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Enhancing heat transfer by using combined conical turbulators and swirling tapes

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Abstract

Effect of insertion combined screw and twisted tapes in a heated tube fitted with converge-diverge conical turbulators on Nusselt number, friction factor and overall performance factor has been experimentally investigated. The air is the working fluid for Reynolds number variety of 15000-65000. The conical nozzles used as turbulators are located inside the heated tube with the combined twisted and screw tapes. The considered compound case is compared with the single twisted and screw tape. The twisted tape is used for three various twist ratios (Y/W=3.0,5.0,and 7.0), while the screw tape for one screw ratio equal to 3.0 . It is discovered that the combined tapes with conical turbulators enhance considerably the heat transfer over that of the conical turbulators alone by about 47.7% and 43.18%,and 39.7% for twist ratio of 3.0,5.0 and 7.0 respectively. The optimal thermal performance is pointed for screw and twist ratio equal to 3.0 .

Keywords: heat transfer enhancement, conical turbulators, screw tape, twisted tape.

1.Introduction

Heat transfer intensification systems are repeatedly utilized in the heat exchanger technique so as to intensify heat transfer of the thermal system. Different styles of turbulators are used to improve the heat transfer in a heat exchanger, for example, truncated hollow-cone,wire coil, conical nozzle, V-nozzle, and conical ring, etc. Naga Sarada [1]made an examinations on a horizontal tube fixed with differing width twisted tape. The Reynolds number ranged from 7000 to 13500. It was realized that the extension of heat transfer with twisted- tape inserts changed from 36 to 48% for full width as contrasted to plain tube . Promvonge [2] also described the impact of the conical turbulators fitted in a circular tube on heat transfer and pressure drop. Obviously, It was obtained that each application of the conical nozzle and the snail can assist to augment significantly the heat transfer above that of the plane tube by around 288% and 206%. Ferroni et al.[3] reported ,through their experiments, the pressure drop affecting according to insertion different number of twisted tape inside the tested tube.The used twisted tape segments were equally spaced, physically separated ,identical and short length. The results showed that, in general, the present used pattern of twisted tapes enhanced coefficient of heat transfer in comparison with that of plain channels and there is 50% decreasing in pressure drop of this twisted tapes pattern in comparison with that of continues typical twisted tapes (full length twisted tapes). Promvonge [4]examined the augmentation efficiency in the tube by using conical turbulators with free positioning snail entrance at various pitch ratios. The heat transfer gotten from utilizing nozzle turbulators, in general, was obtained to be superior than that from the plain tube .Experimental examinations were reported by Deepali [5] to verify the influences of the (V-nozzle)turbulators on heat transfer, and thermal enhancement efficiency in a heated tube. It was discovered that using the V-nozzle can assist to augment significantly the heat transfer at about 140% above the plain tube. An experimental device was used by vahidifar [6] to report the heat transfer and flow factor in a test tube with wire-coil and rings inserts. The optimum heat transfer is reached for the minimum ring pitch ratio (P/D=1.0). Eiamsa-ard et al. [7] studied experimentally, the heat transfer and pressure loss in a test tube with wire- coil and twisted- tape .They showed that the coil- wire had a large effect on the augmentation of heat transfer. The results appeared that the highest thermal performance is pointed at combined devices of the twisted tape with wire coil as compared with the wire coil alone. Smith et al. [8] investigated the fully - developed turbulent flow through a equivalent heat flux tube fixed with diamond conical turbulators. The influence of the this arrangements on heat transfer and flow factor was reported. It was discovered that both the enhancement efficiency and pressure loss increases with increasing the cone angles .Promvonge [9] also described the influence of the conical- ring arrangements (converge conical, diverge conical, and converge–diverge conical fitted in a test tube on the augmentation of heat transfer .The results showed that the enhancement efficiency of diverge conical array is the highest compared to those of the converge and converge-diverge conical for all similar diameter ratios. Kongkaitpaiboon [10]examined the augmentation efficiency in a test tube by using Perforated conical-ring with various pitch ratios. All of the perforated conical turbulators were placed in diverge conical ring arrangements. The results appeared that the highest thermal performance of around 0.92 was found at pitch ratio equal 4.0 and number of hole equal to 8.0 with

Reynolds number of 4000. Experimental examinations testified by Smith et al. [11] to demonstrate the effects of a screw tape with or without center-rod on Nusselt number and performance factor characteristics in a heated tube heat exchanger. It was realized that the heat transfer from utilizing the screw tape without center rod is superior than that from the plain tube by around 340%. The enhancement thermal for the screw tape without center-rod was viewed to be larger than that with center rod at approximately two times. Nanan [12] also described the impact of perforated helical twisted tapes in a tube on the Nusselt number, and performance factor characteristics. The results revealed that the greatest performance factor of 1.28 is obtained by utilizing the perforated tape with the minimum hole diameter and the biggest perforation pitch at the smallest Reynolds number of 6000. Gowrisankar [13]expermintally studied the friction factor and Nusselt number behavior of a diverge conical turbulators inserted in atube with different pitch ratios. It was realized that the enhancement of heat transfer is pointed with small pitch ratio of conical inserts. As contrasted to the plain tube this enhancement was varied from 36 to 48%.An experimental device is used by Rahul et al . [14] to investigate the heat transfer intensification and pressure loss for conical -springs located in three various arrangements, converge conical- spring, converge–diverge conical -spring and diverge conical -spring for different Reynolds Number.It was obtained that the Diverge -spring arrangement has a better heat transfer than the converge -diverge and converge arrangement. The augmentation efficiency in a tube by using combined screw tape with twisted at different pitch ratios were examined by Eiamsa [15]. In general, the heat transfer gotten from utilizing the combined tapes, was larger than that of helical tape alone. Nishidha [16] investigated the heat augmentation efficiency and pressure loss in a tube by using conical converge spring . Five conical- spring inserts are manufactured with identical length and diameter. It was realized that the heat transfer in atest tube with conical -spring inserts is more as contrasted to smooth tube. Experimental investigations were demonstrated by Aiwu et al [17] to show the effects of a tube conical -strip on Nusselt number and performance factor The results appeared that the heat transfer is improved by around 5 times that of the plain tube, which verified that the conical- strip has a better influence of heat transfer enhancement Jian Guo [18] also described the impact of reducing the upwind area of conica strip tube inserts on enhancement efficiency and friction factor characteristics. Experimental results appeared that the Nusselt number enhanced by about 53–56% for the state with conical strip embeds compared with conical-ring inserts. It was realized that the thermohydraulic performance is augmented by 36–61% when changing conical ring inserts with conical-strip inserts. An experimental study was reported by Eknath [19] to investigate the impact of the inclined Vortex- rings added in a tube on turbulent heat transfer and flow friction properties The sloping vortex rings were mounted repeatedly in the tube with three various angles and three different width ratios at constant ring pitch-ratios .It was realized that the Nusselt number is greatest for vortex ring- angle 35^0 with a considerable rise in the pressure loss Promvonge [20] investigated the influence of conical turbulators and twisted tapes on heat transfer ,and pressure drop characteristic. The conical-ring utilized as a turbulators were located in the tested tube. The results proved that there was a considerable improve in heat transfer and pressure drop for for utilizing the conical turbulators and the twisted tape of twist ratio equal to 3.75. In the present work, the main interest is to experimentally examine the heat transfer and turbulent flow structure of a heated pipe fitted with converge diverge conical turbulators and combined twisted and screw tapes as presented in Fig.1. The twisted tape is used for three changed twist ratios (Y/W=3.0,5.0,and 7.0), while the screw tape for one screw ratio (p/w=3.0) for conical turbulators pitch ratio equal to 2.0. This investigation is performed for Reynolds number range of 15000 to 65000. To knowledge of the authors there is no study reported on this combined flow geometry.

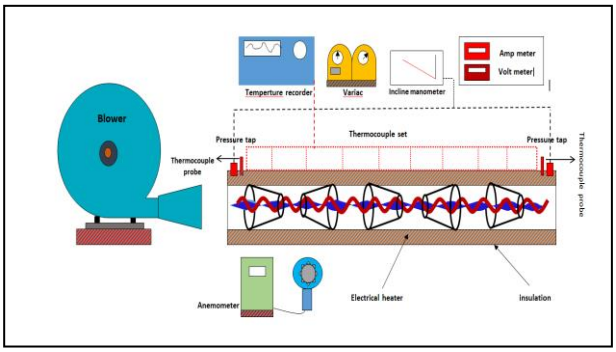

Fig. 1: Schematic diagram of experimental apparatus

2. Experimental set up

The investigation was managed in an open loop experimental as displayed in Fig. 1.The loop consisted of 1.1 KW blower, anemometer is used to measure the velocity of air inter through the test section .The aluminum test tube has a length of L = 1200 mm, with 60.0 mm inner diameter (Di), 65.0 mm outer diameter (Do) and 2.5 mm thickness (t).The test section was heated by an electrical-wire continuously around the tube giving constant heat flux boundary condition. The electrical output power was regulated by a variac -transformer to get a required heat flux along the whole length of the test section. The outside surface of the test section was completely insulated to limit convective heat loss to the atmosphere, and the significant protections were taken to prevent leakages from the system. The recorder temperature was utilized to get multi-channel temperature estimations. Ten thermocouples were appointed on the wall of the tube to evaluate the temperature of the wall. Two thermocouples were located at the inlet and outlet of the heated tube to quantify the temperature of the bulk air. Fig.1shows the converge-diverge conical turbulators inserted the combined screw and twisted tape.

The conical turbulators were made of aluminum with 60.0 mm in length (l) and its small end diameter (di) was

30 mm ,with a 1.5mm thickness and 120mm as a pitch length. The twisted tape made of aluminum with twist ratios Y=Y/W=3.0,5.0 and 7.0 respectively. Also the screw tape made of aluminum with screw ratio equal to 3.0.

2.1.Twisted tape

The geometrical formation of twisted tape is presented in fig .2 .The twisted tape was made from aluminum with length 1200mm, thickness 1mm and width 15mm. The tapes is manufactured by turning a straight tape about its longitudinal alignment and twisted with three twist ratios (Y/W) of 3.0, 5.0, and 7.0 respectively for creating different swirl intensities

Fig .2 Typical twisted tape

2.2.Screw tape

The geometrical formation of screw tape is showed in Fig .3. Screw tape was made from aluminum with length 1200 mm, thickness of 1mm and diameter of 18 mm. Screw tape was arranged at fixed width 15 mm with screw ratio(P/W) equal to 3.0 for the length 45mm.

Fig .3 Screw tape

2.3.Combined tapes

Every twisted tape was incorporated into a screw tape and combined tapes were consequently provided inside the tube for producing swirl flow as displayed in fig .4. Both twisted and screw tapes are combined in three different values of twist ratio 3.0, 5.0, and 7.0 while the screw ratio fixed at p/w=3. Table 1 represents the considered geometrical parameters for the physical problem.

Fig.4 Photographic view of the combined screw and twisted tapes**.**

Table . 1. Geometrical parameters for the physical problem.

Test tube	
Parameter	Values
Length	1200mm
Outer diameter	65mm
Inner diameter	60mm
Thickness	2.5mm
Material	Aluminum
Fluid	Air
Reynolds number	15000-65000
Twisted tape	
Parameter	Values
Tape width	15mm
Twist ratio	3.0 ,5.0 ,and 7.0
Material	Aluminum
Thickness	1mm
Tape width	15mm
Screw tape	
Parameter	Values
screw length	45 mm
Thickness	1mm
Tape screw ratio	3.0
Material	Aluminum
Combined tapes	
parameter	Values
Twist ratio	3.0,5.0 and 7.0
Screw ratio	3.0
Thickness	1mm
Material	Aluminum

3. Experimental calculations

The characteristics of air flow, Reynolds numbers, friction factor and Nusselt number are based on air flow velocity, the drop in pressure across the testing tube, the average temperature of the tube wall and inlet and outlet air temperature are measured for tube occupied with twisting tapes, screw tapes and combined tapes of modified designs at steady state of each test run. In this work, the working fluid is flowed through the insulated tube that subjected to uniform heat flux. So, this section verifies the necessary equations to calculate the designed variables.

The net heat input to the fluid was specified from the electrical energy input to the system as follows:

$$Q_{air} = Q_{conv} \quad (1)$$

Where ;

$$Q_{air} = m^{\cdot}\, Cp(T_o - T_i) = V.I \quad (2)$$

The convection heat transfer from the test section can be written;

$$Q_{conv} = \bar{h}\, A\, (T_w - T_b) \quad (3)$$

$$T_b = (T_o - T_i)/2 \quad (4)$$

$$T_w = \frac{\sum_{i=1}^{10} T_{wi}}{10} \quad (5)$$

The average Nusselt number, Nu is valued as follows:

$$Nu = \frac{\bar{h}\, D_h}{k} \quad (6)$$

Where D_h is the hydraulic diameter.

$$Re = \frac{U\,.D_h}{\nu} \quad (7)$$

The friction factor (f) can be written as:

$$f = 2\,\Delta P\,(D_h/L)/\rho\, U^2 \quad (8)$$

Where U is the mean air velocity in the tube.
The thermal performance factor (Ƞ) for conical turbulators tube with combined tapes can be represented as:

$$Ƞ = (Nu/Nu_p)\,/\,(f/f_o)^{1/3} \quad (9)$$

٤.Results and discussion

in this section ,the experimental results of Nusselt number ,friction factor and thermal performance factor for a circular tube roughened with conical turbulators and combined twisted and screw tapes are documented as follows.

4.1. validation

The collected experimental results are validated with existing known related empirical correlations (eq .10, eq.11and eq.12) and with the published results .The validations includes the Nusselt numbers and friction factor as displayed in Fig 5. and Fig .6 respectively. The average deviation for average Nusselt number and friction factor is7.5% and 9%.

$$Nu = 0.023\, Re^{0.8}\, Pr^{0.4} \quad \text{for } Re \geq 1 \times 10^4 \quad (10)$$

$$f = 0.316\, Re^{-1/4} \quad \text{for } Re \leq 2 \times 10^4 \quad (11)$$

$$f = 0.184\, Re^{-1/5} \quad \text{for } Re \geq 2 \times 10^4 \quad (12)$$

fig.7 shows the validation of the present results for converge-diverge conical turbulators with published results of promvonge [9]. It is observed that the average deviation does not exceeds 7.9%

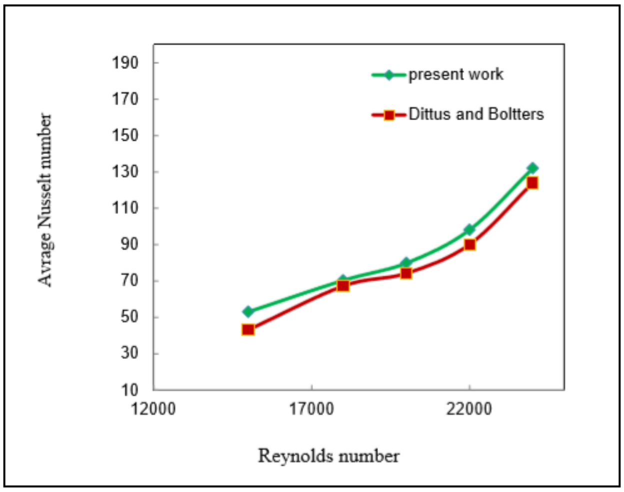

Fig.5 Validation of the present results of average Nusselt number with Dittus and Boltters correlations [11].

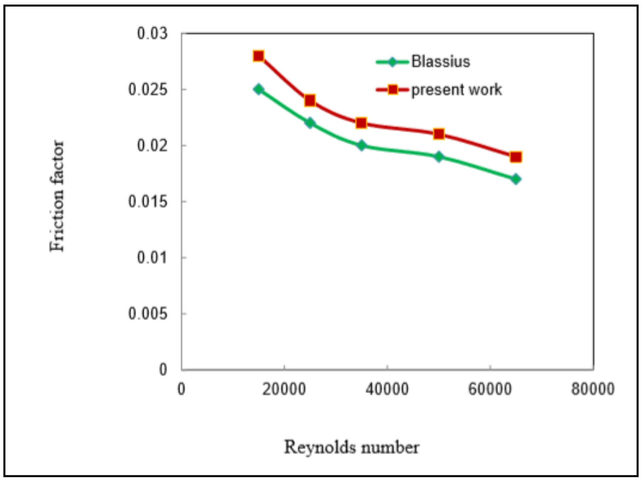

Fig .6 Validation the present results of average friction factor with Blasius[2].

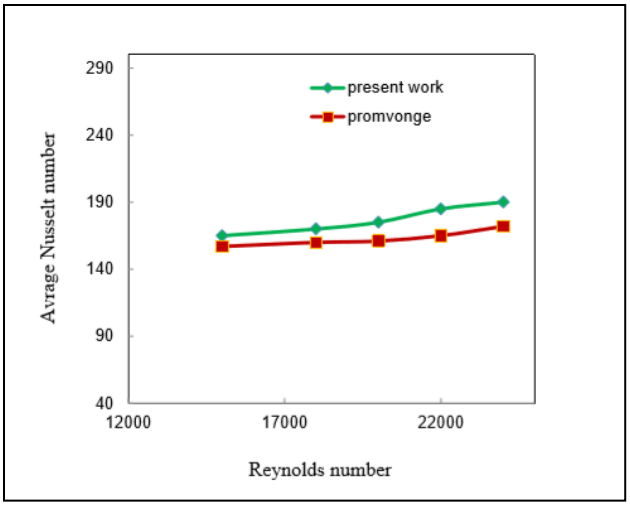

Fig.7 Comparison of the present results with results of promvonge[9] for CD conical turbulators

4.2. Effect the combined screw and twisted tape on Nusselt number and friction factor.

Influences of combined the screw-tape with twisted tape on the Nusselt number are showed in Fig. 8. It is discovered that the tube including the combined the screw-tape and twisted tape fitted with converge –diverge conical turbulator gives greater heat transfer than that of the converge-diverge conical turbulators alone . This can be ascribed to swirling influence created from the utilization of the combined screw-tape with twisted tape inserts , producing higher temperature gradient and pressure loss in the radial direction. Over the range examined Reynolds number, the optimum increase in mean Nusselt numbers for the augmentation device with the combined screw-tape and twisted tape insert is 47.7% above the conical turbulators alone for p/w=3.0and y/w=3.0.

Fig. 9. demonstrates the variant of flow friction with Reynolds number for the combined screw-tape and twisted tape in a tube fitted with converge –diverge conical turbulators. As expected , the friction factor acquired from the tube with the combined screw-tape and twisted tape are greater than that from the plain tube and from converge - diverge conical turbulators alone . Results of the friction factor for the introduce the combined screw-tape with twisted tape are larger than those for the CD conical alone around 45% for p/w=3.0 and y/w=3.0 due to higher swirling flow or turbulence flow.

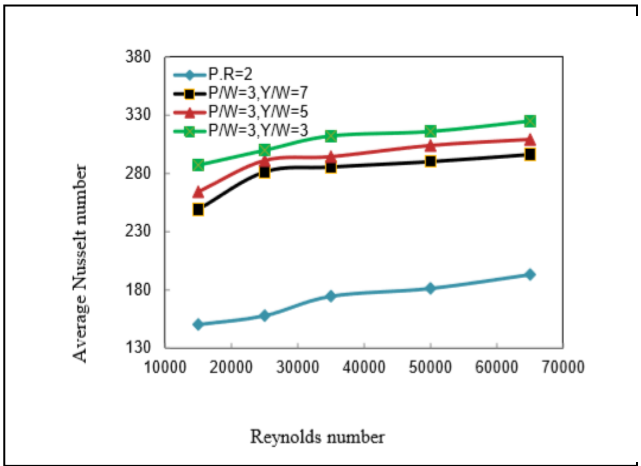

Fig.8 Effect of compound screw and twist ratio on Nusselt number for converge-diverge conical tabulators with combined tapes at P.R=2.0

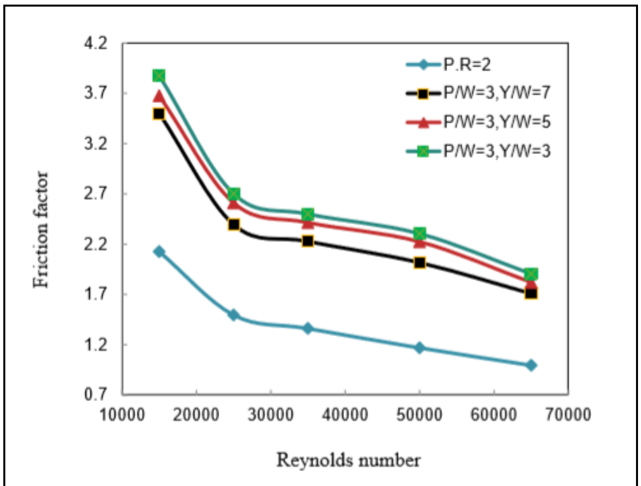

Fig.9.Effect of compound screw and twist ratio on friction factor for converge-diverge conical tabulators with combined tapes at P.R=2.0

4. 3. Influence of twisted and screw ratio on thermal performance factor for CD turbulators.

Fig .10 shows the variation of thermal performance with Reynolds number for the heated tube fitted with converge -diverge conical turbulators by inserts the combined screw tapes with twisted tape. According to the results appeared above, the CD conical turbulators with combined screw and twisted tape offer heat transfer intensification in accompany with the rise of friction factor. The increase of friction factor causes increase of pumping energy. Thus , the real effective of the turbulator relies on the weight of the enhance in heat transfer and the rise in friction, which can be resolved from performance evaluation . It is discovered that the thermal performance reductions with growing Reynolds number and it is also noticed that the combined tape with the smallest twist and screw ratios (Y/W=3.0,and P/W=3.0) provide the highest thermal performance factor for converge-diverge conical turbulators.

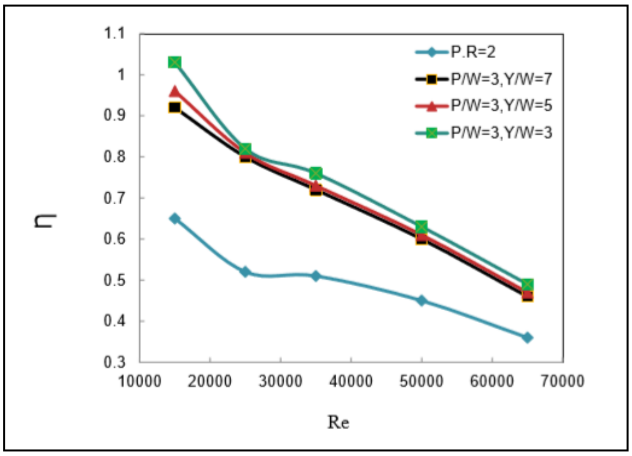

Fig.10 Effect of compound screw and twist ratio on thermal performance factor for converge-diverge conical tabulators with combined tapes at P.R=2.0

4.4Empirical correlations

The present experimental results of Nusselt number and friction factor are fitted, utilizing least squre regression analysis. The resultant correlations for converge-direrge conical turbulators with combined tape are shown in the following equations.

Nusselt number correlation:

$$Nu = 141.5658746\ Re^{0.0978743}\ Pr^{0.4}\ (Y/W)^{-0.110844}$$

Friction factor correlation:

$$f = 302.871614\ Re^{-0.44255}\ (Y/W)^{-0.132074}$$

These correlations are subject to the evaluation of their reliabilities and it is found that the deviations for Nusselt number and friction factor are within 2% and 3%,respectively.

5. Conclusions

The heat transfer intensification in a heated tube by using conical turbulators and combined twisted tape and screw tapes has been numerically investigated .In this section ,the following conclusions can be collected.

١-The heat transfer in the tube could be augmented highly by fitting it with conical turbulators insert and combined tapes.

٢-Conical nozzle turbulators with or without twisted and screw tapes could be inserted inside the flow tube for augmenting heat transfer rate.

٣- The lower twisted and screw ratios accomplishes better intensification of heat transfer rate.

4-Over a range of Reynolds numbers, combined tapes yielded higher Nusselt number and friction factor in comparison with the other tapes, especially in low Reynolds number conditions.

5-Combined screw and twisted tape inserted inside a heated tube fitted with converge-diverge conical turbulators are offered greater heat transfer rates by about 47% as compared with those of the tube fitted with conical turbulators alone.

6-Correlations for the Nusselt number and friction factor based on the present experimental data are introduced for practical use.

7-Over the range tested, the highest performance factor of 1.02 is found by use of combined screw and twisted tape with p/w=3.0 and y/w=3.0.

Nomenclature

A surface area of the test tube (m^2)
C_p specific heat capacity (J/Kg K)
CD converge-diverge conical turbulators
D_i inner diameter of the test tube (m)
D_o outer diameter of the test tube (m)
f friction factor
f_0 friction factor at the plain tube
h average heat transfer coefficient (W/m2k)
k thermal conductivity (W/m K)
l the length between turbulators (m)
L length of the test tube(m)
m air mass flow rate(kg/s)
Nu Nusselt number
Nu/Nu_p enhancement efficiency
ΔP pressure drop (pa)
P.R pitch ratio of the conical turbulator
P/W screw ratio
Q heat transfer rate (W)
Re Reynolds number
t thickness of the test tube (m)
T_w wall temperature (C^0)
T_b bulk temperature (C^0)
U mean velocity in the test tube (m/s)
Y/W twist ratio

Greek symbols

υ kinematics viscosity (m^2/s)
Ƞ Thermal performance factor
ρ fluid density (kg/m^3)

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