

Enhancement of Combustion Characteristics and Heat Transfer by Using Annular Ribs for the Triple Flame

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ABSTRACT: The present study deals with the experimental study of the issue by using annular ribs with different figures (triangle and square) inside a longitudinal flame tube on combustion characteristics, heat transfer and gas analysis at different locations by utilizing a triple flame. In the experimental investigation a test rig is set up in order to run out the measurements using LPG flame.

The expected effects of changing the shape and the axial location of the annular ribs on the heat flux and combustion are achieved. The results of the present work indicate that using the annular ribs increases the rate of heat transfer across the longitudinal flame tube. Also the effect of the triangle rib is investigated and the results show that the effect of these triangle ribs in combustion processes, heat transfer and gas analysis is greater than the effect of the square one. There was an obvious enhancement of the flame and wall surface temperature due to using the annular ribs.

KEYWORDS: Annular ribs, Heat transfer, Gas analysis, Triple flame.

I. INTRODUCTION

Heat transfer enhancement is very important in the applications of thermal systems in energy field such as the conventional heat exchangers which can be generally improved by means of various techniques with several types of enhanced surfaces. This is because the enhanced surfaces can create a combination of the following conditions favorable for the increase in heat transfer rate:

(1) Interruption of thermal boundary layer development and increase in turbulence intensity, (2) Increase in heat transfer area, and (3) Generating of swirl and vortex by using winglets which mix the hot fluid near the surfaces with cold main flow, this process enhances heat transition from the surfaces. So far, many investigations have been focused on passive heat transfer enhancement methods and the fluid flow. Swirl flow devices form an important group of the passive augmentation technique. Recirculation flow devices are widely used in heat transfer engineering applications.

Several studies have been carried out to investigate the effect of using ribs on heat transfer and combustion enhancement, the following are some of these researches. Liou and Hwang [1,2] investigated experimentally the performance of square, triangular and semi-circular ribs and found that the square ribs give the best heat transfer performance among them. This is contrary to the experimental result of Ahn [3] indicated that the triangular rib performs better than the square one. Tanda [4] examined the effect of transverse, angled ribs, discrete, angled discrete ribs, V-shaped, V-shaped broken and parallel broken ribs on heat transfer and friction and reported that 90° transverse ribs provided the lowest thermal performance while the 60° parallel broken ribs or 60° V-shaped broken ribs yielded a higher heat transfer augmentation than the 45° parallel broken ribs or 45° V-shaped broken ribs. Parallel angled discrete ribs were seen to be superior to parallel angled full ribs and its 60° discrete ribs performed the highest heat transfer. SooWbanAbn and Kang Pil Son [5] found that the heat transfer can be enhanced by the use of rough surfaces.

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Four different shapes such as a semicircle, sine wave, trapezoid, and arc were suggested to investigate the heat transfer enhancement and friction factor on rectangular duct. They measured the friction factor and heat transfer enhancement on smooth duct and compared it to the results. Square shape geometry gave the highest value because of its strongest turbulence mixing caused by rib. Non-circular ducts such as the equilateral triangle, Square and rectangular ducts have lower frictional factors and heat transfer as compared to circular ducts. Chien-Nan Lin and Jiin-Yuh Jang [6] studied the use of fins with embedded wave-type vortex generators to enhance heat transfer in fin-tube heat exchangers. An infrared thermo vision is used to visualize the temperature distribution on the surface of a scaled-up plain fin and upon fins with embedded vortex generators. The current results indicate that heat transfer and friction losses are strongly dependent on the geometric parameters of the vortex generators. This study identifies maximum improvement of (120) % in the local heat transfer coefficient and an improvement of (18.5) % in the average heat transfer coefficient.

Pesteei, et al [7] measured Local heat transfer coefficients on fin-tube heat exchanger with winglets using a single heater of 2 inch diameter and five different positions of winglet type vortex generators. The measurements were made at Reynolds number about 2250. Flow losses were determined by measuring the static pressure drop in the system. Results showed a substantial increase in the heat transfer with winglet type vortex generators. It was observed that average Nusselt number increased by about (46) %, while the local heat transfer coefficient was improved by several times as compared to plain fin-tube heat exchanger. In a Joardar and Jacobi [8] the effectiveness of delta-wing type vortex generators were experimentally evaluated by full-scale wind tunnel testing of a compact heat exchanger typical to those used in automotive systems. The mechanisms important to vortex enhancement methods are discussed, and a basis for selecting a delta-wing design as a vortex generator is established. The heat transfer and pressure drop performance are assessed at full scale under both dry- and wet-surface conditions for a louvered- fin baseline and for a vortex-enhanced louvered-fin heat exchanger. An average heat transfer increase over the baseline case of (21) % for dry conditions and (23.4) % for wet conditions was achieved with a pressure drop penalty smaller than (7) %. Vortex generation is proven to provide an improved thermal-hydraulic performance in compact heat exchangers for automotive systems.

Kamali and Binesh [9] studied turbulent heat transfer and friction characteristics in a square duct with various-shaped ribs mounted on one wall. The simulations were performed for four rib shapes, i.e., square, triangular, Trapezoidal with decreasing height in the flow direction, and Trapezoidal with increasing height in the flow direction. The results shown the inter-rib distribution of the heat transfer coefficient were strongly affected by the rib shape and Trapezoidal ribs with decreasing height in the flow direction provide higher heat transfer enhancement and pressure drop than other shapes. Bilenetal. [10] Presented an experimental study of surface heat transfer and friction characteristics of a fully developed turbulent air flow in different grooved tubes. Tests were performed in the Reynolds number range 10,000–38,000 and for different geometric groove shapes (circular, Trapezoidal and rectangular). Among the grooved tubes, heat transfer enhancement was obtained up to 63% for circular groove, 58% for Trapezoidal groove and 47% for rectangular groove, in comparison to the smooth tube at the highest Reynolds number ($Re=38,000$).

II. EXPERIMENTAL SET UP:

In order to investigate the effect of inserting the annular ribs inside a cylindrical combustion chamber on heat transfer enhancement, combustion and flame stability by using a triple flame burner type which inject the gas fuel co-axially with the combustion chamber axes through a triple flame burner which is a partially premixed flame that contains two premixed reaction zones (one fuel lean and the other rich) that form exterior wings and a non-premixed reactions zone that is established in between these wings. The three reaction zones merge at a " triple point ". The geometry of the burner is shown in fig. (1).

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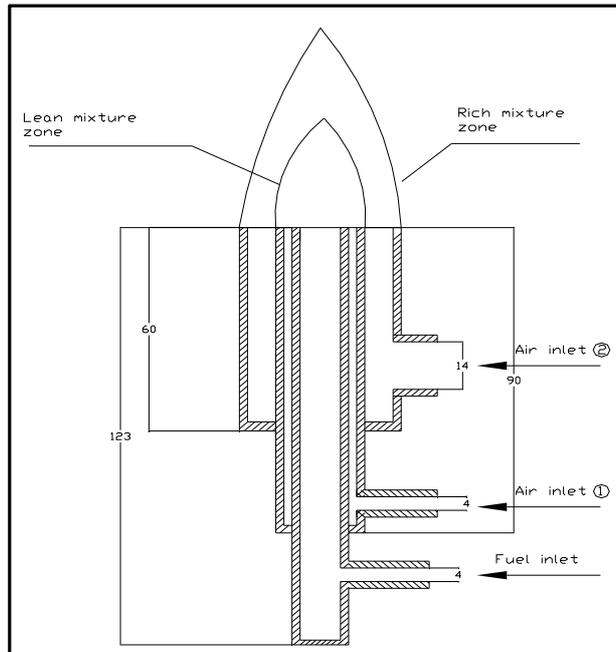


Fig. (1). Schematic diagram of triple flame burner.

The test rig as shown in fig. (2) is constructed with facilities to carry out the measurements and experimental work of LPG flame using a triple flame burner, the flow rates are measured by a set of calibrated turbine flow meters with electronic circuits, thermocouples and thermometers were used to measure temperatures, the heat transfer and firing rate are calculated based on the above measurements.

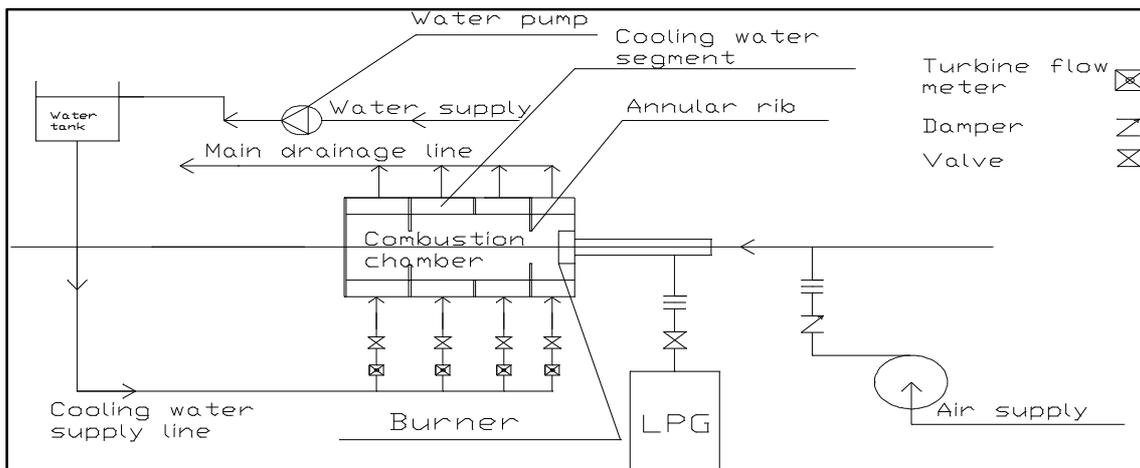


Fig. (2). Schematic diagram of experimental apparatus.

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Two kinds of steel ribs are selected to be tested in the experiment:

a- Square rib:

Fig. (3) Shows the dimensions and the formation of the rib.

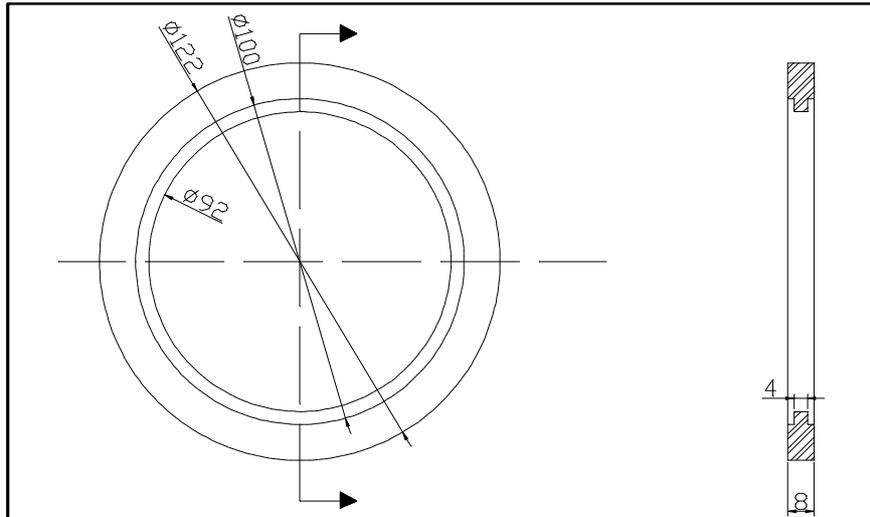


Fig. (3).square rib

b- Triangle rib:

Fig. (4) Shows the dimensions and the formation of the rib.

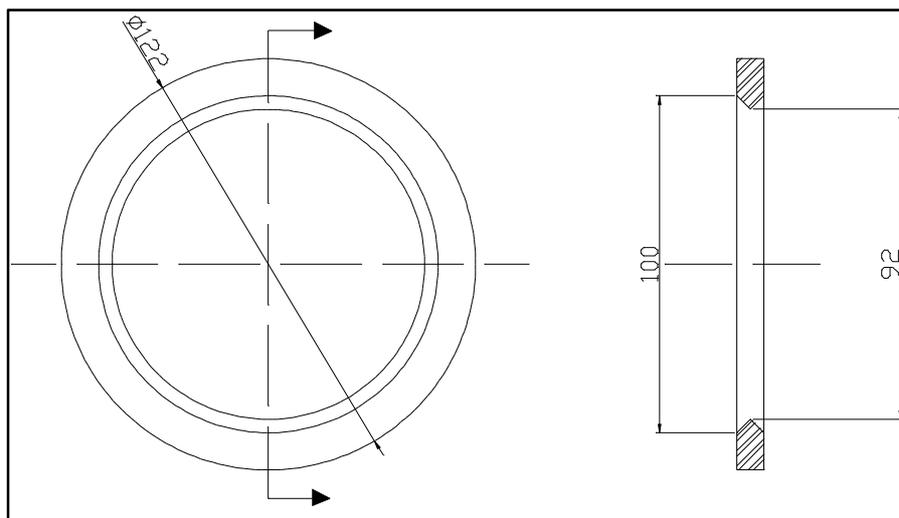


Fig. (4) Triangle rib

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The readings of flame temperature, surface, water inlet and water outlet temperature are recorded without inserting the ribs at different types of combustion (lean, rich, and stoichiometric) with equivalence ratio $\Phi=(1.1)$ for lean, (0.9) for rich, and (1) for stoichiometric and calculate the amount of heat transfer through each segment before and after inserting the ribs by the heat transfer flux formula.

$$q = \frac{\dot{m}_w \cdot C \cdot (T_{out} - T_{in})}{A_{segment}}$$

Where

- q** : Heat flux [watt/ m²].
- \dot{m}_w** : Water mass flow rate, [kg/s].
- C** : Water specific heat capacity, [kJ/kg.C].
- T_{out}** : Water outlet temperature from the cooling segment, [C].
- T_{in}** : Water inlet temperature to the cooling segment, [C].
- $A_{segment}$** : Cooling water segment surface area, [m²].

III. EXPERIMENTAL RESULTS

The effect of using square rib is shown in fig. (5) For lean combustion.

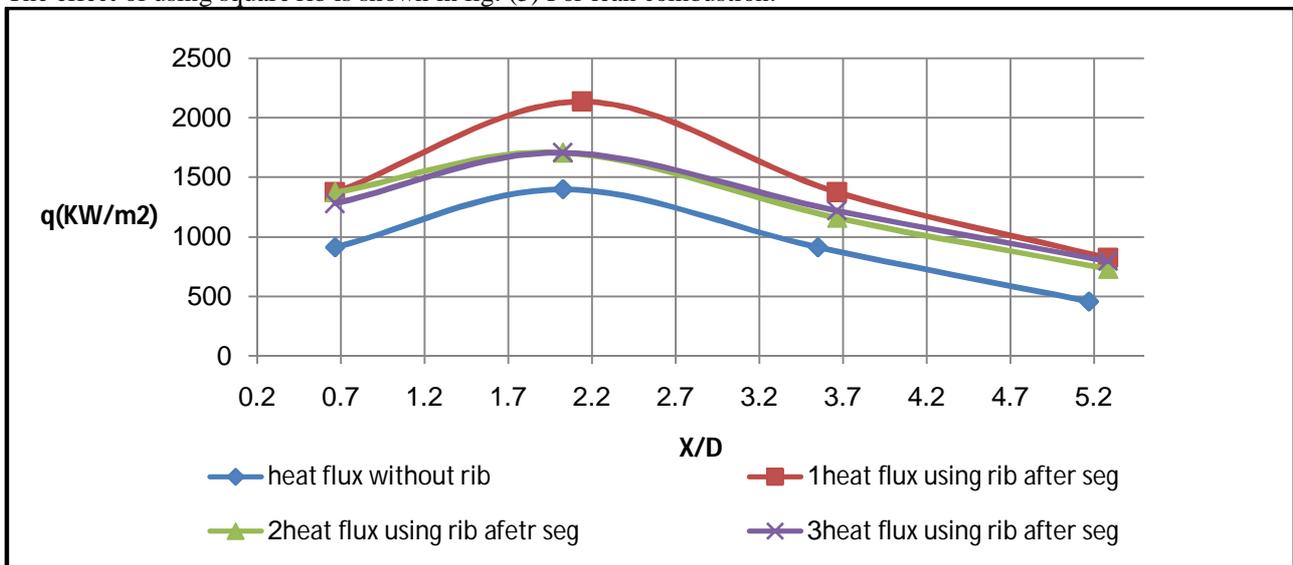


Fig. (5). Heat flux of lean combustion with square rib

It is clear that using square rib enhance the heat flux in comparison with the heat flux without rib and a better heat flux by using rib after segment (1).

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Fig. (6) shows the effect of using rib with rich combustion.

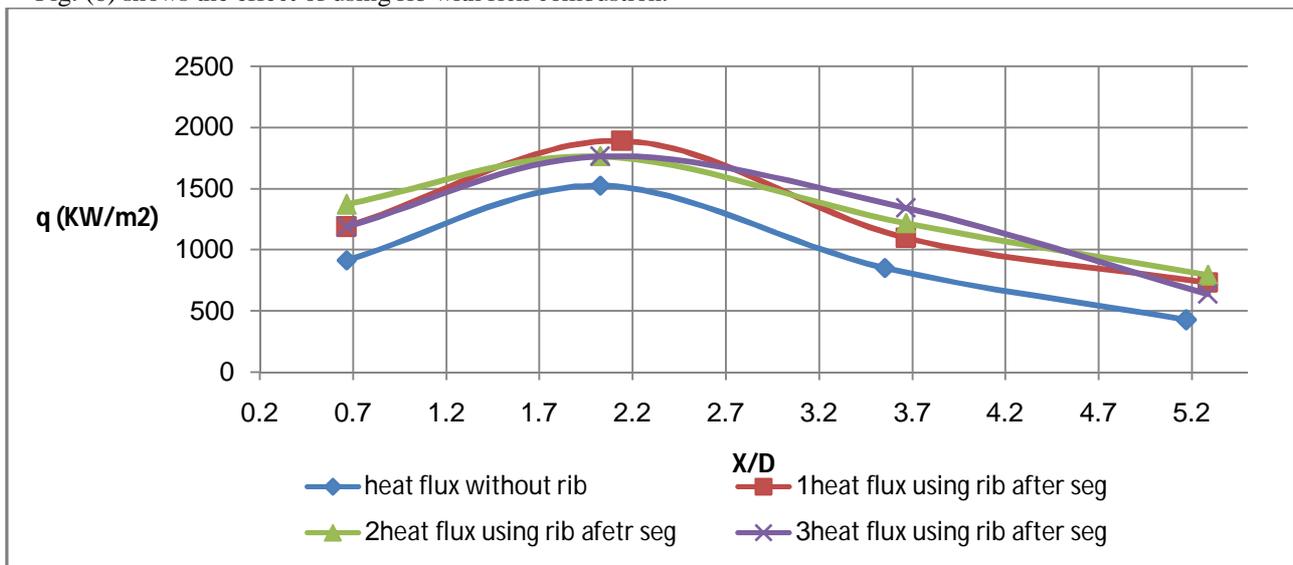


Fig. (6). Heat flux of rich combustion with square rib

Heat flux is increased after using rib in all segments with the highest heat flux at $x/d=2.2$ and the rib after segment (1).

Fig. (7) Shows the effect of using rib with stoichiometric combustion.

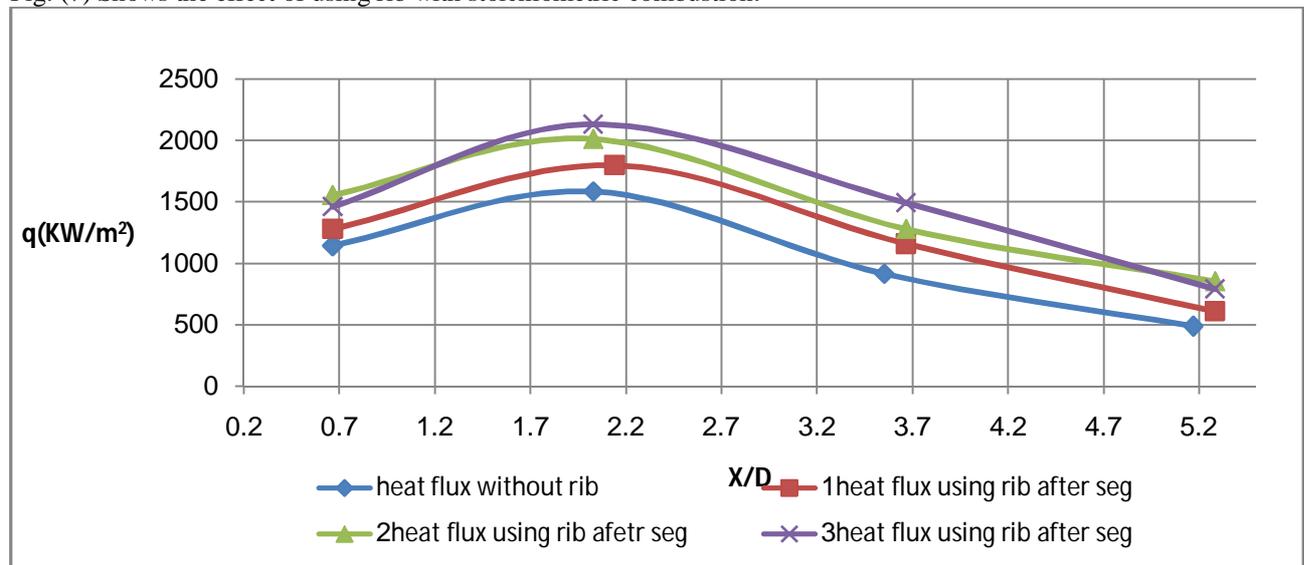


Fig. (7). Heat flux of stoichiometric combustion with square rib

A remarkable enhancement in heat flux, especially at $x/d=2.2$ and using the rib after segment (3).

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Fig. (8) Shows the effect of using triangle rib with lean combustion.

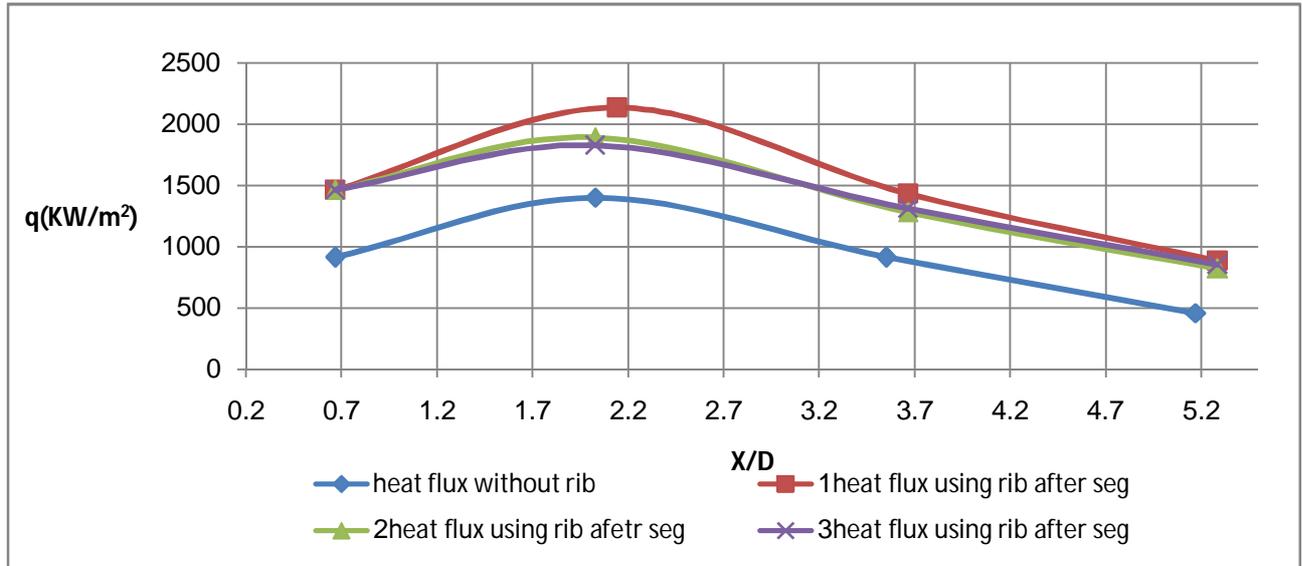


Fig. (8). Heat flux of lean combustion with triangle rib

It is obvious there is an enhancement in heat flux by using the rib after segment (1) and a slight difference after segments (2), and (3).

Fig. (9) Shows the effect with rich combustion.

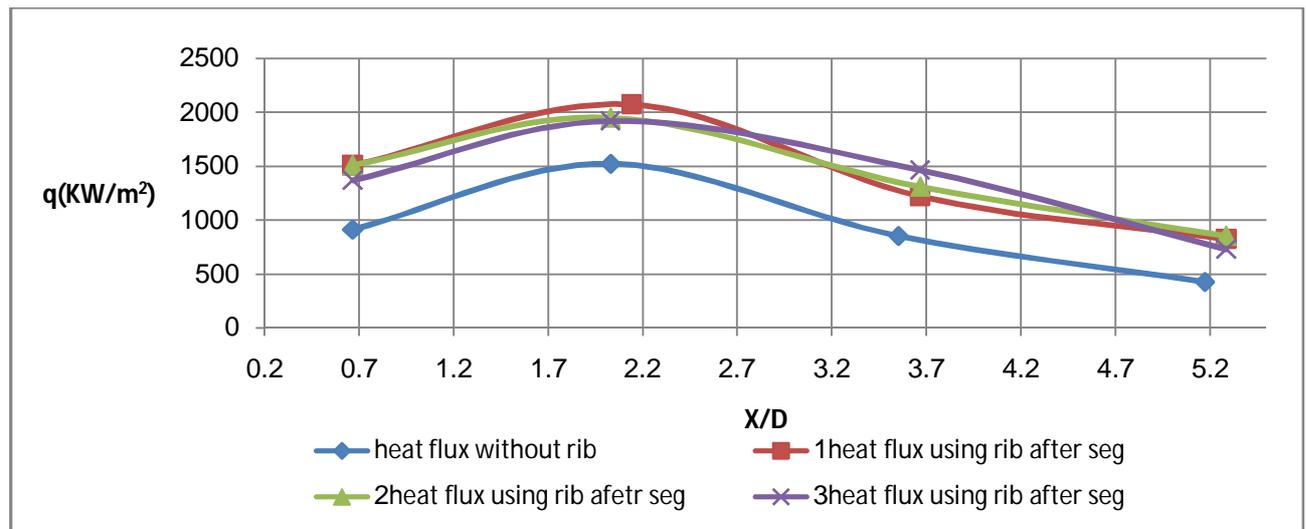


Fig. (9). Heat flux of rich combustion with triangle rib

Using of the rib after segment (1) shows the highest heat flux with rich combustion at X/D=2. 2

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Fig. (10) Shows the results with stoichiometric combustion.

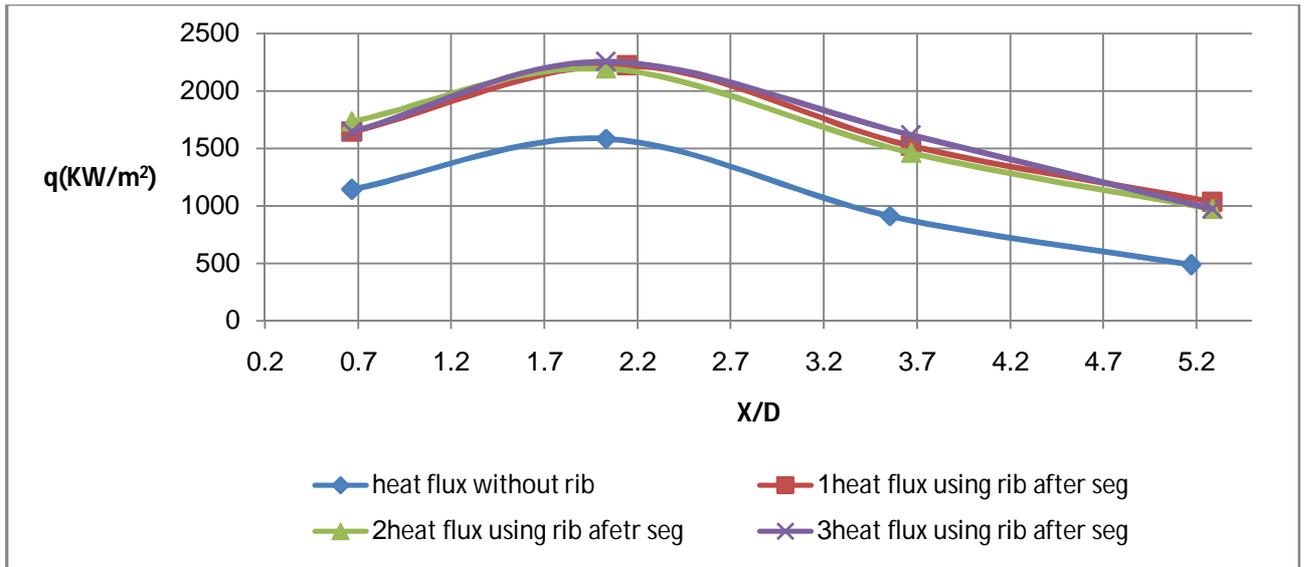


Fig. (10). Heat flux of stoichiometric combustion with triangle rib

It is obvious there is an enhancement in heat flux after using the rib with little differences after segment 1, 2, and 3.

Fig. (11-a) shows a comparison between results of heat flux by using square and triangle ribs after segment (1).

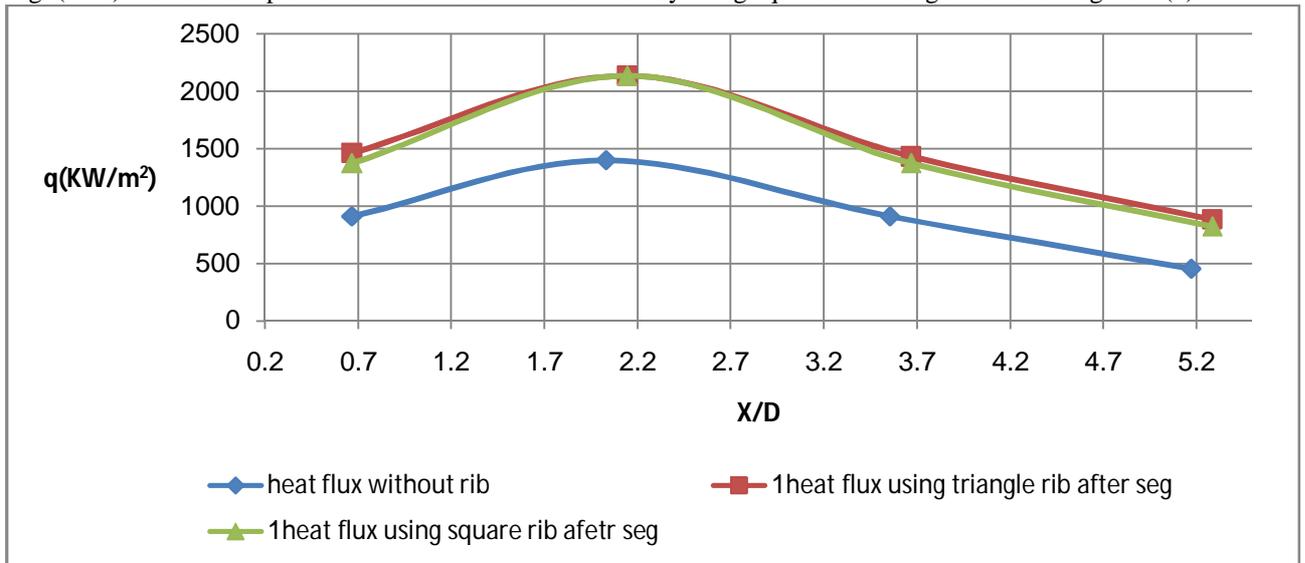


Fig.(11-a).Heat flux of lean combustion with square and triangle rib after segment(1)

The fig. Shows a slight enhancement in heat flux with triangle rib at X/D=0.7, 3.7 and 5.2.

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Fig. (11-b) shows the comparison with using ribs after segment (2).

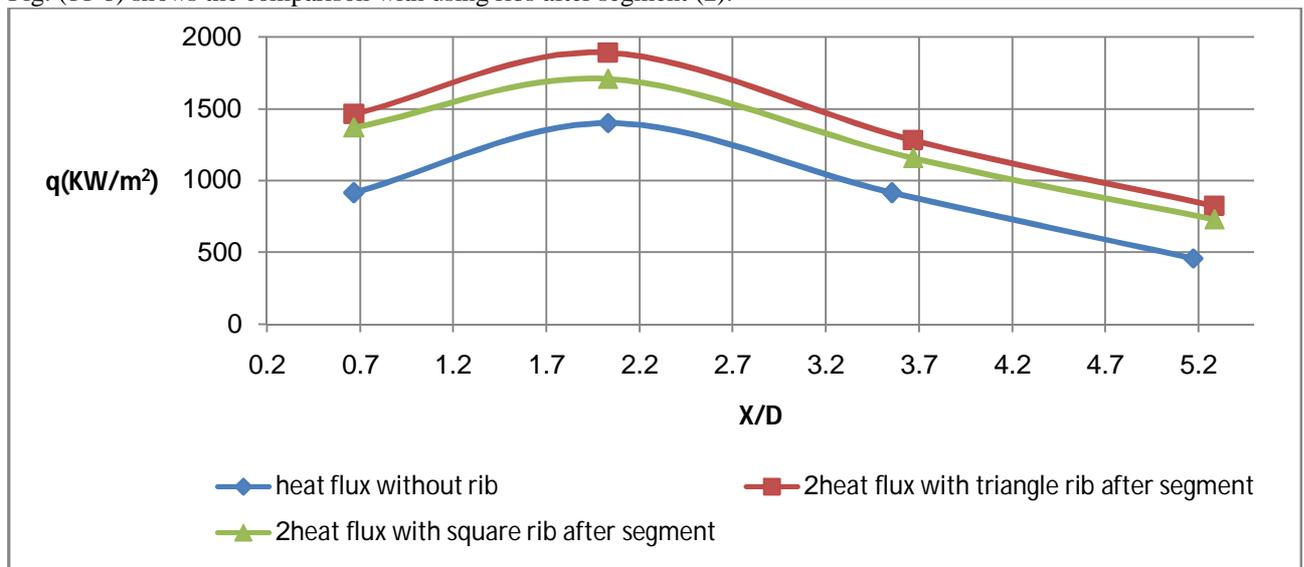


Fig.(11-b). Heat flux of lean combustion with square and triangle rib after segment (2)

The fig. Shows an increase in heat flux for triangle rib over square one.

Fig. (11-c) shows the comparison with using ribs after segment (3).

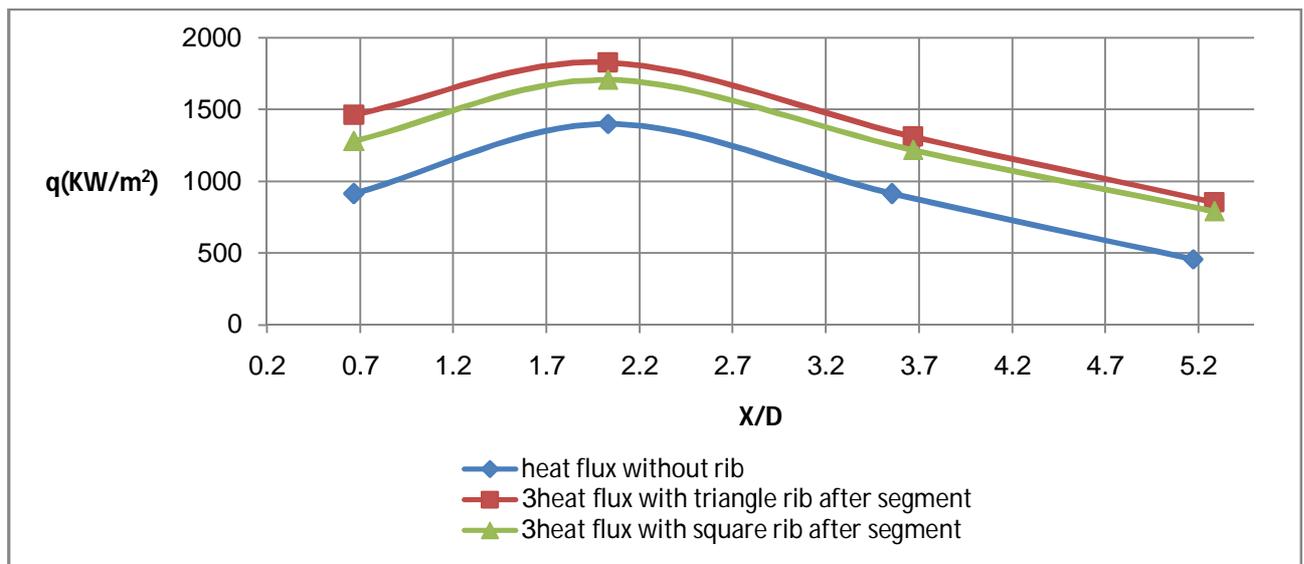


Fig.(11-c). Heat flux of lean combustion with square and triangle rib after segment (3)

Heat flux with triangle rib is higher than in square one until they matched at X/D = 5. 2.

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Fig. (12-a) shows a comparison between the two types of ribs after segment (1) with rich combustion.

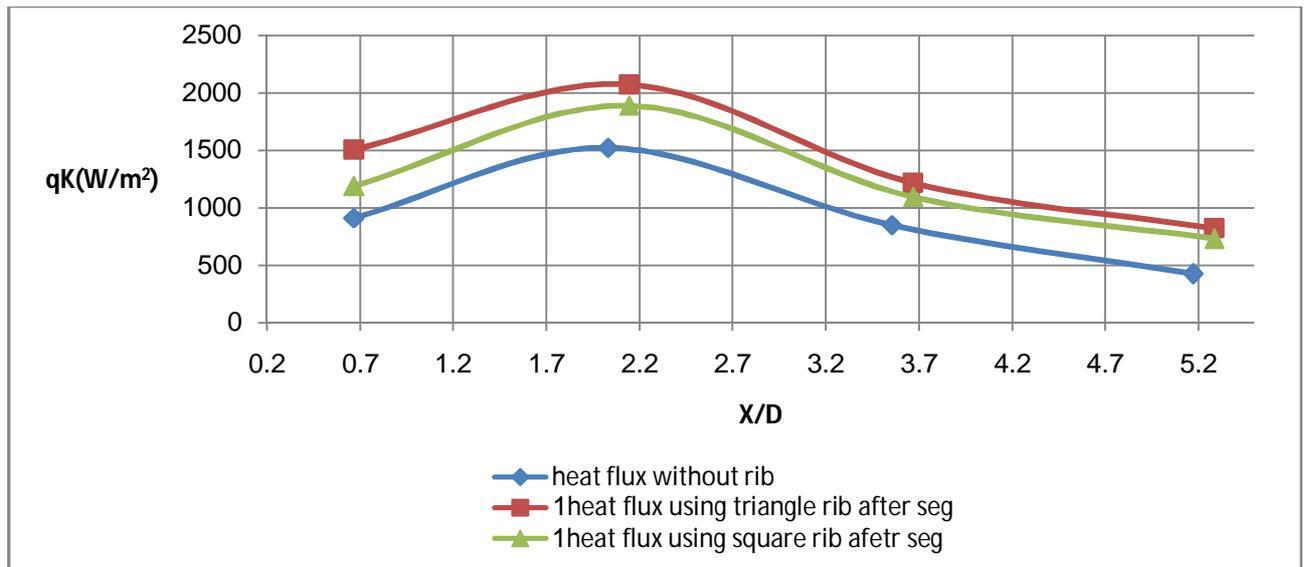


Fig.(12-a).eat flux of rich combustion with square and triangle rib after segment (1)

There is an improvement in heat flux by using the triangle type along different positions.

Fig. (12-b) shows a comparison between the two types of ribs after segment (2) with rich combustion.

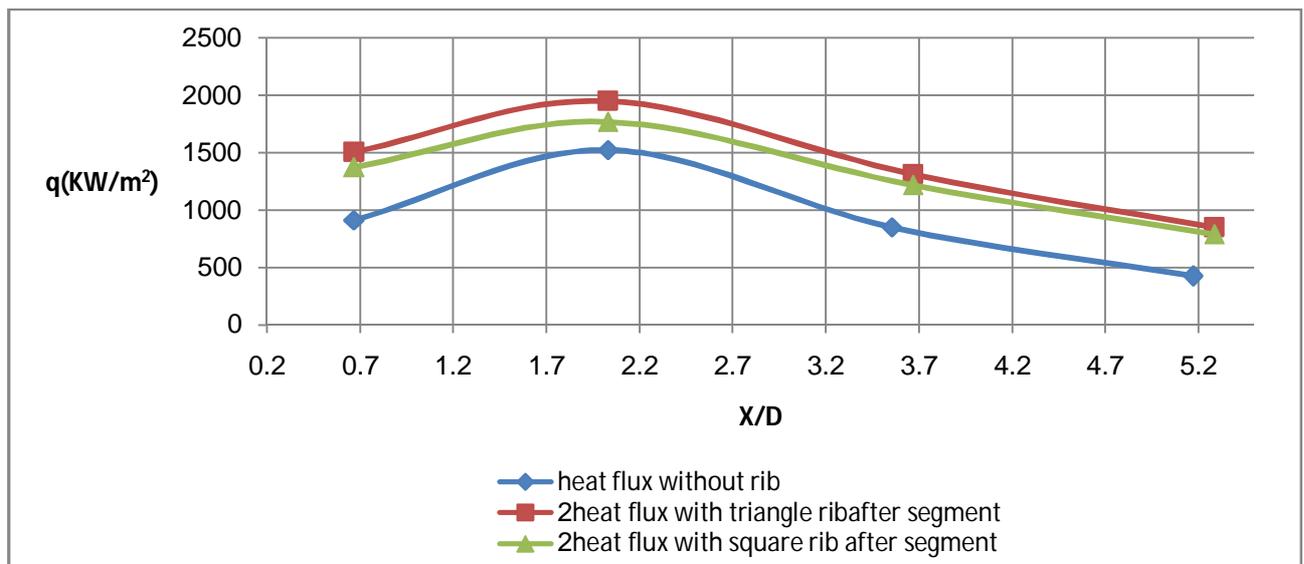


Fig.(12-b). Heat flux of rich combustion with square and triangle rib after segment (2)

Triangle rib has a better performance than the square rib.

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Fig. (12-c) shows a comparison between the two types of ribs after segment (3) with rich combustion.

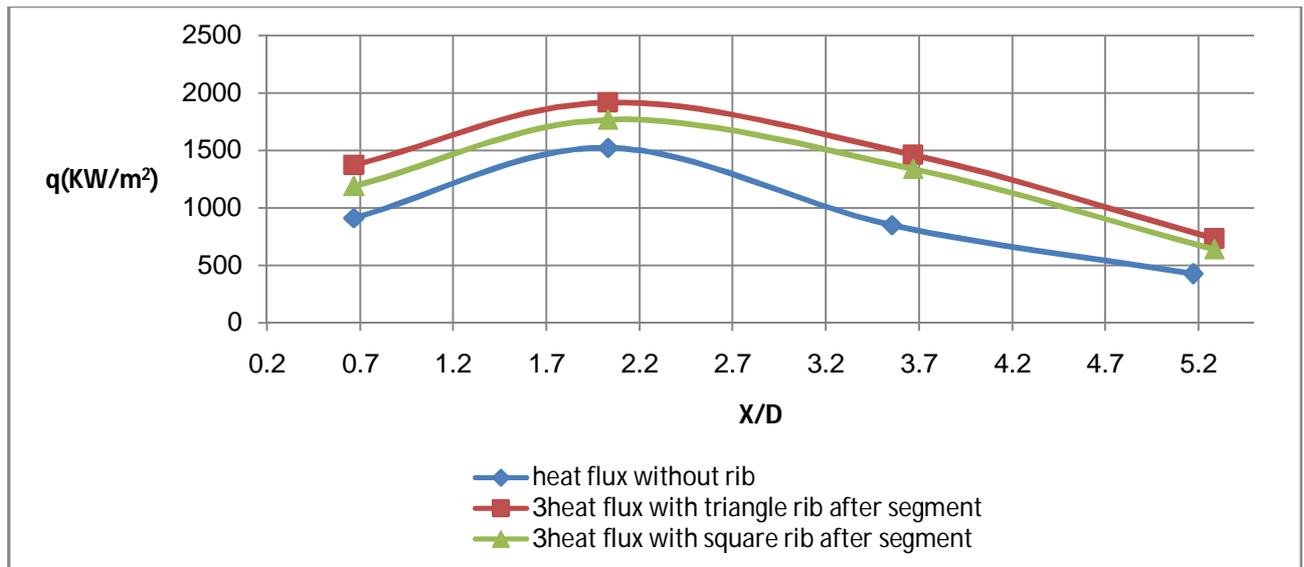


Fig.(12-c). Heat flux of rich combustion with square and triangle rib after segment (3)

In all positions the triangle rib is better than square rib.

Fig. (13-a) shows a comparison between the two types of ribs after segment (1) with stoichiometric combustion.

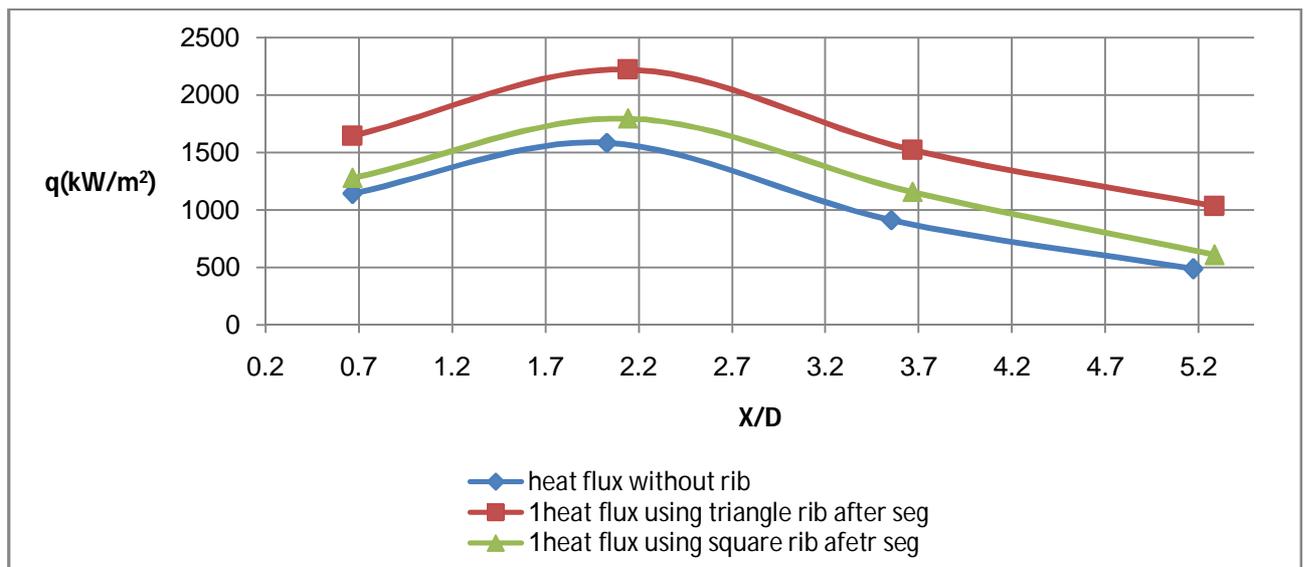


Fig.(13-a). Heat flux of stoichiometric combustion with square and triangle rib after segment (1)

It is clear superiority of triangle over square rib.

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Fig. (13-b) shows a comparison between the two types of ribs after segment (2) with stoichiometric combustion.

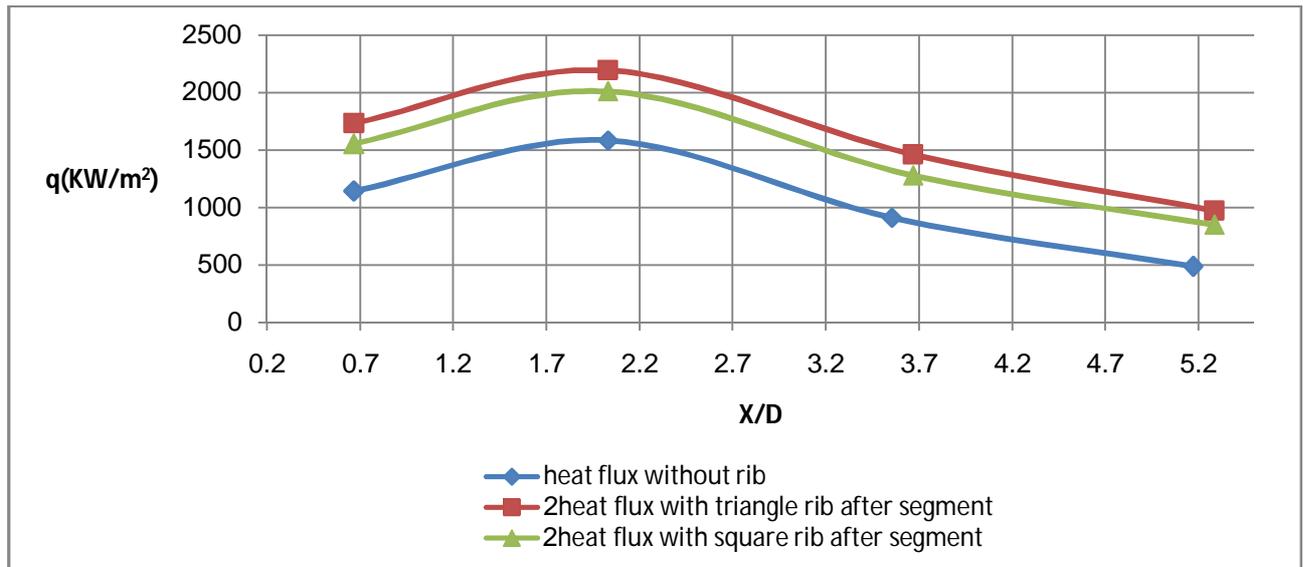


Fig.(13-b). Heat flux of stoichiometric combustion with square and triangle rib after segment (2)

Triangle rib is better than the square one.

Fig. (13-c) shows a comparison between the two types of ribs after segment (3) with stoichiometric combustion.

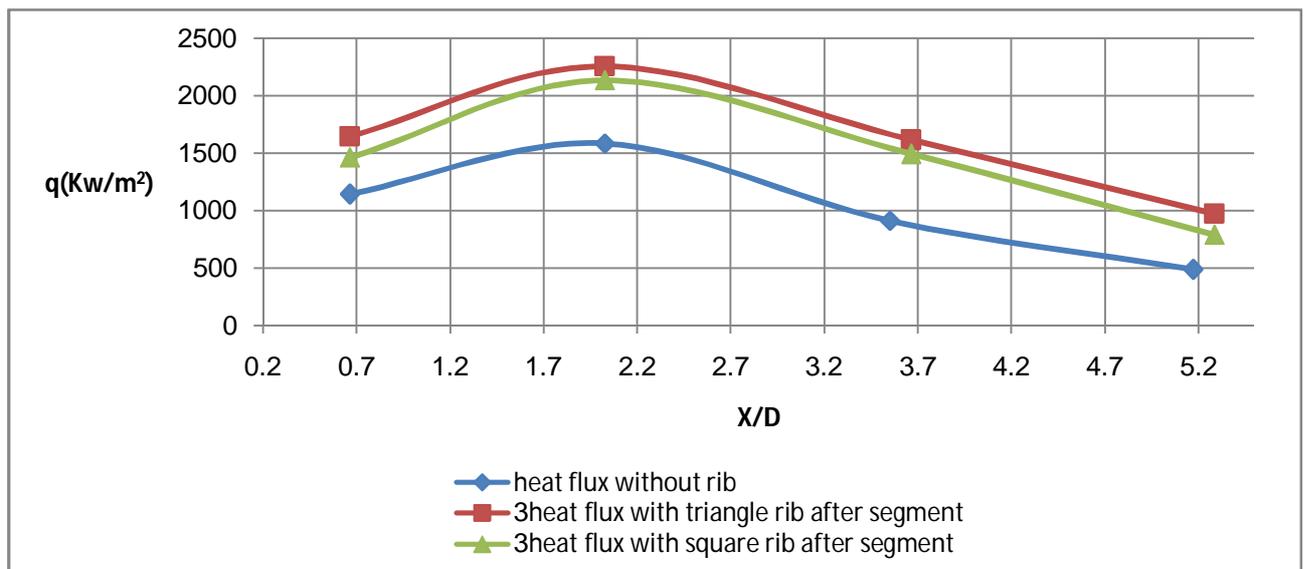


Fig.(13-c). Heat flux of stoichiometric combustion with square and triangle rib after segment (3)

In different positions triangle is better than square rib.

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The effect of using square rib is shown in fig. (14) For lean combustion.

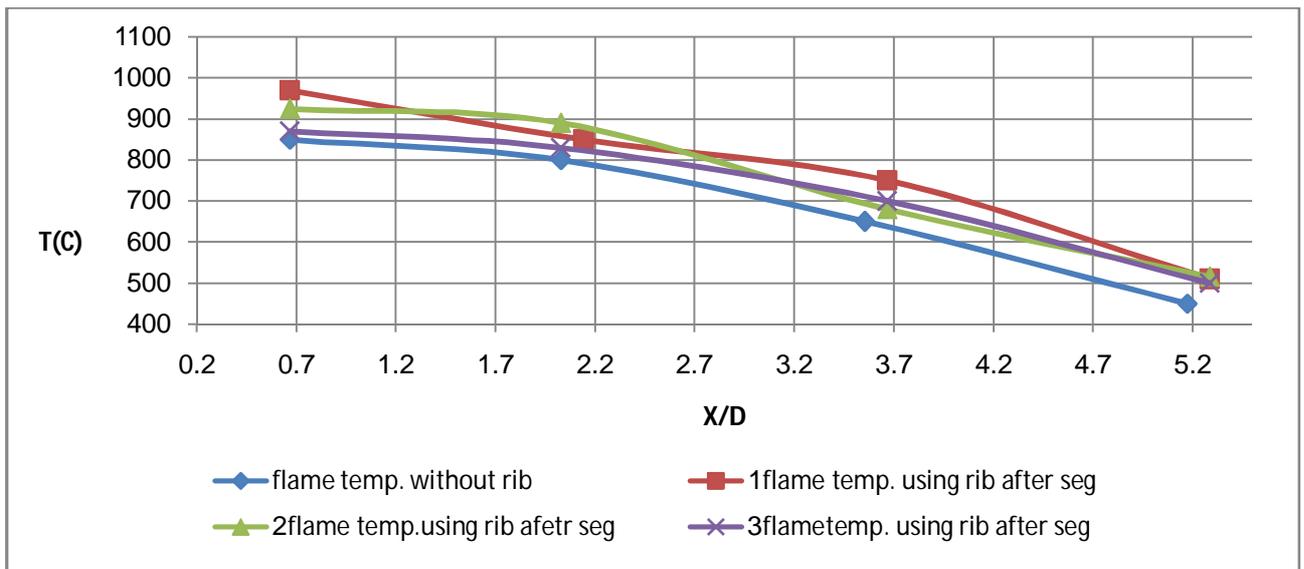


Fig. (14). Flame temp. In lean combustion with square rib

It is clear that the lowest temperature without using the rib.

Fig. (15) shows the effect of using rib with rich combustion on flame temperature.

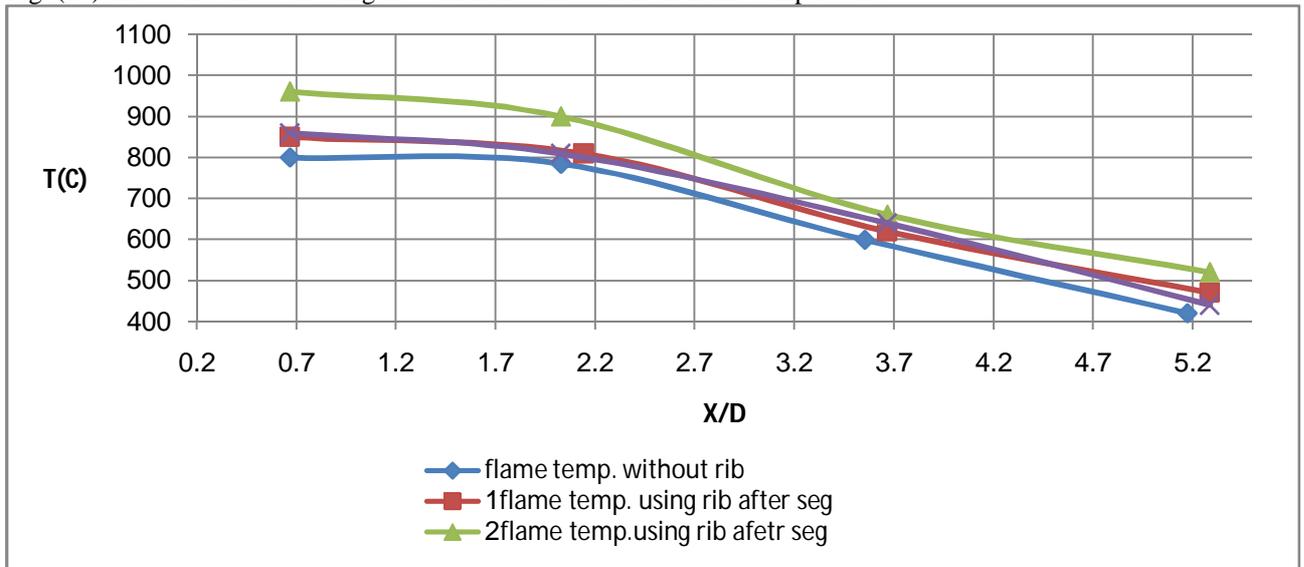


Fig. (15). Flame temp. In rich combustion with square rib

As illustrated in the fig. Flame temperatures with the square rib had a high temperature level than without the rib.

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Fig. (16) Shows the effect of using rib with stoichiometric combustion.

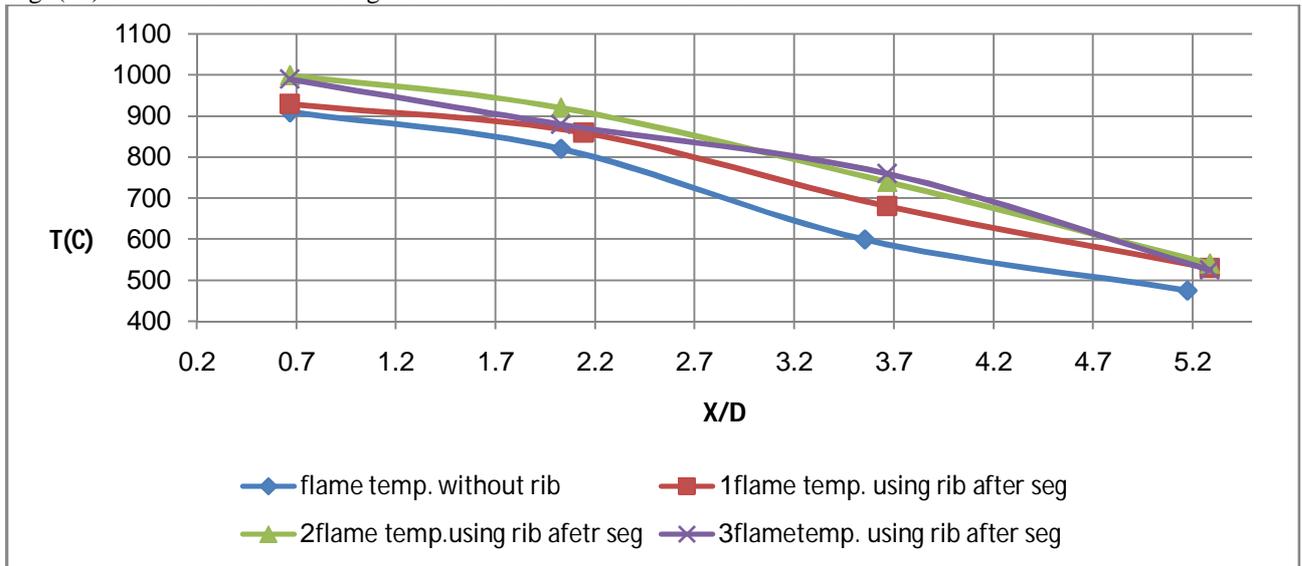


Fig. (16). Flame temp. of stoichiometric combustion with square rib

It is obvious that there is a clear change in the flame temperature with the rib and without, in addition a slightly difference with using rib in different positions.

Fig. (17) Shows the effect of using triangle rib with lean combustion.

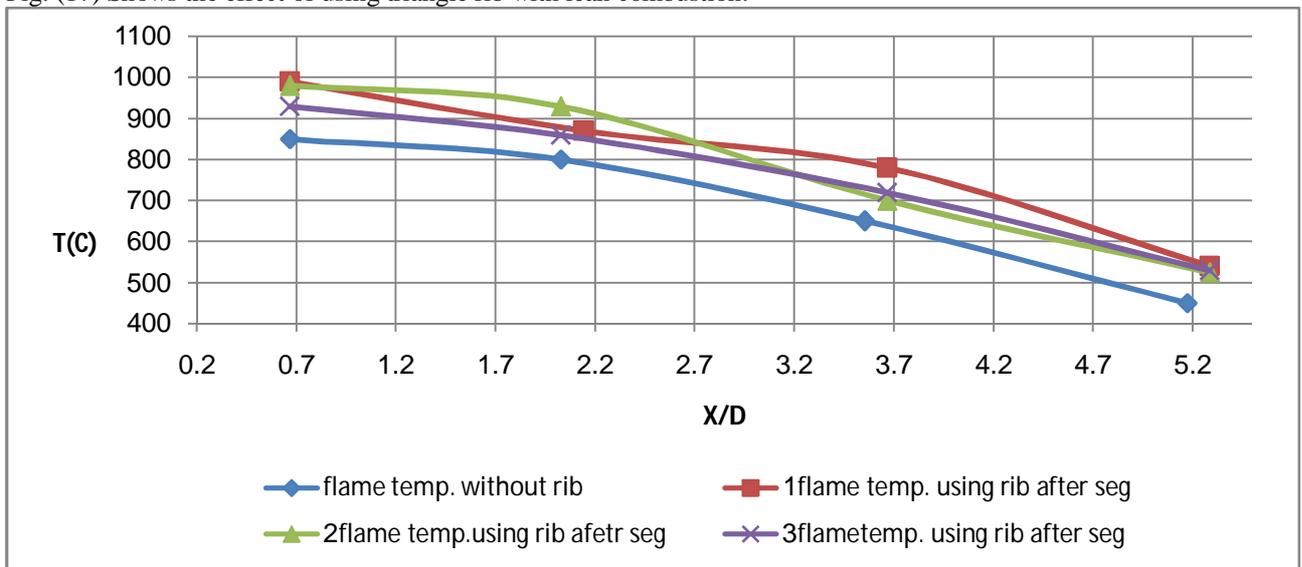


Fig. (17). Flame temp. In lean combustion with triangle rib

Using the rib after segment (2) has high temperature levels from X/D=0.7 to 2.7 then the rib after segment (1) has priority.

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Fig. (18) Shows the effect with rich combustion.

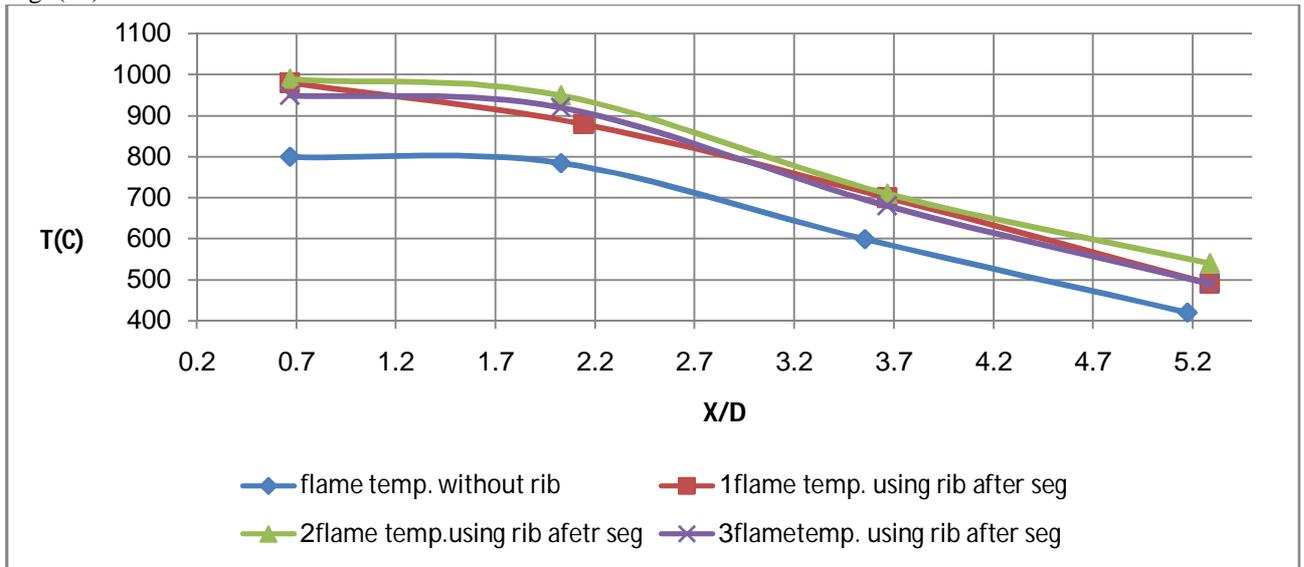


Fig. (18). Flame temp. In rich combustion with triangle rib

The highest temperature at using the rib after segment (2) all over X/D positions.

Fig. (19) Shows the results with stoichiometric combustion.

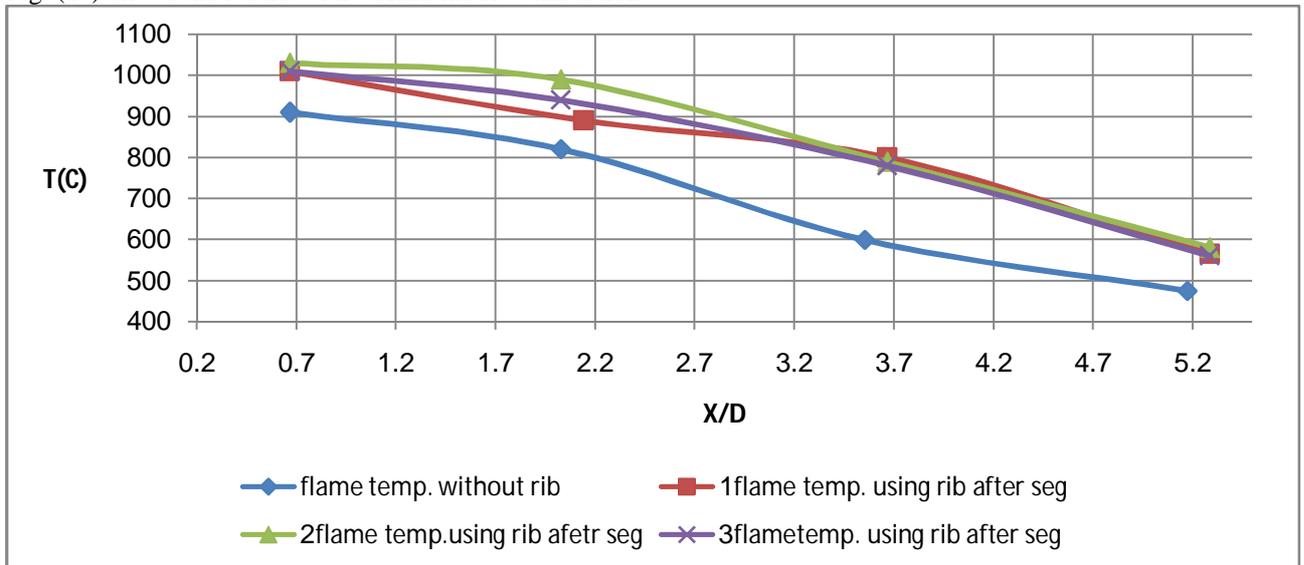


Fig. (19). Flame temp. of stoichiometric combustion with triangle rib

It is cleared that highest temperature curve is by using rib after segment (2) until X/D=3. 5 after that the three types are equal.

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Fig. (20-a) shows a comparison between the results of flame temperature by using square and triangle ribs after segment (1).

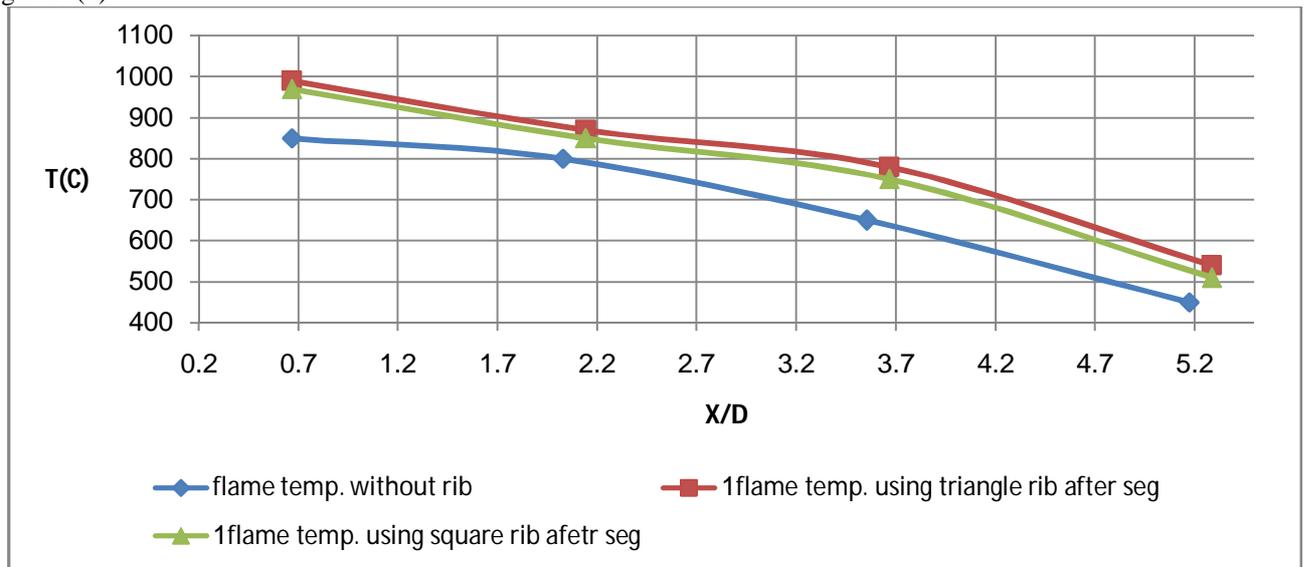


Fig.(20-a). Flame temp. of lean combustion with square and triangle rib after seg. (1)
Triangle rib from the fig.Is higher in flame temperature than the square one.

Fig. (20-b) shows the comparison with using ribs after segment (2).

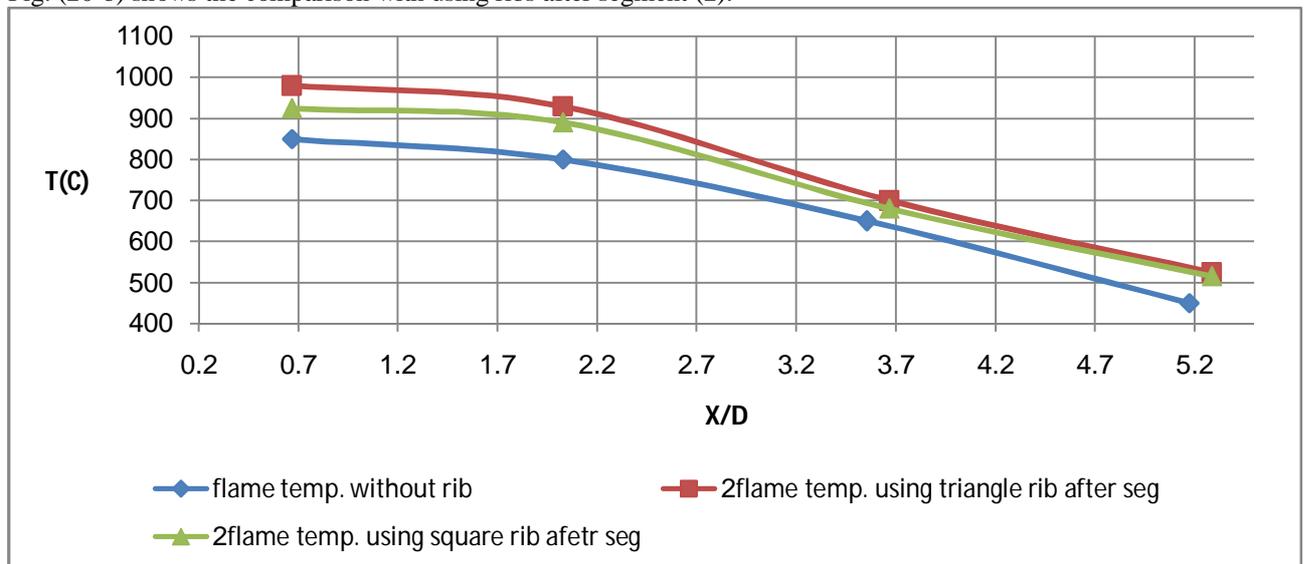


Fig.(20-b). Flame temp. of lean combustion with square and triangle rib after seg. (2)

As is evident superiority of flame temperature with triangle rib over the square one.

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Fig. (20-c) shows the comparison with using ribs after segment (3).

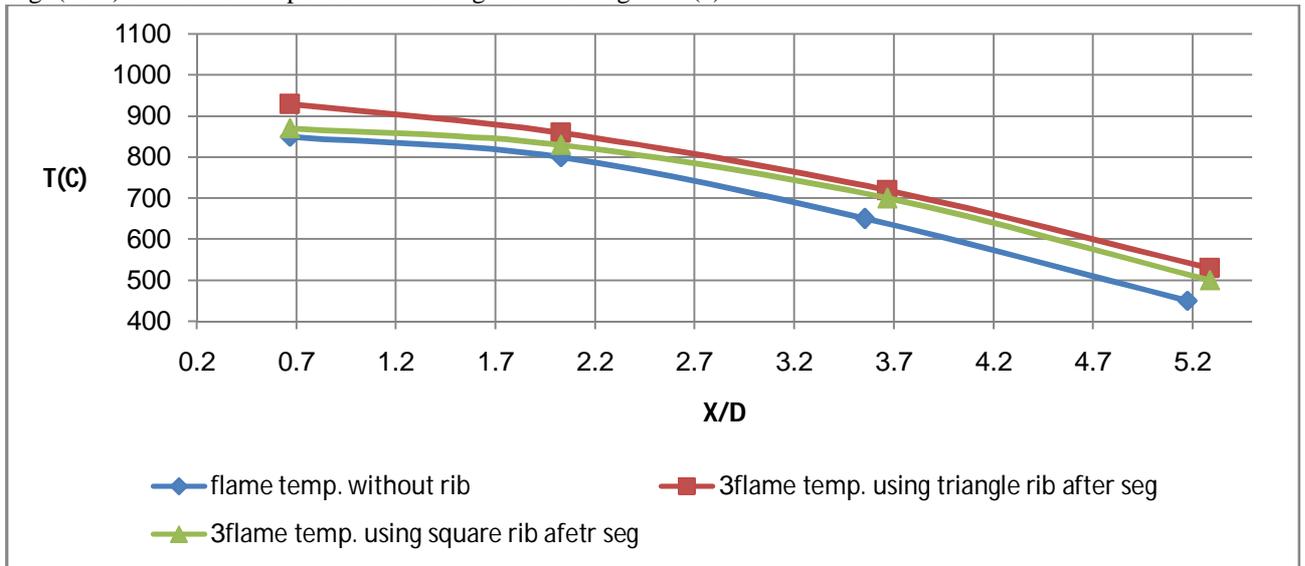


Fig.(20-c). Flame temp. of lean combustion with square and triangle rib after seg. (3)

From the fig. Triangle rib has a higher temperature level than square one.

Fig. (21-a) shows a comparison between the two types of ribs after segment (1) with rich combustion.

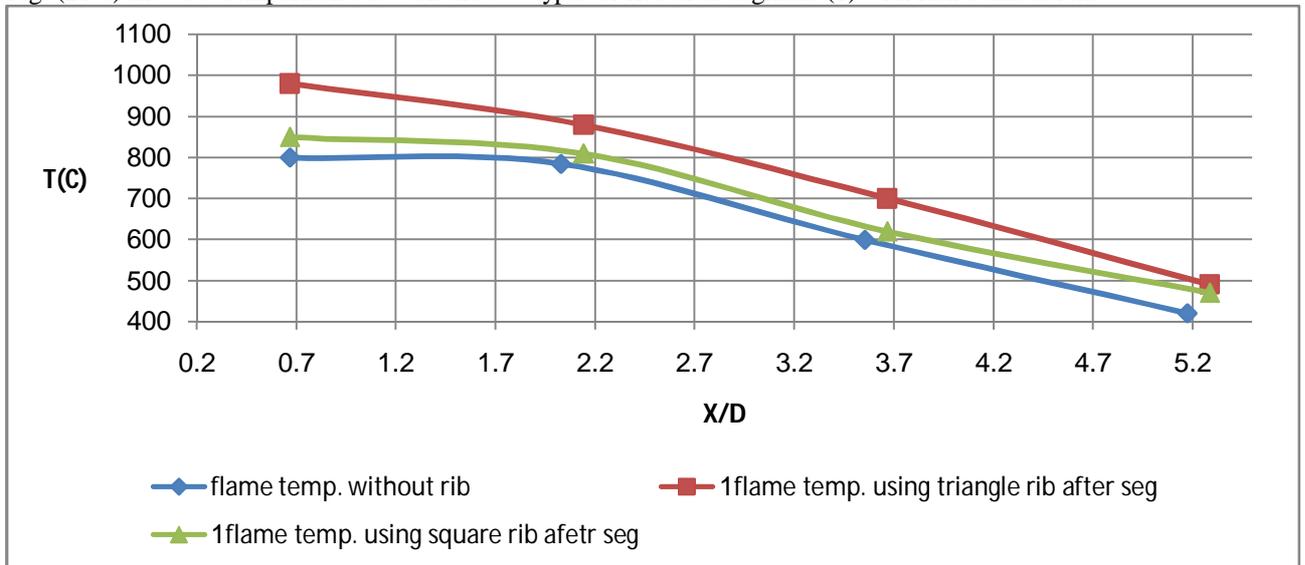


Fig.(21-a). Flame temp. of rich combustion with square and triangle rib after seg. (1)

It is obvious that flame temperature with triangle rib is higher than the square rib.

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Fig. (21-b) shows a comparison between the two types of ribs after segment (2) with rich combustion.

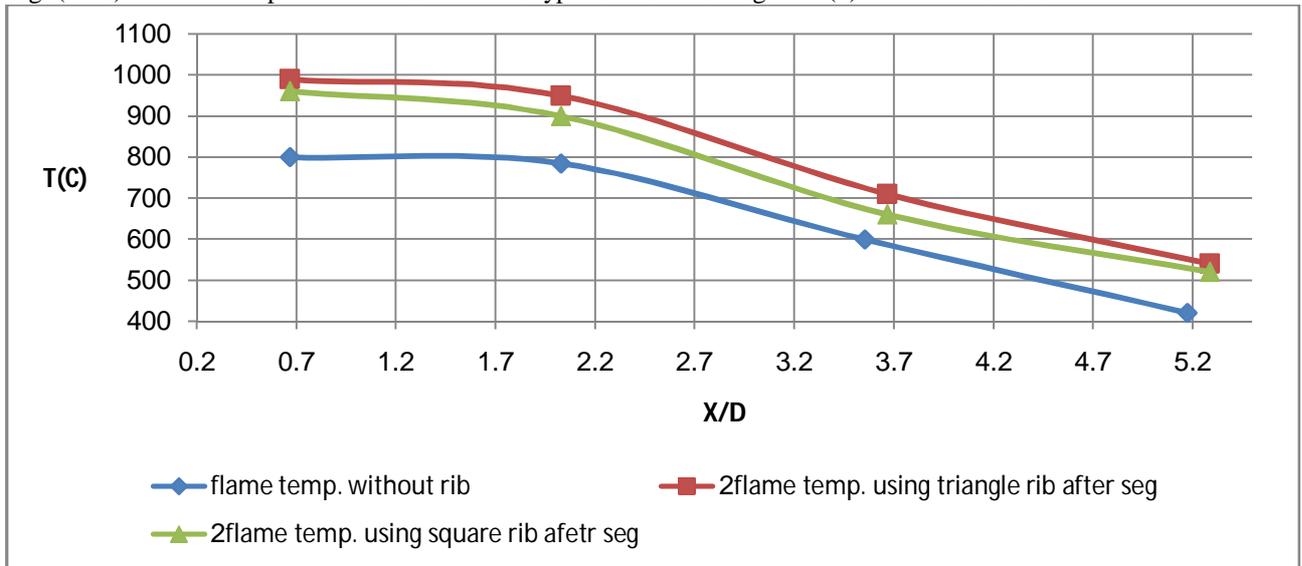


Fig.(21-b). Flame temp. of rich combustion with square and triangle rib after seg. (2)

From the fig. It is clear that using the triangle rib keeps the flame temperature slightly higher than the square rib.

Fig. (21-c) shows a comparison between the two types of ribs after segment (3) with rich combustion.

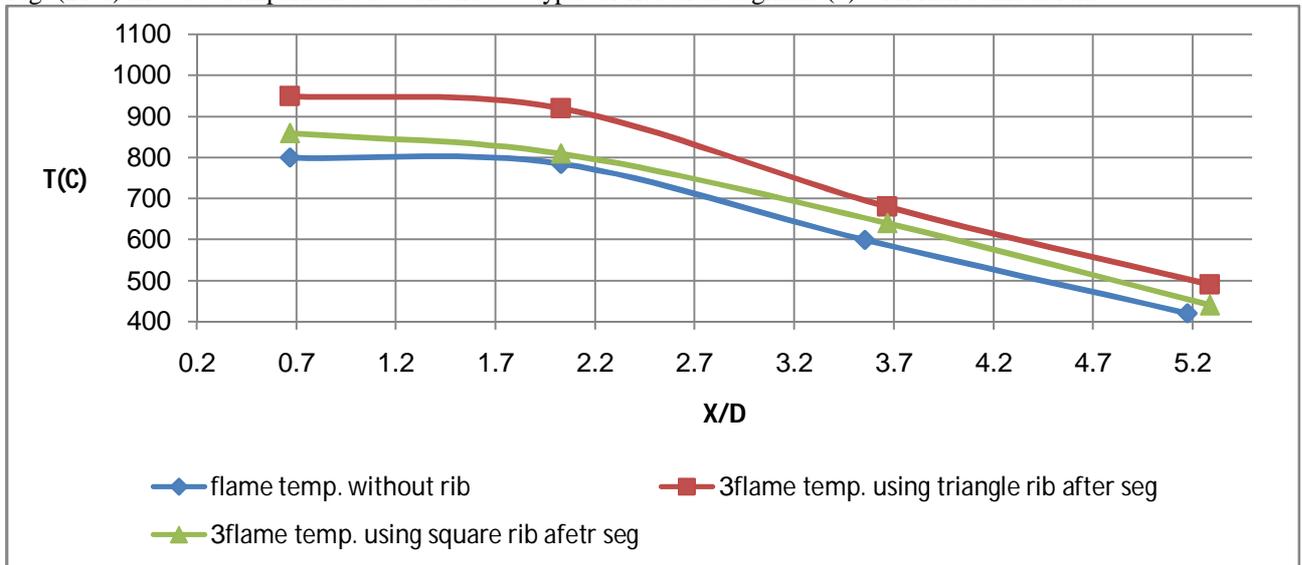


Fig.(21-c). Flame temp. of rich combustion with square and triangle rib after seg. (3)

Flame temperature by using triangle rib has superiority over the square one.

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Fig. (22-a) shows a comparison between the two types of ribs after segment (1) with stoichiometric combustion.

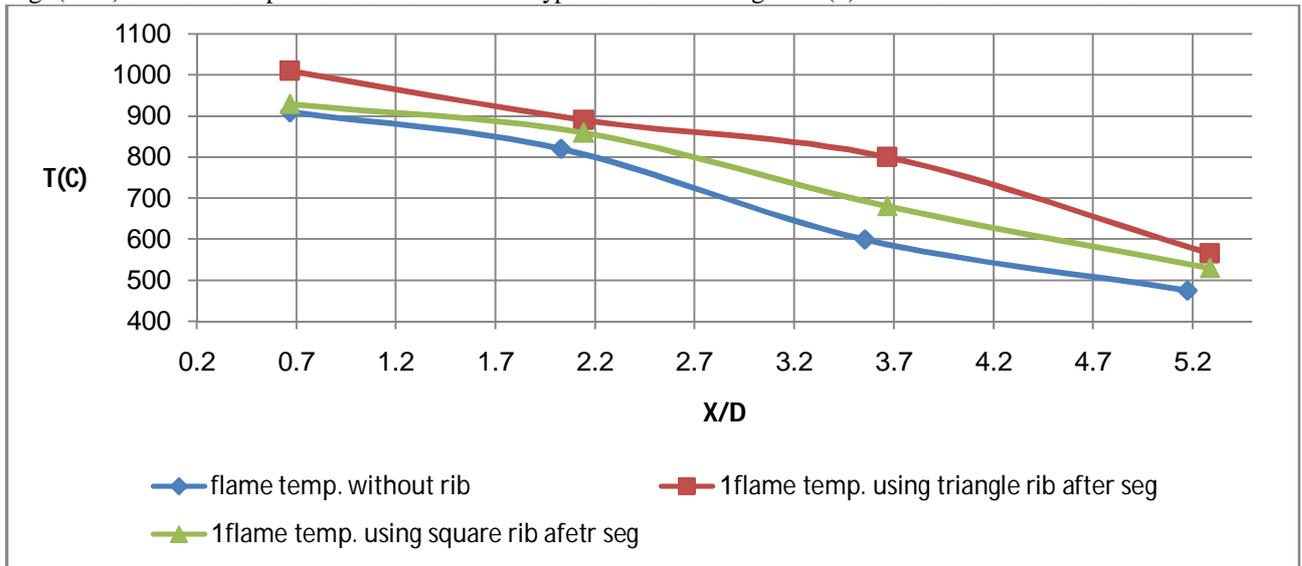


Fig.(22-a). Flame temp. of stoichiometric combustion with square and triangle rib after seg. (1)

It is obvious that flame temperature by using triangle rib is higher than the flame temperature with using square rib all over X/D positions.

Fig. (22-b) shows a comparison between the two types of ribs after segment (2) with stoichiometric combustion.

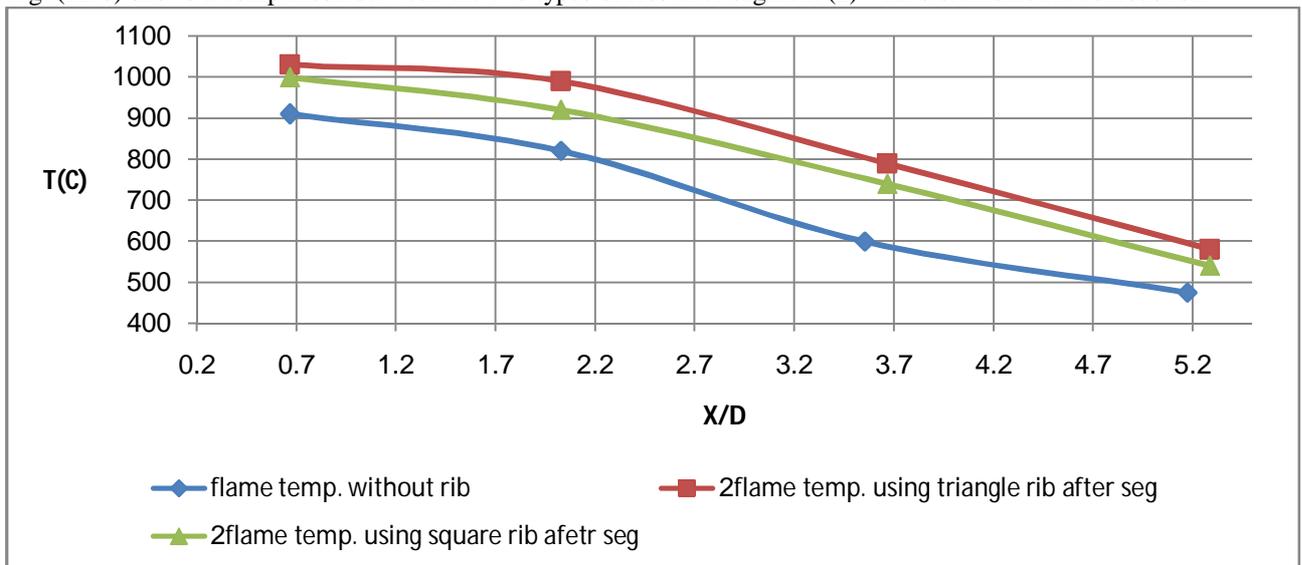


Fig.(22-b). Flame temp. of stoichiometric combustion with square and triangle rib after seg. (2)

It is obvious the triangle type has the priority over the square one.

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Fig. (22-c) shows a comparison between the two types of ribs after segment (3) with stoichiometric combustion.

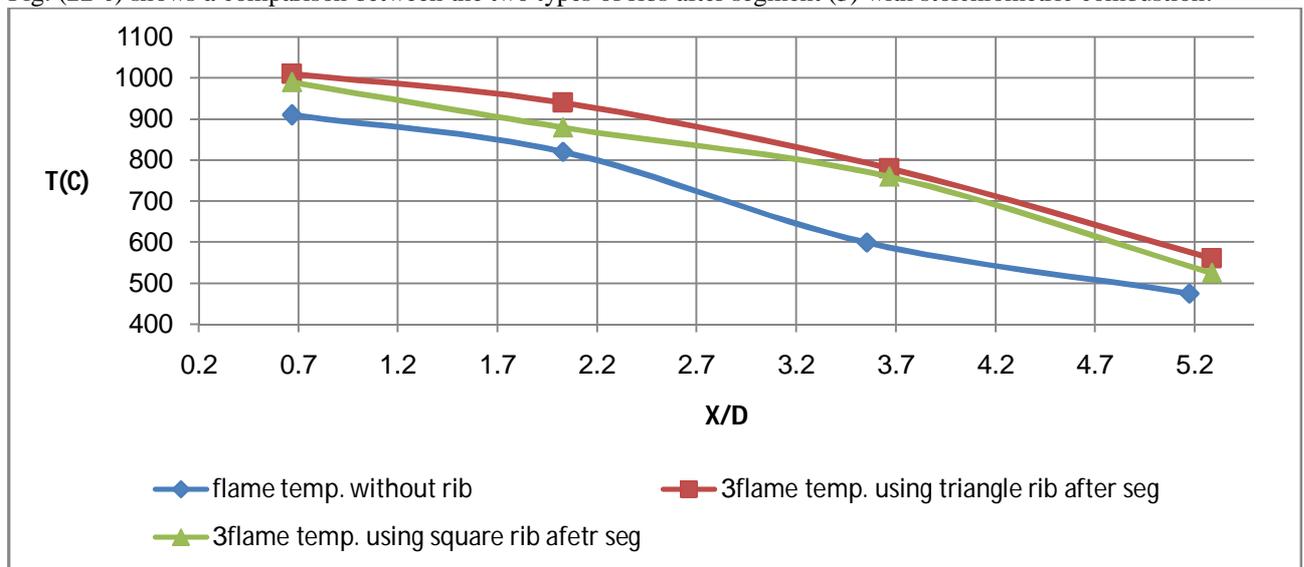


Fig.(22-c). Flame temp. of stoichiometric combustion with square and triangle rib after seg. (3)

Flame temperature using the triangle rib is higher than the temperature with using the square one.

In this experiment, a gas analysis tests have achieved from using rib (triangle, square) and without using rib. The following charts will illustrate the results of gas analysis for different types of combustion.

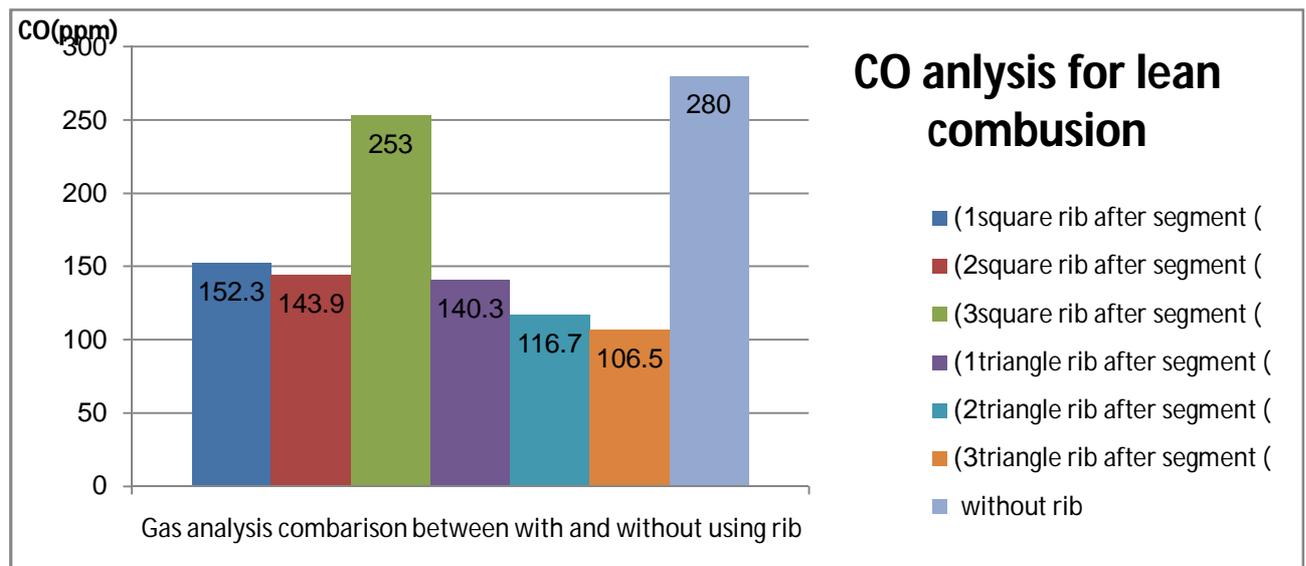


Fig. (23). CO analysis of lean combustion for square and triangle rib

The lowest emissions of CO by using triangle rib after segment (3) and the highest emissions without using rib.

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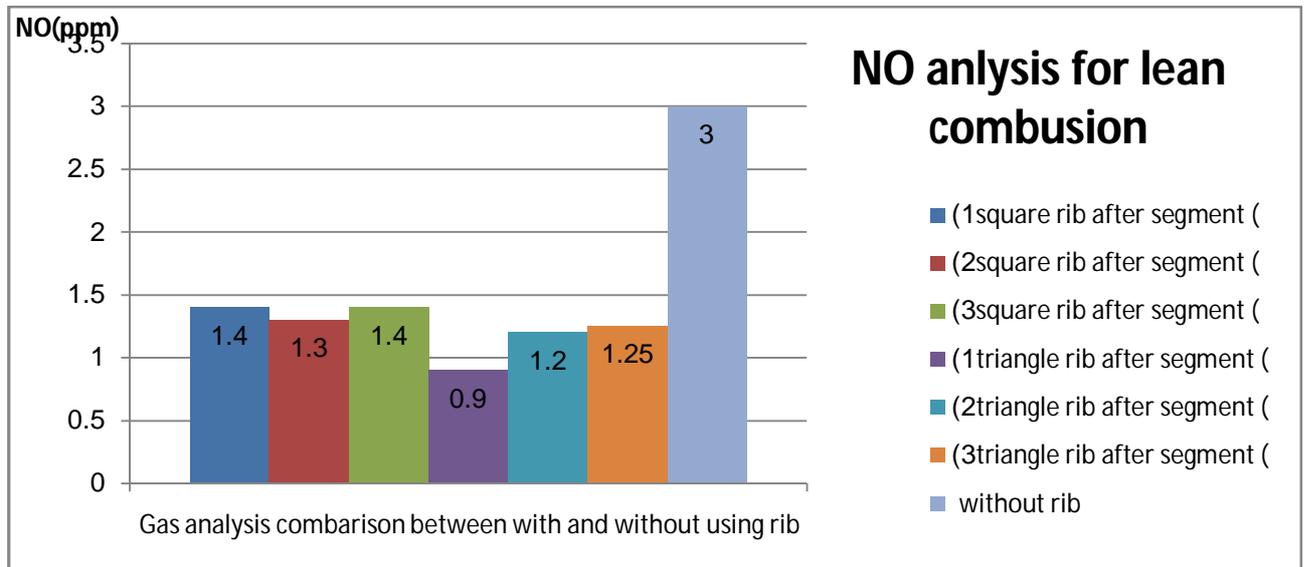


Fig. (24). NO analysis of lean combustion for square and triangle rib

For (NO) analysis as shown in the fig. The lowest level of emissions with triangle rib after segment (1).

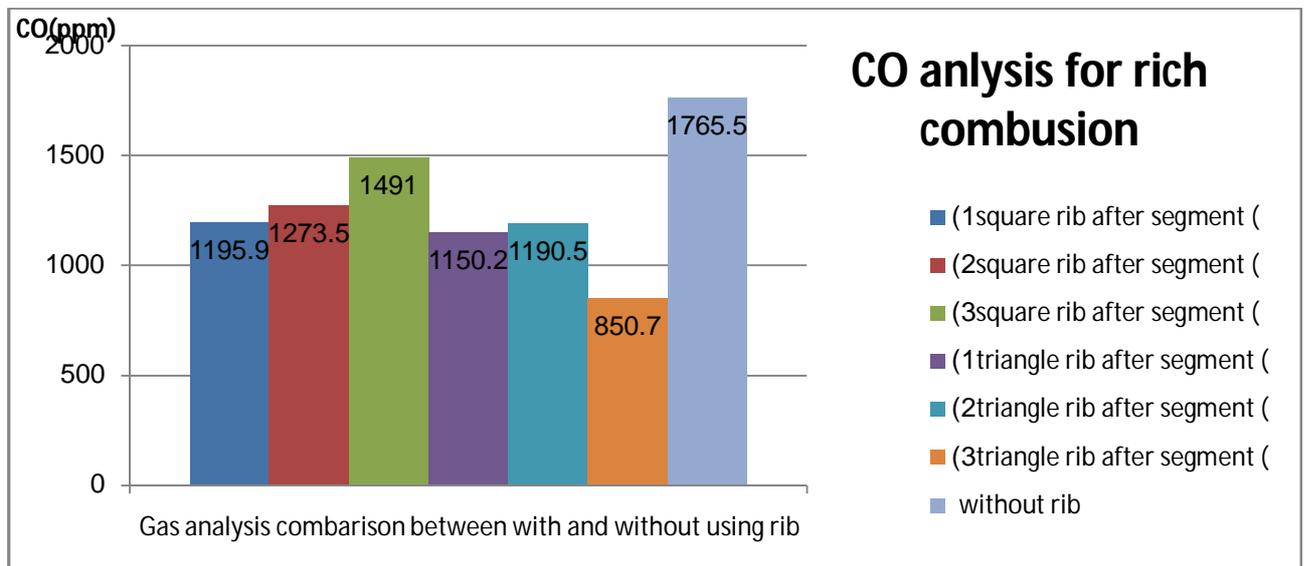


Fig. (25). CO analysis of rich combustion for square and triangle rib

As shown from the chart the lowest level of emissions by using triangle rib after segment (3).

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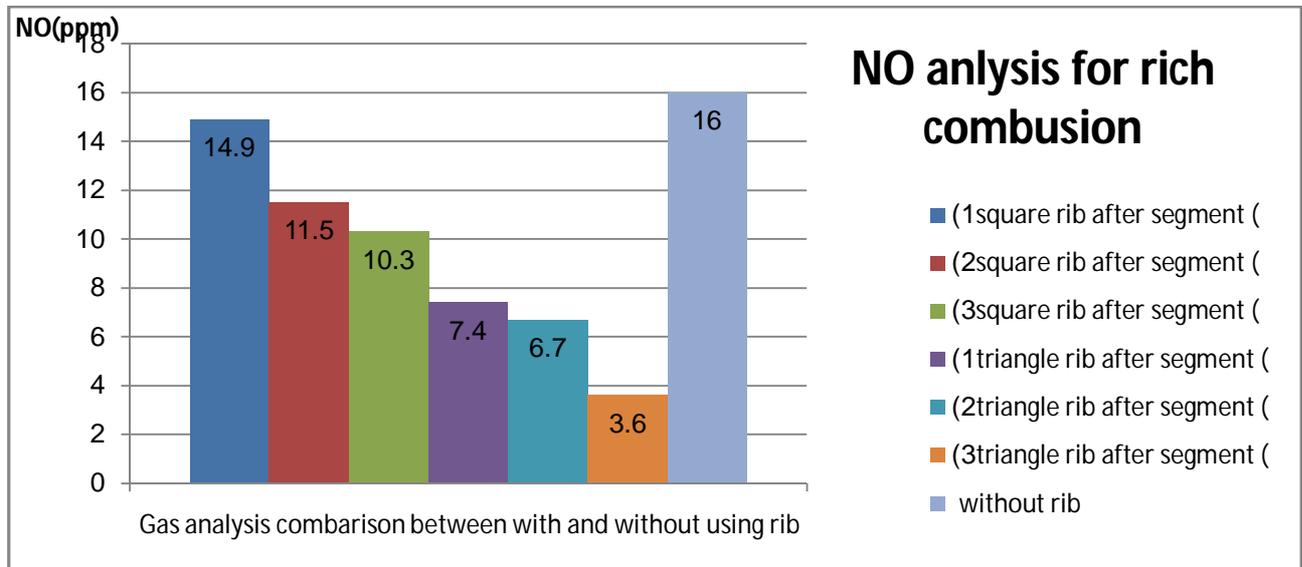


Fig. (26). NO analysis of rich combustion for square and triangle rib

The lowest emissions at triangle rib after segment (3).

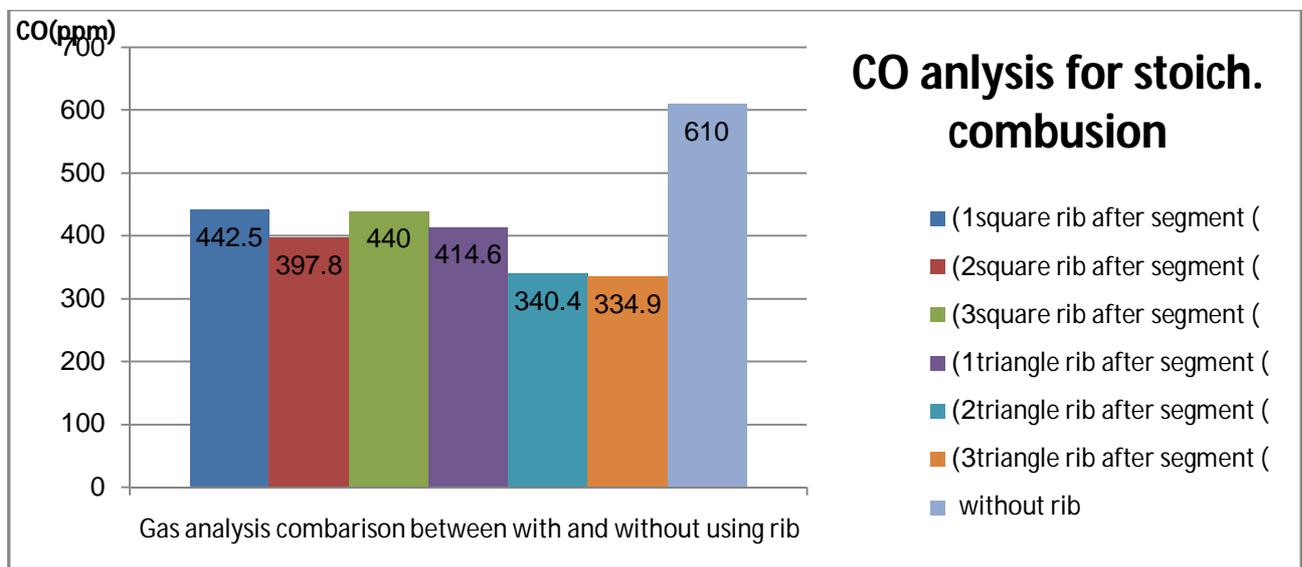


Fig. (27). CO analysis of stoichiometric combustion for square and triangle rib

Using triangle rib has the lowest emissions of CO.

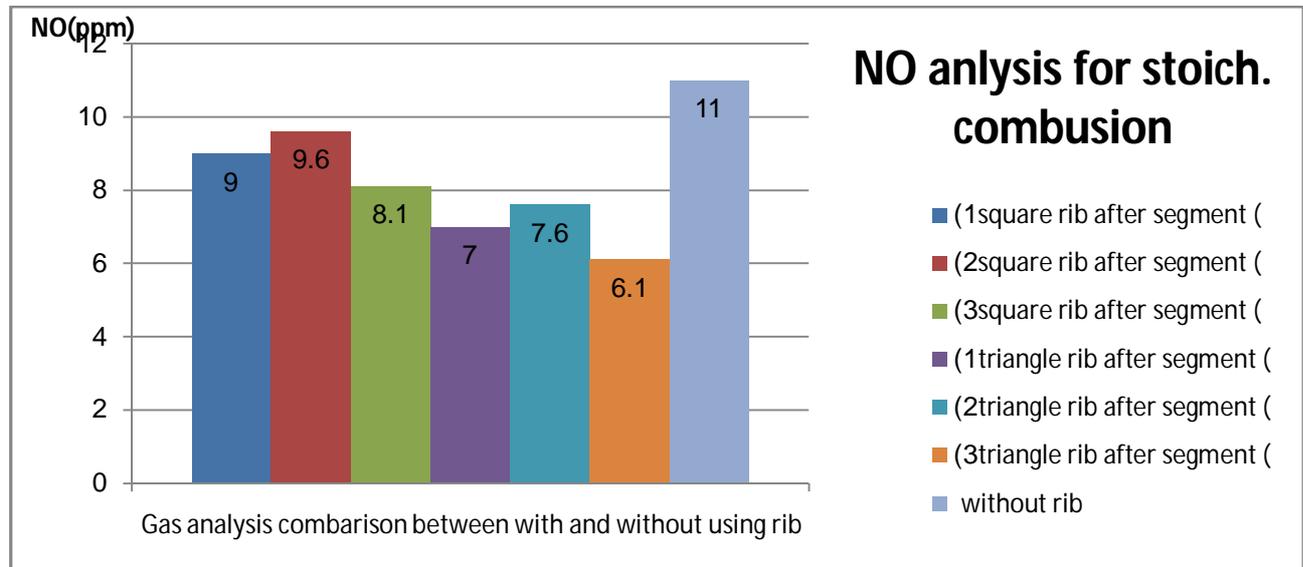


Fig. (28). NO analysis of stoichiometric combustion for square and triangle rib

The lowest emissions of NO by using triangle rib after segment (3).

IV. CONCLUSION

The present work deals with the study of heat transfer, flame temperature, and gas analysis of flue gases with a triple fame burner inside a longitudinal flame tube by experimental work. On the basis of the present study, following conclusions is drawn:

- The ribs (square and triangle) have a significant enhancement in heat flux all over X/D positions in all segments.
- The flame temperature has increased clearly after using square and triangle ribs.
- Triangle rib had superiority over the square one in heat flux with using it after segment (1), (2), (3) because of increasing turbulence by generating of swirl and vortex.
- Almost triangle rib has a higher flame temperature than the square one in the most positions as a result of increasing turbulence.
- The highest heat flux with triangle rib after segment (2) in stoichiometric combustion with X/D=2.2.
- The highest flame temperature with triangle rib after segment (2) in stoichiometric combustion with X/D=0.7.
- The lowest emissions of CO and NO were at using triangle rib after segment (3) in a lean combustion.

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