THE EFFECT OF TURBULENCE GENERATOR ON TEMPERATURE PROFILE OF NON-PREMIXED TURBULENT FLAME

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الملخص

يرتكز البحث على دراسة عملية خاصة عن اللهب المضطرب متـأخر الخلـط ، حيـث تـم قياس توزيع درجة الحرارة للهب المضطرب متـأخر الخلـط باسـتخدام حـارق بنـسون ذو قطرين داخليين مختلفين 17.7 مم و 25.5 مم على الترتيـب وشـبكتين صـفائحيتين مختلفـة أقطار الفتحات وعند إرتفاعين مختلفين داخـل الحـارق. تمـت عمليـة القيـاس بإسـتخدام المزدوج الحراري عند إرتفـاع 3 مـم مـن فوهـة الحـارق. أثبتـت الدراسـة أن درجـة الحرارة القصوى تتحقق عند حافة اللهب وتتناقص كلما أتجهنا عن حافـة اللهـب فـي كلتـا الجهتين ، كما أثبتت الدراسة أن عرض حافة اللهب يتغيـر علـى حـسب شـدة إضـطراب اللهب.

ABSTRACT

The present study was carried out on the topic of non-premixed turbulent flame. A simple type of Bunsen burner with two different inside diameters 17.7 mm and 25.25 mm low and high removable turbulence generators were used to vary the characteristics of the nozzle turbulence designed in order to achieve turbulence. The temperature profiles were obtained at the two diameters and different positions for the perforated plates inside the burner. The temperature profiles were measured by using a fine thermocouple at a height of 3 mm above the burner rim. The maximum temperature for all tested conditions was found at flame edge. It was also observed that the temperature decreases as we move away from the flame edge.

KEYWORDS: Turbulence generator; Temperature profile; Non-premixed; Turbulent flame; Bunsen burner.

INTRODUCTION

In recent years many experimental and theoretical research have been carried out in order to examine the structure and properties of non-premixed turbulent flames [1-3]. Most of the previous research of flames had been conducted on premixed combustion where there is a homogenous distribution of air and fuel [4-6].

In non-premixed flames the air and fuel are introduced separately, [7-8]. The flow was made to be turbulent, starting from the burner edge, i.e. the laminar and transition flows were neglected, in order to give a truly turbulent flame, [2, 9]. In previous studies very few theoretical researches have been carried out.

Most of the experimental researches were carried for evaluating the velocity and temperature profiles have used the Laser Doppler Anemometry (LDA) [10], and fine thermocouples respectively [11]. In the case of diffusion flames, 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), [12, 13]. There is one good advantage of diffusion flames rather than a premixed flame that is the consumption rate can be found from the rate at which both fuel and oxidizer are brought together in the proportions for reaction. But also the premixed flame has a well-defined propagation speed, which is nevertheless hard to measure [14].

The present work is not directed primarily towards investigating chemical reaction rates. Instead it concentrated on the general behaviour of buoyant turbulent diffusion flames. It is considered that the fluctuating values, especially for velocity as a function of time and length scale. The turbulence level is characterized by means of the Reynolds number (R_e) where the density and dynamic viscosity depend upon the temperature [15].

APPARATUS

The test unit of the flame measurement is shown in Figure (1). The experimental unit consists of major and minor apparatus used to achieve the best temperature profile across the burner rim. The apparatus consists of the Bunsen burner, which was designed and manufactured to produce a turbulent flame at the exit, 2-D traverse system which was designed to give a uniform and smooth movement crossing the burner rim, flame trap to protect the system from the back fire, turbulence generators with different holes diameter in order to achieve a turbulent flame and safety devices, control valves and gas sensor.

The burner

The arrangement of the used burner is the same as that for the normal Bunsen burner, where the gas is flowing inside the burner and the air flow will surround it. The construction of the burner is shown in Figures (2a, 2b and 2c). It consists of an outside sleeve with an inner diameter 33mm and two sets of three spacers of diameters 25.5mm and 17.7 mm respectively. Each set has two spacers of the same height of 25mm, and one spacer of height 50 mm.

The spacers have been designed in such a way 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 100 mm and from the top by a threaded cap as shown in Figure (3).

The conical cap

The cap with a circular conical shape has been designed for two reasons, first to fit the turbulence generators and spacers, and the second reason is to achieve the correct directional streams of air which will produce a turbulent flow.

Turbulence generators

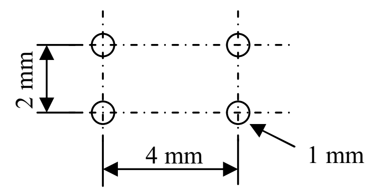
The turbulence generators are flat plates; each plate has a number of regularly spaced holes in it in order to produce a turbulent flow. Different plates, with different sizes of holes can be used to produce different turbulence characteristics. This in turn changes the blockage ratio of the plate.

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. The plates are supplied as square sheets, and have to cut into a circular shape to be inserted in the 33 mm diameter sleeve in the burner. Two plates were made initially, one with a 1 mm hole diameter, and blockage ratio of 90%, and the other with 2 mm diameter hole, and a blockage ratio of 65%. A simple example for calculating the blockage and open area is shown as follows;

Case i

Plate of 25.5 mm diameter and 1 mm hole diameter:

Rectangular area = $4 \times 2 = 8\ mm^2$



The open area of rectangular = $(3.14/4) \times 1^2$
$= 0.785\ mm^2$

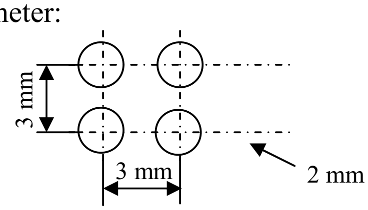
The blockage area ratio = $[1-(0.785/8)] \times 100 = 90\ \%$

Then, the open area ratio = $100 - 90 = 10\ \%$

Case ii

Plate of 25.5mm diameter and 2mm hole diameter:

Squarer area = $3 \times 3 = 9\ mm^2$



The open area of rectangular = $(3.14/4) \times 2^2$
$= 3.14\ mm^2$

The blockage area ratio = $[1-(3.14/9)] \times 100 = 65\ \%$

Then, the open area ratio = $100 - 65 = 35\ \%$

The three spacers are inserted inside the burner, and the turbulence generator fixed on the upper spacer which is the upper position. The lower position is the position where the turbulence generator fixed under the lower spacer.

Flame trap

A flame trap is a dense mesh wire and is connected to the gas feed pipe by a specially made connector. Its purpose is to stop any back fire that may form in the gas pipe, possibly damaging the valves and the measuring devices. The construction of flame trap is shown in Figure (4).

2-D traverse system

The traverse mechanism is a very heavy unit with two-dimensional movement in such a way that it can move the thermocouple across the burner exit. It has a special groove where the holder of the thermocouple can be fixed. The 2-D traverse system was positioned in such a way that the thermocouple junction or the probe was located above the burner exit by approximately 3 mm. 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 2-D traverse system.

Safety devices

These are the most important units. This is especially true in the experiment, because there is a possibility of the 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 include the following:

Control valve

The safety valve acts as a pressure regulator in order to control the flow through the circuit, and acts as an on-off switch for the flow.

Gas sensor

This is an electronic sensor connected to an alarm. This device is very sensitive to the pressure of methane, in such a way that the alarm will operate if there is any gas leakage.

The natural gas composition

The natural gas used in the present work is high in methane content. Analysis showed that methane accounts for more than 90% and the rest is ethane, heavier hydrocarbons and nitrogen. The natural gas composition is as follows:

Methane	92.5%
Ethane	1.0%
Propane	0.6%
Nitrogen	5.9%

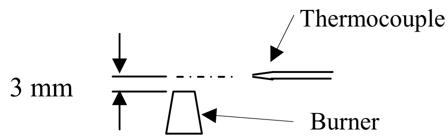
It can be observed that methane has the highest percentage, and the composition can be taken as 100% methane.

THERMOCOUPLES IN A GAS STREAM

Thermocouples are widely used in all temperature ranges except the very highest. The simple thermocouple consists of two dissimilar wires for example iron and constantan, where one end of iron is connected to one end of constantan to form the measuring junction. The other remaining junction ends are connected to the measuring instrument or system in such away the two wires of thermocouple form a part of a closed circuit, where an electric current can flow [11,13]. The thermocouple used in this experiment was a nickel-chrome, nickel-alumel thermocouple with a diameter of 2 mm. The thermocouple used to measure the local temperature in the gas flowing out of the burner indicates the measured value. The exact value of measured temperature is determined by a balance of heat transfer from the thermocouple junction, by three ways conduction, convection and radiation [12].

TEMPERATURE PROFILE MEASUREMENT

The thermocouple was prepared in such away that it can be moved in the horizontal and vertical directions to keep the thermocouple junction at the burner centreline. The 2-D traverse system has two channels one over the other, each having a scale in mm to measure the moved distance. The thermocouple was mounted at 3 mm above the burner rim [11]. The thermocouple is first fixed horizontally at 50 mm from the centre line of the burner (i.e. outside the flame), where the temperature is approximately equal to 30 ºC. Then the thermocouple is moved toward the centre line of the burner in steps, and the temperature is recorded at each step. More concentration has been taken at the region of the burner front, and the distance between the measuring points were kept small to resolve the sharp changes in the temperature. The measurements of flame temperature were taken using burner port diameters of 25.5 mm and 17.7 mm and using the two different turbulence generators. These measurements were obtained at different room temperatures, and it can be seen that the room temperature has little effect on the temperature profile.



Position of measuring point for all results

Results of the experimental tests are shown in Figures (5a) to (5h). At burner diameter 25.5 mm and 1 mm turbulence generator, 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 that at distance from 50 mm to 20 mm (i.e. out side the burner), the profile is almost a horizontal line, and the temperature starts to increase sharply after 20 mm and reaches a maximum at the flame front when the air and fuel are considered to reach the front in stoichiometric proportions and to react to form products instantaneously. 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 centreline where the temperatures in both plate positions were varied from 39°C to 45°C. It can be seen from the Figures that the centre line of the burner is at the origin.

CONCLUSION

After having designed, constructed and assembled the experimental rig, several experiments were carried out to investigate the effect of burner diameter, perforated plates and their positions on the temperature profile. Finally the following points were concluded:

- The room temperature has a little effect on the temperature profile.
- Using 25.5 mm and 17.7 mm burner diameters with both perforated plates at the upper and lower positions, the mean temperature was maximum at the flame vertical edge and decreases on both sides.
- The top of the curve at 2mm perforated plate is more flat than at 1mm, due to the change in the perforated plate hole size which causes change in the turbulent intensity which in turn increases the fluctuation of the outer layer of the flame edge.

REFRENCES:

[1] Bilger R. W., "The structure of turbulent non-premixed flames", Twenty second International symposium on combustion, 1998.

[2] Ibrahim S. M. A. and Elmahallawy F. M., "The structure of turbulent free diffusion flames combustion and flame", V60, pp.141-155, 1985.

[3] Fristom R. M. and Westenberg A. A., "Flame structure", pp. 133-145, 1965.
[4] Glassman I., "Combustion", Second edition, 1987.
[5] Yule A. J., "Experimental methods in thermofluids", 1988.
[6] Smyth K. C., Miller J. H., Dorfman R. C., Mallard W.G. and Santoro J., "Soot inception in a methane/air diffusion flames as characterized by detailed species profiles", Combustion and flames, V62, pp. 157-181, 1985
[7] Kuo K. K., "Principles of combustion", 1986.
[8] Glassman I., "Combustion", First edition, 1977.
[9] Milosavljevic V. D., Taylor A. M. and Whitelow J. H., "The influence of burner geometry and flow rates on the stability and symmetry of swirl-stablized non-premixedflames", Combustion and flames, V80, pp. 196-208, 1990.
[10] Chigier N. A., "Laser velocimetry for combustion measurements in jet propulsion-System combustion measurements", pp. 67-87, 1989.
[11] Katsuki M., Mizutani Y. and Matsumoto Y., "An improved thermocouples technique for measurement of fluctuating temperature in flames", Combustion and flames, V67, pp. 27-36, 1987.
[12] Kreith F. and Black W. Z., "Basic heat transfer", pp. 240-284, 1980.
[13] Holman J. P., "Heat transfer", pp. 207-373, 1989.
[14] Hottel H. C. and Hawthorne W. R., "Diffusion in laminar flame jet", Hawthorne W. R. thesis, Massachusetts Institute of Technology, 1939.
[15] Goldstin R. J., "Fluid mechanics measurements", 1983.

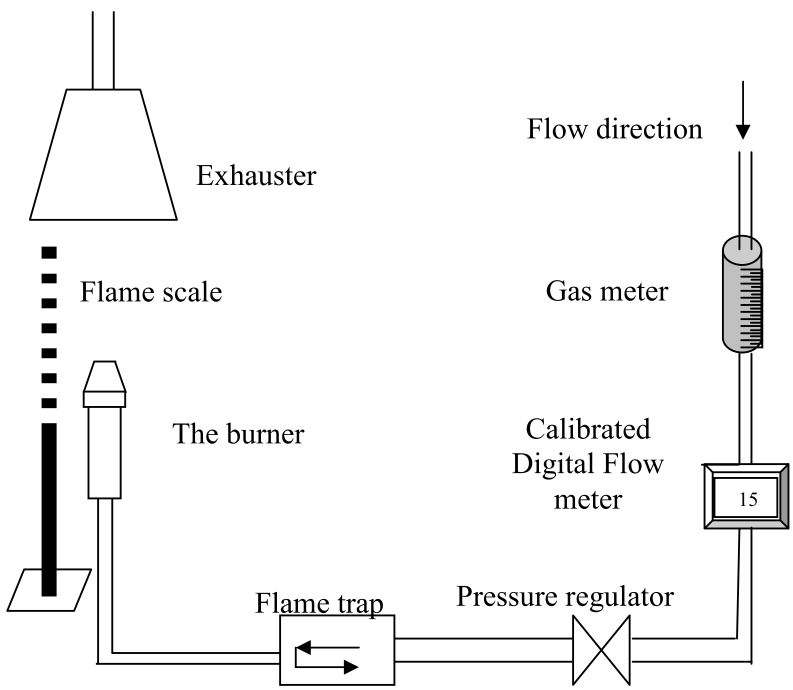


Figure 1: Schematic diagram of the testing unit

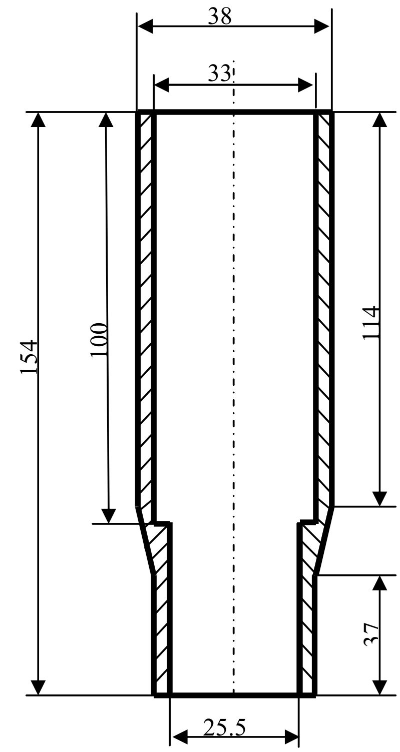


Figure 2a: The outer sleeve of the burner (Dimensions in mm)

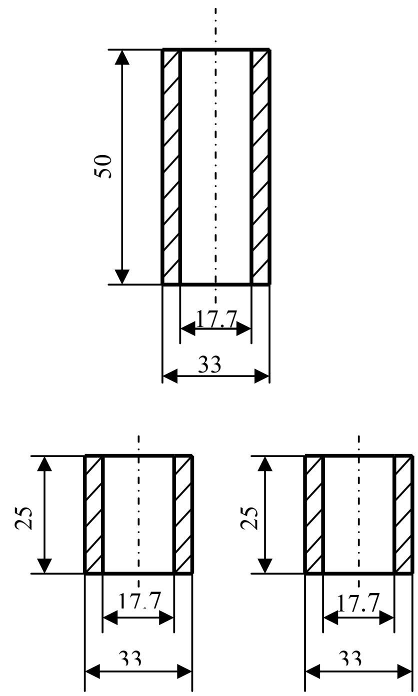


Figure 2b: The 17.7 mm spacers

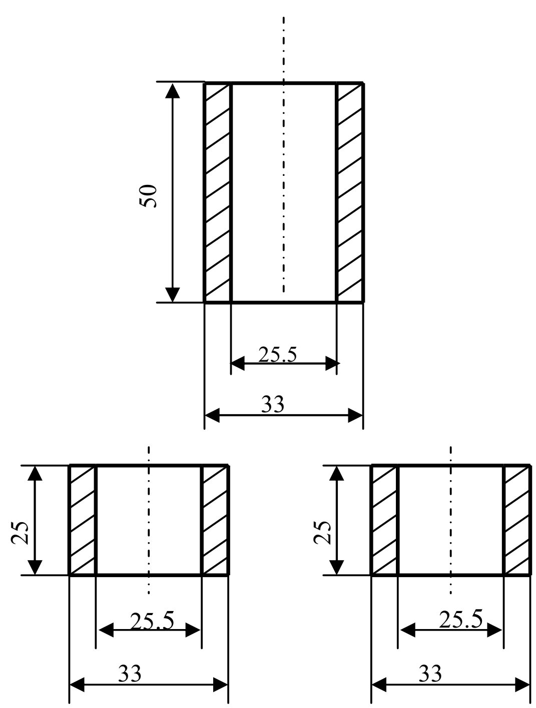


Figure 2c: The 25.5 mm spacers

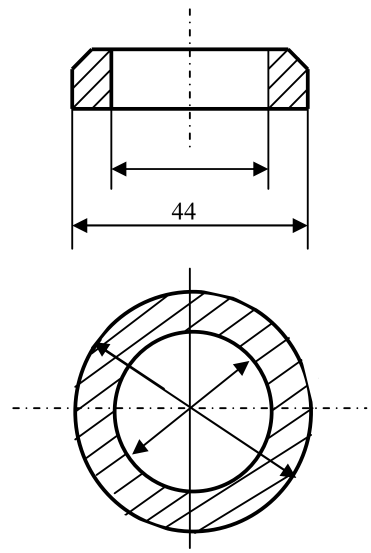


Figure 3: The burner cap

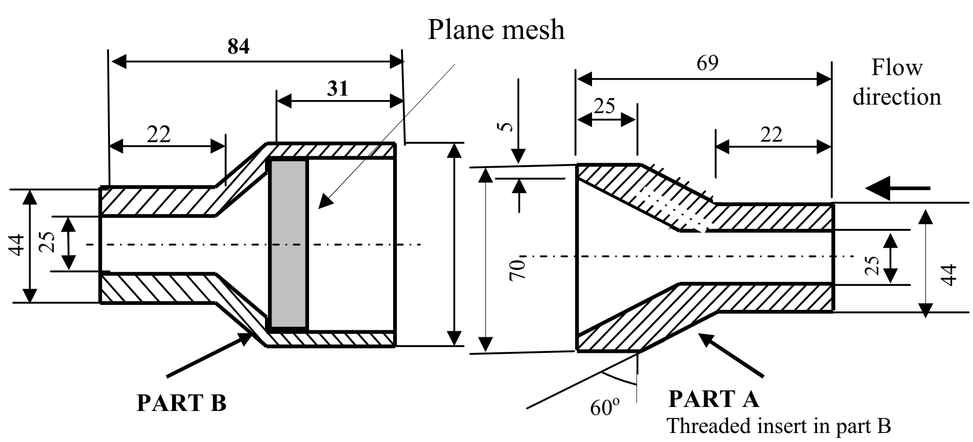


Figure 4: The flame trap

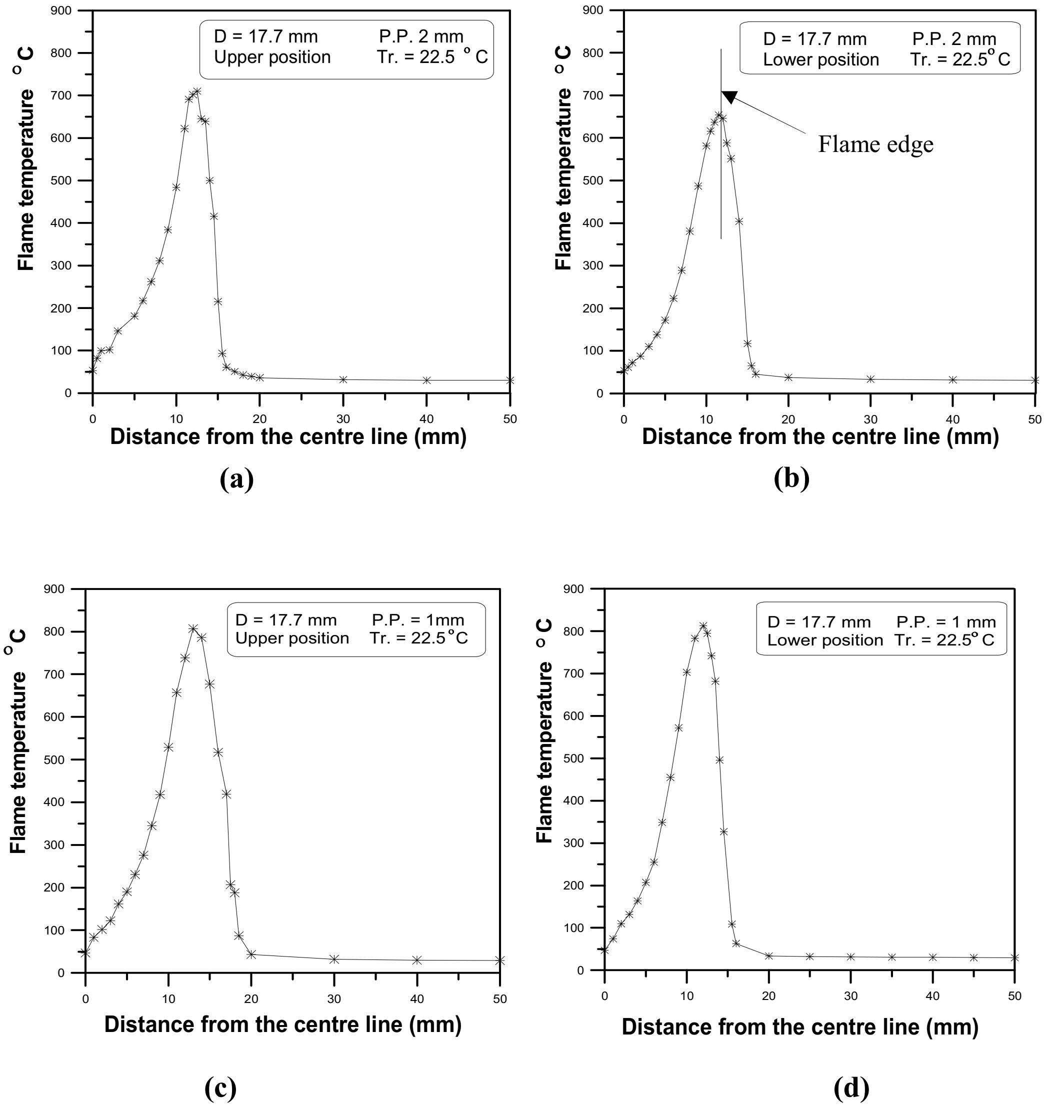
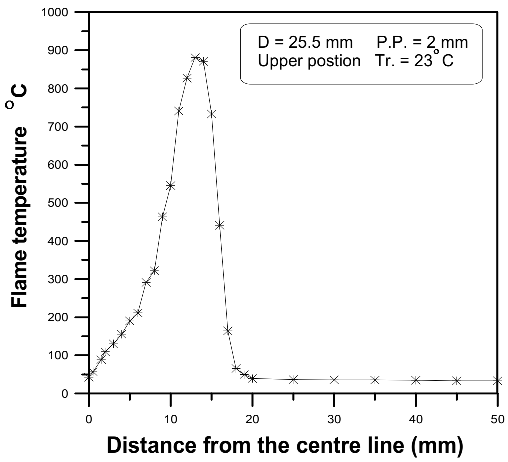
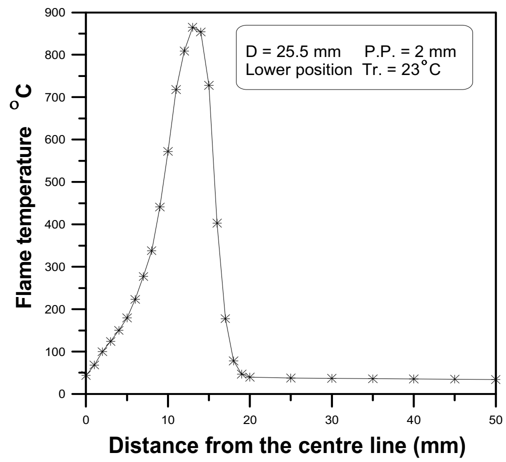


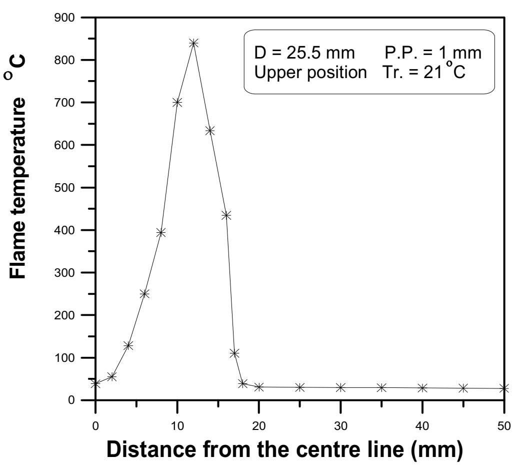
Figure 5(a-d):Flame temperature variation cross traveling distance at the burner exit with internal diameter (D), different position of turbulence generators (P.P.) and different room temperature



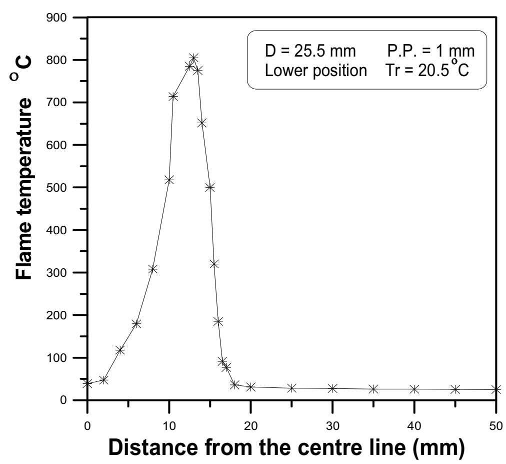
(e)



(f)



(g)



(h)

Figure (5e-5h): Flame temperature variation cross traveling distance at the burner exit with internal diameter (D), different position of turbulence generators (P.P.) and different room temperature