ENHANCEMENT THE TURBULENT HEAT TRANSFER BY USING FINNED CONVERGING-DIVERGING NOZZLES

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ABSTRACT

The present work shows the effect of insertion converge-diverge conical-nozzle turbulators fitted with triangle fins inside a heated circular pipe on turbulent flow heat transfer, friction and overall performance index. The study is performed experimentally for turbulent flow system with use of air as a working fluid for a range of Reynolds number between 10000 to 50000. The conical nozzles integrated with triangle fins are utilized as turbulators to generate more complex mixing flow along the pipe wall. The plane conical nozzles turbulators are used for three various pitch ratios (Pr=1.0,1.5 and 2), and those fitted with triangle fins are tested at pitch ratio Pr=1.0 with two various area ratios of 0.064 and 0.149 respectively. The heat transfer of conical turbulators integrated with triangle fins is enhanced by 274% as compared with plain pipe and 55% as compared with inserted conical nozzle turbulators alone for the larger area ratio (Ar =0.149). In the addition, the Conical nozzle turbulators fitted with triangle fins give optimum overall thermal performance as compared with unfinned conical nozzle turbulators and plane tube.

Keywords: turbulators, conical nozzle, heat transfer.

INTRODUCTION

Enhanced heat transfer process is crucial matter for compact designs and saving energy for various thermal applications. The enhancement techniques include the active techniques and the passive techniques or compound techniques. The active techniques require extra external energy input to cause the required flow alteration and improvement in heat transfer. A passive techniques commonly used surface or geometrical adjustments to the flow duct by additive devices or integration of different inserts such as conical nozzle turbulators, strip or fins insert, circular ring and swirling flow devices, all of these do not requirement external energy and working as the enhancement devices. These techniques are widely used due to easy setting up and the low cost. Many researchers studied enhancement techniques problems experimentally and also theoretically. Muthusamy *et al.* [1] investigated the effect of conical turbulator fitted with interior fins in circular pipe with three different pitch ratios on heat transfer, thermal performance and pressure drop. The conical turbulators located in two different arrangements, converging conical turbulator and diverging conical tabulators. It was found that heat transfer is improved by 315% for the minimum pitch ratio of diverge conical turbulator arrangement. .Parmar *et al.* [2] experimentally reported the impact of inwardly finned pipes on the heat transfer during a laminar flow. Two kinds from internal fins, rectangular and cylindrical were inserted at the interior surface for single heat exchange with various cross section for same hydraulic diameter. The results appeared that the largest heat transfer is pointed at rectangular fins as compared with a cylindrical fin. Experimental investigations testified by. Zdaniuk *et al.* [3] to show the effect for helically-finned tubes on thermal performance and pressure loss for different Reynolds numbers. Eight tubes fitted with helically-fins with one smooth pipe tested for various angles and different fin numbers. It was shown that using the three helically tubes can assist to improve significantly Nusselt number respect to pressure loss above the other tubes. Lihua Guo *et al.* [4] made an experimentally study to depict the lubricant side of pressure properties and heat transfer of this type from strip fin in a pipe fixed with internal fins. The speed and temperature allocation in a pipe were as the function of fin numbers and height. Experimental results detected that the value of Nusselt number raised with the fin height. Experimental examinations were demonstrated by El-Sayed *et al.* [5] to verify the impacts of internally longitudinal fins fitted in the circular pipe on pressure loss properties. The longitudinal fins discontinuous in the flow wise direction with two various arrangement, inline and staggered manner. The results verified that, at the periodic fully developed region, the pressure loss for continuous fins is greater than that of the fins in inline arrangement and lesser than that of the fins in staggered arrangement. Kongkaitpaiboon *et al.* [6] experimentally described the improvement efficiency by using Perforated conical-ring for various perforated hole numbers and pitch ratios. The range of Reynolds number was between 4000 to 20000. The perforated conical rings were in arrangements in diverge array. The results appeared that the larger thermal performance is about 0.92 at number of hole N=8, pitch ratio equal to 4 and Reynolds number of 4000. Promvonge *et al.* [7] made an investigation on a circular pipe to study the effect of conical nozzle tabulators on heat transfer properties and pressure loss. These tabulators were placed in two various types from arrangement (diverging and converging nozzles) into the pipe with differing pitch ratios. The Reynolds number was in a range between (8000 to 18,000). The highest heat transfer was founded in diverging arrangement for minimum pitch ratio. Durmus [8] also described the influences of conical turbulators that placed inside a heat exchanger pipe at constant external temperature. The saturated vapor was heated the outer surface while the air was flow during the tube. The range of Reynolds number was between 15000 to 60000 and the experiment was made with and without turbulators for analyses exergy and pressure losses. The results appeared that heat transfer had been improved of the conical turbulators with increase pressure losses when placed in direct flow area. Promvonge [9] experimentally investigated the thermal performance and pressure loss with conical ring as tabulators put in a heated tube. The rings arranged in three various diameter ratios to tube diameter and placed in three various arrays (CR, DR and CDR) for Reynolds numbers from 6000 to 26,000. It was obtained that the conical ring had a higher influence on heat transfer improvement than the plain tube. The results appeared that the highest heat transfer obtained in *DR* array than other arrays up to 237%. Gowrisankar *et al.* [10] experimentally investigated in the heat transfer increment through the circular tube by using diverging nozzles with diverse pitch ratios=(2,4,6,8 and 10) and various flow rates for Reynolds number from 9382 to 16921.The results appeared that heat transfer improved for PR=2 at divergent nozzle insertion compared with the twisted tapes insertion for same pitch ratio. Experimental determination reported by Eiamsa *et al.* [11] to show the influences for insertion V-nozzle fitted in the circular pipe on turbulent heat transfer characteristic and actual pressure losses with three different pitch ratios. It was obtained that the heights enhancement efficiency occur at the lowest pitch ratio. Anvari *et al.* [12]] also described the effects of forced convection performance in the horizontal pipe on turbulence heat transfer with conical rings turbulators inserts. The transient flow regime had used for the experiment. These turbulator located in two various arrangements, converging conical ring and diverging conical ring. The results detected that the Nusselt number augmented by up to 521% of diverging conical rings compared to an increase the pressure loss. Keklikcioglu *et al.* [13] numerically investigated heat transfer increment with insert stepped conical nozzle in a tube by using FLUENT code. The conical turbulators were mounted in the pipe with three diverse pitch ratios and three various step numbers. The results appeared that the greatest Nusselt number was found for step ratios equal to 2 and 4 model, also the maximum overall enhancement 11% at Re=6000 for the step and spacing ratios =2, 4 respectively. Smith *et al.*[14] studied experimentally, the fully - develop turbulent flow during steady heat flux with diamond conical turbulators fitted inside the tube, where arrangement with many cone angles and different ratios of tail length. The results proved that both the effective Nusselt number and pressure drop rise with raising the cone angles and reduce with decreasing ratio of tail length. Experimental investigations were inspected by Promvonge *et al.* [15] to portray the effective thermal performance for inserted conical turbulators and swirl generator in the circular pipe with three values from pitch ratios. Experimental results indicated that the insertion of combined conical turbulators and snail enhanced heat transfer of about 316% at minimum pitch ratio. Rahul *et al.* [16] examined experimentally the enhancement efficiency and friction properties for conical - springs mounted into a circular pipe in three various arrangements, diverge conical –spring, converge–diverge conical - spring and diverge conical spring of various Reynolds Number. The results appeared that heat transfer for diverging conical spring is the greatest than the arrangement of Converging and converging-diverging conical spring.

In the current study, an experimental work has been conducted to augment heat transfer by using the combined conical nozzle turbulators and triangle fins inside the heated tube under a steady heat flux as in Figure-1. The conical nozzle turbulators are used for three diverse pitch ratios 1.0,1.5 and 2.0 respectively, while the conical turbulators fixed with triangular fins as arrangement at minimize pitch ratio (PR=1). The considered Reynold number range is between 10000 to 50000 with air as a working fluid.

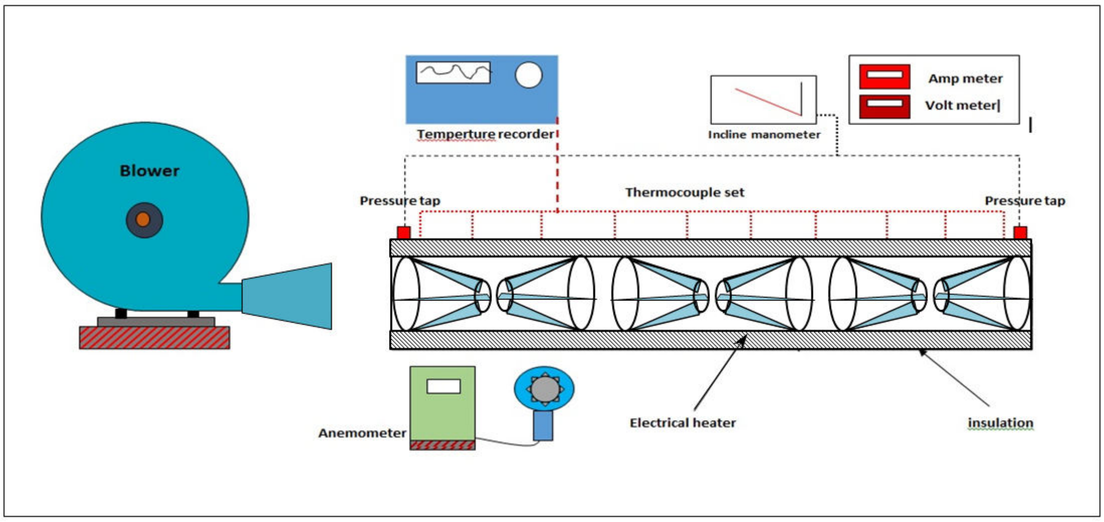

Figure-1. Schematic diagram for experimental device.

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EXPERIMENTAL SET UP

The experiment rig is managed in the open test loop as indicated in Figure-1. The loop consisted of 1.1 KW blower, anemometer to measurement the inter air velocity during the test section. The test section comprises an aluminum tube having 1200 mm length, 60 mm internal diameter, 65 mm external diameter and thickness of 2.5 mm. To a steady obtain heat flux; the aluminum tube was heated by a flexible electric wire continuously rolling around the pipe. The electrical output power was organized by a variac- transformer to achieve regular heat flux along length of a pipe section. The exterior surface for the tube section was entirely insulated to decrease the losses of convective heat to the outer surroundings. A multichannel temperature assessment as showed by using a digital temperature recorder connected to ten thermocouples fixed on the local wall of the pipe suction to measurement the wall temperature. A bulk temperature of air was estimated by using two thermocouple placed at inlet surface and outlet surface of tube section. In the current study Figure. (1) shows the conical nozzles turbulators fitted with triangle fins. The converge-diverge conical turbulators are manufactured from the aluminum metal with length (l=60mm) and with cone ends diameter (D=60 mm and d=30 mm) with the thickness 1.5mm and pitch length 60mm. The Conical turbulators are arranged in a circular pipe with three various pitch ratios are 1.0,1.5 and 2.0 respectively. The triangle fins are made from aluminum with 60mm in length, thickness 1mm with two defferent height values 6mm and 14mm respectively. It is made by cut aluminum piece with length 60mm equal to coin length and with two different heights are 6mm small height and 14mm long height for each experiment to test the impact of fins height on the thermal performance and the loss of pressure. The geometrical parameter detail for the considered problem is appeared in the Table-1.

Table-1. Geometrical parameters for the physical problem.

Test pipe section	
Parameter	**values**
Length	1200mm
Inner diameter	60mm
Outer diameter	65mm
Material	Aluminum
Thickness	2.5mm
Fluid	Air
Reynolds number	10000-50000
Triangle fin	
Parameter	Values
Fin length	60mm
Fin height	6mm and 14mm
Material	Aluminum
Thickness	1mm

Data reduction

In the current study, the working fluid is air that flowed through a well insulted tube under a constant heat flux. The rate of heat transfer for air (*Qair*) is calculated as:

$$Q\ air = Q\ conv$$

Where :

$$Q\ air = m\ C\ p\ (To - Ti) = V.I$$

A heat transferred by the convection from a pipe section to the exterior surface can be determined as;

$$Q\ conv. = h\ A(\bar{T}w - Tb)$$

Where

$$T\ b = (To + Ti\ )\ /\ 2$$

$$Tw = \sum Twi/\ n$$

Where n is number of thermal sensors.

The mean Nusselt number, (Nu) can be determine by the next relation:

$$Nu = \bar{h}.\ Dh/\ k$$

The Reynold number is find by using the relation:

$$Re = U.\ Dh/\ \nu$$

The friction factor (f) can be evaluated by:

$$f = 2\Delta p\ \frac{(Dh/l)}{\rho U2}$$

Where U is the mean air velocity in the pipe.

All of the thermo physical characteristic for the air are regulated at the whole bulk temperature.

For conical nozzle turbulators with triangle fin, The overall thermal performance factor (Ƞ) can be found as:

$$Ƞ = (Nu_w\ /Nu_p)\ /(f_w/f_p)^{1/3}$$

RESULTS AND DISCUSSIONS

In this part, an experimental results on flow characteristics and heat transfer: (Nusselt number, friction factor and overall thermal performance factor) in the heated circular pipe integrated with unfinned and triangular finned Conical nozzle-turbulators are presented.

Validation

An experimental result of a plain pipe is validated with past empirical correlations of Dittuss and Blassius. The validation includes the variation in the flow factor and the average of Nusselt number versus Reynolds number as displayed in Figure-2. And Figure-3. The average deviation for Nusselt number and friction is about 6.4% and 10% respectively.

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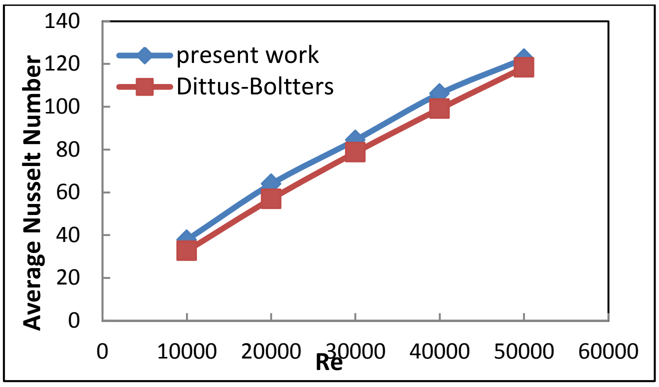

Figure-2. Validation of the present work of Nusselt number of a plain tube versus Dittus and Boltters correlations .

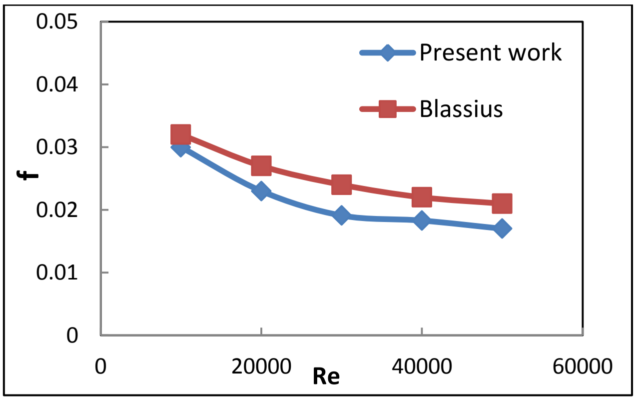

Figure-3. Validation of the present work of average friction factor of a plain tube versus Blasius corralations.

Figure-4. appears the validation of the present work for unfinned converge-diverge conical nozzle turbulators with issued results of promvonge [9]. It is that observed the ratio for the average deviation between them does not exceeds 9.9 %.

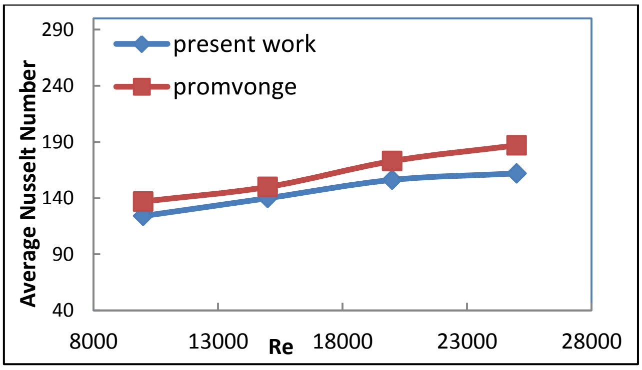

Figure-4. Comparison of the present work of Nusselt number versus Reynolds number with results of promvonge [9] for CTW.

Effect of pitch ratio on the Nusselt number and friction for CTW

The influence of using different pitch ratios for conical nozzle turbulators on mean Nusselt number the Reynold number is depict in Figure-5. It is seen that the mean Nusselt number is bigger than that of a plain pipe at same Reynolds number and intensification with rising Reynolds number. All the conical turbulators creates high turbulence due to secondary flow near the wall that leading to the fragmentation for the thermal boundary layer. The uses for the conical turbulators are utilized as a way for enhancement heat transfer during the pipe section tube by producing a good mixing of the flow between the wall and a core region. The mean Nusselt numbers of using the conical turbulators for PR= 1.0, 1.5 and 2.0 respectively, is improved by 188 %, 182 % and 176 % over the plain pipe. The variation for friction with various Reynold number for using converging-diverging conical nozzle turbulators are describe in Figure-6. This figure appear that there is the substantial increment in the friction for utilizing the conical nozzle turbulators compared with that of a plain pipe at same Reynolds numbers. This rise for friction index is much bigger than that created by axial flow in plain pipe. The maximum friction index is obtained at pitch ratio
PR=1.0

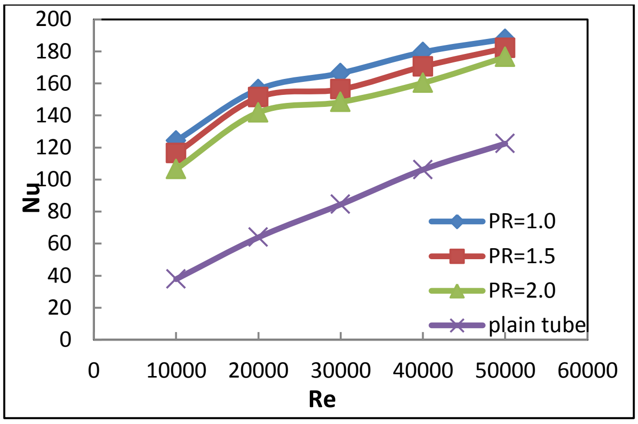

Figure-5. Effect for pitch ratios on Nusselt number variation with Reynolds number of CTW.

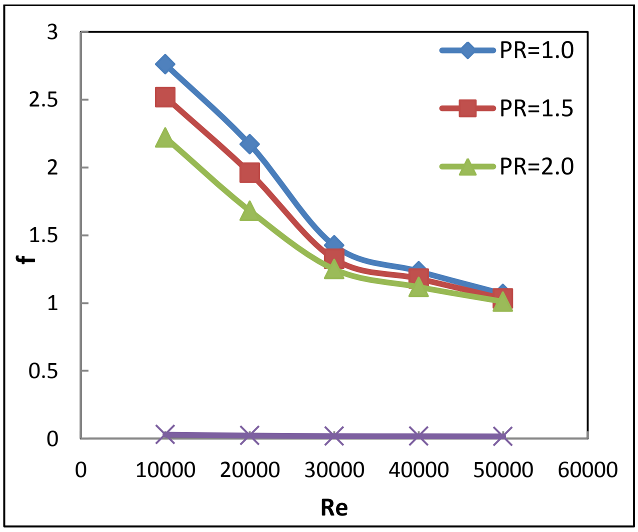

Figure-6. Effect for pitch ratios on friction factor variation with Reynolds number of CTW.

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Effect of pitch ratio on the overall thermal performance factors for CTW

The thermal performance represents the Comparison performance of tube with the conical turbulators to a plain pipe. The difference between overall thermal performance factor and the Reynold numbers at variant pitch ratios is shows in Figure-7. It is seen that a thermal performance is minimize with the rising Reynold number and increase of pitch ratio, this is because of increases the Nusselt number larger than increasing in the friction index at rise Reynolds numbers with all pitch ratios. It is can be shown that the maximum overall thermal performance of 0.73 is achieved in pipe fitted with converge - diverge conical turbulators at minimum pitch ratio PR=1.0 and the lower Reynolds number of all studied cases.

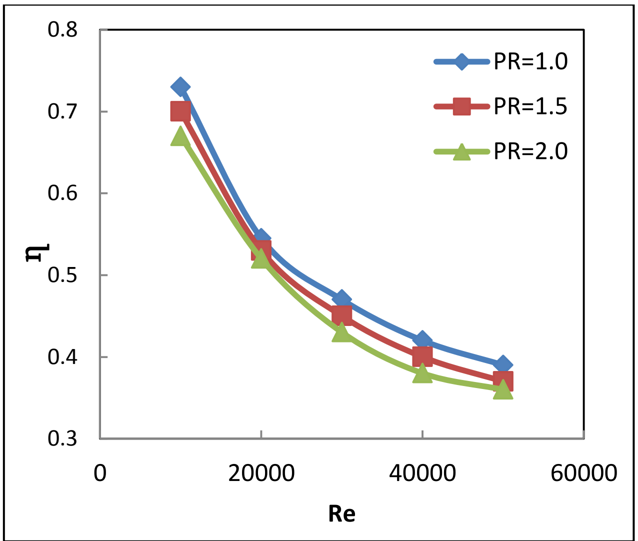

Figure-7. Influence of pitch ratios on overall thermal performance factor variation with Reynolds number of CTW .

Effect of fin size on Nusselt numbers and friction facto of CTRF

The influence for insertion conical-nozzle turbulators fitted with triangle fins in a heated tube on the Nusselt number is showed in Figure-8. It is obtained that the presence for triangular fins gives considerably enhance of heat transferred over that of the converge – diverge conical-nozzle alone. This increase in the thermal convection with the internal triangle fin is because of a high turbulence that generated from the presence for fins that gives an increase in an accelerated flow and longtime of residence of flow and hence enhance the radial and tangential turbulent fluctuations in the pipe section.. It can be note that this increase because of increase the strength of mixing flow.

Figure-9 shows difference between friction factor and the Reynold numbers for variant values of fin size From this case, it is depict that the friction is larger than that from insertion conical turbulators only and from the plain pipe. The increase in the friction index is due to flow disturbance at the entry for the conical turbulator that created by the fins and dispersal of the dynamic pressure of liquid because of large viscosity loss at the tube wall. The flow friction can occur at the contact between inertial forces and the pressure forces during the boundary layer. The experimental results appeared that the fiction factor of these turbulators fitted with internal triangle fins are greater than that of a conical turbulators only by around 40 % for area ratio Ar=0.149.

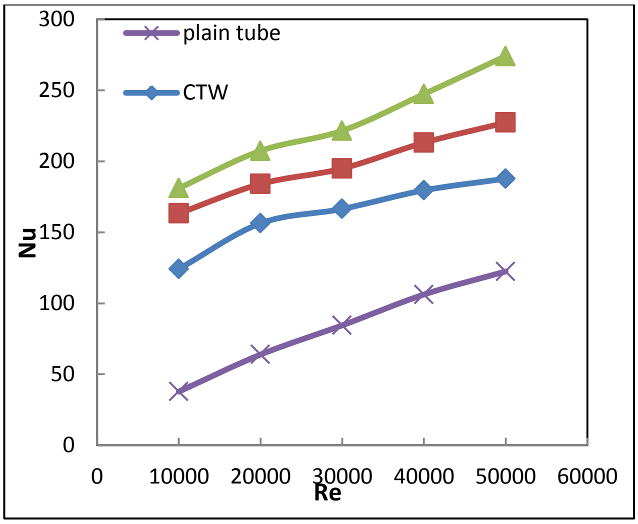

Figure-8. Effect of fin size on Nusselt number for CTRF at PR=1.0.

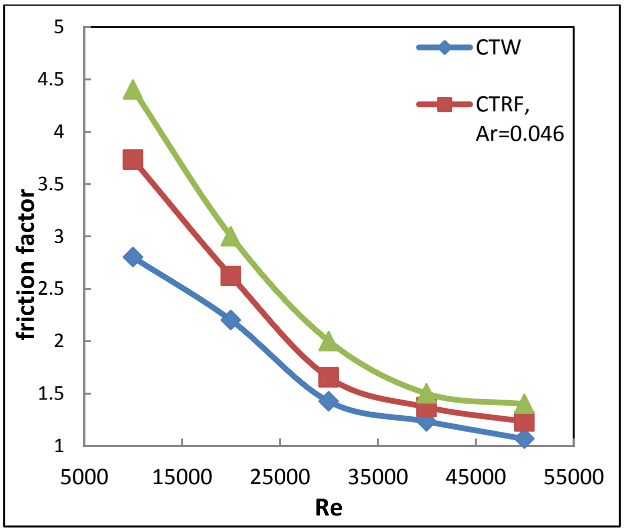

Figure-9. Effect of fin size on friction of CTRF at PR=1.0.

Effect of fin size on overall thermal performance factor for CTRF

The difference between overall thermal performance and the Reynold numbers for insertion conical turbulators integrated with the triangle fins in a circular tube are depicted in Figure-10. Throughout the results, it is appeared that the utilize of triangle fins yields considerable improvement of turbulance heat transfer with friction factor rise than using conical turbulators alone. This increase is due to increase the turbulence intensity

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created by fins. It is obtained that PR=1.0 and Ar=0.149 provide the maximum overall thermal performance factor that reduces with rising Reynolds number.

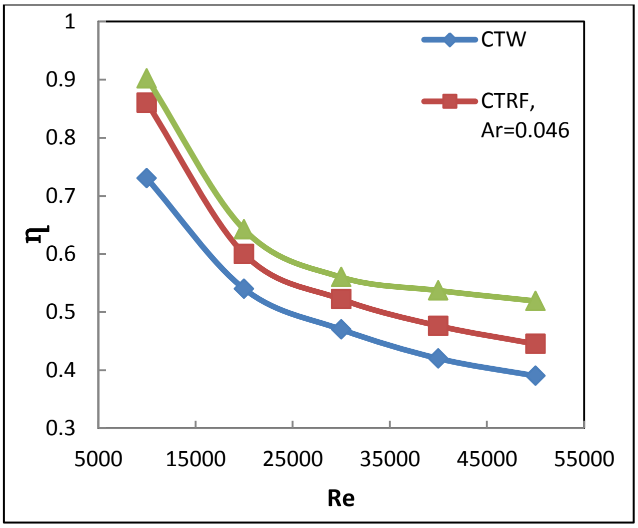

Figure-10. Effect of fin size on overall thermal performance factor for CTRF at PR=1.0.

CONCLUSIONS

Experimental examination has been performed to test the combined influence of conical turbulators integrated with internal triangle fins on heat transfer, flow friction and overall thermal performance factor under a regular heat flux pipe using the air as the working liquid. In this part, the conclusions include the following:

a) The Conical tabulators with or without internal fins should be inserted into the heated tube for enhancement heat transfer.

b) The converge-diverge conical turbulators fitted with triangular internal fins offer considerably enhance of flow heat transfer by 32% as compared with those fitted with a conical turbulators alone.

c) The optimum enhancement efficiency of 310 % is found for converge-diverge conical turbulators fitted with triangle fins at pitch ratio PR=1.0.

d) The Friction index for triangle fin inserted in CD conical turbulator is much bigger than plain pipe and CD conical turbulators insert alone.

e) The optimum thermal performance is about 90% is found for utilizing the CD conical turbulators fitted with triangle fins at pitch ratio PR=1.0.

NOMENCLATURE

	As surface area of the plain pipe (m^2)
Ar	area ratio (A/A)
CD	converge-diverge conical-nozzle turbulators
CTW	conical turbulators without fin
CTTRF	conical turbulators fitted with triangle fin
C_p	specific heat capacity (J/Kg K)
D_i	inner diameter of the plain pipe (m)
D_o	outer diameter of the plain pipe (m)
f	friction factor
f_0	friction factor of the plain pipe
h	mean heat transfer coefficient (W/m^2k)
k	thermal conductivity (W/m K)
l	the distance between conical nozzles (m)
L	the length of plain pipe (m)
Nu	Nusselt number
ΔP	pressure drop (pa)
PR	pitch ratio for the conical- turbulator
Q	the rate of heat transfer (W)
Re	Reynolds number
T_w	wall temperature (C^0)
T_b	bulk temperature (C^0)
U	mean velocity (m/s)
Greek	symbols
υ	kinematics viscosity (m^2/s)
η	Thermal performance factor
ρ	fluid density (kg/m^3)

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