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# Temperature Profile Measurement in Non-Premixed Turbulent Flame Near Lean Limit of LPG/Air Mixture

**Hayder Abed Dhahad***

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**Abstract**

The current research was carried out on the topic of non-Premixed turbulent flames.

The temperature profile of non- premixed turbulent flame of lean LPG/Air mixture were obtained.

A simple jet burner with two different inside diameter and having two different perforated plates was designed in order to achieve turbulent flow .

The temperature was obtained at the two diameters and different positions for perforated plates. The temperature profiles were obtained by using a fine thermocouple ( 0.2mm diameter ) at height ( 3mm ) above the burner mouth. The maximum temperature for all cases was found at flame edge, and start decreasing for both sides .

**Keywords**: turbulent flame , non-Premixed , Lean limit , temperature profile, Bunsen burner

## قياس توزيع درجة الحرارة للهب الاضطرابي غير المسبق الخلط بالقرب من الحد الضعيف لخليط LPG / الهواء

**الخلاصة**

هذا البحث يقع في مجال دراسة اللهب الاضطرابي غير المخلوط مسبقا ، حيث تم تحديد توزيع درجة الحرارة خلال اللهب الاضطرابي لخليط ضعيف من الغز البترولي المسال ( L P G ) والهواء . استخدم في التجارب محرق بنسن مع قطرين داخليين مختلفين مع استخدام نوعين مختلفين من الصفائح المثقبة والتي صممت للحصول على الجريان المضطرب .

توزيع درجة الحرارة تم إيجاده عند القطرين الداخليين المختلفين وكذلك عند ثلاث مواضع مختلف للصفيحة المثقبة .

عملية القياس تمت باستخدام مزدوج حراري صغير جدا ( بقطر 0.2 mm ) وعند ارتفاع 3mmعن انف المحرق ، درجة الحرارة العظمى في جميع الحالات كانت عند حافة اللهب ثم تبدأ بالنقصان كلما اتجهنا إلى الإطراف.

*Center of Training and Workshops, University of Technology/ Baghdad



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2412-0758/University of Technology-Iraq, Baghdad, Iraq

## Introduction

In the recent years much experimental and theoretical research has been carried out in order to examine the structure and properties of non-Premixed turbulent flames ( 1-7 ) . Much of the previous consideration of flames has concentrated on premixed combustion where there is a homogeneous distribution of air and fuel (8) .

In non-Premixed flames the air and fuel are introduced separately(9),and (10). We have carried out an experiment, where the flame and the flow are made to be turbulent, starting from the burner edge, i.e. we wish to neglect the laminar and transitional flow, in order to give a truly turbulent flame(7) and (11). In previous research into this topic no one has developed a comprehensive theory.

Most of the experimental research carried out for finding the velocity and temperature profiles has used the Laser Doppler Anemometry (LDA)(12), and thermocouples respectively (13). In the case of buoyant convection, which will be studied here, the density is changing substantially as a result of a heat release for most reacting gases (notably for all practical combustion reactions) (14) and (15). There is one good advantage of diffusion flames rather than premixed flames, that is the consumption rate can be found from the rate at which both fuel and oxidizer are brought together in proportions for reaction. But also the premixed flame has a well-defined propagation speed, which is nevertheless hard to measure (8).

The present work is not directed primarily towards investigating chemical reaction rates .Instead the present experimental study is concentrated on the general behavior of buoyant turbulent diffusion flames, The non- premixed turbulent flame of lean LPG – Air mixture has a great importance in the practical application where the major of burners which is used LPG as a fuel work by lean mixture with turbulent flame so the results of the research has a great importance in

the design of these burners especially for the turbulence level and the position of turbulence generator .

In the present experiment we have to consider that the fluctuating values, especially for velocity are function of time and length scale. The turbulence level is characterized by means of the Reynolds number (Re) where the density and dynamic viscosity depend upon the fluid properties(16).

**Apparatus:**

There are major and minor apparatus used in the present experiment in order to achieve the best temperature profile across the mouth of the burner.

The apparatus were the simple jet burner, which was designed and manufactured to produce a turbulent flame at the exit, traverse mechanism which was designed to give a uniform and smooth movement crossing the mouth of the burner, flame trap to protect the system from the back fire, perforated plates with different holes diameter in order to achieve a turbulence flame, safety devices, control valves, and gas sensor.

The arrangement of the burner used in this experiment is the same as that for simple jet burner, where the gas is flowing inside the burner and the air will surround it.

The construction of the burner is shown in the figures (1.a,b,and c). It consists of an out side sleeve with an inner diameter 33mm and two sets of three spacers of diameters25.5mm, and 17.7mm respectively. Each set of spacer has two spacers of the same height of 25mm, and one spacer of height 50mm, the spacers have been designed in such away that there is a small clearance to insert them easily. These spacers are fixed from the bottom by a slight contraction or throat at a height of 100mm, and from the top by a threaded cap (see fig.1-c)

The cap with a circular conical shape has been designed for two reasons, first to fit the perforated plates and spacers, and the second to achieve the correct directional streams of air which will produce a turbulent flow (11)

perforated plates are a circular flat plate, which has a number of regularly spaced holes in it in order, to produce a turbulent flow. Different plates ,with different sizes of holes can be used to produce different turbulence characteristic. This in turn changes the blockage ratio of the plate.

In the design of the plates it is difficult to achieve correct spacing between the holes .The pressure drop across the plate varies according to the blockage ratio. These different plates were obtained ready-made from a commercial source saving a lot of time in setting up the experiment. The plates are supplied as square sheets, and have to cut into a circular shape to be inserted in the 33mm diameter sleeve in the burner(11).

Two plates were made initially, one with a 1mm hole diameter (P d ), and a blockage ratio of 81% , and the other with a 2mm hole diameter (P d ), and blockage ratio of 75%.

Gas flow rate was 0.006 $m^3/s$ , this will make the Reynolds number at a perforated plates between 28340 to 35620 ,depended to a blockage ratio

Traverse mechanism is a very heavy unit with two-dimensional movement in such away that it can move forward and backward or to the right and left-hand side It has a special groove where the holder of the thermocouple can be fixed. The traverse mechanism was positioned in such away that the thermocouple junction, or the probe was located above the burner exit by approximately 3mm . The distance moved was measured by means of a dial gauge with accuracy of 0.002 mm. The dial gauge has a magnetic base to fix its position. And a special spring rod touches the moving part of the traverse mechanism

Safety devices are the most important thing in any work. This is especially true in this experiment, because there is likelihood of gas leakage, or of partially premixed combustion due to the presence of air inside the gas pipe during starting up or shutdown. These safety devices are( Control valve, Flame Trap and Gas sensor as a leakage sensor )

**L P G Composition**

The liquefied Petroleum Gas (LPG), which has been used in this experiment was supplied from

Alzawai refinery in Libya , with the following composition

| | |
|---|---|
| Ethane | 3.33% |
| Propane | 57.1% |
| Isobutene | 16.45% |
| n- butane | 21.9% |
| Iso Pentane | 1.22% |

**Thermocouples in A Gas Stream**

When a thermocouple is used to measure a local temperature in the gas flowing out of the burner, it indicates a temperature ( which is the measured value ) between the temperature at the edge of the burner and the temperature at the tip of the flame, where the measured value can be denoted as ( Tth ). The exact value of Tth is determined by a balance of heat transfer from the thermocouples junction, by three ways ( conduction, convection, and radiation ) (14).

The thermocouple used in this experiment was a nickel – chrome, nickel – alumel thermocouple with a diameter of 0.2mm, It is K type (17).

**Temperature Profiles Expeiments**

The thermocouple could be moved in the horizontal and vertical directions to keep the thermocouple junction at the burner centerline. The thermocouple was fixed on the traverse mechanism in a special way where the traverse mechanism has two channels on over the other, each having a scale in mm to measure the distance moved. The thermocouple was mounted at 3 mm above the burner port (13) .

The measurements of the flame were take over the radius of the burner from the center line out to 30 mm , concentrated at the region of the burner edge and the distance between Measurement points were kept small to resolve sharp changes in the temperature .

Thermocouple measurements were taken with burner port diameters of 25.5mm and 17.7mm, and using the two different perforated plates.

**Results and Discussion**

The temperature profiles were obtained at nozzle diameter of 25.5mm and 17.7mm with 2mm and 1mm perforated plates in the upper and lower positions, as shown in figs (3 to 10).

At burner diameter 25.5mm and 1mm perforated plate, the temperature profile is border with the plate in the upper position than it is with the plate in the lower position. This is mainly because the boundary layer has a greater distance to grow inside the nozzle when the plate is in the lower position. It can be seen at both positions had same that the profile.

The thermal diffusivity coefficient of a lean L P G - –air mixture is greater than the mass diffusivity of deficient reactant (L P G diffusing in air) (24 ) . Thus, Lewis number, Le, which's the ratio of thermal diffusivity to mass diffusivity, is greater than unity producing preferential diffusion. According to [25 ] and [ 26 ], the combination of stretch rate and Lewis number effect should cause the flame temperature to decrease Le > 1.

The maximum flame temperature was about ( 900 C ) because the Lewis number effect and the mixture was very lean

Is almost a horizontal line from 30mm to 20mm radius ( i.e. out side the burner ), and the temperature starts to increase sharply after 20mm and reaches a maximum at the flame edge.

The temperature with the plate in the upper position is slightly higher than that for the plate in the lower position due to the difference in the boundary layer. At both cases the temperature starts decreasing for radii inside the flame edge and reaches a minimum at the centre line where the temperatures in both plate positions were about 48 c .

## Conclusions

**1)** Using 25.5mm and 17.7mm burner diameter, with both perforated plates at the upper and lower positions, the mean temperature was maximum at the flame edge and decreases on both sides.

**2)** The profile top at 2 mm perforated plate is more flat than at 1 mm, due to the change in the perforated plate hole size which causes change in the turbulent length scale which in turn increases the fluctuation of the thin flame.

**3)** The results of the research has a great importance in the design of these type of burners especially for the turbulence level and the position of turbulence generator ( perforated plates )

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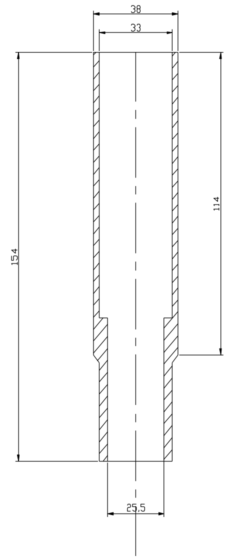


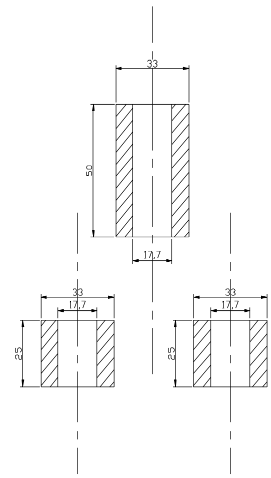


Figure (1-a) the outer sleeve of the burner

Figure (1-b)the 17.7mm spacers

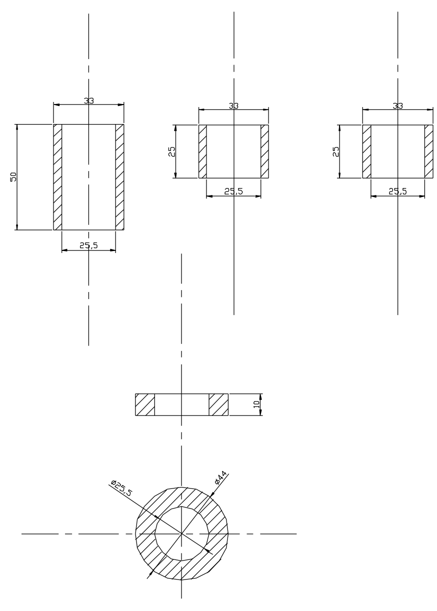


Figure (1-c) the 25.5 spacers and the burner cap

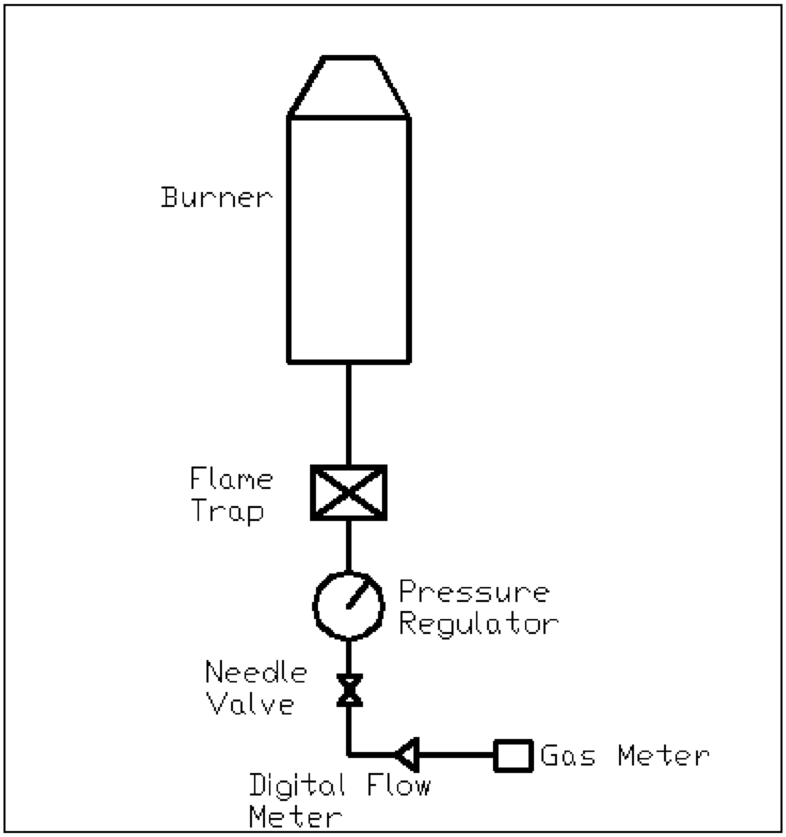


**Figure ( 2 ) Schematic diagram of the experiment**

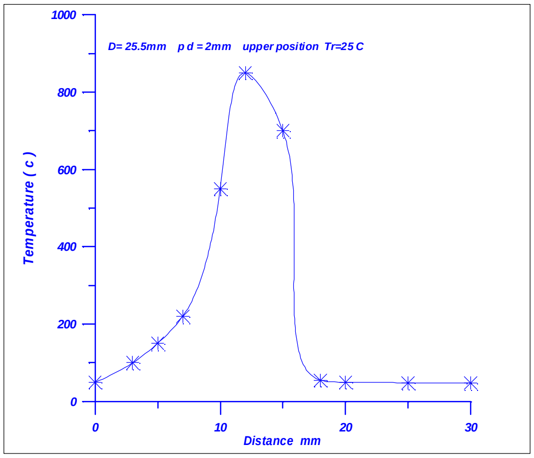


**Figure (4) temperature profile at D=25.5mm ,pd=2mm , upper position**

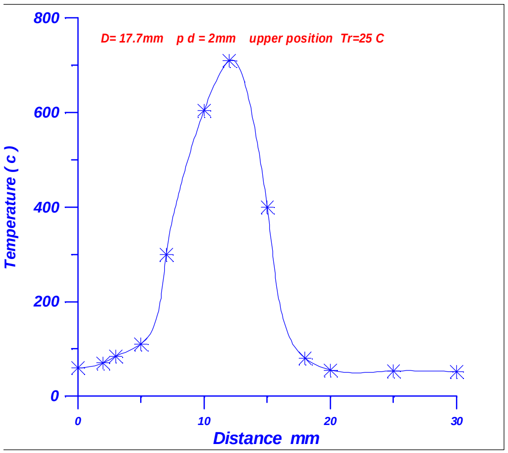


**Figure ( 3) temperature profile at D=17.7mm ,pd=2mm , upper position**

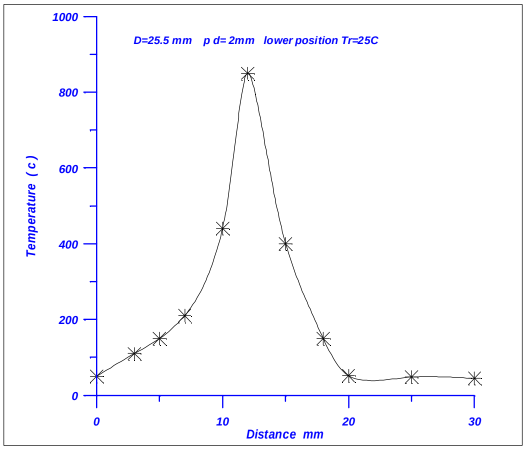


**Figure (6) temperature profile at D=25.5mm ,pd=2mm , lower position**

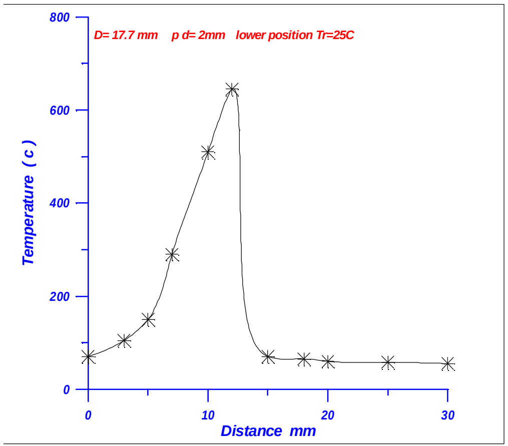


**Figure (5) temperature profile at D=17.7mm ,pd=2mm , lower position**

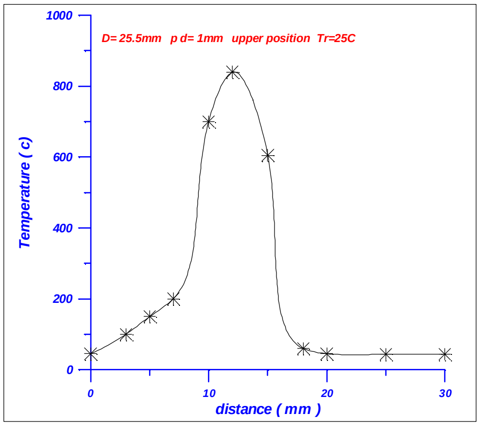


**Figure (8) temperature profile at D=25.5mm ,pd=1mm , upper position**

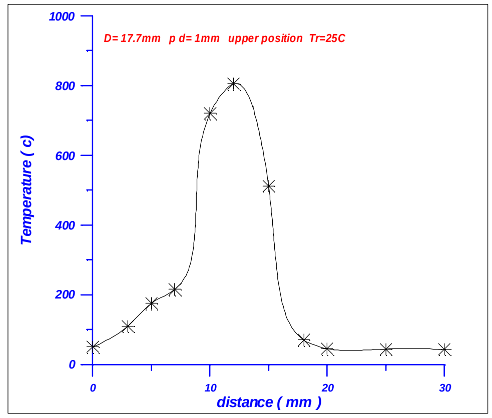


**Figure (7) temperature profile at D=17.7mm ,pd=1mm , upper position**

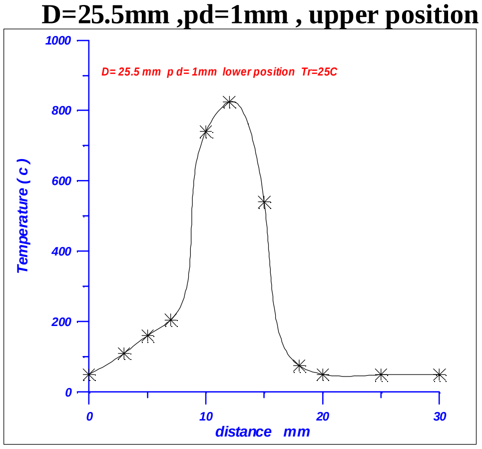


**Figure (10) temperature profile at D=25.5mm ,pd=1mm , lower position**

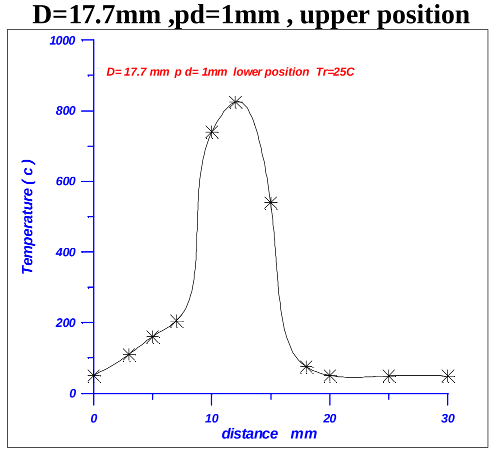


**Figure (9) temperature profile at D=17.7mm ,pd=1mm , lower position**