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(Full length research article)

Heat Transfer Analysis in a Channel Flow with Incline Blocks and Equilateral Triangles as Obstacles

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Abstract

In the present experimental work, heat transfer analysis has been performed in a channel with heated plates having inclined blocks, with and without equilateral triangles as obstacle. The experimental results are compared with the plane channel. The main aim of this experimental work is to find the enhancement in the heat transfer and to find the pressure drop because of the use of inclined blocks and equilateral triangles as obstacles. The equilateral triangular obstacles are used as a passive element which did not need extra energy and blocks are used in inclined manner which produces flow disturbance and recirculation effects. The results show a substantial enhancement in heat transfer with the use of equilateral triangle as an obstacle along with the inclined blocks. Further experiments are performed for different Reynolds numbers 17037, 19799, and 26246

***Key words**: Heat transfer enhancement, pressure drop, inclined blocks*

1. Introduction

The design method of heat exchangers is quite complex, as it needs exact analysis of heat transfer rate and pressure drop estimations apart from long-term performance and the economic aspect of the equipment. The major challenge in designing a heat exchanger is to make the equipment more compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. Heat transfer enhancement techniques play a vital role in the design of compact heat exchanger. Barriers in widespread diffusion of enhancement techniques are cost, pumping power, and fouling problems.

During recent years, many attempts have been made to apply different active and passive mechanisms for heat transfer enhancement. To study those investigations, a literature review has been done which leads to motivate the authors to perform the present experimental work. Valencia (1998), carried a numerical investigation which was conducted in channel flows with a tandem of transverse vortex generators in the form of rectangular cylinders. Results were obtained by numerical solution of the full Navier -Stokes equations and the energy equation. A heat transfer enhancement of up to a factor 1.78 was observed as compared to plane channel flow. (Abbassi et al., 2001), visualized that the superposition of Von Karman street and convective cells in a horizontal plane channel containing a triangular prism and heated from below constituted the principal subject of the numerical investigation. The numerical scheme was based on the control volume. Finite element method was adapted to the standard staggered grid with the SIMPLER algorithm for pressure–velocity coupling and an Alternating Direction Implicit. (Dewan et al. 2004), studied heat transfer augmentation techniques (passive, active or a combination of passive and active methods) that are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. (Tae et al. 2006) performed experiments to investigate heat dissipation from a heated square cylinder in a channel by oscillating flow. The effects of the Reynolds number based on the mean flow velocity (*Re* = 350 and 540) and the oscillating

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frequency (0 Hz to 60 Hz) on the heat transfer enhancement are examined. (Zhang 2007), studied heat transfer to thermally developing, hydro dynamically developed forced convection inside tubes of rectangular cross-section with various aspect ratios. (Naphon, 2008), studied the heat transfer and flow developments in the corrugated channel under constant heat flux conditions numerically. A finite volume method with the structured uniform grid system was employed for solving the model. Due to the breaking and destabilizing in the thermal boundary zone, the corrugated surface had significant effect on the enhancement of heat transfer and pressure drop. (Oztop et al. 2009) studied a laminar, two-dimensional, steady forced convection heat transfer and fluid flow in an isothermally heated blocks located in a channel numerically. (Sahu et al. 2009), investigated numerically, the effects of the Reynolds and Prandtl numbers on the rate of heat transfer from a square cylinder in the unsteady two-dimensional periodic flow regime, for the range of conditions $60 \leq Re \leq 160$ and $0.7 \leq Pr \leq 50$. A semi-explicit finite volume method has been used on a non-uniform collocated grid arrangement to solve the governing equations.(Henze et al. 2010), experimentally investigated the velocity field and wall heat transfer distributions for internal flows in the presence of longitudinal vortices. Results show that the modified rectangular wing pairs (MRWPs) have better flow and heat transfer characteristics than those of rectangular wing pair (RWP).(Chunhua et al. 2010), used a modified rectangular longitudinal vortex generator (LVG) obtained by cutting off the four corners of a rectangular wing.

The above literature survey shows that various attempts have been made to apply passive techniques for heat transfer augmentation in heat exchangers. Based on the literature survey and to the best of authors knowledge no attempt so far has been made experimentally in which heated plate with inclined blocks has been used along with equilateral triangles as obstacle, to enhance the heat transfer.

2. Problem formulation

The present experimental set-up is shown in Fig. 1(a).The experiments were performed for a smooth plate of dimensions (300×150×6mm) heated by a plate type heater, placed in the test section of dimensions (600×200×120mm), the test plate having six inclined blocks of dimensions (50×20×12mm) and with an inclination angle of blocks,20^{o} (with the flow direction) and three equilateral triangular obstacles of side 50 mm placed in the test section at a distance of 60mm from the top surface along with test plate having inclined blocks.

2.1 Experimental Set Up

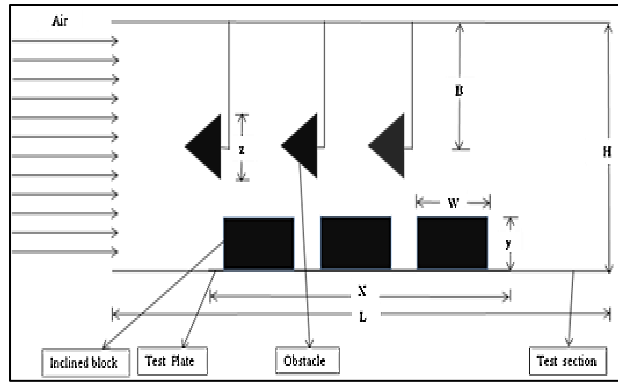

Fig.1 (a) Schematic diagram of test section having heated plate with inclined blocks along with equilateral triangles as obstacle

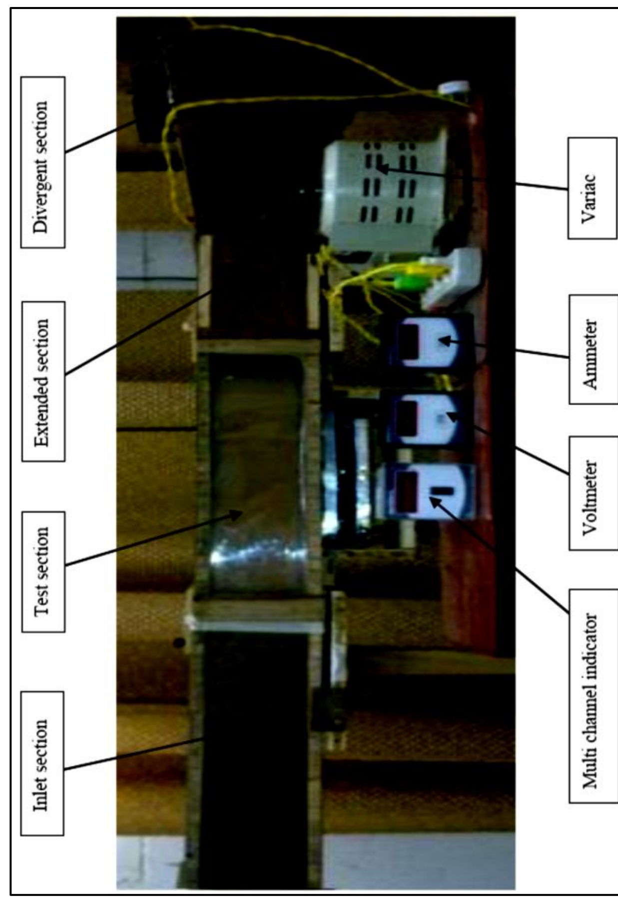

Fig.1 (b) Experimental Set-up

The experimental apparatus used for heat transfer analysis as shown in Fig. 1(b) and 1(c) consist of a rectangular duct which was made up of plywood having the total length of 1750 mm. Experimental set up consists of four parts i.e., inlet section, test section, extended section and divergent section

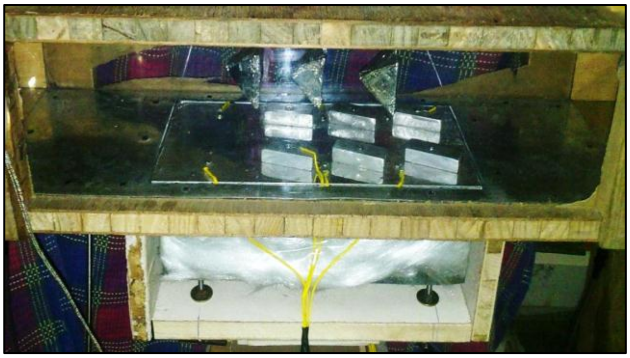

Fig. 1(c) Experimental test section having heated plate with inclined blocks along with equilateral triangles as obstacle

2.2 Methodology

On the basis of schematic diagram a proto-type model shown in Fig. 2 by using thermocol sheets was made to visualize the dimensions that are selected for the setup. By analyzing the model some changes are made in the schematic diagram and model just to make it convenient for fabrication purpose.

Fig.2 Prototype Model

2.3 Fabrication

The whole experimental set up is made in four parts, inlet section, test section, extended section and divergent section. All the four parts are made of plywood and their inner portion is covered with sun mica sheet to make the inner surface smooth. The inner portion of the bottom part of the test section is covered with galvanized iron sheet to avoid the damage caused by the heated test plate and other two sides are made of plexi glass to visualize the test section. All the four parts of experimental set up are assembled with screws and support is provided to give them stability. A plate type heater is attached with the test plate which is made up of aluminum and having six aluminum inclined blocks of Inclination angle, 20^{o}. Eight k-type thermocouple wires are screwed to test plate and inclined blocks with the help of thimbles. Three equilateral triangular obstacles were placed at a distance of 60 mm from top surface in test section with the help of stiff steel wires.

2.4 Equations Used

The Reynolds number based on the channel hydraulic diameter D_h is given by

$$Re = UD_h/ \nu \qquad (1)$$

Where U is the mean air velocity of the channel, ν is the Kinematic viscosity of the air and D_h is the hydraulic diameter. The value of heat transfer coefficient is calculated by using Newtons law of cooling

$$Q_{conv} = h*A*(Ts-T_b) =VI \qquad (2)$$

Where the T_s is the average surface temperature, T_b is the bulk temperature, V is the Voltage, I is the Current and h is the convective heat transfer coefficient

$$Q_{conv} / A\ (T_s- T_b\ ) \qquad (3)$$

The term A is the convective heat transfer area of the heated plate.

Nusselt number

$$N_u = h\ D_h / k \qquad (4)$$

Where k is the thermal conductivity of air

Pressure drop:

$$\Delta p = (\rho fLU^2)/ 2*\ D_h \qquad (5)$$

where U is the Mean air velocity of the channel
ρ = Density of air
f = friction factor
L= length between two points where pressure is to be measured

3. Result and discussion

In the present experimental work, heat transfer analysis has been performed in a channel with heated plates having inclined blocks, with and without equilateral triangles as obstacle. The experiment has also been compared for the plane channel flow. The main aim of this experimental work is to enhance the heat transfer and to find the pressure drop because of inclined blocks and equilateral triangles used as obstacle. The equilateral triangular obstacle is used as a passive element which did not need extra energy and blocks are used in inclined manner produces flow disturbance and recirculation effects.

3.1 Variation of average surface temperature at constant heat flux conditions at different Reynolds numbers

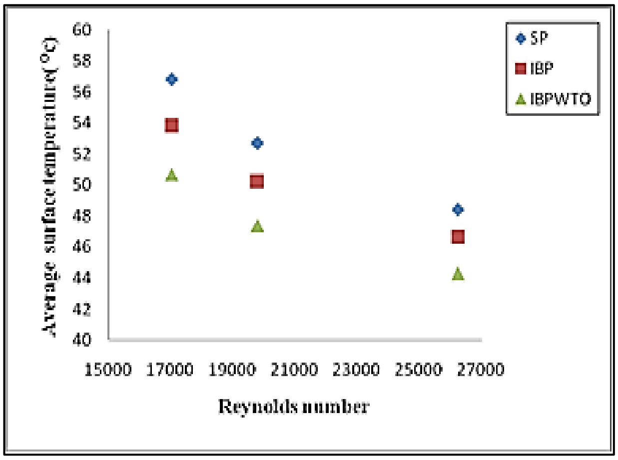

Fig 3 Variations of average surface temperature at constant Wattage (25 Watt) with Reynolds number

Above shown Fig.3 shows the variations of average surface temperature of SP (smooth plate), IBP (Inclined block plate) and IBPWTO (Inclined block plate with triangular obstacles) at different Reynolds number and constant heat flux condition. By increasing the Reynolds number, the inertia of the fluid increases and it results in more transfer of fluid in the same time, therefore the average surface temperature decreases with the increase in the Reynolds number. Therefore, for constant heat flux condition, average surface temperature of SP, IBP, IBPWTO decreases as the Reynolds number increases. Graph clearly indicates that for a particular value of Reynolds number, the average surface temperature of IBP is less than the SP. This can be explained as, with the use of blocks in inclined manner causes the disturbance in the air flow and a swirling effect is produced between the blocks causing disruption of boundary layer. Due to this effect more heat is transferred from the plate surface hence the average surface temperature of IBP is less than SP. It can also be observed that for a particular value of Reynolds number minimum average surface temperature is observed with IBPWTO. Reason for that could be, that the use of equilateral triangular obstacle and blocks in inclined manner produces the recirculation and swirling effects, these effects produces a temperature gradient which ultimately leads to decrease in average surface temperature of IBPWTO. Maximum average surface temperature is observed with SP at Reynolds number, 17037 and minimum average surface temperature is observed with IBPWTO at Reynolds number 26246.

3.2 Variation of Nusselt number at constant heat flux conditions at different Reynolds numbers

Fig. 4 shows the variations of Nu_m/ Nu_{mo} with the Reynolds number. It is clear from graphs that the Nusselt number increases with the increase in Reynolds number. When compared with smooth plate, Nusselts number of the IBP enhanced by 25-40% at 25 Watt for the Reynolds numbers (17037, 19799, and 26246). The reason for that could be, as fluid flowing through surface of the test plate with inclined blocks, the fluid re-circulation or the swirl flows are generated. The growth of recirculation zones promote the thinning of boundary layer thereby enhancing the convective heat transfer. So the use of inclined blocks is helpful in enhancement of the heat transfer.

When compared with smooth plate, Nusselts number of the IBPWTO is increased 45-65% at 25 Watt for the Reynolds numbers (17037, 19799, and 26246). The reason for enhancement of heat transfer with IBPWTO as compared to SP could be the use of equilateral triangular obstacle produces vortex shedding effect and recirculation in the air flow hence the swirling effect increases the Nusselt number and hence the heat transfer.

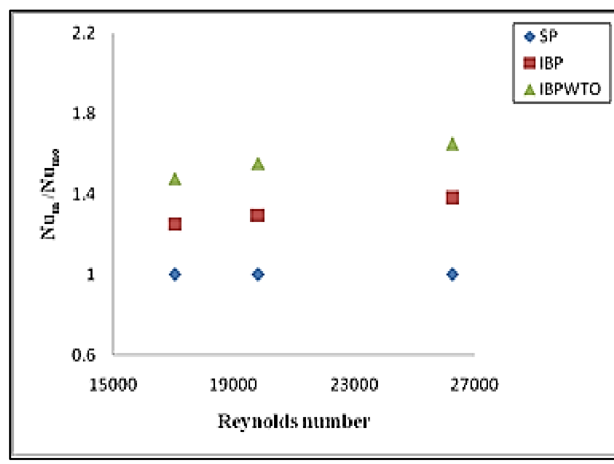

Fig 4 Variations of Nusselts number at constant Wattage (25 Watt) with Reynolds number

3.3 Variation of Pressure drop with Reynolds number

Fig.5 shows the variation of $\Delta P/\Delta P_o$ with Reynolds number. Here ΔP represents the pressure drop for SP (smooth plate), IBP (inclined block plate), IBPWTO (inclined block plate with triangular obstacle) and ΔP_o represents the pressure drop for smooth plate case. Graph shows that pressure drop ratio ($\Delta P/\Delta P_o$) increases as the Reynolds number increases. The reason could be that when inclined blocks and equilateral triangular obstacles are used instead of smooth plate, they provide blockage to the flow, hence due to form drag the pressure drop increases. Maximum pressure drop is observed with IBPWTO at Reynolds number of 26246.

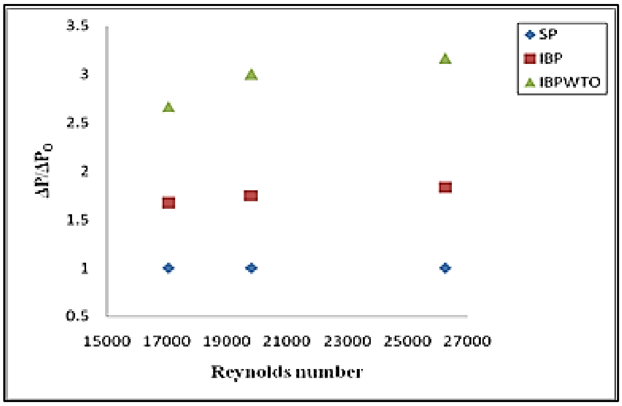

Fig 5 Variation of pressure drop with Reynolds number

Conclusion

From the above experimental study it can be concluded that the

1.) Average surface temperature of SP (smooth plate), IBP (Inclined block plate), IBPWTO (Inclined block plate with triangular obstacles) decreases as the value of Reynolds number increases.
2.) The presence of equilateral triangular obstacle significantly improves the heat transfer performance.
3.) The enhancement of heat transfer achieved by the use of equilateral triangular obstacles and inclined blocks is accompanied with increase in pressure loss. Pressure drop across the test section increases as the value of Reynolds number increases.

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