at different pressures.

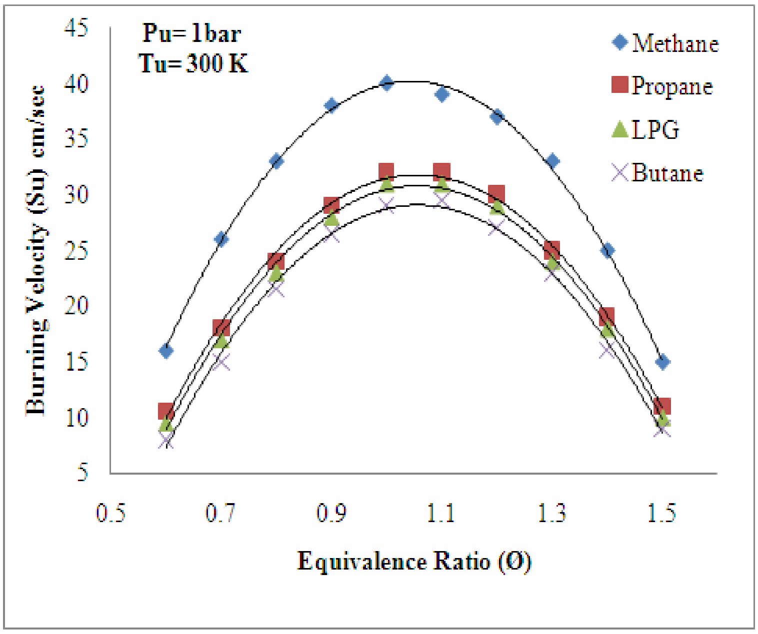

Fig. 8, Variation in burning velocity with equivalence raio for different mixtures according to the results of the emperical equation

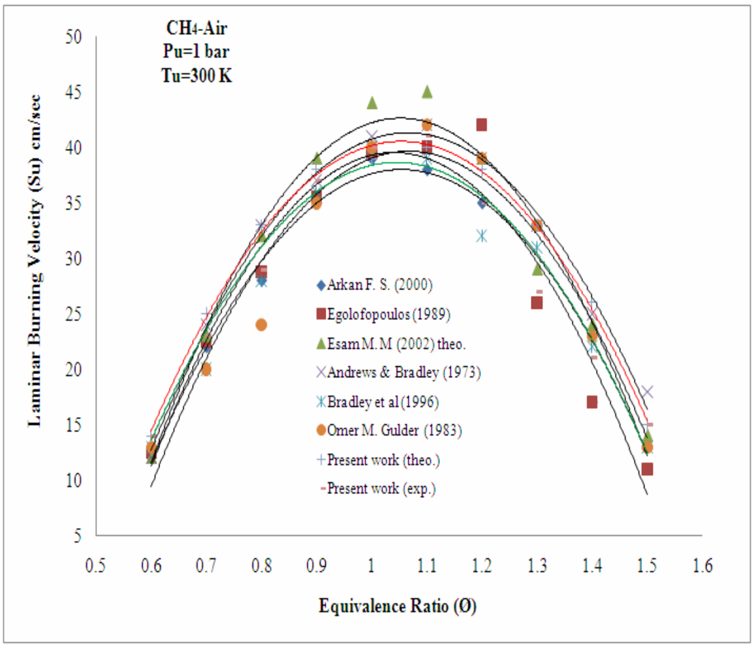

Fig. 9, Compareson of emperical equation results with the buplished results of methane – air mixtures.

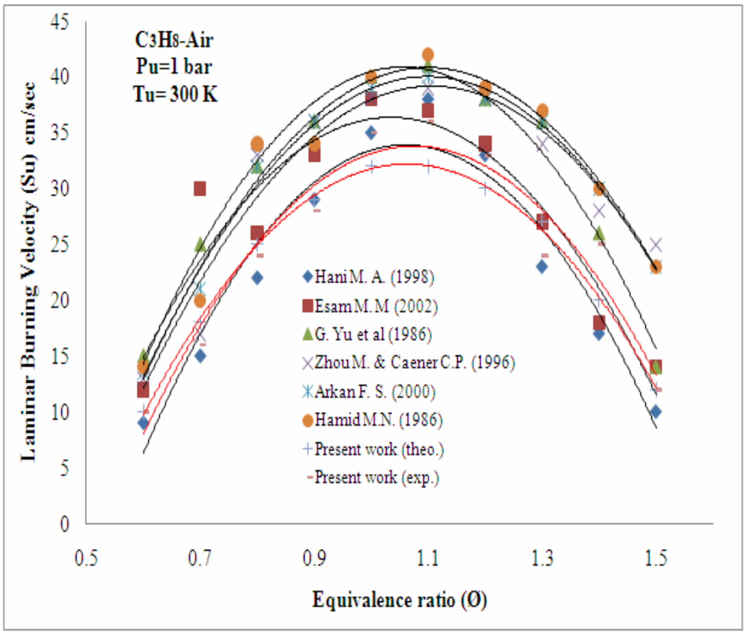

Fig. 10, Compareson of emperical equation results with the buplished results of propane – air mixtures.

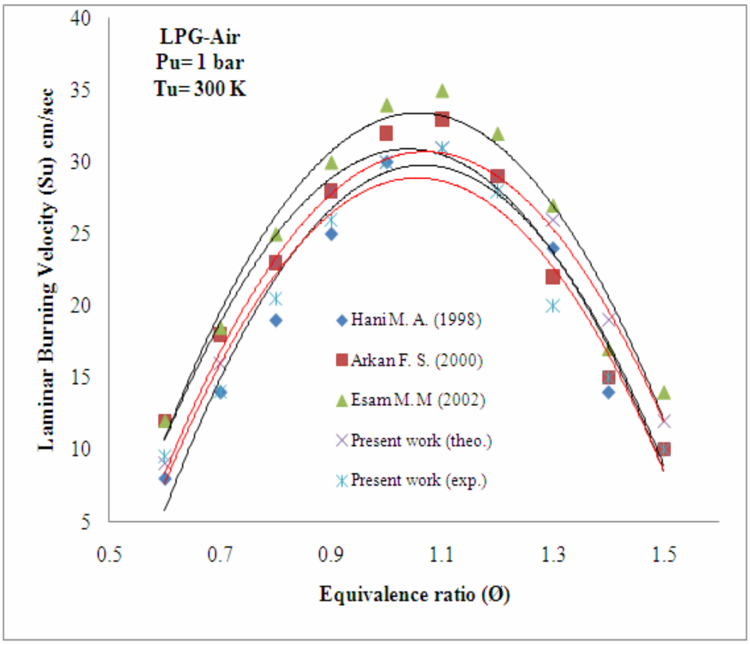

Fig. 11, Compareson of emperical equation results with the buplished results of LPG – air mixtures.

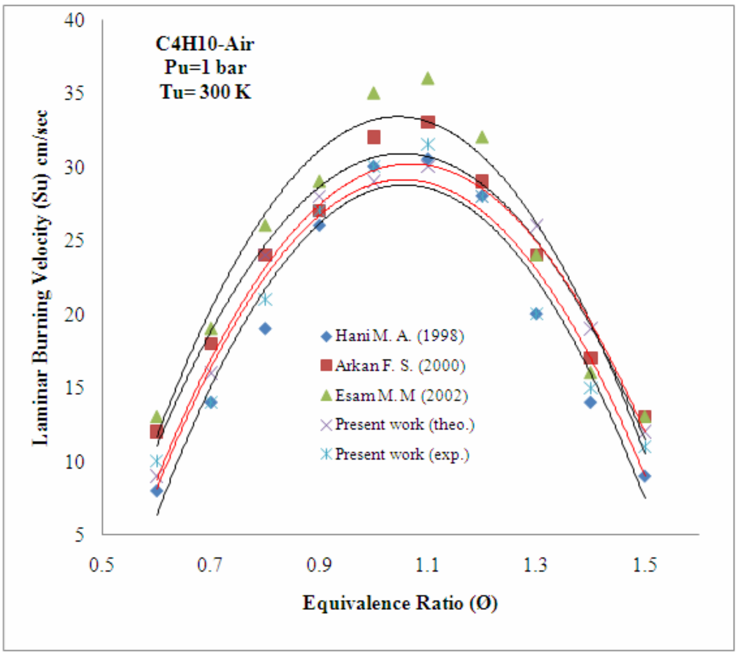

Fig. 12, Compareson of emperical equation results with the buplished results of butane – air mixtures.

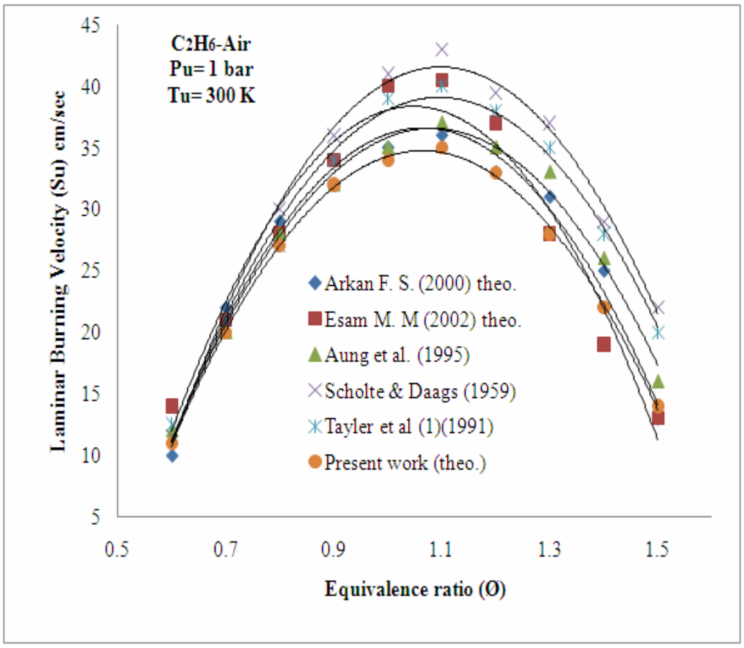

Fig. 13, Compareson of emperical equation results with the buplished results of ethane – air mixtures.