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# CFD ANALYSIS ON INTERNAL GROOVED TUBES IN SOLAR WATER HEATER

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## ABSTRACT

*This paper presents computational fluid dynamics studies on friction factor & heat transfer rate of a plain tube and tube equipped with two types of internal grooves (circular and trapezoidal) in solar water heater. Tests were performed for Reynolds number ranges from 6000 to 12000 for plain tube and different geometry inside grooved tubes. The Heat transfer rate were increased with increase of Reynolds number for the plain tubes, circular grooved tubes and trapezoidal grooved tubes. The maximum increase of heat transfer rate was obtained from numerical modeling is 22% for circular grooved tube and 28% for trapezoidal grooved tube when compared to the plain tube of solar water heater.*

***Keywords:*** *CFD, Solar water heater, Heat transfer*

## 1. INTRODUCTION

### 1.1 GENERAL

The usage of renewable sources of energy for the production & consumption of energy becomes more common in nowadays. Among the different types of renewable sources of energy solar energy plays a vital role, as it is abundantly available, clean and cheap. Hence in this paper the solar water heating system is considered as the application of solar energy and the plain tubes in solar water heater are replaced by grooved tubes to achieve better heat transfer and the parameters are analysed between plain tubes and grooved tubes using computational fluid dynamics.

### 1.2 ARRANGEMENTS & COMPONENTS OF SOLAR WATER HEATER

A solar water heater usually consists of a collector to collect solar energy which is made up of blackened glass fibre reinforced polyester (GFRP) as main materials and an insulated storage tank to store the generated hot water. The solar energy incident on the absorber panel transfers the heat to the riser tubes underneath the absorber panel. The water passing through the risers with the help of pump gets heated up and is delivered to the storage tank. The re-circulation of the same water through absorber panel in the collector raises the temperature to 75° C (Maximum) in a good sunny day. The total system with solar collector, storage tank and pipelines is called solar hot water system. In this project, the tubes located underneath the absorber panel are grooved internally with square, circular and trapezoidal cross section with equal pitches.

## 1.3 LITERATURE REVIEW

P.G.Vicente et al [1] has conducted an experimental study in order to obtain their heat transfer and isothermal friction characteristics. The use of water and ethylene glycol as test fluids has allowed covering a wide range of turbulent fluid flow conditions: Reynolds number from 2000 to 90000 and Prandtl number from 2.5 to 100. A comprehensive experimental study has been carried out on a family of corrugated tubes. Corrugated tubes present higher-pressure drop and heat transfer than the smooth tube under the same flow conditions. Increases from 20% to 300% in friction factor coefficient and up to 250% in Nusselt number were observed.

Alberto Garcia et al. [2]carried out experimental study on Helical-wire-coils fitted inside a round tube in order to characterize their thermohydraulic behaviour in laminar, transition and turbulent flow. Results have shown that in turbulent flow wire coils increase pressure drop up to nine times and heat transfer up to four times compared to the empty smooth tube. Within the transition region, if wire coils are fitted inside a smooth tube heat exchanger, heat transfer rate can be increased up to 200% keeping pumping power constant. Wire coil inserts offer their best performance within the transition region where they show a considerable advantage over other enhancement techniques

AlokChaube et al. [3]has conducted a computational analysis of heat transfer augmentation and flow characteristics due to artificial roughness in the form of ribs on a broad, heated wall of a rectangular duct for turbulent flow (Reynolds number range 3000–20,000, which is relevant in solar air heater) has been carried out. The results predict a significant enhancement of heat transfer in comparison to that for a smooth surface.

IrfanKaragozet al. [4]presented a computational fluid dynamics (CFD) calculation to investigate the flow field and the heat transfer characteristics in a tangential inlet cyclone which is mainly used for the separation of the dense phase of a two phase flow. It is determined that heat transfer increases at all surfaces with the inlet velocity and decreases towards to cone apex. The maximum value of the Nusselt number occurs on the region opposite to the inlet section and this region displaces down slightly for high inlet velocities. Results obtained from the computer modeling have demonstrated that CFD is suitable for simulating the flow and heat transfer characteristics in cyclone separators.

T.J. Craft et al. [5]presented computations of the flow and heat-transfer from a row of round jets impinging onto a concave semi-circular surface, designed to reproduce important flow features found in internal turbine blade cooling applications.

Ling Li et al. [6]has conducted a numerical study on the periodicity of convection heat transfer in channels with periodically grooved parts using an unsteady-state model. The results shows that the convection heat transfer will change from steady-state to unsteady-state as Reynolds number is increased. The Flow interruption at periodic intervals is the technique used in this experiment for heat transfer enhancement.

P.Promvonge. [7] has conducted an experiment in twisted tape with insertion coil and snail entry are fixed inside the round tube, to increase the heat transfer of the air entering in to the round tube. If the combined wire coil and twisted tape tubulators are compared with a smooth tube at a constant pumping power, a double increase in heat transfer performance is obtained especially at low Reynolds number.

P.Promvonge. [8] has conducted an experiment in twisted tape with insertion coil are fixed inside the round tube, to increase the heat transfer of the air entering in to the round tube. If the combined wire coil and twisted tape tubulators are compared with a smooth tube at a constant pumping power, a double increase in heat transfer performance is obtained especially at low Reynolds number.

Xiaoyan Zhang et al [9] has conducted an experimental study on evaporation heat transfer of R417A (R125/R134a/R600) flowing inside horizontal smooth and two internally grooved tubes with different geometrical parameters. The result shows that the evaporation heat transfer coefficients rather strongly for R417A inside internally grooved tubes.

Rahimi et al [10]presented experimental and Computational Fluid Dynamics (CFD) investigations on the friction factor, Nusselt number and thermal–hydraulic performance of a tube equipped with the classic twisted tape and three modified twisted tape inserts (Perforated, Notched & Jagged twisted tape). The result shows that the Nusselt number and performance of the jagged insert were higher than other ones. Maximum increase of 31% and 22% were observed in the calculated Nusselt number and performance of the jagged insert as compared with those obtained for the classic one.

## 2. PROJECT METHODOLOGY

### 2.1 DESCRIPTION OF PROBLEM

The main objective of the present work is to find out the increase of heat transfer rate in the working fluid (water) for a circular tube with internal grooving and comparing it with plain circular tube. Thus the Friction factor & Heat transfer rate has been found out for the Reynolds number ranging from 6000-12000 in the turbulent flow condition. The values of Heat transfer rate & Friction factor were compared between plain circular tube & circular tubes with Circular grooves and Trapezoidal grooves.

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## 2.2 TWO DIMENSIONAL DIAGRAM

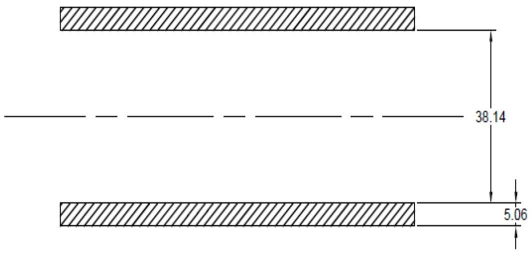


Fig. 2.2.1: Plain Tube

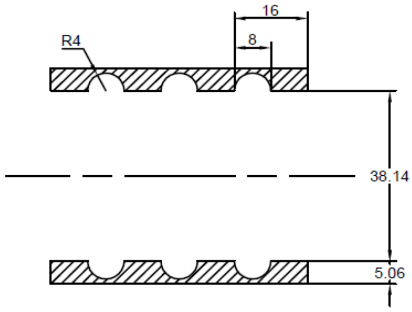


Fig. 2.2.2: Circular Grooved Tube

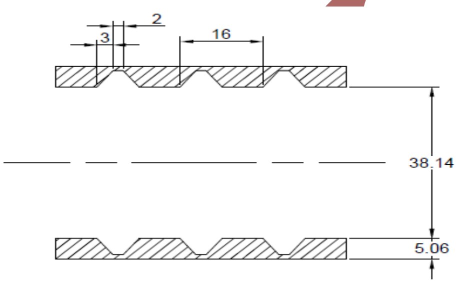


Fig. 2.2.3: Trapezoidal Grooved Tube

## 2.3 THEORETICAL CALCULATION PROCEDURE:

By fixing the Reynolds number ranges from 6000 to 12000, the calculations have been carried out as follows,

And the initial boundary condition of a problem for theoretical calculation is:

Inlet temperature (Ti) = 35$^o$C

Outlet temperature (To) = 75$^o$C

Wall temperature (Tw) = 125$^o$C

Mean temperature(Tm) is calculated based on the below said formula,

$T_m = (T_i + T_o)/2$ $^o$C (2.1)

Nusselt number (Nu) is calculated based onDittus-Boelter equation,

$Nu = 0.023\ (Re)^{0.8}\ (Pr)^{0.4}$ (2.2)

Heat transfer coefficient (h) is calculated based on the below said formula,

$h = Nu*K / D_i$ W/m$^2$K (2.3)

Friction factor (f) is calculated based on Blasius equation as follows,

$f = 0.316*Re^{-0.25}$ (2.4)

Pressure drop (ΔP) is calculated based on the below said formula,

$\Delta P = f * [\rho*(L/D_i)*(U^2/2)]$ N/m2 (2.5)

Mean velocity (U) is calculated based on the below said formula,

$Re = (U*D_i) / \nu$ m/s (2.6)

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Heat transfer rate (Q)is calculated based on the below said formula,

$Q = h*A*(T_w-T_m)$ W (2.7)

Properties values of water at 55 $^oC$ (from HMT data book, [42])

- Density (ρ) = 987.5 $Kg/m^3$
- Viscosity (ν) = 0.522×10-6 $m^2/s$
- Prandtl no (Pr) = 3.35
- Specific heat ($C_p$) = 4181.75 J/kg K
- Thermal Conductivity (K) = 0.6455 W/mK

## 2.4 IMPORTANT STEPS INVOLVED IN ANSYS FLUENT

### 2.4.1Geometry

First, the fluid flow (fluent) module from the workbench is selected. The design modeler opens as a new window as the geometry is double clicked. After designed a tube in solid work, design is exported to fluent.

### 2.4.2 Meshing

Initially a relatively coarser mesh is generated. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries

**FOR PLAIN TUBE:**

- Relevance centre: fine meshing
- Smoothing: high
- Size: 1.0m
- Method of mesh: Hexa mesh
- Type of meshing : Edge meshing
- Nodes: 49620
- Elements: 47120

**FOR CIRCULAR GROOVED TUBE:**

- Relevance centre: fine meshing
- Smoothing: high
- Size: 0.8m
- Method of mesh : hexa mesh
- Type of meshing : face meshing
- Nodes: 55857
- Elements: 105176

**FOR TRAPEZOIDAL GROOVED TUBE:**

- Relevance centre: fine meshing
- Smoothing: high
- Size:0.8m
- Method of mesh : hexa/Tetra mesh

- Type of meshing : face meshing
- Nodes: 154823
- Elements: 148023

### 2.4.3 Problem setup

The analysis type is changed to Pressure Based type. The velocity formulation is changed to absolute and time to steady state. Axis symmetry option is selected for 2D tube.

### 2.4.4 Boundary Conditions

Boundary conditions are used according to the need of the model. The inlet and outlet conditions are defined as velocity inlet and pressure outlet. As this is a single phase flow with one tube so there are one inlet and one outlet. The wall is specified with respective boundary conditions at edge, since the model is Axis-symmetry.

| Zone | Boundary Condition |
|---|---|
| Tube | Wall temperature = 39 |
| Inlet temperature | Temperature = 308 k |
| Pressure(atm) | 101395.8 pa |

### 2.4.5 Reference Values

The inner inlet is selected from drop down list of "compute from". The values are:

- Area = 1 $m^2$
- Density = 987.5 $kg/m^3$
- Length = 1m
- Temperature = 308 K
- Viscosity = 0.0005161 kg/m-s
- Ratio of specific heats = 1.4

### 2.4.6 Solution Methods

The solution methods are specified as follows:
Scheme = Simple
Gradient = Green Gauss Cell Based
Pressure = Standard
Momentum = Second Order Upwind
Turbulent Kinetic Energy = Second Order Upwind
Turbulent Dissipation Rate = Second Order Upwind

## 2.5 CFD RESULTS AND ANALYSIS

Each case was made running using higher order residual schemes for each governing equations. It was ensured that residuals dropped to at least $10^{-6}$ for each case. Friction factor for plain tube are validated with theoretical relations and then they are determined for plain, circular grooved & trapezoidal grooved tube. Friction factor calculated for the plain tube and plain tube with square grooved, circular grooved & trapezoidal grooved for Reynolds no. of 6000, 8000, 10000 & 12000. The Friction factor & Heat transfer rate for the tube with grooving are compared with corresponding values of Plain tube. Each case is solved for 3 equations Energy, Momentum and Turbulence and results are plotted on corresponding graphs as shown below.

## 2.6 VALIDATION FOR PLAIN TUBE

The results obtained by computational fluid dynamics have been compared with theoretical values for Nusselt number for plain tube. The average deviation of the theoretical values with CFD values of Nusselt number is 3%.

It has been observed that the results obtained by Renormalization-group (RNG) *k-e* model are in good agreement with theoretical results. It is therefore, for the present numerical study (RNG) *k-e* model has been employed to simulate the flow and heat transfer. The friction factor results obtained by computational fluid dynamics have been compared with theoretical values for plain tube. The average deviation of the theoretical values with CFD values of friction factor is 4%. The heat transfer co-efficient obtained by CFD have been compared with Theoretical values for plain tube. The average deviation of the Theoretical values with CFD values of heat transfer co-efficient is 2%.



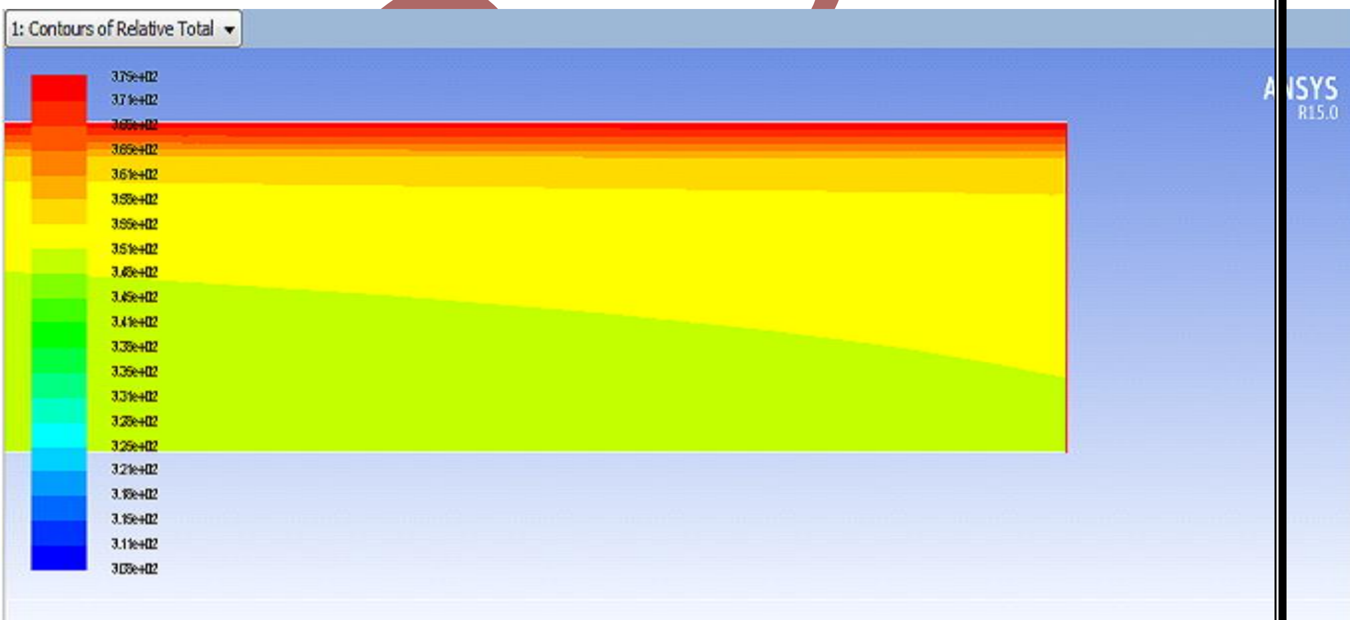


**Fig. 2.6.1: Temperature variations for the plain tube (Re = 6000)**

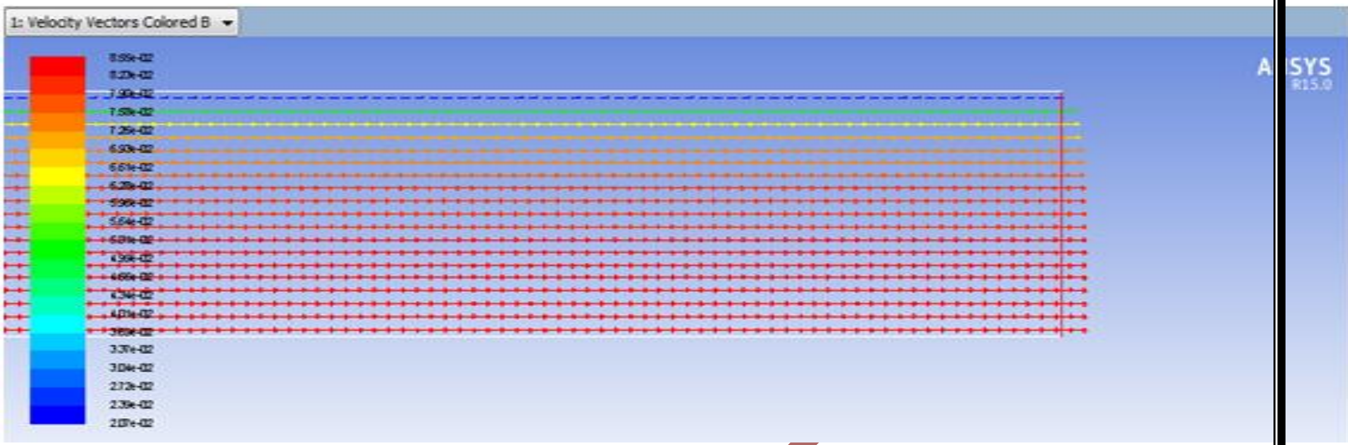


**Fig. 2.6.2: Velocity vector for the plain tube (Re= 6000)**

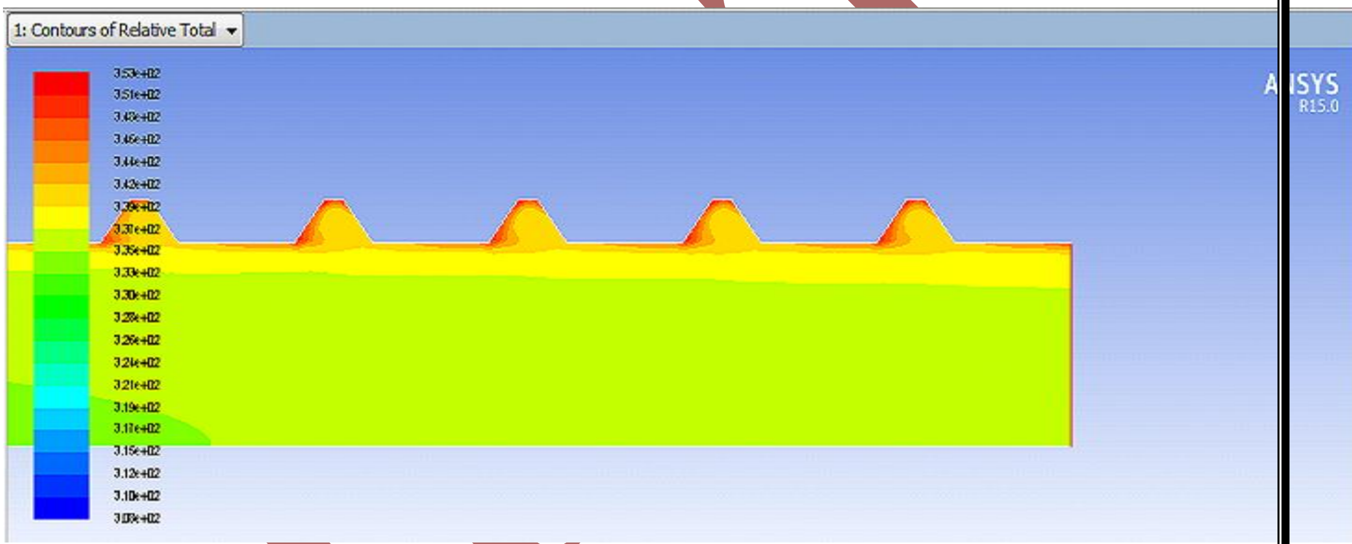


**Fig. 2.6.3: Temperature variation for Trapezoidal grooved tube (Re=6000)**

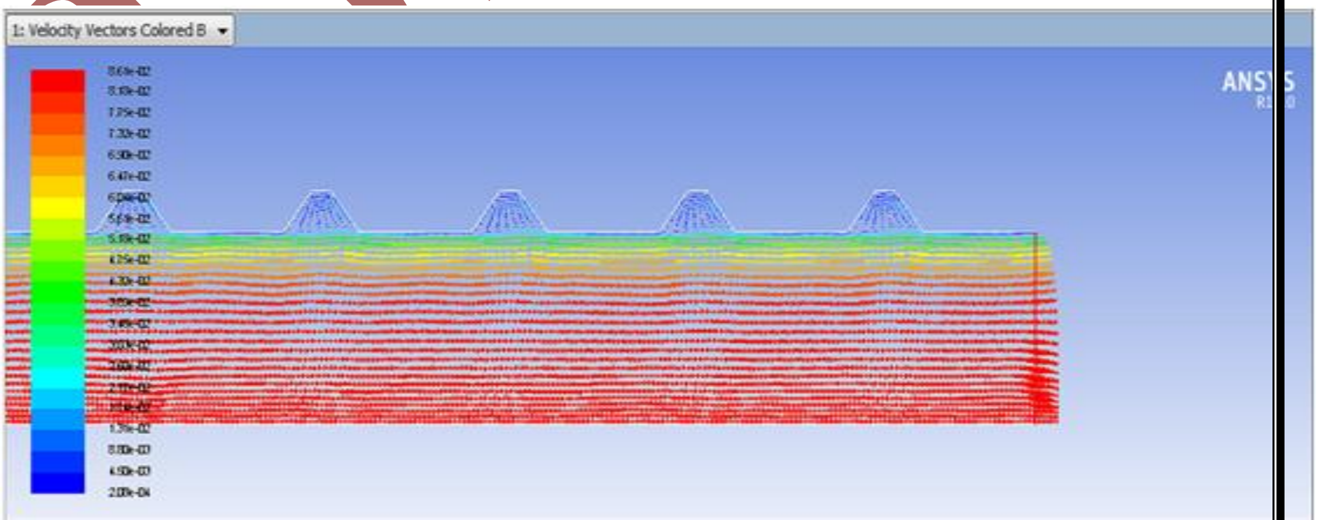


**Fig. 2.6.4: Velocity vector for Trapezoidal grooved tube (Re = 6000)**

## 2.7 COMPARISON OF THEORETICAL AND CFD RESULTS

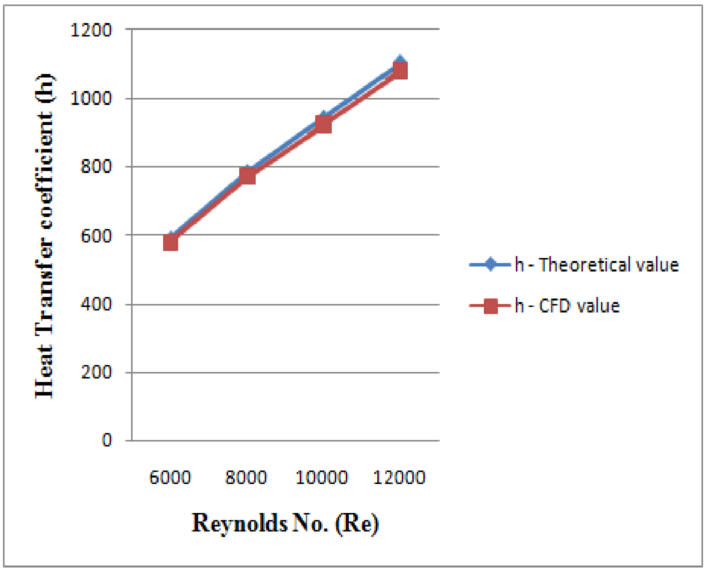


**Fig. 2.7.1: Reynolds Number Vs Heat Transfer Coefficient**

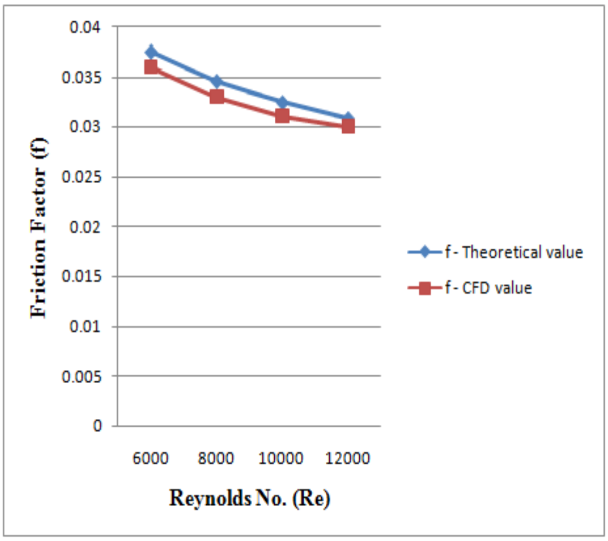


**Fig. 2.7.2: Reynolds Number Vs Friction Factor**

## 2.8 COMPARISON OF RESULTS OF PLAIN TUBE, CIRCULAR GROOVED & TRAPEZOIDAL GROOVED TUBE

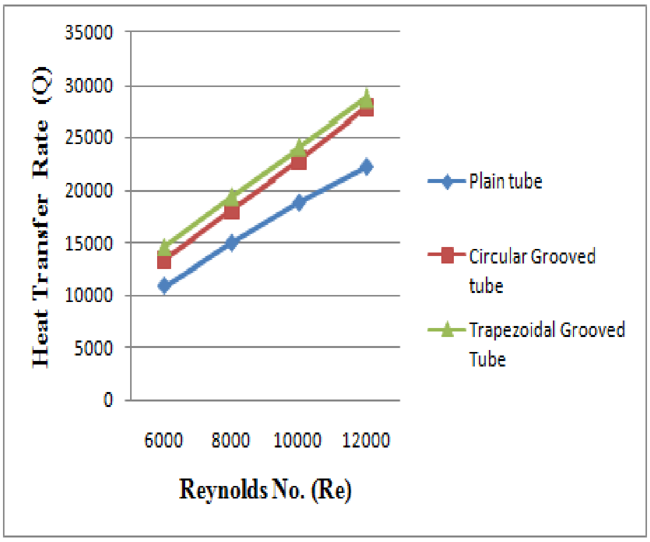


**Fig. 2.8.1: Reynolds Number Vs Heat Transfer Rate**

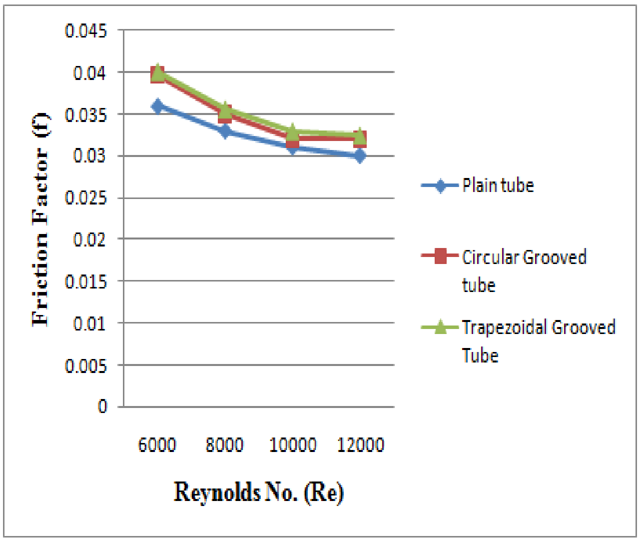


**Fig. 2.8.2: Reynolds Number Vs Friction Factor**

## CONCLUSION

The different geometry grooved tube like circular, trapezoidal and plain tube were used for this analysis. The CFD had been used as a powerful tool to assess the heat transfer characteristics for turbulent flow inside the tubes of solar water heater. The Heat transfer coefficient, Heat transfer rate was increased with corresponding increase in Reynolds number. However the friction factor was decreased with increasing Reynolds number for all the grooved tubes and plain tubes of solar water heater. It has been observed that RNG *k-e* model results have been found to have good agreement with plain tube results. Based on CFD analysis higher heat transfer coefficient, heat transfer rate were obtained for the trapezoidal grooved tube compared with plain tube, circular grooved tube for the Reynolds number ranging from 6000 to 12000. The maximum increase of heat transfer rate was obtained from numerical modelling is, 22% for circular grooved tube and 28% for trapezoidal grooved tube when compared to the plain tube of solar water heater. Hence it is found in this paper, that the heat transfer rate can be increased using internal grooved tubes.

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