

Experimental and CFD Analysis of CuO-H₂O (DI) Nano fluid Based Parabolic Solar Trough Collector

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ABSTRACT: Parabolic solar trough collectors have been used for power production in solar thermal power plants. Nano science play very important or major role in the heat transfer solar applications, when used as a working fluid in parabolic collector enhances its efficiency due to its improved thermo-physical properties like thermal conductivity, heat capacity, density and viscosity. In order to achieve better heat transfer rate and to have efficiency heat exchangers, this can be done by changing the nature and properties of working fluids. Nano fluids are a suspension of nano particles in a base fluid like water, ethylene glycol. In this paper both experimental and computational fluid dynamics study has been presented. Nano fluid possess enhanced thermal conductivity and better heat transfer coefficient as compared to the base fluid Nano fluid used is 0.01% CuO- H₂O (DI). System performance is conducted under mass flow rate of 18 Litres/hr. In ANSYS FLUENT 14.5 based computational fluid dynamics tool, the absorber tube is modeled as metallic copper tube with working fluid flowing in it. Nano fluid is simulated using one-phase modeling techniques, while solar load cell and solar ray tracing are used for modelling the solar fluxes. Solar load model has been used for modeling solar fluxes. S2S radiation model has been used for modeling heat transfer comprising of conduction, convection and radiation. It has been reported from both experimental and CFD analysis that system performance is enhanced by using Nano fluid as working fluid as compared with conventional fluid likes water. Also both experimental and CFD simulated data gives good result agreement.

KEYWORDS: Computational fluid dynamics, efficiency, Nano fluid, parabolic solar collector.

I. INTERODUCTION: SOLAR ENERGY

Owing to the increasing rate of development and modernization, great threat has been posed to conventional resources like coal, oil, and so forth as their reserves have become marginally scarce. The Sun is a sphere, comprising of intensely hot gaseous matter having a diameter of 1.35×10^6 Km .In fact sun is a fusion reactor in which hydrogen is converted into helium. About 1.75×10^{11} MW sun's energy is intercepted by the earth, even this energy is very immense and it has been reported that solar radiation for 30 min. is capable enough to fulfill world's annual demand. Various devices have been made to receive this source of energy. Parabolic solar collector is one of them. Parabolic solar collector consists of parabolic shaped reflector, absorber tube. Main purpose of parabolic Shaped reflector is to reflect and concentrate all the sun radiations towards absorber tube, where a working fluid is flowing. Glass enclosure is provided over the absorber tube to minimize the re-radiation losses. Main utility of parabolic solar collector is for power production in solar thermal power plants. The efficiency of parabolic shaped collector depends upon various factors like Intensity of solar radiation, collector design, working fluid, absorber material, and nature and thermo physical properties of the working fluid

II. NANOFLUID IN SOLAR ENERGY

Nano fluid based solar collectors are basically thermal collectors where nano particles in a liquid medium can scatter and absorb solar radiation. In this era of increasing demand of energy various alternatives has been suggested from time to time. Use of Nano fluid as working fluid in solar collector has been adopted widely, because it enhances the system performance due to its improved thermo-physical properties like: thermal conductivity, viscosity, heat capacity and

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density. Nano fluid is basically a suspension of nano particles in a conventional base fluid like water. Nano fluids have recently found relevance in applications requiring quick and effective heat transfer such as industrial applications, cooling of microchips, microscopic fluidic applications, etc. Various different types of nano particles are used such as gold, copper, Aluminium, Aluminium oxide, copper oxide, etc. Nano fluid provides following benefits when used as a working fluid in solar collector: (1) Nano fluid absorbs solar energy directly without avoiding intermediate heat transfer activities. (2) Nano fluids have high absorptivity in solar range and low emissivity in infrared range. (3) More uniform temperature is obtained inside the absorber tube. (4) Enhances the system efficiency due to its improved thermo physical properties. The effect of surface to volume ratio on the thermal conductivity is more than the effect of the surface size of nano particles. The effective volume of a cluster is considered much larger than the volume of the particles due to the lower packing fraction of the cluster. Since, heat can be transferred rapidly within the clusters; the volume fraction of the highly conductive phase is larger than the volume of solid, thus increasing thermal conductivity. Recently many researchers have investigated the effect of Nano fluid in improving the heat transfer both experimentally and theoretically. Finite difference technique was used for computational fluid dynamics.

III. EXPERIMENTAL METHODOLOGY

The experimental set up conducting experiment on CuO- H₂O (DI) consists of parabolic shaped reflector, absorber tube (copper tube) with glass cover, ball valve, and storage device.

Table 1. Different Parameters of Parabolic Solar Collector

Collector Length	1.18m
Collector Breath	0.816m
End Plate Thickness	1.9mm
Focal Length	0.28m
Receiver Inside Diameter	0.024m
Receiver Outside Diameter	0.025m
Receiver Length	1005mm
Glass Envelope Inside Diameter	0.060m
Glass Envelope Outside Diameter	0.064m
Concentration Ratio	10:28

Main components of the parabolic solar collector are absorber tube (HCE), reflector, and storage tank with associated pumping arrangement and insulating piping arrangement. The working fluid from the storage tank is made to circulate with the help of pump in the absorber tube, which is centrally placed in order to have maximum solar radiations falling upon it directly and also reflected rays from the parabolic shaped reflector. The working fluid taken is H₂O (DI) and 0.01% CuO-H₂O (DI). Flow rate of 18 litres/hr. The working fluid after been traversing through the absorber tube is made to flow into the storage tank, from where again working fluid is circulated into the system. While inlet and outlet temperatures are recorded using thermometer. Solar power is used to measure the solar flux, while wind velocity is measured through anemometer. Absorber tube is insulated with the help of glass cover so as to avoid the radiation losses. Manual tracking arrangement is used to track the solar collector. Solar collector is tracked throughout the day with the help of manual tracking arrangement incorporated in the system.

Sonication is highly effective for processing nano particles. Sonicator have become the industry standard for dispersing, particle size reduction and particle synthesis and precipitation. Sonication is the procedure of dispersing the agglomerated nano particles. CuO-H₂O Nano fluid is generated by two step method. CuO nano particles are mixed with double distilled water. Volume concentration of 0.01% is obtained and mixture is stirred for around 40 minutes. Then, the stirrer mixture is then placed into a Sonicator tank of ultrasonicator, where Sonicator of Nano fluids is done around 2 hours. After sonicating the Nano fluid is ready for used. Moreover, pump is also placed within the storage tank in order to avoid the settling of the nano particles.

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IV. COMPUTATIONAL FLUID DYNAMICS METHODOLOGY

1. Geometric Modeling: Firstly, the 3-D geometry of the collector element is created. The geometry consists of two concentric cylinders (glass and HCE pipe) with two fluid regions for the working fluid (inner cylinder) and the vacuum region (annulus). In the present analysis, the geometry is considered to be oriented along the z-axis, with positive Z denoting the south direction while the positive X denotes the east direction. Upper part is mainly incident by incoming solar radiation while lower part is incident by reflected and concentrated solar radiation with the help of mirror reflector.

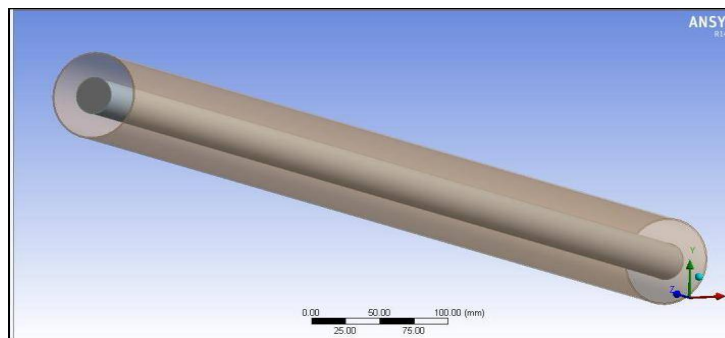


Figure 1. HCE (absorber tube)

2. Material Models: In ANSYS FLUENT 14.5, material model is applied. In material model, various thermo physical properties of the materials are specified. Material models are applied for carrying out CFD simulation of CuO – H₂O (DI) Nano fluid based collector. Table 2 shows the material used along with their thermo-physical properties.

Table 2. Thermo-physical properties

Thermo-physical properties	Water	CuO-Water based Nano fluid(0.01% conc)	Glass
Density(Kg/m ³)	1000	1054	2200
Specific heat(J/Kg/k)	4187	3965.05	910
Thermal conductivity(W/mK)	0.667	0.68701	1.75
Viscosity	0.415 × 10 ⁻⁶	0.396 × 10 ⁻⁶	-

3. Solar Load Model: Solar load model is applied for numerical simulation, where typical inputs include day and time of the experiment and longitude and latitude of location. ANSYS FLUENT provides a model that can be used to calculate radiation effects from the sun's rays that enter a computational domain. It allows simulating solar loading effects and determining the solar transmission through all glazed surfaces over the course of a day. Surface-to-surface radiation model is applied for modeling the radiation mode of heat transfer between diffuse surfaces involved in the system.

4. Boundary Condition: Boundary conditions are applied for carrying out numerical simulation. For numerical simulation of Nano fluid based solar collector some boundary conditions must be imposed. The flow at the inlet was maintained as uniform mass flow at ambient temperature conditions. A low Re is typical for HCE applications for Parabolic Trough Collectors. This variation is due to highly temperature dependent viscosity. The vacuum region is modeled by assuming it to be a fluid with very high viscosity and the velocity components have been fixed at zero

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value. The outlet is maintained to be at ambient pressure.

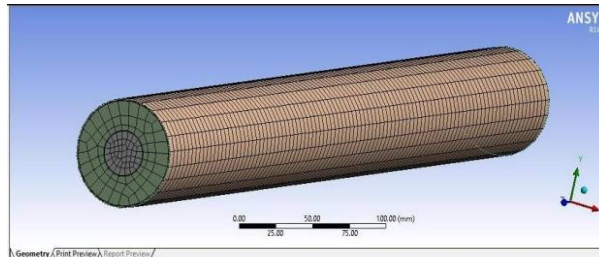


Figure 2. Meshed Geometry of an absorber tube

V. RESULTS

Variations of temperature rise, both experimental and calculated and simulated values with time of day .For water as a working fluid having flow rate of 18 litres/hr CFD results is depicted in figure. 5, which shows the temperature growth within the absorber tube (HCE). Temperature gain of around 6 degrees is obtained. It is seen that both experimental and simulated values of temperature rise are in close agreement with a difference of 6 percent.

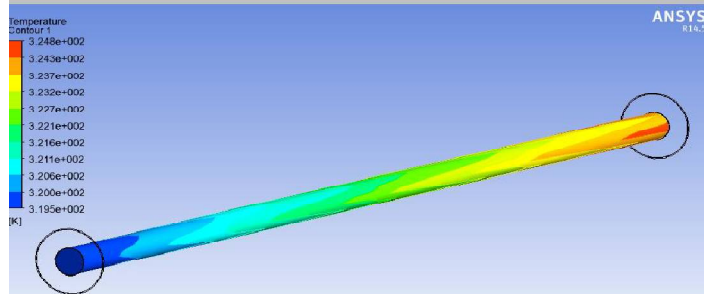


Figure 3. Temperature contours with water at flowrate of 18 litres/hr

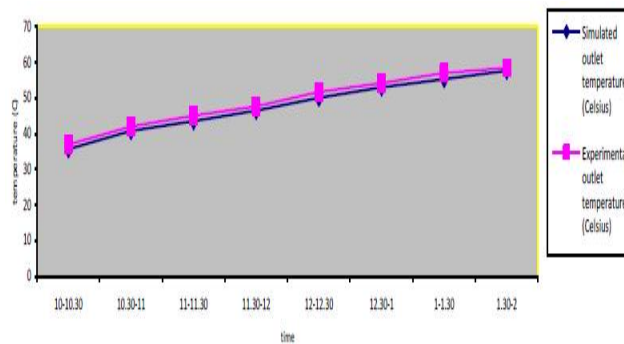


Figure4.Simulatedvs.experimental outlet temperature with water at flow rate of 18 litres/hr.

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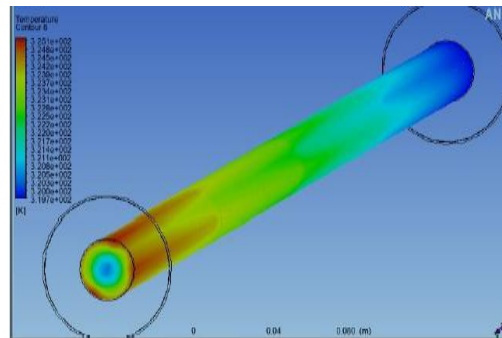


Figure 5. Temperature contour with 0.01% CuO -H₂O (DI)

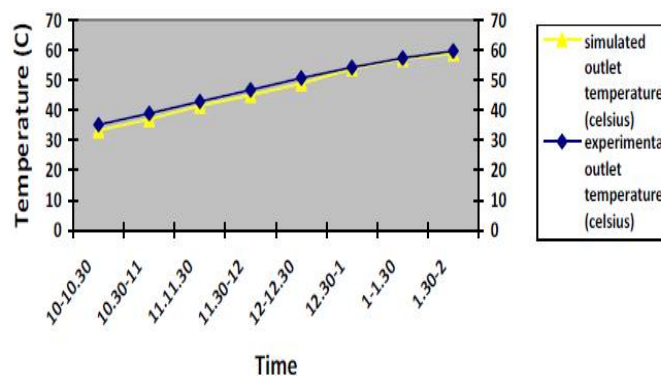


Figure 6. Simulated vs. experimental outlet temperature with 0.01% CuO -H₂O (DI) as a working fluid

VI. CONCLUSIONS

Nano fluid due to its better thermo physical properties as compared to its base fluid tends to improve the performance of a solar collector which can be found from both experimental and computational fluid dynamics simulated results. Nano fluid when used as a working fluid improves the parabolic solar collector efficiency due to its improved thermo-physical properties like specific heat, thermal conductivity and others. From both the experimental and CFD analysis it is found out that the thermal efficiency improved by and 6% when 0.01% CuO-H₂O Nano fluid is used, as compared with conventional working fluid like water at flow rate of 18 litres/hr. It has been seen that there is an improvement in both thermal and instantaneous efficiency of the parabolic solar collector, when Nano fluid is used. Both experimental and CFD outlet temperature are found out to be in close agreement for 0.01% CuO-H₂O Nano fluid with a difference of 5.75% at flow rate of 18 litres/hr.

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