The Effect of Initial Temperature on Burning Velocity of Hydrogen – Air Mixtures

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Abstract

In present work, the burning velocity of hydrogen-Air mixtures varies with hydrogen concentration and initial temperature of the unburned mixture. Laminar flame speed has been measured experimentally inside tube using the optical technique. The experimental work was carried out in a pre-pressure period in order to apply the density ratio method for calculation of laminar burning velocity. Mixture strength and unburned mixture temperature dependence of burning velocity is represented by empirical function over the ranges of hydrogen concentration (x_{H2} = 10 – 70 %) and unburned temperature (Tu = 298K– 348K), which is extended to (473K) through the previously published data all at a pressure of (1 atm). In overlapping ranges, the results show good agreement with those previously published.

الخلاصة

تم في هذا البحث قياس سرعة انتشار اللهب الطباقية (Laminar Burning Velocity) لخلائط الهيدروجين مع الهواء المسبقة الخلط باستخدام طريقة الأنبوب والتقنية البصرية) الخلايا الضوئية(ولمدى واسع من تركيز الهيدروجين في قياس الزمن الذي تستغرقه جبهة اللهب في الخليط ولمسافة محددة. وتم قياس درجة حرارة اللهب باستخدام هذه الخلايا الضوئية .

كما تم دراسة تأثير تغير درجة الحرارة الابتدائية) درجة حرارة الغاز غير المحترق (على سرعة انتشار اللهب الطباقية . جميع تلك القياسات أجريت خلال فترة ثبوت الضغط Pressure Period ( )-Pre وذلك لاستخدام طريقة نسبة الكثافة (Density Ratio Method) في حساب سرعة انتشار اللهب الطباقية عند الظروف المختلفة.

النتائج التي تم الحصول عليها لسرعة انتشار اللهب كانت مقاربة للنتائج العملية المنشورة ووجود توافق بينها .

تم كذلك اشتقاق معادلة تطبيقية لسر عة انتشار اللهب الطباقية للنتائج التي تم الحصول عليها إضافة إلى النتائج المنشورة سابقاً . المعادلة تأخذ بنظر الاعتبار تأثير نسبة تركيز الهيدروجين ودرجة الحرارة الابتدائية على سرعة انتشار اللهب الطباقية، والتأثير المتبادل لهذه المتغيرات على بعضها البعض .

: Nomenclature

I : Flame thickness factor
N: Mole Ratio = moles of unburned gases in equilibrium at (T_{ad}) per moles of burned gases.
S_f : Laminar Flame Speed (cm/s(
S_u: Laminar Burning Velocity (cm/s(
T_{ad}: Adiabatic flame temperature (K(

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T_b: Burned gas temperature (K)
T_u: Unburned gas temperature (K)
r_b : Burned gases density (kg/m^3)
r_u : Unburned gases density (kg/m^3)

1. Introduction

Burning velocity is a physicochemical constant for a given combustible mixture. Unfortunately, although its theoretical definition is simple, the same cannot be said of its practical measurement. Andrews and Bradley [1] have critically reviewed the various methods for measuring burning velocity and concluded that one of the convenient and reasonably accurate methods was the double kernel technique of Raezer and Olsen [2]. Nowadays, the progress in science has reached high levels and the optical techniques advances more and more. So, there is no agreement on a standardized method of measurement and that conflicting values of burning velocity continue to be published.

The propagation of flames in channels has long attracted the attention of many investigations, and the recent interest in burning velocities at high temperatures and pressures has the effect on the measuring device development.

The present work uses the more advanced technique. The optical technique has been used in measuring the laminar burning velocity for Hydrogen–Air mixtures and unburned temperature dependence for a wide range of Hydrogen concentrations.

2. Experimental Method (Apparatus & Procedure):

The present investigation used a copper tube of (1920-mm) length, (100mm) inner diameter, and (6mm) thickness. The high thermal conductivity of copper was used to heat the mixture to a certain temperature. Figure (1) shows the details of the rig used in the research.

Preparing operation plays an important role in amelioration of the combustion phenomenon. This operation was made depending on the partial pressures of the constituents.

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

The flame speed of the gases 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. Therefore, the fourth photocell and the low-pressure transmitter were attached to the oscilloscope, which received the output signal as shown in figure (2).

3. Experimental Results:

The flame speed have been measured experimentally, figure (3) represents the measured flame speed for a wide range of concentrations at (T_u=298-348K) and P_o=1 atm.

The density ratio method introduced by Andrews and Bradley [3] have been used to calculate the burning velocity which represents the relationship between the flame speed and the burning velocity:

$$S_u = \frac{r_b}{r_u} \cdot S_f \qquad ...(1)$$

$$; \frac{r_b}{r_u} = \frac{T_u}{T_b} \cdot N \cdot I \qquad ...(2)$$

The magnitude of (N) and (I) has been calculated depending on the relations of the research of Andrews and Bradley. Fig. (4) represents the variation of (N) and Fig.(5) represents the variation of (I), both with Hydrogen concentration.

Adiabatic flame temperature (T_{ad}) used in equation (2) instead of (T_b) has been calculated according to Van Wilen and Sonntage [12]. Fig.(6) shows the variation of adiabatic flame temperature with hydrogen concentration at multiple initial temperatures of the unburned mixture.

The burning velocity has been calculated from the following equation:

$$S_u = \frac{T_u}{T_b} \cdot N.I.S_f \qquad ...(3)$$

Fig.(7) represent the variation of laminar burning velocity with hydrogen concentration at multiple initial temperatures.

4. Discussion and Conclusions:

- In this work, the burning velocity of hydrogen-Air mixtures has been measured for a wide range of Hydrogen concentrations, at multiple unburned mixture temperature (T_u = 298K, 323K and 348K), and P_o =1 atm. As shown in Fig.(7), as the hydrogen concentration increases, the burning velocity increases and the maximum point approximately about ($x_{H2} \cong$ 42%), then as the hydrogen concentration increases, the burning velocity decreases.
- Temperature dependence of the burning velocity is illustrated in Fig.(8) in addition to Fig.(7). The figures shows a temperature dependence in the following empirical form:

$$S_u = S_{uo} \cdot \left(\frac{T_u}{T_o} \right)^{a} \qquad ...(4)$$

The exponent (α) varies with Hydrogen concentration (x_{H2}). It has been introduced by fitting the data using curve-fitting method illustrated by Al-Ani [4]. Also, the burning velocity (S_{uo}) at (T_o = 298K & P_o = 1 atm) has been fitted by least square. The results are as follows:

$$S_{uo} = a + b \cdot (x_{H2}) + d \cdot (x_{H2})^2 \qquad ...(5)$$

where; *a* = -202.516, *b* = 2356.8, *d* = -2784.93.

and the exponent (α):

$$a = C_1 + C_2(x_{H2} - 0.42) + C_3(x_{H2} - 0.42)^2 + C_4(x_{H2} - 0.42)^3 \quad ...(6)$$

where the constants are as in table [1]:

Table [1]: constants of (α) equation

	$x_{H2} < 0.42$	$x_{H2} \geq 0.42$
C_1	*1.5842*	*1.73226*
C_2	*-3.5448*	*-1.53362*
C_3	*-36.6362*	*23.2672*
C_4	*-97.0467*	*-59.0393*

§ The empirical correlation derived previously can be used with an error (± 5 %) for the following conditions (T_u =298K - 473K), (x_{H2} =10 – 70%) with P_o=1 atm and T_o=298K. Fig.(9) shows the experimental burning velocity compared with the burning velocity calculated by the derived equation. The equation derivation depends on the experimental results of the present work in addition to the published results of other investigations.

§ The burning velocity (S_u) increases as initial temperature (T_u) increases. This is mainly due to the preheating effect as demonstrated by Kuo, K. (1986) [5], which leads to increase the heat released due to increasing in (α_u.Q / r_u) value, which is resulted from the increase in thermal conductivity of the reactants. Figs.(7) and (8) shows the variation of (S_u) with (T_u).

§ The results of laminar burning velocity have been compared with the published results as shown in Figs.(10), (11) and (12), where there is a good compatibility between the present and published results.

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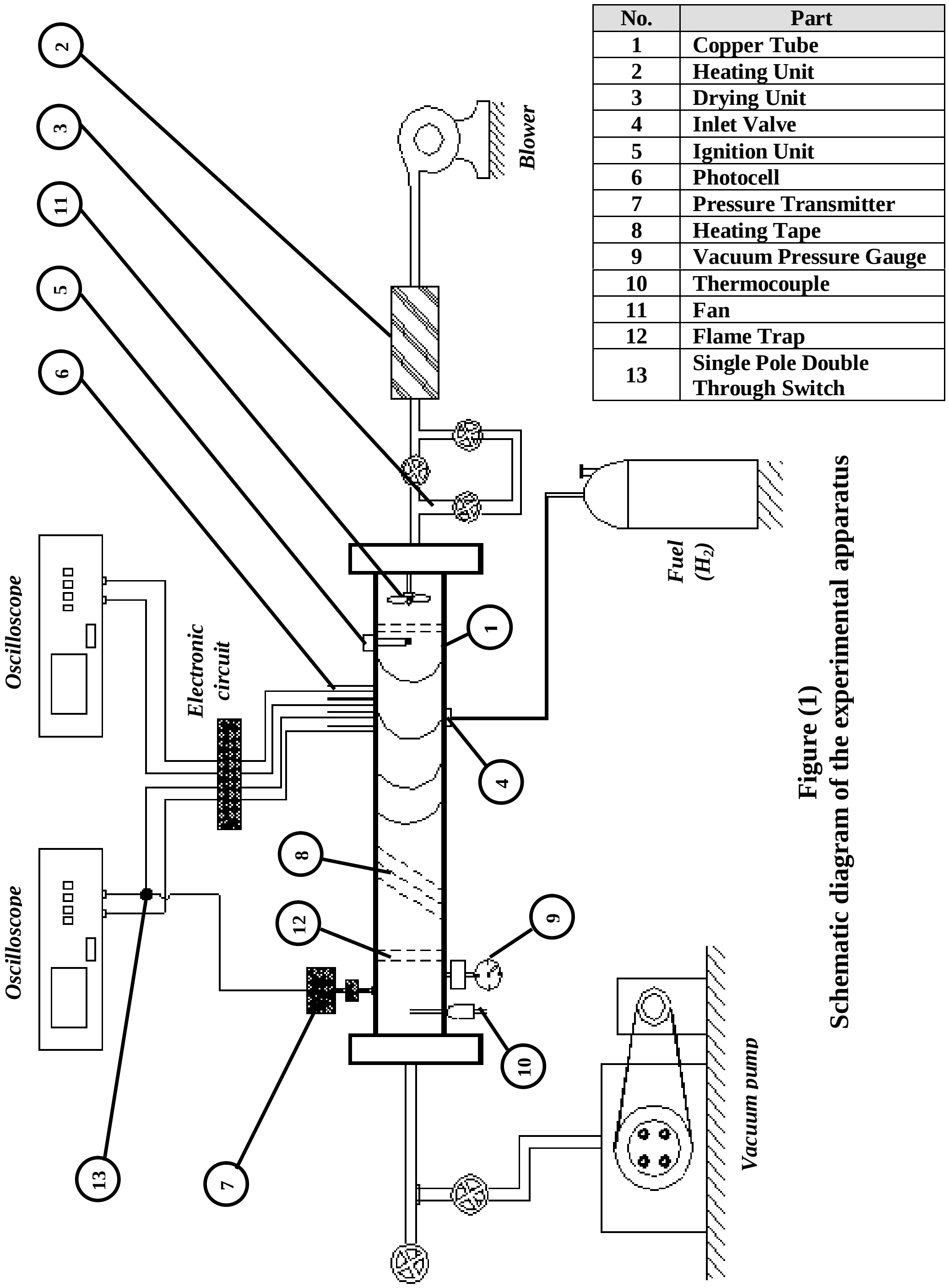

No.	Part
1	**Copper Tube**
2	**Heating Unit**
3	**Drying Unit**
4	**Inlet Valve**
5	**Ignition Unit**
6	**Photocell**
7	**Pressure Transmitter**
8	**Heating Tape**
9	**Vacuum Pressure Gauge**
10	**Thermocouple**
11	**Fan**
12	**Flame Trap**
13	**Single Pole Double Through Switch**

Figure (1)
Schematic diagram of the experimental apparatus

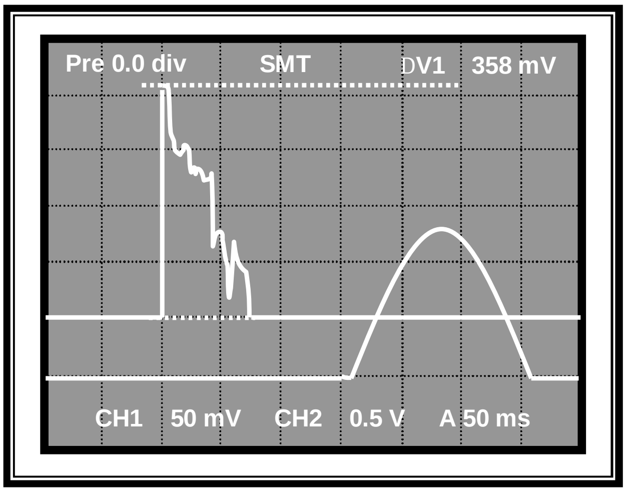

Figure (2)
Output signal on the oscilloscope screen

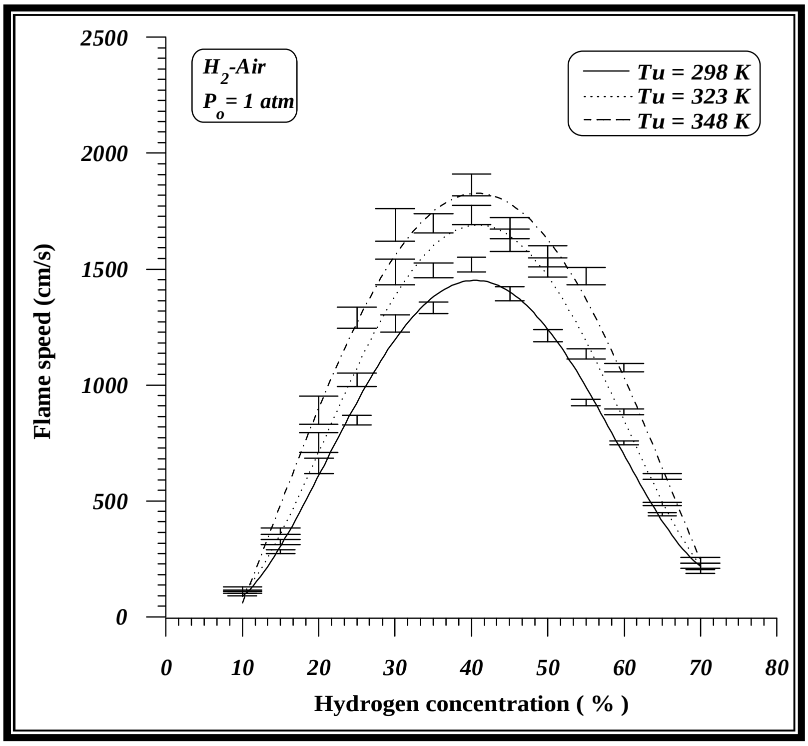

Figure (3)
Flame speed as a function of Hydrogen concentration

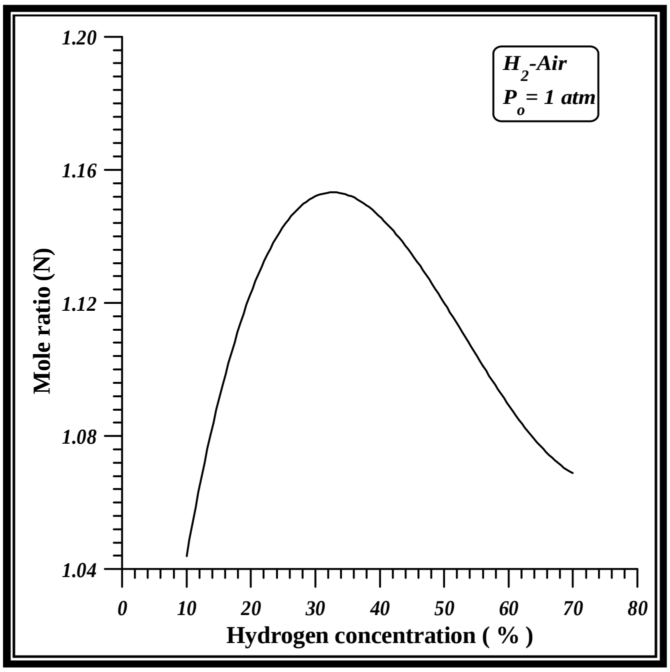

Figure (4)
Variation of mole ratio with Hydrogen concentration

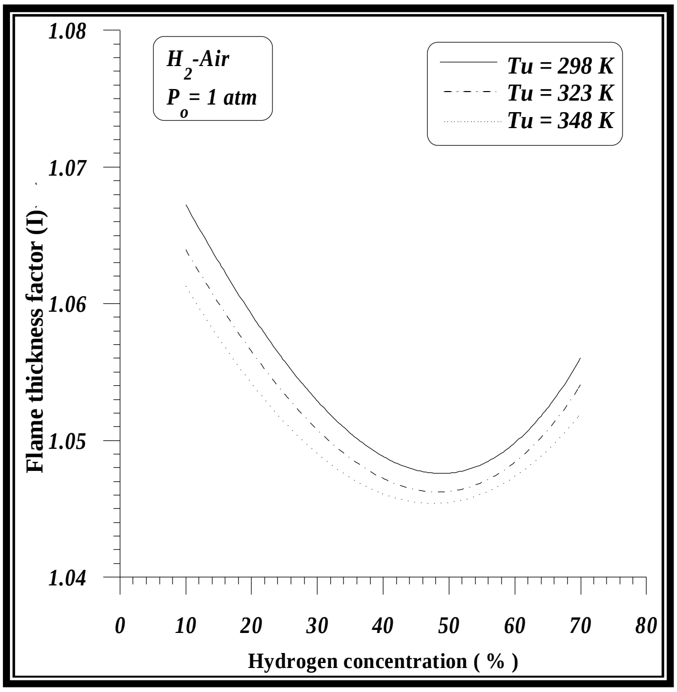

Figure (5)
Variation of flame thickness factor with Hydrogen concentration

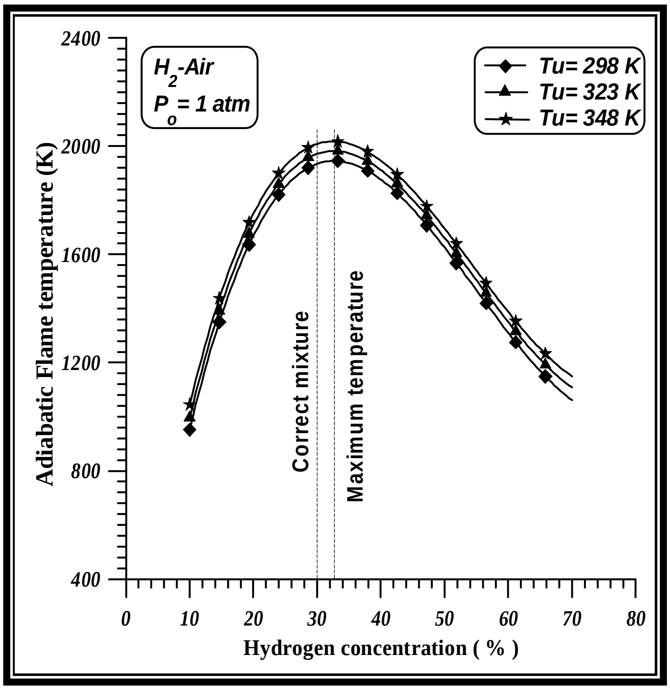

Figure (6)
Flame temperature as a function of Hydrogen concentration

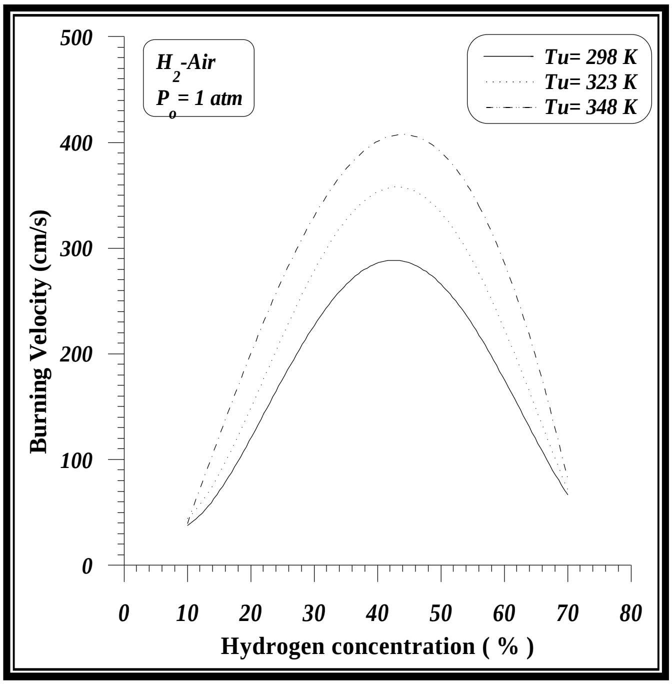

Figure (7)
Burning velocity as a function of Hydrogen concentration

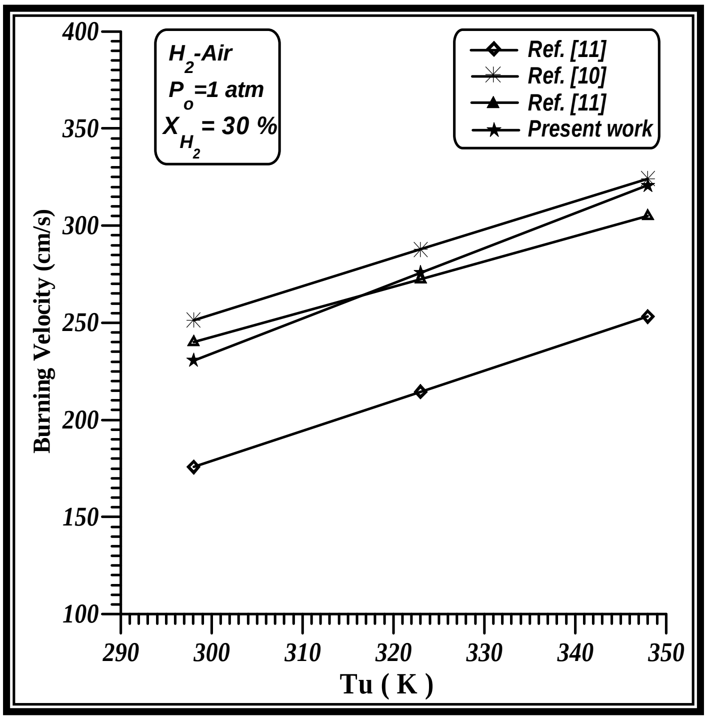

Figure (8)
Variation of burning velocity with Initial temperature

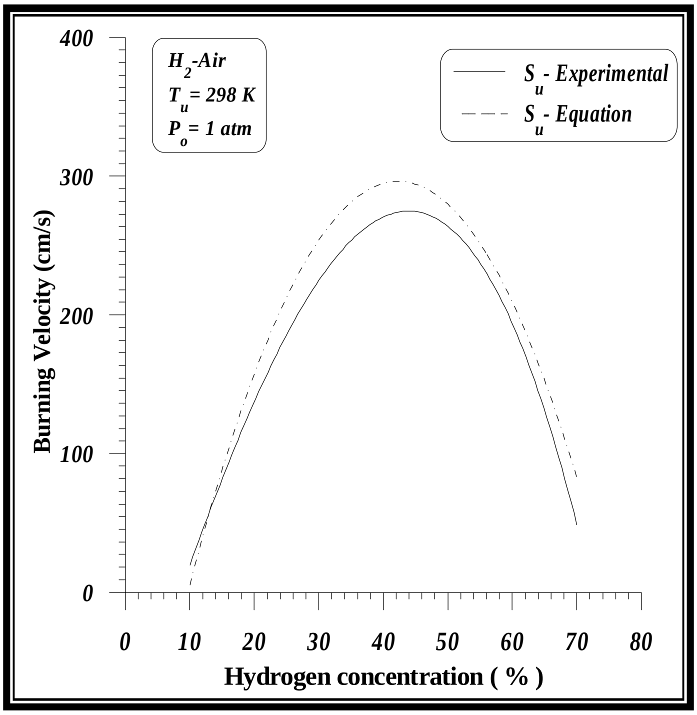

Figure (9)
Comparison between experimental S_u and S_u calculated from equation

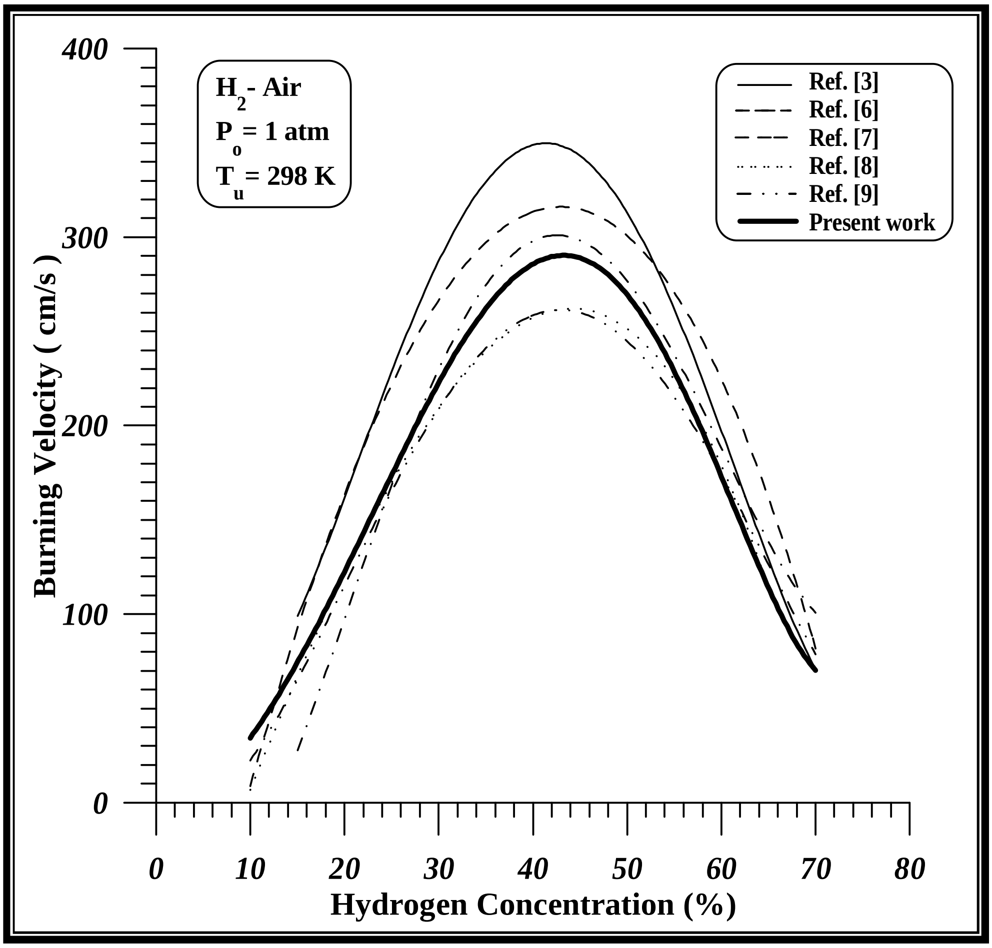

Figure (10)
Comparison of present results with the published data at (T_u =298K)

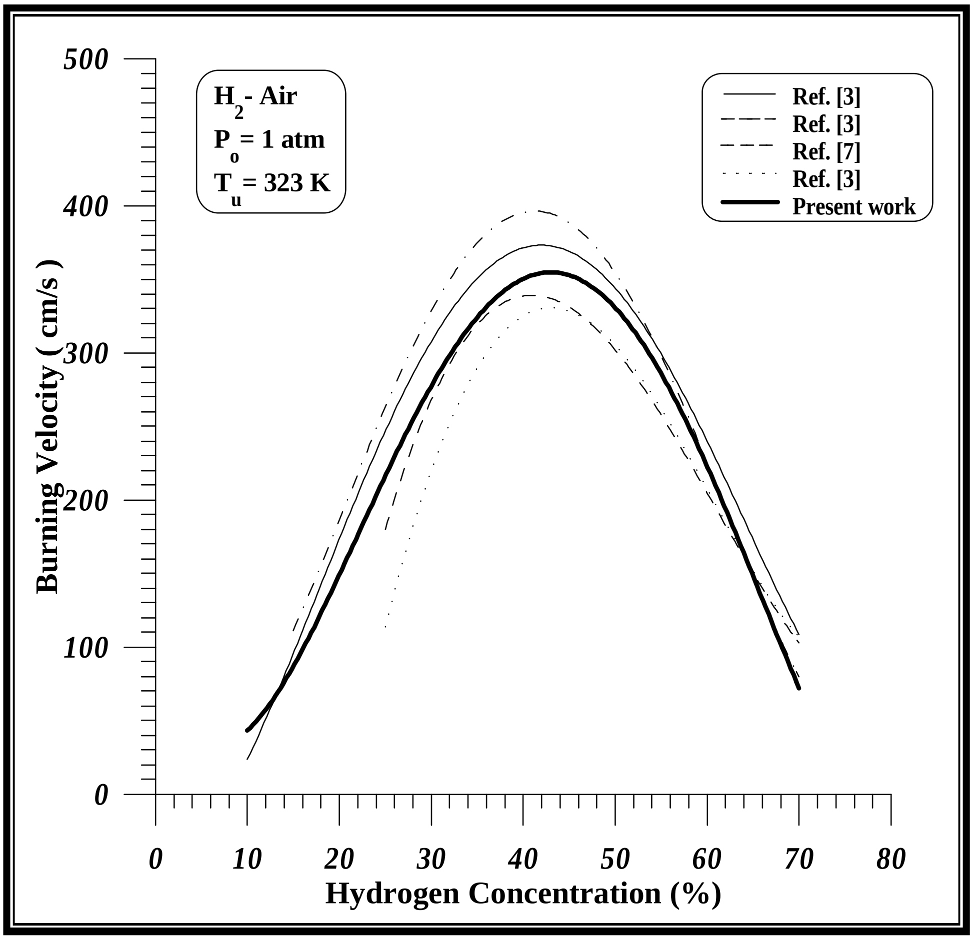

Figure (11)
Comparison of present results with the published data at (T_u =323K)

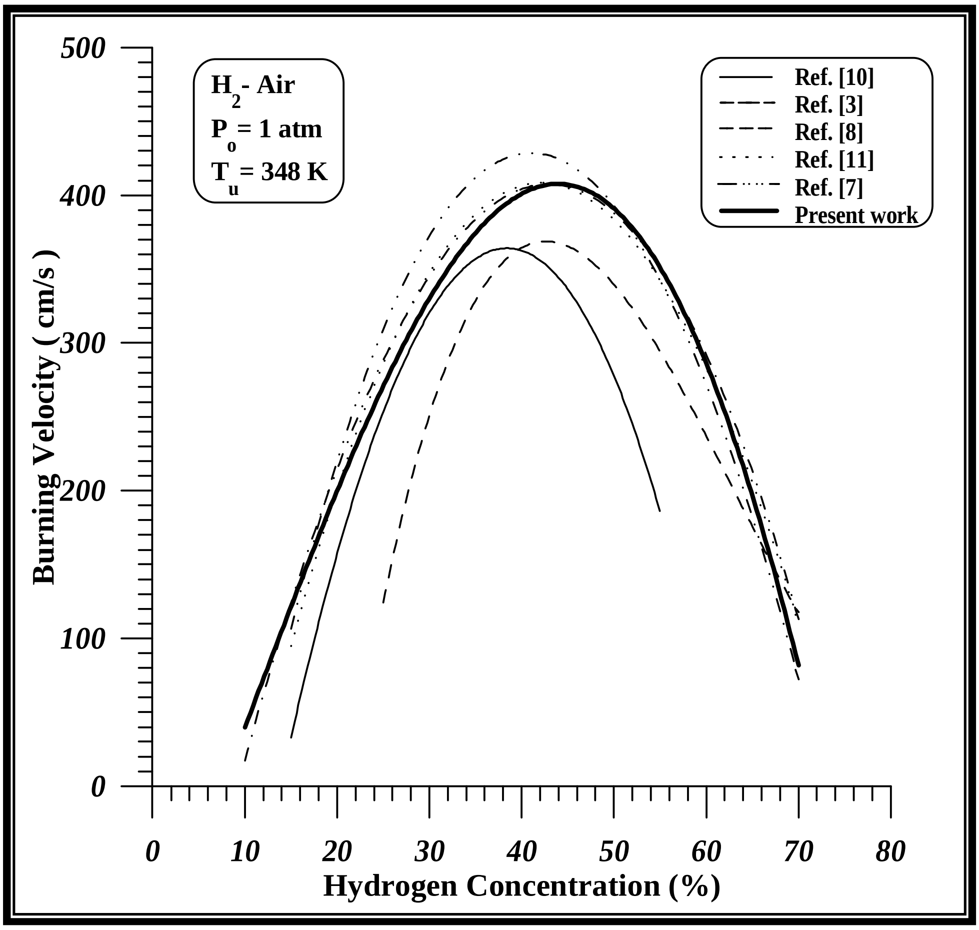

Figure (12)
Comparison of present results with the published data at (T_u =348K)