# Modeling and Analysis of Solar Flat Plate and Parabolic Trough Collectors

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**Abstract:** Solar thermal energy collector can be described as an energy balance between the solar energy absorbed by the collector and the thermal energy removed or lost from the collector. If no alternative mechanism is provided for removal of thermal energy, the collector receiver heat loss must equal the absorbed solar Energy.
This paper will focus on thermal and CFD analysis with different fluid air, water and different solar collector's i.e. flat plate and parabolic trough was modeled by using SOLIDWORKS design software. Thermal analysis has done one the solar collectors with different materials (aluminum & copper). These values are taken from CFD analysis. Furthermore, CFD analysis to determine the heat transfer coefficient, heat transfer rate, mass flow rate, pressure drop and thermal analysis to determine the temperature distribution, heat flux with different materials.

**KEYWORDS:** Flat plate, parabolic trough, CFD, SOLIDWORKS



DOI of the Article: https://doi.org/10.46501/IJMTST0707064

Available online at: http://www.ijmtst.com/vol7issue07.html



**To Cite this Article:** D Archana and Dr K.Vasantha Kumar. Modeling and Analysis of Solar Flat Plate and Parabolic Trough Collectors. *International Journal for Modern Trends in Science and Technology* 2021, *7*, pp. 391-396. https://doi.org/10.46501/IJMTST0707064

**Article Info.** Received: 14 June 2021; Accepted: 12 July 2021; Published: 27 July 2021

## INTRODUCTION

A parabolic trough is a type of solar thermal energy collector. It was constructed as a long parabolic mirror (usually coated silver or polished aluminum) with a Dewar tube running its length at the focal point. Sunlight is reflected by the mirror and concentrated on the Dewar tube. The trough is usually aligned on a north-south axis, and rotated to track the sun as it moves across the sky each day. Alternatively the trough can be aligned on an east-west axis; this reduces the overall efficiency of the collector, due to cosine loss, but only requires the trough to be aligned with the change in seasons, avoiding the need for tracking motors. This tracking method works correctly at the spring and fall equinoxes with errors in the focusing of the light at other times during the year (the magnitude of this error varies throughout the day, taking a minimum value at solar noon). Due to these sources of error, seasonally adjusted parabolic troughs are generally designed with a lower solar concentration ratio.

A. Flat Plate Collectors

These collectors consist of airtight boxes with a glass, or other transparent material, cover. There are several designs on the arrangement of the internal tubing of flat plate collectors as shown in Figure 1.

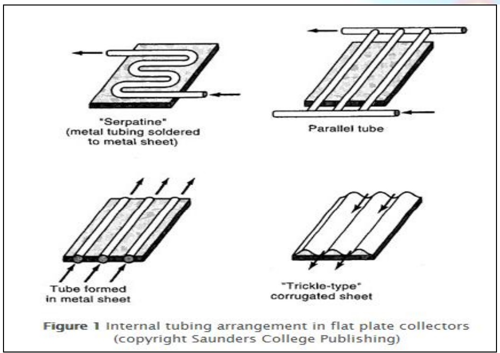



Figure 1 Internal tubing arrangement in flat plate collectors (copyright Saunders College Publishing)

**Fig.1.internal tubing arrangement in flat plate collectors**

Traditional collectors, like the Serpentine and Parallel tube examples above, consist of a number of copper tubes, known as risers that are orientated vertically with respect to the collector and placed in thermal contact with a black colored, metal absorbing plate. The use of selective surfaces on absorbers improves the efficiency of solar water heaters significantly due to a very high absorbance (percentage of incoming energy that a material can absorb) and low remittance (percentage of energy that a material radiates away) of electromagnetic radiation. At the top and bottom of the metal absorbing plate, thicker copper pipes, known as headers, assist in the removal of heated water and the arrival of colder water to be heated. Insulation is placed between the absorbing plate and the external wall to prevent heat losses.

Whilst the principles of operation for flat plate collectors are fairly consistent, significant improvements in the design of systems, particularly absorber plates have occurred. Flooded plate collectors are similar to their tubed cousins, except that two metal absorbing plates are sandwiched together, allowing the water to flow through the whole plate. The increased thermal contact results in significant improvements in the efficiency of the system. In recent years, much research has been conducted on selective surfaces, which has seen significant improvements in the efficiency of solar water heaters. Today, a majority of absorber plates are composed of solar selective surfaces, made of materials that strongly absorb electromagnetic radiation (i.e. sunlight) but only weakly emit.

## LITERATURE REVIEW

**A Novel Parabolic Trough Concentrating Solar Heating for Cut Tobacco Drying System.[1]** A novel parabolic trough concentrating solar heating for cut tobacco drying system was established. The opening width effect of V type metal cavity absorber was investigated. A cut tobacco drying mathematical model calculated by fourth-order Runge-Kutta numerical solution method was used to simulate the cut tobacco drying process. And finally the orthogonal test method was used to optimize the parameters of cut tobacco drying process. The result shows that the heating rate, acquisition factor, and collector system efficiency increase with increasing the opening width of the absorber. The simulation results are in good agreement with experimental data for cut tobacco drying process.

**Design, Fabrication and Experimental Testing of Solar Parabolic Trough Collectors with Automated Tracking Mechanism.[2]**

This paper was concerned with an experimental study of parabolic trough collector's with its sun tracking system designed and manufactured. To facilitate rapid diffusion and widespread use of solar energy, the systems should also be easy to install, operate and maintain. In order to improve the performance of solar concentrator, different geometries and different types of reflectors were evaluated with respect to their optical and energy conversion efficiency. To assure good performance and long technical lifetime of a concentrating system, the solar reflectance of the reflectors must be high and long term stable.

Development of a Compound Parabolic Solar Concentrator to Increase Solar Intensity and Duration of Effective Temperature.[3] For efficient drying of product through indirect drying method, a compound parabolic concentrator (CPC) was installed. Six numbers of semi-cylindrical parabolic concentrators were interpolated on are Receiver plate for direct conversion of solar energy to thermal energy by trapping the maximum incident rays into metallic tubes which were placed on focus lines of the parabolas. Experiments were carried to study the comparative performance of a solar flat plate collector and compound parabolic concentrator of same size.

Dehydration of Persimmon by Concentrating Parabolic Trough Solar Air Heater. [4] Parabolic Trough Solar (PTS) air heater was developed locally to solve the drying of persimmon with a parabolic trough and a drying box which contains a reflected steel sheet, an absorber tube, an angle iron and a fully insulated home script refrigerator. Solar irradiance results were noted for the months of Oct- Dec, 2012. Four air mass flow rates were conducted with one natural flow rate of 0.53 kg minute-1 (M-1) and three convective air mass flow rates of 1.35 kg M-1, 1.87 kg M-1 and 1.97 kg M-1 respectively.

## MODELING AND ANALYSIS OF PARABOLIC SOLAR TROUGH AND FLAT PLATE COLLECTORS

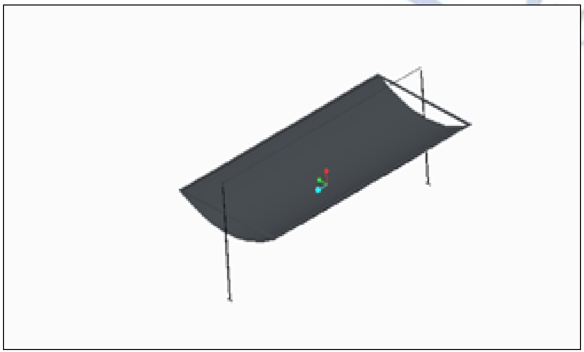


**Fig: 2 3D model of parabolic trough**

**Design Parameters:**

Diameter of parabolic trough-225mm

Length -1115mm

Stand height- 400 mm

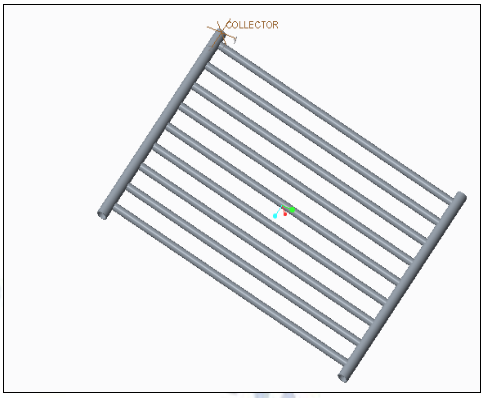



**Fig: 3 3d Model of Flat plate collector**

**Design Parameters:**

Diameter of tube-30mm

Length -1005mm

Thickness -6mm

### A. ANSYS

ANSYS is capable of both steady state and transient analysis of any solid with thermal boundary conditions. Steady-state thermal analyses calculate the effects of steady thermal loads on a system or component. Users often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis; performed after all transient effects have diminished. ANSYS can be used to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time.

### B. CFD

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial experimental validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

**Refrigerant properties**

**R- 30 properties**

Density = 1326.6 kg/m3

Specific heat = 1043.0 j/kg/k

Thermal conductivity = 0.0042 w/m-k

Viscosity = 0.000279 kg/m-s

**R-160 properties**

Density = 921.0 kg/m3

Specific heat = 1023.0 j/kg/k

Thermal conductivity = 0.0337 w/m-k

Viscosity = 0.00043 kg/m-s

## ANALYSIS OF SOLAR FLAT PLATE AND PARABOLIC SOLAR TROUGH

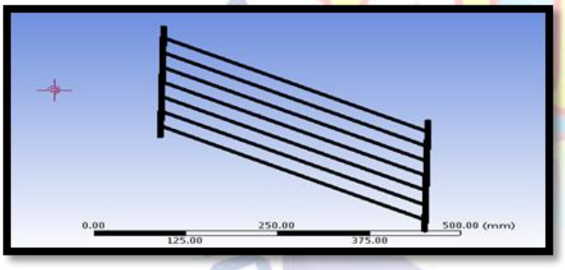



Fig 4: Meshed model

The model is designed with the help of SOLIDWORKS and then import on ANSYS for Meshing and analysis. The analysis by CFD is used in order to calculating pressure profile and temperature distribution. For meshing, the fluid ring is divided into two connected volumes. Then all thickness edges are meshed with 360 intervals. A tetrahedral structure mesh is used. So the total number of nodes and elements is 6576 and 3344.

**CFD Boundary conditions**

Mass Flow Rate → 0.0105Kg/s and Inlet Temperature – 303K

**Thermal analysis Boundary conditions**

Temperature – 313K

Convection -1.80e+03

### a) CFD ANALYSIS OF SOLAR FLAT PLATE

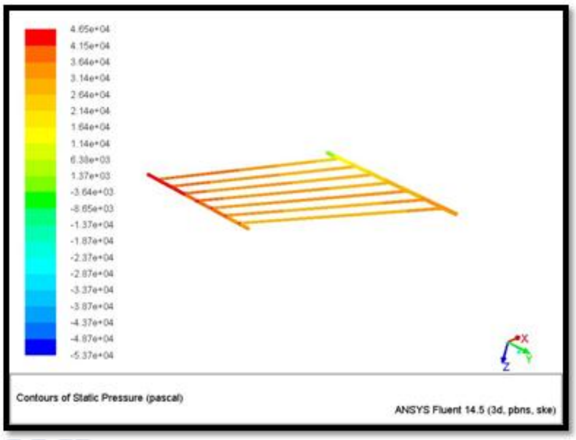



Fig 5: Static Pressure

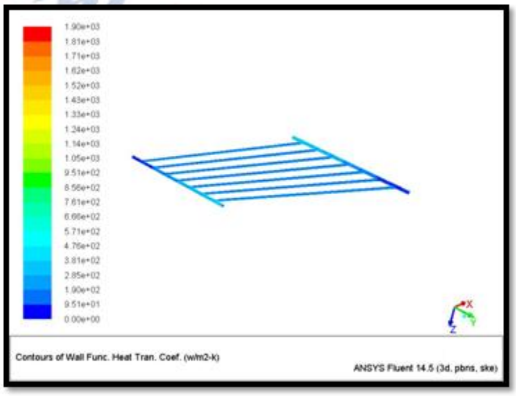
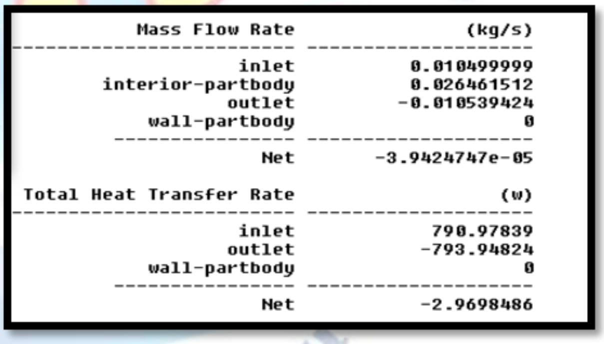



Fig 6: heat transfer coefficient



| Mass Flow Rate | (kg/s) |
|---|---|
| inlet | 0.010499999 |
| interior-partbody | 0.026461512 |
| outlet | -0.010539424 |
| wall-partbody | 0 |
| Net | -3.9424747e-05 |

| Total Heat Transfer Rate | (w) |
|---|---|
| inlet | 790.97839 |
| outlet | -793.94824 |
| wall-partbody | 0 |
| Net | -2.9698486 |

Fig 7: Mass Flow Rate

### b. CFD Analysis of Parabolic Solar Trough

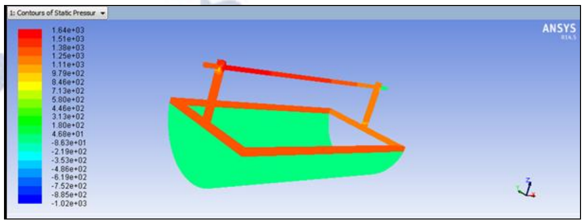



Fig 9: Static Pressure

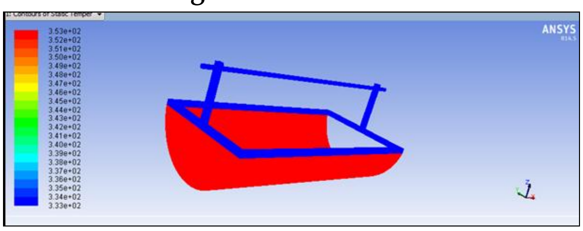



Fig 10: Temperature

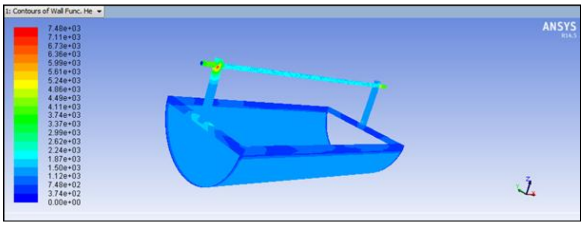


Fig 11: heat transfer coefficient

```
        Mass Flow Rate                    (kg/s)
-------------------------------- --------------------
                 inlet              1.4999995
      interior-____msbr            -9.4357023
                outlet             -1.5012258
          wall-____msbr                     0
        ---------------------- --------------------
                   Net           -0.001226306
```

Fig 12: Mass Flow Rate

```
Total Heat Transfer Rate                    (w)
---------------------------- --------------------
                  inlet              218614.02
                 outlet             -219101.16
           wall-___msbr              310.48871
           ----------------- --------------------
                    Net             -176.65192
```

Fig 8: Heat Transfer Rate

### c. Thermal Analysis of Solar Parabolic Trough

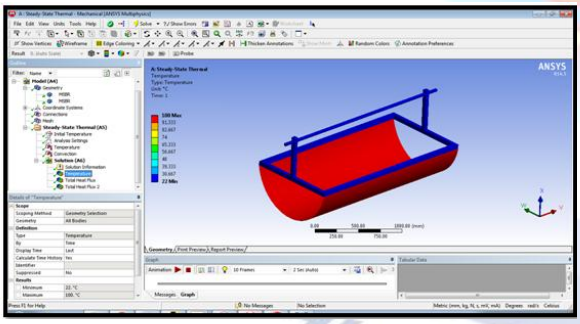


Fig 13: Temperature

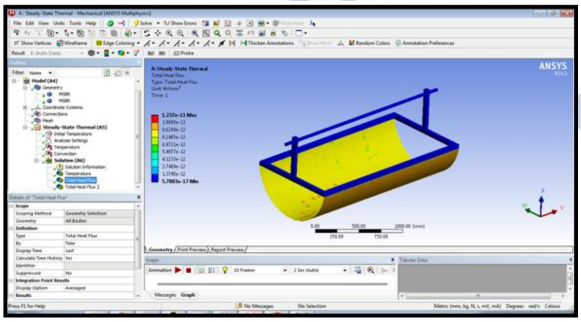


Fig 14: Heat flux

### d. Thermal Analysis Solar Flat Plate Collector

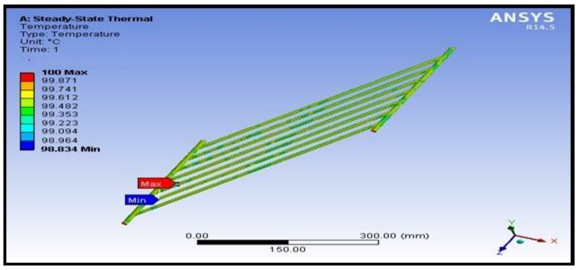



Fig 15: Temperature

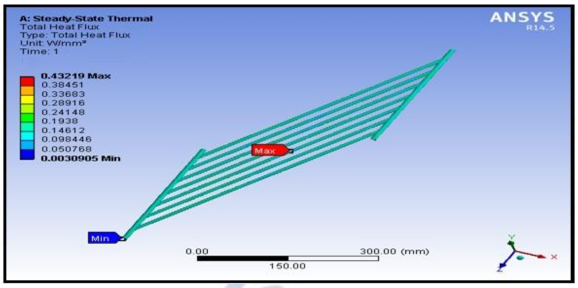



Fig 16: heat flux

## RESULTS AND DISCUSSIONS

### A) CFD ANALYSIS

In this CFD analysis the heat transfer rate was found by using the different refrigerants.

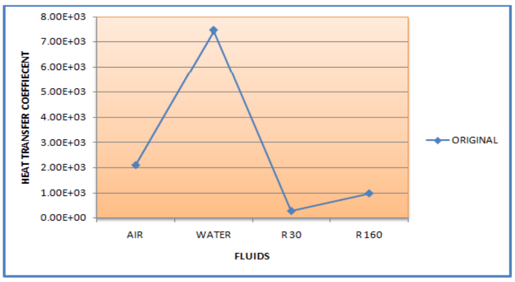
**Table: 1 CFD Analysis results of Solar Flat Plate**

| Fluids | Pressure (Pa) | Heat transfer coefficient (w/m$^2$-k) | Mass flow rate (kg/s) | Heat transfer rate(w) |
|---|---|---|---|---|
| AIR | 3.55e+004 | 1.44e+03 | 1.0958e-05 | 0.82574 |
| WATER | 4.65e+04 | 1.90e+03 | 3.9424e-05 | 2.9698 |
| R30 | 4.68e+04 | 1.64e+03 | 2.5503e-05 | 1.920105 |
| R160 | 3.70e+04 | 1.22e+03 | 5.0231e-05 | 3.1235e-05 |

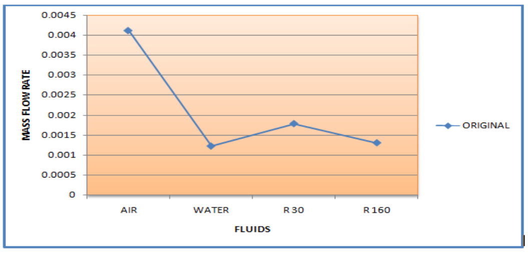
**Table: 2 CFD Analysis results parabolic trough**

| FLUID | PRESSURE (pa) | HEAT TRANSFER COFEEICENT | MASS FLOW RATE | HEAT TRANSFER RATE |
|---|---|---|---|---|
| AIR | 1.30E+06 | 2.11E+03 | 0.00412 | 150.8656 |
| WATER | 1.64E+03 | 7.48E+03 | 0.0012263 | 176.651 |
| R 30 | 1.24E+03 | 2.87E+02 | 0.001788 | 48.89 |
| R 160 | 1.79E+03 | 9.84E+02 | 0.0013078 | 51.32959 |

**Graph: 1 plotted between heat transfer coefficient and different working fluids**



**Graph : 2 plotted between mass flow rate and different working fluids**




Taking into account the effects of the above CFD study, the coefficient of heat transfer is more for parabolic trough collector. By comparing the results between fluids the heat transfer coefficient is higher for refrigerant R30.

### B) THERMAL ANASYSIS

In this thermal analysis, the rate of heat transfer for different materials is shown below.

**Table: 3 Thermal analysis results of parabolic trough**

| MATERIAL | HEAT FLUX |
|---|---|
| STEEL | 1.7002E-12 |
| ALUMINUM ALLOY | 4.5574E-12 |
| COPPER | 1.237E-11 |

**Table: 4 Thermal analysis results of solar flat plate**

| MATERIAL | HEAT FLUX |
|---|---|
| Aluminum alloy | 0.42828 |
| Copper alloy | 0.43219 |

By comparing the results between materials the heat transfer coefficient is higher for copper.

## CONCLUSION

In this paper, the fluid flow through solar collectors (flat plate and parabolic trough) is modeled using design software. The thesis will focus on thermal and CFD analysis with different fluids air, water, R30 and R60 of the solar collectors. Thermal analysis done for the solar collectors by aluminum & copper materials.

By observing the CFD analysis the pressure drop & velocity values are more for water fluid at solar parabolic trough collectors compared with flat plate collector. The more heat transfer rate at fluid water.

By observing the thermal analysis Heat flux value is more for copper material than aluminum and steel at solar collectors

So we can conclude the copper material is better for solar collectors.

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