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REVIEW ON DESIGN & DEVELOPMENT OF SPIRAL COIL TYPE SOLAR WATER HEATER SYSTEM

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Abstract:
Solar energy is the most reliable energy and in near future, everyone will be depending on it completely due to a lack of resources. The task is to design and develop a compact and more efficient solar water heater that can be affordable to everyone. Current solar water heaters are quite expensive and very bulky as well. There are many kinds of solar water heaters already available in the market offered by various brands they offer a limited supply of water when used for extended periods they can waste up to 15% energy through radiant loss. But what makes this product outstanding is the use of a spiral coil instead of a traditional square design which gives water more time to circulate and heat up quickly. The basic design of our solar water heater can be considered a flat plate collector but as an added feature vacuum is induced in the gap between the spiral coil and glass which makes an amalgamation of the evacuated tube and flat plate collector. And also PCM is used in an insulated tank to make sure water is warm for a long period. By introducing all these small changes and innovations the goal is to achieve a product that is more efficient and cost-effective as well. The design of the current system is to heat 60 liters of water with the help of sun rays within the estimated time which will provide hot water to a maximum of 3 people.

Keywords: **Solar Energy, Spiral Coil Collector, PCM (Paraffin Wax), Thermal Energy Storage, Renewable Energy.**

1. INTRODUCTION

Solar energy has multiple capabilities of alternative energy sources. Due to the increasing ultimatum for energy and the rising expense of fossil fuels (like gas or oil) solar power is viewed as an attractive source of renewable energy that can be used for heating the water in both houses and industries. The average family consumes nearly 20-30% of total energy. Solar water heating techniques are the most affordable and clean energy unrestricted to homeowners that may deliver most of the hot water needed to the family. Solar Energy is available in plenty at the lowest price. The solar radiation happening on the earth's surface can be conveniently used for the benefit of humans. Solar Hot Water System (SHWS) is one of the prevalent appliances that trap solar energy. In the current scenario, the government is raising awareness regarding pollution and all the harmful effects of using fossil fuels. Harnessing solar energy is the future, we will be eventually short of fossil fuels and we'll have to look for alternate energy solutions.

For heating water, and creating steam for household and commercial objectives by employing solar energy, a device called Solar Water Heater is employed. The energy that is reaching in the form of solar radiation in limitless amounts is solar energy, when these solar radiations drop on the absorbing plate or surface, then heat conversion takes place; this heat is operated for heating the water. Due to modes of heat transfer like convection & radiation solar collector will be affected by some heat losses. As the temperature of the operating fluid increases, such losses will also rise rapidly.

There are many kinds of SWHS available in the market like an evacuated tube, flat plate collector, etc. But we have decided to operate on a flat plate collector. A flat plate collector is a heat exchanger for SWHS which helps to heat water by trapping the solar energy from the sun incorporated with PCM to reserve the heat energy.

India gets over 7 sun hours on average every day which is enough to heat water for daily use. Our compact heat exchanger is a new generation flat plate collector which is more cost effective and efficient compared to the current SWHS present in the market.

2. LITERATURE REVIEW

2.1 Solar Water Heating System

Vishal G. Shelke et al. [1]: have worked on existing solar water heating systems with their applications. The satisfactory usefulness of solar energy is controlled by the unstable nature of its availability, limiting its usage and importance in household and commercial applications, particularly in water heating. Different resources like coal, diesel, gas, etc., are utilized to heat water and occasionally for steam production. Solar power is the foremost choice to replace conventional energy sources. Aspects that impact the dimension of the design are the quantity of solar radiation available, the need for temperature, geographical situation, the structure of the solar design, etc. Thus, it is required to design the solar water heating system as per the above parameters. This literature is studied to comprehend the structure, design, and uses of the solar thermal system.

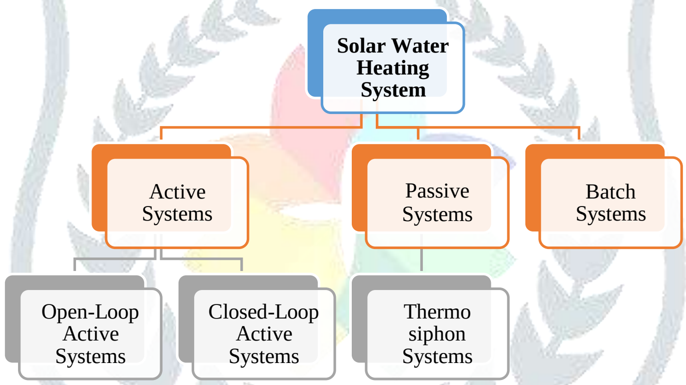

Fig. 1: Types of Solar Water Heating System

Murtuza Vasanwala et al. [2]: Solar water heater by evacuated tube uses evacuated tube solar collector which is more efficient than flat plate collector. In this evacuated tube, a copper heat pipe is filled with non-toxic liquid. As the sun heats the liquid it vaporizes and rises to the top of the heat pipe and it causing the heating of the water to pass around it. This system has good thermal efficiency and low maintenance. Conductive and convective heat loss is very low in this system. The result of less heat loss is fast heating of water as compared to flat plate solar water heater etc.

F. Kreith and J. F. Kreider et al. [3]: propose a foundational study of the Principles of Solar Engineering, presenting a thorough analysis of the root principles underlying solar energy system design. Their work highlights the fundamental conceptions of fluid mechanics and heat transfer, including heat exchanger design and radiation heat transfer—key components in developing efficient solar techniques. This research provides an organized study of solar thermal energy collection and delivery methods, representing a variety of flat-plate and concentrating collectors. The book additionally examines the research and optimization of solar energy techniques, integrating design components with financial evaluation to sustain functional performance. Notably, the field of solar uses, including space and water heating, as well as solar-driven cooling and dehumidification, makes it a crucial regard for researchers and engineers in the field.

Maheshwaran. S., Kalidasa Murugavel. K. [4]: performed a practical analysis of a passive solar water heater comprising a spiral flow flat-plate collector. A spiral-shaped copper tube was used and attached to an aluminum absorber plate in the design to enhance heat absorption. Testing was performed under natural sunlight in Kovilpatti, India, during the summer season. It was discovered in the study that heat transfer was especially enhanced by the spiral configuration, with a peak outlet water temperature of 95°C and a thermal efficiency of 65.98% achieved at a flow rate of 0.015 kg/s. The significance of spiral flow arrangements in enhancing the thermal performance of solar water heating systems, particularly in regions with high solar insolation, is emphasized by these outcomes.

Cristofari et al. [5]: analyzed the modeling and performance of a solar flat-plate thermal collector completely created from copolymer materials. The study concentrated on assessing the thermal conduct of this polymer-based collector under different operating parameters, including insulation thickness, fluid flow rate, and fluid layer thickness. Employing a limited difference thermal model, the study examined the performance in a Mediterranean climate. The copolymer collector's efficiency under mild wind conditions was 56.5% on average. This dropped to 49.0% at a wind speed of 5 m/s. The use of copolymer materials reduced collector weight by 50% compared to traditional metal collectors, making installation easier. The analysis figured that copolymer-based solar collectors deliver a cost-effective and efficient option for solar water heating applications, especially in regions with high solar insolation.

Douglas Reindl et al. [6]: have worked on to simplify small-scale thermal storage systems by the use of a spiral-jacketed storage tank that combines the function of both the heat exchanger and storage tank. The new storage tank is designed and manufactured to maintain performance comparable to a conventional system, and its functional performance validated by retrofitting an existing system and operating it under real conditions over a multiple month period. The system retrofitted with a spiral-jacketed storage tank showed performance competitive with the previous system that utilized a typical storage tank and heat exchanger during a day with a good solar radiation but experienced somewhat diminished performance during a month that included cloudy days. The spiral-jacketed storage tank considered in this study has a capacity of 400 L with the exterior tank envelope surrounded by an annular jacket arranged in a spiral orientation. An antifreeze solution circulates through the collector to this flow passage, thereby transferring heat from the outside wall of the tank to the water stored inside the tank. To establish operating conditions for the passage design, one day was selected with good solar radiation. Solar radiation data as well as the average temperature of the storage tank for the existing system were established at 12:00 on Oct. 15, 2003 as standard status.

Vikram S. et. al. [7]: have worked on development of performance of solar flat plate collector. The prevention of the escape of the diffuse radiation from top surface is done by reflector sheet. The radiation that falls on the reflector is reflected back to the collector. This causes more radiation to be absorbed by the water and consequently a higher temperature rise is obtained. Without using reflector at zero wind speed the efficiency varies between 5.4 to 9%. But with use of reflector, the efficiency reaches a peak of 32%. Similarly, at a wind speed of 3.5 m/s, the efficiency varies between 18% and 32% without reflector and between 30% and 67% with reflector. Similarly, in both the cases with reflector, the outlet temperature reaches a temperature above 90°C. This analysis helps to evaluate the amount of savings obtained by using a reflector in a flat plate collector. This system can help in reducing the electrical energy consumption that is used for water heating purposes. The use of solar energy for heating can have a large potential to reduce the Green House Gases (GHG) emissions.

2.2 Phase Change Materials

Abdullahi Bello Umar et al. [8]: have worked on continuous and extensive research in the field of materials science and technology into coming up with better materials than the ones currently in use. Presently both single organic and inorganic phase change materials (PCMs), and also the mixture of both materials are called eutectics. This research tries to study the different characteristics of importance and their advantages as well as disadvantages. The different techniques utilized for the advancement of these materials are emphasized. In hot countries with clear climatic conditions at most times of the year, trapping solar energy in the form of thermal as well as photovoltaic forms is favorably achievable both in terms of upcoming techniques as well as cost. Similarly, big countries like India and China with a population of about 1.3 billion people represent a large market for solar energy, especially in the Asian continent and if such a market is captured, it will rejuvenate the economy by improving the total solar energy output which will reduce the importation of crude oil into such counties.

G. Murali et al. [9]: have worked on the energy storing material (i.e. PCM) which is employed in solar water heaters to reserve the additional quantity of heat energy open during the full sunlight hours. The preliminary objective of this paper is to analyze the performance of a PCM-integrated thermo- siphon solar water heating system utilizing a flat plate collector as a heat origin. In this analysis, a cylindrical aluminum tank incorporated with PCM serves as a heat energy storage unit. It is operated in the top part of the tank containing water that is insulated. PCM in the form of paraffin wax is operated. The effectiveness of time-wide deviation of PCM and (heat transfer fluid) HTF temperatures during experimentations are examined and the execution parameters, such as thermal efficiency, and charging energy efficiency were also studied. For validation purposes with the help of Computational Fluid Dynamic, the simulation of the discharging experiments is done. It is indicated from the experimentations that the PCM enhances the execution of the system by improving the stratification number, charging energy efficiency, and thermal efficiency of the storage tank.

Table 1: [9] Properties of Paraffin Wax

Properties	Solid phase	Liquid phase
Melting point	56 (°C)	56 (°C)
Latent heat	142.7 (kJ/kg)	142.7 (kJ/kg)
Thermal conductivity (k)	0.4 (W/m °C)	0.2 (W/m °C)
Density (ρ)	670 (kg/m³)	640 (kg/m³)
Specific heat (C_p)	2.4 (kJ/kg °C)	1.6 (kJ/kg °C)

Papade C. V., & Kanase-Patil A. B. [10]: regarding previous research works, the conventional solar cooker performs foremost during the daylight having less cooking ability after sunset. The reason is to develop the system to work during the day and night time. The system works on the impact of solar radiation; we are using heat energy for cooking with the help of a parabolic collector. PCM gives backup stored energy for cooking up to 4 hours after sunset. The merit of deploying this system is it can make 2 food materials at a time, till now this is not done by using a parabolic collector. The benefit of using binary salts as a PCM improves the overall cooking performance, is found in the observation. The results show that during sunlight, cooking took 19 to 21 minutes, with a temperature difference of 49 to 60°C. And during nighttime, it took 22 to 25 minutes with a temperature difference of 52 to 70°C. Hence, it proves that the selected PCM has the adequate thermal storage medium in food-making industries and domestics.

C. V. Papade; A. B. Kanase-Patil [11]: study describes following points:
<u>Constraints of Conventional Solar Cookers</u>: Traditional solar cookers are limited to daylight use and have lengthy cooking times due to dependency on natural solar radiations.
<u>Improved Thermal Storage</u>: This new system comprises Nano-enhanced Phase Change Materials (PCMs) to reserve solar energy efficiently for usefulness during both day and night time.
<u>Nanomaterial's performance</u>: Adding nanomaterial's to PCMs enhances thermal conductivity and overcomes problems like high melting points, improving overall cooker performance.
<u>Double Cooking Power</u>: The parabolic cooker can make 2 dishes simultaneously and can fulfill domestic needs.
<u>Practical Cooking Outcomes</u>: The time to cook 200g of rice and dal was 17 to 20 minutes in the daytime, and 19 to 22 minutes in nighttime, with consistent performance with observes temperature drops.

C.V. Papade, M.A. Boda [12]: study summarizes following points:
<u>Objective</u>: The study sought to develop indirect solar dryer including thermal energy storage to facilitate drying during the duration of low solar radiation, especially in cloudy and evening time.
<u>Design Methodology</u>: The dryer was so designed based on measures applying the mass of water to be evaporated, energy requirements, heat gain by air, drying time, air velocity, average drying rate, heat losses, and insulation thickness.
<u>Energy Storage</u>: The design employed latent heat storage materials, particularly Phase Change Materials (PCMs), to reserve solar thermal energy efficiently, improving the dryer's performance during non-sunny periods.

Performance Analysis: The comparison between convergent and divergent air duct geometries was carried out using Computational Fluid Dynamics (CFD) analysis. Results showed that the convergent section improved air velocity, thereby enhancing drying efficiency.
Results and discussion: To reduce the moisture content present in various agricultural products, drying experiments were demonstrated with a designed dryer. Depending on the product type drying time changes approximately 6 to 8 hours for 5kg batches.

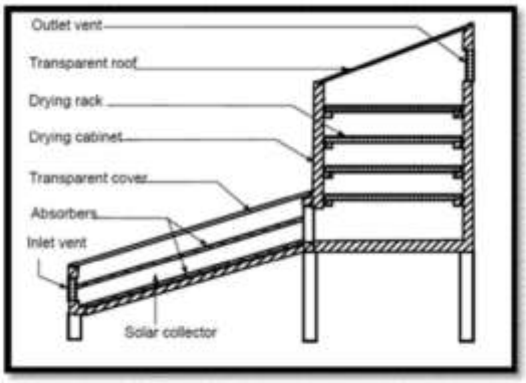

Fig. 2: [12] Indirect Solar Water Heater

Anand Patil et. al. [13]: have worked on use of PCM based solar water heater. The major conclusion drawn from this work is by using PCM the though the intensity of solar energy decreases with time due latent heat of PCM the water temperature increases because the PCM behaves like good phase change material.

R.R. Shinde, C.V. Papade, and B.K. Sonage [14]: delivered a study titled "A Review on Revampment of Phase Change Material", concentrating on the implementation enhancement of PCMs for thermal energy storage applications. The paper emphasizes the restrictions of conventional PCMs, such as lower thermal conductivity and leakage, and examines different approaches to overcome these problems and the use of nano-enhanced materials, encapsulation techniques, and composite formulations. The authors highlight that such modifications are crucial for efficient heat storage and release, specifically in solar thermal techniques and temperature constraint technologies. The study provides an understanding of material choosing based on thermal performance, financial feasibility, and environmental effects, thereby operating as a basis for future advancements in PCM-based energy resolutions.

Fig. 3: [14] Classification of PCM

2.3 Analysis of Solar Water Heating System

Donatas Dervinis et al. [15]: have worked on the idea to investigate the possibility to use solar energy for water heating in Lithuania. Lithuania is somewhere between central and north Europe. So it means that geographical position is not as favourable as it is in the Mediterranean region but as harsh as it is in northern Europe. This paper presents the first steps to investigate a small thermosiphon solar thermal system. Thermosiphon solar thermal systems are more common in the south but not in central or even in the north of Europe. Basically, this research relates to domestic heating of hot water. A thermosiphon system works on the principle of natural convection to circulate the heat transfer in the liquid between collector and storage. This paper aims to evaluate the heat exchange between the thermosiphon-type water heater and the environment.

From this research work, we conclude that we can install the SWHS according to the geographical position of the country.
Following is the 2D line diagram setup based on above research.

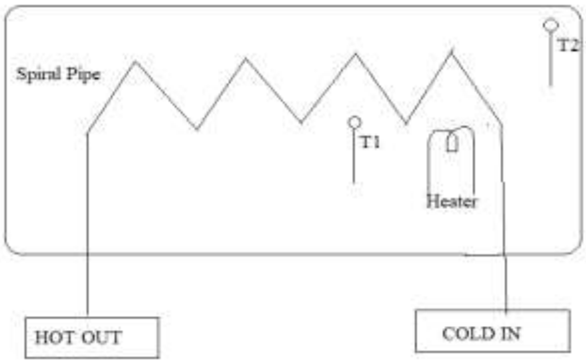

Fig. 4: [15] Construction of Thermo-siphon Water Heater

Ijemaru Gerald Kelechi et al. [16]: have worked on the demand for energy in Nigeria is usually met by burning fossil fuels such as charcoal, petroleum, natural gas, kerosene, etc., or by the use of electricity. Electricity generation in Nigeria is not sufficient enough to meet the energy demand. This project seeks to model a thermosiphon system, which relates the effect of efficiency and also the gross area of the solar collector on the volumetric flow, from experimental results in Akure, Nigeria. The outcome of the study shows that if the efficiency of the system is increased, the area is increased resulting in an increase in the volumetric flow, which can be utilized to estimate the quantity of water being warmed per time. In this research, we figure that choosing the proper solar water heater for an installation depends on three essential aspects i.e. climate, budget, and water usage needs. We noticed a volumetric flow and volume are directly proportional to each other. Thus, the bigger the water quantity to be heated, it will take more time. This is because the efficiency and area of the solar collector affect the time it would take to heat the water for an average of 20.05℃ temperature difference.

Table 2: [16] Average reading of the solar water heating system over a week (between 9 am and 4 pm)

Hour	T_{air} (°C)	T_{in} (°C)	T_{out} (°C)	Radiation intensity (I) W/m^2	Collector Efficiency (ηc)
09.00	28.4	28.9	35.8	126.05	6%
10.00	29.6	30.5	41.6	176.91	10%
11.00	31.1	39.2	47.8	210.91	12%
12.00	32.6	36.8	56.4	233.2	15%
01.00	34.1	34.4	65.6	258.66	19%
02.00	34.8	32.6	69.9	280.55	27%
03.00	32.9	38.3	64.5	228.00	60%
04.00	31.3	39.1	58.6	198.93	92%

Esdras Nshimyumuremyi et. al. [17]: have worked on thermal efficiency and cost analysis of solar water heaters. The results show that the efficiency of solar collectors is highly dependent on the design and material of the absorber plate. The absorber plate performance is also depending on the thermal conductivity of the absorber plate material. It has been seen that in the regions where the solar radiation is high, the performance of both collector and tank is also good. For the coldest region, the performance of the solar water heater falls a bit due to insufficient solar radiation. Solar water heaters manufactured in Rwanda at Tumba College of Technology have efficiencies ranging between 60% and 76%. The payback period of 2 years is lower compared to those in other literature (2.5 3.5 years); this is because of its high efficiency and design which eliminate the oversizing of the system. It has been noticed that in the coldest region the thickness of the insulating materials should be increased so that the tank of the solar water heater can keep hot water for a good period.

S. Khan et al. [18]: study offers a year-long performance evaluation of two solar water heaters, with capacities of 100 liters and 200 liters, installed at the Bangladesh University of Engineering and Technology (BUET). Flat-plate solar collectors which operate on the thermo-syphon principle are used which allows the natural circulation of water without the need of any pumps. According to the results during winter, the solar heaters could boost the temperature of tap water by around 30°C during the daytime and nearly 25°C in the afternoon, indicating their significance even in cooler months. Given Bangladesh's advantageous geographical place, with everyday solar radiation from 4.0 to 6.5 kWh/m², Domestic hot water needs can be practically and sustainably met through the use of solar water heaters. The conclusions support the wider adoption of solar thermal technology in areas with similar climatic conditions to decrease reliance on traditional energy origins.

Abdulsitar A. et al. [19]: This analysis offers a performance analysis of a spiral-flow solar water heating system developed to improve heat absorption and energy efficiency. The experimenters assessed the design under variable solar radiation, atmospheric temperature, wind speed, and mass flow rates. Improved heat transfer was achieved in the spiral configuration due to the extended flow path and increased contact area with the collector surface. The system attained a peak thermal efficiency of 66.3% at a flow rate of 0.042 kg/s, with a considerable rise in water temperature observed in the storage tank. The analysis figures that spiral flow structures are highly adequate for domestic solar water heating applications, delivering both simplicity and enhanced thermal performance compared to conventional layouts.

Moravej et al. [20]: performed practical research into the thermal performance of a circular flat-panel solar collector including spiral-shaped pipes. The study aimed to assess how the spiral pipe arrangement within a flat plate collector influences heat collection efficiency under changing operating requirements. The collector was tried under natural daylight with various water flow rates to evaluate temperature distribution and thermal output. Results showed that the spiral arrangement adequately improved heat transfer performance due to its greater surface area and consistent fluid circulation, leading to better useful solar energy absorption. The system exhibited improved efficiency with increasing water flow rates and higher solar radiation stages. The study figures that spiral-type pipe integration in circular flat-plate collectors delivers a fortunate approach to enhancing the general performance of solar thermal systems.

Jamil Basharat et. al. [21]: have worked on the Estimation of solar radiation and optimum tilt angle. Energy falling on a surface can be significantly improved by making adjustments in the surface inclination. Due to the change in the Sun's position, different months have different optimum tilt angle values. It is recommended that, where possible, the surface must be inclined at the monthly or seasonal optimum tilt angle for better solar radiation utilization. Yearly optimum inclined angle can be taken for surfaces with a fixed angle of inclination, where changing the tilt angle is not achievable, which also reduces setup and operating expense. The following are the results and discussion of the above research over year in Aligarh and New Delhi.

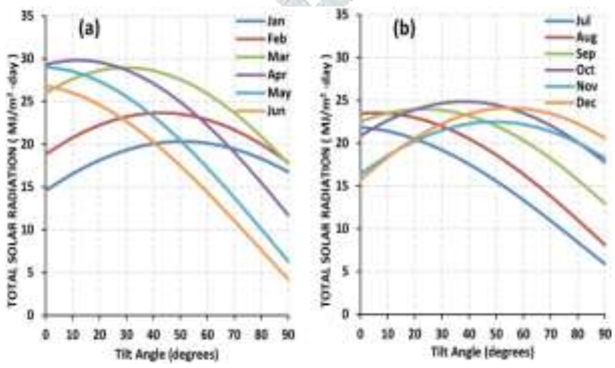

Fig. 5: [21] Monthly average daily total solar radiation versus tilt for south-facing surface in Aligarh.

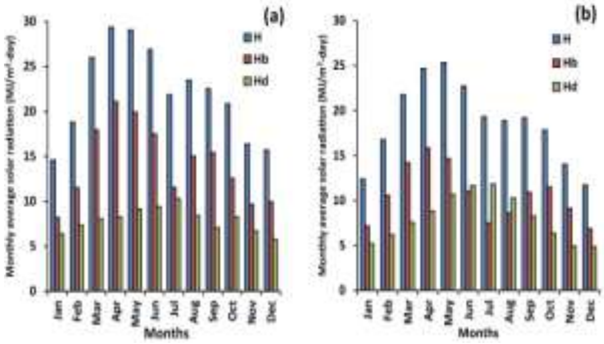

Fig. 6: [21] Monthly average solar radiation data for (a) Aligarh and (b) New Delhi.

3. METHODOLOGY

Fig. shows a schematic diagram of the proposed experimental setup. The following steps will be followed in this project work.

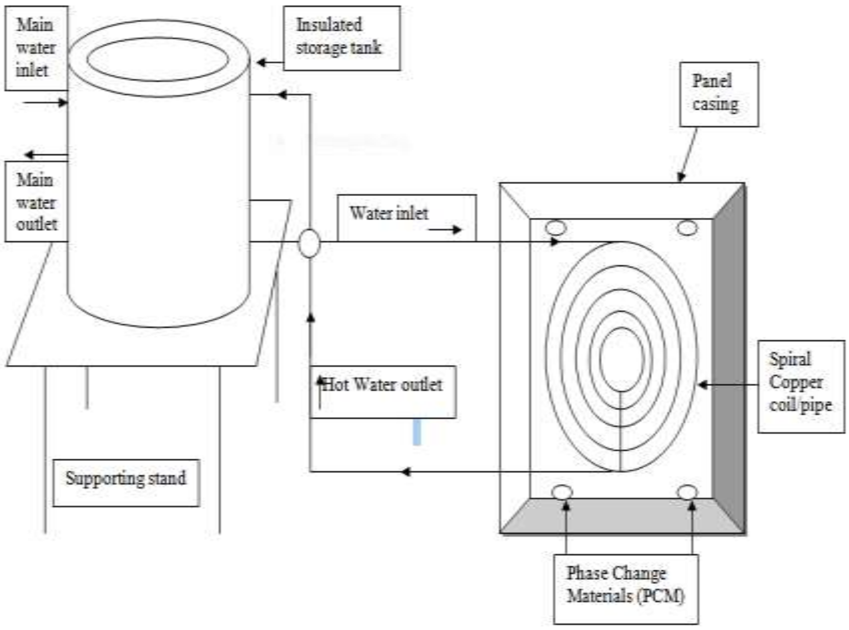

Fig. 7: Spiral Coil Type Solar Water Heater

- Literature related to existing solar water heating systems using passive techniques studied in detail. This main focus will be kept on heat storing/transfer using PCM materials and spiral pipe for obtaining more.
- Energy storing devices such as PCM (organic, inorganic, eutectic, etc.) is used to store the energy as well to transfer whenever required which is very important to understand.
- Detail study will be done on the effect of transfer heat by natural circulation as a result of buoyancy due to temperature difference between two regimes; hence they do not require pumps to operate.
- Results obtained in the case of PCM & heat transferred through the spiral pipe will be studied. The gap in the research will be identified from the existing literature.
- Project and its objective will be decided depending on gaps in previous research work.
- Equipment required for experimental setup will be collected and fabrication will be done. All the parts will be assembled to form the experimental setup as shown in Fig.1
- Material will be selected to manufacture the compact design PCM type solar water heater after studying the properties of various materials. Manufacturing of the spiral pipe will be done after selecting a material for the spiral pipe.

- Firstly, the experiment will be done using a compact flat plate collector type of SWH to obtain certain values & these obtained values will be compared with values obtained from a compact PCM type solar water heater with spiral pipe to validate the Experimental Setup.
- Once setup is validated, PCM will be inserted inside the flat plate section. The experimental investigation will be carried out to obtain the little extra heat from the bottom side which is just an added advantage.
- Different observations will be taken by varying/changing the geometry of the copper pipe. This effect of the geometrical parameter on heat transfer rate will be studied and the optimum geometrical combination will be found for copper. At the end of the research work report will be prepared.

CONCLUSION

The above studies suggest that introducing a spiral-shaped heat exchanger with phase-change materials (PCMs) can significantly improve the thermal performance of a solar water-heating system. The spiral layout will provide more vigorous mixing within the working fluid, keeping low pressure losses and an advantage over a flat plate collector. When this arrangement is combined with PCMs, i.e., Paraffin Wax, the system can store relatively more solar energy and deliver it slowly.

Overall, a solar water heater having a spiral coil with a PCM material turns up to be a productive and practical choice over classical designs. In the future, the preference and insulation of storage materials, optimization of coil geometry, and analysis of long-term thermal performance are required to ensure that these systems remain credible in real operating environmental conditions.

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