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Improvement Of Thermal Performance Of Circular Solar Radiation Collector Tube

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ABSTRACT:

Non-conventional energy sources are abundant and free of cost. However, their diffused nature, or extremely low energy density, presents significant technological challenges to their practical use. The setup needed for non-traditional energy resources becomes large and costly, making them economically unfeasible to obtain the same quantity of energy as conventional resources.

The equipment that is utilized to capture the free solar energy is called a solar collector. In order to transport solar energy to the internal fluid, solar collectors undergo a variety of design alterations. The most studied approach involves using twisted tapes, but these tapes raise frictional losses, which raises the need for pumping. In this case, we created a collector that raises collector efficiency without appreciably increasing pumping loss.

Here we designed a collector tube that increases the heat transfer in evacuated tube solar collector. Because of reduced convection heat loss due to vacuum envelope around the absorber tube, evacuated tube collectors are better in performance. A phenomena known as natural circulation caused the water to flow against gravity which implies, as the tube is heated by the top half of the tube wall, the water near the top half of the tube wall flow toward the tank driven by the body force due to the density decrease. At the same time, the water near the bottom half of the tube wall flow downward driven by gravity due to its larger density. For this reason, the velocity of the water near the tube wall is higher than other regions. Furthermore, the velocity of the water near the top half of the tube wall is higher than the water near the bottom half of the tube wall due to its higher temperature. In this study the effect of increasing taper angle of the circular solar collector tube is analyzed. The different taper angles 0º, 0.5º, 0.75º is used in solar collector tube induces increased amount of Eddies which is responsible for increase heat transfer coefficient. By combined effect of increasing taper angle and natural circulation, results in increased value of nusselt number. So heat transfer which is the multiplication of convective heat transfer coefficient, surface area of heat transfer and temperature difference between average tube wall temperature and mean temperature of fluid, is increases with convective heat transfer coefficient.

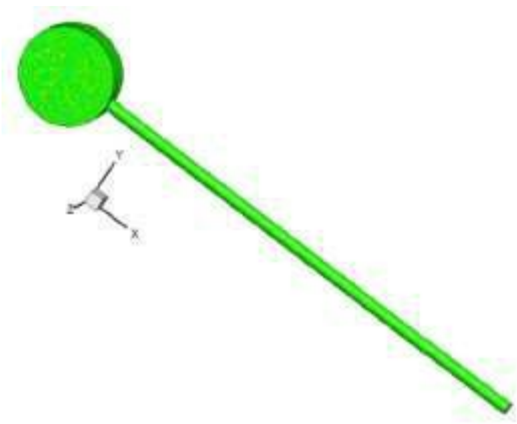
Keywords: Enhancement, Heat Transfer, Taper angle, Computational Fluid Dynamics, Evacuated Solar Collector tube, Nusselt number

Introduction:

An evacuated tube collector, also known as a vacuum tube solar water heater, works by using a heat pipe to transfer heat from the sun to a heat transfer fluid. Evacuated tubes are comprised of an array of single or twin wall glass tubes with a vacuum that provides excellent insulation against heat loss. Radiation from the sun can pass through the vacuum but there is no air to convect or conduct heat out so heat loss is minimized. Heat transfer performance of solar water heater is investigated with elliptical tube by Kaichun Li et al. (3) , Water in glass evacuated tube solar water heater as discussed by Morrison et. Al. (4), Natural circulation flow through water-in-glass evacuated tube solar collectors (3) but the main problem of fluid flow inside the tube is fiction factor as discussed by Maradiya C et al. and others (4, 5). Performance evaluation of all-glass evacuated tube solar water heater with twist tape inserts studied by Yao K et al. (6). Solar water heater with elliptical collector tube also discussed by Lia K et al. (7). 3-D numerical simulation of heat transfer and turbulent flow in a receiver tube of solar parabolic trough concentrator with louvered twisted-tape inserts was discussed by Ghadirijafarbeiglooa S H et al. and other (8,9). Researchers also disscudded solar flat collector (10) , effect of nano fluids (11), thermosyphon solar water heater system (12), Solar water heaters with phase change material in (13).

Methodology:

The tubes of the solar collector tube in this thesis are circular inner and outer tube. In this thesis NUSSELT NUMBER, TEMPERATURE and VELOCITY magnitudes are validated by using ANSYS FLUENTwith Kaichun Li et al. (1), and the same parameters are carried forward to analyze the heat transfer behavior on tubes which are designed with taper angle of 0˚, 0.5˚ and 0.75˚.



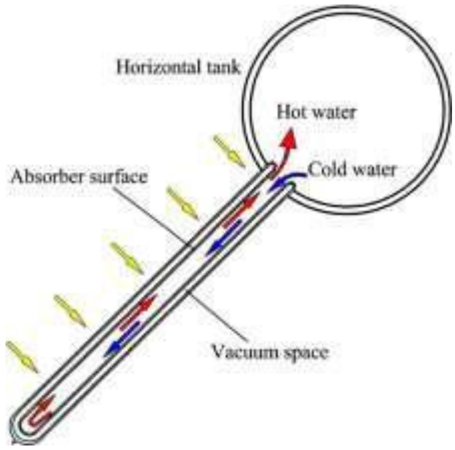


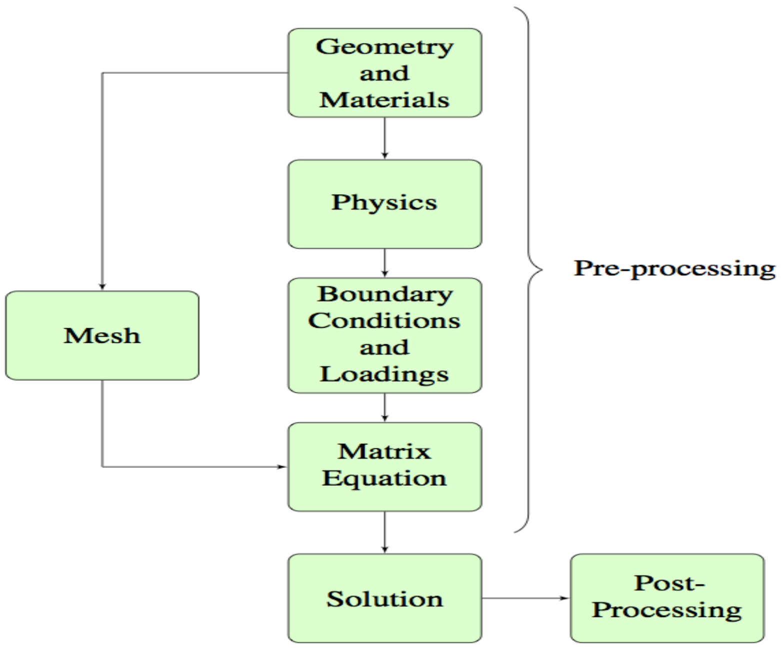
Fig 1. Computational domain by Kaichun Li et al. **Fig.2 Natural circulation in water -in-glass collector.(Copper pipe considered by Morrison et. Al,2**

As per Kaichun Li et. Al.; Mass flow rate ṁ is 0.02kg/s. The general structure of the inner tube cross section of the collector tube is 0.047m in diameter. The length of the collector *L* was 1.8m, and the tilt angle of the solar collector was 45°.

Table 1 - Specification of CAD model taken for validation in present workBy using mixed (Hybrid) meshing as tetra on tank and hexa in tube

Taper angle in CAD model	0˚
Nodes	149550
Elements after mesh	232689

Steps in Solving our CFD Problem



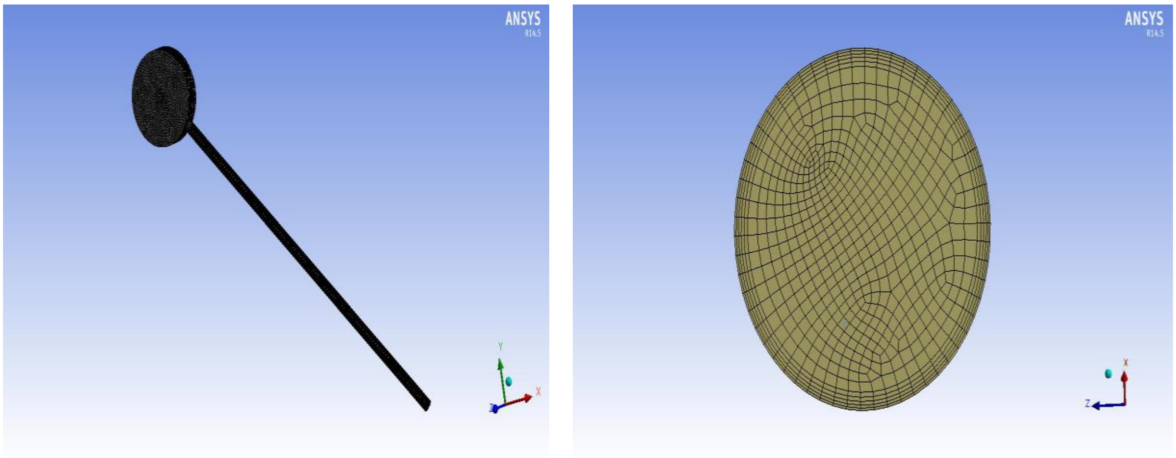


Fig. 3Meshing in Circular tube without taper cad model

Boundary conditions and solution scheme:

Operating Condition: Pressure = 101325 Pa

Periodic: (Tank inlet and outlet)

Mass flow rate - 0.02 kg/s

Temp : 283 k , 293 k , 303 k (tabular) paper ref

Heat Flux: at top half wall of the tube wall

Heat flux = 750 w/m2

Other all wall are insulated.

“Periodical condition” is imposed at the computational domain of inlet and outlet which is indicationofvelocity,pressure and temperature gradient **repeat themselves** in the domain as follows:

$$u_i\left(\vec{r}\right) = u_i\left(\vec{r}+\vec{L}\right) = u_i\left(\vec{r}+2\vec{r}\right) = \ldots$$

$$\Delta p = p\left(\vec{r}\right) - p\left(\vec{r}+\vec{L}\right) = p\left(\vec{r}+\vec{L}\right) - p\left(\vec{r}+2\vec{L}\right) = \ldots$$

$$\sigma = \frac{T\left(\vec{r}+\vec{L}\right) - T\left(\vec{r}\right)}{L} = \frac{T\left(\vec{r}+2\vec{L}\right) - T\left(\vec{r}+\vec{L}\right)}{L} = \ldots$$

where $\vec{r}$, $\vec{L}$, Δp and σ are respectively position vector

length vector of a period, pressure drop of a period andtemperature of a period.

The mass flow rate through the inlet and outlet is 0.02kg/s.

On all the walls no slip condition is applied which means the velocity magnitude near the wall is zero:u_i=0

On the top half of the tube wall uniform heat flux condition is imposed:q=$q_{w,}$
where q_w=750*W/ m*^{2}. All the other walls are assumed to be thermally insulated.The numerical model used in this work is a single tube connected to tank. In addition, the heat transformed from the radiation replaced by the uniform heat input.
In the present study, the governing equations are solved by finite volume approach. The second order upwind scheme is used to discrete momentum and energy equation.

Equations used for calculation:

Total heat transfer rate is obtained by, $Q = mC_p(T_{out} - T_{in})$

T_{in} and T_{out} are calculated by,

$$T = \frac{\sum_{i=1}^{n} T_i \rho_i \left| \vec{u_i} \cdot \vec{A_i} \right|}{\sum_{i=1}^{n} \rho_i \left| \vec{u_i} \cdot \vec{A_i} \right|}$$

Where u_i, A_i, T_i and ρ_i are respectively velocity vector, area vector, temperature and densityof area element i which is at inlet or outlet of the tank.

The heat transfer coefficient is given by$\square = Q/[A(T_w - T_b]$

$$T_b = (T_{in} + T_{out})/2$$

The *Nu* is given by, $Nu = hd/k$

Table2 - Parameters used to calculate Nusselt number

Tube cross section	mass flow inlet (kg/s)	Conductivity, k of water (w/mk)	C_p of water (W/mk)	Nusselt number (Nu)
Circular 0˚ taper	0.02	0.547	4191	16.45677
	0.02	0.599	4183	18.59306
	0.02	0.618	4174	22.3747

Objective:

1. To study the existing design of collector tube and to modify the design to increase heat transfer along with the visualization of flow under natural circulation by testing the model under CFD simulation software.
2. To obtain the output temperature of modified collector tube for different taper angles then analyze the result and suggest the future scope of the work.

Results and discussion :

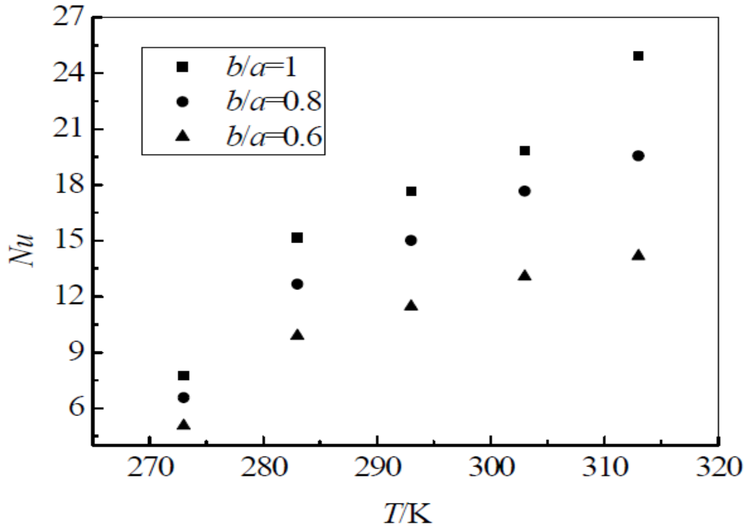
Validation of Nusselt number

b/a=1 is taken for validation with present analysis for circular tube -0 degree taper.

Deviation between the results is minimum and very limited Thus the present numerical simulations have reasonable accuracy

To validate the accuracy of the numerical solutions, the predicted results in this paper are compared with the numerical results of Kaichun Li et. Al.

Results showing that variation in results of these two methods is minimum and present analysis is well acceptable because variation is within 3%.

<table>
<tr><td>As per Kaichun Li et al.</td><td>
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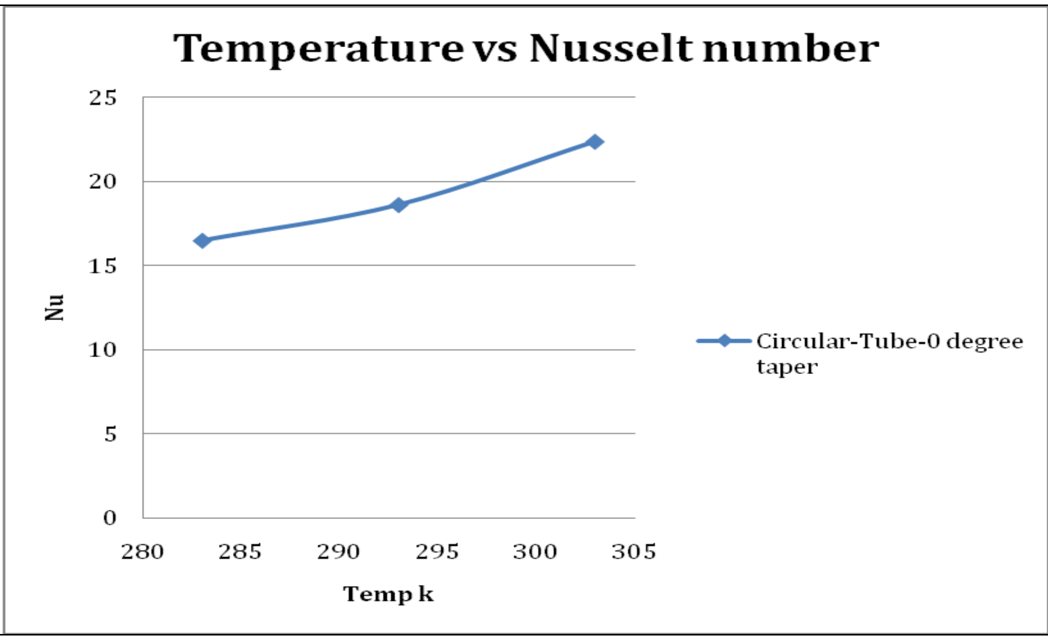
<tr><td>Present analysis</td><td>
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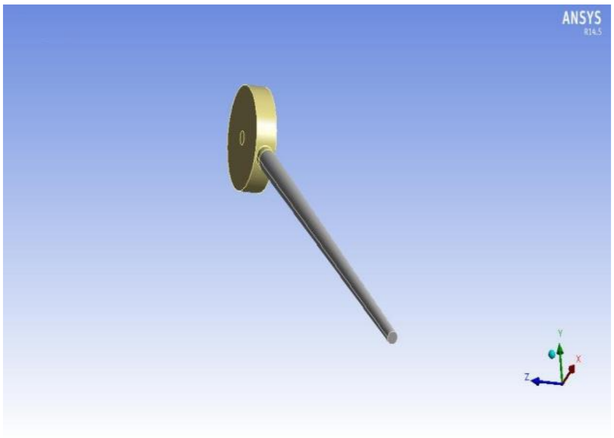
Table 3.5 - Results of Nusselt number by Kaichun Li and present analysis



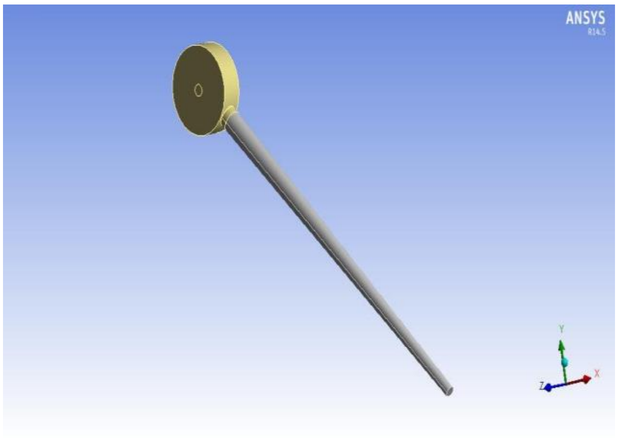


Fig.4.Circular tube with 0.5˚ taper cad model **Fig.5 Circular tube with 0.75˚ taper cad model**

Table 3 - Temperatures involved in calculation with 0˚, 0.5˚ and 0.75˚ taper angles inlet temperature 283, 293 and 303 K

Tube cross section	Water inlet temperature T_{in} (K)	Water outlet temperature T_{out} (K)	Temperature difference	Average temperature of tube, T_w (K)
Circular 0˚ taper	283	284.1495	1.1495	285.4681
	293	294.0932	1.0932	294.9992
	303	304.1762	1.1762	304.8442
Circular 0.5˚ taper	283	284.5322	1.5322	285.2841
	293	294.4822	1.4822	294.9078
	303	304.5065	1.5065	304.7497
Circular 0.75˚ taper	283	284.681	1.681	285.4045
	293	294.6914	1.6914	295.0302
	303	304.7041	1.7041	304.9413

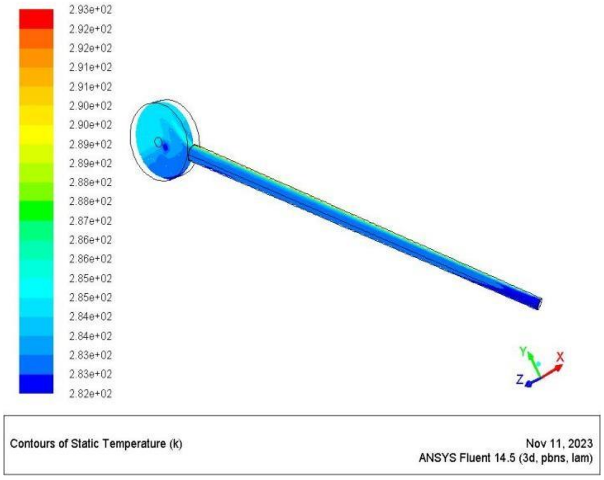


Fig.(6) Temp variation at different location of the tube at 283 K in

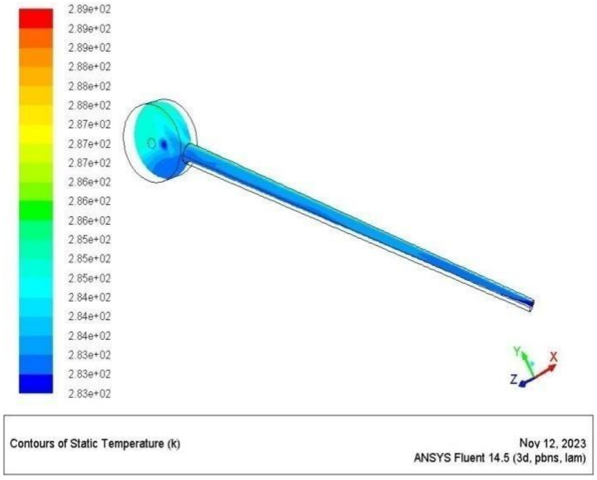
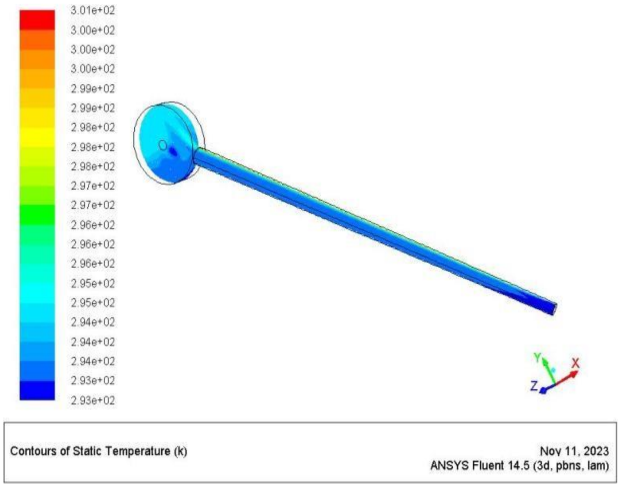


Fig.((7) Temp. variation at different location of the tube at 283 K in circular tube with 0.75 taper



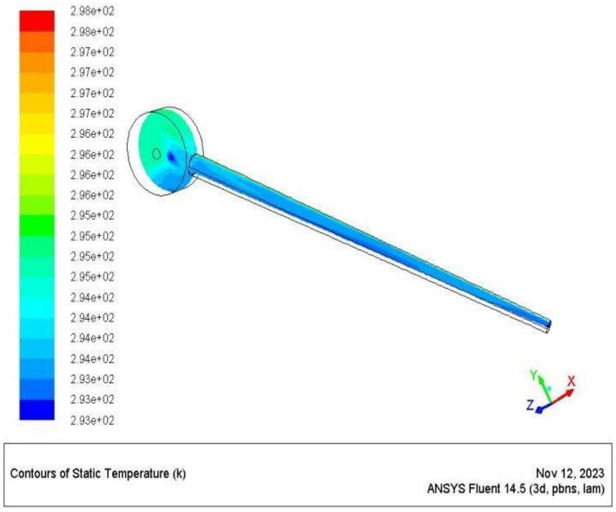


Fig.((8) Temp.variation at different location of the tube at 293 K in circular tube with 0.5˚ taper circular tube with 0.5˚ taper

Fig.(9) Temp.variation at different location of the tube at 283 K in circular tube with 0.75 taper

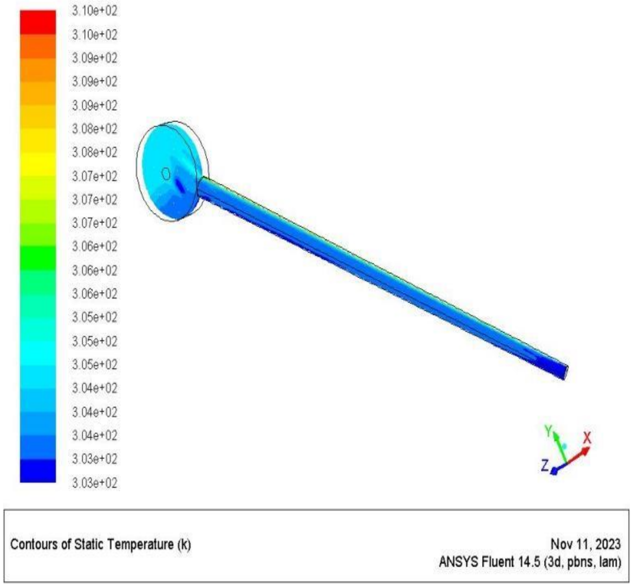


Fig.(10) Temp.variation at different location of the tube at 303 K in circular tube with 0.5˚ taper

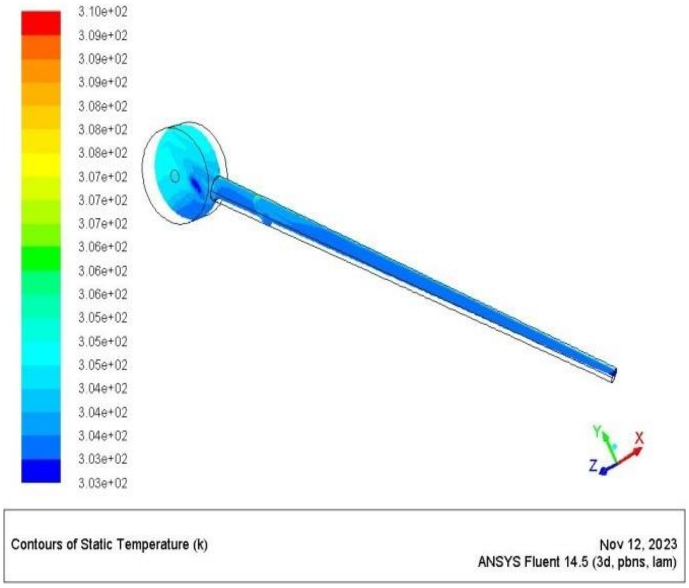


Fig.(10) Temp. variation at different location of the tube at 303 K in circular tube with 0.75˚ taper

Tube cross section	mass flow inlet (kg/s)	Conductivity, k of water (w/mk)	C_p of water (W/mk)	Nusselt number (Nu)	Heat transfer, Q (W)
Circular 0˚ taper	0.02	0.547	4191	16.45677	96.35109
	0.02	0.599	4183	18.59306	91.45711
	0.02	0.618	4174	22.3747	98.18918
Circular 0.5˚ taper	0.02	0.547	4191	25.53225	128.429
	0.02	0.599	4183	32.07474	124.0009
	0.02	0.618	4174	38.08849	125.7626
Circular 0.75˚ taper	0.02	0.547	4191	27.18794	140.9014
	0.02	0.599	4183	36.05179	141.5025
	0.02	0.618	4174	39.41374	142.2583

Table 4 - Increasing Nusselt number with 0˚, 0.5˚, 0.75˚ taper angles at 283,293 and 303K inlet temperature

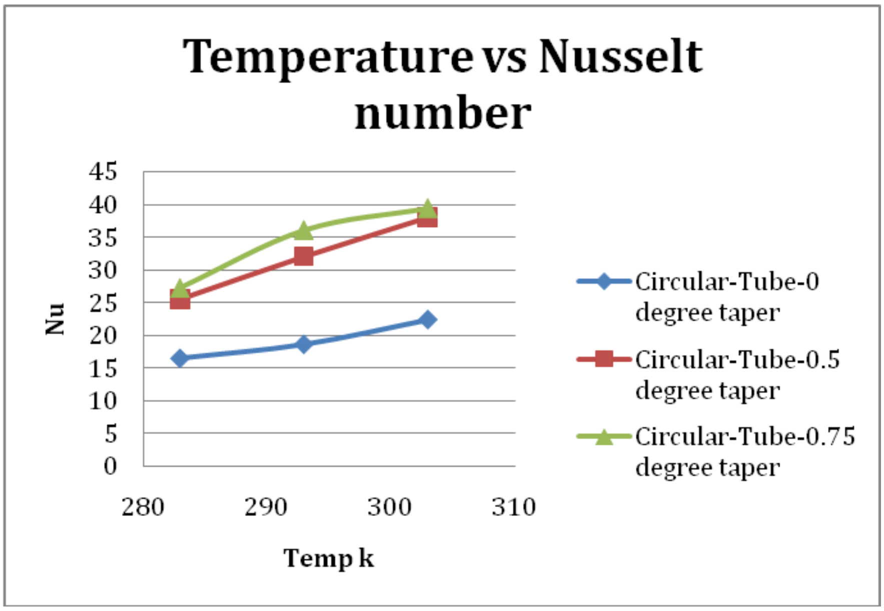
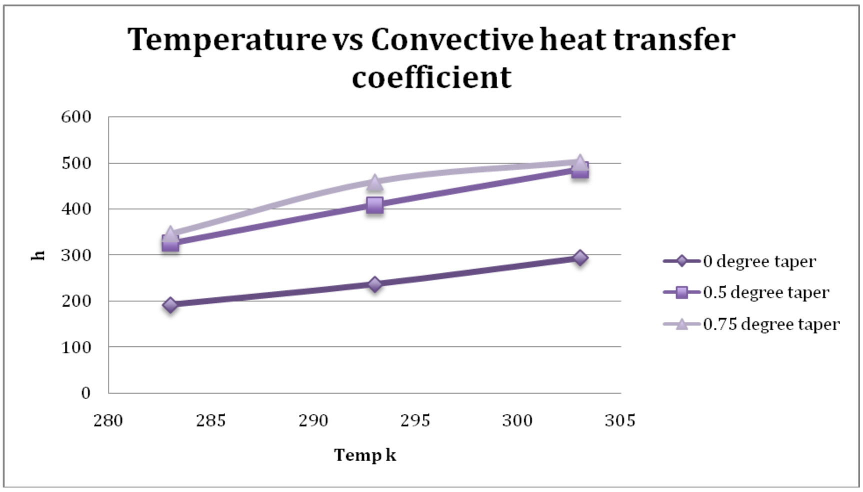


Figure 11. Graph showing increasing Nusselt number with taper angle

It is clearly visible by increasing taper angle, nusselt number increases. Nusselt number is the dimensionless number which depends on convective heat transfer coefficient. By definition, nusselt number is the ratio of conduction resistance offered by fluid to surface convective resistance. Increased value of nusselt number clearly shows that convective resistance is decreasing which also means that convective heat transfer coefficient is increasing. These taper angles we used in collector induces increased amount of Eddies which is responsible for increase heat transfer. By combined effect of increasing taper angle and natural circulation, results in increased value of nusselt number. So heat transfer which is the multiplication of convective heat transfer coefficient, surface area of heat transfer and temperature difference between average tube wall temperature and mean temperature of fluid, is increases with convective heat transfer coefficient.

Conclusion :

In the present study, a numerical model of the collector tubes was developed for the solar water heater, in which for constant mass flow rate and initial temperatures with gradual expanding cross section is introduced to account for heat transfer performance of solar water heaters. The contours of the velocity and temperature fields were obtained for the solar water heater with gradual expanding cross section. It is clearly seen that there is a significant temperature rise in a gradual expanding cross section area collector tube than the uniform cross sectional area collector tube. Thus this method can be used for increasing the heat transfer coefficient of the collector tube. All the other method employed for increasing the heat transfer coefficient of the collector tube like twisted tape method increases the frictional losses of the fluid as there is a significant increase in the contact area. The major advantage of using this method lays in no increase in the frictional losses as there any significant contact area increase between the fluid and the tube.



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