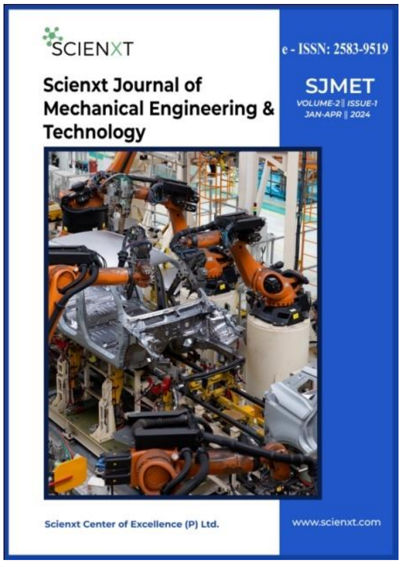


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# *An assessment of the impact of heat transfer enhancement on solar water heating systems utilizing evacuated tube heat pipes*

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## Abstract:

The Evacuated tube collector includes a number of rows of parallel transparent glass tubes connected to a header pipe and that are used in region of the blackened warmness absorbing plate we saw in the previous flat plate collector. Different types of glass materials of heat pipe have been used with different profile. Inside the fluid flow (octadecane) nano fluid on heat pipe. We found that they gives better temperature distribution and mass transformation in capillary tube of heat pipe

## Keywords:

Heat Pipe, Evacuated Tube, CFD

## 1. Introduction:

Evacuated tube solar collectors are widely employed due to their excellent thermal insulation properties and their ability to capture sunlight from various angles. Sabiha et al. conducted an extensive review outlining the advancements and preferences surrounding evacuated tube solar collectors. The review highlights three prevalent types: (a) Water-in-glass evacuated tube solar collectors, (b) U-type evacuated tube solar evacuated tube heat pipe solar collectors. Collectors, and (c) evacuated tube heat pipe solar collectors.

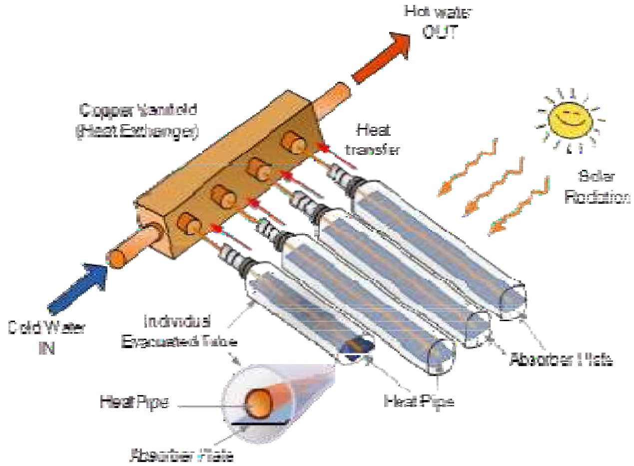



***Figure. 1.1: Evacuated tube collectors***

The evacuated tube collector consists of multiple rows of transparent glass tubes connected to a header pipe. In contrast to the flat plate collector with a blackened heat-absorbing plate, these glass tubes are cylindrical in shape.

This design ensures that sunlight is consistently perpendicular to the heat-absorbing tubes, enabling optimal performance even during periods of low sunlight, such as early mornings, late afternoons, or when shaded by clouds. Evacuated tube collectors are particularly advantageous in regions characterized by cold, cloudy weather conditions.

Evacuated tube collectors typically consist of one or more rows of parallel, transparent glass tubes mounted on a framework. Each tube varies in diameter, typically ranging from 1" (25mm) to 3" (75mm), and in length from about 5′ (1500mm) to 8′ (2400mm), depending on the manufacturer. These tubes are designed with a thick outer glass tube and a thinner inner glass tube, forming a "dual-glass tube" or a "thermos-flask tube" coated with a special substance that absorbs solar energy while minimizing heat loss. Materials used for the tubes include borosilicate or soda lime glass, known for their strength, high-temperature resistance, and excellent transmittance for solar irradiation. In contrast to flat panel collectors, evacuated tube collectors do not directly heat the water within the tubes. Instead, the space between the two tubes is evacuated, creating a vacuum, hence the name "evacuated tubes." This vacuum acts as an insulator, significantly reducing heat loss to the surrounding environment through convection or radiation, thereby enhancing the collector's efficiency compared to flat plate collectors. Due to this vacuum insulation, evacuated tube collectors typically achieve higher fluid temperatures than their flat plate counterparts and can become quite hot, especially during summer months within each glass tube, a flat or curved aluminum or copper fin is affixed to a metallic heat pipe running through the inner tube. This fin is coated with a selective material that efficiently transfers heat to the fluid circulating through the pipe. Encased within the glass tube, a sealed copper heat pipe facilitates the transfer of solar heat through convection of its internal heat transfer fluid to a "hot bulb," indirectly heating a copper manifold within the header tank. These copper pipes are interconnected to a common manifold, which in turn connects to a storage tank, effectively heating the water throughout the day. The insulated properties of the tank allow the hot water to be utilized during the night or the following day.

The exceptional insulation properties of the vacuum are so effective that while the inner tube can reach temperatures as high as 150°C, the outer tube remains cool to the touch. This means that evacuated tube water heaters can perform efficiently and can heat water to relatively high temperatures even in cold weather conditions, whereas flat plate collectors often struggle due to heat loss

Nevertheless, one drawback is their higher cost compared to conventional flat plate collectors or solar batch collectors. Evacuated tube solar collectors are well-suited for industrial and commercial hot water heating applications and can serve as an efficient alternative to flat plate collectors for residential space heating, especially in regions with frequent cloud cover

Evacuated tube collectors are typically more modern and efficient compared to standard flat plate collectors. They have the ability to extract heat from the air even on damp, dull, overcast days, and they do not necessarily require direct sunlight to operate effectively. The vacuum inside the glass tube enhances overall efficiency across various regions, ensuring better performance even when the sun is not at an optimal angle. The configuration of the vacuum tube is crucial for these types of solar hot water panels. There are several vacuum tube configurations, such as single-wall tubes, double-wall tubes, direct flow, or heat pipe systems, and these variations can determine how the fluid circulates within the solar hot water panel.

Evacuated Tube Collectors offer a highly sustainable method of heating a significant portion of your hot water supply by harnessing the power of the sun. While they can achieve high temperatures efficiently, they are more delicate compared to other types of solar collectors and entail higher installation costs. They can be employed in both active open-loop systems (without a heat exchanger) or active closed-loop systems (with a heat exchanger), but a pump is necessary to circulate the heat transfer fluid from the collector to storage to prevent overheating

## 2. Heat pipe evacuated tube collectors:

In heat pipe evacuated tube collectors, a sealed heat pipe typically made of copper is connected to a heat-absorbing reflector plate within the vacuum-sealed tube. This hollow copper heat pipe within the tube is evacuated of air but contains a small quantity of low-pressure alcohol/water liquid, along with additional additives to prevent corrosion or oxidation

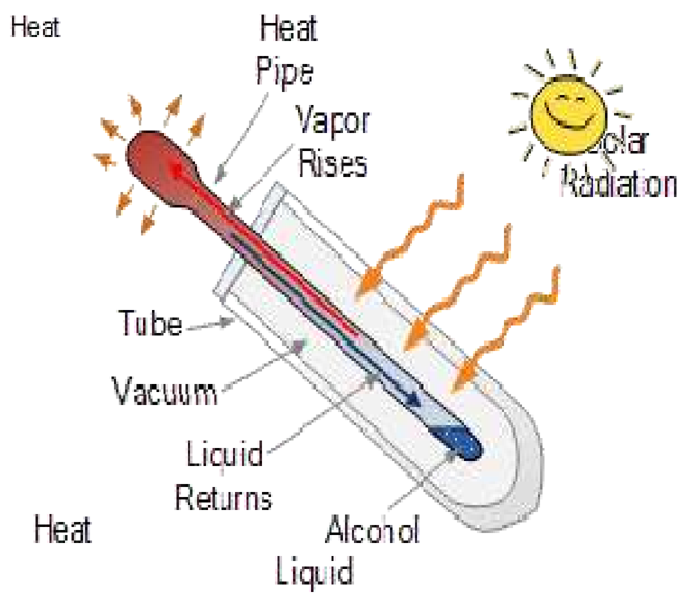



*Figure. 2.1: Heat Pipe Evacuated Tube Collector*

This vacuum enables the liquid to vaporize at much lower temperatures than it would under normal atmospheric pressure. When sunlight, in the form of solar radiation, strikes the surface of the absorber plate inside the tube, the liquid in the heat pipe rapidly transforms into a hot vapor due to the presence of the vacuum. As this vapor is now lighter, it ascends to the top portion of the pipe, heating it to a very high temperature. The upper part of the heat pipe, and consequently the evacuated tube, is linked to a copper heat exchanger known as the "manifold." When the hot vapors within the sealed heat tube enter the manifold, their heat energy is transferred to the water or glycol fluid flowing through the connecting manifold. As the hot vapor loses energy and cools, it condenses back from a gas to a liquid, flowing back down the heat pipe to be reheated.

The heat pipe and consequently the evacuated tube collectors must be positioned with a minimum tilt angle, typically around 30 degrees, to ensure the internal liquid of the heat pipe returns back down to the hot absorber plate at the bottom of the tube. This continuous process of converting liquid into gas and back into liquid persists within the sealed heat pipe as long as sunlight is available. The primary advantage of Heat Pipe Evacuated Tube Collectors is the "dry" connection between the absorber plate and the manifold, simplifying installation compared to direct flow collectors. Additionally, in case of an evacuated tube cracking or breaking and the vacuum being lost, individual tubes can be replaced without draining or dismantling the entire system. This flexibility makes heat pipe evacuated tube solar hot water collectors ideal for closed-loop solar designs, as their modular assembly allows for easy installation and expansion by adding as many tubes as needed.

## 3. Direct flow evacuated tube collector:

Direct flow evacuated tube collectors, also referred to as "U" pipe collectors, distinguish themselves from conventional models by featuring two heat pipes traversing the central axis of the tube. One pipe serves as the flow conduit, while the other serves as the return conduit. Both pipes are interconnected at the tube's base via a "U-bend," thus giving rise to the name. The heat-absorbing reflective plate functions as a partition, segregating the flow and return conduits within the solar collector tubes. Moreover, the absorber plate and heat transfer tube are hermetically sealed within a glass tube, ensuring exceptional insulation properties.

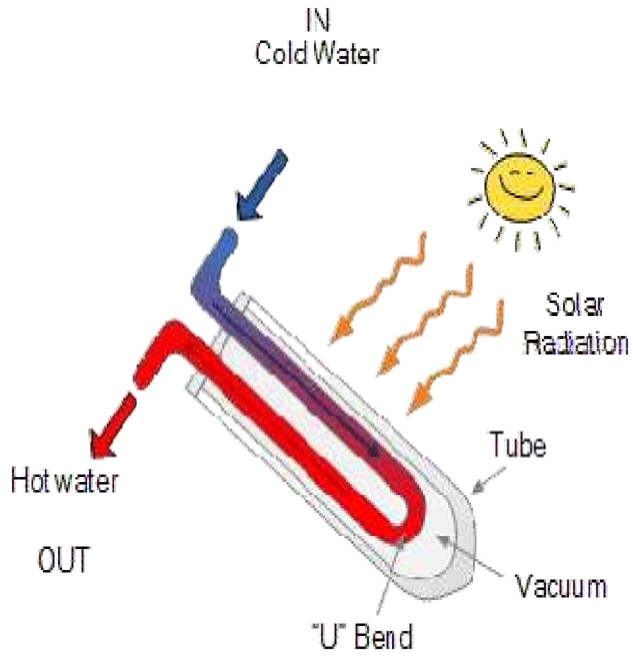



*Figure. 3.1: Direct Flow Evacuated Tube Collector*

The hollow heat pipes and the flat or curved reflector plate are crafted from copper and coated selectively to enhance the overall efficiency of the collectors. This specific configuration of evacuated tubes operates similarly to flat plate collectors, with the notable distinction of the vacuum insulation provided by the outer tube.

Because the heat transfer fluid flows into and out of each tube, direct flow evacuated tube collectors lack the flexibility of heat pipe types. If a tube cracks or breaks, replacement is not easily accomplished. The system necessitates draining due to the "wet" connection between the tube and manifold. Many professionals in the solar industry contend that direct flow evacuated tube designs boast superior energy efficiency compared to heat pipe designs, as direct flow eliminates the n ed for a heat exchange between fluids. Additionally, in an all-glass direct flow construction, the two heat tubes are arranged concentrically, allowing the fluid being heated to pass down the inner tube and then back up through the outer absorber tube.

Direct flow evacuated tubes are capable of collecting both direct and diffusę radiation, eliminatin the need for solar tracking. Nevertheless, to harness additional solar energy and prevent potential loss, various reflector shapes positioned behind the tubes are occasionally employed. These reflectors serve to concentrate a modest amount of solar energy that might otherwise dissipate.

## 4. Literature review:

M.S. Abd-Elhady et.al – The stu y aims to enhance the heating capacity of evacuated tubes equipped with heat pipes. This is achieved by introducing thermal oil into the evacuated tube to improve heat transfer rates. This alteration transforms the mode of heat transfer from the inner surface of the evacuated tube to the heat pipe, involving both convection via the oil and conduction through the installed foamed-copper. The conventional finned surface is replaced by foamed copper for improved performance.

An experimental setup was devised to assess the impact of oil and foamed metals on the perfor ance of evacuated tubes with heat pipes. The results indi ate a notable increase in bulb temperature and heating efficiency of the evacuated tube heat pipe with the insertion of oil and the substitution of the finned surface with foamed copper. Additionally, the thermal oil serves as a means of heat storage.

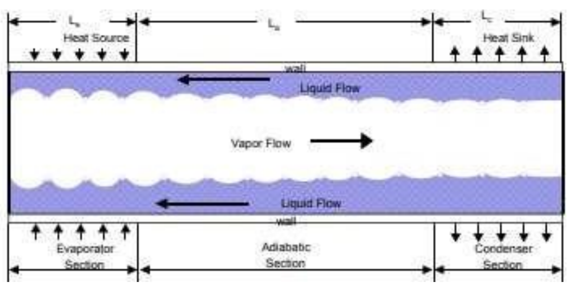
Sarvenaz Sobhansarbandi et.al - In this study, we have advanced the technology of Solar Water Heaters (SWHs), which are widely recognized as a renewable energy solution worldwide. Our focus has been on enhancing Evacuated Tube Solar Collectors (ETCs) by incorporating "dry-drawable" Carbon Nanotube (CNT) sheet coatings to augment solar energy absorption and Phase Change Materials (PCMs) to bolster heat accumulation for SWHapplications. The proposed solar collector integrates Octadecane paraffin as the phase changeaterial, boasting a melting temperature of 28°C and char cterized by its non-toxic nature and long-term chemical stability. While PCMs, especially in powder form, may exhibit limitations such as poor heat transfer rates, low thermal diffusivity, and thermal conductivity, our approach combines CNT layers known for their high thermal diff sivity and thermal conductivity with PCMs. This fusion allows us to overcome the shortcomings of PCMs and engineer an innovative and efficient solar water heater. Utilizin current technology, we achieve a near-ideal black body surface capable of absorbing up to 98% of solar light within the 600 to 1100 nm range, enhancing the performance of the solar heater through additional spectral absorption. By employing CNT sheets alongside PCMs, we enable direct heat storage on the collector, ensuring a more consistent output, even under cloudy conditions, and extending the duration of heat output into the night.

S. SivaKumar et.al. - The investigation into renewable energy sources marks a pivotal step toward meeting our growing energy demands, with solar energy emerging as a prominent contender. Solar energy can be harnessed through both photovoltaic (PV) and solar thermal methods. Solar thermal technology, particularly suited for domestic applications such as space heating, cooling, hot water systems, and drying, holds significant importance in meeting these needs. Among various thermal collectors, the evacuated tube solar collector (ETSC) stands out for its remarkable efficiency even under low solar insolation conditions. This paper focuses on enhancing the heat generation capabilities of the evacuated tube by integrating heat pipes. The primary objective of this research is to design and investigate the heat transfer dynamics of a Heat Pipe Evacuated Tube solar collector. The collector is constructed with Borosilicate glass, featuring a length of 1.8m and outer and inner tube diameters of 0.058m and 0.049m, respectively, tailored for the Coimbatore location.

A.E. Kabeel et.al - The investigation involved the design and production of modified coaxial heat pipes aimed at enhancing the thermal performance of glass evacuated solar collectors. These heat pipes were constructed using two concentric copper tubes, with the annulus volume space between them charged with refrigerant. Additionally, air was utilized as the working fluid at four different mass flow rates (0.0051, 0.0062, 0.007, and 0.009 kg/s), flowing through the inner tube of the heat pipe and then through the annulus between the heat pipe and the glass evacuated solar tubes. To assess the impact of the tilt angle of the evacuated tube on the thermal performance of the collector, experiments were conducted to determine the optimum tilt angle. Furthermore, experimental investigations were carried out to examine the influence of the filling ratio on thermal efficiency, using two types of refrigerants, R22 and R134a, within the filling ratio range of 30% to 60%. The results revealed a significant improvement in thermal efficiency, with a maximum increase of 67% observed compared to configurations without heat pipes, particularly at a mass flow rate of 0.009 kg/s. Furthermore, the experiment results demonstrated similar performance trends between the two refrigerants under investigation.

Piotr Felinski and Robert Sekret - This investigation introduces a novel approach that integrates a phase change material (PCM) into a heat pipe evacuated tube collector, supplemented with a compound parabolic concentrator (CPC). This innovative setup leverages the superb insulating properties of evacuated tubes and harnesses latent heat, offering significant advantages over conventional solar water heaters. However, a challenge arises during the charge cycle of the integrated system, where direct solar radiation only reaches the exposed areas of the evacuated tubes, leading to uneven heating of the PCM due to lower energy input in shaded regions. To address this issue, a CPC is employed to concentrate solar radiation onto the shaded areas of the evacuated tubes, thereby elevating the temperature of the PCM and increasing the quantity of stored heat. For this purpose, a polished, thin aluminum sheet with a concentration ratio of 1.2x serves as a low-cost CPC. Technical grade paraffin, featuring an onset melting temperature of 51.24°C, is utilized as the PCM. The results of the study demonstrate that the application of the CPC facilitates a more rapid increase in the temperature of paraffin on the shaded side of the evacuated tubes, particularly during and after the melting phase. Moreover, incorporating a CPC into the PCM- integrated ETC/S enhances both the average gross charging efficiency (from 31% to 36%) and the maximum charging efficiency (from 40% to 49%).

Pressure Differential at Liquid Vapor Interface




- The vapor pressure diminishes as it moves from the evaporator to the condenser..
- The liquid pressure decreases as it moves from the condenser to the evaporator.
- At any cross-section of the heat pipe, a pressure differential exists between the vapor and liquid phases. This pressure difference is maintained by the surface tension force generated at the liquid/vapor interface at the tip of each groove.
- The smallest delta pressure is experienced at the extreme end of the condenser (zero), while the greatest delta pressure is observed at the far end of the evaporator

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