

# Thermal Performance Enhancement of Nanofluids Based Parabolic Trough Solar Collector for Sustainable Environment

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**Abstract-** The aims to document the latest developments on the applications of nano fluids as working fluid in parabolic trough collectors (PTCs). The influence of many factors such as nanoparticles and base fluid type as well as volume fraction and size of nanoparticles on the performance of PTCs has been investigated. The reviewed studies were mainly categorized into three different types of experimental, modeling (semi-analytical), and computational fluid dynamics (CFD). The main focus was to evaluate the effect of Nano fluids on thermal efficiency, entropy generation, heat transfer coefficient enhancement, as well as pressure drop in PTCs. It was revealed that Nano fluids not only enhance (in most of the cases) the thermal efficiency, convection heat transfer coefficient, and energy efficiency of the system but also can decrease the entropy generation of the system. The only drawback in application of Nano fluids in PTCs was found to be pressure drop increase that can be controlled by optimization in nanoparticles volume fraction and mass flow rate..

**Keywords-** parabolic trough solar collectors; nanofluid; thermodynamic performance; entropy generation; energy analysis.

## I. INTRODUCTION

### 1. Renewable Energy:

The increasing demand of energy and available resources is becoming a huge challenge today, where, solar energy, one of the promising and great source of renewable energy. The surface of the earth is recorded to intercept an average of  $3.6 \times 10^{14}$  TW of solar radiations. Solar thermal collectors are among the most popular source of renewable energy.

PTSC uses direct solar radiations for heating the working fluid. A glass envelope is used to enhance the collector performance and to minimize the losses of convection. The sunlight intensity is increased by using this configuration and the heat generated by sunlight on the receiver. Temperature range for operation of working fluid in PTCs is between 50 °C and 400 °C. About 30% of the PTC system's cost is accounted by solar receiver. A solar tracking system is usually used for efficiency enhancement by changing the position in the direction of sun. Parabolic troughs can be arranged in various sizes in the solar fields and can be linked together easily. However, the axis of the collector must be oriented in North-South or East-West direction to minimize the losses. Therefore, single-axis tracking is mostly used for achieving this purpose.

PTSC provides advantage of higher efficiency with low surface area requirement even with diffused sun light for same output. PTSC can be used on roof surfaces orienting on non-south direction. Higher temperatures can be

produced with PTSC and also provides advantage of integrating with high-temperature systems. The concentrators are made of recyclable materials which reduce the environmental waste as well.

The trackers concentrate the sunlight effectively and transfer converted heat to a working fluid. This phenomenon is steady-state, and working fluid in the annular region with high specific heat is preferred. Conventional Newtonian working fluids constitute water, molten salt, and air flowing through the collectors. These fluids have poor thermophysical properties, hence; lower the efficiency of the collectors. The main parameter in increasing PTSC efficiency is geometry modeling, working fluid selection and receiver tube material . Molten salts were used a working fluids yielding excellent thermal conductivity, reduced corrosion and clogging in the components of the receiver tube. The rate of absorptivity is also very high in the UV-visible region. Furthermore, size and other properties can also be fine-tuned at atomic level bottom up to achieve a much higher conductive phase.

### 2. Applications:

The applications of nano fluids have increased with increase in their popularity, and use in medical devices, solar energy, fuel cells and heat exchangers have been explored. Nano fluids have a great potential in PTSCs as it can help significantly reduction in the cost of the system Selective coatings of black-chrome or black nickel is used for non-evacuated receivers because of their

economic reasons and ease of production. The maximum length of the receiver tube is 5 m because of manufacturing constraints; therefore, the tubes are connected in series to obtain the desired length of PTC. The performance of PTSCs is affected by the geometric parameters and the materials. Semi-finite analytical formulation was reported in the literature, which depicts that the semi-finite method requires special integration, geometrical and optical characteristics are not changed easily by using this method. These methods are used for determining the efficiency, heat flux and absorber tube material in various researches. In another study, enhancement upto 4.3% in the PTC performance system using oil/Al<sub>2</sub>O<sub>3</sub> nanofluid.

### 3. Parabolic Collector:

The most common concentrating technologies are parabolic trough collector (PTC), direct Fresnel glass, solar dish, and solar palace, where, parabolic trough collector is one of the most notorious technologies. This technology uses parabolic shaped mirrors to concentrate the incident radiation onto a receiver tube which is placed at the focal line of the trough. Parabolic trough collector (PTC) is having colorful advantages similar as in artificial brume generation and hot water products. The advantage of solar trough is that it's clean, cheap and can be used to supply thermal energy. This paper presents a simple model of a Solar Parabolic Trough Water Heater. The model proposed has a trough collector of aluminum with mirrors and a copper tube receiver.

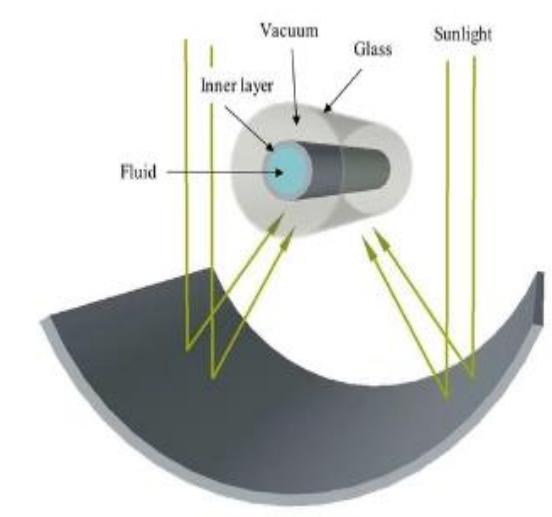


Fig 1. Parabolic Trough Solar Collectors.

Securing a consistent energy supply to power our societies has become crucial in our rapidly developing and evolving planet in order to move forward and protect the natural resources around. The development of renewable energy, such as that obtained from solar collectors, can contribute to giving people around the world a dependable and secure source of power. Water can be heated with evacuated solar tubes in a safe, cost-effective, and efficient way. Because

of their strong and long-lasting construction, they can be successfully used in a wide range of geographical areas and climates. The evaluation of improvements made to evacuated solar tubes' output efficiency for water heating by the inclusion of solar reflectors behind the tubes in various geometric configurations is the main objective of this work.

Water can be heated with evacuated solar tubes in a safe, cost-effective, and efficient way. They may be successfully used in many different geographical areas and climates because of their strong and long-lasting construction. The evaluation of improvements made to evacuated solar tubes' output efficiency for water heating by the inclusion of solar reflectors behind the tubes in various geometric configurations is the main objective of this work. The technique used was to examine a number of quantifiable characteristics through each test configuration in order to assess how well each test performed thermally. As a result, a device was built, and four distinct configurations—a flat background, a 45° V-shaped background, a 60° V-shaped background, and a half-circle background—were evaluated at various distances. Following analysis.

After analyzing the data and weighing the advantages and disadvantages of each arrangement, it was discovered that the energy absorbed by the solar tubes increased in every situation where reflectors were used. Additionally, each test configuration demonstrated an increase in the amount of heat produced and efficiency. It was determined that the -shape configuration is the most advantageous because there was a considerable reduction in power usage for the 60° V-Shape tubes at 15.25 cm.

A thorough mathematical approach was established to estimate the daily collected radiation on a single glass tube within an evacuated tube solar collector arrangement in order to evaluate evacuated solar tube technology. This model was built using information about solar geometry, two-dimensional radiation trans, tilt angle, orientation (the way the equipment is facing), the use of evacuated tube collectors with solar water heating (ETCSWH), and, finally, the location and the solar radiation potential associated with it.

The principal human activity that produces CO<sub>2</sub> is the burning of fossil fuels (coal, natural gas, and oil) to produce energy. Currently, the world's population is greatly dependent on these resources, which give off enough electricity to run it. The largest single source of CO<sub>2</sub> emissions, which accounted for around 37% of all United States (U. S.) CO<sub>2</sub> emissions and 30% of all U. S. greenhouse gas emissions in 2014, is the burning of fossil fuels to produce electricity. The reason there is such support for the development of clean energy generating technologies like solar is due to the tremendous cost to our ecosystem.

Lower CO<sub>2</sub> emissions would result in a safer, cleaner environment, better air quality, and lower disease and health care expenses. Additionally, less gasoline use lowers the budget for fuel for individuals, businesses, and the government, allowing for other uses of the money.

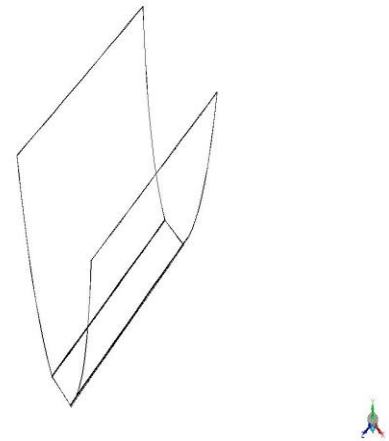
Due to shadows and a lack of sunlight exposure along the backboard facing half of the solar tubes, traditional EST systems without a back reflector are susceptible to solar radiation absorption loss. In order to identify and analyse the best reflector design for future EST deployments, this research project will examine the technology of evacuated solar tubes. This study's objective is to increase the output efficiency of evacuated solar tubes for water heating by incorporating high efficiency reflectors behind the tubes in a geometrical configuration that maximises their performance.

## II. MODELING OF SOLAR COLLECTOR

- Comparison of mass flow rate for the temperature distribution
- The comparison of thermal efficiency of Alumina and CuO at a mass flow rate of 0.0112 Kg/s and 0.0224 Kg/s
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- Here used to analyse the behaviour of absorber tube material and effect of flow rate on efficiency. The simulation was carried out using two different type of nanofluids (Al<sub>2</sub>O<sub>3</sub>) and CuO) with two values of 0.0112 Kg/s and 0.0224Kg/s.
- CFD simulations were used to analyse the behaviour of absorber tube material and effect of flow rate on efficiency. The simulation was carried out using two different type of nanofluids (Al<sub>2</sub>O<sub>3</sub>) and CuO with two values of 0.0112 Kg/s and 0.0224 Kg/s.
- Comparison of mass flow rate for the temperature distribution



(a)



(b)

Fig 2. Design of Parabola.

The decision was made to choose a fixed number from among the numerous configurations of reflectors for the solar tubes in order to achieve the best reflector position while still providing a manageable number for testing. This fixed number would give a range of performance over the reflector angle. The creation of multiple reflector configurations was the first step in the procedure.

For this study, five different arrangements were to be evaluated and tested: a black material background (the control scenario), a reflective background, two different V-shaped backings (45° and 60°), and a half-circle backing with reflective paper made by 3M Corporation. The control side was designed with a black wooden background.

The following assumptions were utilized throughout the completion of this experiment: heat transfer process was steady and conduction from walls of the glass tubes through the structure was negligible. The strategy implemented was to analyze several variables that would be measurable through each test conducted, in order to determine the thermal performance of each test. The test apparatus consisting of two parts was completed where each part was comprised of three double-glass solar tubes. The first part (on the left) would act as the control, while the second part would be considered as the experimental component. The tests for the two parts were conducted simultaneously, in order to minimize errors.

Furthermore, several tests were performed during various weather conditions in order to consider a variety of climate influences. A total of 32 tests were conducted in Morgantown, WV, USA at 39.65° north latitude and 79.92° west longitude, between February and May 2015 with an average of 4.6 hours per test for a total of 192 hours of testing. Several solar tubes were arranged in an array for each configuration with the tubes anchored at the top and bottom of the apparatus. These tubes were then directly fed into the designated manifold along the top.

Inside each of the solar tubes was a hollow copper rod that was filled with acetone compound. Therefore, as heat was captured within the solar tube, it passed through the central copper rod and began to heat up the acetone.

In turn, the acetone evaporates and rises to heat the top of the tube, where a bulb was located. This bulb was located within a copper jacket that was then placed within another horizontal copper pipe that spans across the length of the manifold (Ma et al., 2010). Water continually circulates throughout this horizontal pipe via the copper jackets that received heat from the solar tube's bulb, which then allowed for the collection of heat from the copper jackets. Solar radiation arriving at the Earth's surface is a fairly dispersed energy source. The photons comprising the solar radiation can be converted directly to electricity in photovoltaic devices, or, in concentrating solar power (CSP). In the latter case, the solar radiation heats up a fluid that is used to drive a thermodynamic cycle.

Opposed to photovoltaic cells or flat plate solar thermal collectors, the diffuse part of the solar irradiation which results from the scattering of the direct sunlight cannot be concentrated and can therefore not be used in CSP power plants. In the CSP technology, concentration of sunlight using mirrors or optical lenses is necessary to create a sufficiently high energy density and temperature level. Solar concentrating systems enable the thermal conversion to be carried out at high solar flux and with relatively little heat loss. Different solar concentrating technologies are today developed and demonstrated in solar market and can be divided according to the method of concentration in two groups: line concentrating and point concentrating.

The receiver tube or heat collector element (HCE) is the main component of parabolic trough solar technology. It is composed of an inner steel tube with a selective coating surrounded by an anti-reflective evacuated glass tube. The HCE incorporates conventional glass-to-metal seals and metal bellows to ensure vacuum in annular zone and accommodate for thermal expansion difference between the steel and glass tubes. The vacuum in the HCE is typically maintained at about 0.013 Pa to reduce convection losses within the annulus.

A typical selective coating used above the steel tube is the multilayer cermet coating which result in excellent selective optical properties with high solar absorptivity and low thermal emissivity. Receiver tube is generally about 4 m long between the support braces that support it at the focal line and can be extended to 150 m. The inner steel tube is about 70 mm outside diameter and the glass envelope tube is about 115 mm outside diameter [10]. An aluminium shield is usually used to protect welds and chemical getter (metallic compounds) are also placed in the vacuum space to eliminate gas molecules such as hydrogen that permeate into the vacuum annulus over time.

PTC reflectors have a high specular reflectance (greater than 88%) to reflect as much solar radiation as possible. The reflectors are usually made from low-iron float glass (about 4mm) with high solar transmittance. The mirrors are commonly silvered on the back and covered with several selective coatings since their durability and solar reflectance are better than the polished aluminum and metalized acrylic which are also available in the market. Solar reflectance is about 0.93 for silvered glass mirrors and 0.87 for polished aluminum.

The parabolic reflectors held by a steel support structure on pylons in the foundation. Ceramic pads used for mounting the mirrors to the collector structure are attached with a special adhesive. The installation and mounting of the support structure has high influence on the total plant performance. The support structure has to meet the following structural requirements.

### III. RESULTS AND DISCUSSION

The amount of energy captured (effective heat transfer), the efficiency of energy affecting the tubes compared to energy retrieved in the manifold, and the impacts of the angle of incidence of the solar radiation were all analyzed as results. The four alternative combinations have each yielded fruitful outcomes. All ensuing trends and data were taken into consideration in order to choose the most efficient arrangement. Table 1 compares each reflector configuration's average heat transmission to the control side, which has no reflectors other than the wood it is placed on and has remained the same throughout each test. The highest amount of heat transferred from both the control and experimental sides was used to compute the average heat transfer.

The highest amount of heat moved from both the control and experimental sides were added together to determine the average heat transfer, which was then calculated as a percent increase from those two figures. Due to its ability to display the largest gain that may be produced, this test enables inquiry into the "potential" that a configuration has. The information gathered and the various scenarios in which the tests were carried out are summarized below. Most of the examinations lasted 5.5–6.5 hours, starting at 10.30 AM and concluding around 3.30–4.30 PM. During the testing, the sun azimuth changed, often ranging from 20° at the beginning to 68° later in the afternoon.

The first two test setups consisted of a flat backing with a layer of black material on top. Tests were performed on the same day at a distance of 15.25 cm between the backboard and the centre of the solar tube. The average increase in heat transmission was 15%. On a sunny day, the second test was likewise carried out at a distance of 10.20 cm between the centre of the solar tubes and the backboard. The second test saw a significantly better increase in heat transmission, at 140%. The following tests

were carried out with a flat, reflective backing. Two exams altogether were carried out. On a sunny day, the first test was performed at 15.25 cm. The average increase in heat transmission was 82%. The second test was performed 10.20 cm from the solar tubes' centres. on a beautiful day as well. The increase in heat transmission was 78%. With 45° V-shaped reflective backing, two tests were run. The first test was performed at 15.25 cm, and it was a sunny day. The average increase in heat transport was 136%. The results of the second test, which was carried out at 10.20 cm, were extremely encouraging. The test was conducted in sunny conditions with a 148% increase in heat transmission. Two further experiments were carried out using reflective backing that had a 600 V shape.

The test was conducted with sunshine present throughout at a distance of 15.25 cm, and the findings revealed an average increase in heat transmission of 161%. The second test, however, was carried out 10.20 cm from the solar tubes' centre, and the increase in heat transfer was 72%. The last round of testing was carried out inside a half-circle measuring 15.25 cm in diameter and lined with reflective material. As closely as feasible to the focal point, the solar tubes were positioned. The entire test was conducted in the sun, which resulted in a 94% increase in heat transmission.

The ultimate purpose of a finite element analysis is to recreate mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. In the broadest sense, this model comprises all the nodes, elements, material properties, real constants, boundary conditions, and other features that are used to represent the physical system. In ANSYS terminology, the term model generation usually takes on the narrower meaning of generating the nodes and elements that represent the spatial volume and connectivity of the actual system. Thus, model generation in this discussion will mean the process of defining the geometric configuration of the model's nodes and elements.

The ANSYS program offers you the following approaches to model generation:

- Creating a solid model within ANSYS.
- Using direct generation.
- Importing a model created in a computer-aided design (CAD) system.
- Solid Modeling In the solid modeling,
- Is generally more appropriate for large or complex models, especially 3-D models of solid volumes.
- Allows you to work with a relatively small number of data items.
- Allows geometric operations (such as dragging and rotations) that cannot be done with nodes and elements.
- Supports the use of "primitive" areas and volumes (such as polygonal areas and cylindrical volumes)

and Boolean operations (intersections, subtractions, etc.) for "top down" construction of your model.

- Facilitates your use of the ANSYS program's design optimization features.
- Is required for adaptive meshing.
- Is required in order to do area mesh refinement after loads have been applied (solid model loads are also required).
- Readily allows modifications to geometry.
- Facilitates changes to element distribution; you are not bound to one analysis model.

Meshing: Your ultimate objective in building a solid model is to mesh that model with nodes and elements. Once you have completed the solid model, set element attributes, and established meshing controls, you can then turn the ANSYS program loose to generate the finite element mesh. By taking care to meet certain requirements, you can request a "mapped" mesh containing all quadrilateral, all triangular, or all brick elements.

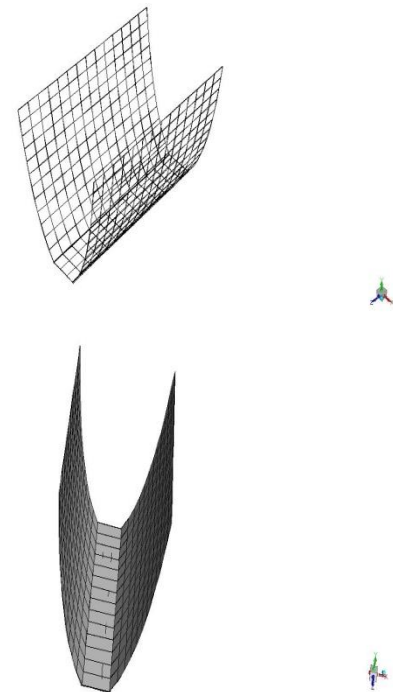


Fig 3. Design of Parabola.

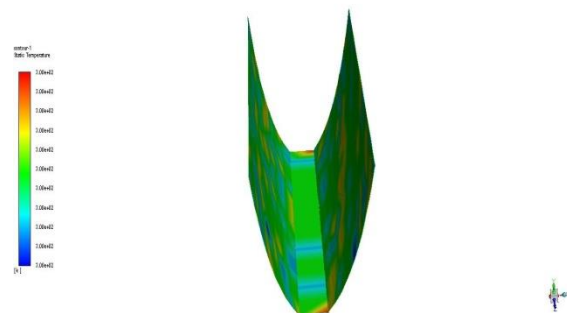


Fig 4. Stress analysis.

#### IV. CONCLUSIONS

When compared to the control configuration model, all of the evaluated configurations demonstrated higher heat generation efficiency. The 60o V-shaped configuration at 16.30 cm and the 45o V-shaped configuration at 12.20 cm were the two best options. The shadowing on the back and sides of the solar tube had the most impact on reflector performance. The most effective reflector angles were 45° and 60°. The shallower 60° angle, however, allowed for more solar radiation to reach the tube in the late afternoon because the bulb was not as shaded. With these setups, the results' sensitivity is near, but it quickly declines at different angles. This leads to the conclusion that the 60o layout is the most advantageous because of how much more sunlight can enter the reflective valley due to its larger angle.

The problems with the setting sun that were mentioned earlier impact the half-circle configuration and may also affect the 45o configuration. In conclusion, EST is a promising renewable and secure energy source that taps into the planet's most plentiful supply of clean natural energy. It is energy-efficient, environmentally benign, and has the ability to generate enough of useful energy for the population while lowering thousands of tonnes of CO<sub>2</sub> annually. It makes sense to move the complete system of solar tubes such that it faces the sun's direct light. The shading impact of sun azimuth on a stationary solar tube configuration is depicted in Figure 6's graph. The shadow on the back and side of the tubes would be reduced, leading to higher efficiency, if the solar tube system could be orientated to face the sun at all times. Future research on this should be done.

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