# CFD Analysis of Evacuated Tube Heat Pipe Solar Water Heater

Prof. V. Y. Chaudhary[1], Bharat Kalamkar[2], Prashant Patel[3], Jignesh Mali[4], Pratik Patel[5]

*Department of Mechanical Engineering, TSSM's PVPIT, Pune University, India*

***Abstract:*** **Use of solar radiations is the major obstacle in the application of thermal energy. Solar energy is one of the cleaner forms of renewable energy assets which achieve the need of people in the field of thermal energy. The study shows the use of solar energy with the help of CFD Analysis involving evacuated tube heat pipe which transforming radiation energy into useful heat. Presently use of nanofluids in solar thermal technology for heat transfer improvement is focus of interest. Geometry consists of two heat pipes. The working fluid used for heat pipe is water and $Al_2O_3$ respectively. The analysis conducted in ANSYS FLUENT 17. Temperatures at the outlet measured for both the cases. The heat absorption rate was more in the unit consisting $Al_2O_3$ as a working fluid inside the heat pipe. Thermal performance of nanofluid contains evacuated tube heat pipe solar water heater is improved than conventional evacuated tube heat pipe solar water heater (SWH). Also the effect of mass flow rate over the condenser and inclination angle on performance of evacuated tube heat pipe is also studied.**

***Keywords*: CFD Analysis, Evacuated Tube, Heat Pipe, Nanofluid, Solar Water Heater.**

## I. INTRODUCTION

To analyse the thermal performance and enhancement of heat transfer rate of wickless heat pipe evacuated tube SWH with nanofluid and its comparison with conventional evacuated tube SWH. Objectives for this project are:

1) To study the thermal performance and enhancement of heat transfer rate of evacuated tube heat pipe SWH using nanofluid ($Al_2O_3$ + water) and its comparison with conventional SWH with evacuated tube heat pipe.
2) To measure the performance at different inclinations of heat pipe.
3) To measure the performance at different mass flow rate over the condenser.

Thermosyphons are two phase heat transfer devices with a very high effective thermal conductivity. It require very small area, cost effective, high rate of heat transfer, lighter in weight, simple the design and less maintenance are its biggest benefits. A typical two phase closed thermosyphon consists of metal pipe with fixed quantity of working fluid vacuum-packed inside. The hollow centre of the heat pipe is a vacuum so even at low temperature the fluid will vaporize. The vapour rises to the tip of the heat pipe then heat is transferred to the water flowing through manifold. Due to this heat transfer vapour will condense then flow back down the heat pipe so that this process will remain repeated again.

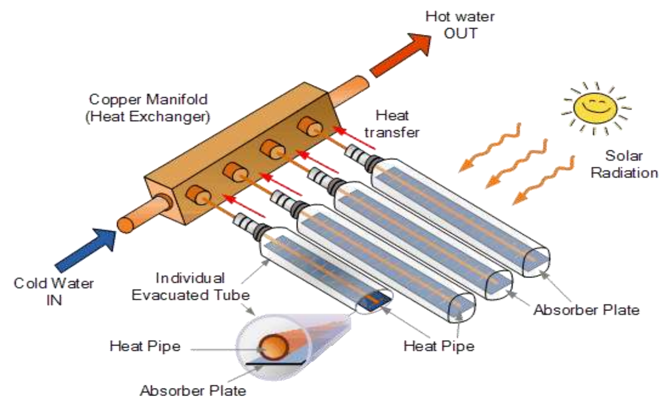


Fig. 1: Evacuated Tube Heat Pipe operation and construction

## II. LITERATURE REVIEW

Dao Danh Tung [1] in this research they proposed that the effective thermal conductivity of this heat pipe with the conditions of experiment and in the case of 100% of fill charge ratio is 18958 W/mK, which is much higher than that of copper 401W/m-K 47 times. The higher the inclination is (angle between the axis of the heat pipe and horizontal direction), the higher the heat transfer performance is. And the heat transfer performance of the heat pipe decreases rapidly when the inclination exceeds a certain value – below $30^0$.

Shubhro Sen [2] in this research they proposed that overall heat transfer coefficient is increased with the use of nanofluids when compared to that of pure water. Thermal resistance along with the temperature gradient across the heat pipe is reduced with the use of nanofluids compared to that of distilled water. Thermal resistance reduces with the increase in heat load with nanofluids the percentage reduction is larger as compared to that of pure water.

Javad Ghaderian [3] in this research they proposed that $Al_2O_3$/distilled water nanofluids with different volume concentrations were employed in the collector throughout the study. The obtained results proved that the addition of 0.06 vol%. $Al_2O_3$ nanoparticles produced a reasonable heat transfer improvement and increased the thermal conductivity in comparison to water. Heat transfer improvement increased with the increase in volume concentration of $Al_2O_3$ nanoparticles.

Vishal A. Barmate, Vishal A. Meshram [6] in this study there is an experimental performance comparison between water and nanofluid used in thermosyphon solar water heater systems (SWHS). Two systems containing two heat pipes are used. Tests were performed under similar environmental conditions. In the first system water was used as working fluid in the conventional SWHS named single phase. In another system $Al_2O_3$+water was used as working fluids in two phase SWHS. In both the systems temperature readings of collector inlet and outlet and water storage tank were taken. The thermal performance of solar collector with heat pipe containing nanofluid is better than that of conventional heat pipe SWH. There is 19-21% rise in instantaneous collector efficiency due to nanofluid. Experimental results also shown that the heat pipe tilt angle effects on thermal performance of evacuated tube heat pipe SWH. The best performance is obtained at 30° for both the SWH.

## III. DESIGN OF CAD MODEL

CAD model is designed as per standard dimensions of domestic solar water heater. The elements like support which are not taking part in fluid flow and heat transfer are neglected. Design data is given below:

Evacuated Glass tube Dimension:

- Tube length: 1.75 m
- Outside diameter tube: 0.049 m
- Total No. of tubes 2 for each collector

Heat Pipe Dimension:

- Outer Diameter of Condenser section: 0.014 m
- Outer Diameter of Evaporator section: 0.008 m
- Length of condenser section: 0.057 m
- Length of Evaporator section: 1.62 m
- Total Length of Heat Pipe: 1.677 m

Fig. 2. CAD Model

The material for heat pipe is copper which is having high thermal conductivity and the thickness is very small which is 0.001m. As compared to its length (1.677 m) thickness is very small which will create problem during meshing, hence thickness is neglected.

CAD model is created in modelling software UG NX 9.0 as per given dimensions. Then it is saved as .STEP file.

## IV. NAMING AND MESHING OF PART

.STEP file is imported in ANSYS FLUENT 17. Where the mesh is generated. Part names are is given in this stage.

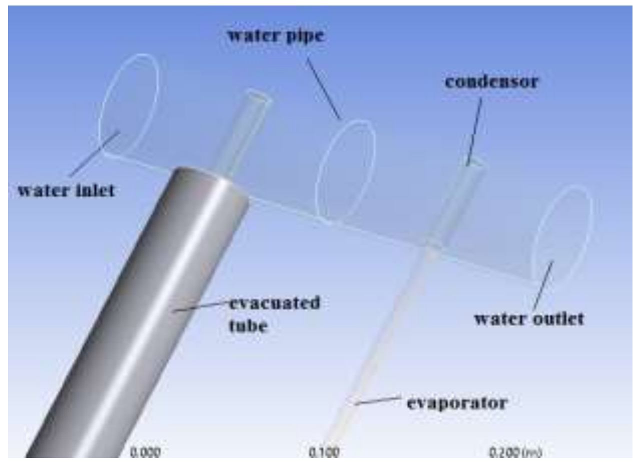


Fig. 3. Naming of parts

Meshing data is given below:

- Type of element: Hexa
- Method used: Multizone meshing
- Element size:
  - Evacuated tube: 0.015
  - Heat pipe: 0.003
  - Water pipe: tetra-0.007
- Meshing result data:
  - Number of nodes: 75,718
  - Number of elements: 1,12,274

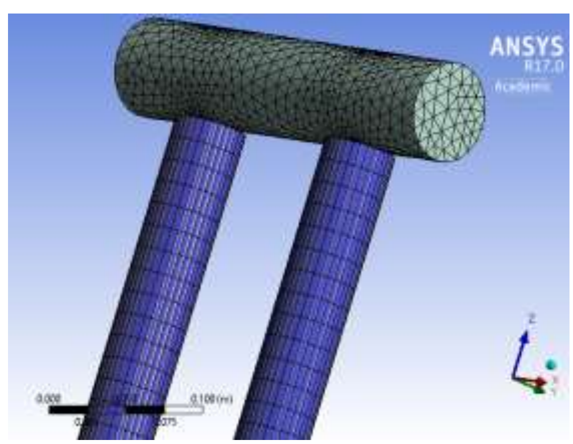


Fig. 4. Meshed model

## V. FLUENT DATA

Mesh file is opened in FLUENT setup. Here the solver setting and boundary conditions are applied.

Models:

- Energy equation: on
- Viscous model: k-epsilon, RNG, standard wall function

Cell zone conditions: here we have assigned fluids for domain

- Evacuated tube: air
- Water pipe: water-liquid
- Evaporator & condenser: We are going to compare the effect of two different fluid on output temperature
  - water-vapour (conventional)
  - Nanofluid ($Al_2O_3$+ water)

Properties of water vapour are available in fluent database.

The thermophysical properties of nanofluid [10] for a volume concentration of ϕ were calculated at the average bulk temperature of the nanofluid using the regression correlations widely used in the literature.

The density of $Al_2O_3$ nanofluid $\rho nf$ was determined using Pak and Cho's equation

$$\rho nf \;=\; \phi.\rho s \;+\; (1-\phi)\,\rho$$

The effective thermal conductivity of dilute nanofluid $k_{nf}$ can also be evaluated using the Maxwell model for nanofluids with volume fraction less than unity. Maxwell equation is given by

$$\frac{\mathrm{knf}}{k} = \frac{ks + 2k + 2\phi(ks - k)}{ks + 2k - \phi(ks - k)}$$

The specific heat of the nanofluid (Cp,nf) is calculated using Xuan and Roetzel's equation

$$(\rho Cp)nf = (1-\ \phi)(\rho Cp) + \phi(\rho Cp)s$$

The viscosity of the dilute nanofluid lnf can be determined using the viscosity correlation proposed by Einstein

$$\mu nf = \mu(1 + 2.5\ \phi)$$

Thermophysical properties of basic fluid, nanoparticle [11] and calculated properties of nanofluid are:

Table 1

| Substance | Density ($kg/m^3$) | Specific heat (J/kg-K) | Conductivity (W/m-K) | Viscosity (kg/m.s) |
|---|---|---|---|---|
| $Al_2O_3$ | 4000 | 880 | 30 | - |
| Water | 998 | 4190 | 0.58 | 0.001003 |
| Nanofluid | 1058.04 | 3939.87 | 0.6134 | 0.000952 |

Nanofluid properties are calculated at 2% volume concentration of $Al_2O_3$ and used for creating new fluid in fluent database.

## VI. BOUNDARY CONDITIONS

Boundary conditions for different parts is given below:

- Evacuated tube: solar radiations
- Inlet of cold water: velocity inlet
- Outlet of cold water: pressure outlet

Inclination of heat pipe is changed by resolving gravity in Y and Z direction.

$$y = -g\ cos\theta$$

$$z = -g\ sin\theta$$

Where $\theta$ is changed from $25^0$ to $45^0$.

As we know convection rate is affected by mass flow rate of water over the condenser, hence analysis is carried out at three different mass flow rates 15LPH, 10LPH, 15LPH.

Analysis is solved on ANSYS FLUENT 17 student version on laptop. By changing inclination and mass flow rate 15 runs are taken for water and similarly 15 runs for Nanofluid. Area weighted average is measured for outlet of cold water and plotted against inclination. Results are compared with water and Nanofluid.

## VII. RESULTS

Fig 5 & 6 shows the comparison between water (conventional) and nanofluid,

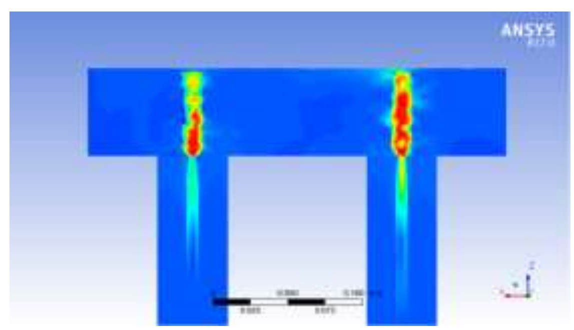


Fig. 5. water as working fluid

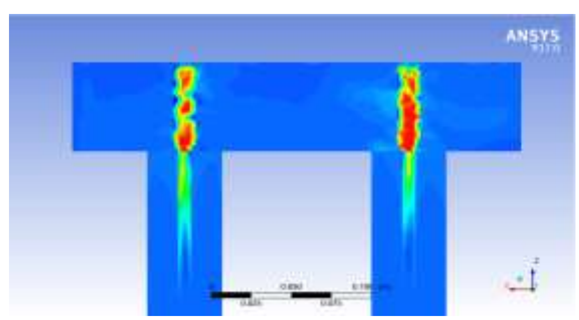


Fig. 6. nanofluid as working fluid

From the above figure the temperature difference of evaporator and condenser for system using nanofluid is lesser than system using water as working fluid. It shows that effective thermal conductivity of heat pipe SWH increases when nanofluid ($Al_2O_3$+water) is used.

The graph of outlet temperature verses inclination to ground is plotted for different mass flow rate over the condenser.

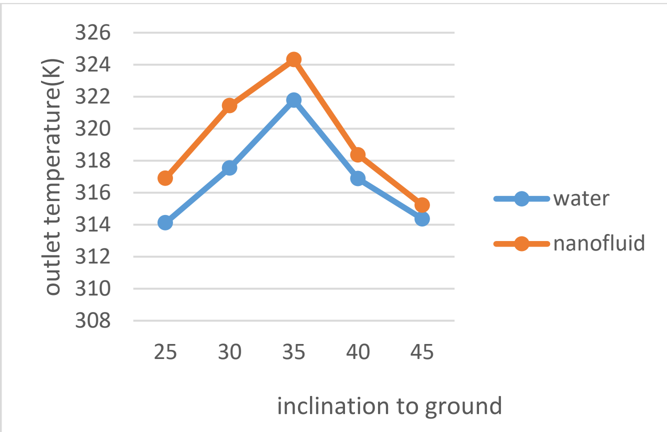


Fig. 7. Variation of outlet temperature with inclination at 5LPH

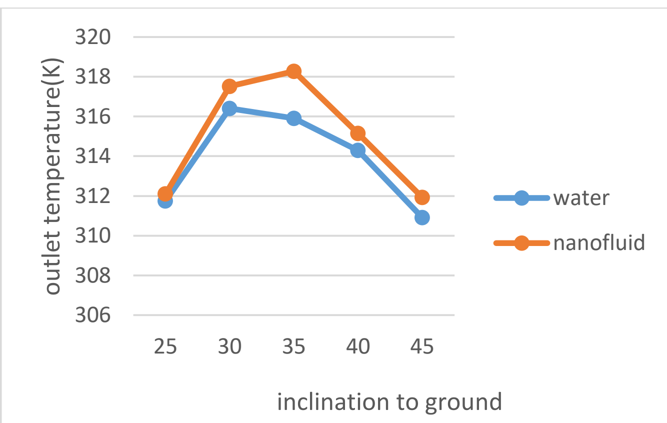


Fig. 8. Variation of outlet temperature with inclination at 10LPH

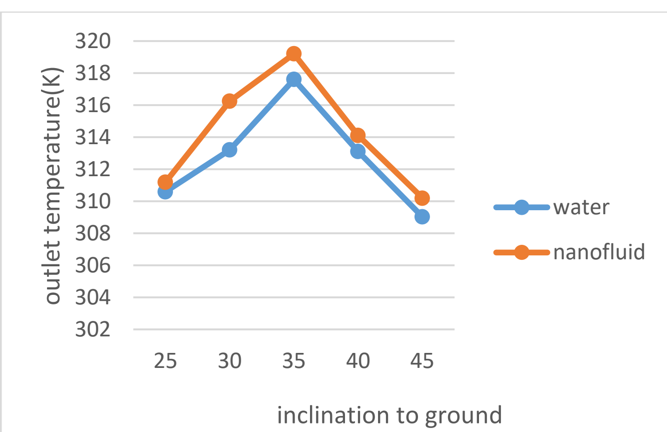


Fig. 9. Variation of outlet temperature with inclination at 15 LPH

From the above four graphs it is clear that the intensity of the solar radiation remained same for the analysis. Hence the temperature varies with mass flow rate and inclination. The solar radiations are calculated by solar calculator in FLUENT and applied as boundary condition for evacuated tube.

## VIII. VALIDATION

In order to validate numerical procedure, the results are compared with the existing results in the literature.

## IX. CONCLUSION

The CFD analysis has been carried out to investigate the thermal performance of two phase closed thermosyphon evacuated tube SWH with working fluid in heat pipe as conventional fluid water and $Al_2O_3$-$H_2O$ nanofluid. Following conclusions are made from experimental study and are detailed as below:

1) the temperature difference of evaporator and condenser surface for system having nanofluid is lesser than system having water as working fluid. It shows that effective thermal conductivity of heat pipe increases when nanofluid ($Al_2O_3$+water) is used.
2) The thermal performance of SWH with heat pipe containing nanofluid is better than that of conventional heat pipe SWH. There is 10-12% rise in outlet temperature due to nanofluid as a working fluid.
3) Analysis results also revealed that the heat pipe tilt angle had crucial effects on thermal performance of evacuated tube SWH. The optimum performance is obtained at 35° for both the system.

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