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# CFD ANALYSIS OF PARABOLIC TROUGH COLLECTOR USING NANO FLUIDS

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**ABSTRACT**
Parabolic trough collector is the most mature technology for utilizing the solar energy in high temperature applications. The PTC system is used for unique fields such as steam and hot water generation and power generation using sterling cycle and water as a heat transfer fluid. This paper aims to give a complete CFD analysis of a PTC using nano fluids and ANSYS. Nano fluids are used as working fluid in parabolic trough collectors (PTCs). The reviewed studies consist of performing computational fluid dynamics (CFD) simulation on parabolic trough collector using ANSYS Fluent software. The main focus was to evaluate the effect of nanofluids on thermal performance of the process and study the temperature changes with the usage different nano particles concentration with base fluid water like $Al_2o_3$,$SiO_2$, cuo & $TiO_2$.It was revealed that nano fluids enhance (in most of the cases) the thermal efficiency, convection heat transfer coefficient, and energy efficiency of the system.

**Keywords:**
Fluent, PTC, and Nano fluids.

## 1. Introduction

In today's world the fastest growing thing is the energy requirement by world, with the reduction in the conventional resource. The most challenging thing in front of the world is how the to fulfill the requirement of energy. Increasing in fuel prices and carbon emissions from the conventional energy resources like thermal energy and fossil fuels usage leads to global warming and air pollution. Due to over use and depletion of conventional energy resources, the world has to think about the alternative sources of energy.

Nowadays, renewable power generation or hybrid renewable power generation systems are attracting the interest of the whole world due to advanced technologies capable of efficient use of renewable resources including reduction of greenhouse gas emissions (Colla L; Sansoni P., (2011)). Renewable energy resources are used generally for three main purposes: electricity generation, bio products and heating/cooling systems. Concentrating solar power generation system, geothermal power generation and hydro-power generation systems are well-disposed technologies, while solar thermal heating, geothermal district heating and pellet-based heating can provide significant benefits in case of heat supply (S. Kakaç, 2009). In many countries, various schemes like development of technologies, increased economies of scale, and strong policy support have contributed.

However, out of the renewable energy resources, the most ample resource is solar which has immense potentiality (Şen, 2004). Technologies are available to harness solar energy to a useful state. Solar has the potency to meet all residential and industrial energy needs. Already the world is moving toward sustainable technologies especially solar energy technologies. Solar PV system is growing so fast of all renewable technologies with an impressive rate (Samuel Sami (2018)). Recently solar concentrating system attracts the attention of many countries. Some countries have established such type of system,

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and in some region of the world, this system is under development. Today the world stands at an exciting transition moment when renewable energy is competing head-to-head with fossil fuel and nuclear energy. Due to increased energy consumption, dependence on fossil fuels, solar power generation can be the main and important factor for the world now.

The parabolic mirrors send the solar beam onto a receiver pipe which is located at the focal line of the parabola and filled with a specialised heat transfer fluid. These receivers have a special coating to maximise energy absorption and minimise infrared re-irradiation. In order to avoid convection heat losses, the pipes work in an evacuated glass envelope.

The thermal energy is removed by the heat transfer fluid (e.g. synthetic oil, molten salt) flowing in the heat-absorbing pipe and transferred to a steam generator to produce the super-heated steam that drives the turbine [3]. Once the fluid transfers its heat, it is recirculated into the system for reuse. The steam is also cooled, condensed and reused.

Furthermore, the heated fluid in Parabolic trough technology can also provide heat to thermal storage systems, which can be used to generate electricity at times when the sun is not shining. Most PT plants currently in operation have capacities between 30-100 MW, efficiencies of around 14-16% (i.e. the ratio of solar irradiance power to net electric output) and maximum operating temperatures of 390°C, which is limited by the degradation of synthetic oil used for heat transfer. The use of molten salt at 550°C and water-steam at 500°C for heat transfer purposes in PT plants is under investigation. High temperature molten salt may increase both plant efficiency (e.g. 15%-17%) and thermal storage capacity.

A nano fluid is a fluid containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nano particles in a base fluid. The nano particles used in nano fluid are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. Due to its novel properties nano fluid find their applications in many fields of heat transfer, including microelectronics, fuel cells, pharmaceutical, processes, and hybrid-powered engines, in grinding, machining, engine-cooling/ vehicle thermal management, domestic refrigerator, chiller, heat ex changer and in boiler flu gas temperature reduction.

They have better thermal conductivity and the convective heat transfer coefficient as that of the fluid in which it is made of. Knowledge of the rheological behaviour of nanofluids is found to be very critical in deciding their suitability for convective heat transfer applications.

Suspended nano particles in conventional fluids, called nanofluids, have been the subject of intensive study worldwide since pioneering researchers recently discovered the anomalous thermal behaviour of these fluids. Existing theories could not explain the enhanced thermal conductivity of these fluids with small-particle concentration. Micrometre-sized particle-fluid suspensions exhibit no such dramatic enhancement. This difference has led to studies of other modes of heat transfer and efforts to develop a comprehensive theory.

## 2. Parabolic trough collector

A parabolic trough collector is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished metal mirror. The sunlight which enters the mirror parallel to its plane of symmetry is focused along the focal line, where objects are positioned that are intended to be heated. In a solar cooker, for example, food is placed at the focal line of a trough, which is cooked when the trough is aimed so the Sun is in its plane of symmetry.

For other purposes, a tube containing a fluid runs the length of the trough at its focal line. The sunlight is concentrated on the tube and the fluid heated to a high temperature by the energy of the sunlight. The hot fluid can be piped to a heat engine, which uses the heat energy to drive machinery, or to generate electricity. This solar energy collector is the most common and best known type of parabolic trough.

When heat transfer fluid is used to heat steam to drive a standard turbine generator, thermal efficiency ranges from 60-80%. The overall efficiency from collector to grid, i.e. (Electrical Output

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Power)/(Total Impinging Solar Power) is about 15%, similar to PV (Photovoltaic Cells) but less than Stirling dish concentrators. Large-scale solar thermal power plants need a method for storing the energy, such as a thermocline tank, which uses a mixture of silica sand and quartzite rock to displace a significant portion of the volume in the tank. It is then filled with the heat transfer fluid, typically a molten nitrate salt.
As of 2014, the largest solar thermal power systems using parabolic trough technology include the 354 MW SEGS plants in California, the 280 MW Solana Generating Station with molten salt heat storage, the 250 MW Genesis Solar Energy Project, the Spanish 200 MW Solaben Solar Power Station, and the Andasol 1 solar power station.[22] and is shown in figure 1.

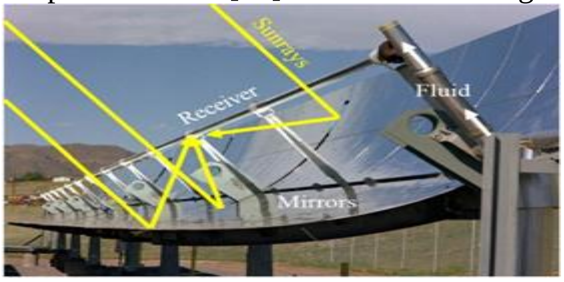

Figure 1: Parabolic trough collector

### 3. Modeling Methodology and Material Specifications

The objective of the project is to simulate the solar collector fluid flow with in the parabolic trough collector with Nano fluid as the working fluid and study the heat transfer capability and working fluid outlet temperature at different volumetric concentrations of Nano fluids. Nano fluids of water based $Al_2O_3$ and water based CUO is used as working fluid at different volumetric concentrations. The dimensions and other parameters of components of the parabolic trough collector are shown in the table 1 and 2 below.

| | |
|---|---|
| Length | 2 m |
| Width | 1.5 m |
| Rim angle (ϕ) | $90^o$ |
| Focus | 0.375 m |
| Thickness | 5mm |
| Reflectivity | 0.9 |

Table 1: Parameters of collector

| | |
|---|---|
| Inner diameter | 0.038 m |
| Outer diameter | 0.042 m |
| Length | 2m |
| Solar absorptivity | 0.94 |
| Thermal emittance | 0.08 |

Table 2: Parameters of absorbing tube

Parabolic trough collector is a concentrated type solar collector system. The solar rays that is reflected from the parabolic trough is concentrated on the surface of the absorber tube. This energy will increase the temperature of the absorber tube and this heat energy is transferred to working fluid flowing inside the absorber tube through convection. The present work focuses on simulating the process of the parabolic trough collector in ANSYS fluent software and perform the CFD flow analysis on working fluid and study the temperature change in the outlet temperature of working fluid with different concentrations of water based $Al_2O_3$ and CUO working fluid. The average size of the Nano particles is 20-60 nm. To calculate the thermo physical properties of both Nano particles and base fluid. The base fluid is water. The properties of the Nano particles $Al_2O_3$ and CUO are shown in the table 3.

| **nanofluid** | **Density** (kg/m³) | **Specific heat** (J/kg°C) | **Thermal conductivity** (W/m°C) | **Viscosity** (N·s/m²) |
|---|---|---|---|---|
| Cuo | 2650.9 | 3088 | 1.297 | 0.00156 |
| $SiO_2$ | 1038 | 3806.2 | 0.521 | 0.0091 |
| $TiO_2$ | 1053.6 | 3526.2 | 0.431 | 0.00160 |
| $Al_2O_3$ | 1060.3 | 3512.2 | 0.445 | 0.00175 |

Table 3: Thermo physical properties of nano particles and water

## 4. Results and discussions

The procedure of solving a problem in ansys fluent is a step by step procedure which includes importing or designing geometry, generating mesh, setting up the physics and solver conditions, solving the problem for solution and observing the results.

To import the geometry file, right click on the geometry will prompt us to import command using which we can browse for the .stp file created and imported in to the ANSYS. Fluid domain needs to be created to simulate the flow of working fluid. Space claim is used to create the fluid domain. A solid cylinder of 38mm diameter and 2m length is modeled in space claim to fit inside the created absorber tube geometry. This cylinder will act as a working fluid that will flow inside the absorber tube. It is shown in the figure 2.

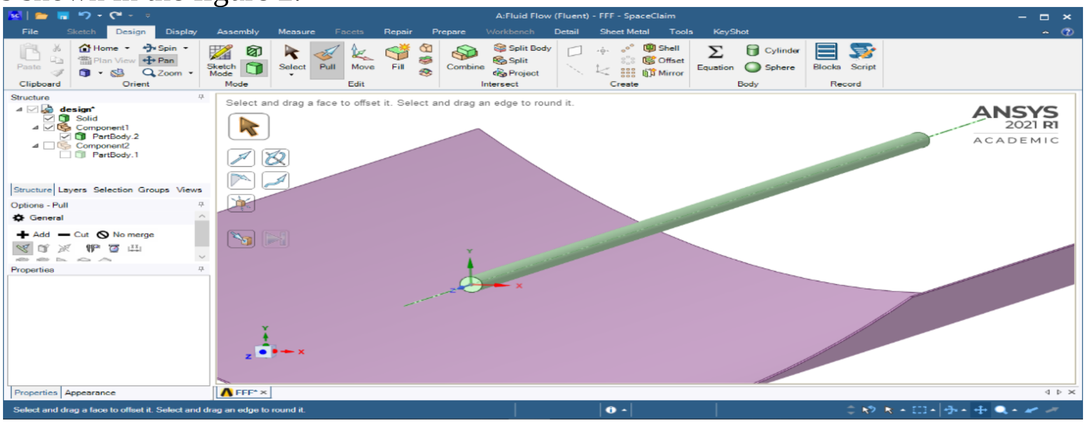


Figure 2: Fluid domain model designed in space claim

Edge Sizing is used to smoothen the edges and to get a good mesh. Body sizing is of 20 mm is applied to the parabolic trough body. As the value of the Body Sizing element decreases the Skewness value of the design decreases. The Body Sizing of the design has to be done in order to create a good mesh and meshes the whole body at once. After meshing is done quality of the mesh has to be checked. The skewness value of the mesh has to be as minimum as possible, and the orthogonal quality of the mesh should be between 0.7-0.95 for a good quality mesh and is shown in figure 3.

Inlet and outlet named selections are given to the faces of fluid domain one on each face. The upper face of absorber tube is given a named selection as absorbing surface, and the upper face of parabolic trough is given a named selection as reflecting surface.

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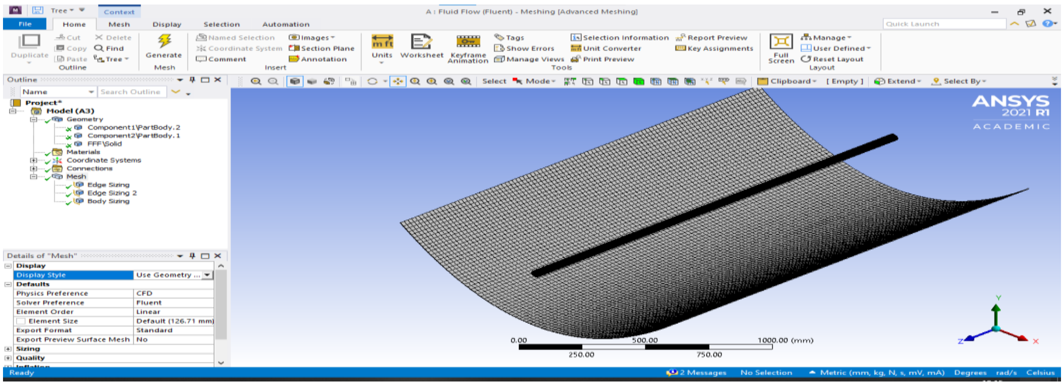


Figure 3: Meshed domain

Fluent analysis of parabolic trough collector with different volumetric concentration of water based $Al_2O_3$ and water based CUO nanofluids was done using ANSYS software and results are shown in figures 4-8.

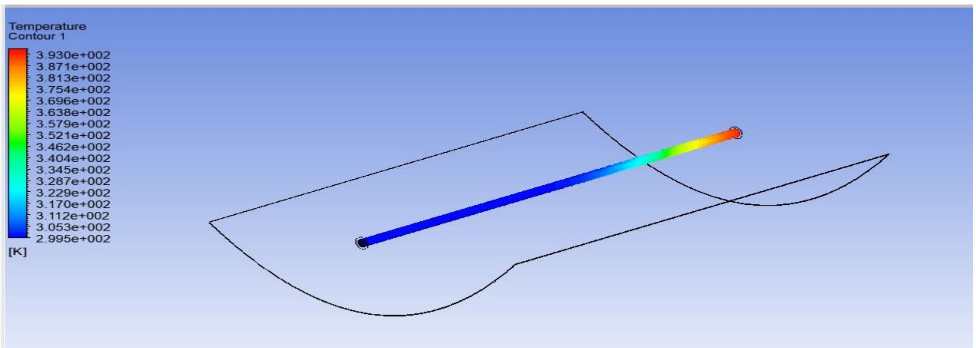


Figure 4: Temperature contour with $Al_2O_3$

The maximum temperature of the outlet of the water observed is 356.3 K. The velocity contour is shown above. It can be observed that the velocity of fluid near the boundary of the wall is minimum because of the shear stress on the fluid by the wall boundary. Because of the usage of the nanofluids as working fluid temperature, at the outlet has improved.

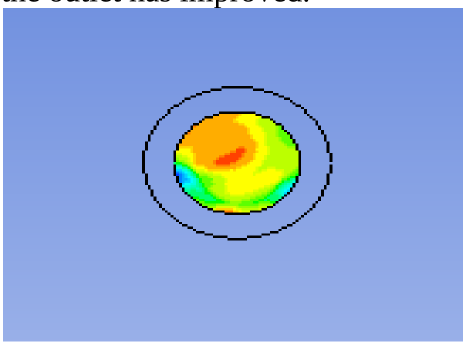

Figure 5: velocity contour with water as working fluid

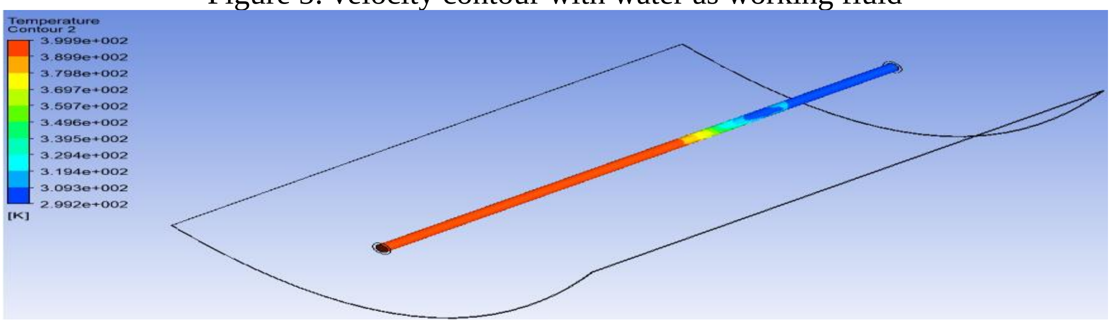


Figure 6: Temperature contour with Cuo

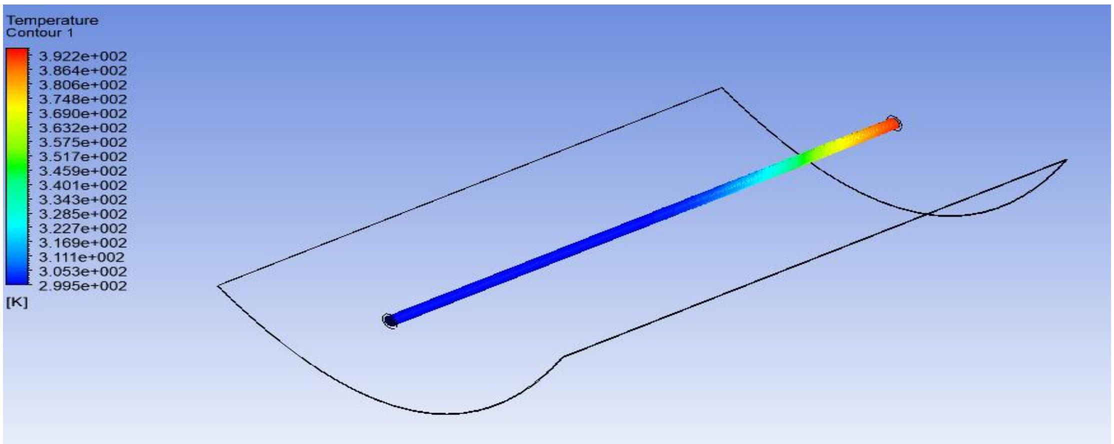


Figure 7: Temperature contour with $TiO_2$

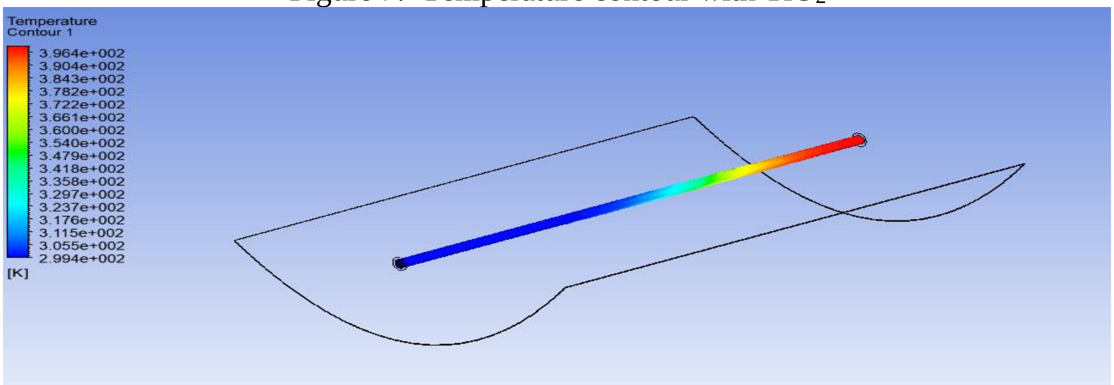


Figure 8: Temperature contour with $SiO_2$

As we can see from the temperature contours the outlet temperature of the working fluid has increased with the usage of nanofluids. So the temperature has increased sequentially with the increase in the volumetric concentration of the nano particles. The increase in temperature is achieved by the improvement in the thermo physical properties of working fluids especially thermal conductivity due to addition of nanoparticle.

With the increase in the volumetric concentration of nano particles there is increase in the properties of working fluid, so is the outlet temperature of working fluid. The maximum outlet temperature of $Al_2O_3$- water nanofluid is shown in the table 4.

| NANOFLUIDS | Maximum temperature [k] |
|---|---|
| $Al_2O_3$ | 393.4 |
| $Sio_2$ | 396.5 |
| $Tio_2$ | 392.1 |
| cuo | 399.0 |

Table 4: Maximum outlet temperature of $Al_2O_3$ - water nanofluid

The maximum outlet temperature of working fluid is observed with 0.3% volumetric concentration of nano particles with water as nanofluid at 50 c. The maximum outlet temperature of CUO - water nanofluid is observed with 399.0k

**4. Conclusions**

Improvement in the thermal performance is reported through the CFD simulation results of parabolic trough collector, when nano fluid is used as working fluid when compared to water. Also, when volumetric concentration is made to increase, corresponding improvement in the performance of the parabolic trough collector is witnessed. With 0.3% vol.con. of CUO - water nanofluid as working fluid, 0.5 kg/s of inlet mass flow rate and 300K inlet temperature the maximum outlet temperature of 399.5K is observed.

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