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In-Depth Analysis of Thermal Performance in a Solar Water Heating System Featuring Heat Pipe Evacuated Tube Collectors

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Abstract:
Solar water heating (SWH) uses solar thermal collerters to turn sunshine into heat, which warms up a working fluid so that it can be used to heat water.
The main study or purpose is to look at the solar energy can be used in hot water system focusing on evacuated tube collecters, when these collectors are used with heat pipe technology, they could make energy costs, usage patterns and the general efficiency of making hot considerably better.
An evacuated tube collectors that work as a heat pipe was made using CREO parametric software and after that ANSYS software was used to do a through study of the model. This study is looking at different mass flow rates and temperatures.
Important parameters for the evacuated tube collectors with heat pipe was study in to the computational fluid dynamics(CFD), Pressure drop, speed, mass flow rate, heat transfer coefficient, and heat transfer rate were some of these factors. Along with the research, a thermometric study was done to measure how much temperatures were distributed and how much heat moved at different times of the year.
The study's results tell us a lot about how well the evacuated tube collector with heat pipe technology works in different situations. The estimated pressure drop, velocity, and heat transfer characteristics give a full picture of how the system works. The thermometric study also gives important information about how temperatures are distributed and how heat moves through the system during different months.
As part of ongoing efforts to use solar energy in the real world, especially for making hot water, this study adds to those efforts. The study aims to help us learn more about how to use solar energy to make hot water in a way that is both efficient and long-lasting by mixing advanced modeling methods with in-depth analysis.

Keywords: Using CREO and ANSYS soft wares was used to the study of the an evacuated tube collectors to the hat pipes.

INTRODUCTION TO SOLAR WATER HEATING SYSTEM

Solar water heating system is a device that helps in heating water by using the energy from sum, this energy is totally free. Solar energy (sun ray) is used for heating of water, water is easily heated temperature of 60- 80°C. The solar water heaters capacity is100-300 liters' maximum suited for the domestic uses.

Also larger systems can be used for the restaurant's, canteens, guest houses, hotels, hospitals, industrial purpose etc.

The sun's energy can be used to heat water for home use through solar water heating. A person normally uses around 20 to 30 gallons of hot water every day. Gallon is a measurement of water ;1 gallon is equal to 4.55 liters of water. This means that a family of four will need between 2,400 and 3,600 gallons of hot water a year, all of which can be given for free by solar energy.

The solar water heating system is made to meet the current hot water needs of your family, so your habits and way of life will not change. The only change you'll notice once the solar water heating system is set up is in your monthly utility bill.

Working of solar water heating system

The solar water heating system is depnds on the sun rays fall on the collectors panel. A black absorbing surface(absorber) inside the collectors absorbs solar radiation and transfers the heat energy to water flowing through it. Heated water is collected in a tank which is insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues automatically due to thermo siphon system.

Based on the collector system, solar water heating can be two types

- A solar water heating constis of a colletor to collect solar energy and an insulated storage tank to store hot water.
- The stored hot water can be used later any time.
- Main components of solar water heating system
- Solar collectors
- Insulated tank
- Supporting stand
- Connecting pipes and instrumentations etc.

The solar water heater for your home is an easy, maintenance-free way to quickly lower your monthly energy costs. Flat plate and evacuated tube solar hot water systems work in the same way.

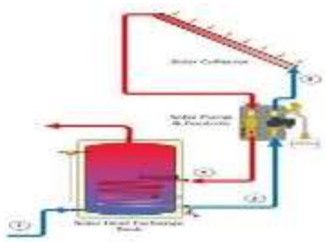


Fig: 1 Home Solar Water Heating System Work

The solar water heating system is mainly used two type of water heating systems available in the markets. They are

- **Flat plate solar water heaters and**
- **Evacuated tube collectors**

Applications:

Over a quarter of the energy used in the average American home goes to heating water. People often cook, wash dishes, do laundry, take showers, and clean with this hot water. A solar hot water system is a great way to save money on energy costs that keep going up.

It is common to use evacuated tube collectors in places where winters are long and cold or where it clouds up a lot. An evacuated tube is much less sensitive to cold temperatures than its flat plate peers because of the way it is built. This means that these systems can heat water for your whole family for free, even on the coldest days.

People who live in homes with large families (three or more people), homes in the middle to northern United States (above the Mason-Dixon Line), and homeowners who want a high-performing collector all year round can all use evacuated tube collectors successfully. Putting in a solar hot water system can help you in many ways.

Money Saving factor:

Using the sun to heat or "preheat" the water in your home can help you save a lot of money on your water heating bill. A lot of people who use solar hot water systems say that their hot water heating bills go down by up to 80%. More than a third of the average American family's power bill goes to heating water. This means that a solar water heating system can lower your bills right away, saving you money over time.

Resources utilization Better and Cleaner Environment:

It is contributes to better and cleaner environment by efficiently utilizing renewable solar energy to heat water. Significantly reducing the reliance on fossil fuels which is produced greenhouse gasses, thereby minimizing air pollution and promoting sustainable resource usage.

Essentially, it harnesses a clean readily available energy source to meet hot water needs without generating harmful emissions Key points for solar water heating system contributes a better and cleaner environment.

- Reduced carbon emissions
- Renewable energy sources
- No air pollution
- Energy efficiency
- Low energy consumption
- Minimal environmental impact
- Grid relief

More Hot Water Availability: -

When you get a solar water heating system, a solar tank is usually added to work with your current hot water tank. You'll be able to store twice as much and get twice as much hot water. You don't have to worry about your electric bill going up when you have friends or visitors over or when you want to take an extra-long soak in the tub. It will be warmer and there will be more water.

Thermo-siphon frameworks:

When thermosiphon devices are used, water moves through them because warm water rises and cool water sinks. So that warm water can rise into the storage tank, the skimmer has to be put below it.

Even though these systems work well, the weight of the holding tank means that the roof needs to be carefully planned. Most of the time, they cost more than inactive systems with integrated collectors and storage.

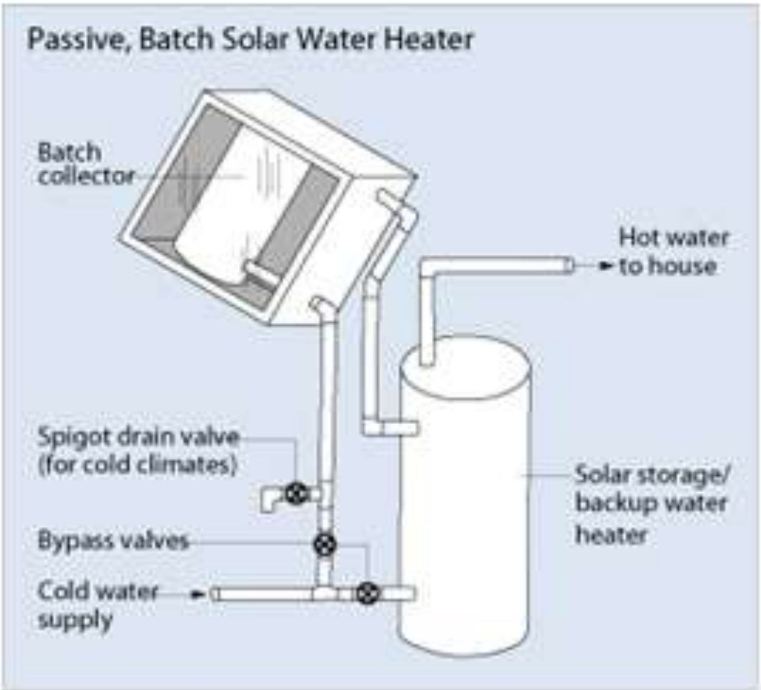


Fig:2 Passive, Batch Solar Water Heater

SOLAR COLLECTORS:

A holding tank that is well insulated is needed for most solar water heaters. There is an extra outlet and inlet linked to and from the collector on the solar storage tanks. In setups with two tanks, the solar water heater warms the water up before it goes into the regular water heater. In one-tank setups, the backup heater and the solar storage are both housed in the same tank.

There are three types of sun collectors that are used in homes:

- Flat plate collectors
- Evacuated tube collectors
- Line focus collectors
- Point focus collectors

REVIEW CRITERIA

The work by M.V. Kulkarni and Dr. D. S. Deshmukh (2014) [1] was mostly about a PCM-type solar water heater. The setup had two heat-absorbing units that worked at the same time. There was one that heated water with sun power and another that stored heat in PCM (paraffin). Normally, the solar water heater heated water during the day. The storage unit, on the other hand, saved heat in PCMs during the day and heated water at night.

In 2012 [2], Eze J. I. and Ojike O. looked into how thermally efficient a passive solar water heater with two tanks for cold and warm water was. Copper pipes were placed in a spiral shape in this design.

In 2012 [3], P. Selvakumar and Dr. P. Somasundaram looked into how the tilt angle of a solar water heater affects how well it heats water. The study looked at the temperatures of drained tubes that were tilted at angles from 0° to 90°. The study's goal was to show that different angles, depending on the needs of the application, could make solar water heaters more appealing in a world that cares about the environment.

Concerns about cost and difficulty were put to rest by the study, which found that lower prices and easier use could get more people to switch from electric water heaters to solar ones.

In Morrison et al.'s study from 2004 [4], water-in-glass sealed tubes were looked at. The results showed that evacuated tube solar collectors worked better than flat plate collectors when used in hot conditions. People thought that water-in-glass tube collectors were better for home use because they were clear and cheaper. These tubes were very famous, especially in China and Europe. In fact, many Indian solar water heater makers buy evacuated tubes from China. The market for solar water heaters with evacuated tube collectors is growing quickly because they are cost-effective and work better than other types. A 100 LPD solar water heater can be installed in as little as 30m2.

MODELING AND ANALYSIS

In the modeling and analysis of the in-depth analysis of thermal performance in a solar water heating system featuring heat pipe evacuated tube collectors process through its Mechanical Design Software called Creo Parametric (originally Pro/Engineer). Parametric technology corporation (PTC) has deep roots in the field of Computer Aided Design/Engineering (CAD/CAE). PTC now has a wide range of products, such as apps for Engineering Math, Aggregates

- Product Lifecycle Management (PLM),
- Internet of Things (IOT), and
- Augmented Reality (AR).

Computerized Product Development utilizing PLM, IOT and AR at first, PTC's products were mostly CAD/CAE programs, but now they offer a wide range of digital product creation programed. PTC's most popular augmented reality (AR) programed, Thing Worx Studio, draws on accurate 3D models of an environment to add to it. The electronic PLM system Wind-chill uses the detail of a 3D assembly to make it easy to make and keep track of different versions of a product to meet customer needs. Then, both of these different technologies can be combined with the IOT-like architecture of the Thing Worx platform. This lets an AR training programmer use data from the PLM system to correctly judge how well it teaches, which is a real technological revolution.

CREO

Even though PTC has a lot of options, the Creo software suite is still its most famous and well-known CAD/CAE product. The main goal of PTC's Creo software suite is to connect the product development stages of modelling and testing. It has tools for idea and industrial design, modelling and analysis, and getting ready for production as a whole. These processes are often separate, but it connects them by adding full-featured tools to their main program, Creo Parametric.

Creo Parametric

Creo Parametric is the main feature of all Creo software. It is a strong modelling tool that focuses on giving precise and immediate feedback for design changes. Because it has surfacing features, users can turn their 2D sketches into full 3D models by building complex surfaces parametrically or naturally. The "Unite" toolset from Creo Parametric even lets you load algorithms from other programs.

Along with 3D modelling, Creo Parametric also supports 2D drawing. This means that a designer can quickly switch between the 3D model and the 2D drawing that goes with it, and any changes made in one view will be reflected in the other. A lot of Creo Para metric’s features show that the Creo suite is focused on real, manufactured goods.

Surfacing
One of the coolest things about Creo Parametric is that it can do surface. With Creo Parametric, a creator can change every curve of a design using either parametric or free-form surfacing, which are both easy to use.
Sheet Metal
The manufacturing focus of CREO is shown again by its sheet metal design features, which make it possible to make sheet metal parts that are ready to be manufactured right away. The set of sheet metal tools can only be used to bend and shape metal in ways that are possible in industrial making. The user doesn't have to worry about how the product will be made; they can just focus on creating it.
CFD
Computational Fluid Dynamics, or CFD, is the use of computer simulations to study systems that have fluid flow, heat movement, and related phenomena like chemical reactions. The process is very reliable and can be used in a lot of different industrial and non-industrial settings.

MODELS OF EVACUATED HEAT PIPE

The models of evacuated heat pipe aye using different types of tubes and analysis of using CREO parametric software is used to make a model of the evacuated heat pipe based on the data book's specs and design formula. The picture below shows an isometric view of the drained tube with a heat pipe. In the sketcher, the outside shape of the evacuated tube with a heat pipe is drawn. Then, the rotate option is used to turn it all the way around. After that, the tubes are planned and put together using the rotation option into an evacuated tube with a heat pipe.

- Single type heat pipe
- U-bend type heat pipe

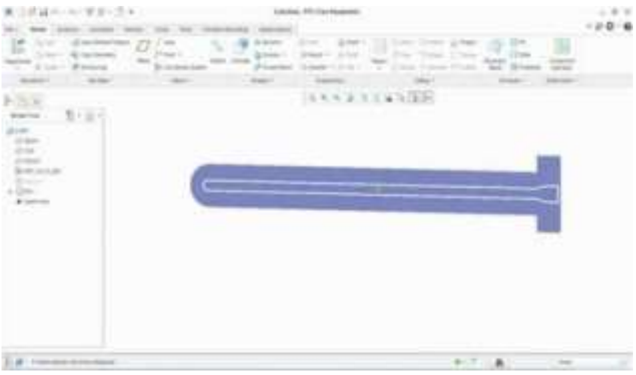


Fig: 3 SINGLE TYPE HEAT PIPE

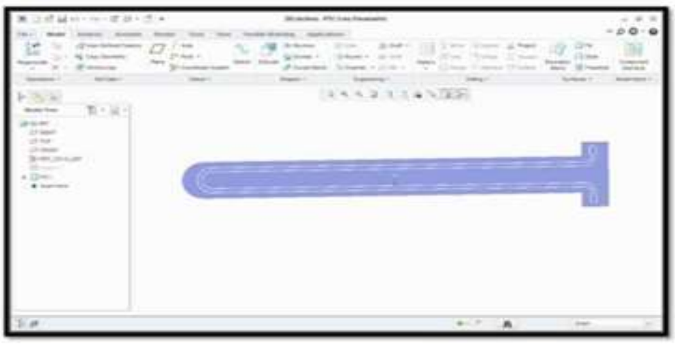


Fig: 4 U-bend type heat pipe

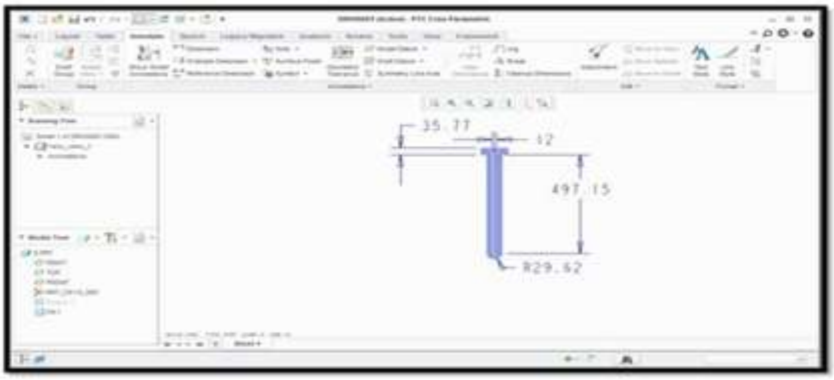


Fig: 5 Drafting image

RESULT AND DISCUSSION

FLUID FLOW ANALYSIS OF EVACUATED TUBE WITH HEAT PIPE

The fluid flow analysis of evacuated tube with heat pipe in the analyze the different tubes in mass flow rate and temperature distribution in the different months.

- Evacuated tube in single heat pipe
- U-bend type of heat pipe evacuated tube

Evacuated tube in single heat pipe, Mass flow inlet - 0.057 & 0.1777 kg/s

Temperature - January to December months avrage.

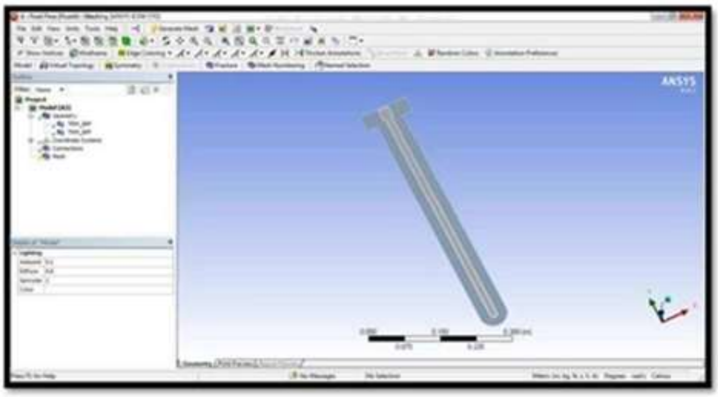


Fig: 6 Imported model from design software

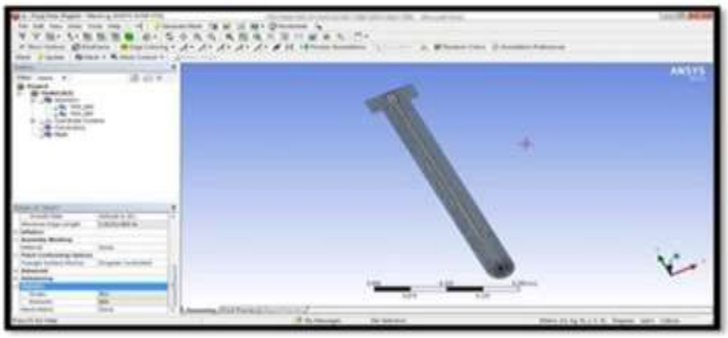


Fig: 7 Meshing model with inlet and outlet conditions

Case 1: mass flow 0.057 kg/s, January month (20.20°C), Pressure plot

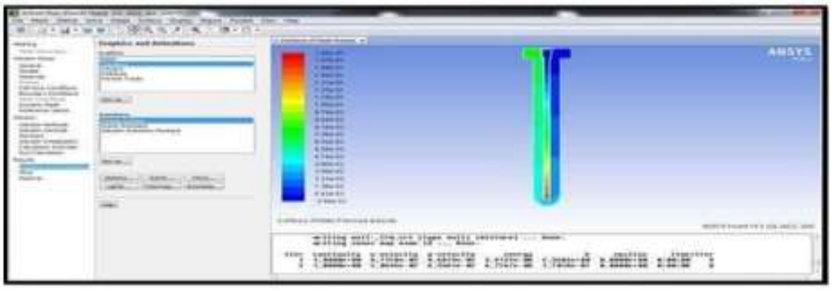


Fig: 8 Case1: Mass flow 0.057kg/s – Pressure plot

Velocity plot

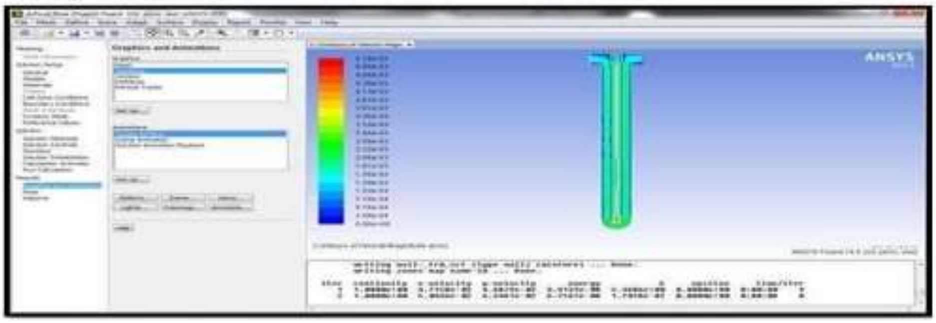


Fig: 9 Case1: Velocity plot

Heat transfer coefficient plot

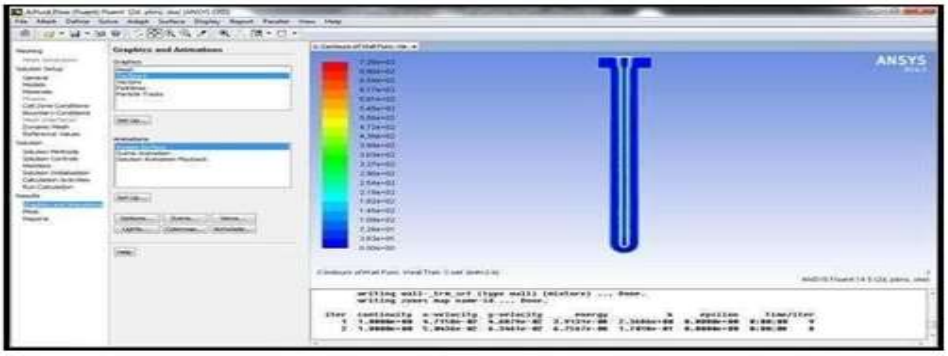


Fig: 10 Case1: Heat transfer co-efficient plot

Mass flow rate

Table: 1 Case:1 Mass flow rate 0.057kg/s (January month)

Mass Flow Rate	(kg/s)
inlet	0.046999998
inlet6tt	0.046999998
interior-_trm_srf	-2.2123306
outlet	-0.047650073
outlet.1	-0.047225751
wall-_trm_srf	0
Net	-0.00087582693

January month (23°C) Heat transfer rate

Table: 2 Case:1 Heat transfer rate (January month)

Total Heat Transfer Rate	(w)
inlet	3940.9092
inlet6tt	3940.9033
outlet	-3995.4209
outlet.1	-3959.8423
wall-_trm_srf	0
Net	-73.450684

February month (24°C) Heat transfer rate

Table: 3 Heat transfer rate (February month)

Total Heat Transfer Rate	(w)
inlet	3940.9092
inlet6tt	4687.8125
outlet	-3995.2043
outlet.1	-4710.209
wall-_trm_srf	0
Net	-76.69165

EVACUATED TUBE – U-BEND HEAT PIPE

Mass flow inlet -0.057&0.177kg/s

Temperature – January to December average

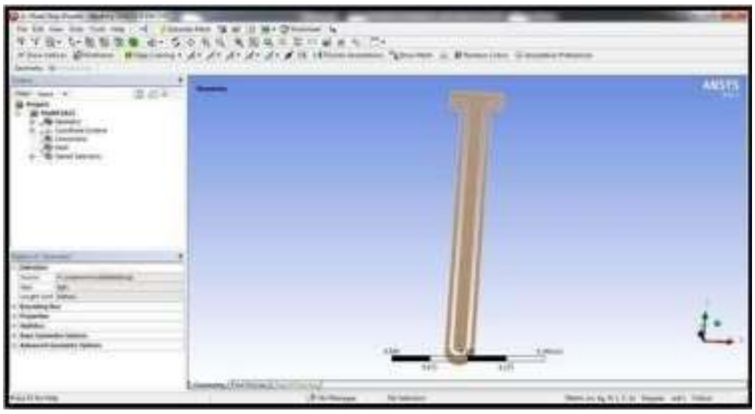


Fig: 11 EVACUATED TUBE-U-BEND HEAT PIPE – Imported model

Meshing model with Inlet and outlet conditions

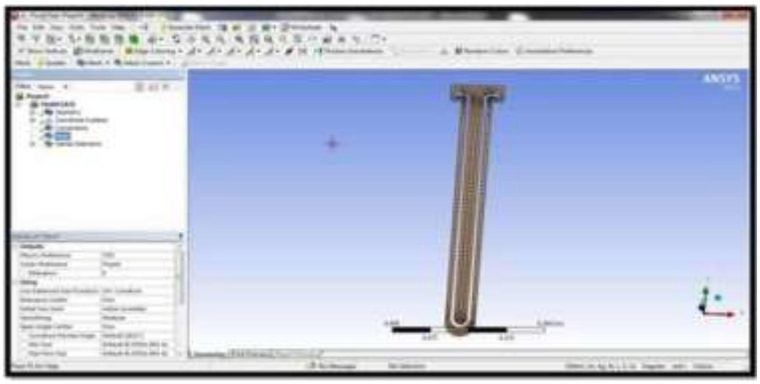


Fig: 12 EVACUATED TUBE-U-BEND HEAT PIPE – Meshing model with Inlet and outlet conditions

Case 1: mass flow 0.057 kg/s

January month (20.20C) Pressure plot

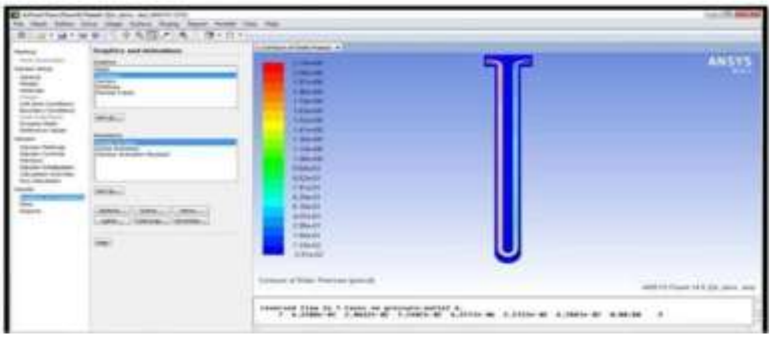


Fig: 13 Case1: Mass flow 0.057kg/s - Pressure plot

Velocity plot

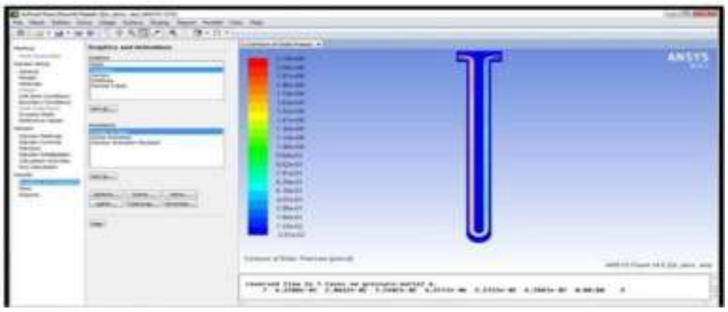


Fig: 14 Case1: Velocity plot

Heat transfer coefficient plot

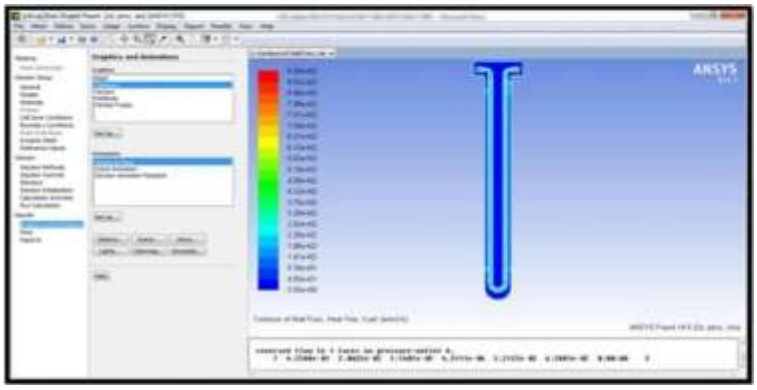


Fig: 15 Case1: Heat transfer co-efficient plot

Mass flow rate

Table: 4 Case:1 Mass flow rate 0.057kg/s (January month) Heat transfer rate

Mass Flow Rate	(kg/s)
inl	0.046999998
inlet	0.046999998
interior-_trm_srf	0.48673099
out	-0.047180731
outlet	-0.046808496
wall-_trm_srf	0
Net	1.0769814e-05

Table: 5 Case:1 Heat transfer rate (January month)

Total Heat Transfer Rate	(w)
inl	3940.9109
inlet	3940.9048
out	-3956.04
outlet	-3951.1704
wall-_trm_srf	0
Net	-25.394775

February month (240C), Heat transfer rate

Total Heat Transfer Rate	(w)
inl	4687.813
inlet	4687.8145
out	-4705.8394
outlet	-4700.5239
wall-_trm_srf	0
Net	-30.73584

Table: 6 Heat transfer rate (February month)

March month (29.40C),Heat transfer rate

Table: 7 Heat transfer rate (March month)

Total Heat Transfer Rate	(w)
inl	5749.2041
inlet	5749.1992
out	-5771.2568
outlet	-5765.915
wall-_trm_srf	0
Net	-38.768555

April month (35.70C), Heat transfer rate

Table: 8 Heat transfer rate (April month)

Total Heat Transfer Rate	(w)
inl	6987.4971
inlet	6987.4985
out	-7014.3423
outlet	-7008.376
wall-_trm_srf	0
Net	-47.722656

SINGLE TYPE HEAT PIPE CFD ANALYSIS RESULT

Table no:-9 Mass flow inlet 0.057kg/s

Mass flow inlet (kg/s)	Pressure(Pa)	Velocity(m/s)	Heat transfer coefficient(w/m2-k)	Mass flow rate(kg/s)
0.057	$1.65e^{-03}$	$5.16e^{-03}$	$7.26e^{+02}$	0.00087582693

Month	Heat transfer rate (W)
January	73.4506
February	76.64165
March	82.057373
April	130.20313
May	144.85
June	144.513
July	127.28906
August	119.93945
September	121.41406
October	118.47852
November	99.036621
December	82.949219

Table: 10 Single Type Heat Pipe CFD Analysis Results (Mass flow inlet 0.057kg/s)

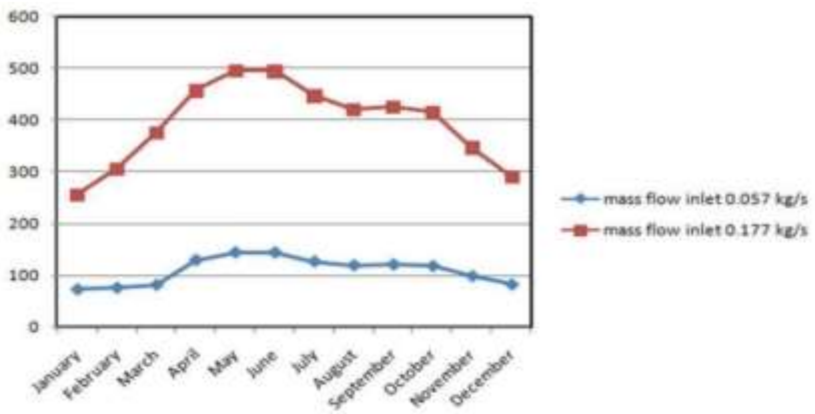
Mass flow inlet 0.177kg/s

Mass flow inlet (kg/s)	Pressure(Pa)	Velocity(m/s)	Heat transfer coefficient(w/m2-k)	Mass flow rate(kg/s)
0.177	$6.43e^{-01}$	$1.87e^{-02}$	$7.26e^{+02}$	0.002565

Table: 11 Single Type Heat Pipe CFD Analysis Results (Mass flow inlet 0.177kg/s)

Month	Heat transfer rate (W)
January	255.94336
February	305.20313
March	375.47
April	456.98633
May	495.191433
June	494.13867
July	446.82617
August	420.75391
September	425.83789
October	415.49023
November	346.73047
December	289.75391

Heat transfer rate plot



Graph: 1 SINGLE TYPE HEAT PIPE CFD ANALYSIS – Heat transfer rate plot

U-Bend TYPE HEAT PIPE CFD ANALYSIS RESULTS

Table no:- 12 Mass flow inlet 0.177kg/s

Mass flow inlet (kg/s)	Pressure(Pa)	Velocity(m/s)	Heat transfer coefficient(w/m2-k)	Mass flow rate(kg/s)
0.057	$2.19e^{+00}$	$1.46e^{-02}$	$9.39e^{+02}$	$1.076984e^{-05}$

Table: 13 U-Bend Type Heat Pipe CFD Analysis Results (Mass flow inlet 0.057kg/s)

Mass flow inlet 0.177kg/s

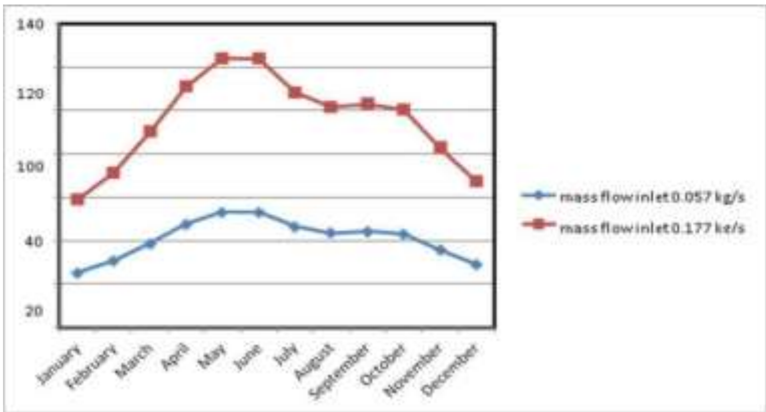
Mass flow inlet (kg/s)	Pressure(Pa)	Velocity(m/s)	Heat transfer coefficient(w/m2-k)	Mass flow rate(kg/s)
0.167	1.38e+01	5.35e-02	9.39e+02	6.3702464e-05

Month	Heat transfer rate (W)
January	59.044922
February	71.488281
March	90.154297
April	111.02344
May	124.15625
June	123.81641
July	108.38086
August	101.74805
September	103.01563
October	100.36133
November	82.888672
December	67.34082

Month	Heat transfer rate (W)
January	25.394
February	30.73584
March	38.768555
April	47.722656
May	53.324941
June	53.274414
July	46.629883
August	43.362305
September	44.362305
October	43.114746
November	35.635254
December	29.059082

Table: 5.56 U-Bend Type Heat Pipe CFD Analysis Results (Mass flow inlet 0.177kg/s)

Heat transfer rate plot



Graph: 2 U-BEND TYPE HEAT PIPE CFD ANALYSIS – Heat transfer rate plot

STEADY STATE THERMAL ANALYSIS OF EVACUATED TUBE: CASE1: SINGLE HEAT PIPE

January month (20.2°C)

TEMPERATURE DISTRIBUTION

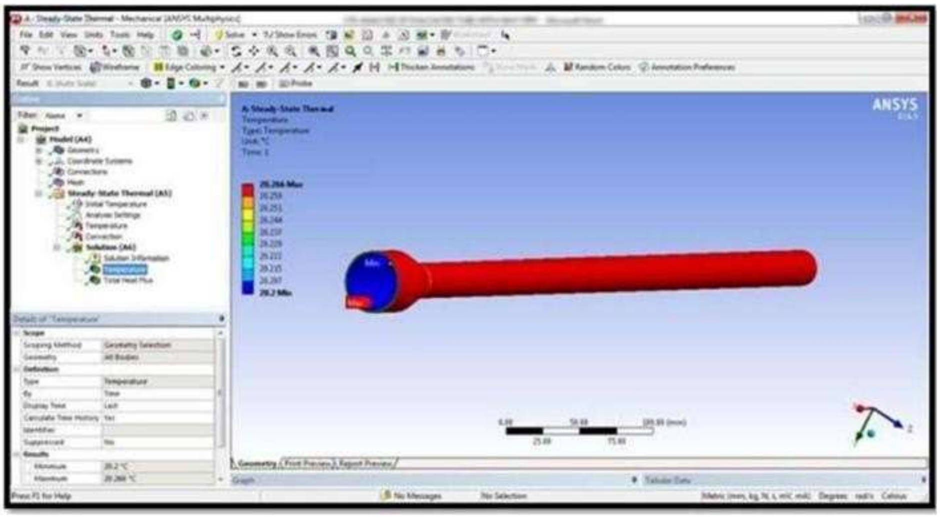


Fig: 16 Case1: Temperature Distribution (January month)

HEAT FLUX

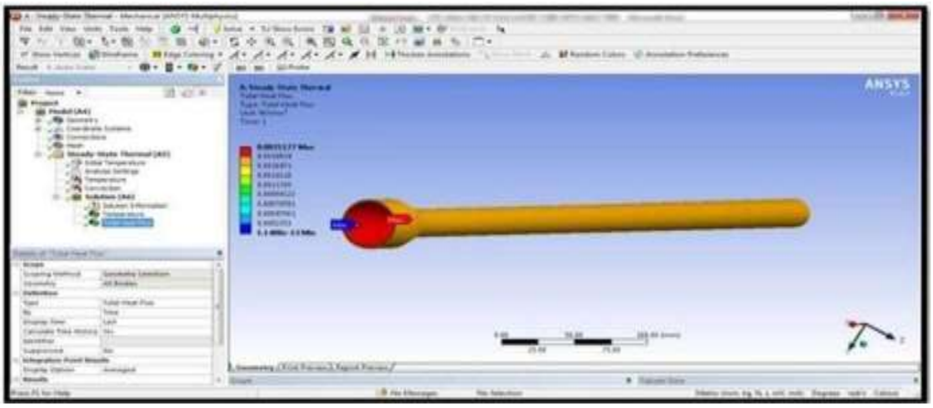


Fig: 17 Heat flux (January month)

STEADY STATE THERMAL ANALYSIS OF EVACUATED TUBE: U-Bend type heat pipe January month (20.20°C)

TEMPERATURE DISTRIBUTION

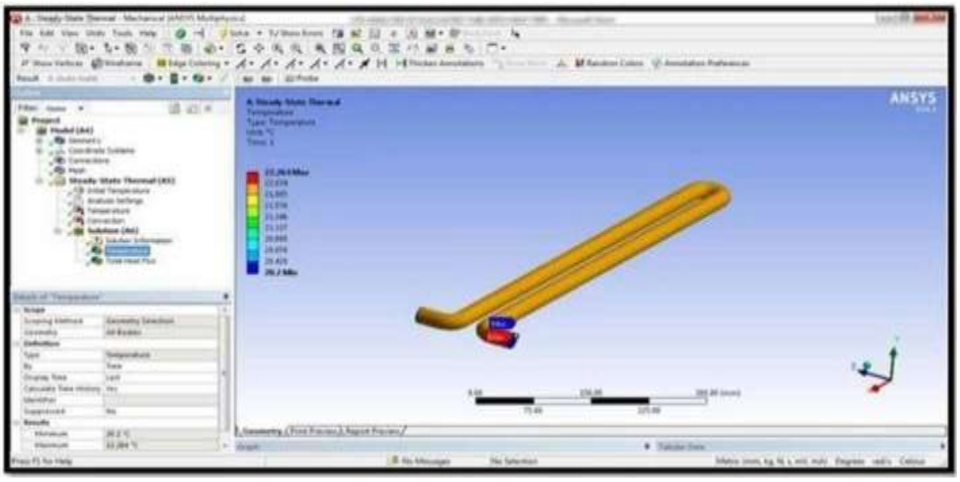


Fig: 18 Temperature Distribution (January month)

HEAT FLUX

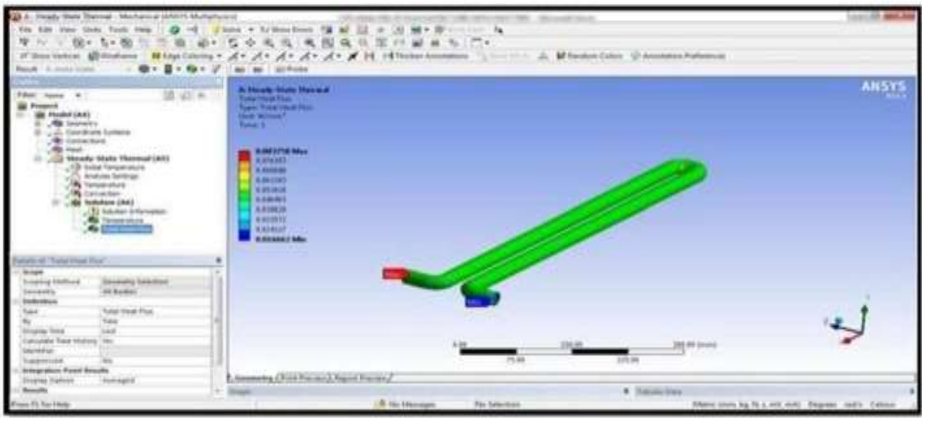
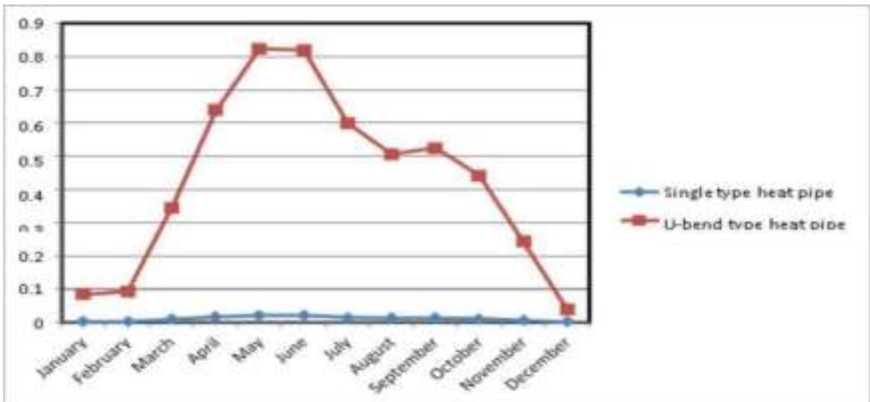


Fig: 19 Heat flux (January month)

Heat flux plot



Graph: 3 STEADY STATE THERMAL ANALYSIS OF EVACUATED TUBE – Heat flux plot

CONCLUSION

This thesis used CREO Parametric software to build an evacuated tube collector with a heat pipe and then ANSYS software to analyses the model. The study looked at different temperatures and mass flow rates (0.057 to 0.177 kg/s) from January to December.

It was the Computational Fluid Dynamics (CFD) study that helped figure out important factors like pressure drop, velocity, mass flow rate, heat transfer coefficient, and heat transfer rate for the evacuated tube collector with a heat pipe. A thermometric study was also done to find out how temperatures are distributed and how heat moves at different times of the year.

The CFD study showed that when the input flow rates were raised, there were clear increases in the pressure drop, velocity, mass flow rate, and heat transfer rate. When the heat transfer rate was compared to other months' normal temperatures, especially in May, differences were found.

This in-depth study puts light on how the evacuated tube collector with a heat pipe works in different situations. It gives us useful information for improving and developing solar thermal systems in the future.

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