© February 2025 | IJIRT | Volume 11 Issue 9 | ISSN: 2349-6002

Transient Thermal Analysis of Evacuated Tube Collector for Solar Water System with Different Configurations at Different Mass Flow Rates

P. Pavan Sai Kumar[1], M.T. Naik[2], K. V. Sharma[3]
[1] *Master Student, Centre for Energy Studies, JNTUH College of Engineering, Kukatpally Hyderabad*
[2,3] *Professor, Centre for Energy Studies, JNTUH College of Engineering, Kukatpally Hyderabad*

***Abstract*—Solar water heating (SWH) uses a solar thermal collector to convert sunlight into heat for water heating. A sun-facing collector warms a working fluid, which is then stored for later use. A detailed assessment of the utilization of solar energy for hot water generation utilizing evacuated tube collectors' technology has been conducted in this work. Solar energy in a hot water-producing system using Evacuated Tube Collector would assist in enhancing energy economics, consumption, and efficiency.**

The evacuated tube collector with heat pipe was modeled in Creo parametric software and analyzed in ANSYS software at different mass flow rates (0.057 and 0.177 kg/s) and varied temperatures throughout the day in this thesis 9 am to 5 pm). For an evacuated tube collector with a heat pipe, CFD analysis was used to calculate the pressure drop, velocity, mass flow rate, heat transfer coefficient, and heat transfer rate. Thermometric study to measure temperature distribution and heat flow at various temperatures throughout the day (9 am to 5 pm).

I. INTRODUCTION

Using the sun's energy to heat your home's water is known as solar water heating. The average person uses twenty to thirty liters of hot water daily. Using the energy from the sun, a family of four may require 2,300 to 3,500 gallons of hot water per month, all of which could be given for free. Your routines and way of life do not need to alter because a SWH is sized to fit your family's current usage. Your monthly payment is the only thing that will change after the solar hot water system is built. China, Europe, Japan, and India dominate the global solar thermal market. However, Israel is one of the first countries to mandate the installation of SWH in 1980, leading to a flourishing industry. This global momentum in solar water heating is a testament to the collective effort towards a sustainable future.

Installing a solar water heater in your house is one easy and maintenance-free approach to instantly lowering your monthly energy expenses. The operation of the evacuated tube and flat plate solar hot water systems is comparable. There are two types of solar thermal installations: passive (also called as "compact") and active (sometimes called as "pumped") systems. To guarantee that hot water is continues accessible, for both usually have an auxiliary energy source turned on when the tank's water drops below a predetermined low temperature. In colder climates, a hot water system can operate year-round by combining solar water heating with backup heat from a wood burner chimney without the supplemental heat requirement of a solar water heating system being met with fossil fuels or electricity.

How a Home Solar Water Heating System Works

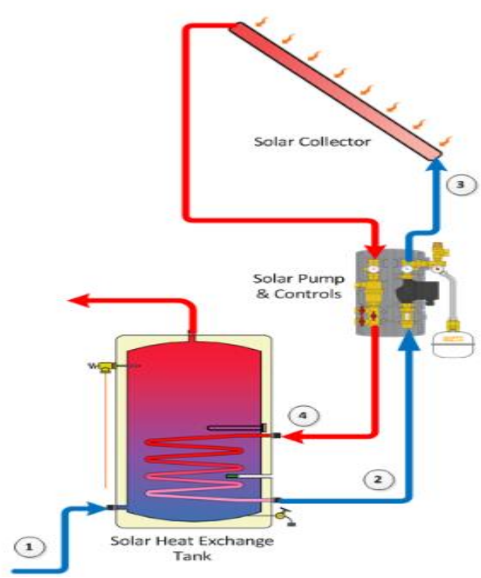

Figure 1 Schematic of Solar Collectors.

Installing a solar water heater in your house is one easy and maintenance-free approach to instantly lowering your monthly energy expenses. The operation of the evacuated tube and flat plate solar hot water systems is comparable. There are two types of solar thermal installations: passive (also called as "compact") and active (sometimes called as "pumped") systems. To guarantee that hot water is continues accessible, for both usually have an auxiliary energy source turned on when the tank's water drops below a predetermined low temperature. In colder climates, a hot water system can operate year-round by combining solar water heating with backup heat from a wood burner chimney without the supplemental heat requirement of a solar water heating system being met with fossil fuels or electricity.

When a solar water heating system is combined with a hot-water central heating system. The solar heat will either be concentrated in a pre-heating tank, that feeds into the central heating tank, or the upper heating element will continue to provide supplemental heat. In contrast, the solar heat exchanger replaces the lower heating element. However, central heating is most necessary when solar gain is reduced in the winter and at night. Because supply and demand are better matched, solar water heating for bathing and washing is frequently better used than central heating. A solar hot water system can supply up to 85% of the energy used for home hot water in certain climes. Domestic non-electric concentrating solar thermal systems may fall under this category. In many northern European countries, combined hot water and space heating systems (solar combi systems) provide 15 to 25% of home heating energy. Large-scale solar heating can provide 50-97% of district heating's annual heat consumption when combined with storage.

A. Evacuated-tube solar collectors

These collectors are most commonly used for commercial applications in the World. They comprise parallel rows of transparent glass tubes, each with a glass outer tube and a metal absorber tube attached to a fin. It prevents radiative heat loss while absorbing solar energy. Solar water heating systems almost always need a backup for cloudy days and periods of higher demand. Conventional storage water heaters typically provide backup and may already be included in the solar system package. An integral-collector storage system may be packaged with a tankless or demand-type water heater for backup.

II. LITERATURE REVIEW

Inclined Solar Water Heaters on their thermal performance is proposed by P. Selvakumar and Dr. P. Somasundaram (2012). The current investigation is being conducted to determine the temperature characteristics of the evacuated tube at tilt angles. 0, 15, 30, 45, 60, and 90 degrees. The application-based angle concept will have a more considerable effect on an environmentally conscious world. The cost and complexity of solar heaters is the primary deterrents. However, if it is clear that there are no restrictions and less complex, the number of people switching from electric water heaters to solar will rise due to low prices.

Eze J. I. and Ojike O. (2012) proposed a passive solar water heater and investigated its thermal efficiency. The solar water heater, It has two storage tanks for cold and warm water. In this copper pipes are placed in spiral shape only.

PCM-type solar water heater proposed by M.V. Kulkarni and Dr. D. S Deshmukh (2014) concentrated on. The system is made up of two heat-absorbing devices that operate simultaneously. One is a solar water heater, and the other is a PCM (paraffin) heat storage system. Throughout the day, the water heater runs smoothly and provides hot water. The storage unit provides hot water at night and retains the heat in PCMs throughout the day.

Water-In-Glass Evacuated Tube is proposed by Morrison et al. (2004). He noted that from his research he said that the evacuated tube solar collectors outperform flat plate collectors while operating at high temperatures. Due to its affordability and ease of use, the water-in glass tube collector is preferable for home use. Large quantities of water-in-glass evacuated tubes are produced in Europe and China. The evacuated tubes are being imported from China by numerous solar water heater producers in India. Due to their improved performance and low cost, the market for solar water heaters with ETC is expanding quickly. 30m2 of the area is needed to put a 100 LPD solar water heater. If a ground-floor resident of a multi-story apartment wants to use a SWH, he must mount the collectors on the building's terrace.

The hot water must travel through a lengthy pipeline, costing the residents more money for plumbing work and resulting in a significant energy loss. Additionally, mounting the solar water heater will be challenging if the terrace is used for other purposes, such as television antennas or advertising hoarding. Researching the evacuated tube's performance at different inclination angles is crucial. If a ground-floor resident of a multi-story apartment wants to use a solar water heater, he must mount the collectors on the building's terrace. The hot water must travel through a lengthy pipeline, costing the residents more money for plumbing work and resulting in a significant energy loss.

Additionally, mounting the solar water heater will be challenging if the terrace is used for other purposes, such as television antennas or advertising hoarding. Researching the evacuated tube's performance at different inclination angles is crucial. If the performance remains constant at all inclination angles, it will be easy to put the collectors.

The thermal performance of water-in-glass evacuated tube solar water heaters with varying collector tilt angles was investigated by Runsheng Tang et al. (2011). The researchers experimented with two distinct angles: 22° and 46°. The daily thermal efficiency does not vary significantly. However, the data for other inclination angles—specifically, 0° and 90°—are not included in this study. The goal of this study is to determine the evacuated tube's temperature characteristics for the following tilt angles: 0°, 15°, 30°, 45°, 60°, and 90°. The application-based angle concept will have a more significant effect on an environmentally conscious world. The cost and complexity of solar heaters is the primary deterrents. However, if it is clear that there are no restrictions and with less complexity, the number of people switching from electric water heaters to solar will rise due to low prices which should also be considered. The experiment is carried out with the tubes oriented both north and south. The findings are intriguing and cast doubt on the claims made in the literature.

Eze J. I. and Ojike O. (2012) propose a passive Solar Water Heater to evaluate the thermal efficiency. The heater, which could be used in households and agro-industries, was composed of a platform, water storage tanks. Mild steel, an excellent heat conductor, made the absorber plate. The mild steel absorber was looped with a copper tube. The absorber traps radiant energy, which heats the water in the loop. In Nsukka, Nigeria, the system was experimentally tested under daytime load settings with ambient temperatures ranging from 21 to 31°C and daily global irradiation levels between 8.3 and 17.4 MJ m-2. The maximum temperature rise of heated water was approximately 83°C, and its maximum daily average usable efficiency was almost 42%. It was concluded that both household and agro-industrial applications could effectively use the technology.

III. MODELING AND ANALYSIS

PTC is deeply rooted in Computer-Aided Design/Engineering (CAD/CAE) through its Mechanical Design Software, Creo Parametric (formerly known as Pro/Engineer). PTC now offers a product catalog of vast scope that includes Engineering Math, Product Lifecycle Management (PLM), Internet of Things (IoT), and even Augmented Reality (AR) solutions. PTC currently has.

A. CFD

Computational fluid dynamics (CFD) is a subfield of fluid mechanics that gives numerical methods and algorithms to address and analyze problems related to fluid flow. It is a reliable means of simulating the behavior of liquids and gases across various uses in scientific and technical domains. CFD allows researchers and engineers to investigate complex fluid dynamics phenomena such as combustion, heat transfer, and turbulence, thus removing the necessity for costly and time-intensive physical experiments. By numerically solving the governing equations of fluid flow, CFD provides detailed insights into flow patterns, pressure distributions, temperature gradients, and other essential parameters. The method is highly potent and encompasses a broad spectrum of both industrial and non-industrial fields of application.

B. CREO

However, despite extensive reach, PTC's primary product in the CAD/CAE realm – its Creo software suite – remains its most developed and widely favored offering. PTC's Creo software suite fundamentally links product development's modeling and prototyping stages. Conceptual and industrial design tools, simulation and analysis, and general production readiness are included. It connects these processes, often kept apart, by offering fully featured tools as add-ons for its leading software, Creo Parametric. Although the Creo suite comprises dozens of unique tools, mastering just a few can significantly enhance a designer or engineer's effectiveness. Creo Parametric is the central platform for all Creo software, offering a strong modeling tool that emphasizes modularity and immediate feedback on design modifications. Thanks to its surfacing capabilities, users can transform their 2D sketches into complete 3D models by either constructing complex surfaces parametrically or shaping them organically.

C. Models of evacuated heat pipe Using CREO parametric software

CREO Parametric, created by PTC, is a top-tier 3D CAD software extensively utilized in product design and engineering. It offers a strong foundation for developing intricate 3D models, simulations, and technical illustrations, allowing users to design complex products accurately. The software features parametric modeling, enabling designers to set dimensions and relationships among components so that any modifications automatically spread throughout the design. The characteristic improves flexibility and minimizes mistakes in the design process. Moreover, CREO Parametric offers sophisticated tools for surface modeling, assembly design, and finite element analysis (FEA), providing a thorough solution for the automotive, aerospace, and manufacturing sectors. Conceptual design and planning are the initial steps when using CREO Parametric. It includes specifying the product's requirements, features, and limitations. Designers produce preliminary drawings or two-dimensional plans to delineate the product's basic structure and measurements. The 3D model is built on these sketches. Working with stakeholders at this stage is vital to guarantee that the design corresponds with the project's aims. The user-friendly interface of CREO Parametric enables users to rapidly convert ideas into digital formats, facilitating the visualization and refinement of concepts prior to detailed modeling. Planning correctly at this point guarantees a more seamless workflow and lowers the likelihood of mistakes in subsequent phases.

D. Drafting images

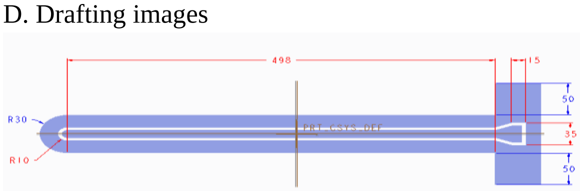

Figure 2 2d Drawing of Straight Tube.

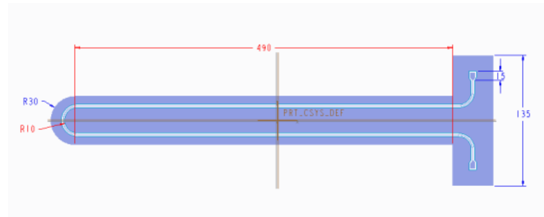

Figure 3 2d Drawing Of U-Bend Tube.

Element Size (mm)	No of Nodes	No of Elements	Heat transfer coefficient (w/m2-k)	
			Straight tube	U-tube
0.1	37588	34695	726	939
0.3	17875	15938	725.81	938.59
0.5	10677	9212	725.59	938.15

Table 1 Meshing Values and Heat Transfer Coefficient.

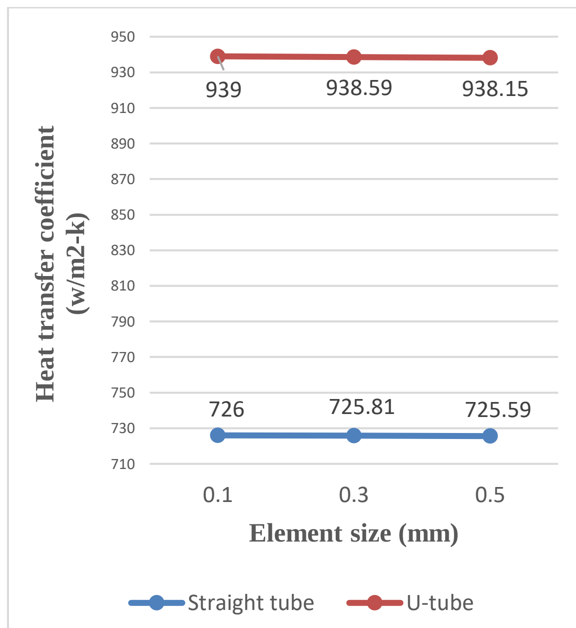

Figure 4 Element Size Vs Heat Transfer Coefficient Plot.

Accuracy usually increases as the number of nodes increases. This work considers a 0.1 element size for higher accuracy because a more minor element size will result in more nodes and elements.

IV. CFD AND THERMAL ANALYSIS OF EVACUATED TUBE WITH HEAT PIPE

Pressure

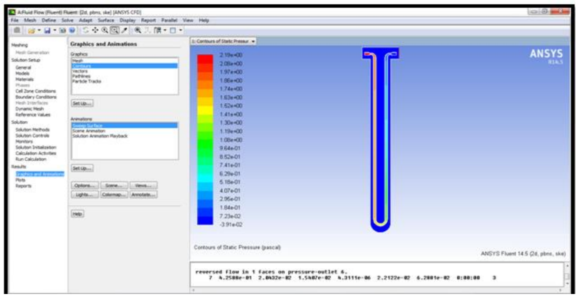

Figure 5 Pressure Counters.

According to the above counter plot, the maximum pressure at the inlet of the face and minimum pressure at the outlet

Velocity

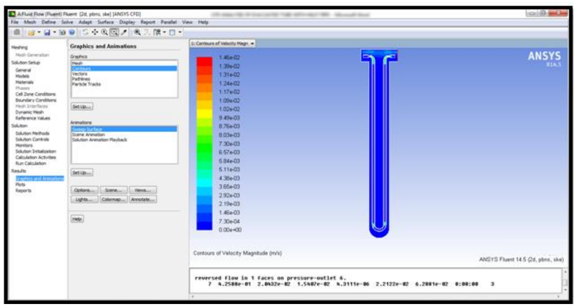

Figure 6 Velocity Counters.

According to the above counter plot, the maximum velocity at the inlet of the face is the same as the minimum velocity at the outlet.

Heat transfer coefficient

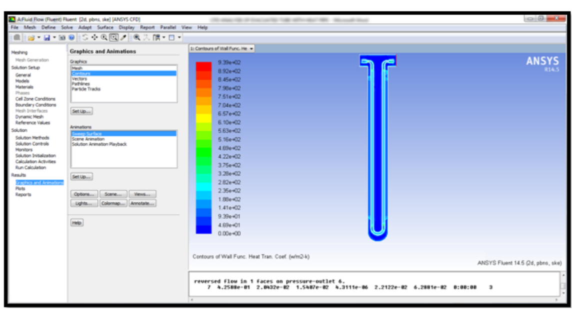

Figure 7 Heat Transfer Coefficient Counters.

According to the above counter plot, the maximum Heat transfer coefficient at the inlet of the face and minimum Heat transfer coefficient at the outlet

Temperature Distribution

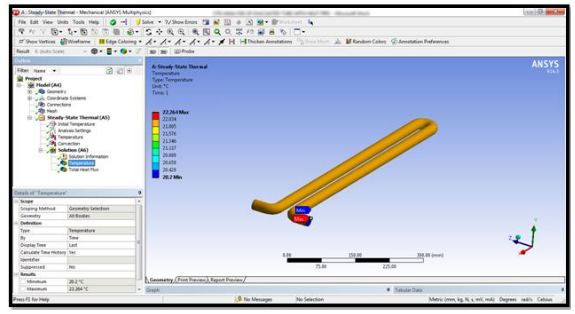

Figure 8 Temperature Distribution.

According to the above counter plot, the maximum temperature distribution outside of the pipe and minimum temperature inside of the tube

Heat Flux

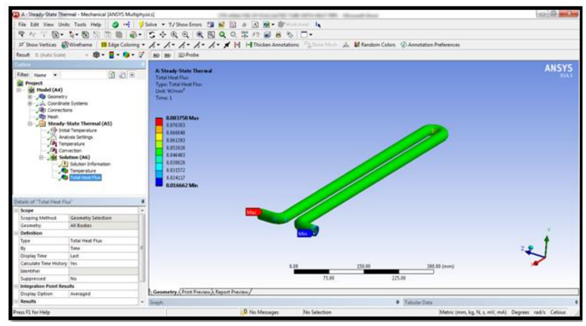

Figure 9 Heat Flux.

According to the above counter plot, the maximum heat flux at the inside side of the pipe and minimum heat at the outside of the tube

V. RESULTS AND DISCUSSION

	For straight tube Heat transfer rate(w)		For U-bend type tube Heat transfer rate(w)	
	Mass flow inlet 0.057kg/s	Mass flow inlet 0.177kg/s	Mass flow inlet 0.057kg/s	Mass flow inlet 0.177 kg/s
Pressure (Pa)	0.00165	0.643	2.19	13.8
Velocity (m/s)	0.00516	0.0187	0.0146	0.0535
Heat transfer coefficient (w/m2-k)	726	726	939	939

Table 2 Pressure, Velocity & Heat Transfer Coefficient Values of Both Configurations.

	For straight tube Heat transfer rate(w)		For U-bend type tube Heat transfer rate(w)	
Temp at different times	At Mass flow inlet 0.057 kg/s	At Mass flow inlet 0.177 kg/s	At Mass flow inlet 0.057 kg/s	At Mass flow inlet 0.177kg/s
9 am (25.20C)	73.45	255.94	25.39	59.04
10 am (270C)	76.64	305.20	30.73	71.48
11:00am (31.40C)	82.05	375.47	38.77	90.15
Noon (35.70C)	130.20	456.98	47.72	111.02
1:00 pm (39.70C)	144.85	495.19	53.32	124.15
1:30 pm (39.60C)	144.51	494.13	53.27	123.81
2:00 pm (39.90C)	127.29	446.82	46.63	108.38
2:30 pm (36.90C)	119.94	420.75	43.36	101.75
3:00 pm (35.30C)	121.41	425.83	44.36	103.01
4:00 pm (33.50C)	118.47	415.49	43.11	100.36
5:00 pm (29.20C)	99.03	346.73	35.63	82.89
6:00 pm (25.80C)	82.95	289.75	29.06	67.34

Table 3 Heat Transfer Rate of Both Configurations.

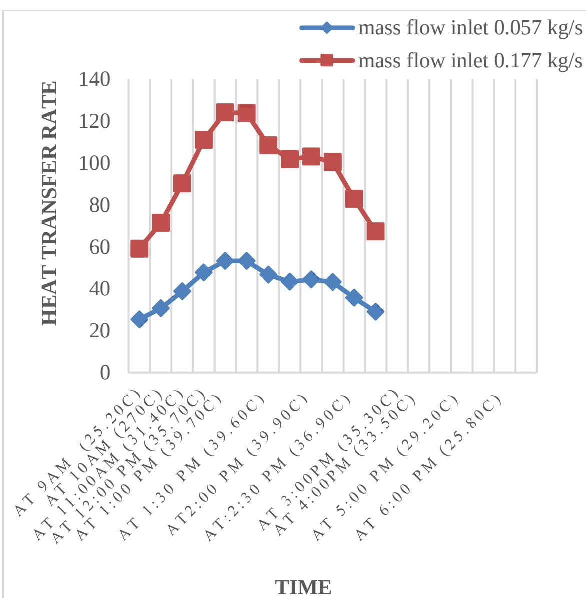

Figure 10 U-bend Tube Heat Transfer Rate Plot.

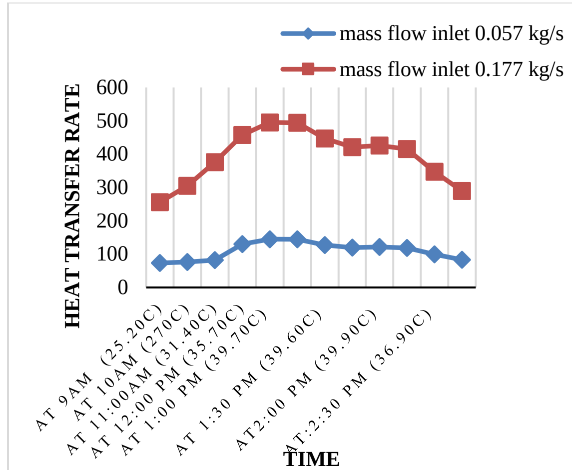

Figure 11 Straight tube Heat Transfer Rate Plot.

Temperature(0C)	Single-type heat pipe	U-bend type heat pipe
9 am (25.20C)	0.0021	0.0837
10 am (270C)	0.0024	0.0930
11:00 am (31.40C)	0.0087	0.3443
Noon (35.70C)	0.0161	0.6374
1:00 pm (39.70C)	0.0208	0.8236
1:30 pm (39.60C)	0.0207	0.8189
2:00 pm (39.90C)	0.0152	0.6002
2:30 pm (36.90C)	0.0128	0.5072
3:00pm (35.30C)	0.0133	0.5258
4:00pm (33.50C)	0.0112	0.4420
5:00 pm (29.20C)	0.0061	0.2419
6:00 pm (25.80C)	0.0009	0.0372

Table 4 Heat Flux for Both Configurations.

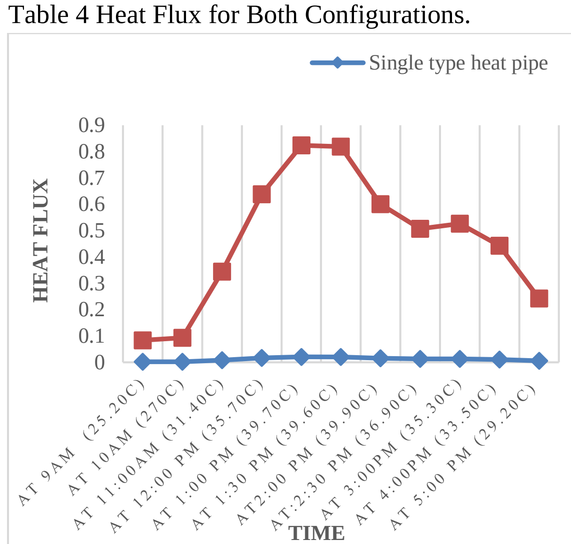

Figure 12 Heat Flux Vs. Time Plot for Both Configurations.

VI. CONCLUSION

In this thesis, the evacuated tube collector was modeled in CREO parametric software and analyzed in ANSYS software at different mass flow rates (0.057 & 0.177 kg/s) and different temperatures Throughout the day (9 am to 6 pm). The following conclusions are made from the experimental study and are
detailed as below:

- A comparison of heat flux between straight and U-bend type heat pipes shows that the U-bend type has 39 times more heat flux than the straight tube.
- Observing the heat transfer rate in all cases is higher at 1:00 pm compared with the remaining Timings temperatures.

REFERENCES

[1] Gili Werner."Text Detection in Natural Scenes with Stroke Width Transform."ICBV, 2013.
[2] B. Epstein, E. Ofek, and Y. Wexler, "Detecting text in natural scenes with stroke width transform," in Computer Vision and Pattern Recognition (CVPR), 2010 IEEE Conference, 2010, pp. 2963–2970
[3] G.D.Rai (2010), “Non-Conventional Energy Sources”, Kanna Publishers, India
[4] G.L. Morrison, I. Budihardjo, M. Behnia (2004), Solar Energy, Vol.76, pp.135-140
[5] Runsheng Tang, Yuqin Yang, Wenfeng Gao (2011), "Comparative studies on the thermal performance of water-in-glass evacuated tube solar water heaters with different collector tilt-angles," Solar Energy, Vol.85, pp.1381-1385
[6] Indra Budihardjo, Graham L. Morrison, Masud Behnia (2007), "Natural circulation flow through water-in-glass evacuated tube solar collectors," Solar Energy, Vol.81, pp.1460-1472.
[7] Ayompe, LM, Duffy, A, McKeever, M, et al. Comparative field performance study of flat plate and heat pipe evacuated tube collectors (ETCs) for domestic water heating systems in a temperate climate. Energy 2011; 36: 3370–3378.
[8] Ersoz, M.A. Effects of different working fluid use on the energy and exergy performance for evacuated tube solar collector with thermosyphon heat pipe. Renewable Energy 2016; 96: 244–256.
[9] Chopra, K, Tyagi, VV, Pandey, AK, et al. Global advancement on experimental and thermal analysis of evacuated tube collector with and without heat pipe systems and possible applications. Appl Energy 2018; 228: 351–389.
[10] Dobriyal, R, Negi, P, Sengar, N, et al. A brief review on solar flat plate collector by incorporating the effect of nanofluid. Materials Today: Proceedings 2020; 21: 1653–1658.