Numerical Investigation of Flow and the Heat Transfer Performance of a Circular Collector Tube Ensuring Minimization of Frictional Loss

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***Abstract*—The solar collector is the technology used to harness the freely available solar energy. In order to transfer solar energy to the fluid inside, various design modifications are done upon. Most researched upon method is that of twisted tapes, but these tapes increases frictional losses and hence increasing the pumping requirement. Here we want to design a collector that increases the collector efficiency without any significant rise in pumping loss**

Keywords— Heat transfer enhancement, Thermal Performance Factor, Computation Fluid Dynamics, Solar Heater Collector

I. INTRODUCTION

Solar collectors absorb heat from the sun and transfer that heat to water. A thermal storage tank stores water for use as needed. A conventional heating system provides backup if storage drops below the desired temperatures. A typical solar system will reduce the need for conventional fuel for water heating by about two-thirds or three quarters. It is not cost effective to meet 100 percent of the water heating load on every day of the year; rather the optimal is to meet the load on an average sunny day, and use conventional fuel to top off the need for heat. But there have been many installations where solar are the only source of heat in developing countries or applications where reliable heat is not a requirement. The primary and secondary circuits sometimes use the same water – simply moving it from the solar collector via pipes and tanks to the taps. This arrangement is called a 'direct' system. However, in most systems the primary and secondary circuits use different liquids (water or water solutions – this is discussed in detail later) and transfer the heat from one liquid to the other via a heat exchanger. Heat exchangers are normally constructed of a series of metal pipes or plates. This arrangement is called an 'indirect' system. There can be more than one heat exchanger. The water is circulated over and over again in a loop, but the heat moves in one direction only. Heat exchangers can be inside the storage tank, inside the collector or separate. The direction of higher temperature liquid leaving a solar collector is called the 'flow' whereas the direction of lower temperature liquid returning to a heat generator is termed the 'return'. These terms are often confused but the trick is to consider where the source of heat is as this is where the heat starts to 'flow'. In the same way, the hottest pipe leaving a gas or oil boiler is called the 'flow'.

II. NUMERICAL METHOD

The tubes of the solar collector tube used in this research were circular inner and outer tube. The general structure of the inner tube cross section of the collector tube was shown in Fig.5.1

A model of a frustum shaped collector tube gradually increasing diameter with the parameter shown in the table 1 was generated on Ansys.

Table 1 PARAMETERS

Length of the pipe	1800 mm
Tube inlet diameter	47mm
Tube outlet Diameter	variable as per cone angle of 0,1, 2,3

FLUID- WATER (H20)	
DENSITY(kg/m^3)	998.2
Cp(Specific Heat)(j/kg-k)	4182
Thermal Conductivity (w/m-k)	0.6
Viscosity (kg/m-s)	0.001003
SOLID-ALUMINUM(al)	
Density (kg/m^3)	2719
Cp(Specific Heat) (j/kg-k)	871
Thermal Conductivity (w/m-k)	202.4
Isotropic Secant Coefficient of thermal expansion	
Coefficient of Thermal Expansion	2.3E-05 C^-1
Reference Temperature	22
Young's Modulus	7.1E+10 Pa
Poisson's Ratio	0.33
Bulk Modulus	6.9608E+10 Pa
Shear Modulus	2.6692E+10 Pa

A. Data reduction

The data is reduced in the following procedure. Firstly, the total heat transfer rate can be obtained by

$$Q = mC_p(T_{out} - T_{in})$$

T_{in} and T_{out} are calculated using

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

where T_i,ρ_i,u_i, A_i are respectively temperature, density, velocity vector and area vector of area element i which on the inlet or outlet of the tank.

The heat transfer coefficient is determined by

$$h = Q/[A(T_w - T_b]$$

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

B. Numerical model

Some assumptions are used to simplify the problem:

(1) The radiation intensity is almost uniform on the top half of the tube, and the bottom half is thermally insulated,

(2) The tank has good heat-retaining performance; the heat loss through the insulation layer is zero,

(3) The tank is positioned horizontally and all the walls are hydraulically,

(4) There is no heat exchange between the evacuated collector tube and outside surrounding due to its good vacuum quality,

(5) The tank is full of water and no air,

(6) The flow in the whole computational domain is laminar.

C. Mesh design

Grid generation is a key issue in numerical simulation as it governs the stability, economy and accuracy of the predictions. The meshed geometry of the tube cross sections are shown in Fig. .The grid system has 8560 nodes and 19725 elements are adopted for the following calculations.

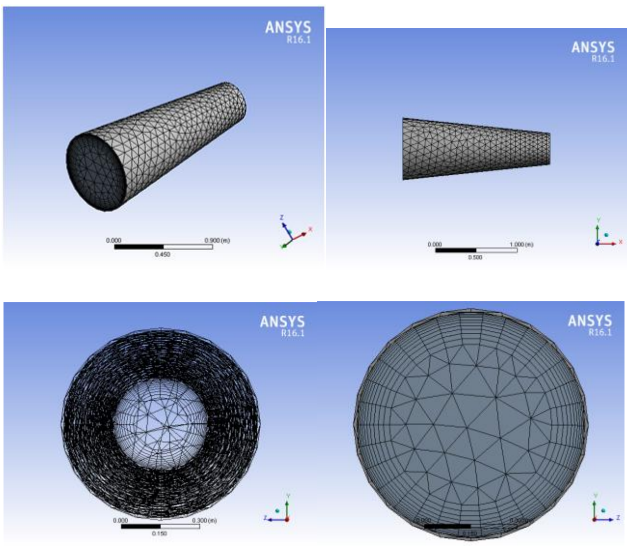

Figure 1-Meshed geometry of the tube

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.

D. Governing equations

The problem under consideration is assumed to be three-dimensional, laminar and steady. Equations of continuity, momentum and energy for the fluid flow are given below in a tensor form,

Continuity equation:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0$$

Momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j}\right) - \frac{\partial p}{\partial x_i} + \rho g_i$$

Energy equation:

$$\frac{\partial}{\partial x_i}\left(\rho u_i C_p T - k\frac{\partial T}{\partial x_i}\right) = 0$$

E. Boundary conditions and solution scheme

The outlet water temperature was obtained simulating the model in mentioned condition. The slope angle of the collector tube was then changed to 0,1, 2 and 3 and the outlet temperature were determined for the different cases keeping the inlet condition and the heat flux condition unchanged.

Uniform heat flux condition is imposed on the top half of the tube wall:

$$q = q_w$$

where 750 W/m^2. All the other walls are thermally insulated.

To know the heat flow from the tube wall to liquid the inlet temperature of the water was given 26ºC.The outlet temperature was monitored for the various conditions.

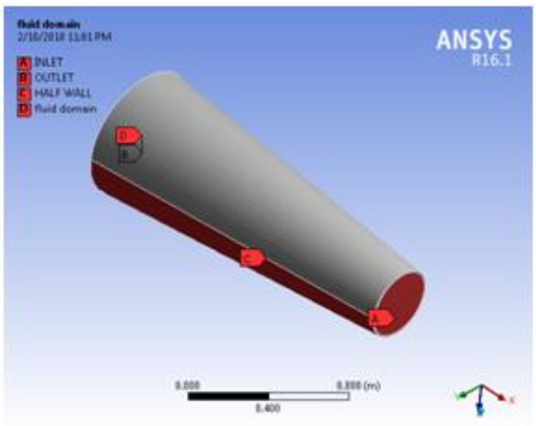

Figure 2- Model of Solar Water Collector

To simulate the solar exposure of the collector tube fluid model was exposed to a constant heat flux on collector tube wall on the upper side only as solar energy is received on one side only of the collector tube. For ambient sunlight

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condition on top half of model as sunlight's falls on one side only the model is simulated for the same the condition. The model generated was exposed to following parameters

Heat flux (from paper)	750 kg/m^{2}s
Mass flow constant	0.02kg/s

No slip condition is applied on all the walls, that is, the velocity magnitude near the wall is zero:

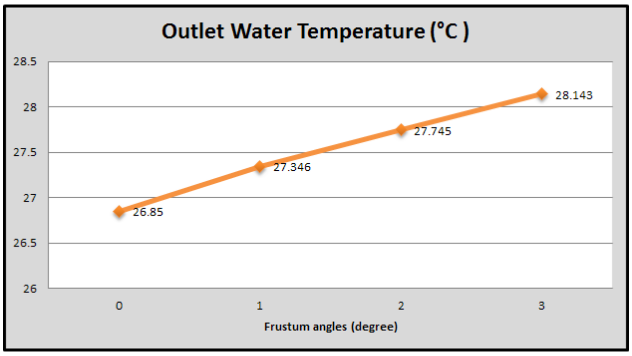
$$U_i = 0$$

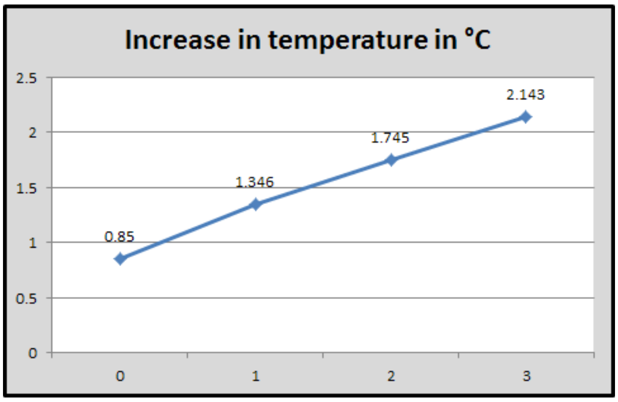
In the work, the governing equations were solved with the finite volume approach.

III. RESULTS AND DISCUSSION

The result obtained in the simulation is presented below

Flow from small to large diameter of a uniformly varying diameter pipe				
Frustum angles (degree)	0	1	2	3
Outlet Water Temperature (C)	26.85	27.346	27.745	28.143
Increase in temperature in C	0.85	1.346	1.745	2.143





It was find that the outlet water temperature increases with increase in the slope of the collector tube thus increasing the heat transfer effectiveness of the collector. This was accompanied by the loss it the velocity head as the diameter was expanding so velocity head getting converted to pressure head. Thus this method of gradually increasing the diameter of the pipe collected diameter can be used to increase the heat transfer efficiency without and any significant pumping losses which increase with use of other methods like twisted tape.

But the drawback related to this method of increasing the diameter lies in the phenomenon which increases the heat transfer efficiency. The modification of simple pipe collector to a gradually increasing slope helps in natural formation of Eddies as there is tendency of fluid to get separated from wall due to slope, these eddies in turn increase the heat transfer thus increasing the collector effectiveness. These eddies beyond a particular limit will act as energy loss, thus increasing the pumping loss. These limits of the slope angle and obtaining the optimum angle for various cross sectional shapes will be the future scope of the research.

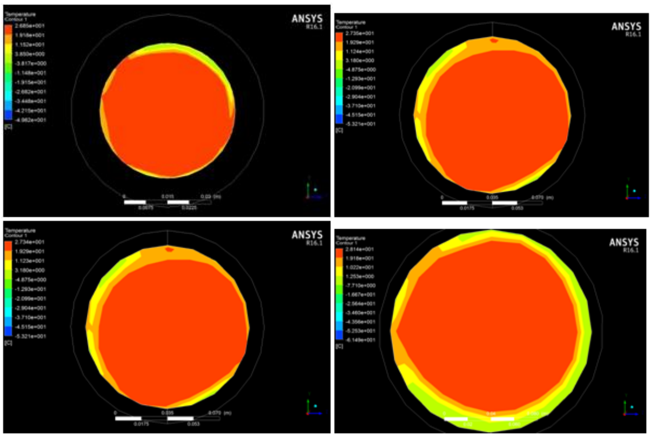


Figure 3 -Temperature Contour with taper angle 0,1,2 & 3 degree

IV. CONCLUSION AND FUTURE WORK

A. CONCLUSION

Solar heat transfer equipments are the need for a sustainable future human progress. In the time when there an immense pressure on humanity to move away from polluting and non renewable conventional energy sources towards renewable non conventional energy source like solar energy.

These are non conventional energy is available in huge amount but in a much diffused form. Thus to use it economically and technically viable way it is the need of hour to concentrate on increasing the efficiency and effectiveness of the collectors of these energy resource.

There were several methods developed to increase this efficiency and effectiveness. The most proven and much research ed on method is that of twisted tape. But the use of twisted tape increases the contact surface area between fluid and collector, which directly increases the frictional resistance to fluids thus increasing the pumping losses. When these tapes are used commercially these are viable as increase in pumping loss is offseted by much increase in the heat transfer efficiency. But in case of domestic use, the increased pumping loss due to tapes will make it infeasible for household use. Thus methods are required to be developed , which can increase heat transfer efficiency without any increase in loss , this method of increasing collector pipe diameter gradually fulfill s our objective, thus can be revolutionary in household solar energy use.

B. FUTURE SCOPE AND FUTURE SCOPE AND WORKED

The method we used is for pipe collector of a circular cross section. Further same analysis can be done for other cross sectional shapes which are used in other fields.

This slope we used in collector induces increased amount of Eddies which is responsible for increase heat transfer. These eddies also result s in energy loss , thus in further analysis there can a limit set on the slope angle beyond which the Eddie loss exceed the efficiency gain thus obtaining an optimum slope angle for various cross sectional shapes.

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