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Research Article

Experimental Investigation of The Turbulence Generators on Heat Transfer Inside Heated Duct

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ABSTRACT

This work investigates the heat transfer inside a square duct experimentally in the presence of detached rectangular and triangular turbulence generators. The effect of the ratio of turbulence generators to the duct height (blocking ratio) is investigated for the values of 0.1, 0.15, and 0.2 for Reynolds number 15413. The results showed that turbulence generators have a positive effect on heat transfer. It was found that using rectangular and triangular turbulence generators augments the heat transfer by (3-9)% and (5-15)%, respectively. Also, it was revealed that increasing the blocking ratio of turbulence generators from 0.1 to 0.2 enhances the heat transfer by 6% and 10% for rectangular and triangular shapes, respectively.

1. INTRODUCTION

Heat transfer enhancement refers to any method aimed at improving the efficiency of a thermal system or increasing the heat transfer coefficient via different approaches. The strategy for enhancing heat transfer has experienced significant and rapid development in recent years, as it plays a crucial role in improving thermal processes and reducing fossil fuels. This is a vital objective globally due to its impact on reducing carbon dioxide emissions and mitigating the greenhouse effect. Moreover, the global surge in energy consumption corresponds with population growth [1-3]. In addition, industrial and technical applications necessitate creating more compact and lightweight heat exchangers while possessing high heat duty, particularly in the fabrication of cooling systems for vehicles and spacecraft. This results in material savings and, thus, a cost decrease [4-5]. Consequently, several endeavors have been undertaken for over a century to identify efficient and economic augmentation techniques that provide the above advantages. The generation of turbulence is a promising technique for enhancing heat transfer, wherein the suppression of turbulent flow separation is achieved by inducing turbulent flow, resulting in improved fluid mixing and impingement flows, ultimately leading to a substantial increase in heat and momentum transfer [6-7].

Many researchers have examined the augmentation of heat transport inside ducts and tubes by various turbulence-creation techniques, such as ribs and baffles. Ozceyhan and Gunes [8] conducted an experimental and computational investigation on the flow and heat transfer from a heated cylinder using turbulence generators of rectangular, triangular, trapezoidal, and elliptical shapes, with Reynolds numbers ranging from 7200 to 14400 and angles of attack of 20°, 26°, and 32°. The average heat transfer is improved by 4-15% using winglet turbulence generators. Wange and Sunden [9] showed the local and summed temperature parameters for turbulent flow in a single heat-fluxed square duct with a hydraulic diameter of 8,000 to 20,000. A heated wall is repeatedly and crosswise attached to four different rib shapes: square, equilateral triangular, trapezoidal, and equilateral triangular, with both decreasing and rising height in the flow direction. The rib blockage ratio (BR) stays at 0.1, and the rib pitch-to-height ratios range from 8 to 15. The tests showed that the triangular rib has the highest Nu. Chunhua et al. [10] presented a modified rectangular lift vortex generator, which was accomplished by truncating the four corners of a rectangular wing. Experiments were conducted to investigate and compare the fluid flow and heat transfer characteristics of this LVG placed in a rectangular channel with those of the LVG originally put in a

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rectangular channel. According to the findings, MRW has higher flow and heat transfer qualities than RW isolating properties. Furthermore, the existence of the LVGs resulted in the formation of strong longitudinal vortices, which contributed to an increase in heat transfer. According to Henze and Wolfersdorf [11], the longitudinal vortices produced by tetrahedral turbulence generators have been investigated within the scope of their research. It depends on the features of the flow approaching the vortices and the heat transfer that is linked with them. The ratio of the VG height to the thickness of the hydrodynamic boundary layer was shown to affect the heat transfer. The most significant increase in heat transfer was seen in the VG, which was the highest. To explore the periodic laminar flow and heat transfer qualities in a three-dimensional isothermal square duct with 20° inline V-ribs, Boonloi [12] conducted a numerical study using the finite volume method and the computations obtained from the data. Reynolds numbers, which are based on the hydraulic diameter of the square duct and may range anywhere from 100 to 2000, illustrate the characteristics of fluid flow and heat transfer. In each main turbulence flow, it was discovered that streamwise twisted turbulence flows have the potential to create impinging flows on the walls of the inter-baffle cavity. This, in turn, leads to a considerable increase in the percentage of heat that is transferred throughout the square duct. When the height of the V-baffle is increased, the values of the Nusselt number and the friction factor experience a rise as a result. According to the results of the computations, the ideal thermal enhancement factor is around 4.2 for BR = 0.20 and 0.15 for the V-Downstream and V-Upstream when compared to each other.
Examination of the literature indicates a need for further enhancement and evaluation of novel vortex generators in thermal systems, owing to the extensive use of heat exchangers and air ducts in industrial applications. This study experimentally examines the impact of triangle and square vortex generators on the thermal performance of a heated duct.

2. TEST RIG

The main components of the rig are the air supply unit, duct, turbulence generators, power supply unit, and measuring devices. The air supply unit includes a blower and a flexible hose. The duct includes three regions: entrance, test section, and exhaust. A bundle of flow straighteners is fixed inside the entrance region of the duct. The turbulence generators are inserted inside the test region of the duct. Among the components that make up the power supply unit are a voltage regulator and voltage-current monitors. A photo and schematic diagram of the test rig is shown in Figure (1).

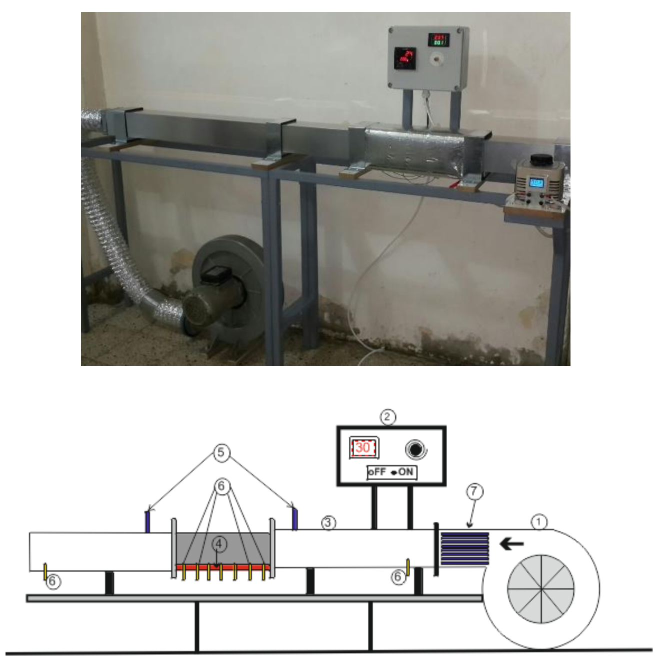

Fig. 1. Test rig (1) Centrifugal blower, (2) control Board and temperature recorder, (3) duct,(4) heater, (5) Pressure taps, (6) thermocouples, (7) flow straighteners

The air supply unit consists of a blower and a flexible hose. Figure 2 shows the centrifugal blower, which is the air supply source into the duct. The blower is connected to the duct through a flexible hose. The mass flow rate of the supplied air is controlled by a gate fixed at the suction port of the blower.

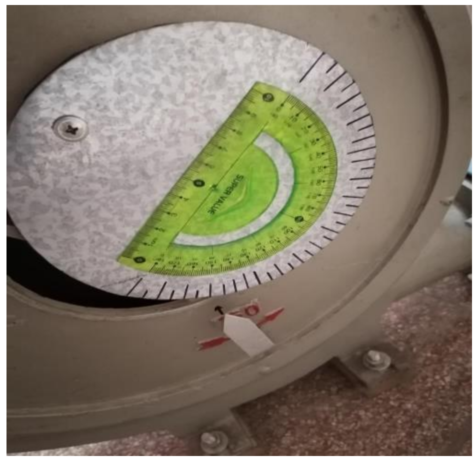

Fig. 2. The centrifugal blower

A flexible hose connects the blower to the duct because the outlet and duct inlet are different shapes. Also, the flexible hose reduces vibration transmission from the blower to the duct. The duct consists mainly of three regions, including the entrance region, the test region, and the exhaust region. The entrance region is necessary to ensure a sufficient length for the flow to achieve a fully developed velocity profile. The entrance region length is 120 cm, greater than required for a fully developed condition (10 D_H). Flow straighteners are fixed inside the entrance region at the inlet to eliminate the eddies of the supplied air. The flow straighteners are a pocket of straws of length to diameter ratio designed according to BSI, 1981 **[13]**. The test region represents the second region in the duct. The test region is of (40 cm) length. The bottom of the test region is heated with an electrical heater. A voltage regulator controls the power of the heater. Six type-K thermocouples are soldered to the bottom of the test region to measure the local surface temp. The turbulence generators are installed in the test region on a railway fixed at the sides of the duct. Pressure taps are installed, and the inlet and outlet of the test region are used to measure the pressure drop along this region. The last section of the duct exhausts the air to the ambient and protects the test region from the effects of the environmental conditions.

-The main aim of this work is to investigate the effect of turbulence generators on heat transfer inside the test section. For this purpose, rectangular and triangular shapes were fabricated using a 3D printer, as shown in Figure (3). For each shape of the turbulence generator, three heights were fabricated, including 10mm, 15mm, and 20 mm. The turbulence generators were installed at the entrance of the duct test section.

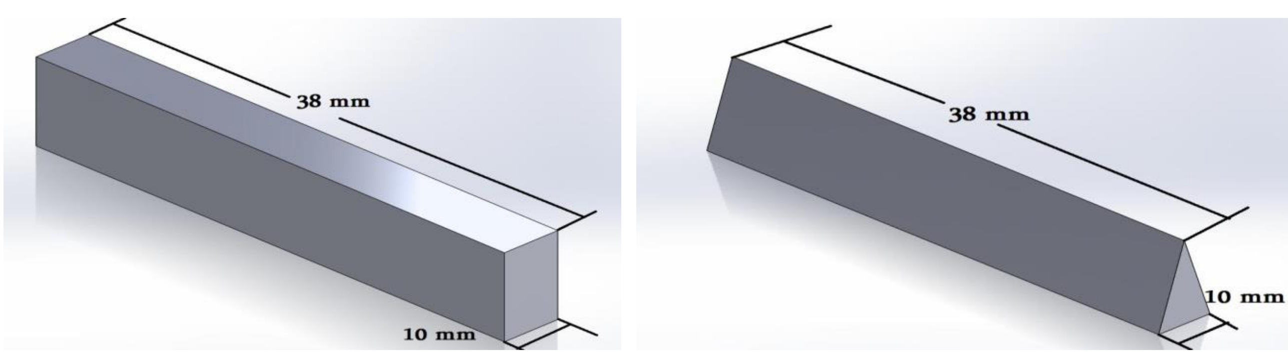

Fig. 3. Tested turbulence generators.

3. MEASUREMENT DEVICES

The measured quantities are temperature, pressure, and velocity. Thermocouples of Type-K were used to measure the test region's surface temperature and the air temperature at the inlet and the outlet. A selector switch connects these thermocouples to a single-channel digital reader. A vane meter is used to measure the velocity at the duct outlet.

4. CALCULATIONS

1. The properties of air are computed based on the mean air temperature T_f (ºC) of the plate:

$$T_f = \frac{T_i+T_o}{2} \tag{1}$$

Where T_i and T_o are the air inlet and outlet temperatures, respectively.

2. The local convective heat transfer coefficient h_x (W/m^2.ºC) is computed as :

$$h_x = \frac{VI}{A_S(T_x-T_f)} \tag{2}$$

Where V is the supplied voltage (volt), I is the supplied current (amp), A_s is the area of the test section bottom (m^2), and T_x is the temperature of the surface at a specific location.

3. Local Nusselt number is calculated as:

$$Nu_x = \frac{h_x D}{K} \tag{3}$$

Where D is the hydraulic diameter of the duct and k is the thermal conductivity of air at film temperature (W/m.K).

4. Average Nusselt number is calculated by averaging the local Nusselt numbers for each temperature measurement point.

5. RESULTS

The present work investigates the heat transfer inside a square heated duct experimentally. The effect of the turbulence generator's shape and blocking ratio is tested. The tested blocking ratios are 0.1, 0.15, 0.2.

5.1 Validation Of The Experimental Data

To assess the accuracy of the collected data, a comparison is made with data obtained from the correlation from the literature. Figure (4) shows a comparison of the average Nusselt number distribution from the current data and from the correlations by Affrawi [14], Dittus [15], and Abdel Moneim [16] for different Reynolds numbers (Re). It reveals that the present data are slightly higher than the data from Dittus and Abdel Moneim, and it is agreed with the data from Affrawi. The discrepancy between the present data and those from correlations is due to the sensitive nature of the experiments. The data scatter may be partially due to the differences in inlet conditions, thermal boundary conditions, and measurement uncertainty.

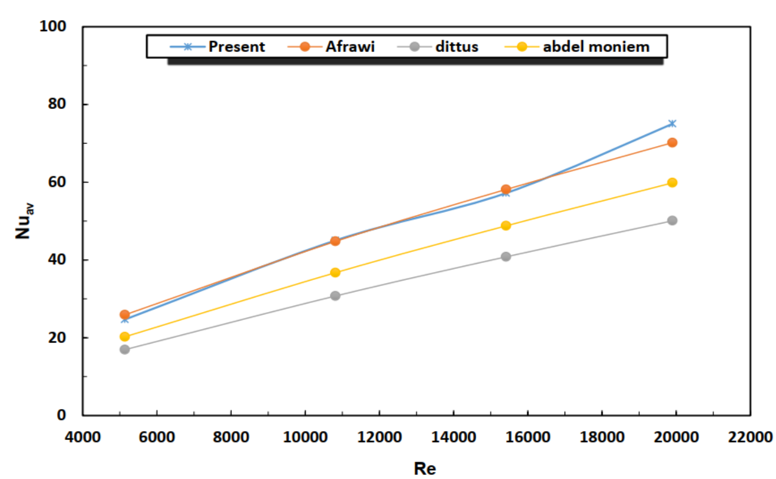

Fig. 4. Comparison with literature.

5.2 Effect of Blocking Ratio (Br)

Figures (5) and (6) present the effect of the blocking ratio of the turbulence generator placed at the entrance of the test section on the local Nusselt number (Nux) at the bottom surface of the test section for rectangular and triangular turbulence generators, respectively. The horizontal axis represents the distance from the entrance of the test section. It can be observed that the blocking ratio causes an increase in the heat transfer that occurs in the area close to the entrance of the test section. This may be due to the turbulence generated, further enhanced by an increased blocking ratio.

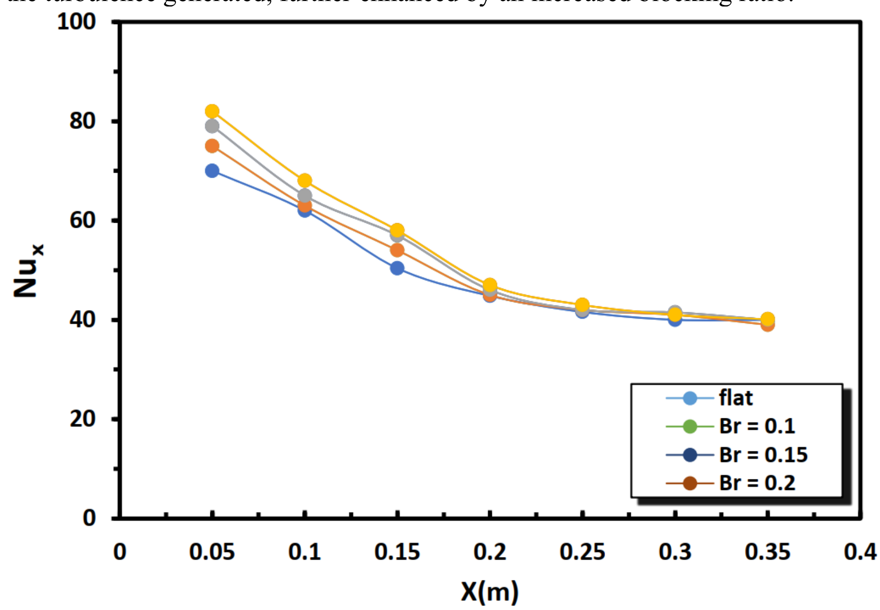

Fig. 5. Variation of Nu number for different blocking ratios rectangular turbulence generators.

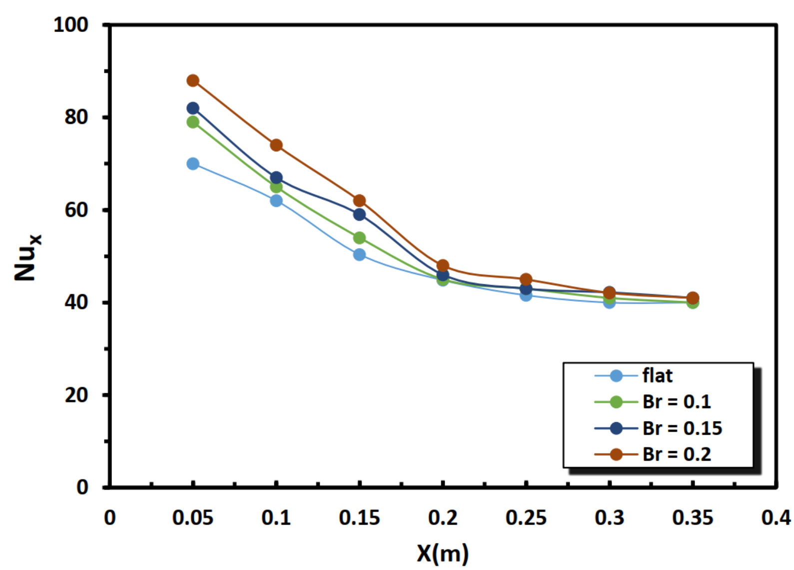

Fig. 6. Variation of Nu number for different blocking ratios triangular turbulence generators.

Figure (7) shows the enhancement ratio of the average Nusselt number due to the presence of rectangular and triangular turbulence generators at the entrance of the test section. The y-axis represents the ratio of the average Nusselt number in the case of turbulence generators' presence to the values without turbulence generators (Nu_o). The maximum enhancement is 14% and 8% at Br = 0.2, respectively. The triangular turbulence generator exhibits the highest heat transfer enhancement. This is because as the air impinges on the attacked side of the triangle, it slides to impinges the bottom surface of the test section as an additional enhancement due to the turbulence generated beyond the turbulence generators.

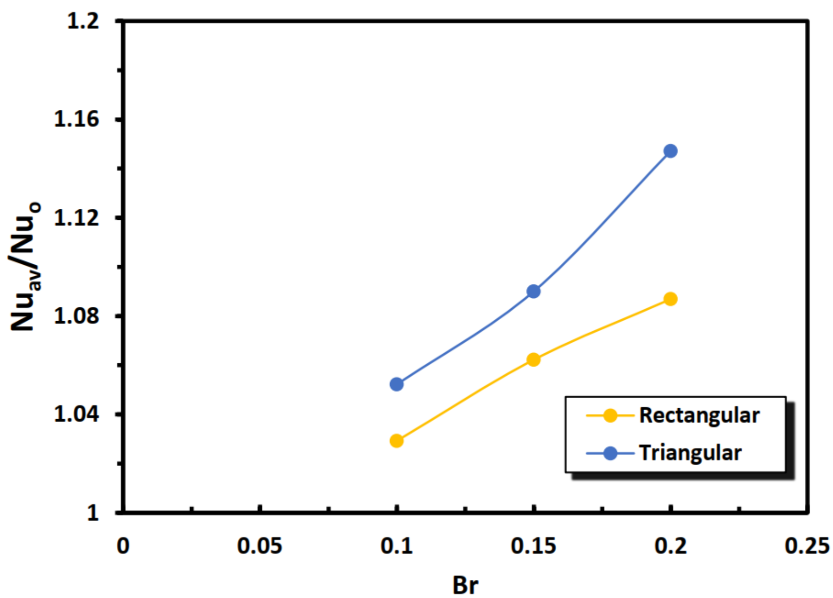

Fig. 7. Enhancement ratio of Nusselt number.

6. CONCLUSIONS

This work presents an experimental investigation of heat transfer characteristics in a heated square duct. The investigation was conducted in the presence of rectangular and triangular turbulence generators installed on the duct's center line. In every instance, the Reynolds number was maintained at 15413, and the blocking ratios evaluated were Br = 0.1, 0.15, and 0.2. As a result of this investigation, the following results have been found :

1. In general, turbulence generators positively influence heat transfer due to the augmentation in turbulence level.
2. The amount of heat transfer enhancement in proportion to the blocking ratio increases.
3. Triangular turbulence generators have the greatest rate of heat transfer augmentation among all possible generators
4. The local heat transfer enhancement is insignificant after X=0.2 m

Conflicts Of Interest

None

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None

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