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CFD and Experimental Studies of Heat Transfer and Pressure Drop in a Tube Equipped With Drilled Twisted Tape Inserts

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Abstract: **— The present report focused on CFD and Experimental study of heat transfer, friction factor and Performance Evaluation Criteria(PEC) of tube in tube type heat exchanger fitted with drilled twisted tape inserts. The inner and outer diameters of the tube are 20mm and 40mm respectively and cold and hot water are used as a working fluid in shell and tube side,. The tapes are inserted in a tube at three different twist ratio(y) of(2.5, 3.33, 5) having 45mm, 60mm and 90mm pitch. The drilled twisted tape are having a drilled holes of 5mm and 8mm along the pitch of the tape. The result obtained from tube with plain twisted tape inserts, and drilled tape inserts are compared with the plain tube, within the Reynolds number range from 3223.6 to 22344.05.CFD simulation was also performed on a plain tube by using standard k-e and sst-k-w model.. Sst-k-w model was selected for further studies as it is more reliable model and also provides more accurate prediction of flow separation and also in the present work the enhancement in heat transfer rate matches with the sst-k-w model when compared with that of standard k-e model for the experimental reading of plain tube. The experimental as well as simulation results shows that both the heat transfer rate and friction factor in a tube equipped with twisted tape inserts as well as drilled tape inserts were significantly higher than the plain tube, Over the range of Reynolds number investigated, Based on thermal performance factor for plain twisted tape 90mm pitch tape gives maximum ηth as compared with 45mm and 60mm pitch. And for drilled tape inserts both 5mm and 8mm drilled tapes provides the maximum ηth with 90mm pitch tape, over the provided set of Reynolds number value.**

Index Terms**—twisted tape inserts, Heat transfer enhancement, Twist Ratio(y=l/w), thermal performance factor (ηth).**

I. INTRODUCTION

Heat transfer is a transition of thermal energy from a hotter mass of fluid to a cooler mass. Heat exchanger are the device which is used to transfer the heat from a hotter mass of fluid to a colder mass with maximum rate and minimum investment and running cost. Heat exchangers are widely used in many fields such as power generation, chemical industry, metallurgy, steel production, refrigeration, air-conditioning etc are indispensible general device for heat exchanger. In general the most significant variable in reducing the size and cost of heat exchanger are heat transfer coefficient and pressure drop.

In general the heat transfer enhancement techniques is mainly divided into two categories: (1) active technique which need external power source (2) passive technique which do not need external power source. Some examples of passive techniques include insertion of porous[a], twisted strips and tapes[b], wire coil and helical wire inserts[c], helical screw tapes[d], regularly spaced twisted tapes[e] and many others .

A lot of the active and passive methods that are available for the enhancement of heat transfer rate has been discussed by the Bergles[1] and bergles and webb[2]. Eiamsa [3] has investigated the 3D numerical simulation of swirling flow induced by means of loose fitted twisted tape inserts .Xiaoyu Zhang, Zhinchin Liu, Wei Liu[4] has studied the heat transfer and friction factor in a tube fitted with helical screw tape without core rod inserts. S R Shabanain, M. Rahimi, M. Shahhosseini, A.A Alsairafi[5] has reported the CFD simulation of heat transfer and friction factor in an air cooled heat exchanger equipped with three tube inserts mainly classical, butterfly and jagged inserts,in the studied range of Reynolds number. Many authors has seemed to be done a lot of work in an heat transfer enhancement using many passive technique devices, But no one used twisted tape having drilled holes, In the present work both experimental as well as numerical simulation was done on a heat exchanger tube by using plain as well as drilled twisted tape inserts.

Nomenclature
A Area, (m^2)
Q heat transfer rate(W)
Cp Specific heat capacity(kj/kgK)
ηth thermal performance factor
D tube Diameter(m)
f friction factor
h heat transfer enhancement(w/m^2K)
k thermal conductivity(w/mK)
Δp pressure drop(cm of Hg)
L length of the tube(m)
m mass flow rate(kg/s)
Nu Nusselt number
Re Reynolds number
Pr Prandlts number
l pitch of the tape
w width of the tape

Greek letter
υ kinematic viscosity(m^2/s)
ρ density(kg/m^3)

Highlight a section that you want to designate with a certain style, and then select the appropriate name on the style menu. The style will adjust your fonts and line spacing. **Do not change the font sizes or line spacing to squeeze more text into a limited number of pages.** Use italics for emphasis; do not underline.

II. EXPERIMENTAL APPARATUS

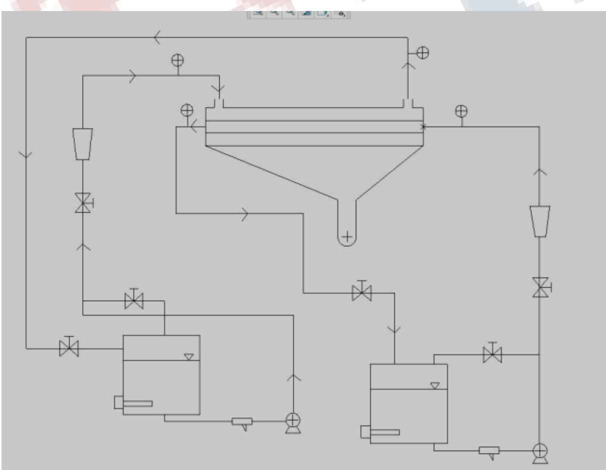


Fig1: Schematic Diagram of an experimental setup

Above figure shows an schematic view of an heat exchanger setup, The heat exchanger is of counter flow type. The tube length used is of 1500mm and tube diameter used is of 20mm thermocouples are placed at inlet and outlet to measure the inlet and outlet temperature of hot and cold water, rotameter as used to control the flow rate of hot and cold water respectively the flow rate varies from 2lpm to 10lpm for the hot water side and cold water flow rate is maintained constant at 15lpm. friction factor is determined by means of pressure difference at the hot water side by means of U-tube manometer, Experiments was repeated for the plain tube as well tube having twisted tape inserts within the given set of Reynolds number range between 3223.6 to 22344.05

Fig2: Actual image of 45mm, 60mm, 90mm pitch twisted tape with 5mm drill

Fig3: Actual image of 45mm, 60mm, 90mm pitch twisted tape with 8mm drill

The above figure shows actual image of twisted tape having 45mm, 60mm and 90mm pitch with 5mm and 8mm drill used for heat transfer enhancement. The twisteed tape helps in creating the turbulence which increases the tangential flow established by the inserts and enhances the

heat transfer rate.
The twisted tape used are made of Aluminum strip with 2mm thickness, 18mm width and 1500mm length,. The tapes are inserted in a tube at three different twist ratio(y) of(2.5, 3.33, 5) having 45mm, 60mm and 90mm pitch

III. DATA REDUCTION

The mean Nusselt number and friction factor are based on the inside diameter of the plain tube. Heat transfer to the cold water in the annulus, **Qw,c** can be written as

$$\mathbf{Qw.c= Mw,c\ Cp,w\ (Tw,c,out - Tw,c,in)}$$

Where **Mw,c** is the mass flow rate of cold water, **Cp,w** specific heat of water, **Tw,c,in** and **Tw,c,out** are the inlet and outlet cold water temperatures, respectively Similarly, heat transfer rate from hot water **Qw,h** in the test tube can be determined

$$\mathbf{Qw,h=Mw,h\ Cp,w\ (Tw,h,out-Tw,h,in)}$$

Where **Mw,h** is the mass flow rate of hot water, **Tw,h,in** and **Tw,h,out** are the inlet and outlet hot water temperatures respectively

The average heat transfer rate,**Qavg** used in the calculations is estimated from the hot water and cold water sides as follows

$$\mathbf{Qavg=\frac{Qw,c+Qw,h}{2}}$$

For the fluid flow in concentric tube heat exchanger, the heat transfer coefficient, **hi** is calculated from

$$\mathbf{Qavg=UAi\Theta m}$$

Where Ai= πDiL
The tube side heat transfer coefficient ho is calculated by using Dittus and Boelter

$$\mathbf{Nu0=}\frac{hoDh}{k}= 0.023*Re^{0.8} * Pr^{0.3}$$

Then

$$\text{ho}=\frac{k}{Dh}\text{Nu0}$$

where Dh=hydraulic diameter=Dh-D0 thus

$$\text{Nu}=\frac{\boldsymbol{hiDi}}{\boldsymbol{k}}$$

The thermal conductivity “k” of the fluid is calculated from the fluid properties at the mean bulk temperature. The Reynolds number is based on different flow rate here the flow rate varies from 2lpm to 10lpm

Pressure Drop:

The pressure drop during the flow in a tube of length L is expressed as

$$\Delta\text{p} = \frac{f\,L\,\rho V^2}{2D}\ \ (\text{N}/m^2)$$

Where f is the friction factor. The required pumping power to overcome the specified pressure drop Δp is determined from.

$$\text{Wpump} = \text{V}^*\Delta\text{p} = \frac{m*\text{□ p}}{\rho}$$

IV CFD MODELING

CFD analysis was carried out in ANSYS WORKBENCH 15.0 to predict the actual behavior of the fluid flow inside the tube using twisted tape inserts, CFD was carried out to solve the PDE using the governing equations, This governing equations are solved using the digital computers.

In the present study sst-k-**ω** model and standard k-€ model are selected for the simulation purpose, The governing equation set for the both the models are

<u>Standard k-€ model</u>

$$\frac{\partial}{\partial t}(\dot{\rho}\text{k}) + \frac{\partial}{\partial xj}(\rho kui) = \frac{\partial}{\partial xj}[(\text{ч} + \frac{\text{ч}t}{бk})\frac{\partial k}{\partial xj}] + \text{Gk} - \beta 1\text{k}\omega$$

$$\frac{\partial}{\partial t}(\dot{\rho}\ \omega) + \frac{\partial}{\partial xj}(\rho\omega\ ui) = \frac{\partial}{\partial xj}[(\text{ч} + \frac{\text{ч}t}{б\omega})\frac{\partial\omega}{\partial xj}] + \text{G}\omega - \beta 2\text{k}\omega^2$$

The model constant are β1= β2=0.072

<u>SST k-ω model:</u>

Turbulene kinetic Energy

$$\frac{\partial\text{k}}{\partial\text{t}} + \text{uj}\,\frac{\partial\omega}{\partial xj} = \text{Pk} - \beta^*\,\text{k}\boldsymbol{\omega} + \frac{\partial}{\partial xj}[(\nu + \boldsymbol{\sigma}\text{k}\ \nu\text{t})\frac{\partial k}{\partial xj}]$$

Specific Dissipation Rate:

$$\frac{\partial\omega}{\partial t} + \text{uj}\,\frac{\partial\omega}{\partial xj} = \alpha s^2 - \beta\omega^2 + \frac{\partial}{\partial xj}[(\nu + \boldsymbol{\sigma\omega}\ \nu\text{t})\frac{\partial\omega}{\partial xj}] + 2[(1-\text{F1})\boldsymbol{\omega}2\frac{1}{\omega}\frac{\partial k}{\partial xi}\frac{\partial\omega}{\partial xi}$$

Based on the above model used SST-K-**ω** model is selected for the further studies as this model is not overly sensitive to inlet boundary condition like the standard k-w model .The use of a k-ω formulation in the inner parts of the boundary layer makes the model directly usable all the way down to the wall through the viscous sub-layer, hence the SST k-ω model can be used as a Low-Re turbulence model, without any extra damping functions.. Literature shows that this model provides more accurate prediction of flow separation over other RANS model

Here SIMPLE algorithm is chosen under the solution scheme to resolve the link between velocity and pressure field, the residuals sets for the present simulation is 10^-6, Here the solution is set to be converged when the normalized residual value was below the set value of residuals.

V RESULTS AND DISCUSSION:

EXPERIMENTAL RESULTS:

1) Results for the plain twisted tape without drill holes:

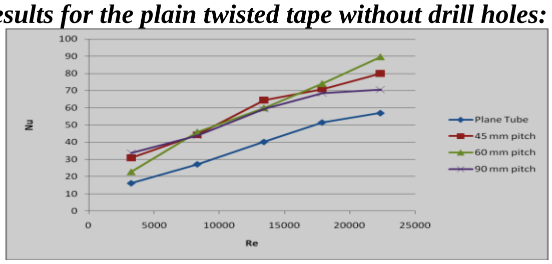


Fig4: variation of Nu v/s Re for 45mm, 60mm and 90mm pitch.

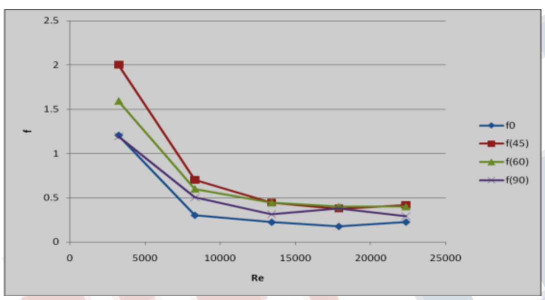


Fig5: variation of f v/s Re for 45mm, 60mm and 90mm pitch.

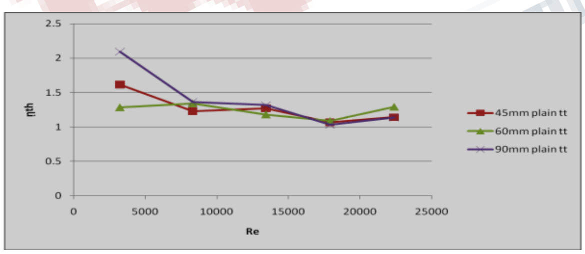


Fig6: variation of ηth v/s Re for 45mm, 60mm, 90mm pitch

2) Results for twisted tape set with 5mm drill:

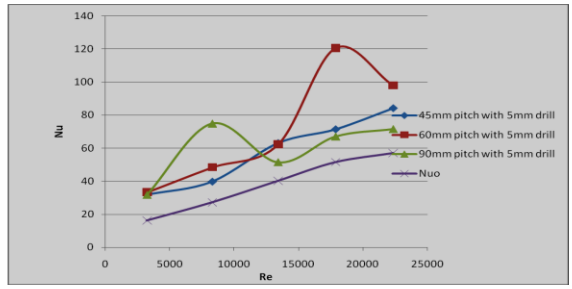


Fig7: variation of Nu v/s Re for 45mm, 60mm, 90mm pitch with 5mm drill

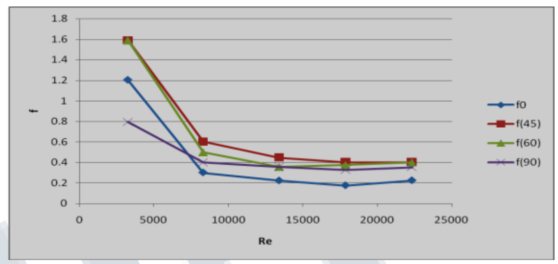


Fig 8: variation of f vs Re for 45mm, 60mm, 90mm pitch with 5mm drill

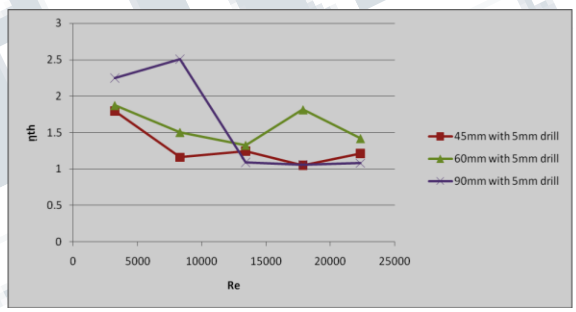


Fig 9: variation of ηth v/s Re for 45mm, 60mm, 90mm pitch with 5mm drill.

3) Results for the twisted tape set with 8mm drill:

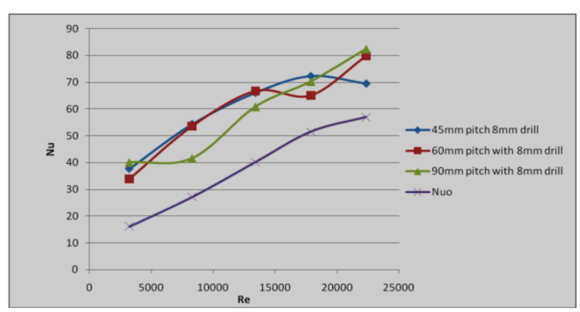


Fig 10: variation of Nu v/s Re for 45mm, 60mm, 90mm pitch with 8mm drill

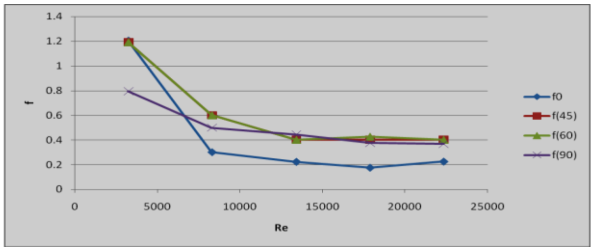


Fig 11: variation of f v/s Re for 45mm, 60mm, 90mm with 8mm drill

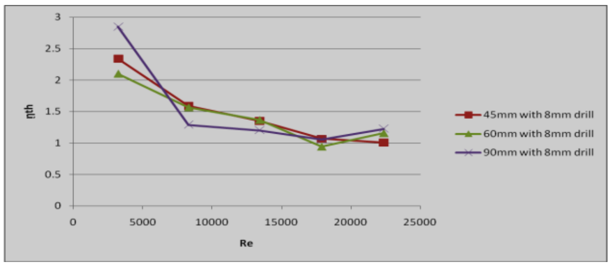


Fig 12: variation of ηth v/s Re for 45mm, 60mm, 90mm with 8mm drill

V RESULTS AND DISCUSSION

Experimental results revealed that the nusselt number rise is 35%, 33% and 31% for 45mm, 60mm and 90mm pitch twisted tape when compared with the plain tube results, and the nusselts number rise for 5mm drill tapes are 35.4%, 36.12% and 37.73% when compared with that of plain tube and the nusselts number rise for 8mm drill tapes are 38.56%, 39.4% and 37% when compared with that of plain tube**,** the friction factor increases 2 times for 45mm and 60mm pitch and 0.9 times for the 90mm pitch tape when compared with plain tube within the Reynolds number range from 3223.6 to 22344.05.

B CFD Results:

CFD results for a plain tube using sst-k-**ω** and standard k-€ model and comparison of these results using the plain tube

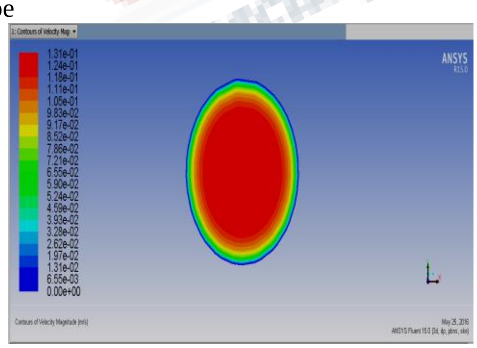


Fig 13: Velocity contours for the plain tube using standard k-€ model

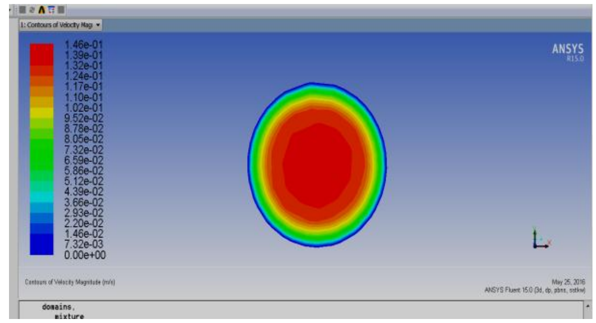


Fig 14: Velocity contours for the plain tube using sst-k-ω model

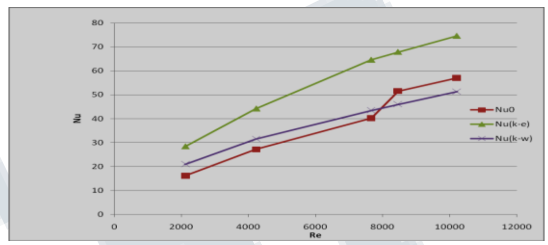


Fig15: variation of Nu v/s Re for a plain tube using sst-k-ω and standard k-€ model.

Above results shows that sst-k-**ω** model are in better agreement with the experimental reading hence sst-k-**ω** model are chosen for the further simulation purpose.

VI DATA REDUCTION:

During CFD investigation the value of wall shear stress is determined at the outlet of the tube, Based on that the value of friction factor is calculated at each flow rate for a turbulent flow, The friction factor for a turbulent flow in a tube is given by

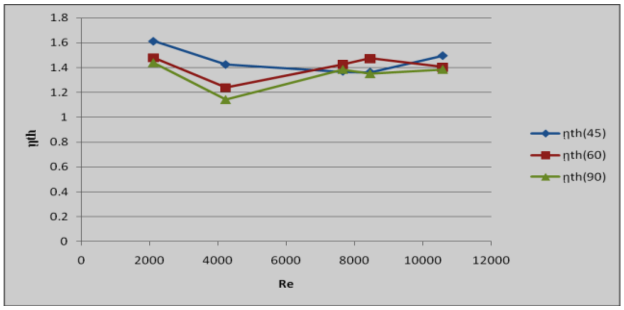
$$f=\frac{8*\tau_w}{\rho*v^2}$$

The nusselts number in turbulent flow is related to the friction factor through the **Chilton-Colburn** analogy expressed as

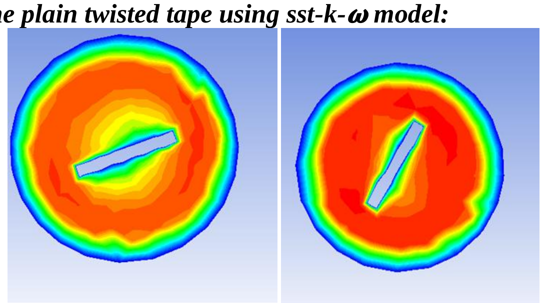
$$\mathbf{Nu=0.125*f*Re*}Pr^{\frac{1}{3}} \text{ (turbulent flow)}$$

This above equations are used for calculation of friction factor and nusselts number for the numerical simulation of plain tube and tube equipped with twisted tape inserts.

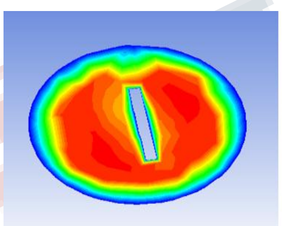
4: CFD Results



*for the plain twisted tape using sst-k-**ω** model:*



45mm pitch ***60mm pitch***



90mm pitch

Fig16: velocity contours for 45mm, 60mm, 90mm pitch using sst-k-ω model

Results for the twisted tape having 45mm, 60mm and 90mm pitch:

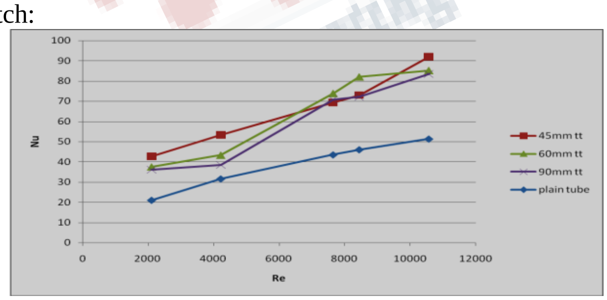


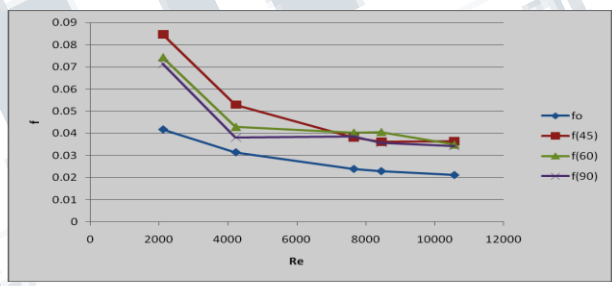
Fig 17: variation of Nu v/s Re for a twisted tape using sst-k-ω- model:

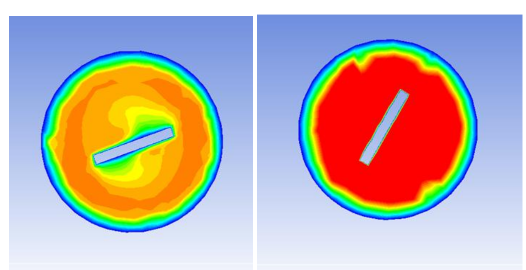
Fig 18: variation of f v/s Re for twisted tape using sst-k-ω

model:

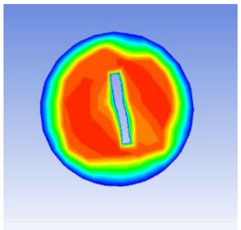
Fig 19: variation of ηth v/s Re using sst-k-ω model

5: CFD results for the twisted tape set having 5mm drill using sst-k-ω model:





45mmm pitch ***60mm pitch***



90mm pitch

Fig 20:velocity contours for 45mm, 60mm and 90mm pitch with 5mm drill using sst-k-ω model

Results for 45mm, 60mm and 90mm pitch twisted tape set having 5mm drill:

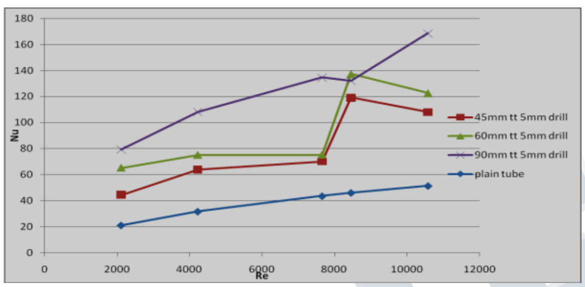


Fig21: variation of Nu v/s Re for the 5mm drill tape using sst-k-ω model

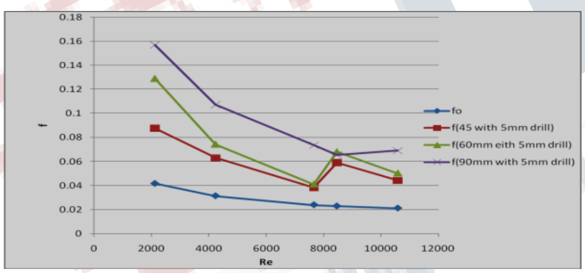


Fig 22: Variation of f v/s Re for 5mm dril twisted tape using sst-k-ω model

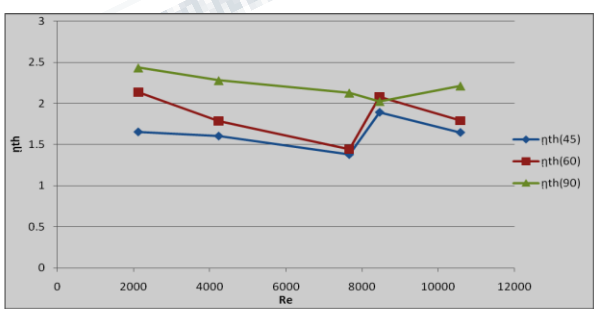
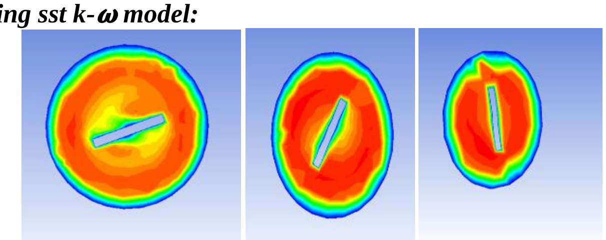


Fig 23: variaton of ηth for a 5mm drill twisted tape using sst-k-ω model

6: CFD results for a twisted tape set having 8mm drill using sst k-ω model:



45mm pitch *60mm pitch* *90mm pitch*

Fig 24: velocity contours for a twisted tape having 45mm, 60mm and 90mm pitch with 8mm drill

Results for 45mm, 60mm and 90mm pitch twisted tape with 8mm drill

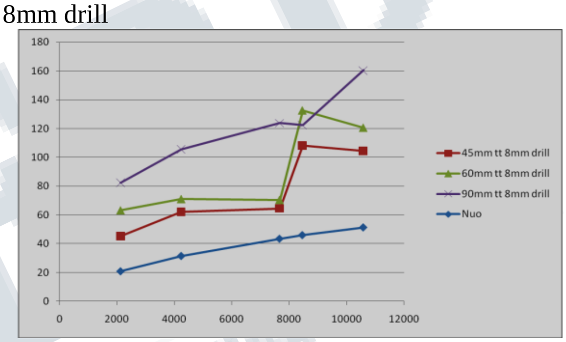


Fig 25: variation of Nu v/s Re for 8mm drill twisted tape using sst-k-ω model

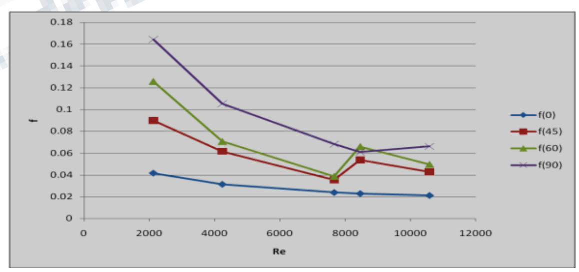


Fig 26: variation of f v/s Re for 8mm drill twisted tape using sst-k-ω model

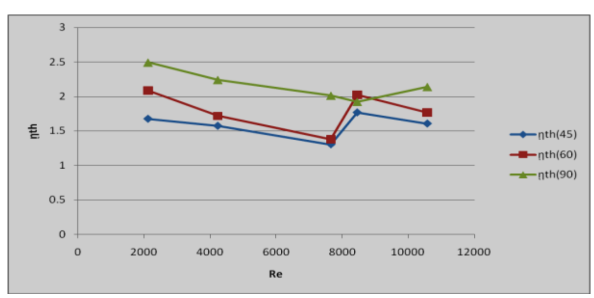


Fig 27: variation of ηth v/s Re for 8mm drill tape using

sst-k-ω model

VII RESULTS AND DISCUSSION:

CFD results revealed that the nusselt number rise is 42.36%, 39.28% and 34% for 45mm, 60mm and 90mm pitch twisted tape when compared with the plain tube results, simultaneously the friction factor rise is 2 times for 45mm pitch and 1.8 times for 60mm and 90mm pitch tape. and the maximum **ηth** is 1.6133 with 45mm pitch tape, nusselts number rise for 5mm drill tapes are 52.82%, 58.69% and 69% for 45mm, 60mm and 90mm pitch when compared with that of plain tube and friction factor rise is 2 times for 45mm pitch and 2.3 and 4 times for 60mm and 90mm pitch tape when compared with the plain tube and the maximum ηth is 2.43 with the 90mm pitch tape.,the nusselts number rise for 8mm drill tapes are 48.92%, 56% and 63% when compared with that of plain tube**,** and the friction factor rise is 1.5 times for 45mm pitch and 2 and 3 times for the 60mm and 90mm pitch tape when compared with the plain tube, and the maximum ηth is 2.49 obtained with 90mm pitch tape, within the Reynolds number range from 2113.57 to 10578.

VIII CONCLUSION

In the present paper both the CFD and Experimental investigation of heat transfer, friction factor and "ηth" of tube in tube type heat exchanger , The maximum heat transfer rate is obtained by using 60mm pitch with 8mm drill at expense of increase in friction factor by 2 times as compared with that of the plain tube within the Reynolds number set between 3223.6 to 22344.05, the maximum ηth is 2.85 for 90mm pitch with 8mm drill. By using CFD analysis the maximum heat transfer rate is obtained by using the 90mm pitch with 5mm drill at the expense of increased friction factor 2.3 times when compared with the plain tube. The maximum ηth is 2.49 obtained by using 90mm pitch with 8mm drill holes within the Reynolds number set between 2113.57 to 10578.

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[3] Eiamsa-ard K Wongcharee S Sripattanapipat Experimental investigation of heat transfer and friction factor in a circular tube fitted with regular twisted tape Department of Mechanical Engineering, Faculty of Enginnering Mahanakron University of technology Bangkok Thialand

[4] Xiaoyu Zhang, Zhinchin Liu, Wei Liu[4] Numerical studies on heat transfer enhancement without core rod inserts school of energy and power Engineering Huazhong University of science China

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