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Utilizing Phase Change Material (PCM) with a Focusing Lens for Solar Energy Storage

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ABSTRACT

This experimental study investigates water desalination processes utilizing phase change material (PCM) connected to a solar system. The PCM serves to store solar thermal energy collected during the day as latent heat, ensuring continuous operation by providing heat during the night. The thermal energy storage system (TES) consists of components such as a basin, tray, cooled glass, and focusing lens. Water is held in the basin, while the PCM is heated by direct solar radiation. Desalinated water is collected in a tray fixed within the basin. Water vapor produced from the basin condenses on the inner surface of the water-cooled glass cover, converting saltwater to freshwater. The utilization of the focusing lens is examined to increase freshwater production. The rate of desalinated water production is found to be directly proportional to ambient temperature and hot water circulation flow rate. An optimal cooling water flow rate (approximately 12 ml/s) is identified, maximizing unit productivity. Moreover, as the water level in the basin rises, productivity decreases. The unit demonstrates a capability of producing 5600 ml/day.m2, with 55% of production occurring after sunset. This system presents economic viability in desert and rural areas, particularly in remote regions.

Keywords: *Phase Change Material, Thermal Energy Storage System, Focusing Lens.*

1. INTRODUCTION

The objective of this study is to investigate Energy Storage Systems, encompassing both Solar Water Heating Systems (SWHS) and Thermal Energy Storage Systems (TESS), to tackle real-world challenges. SWHS and TESS incorporate Phase Change Material (PCM) materials to facilitate energy processes in both solar and thermal domains. The focus is on addressing issues related to high and low heat energy conversion within PCM materials.

The thesis is structured into seven chapters, beginning with an Introduction that outlines the motivation, research statement, relevance, and contributions of the work. It also discusses the scope, literature review, Computational Fluid Dynamics (CFD) analysis, comparative analysis of results, and conclusions and suggestions.

A significant aspect of this study is the exploration of PCM materials, which play a crucial role in various real-life scenarios, particularly in power conversion challenges. PCM materials serve as effective tools for power conversion, aiding in finding optimal solutions for energy storage systems within reasonable timeframes. The study proposes a robust set of techniques and utilizes parallel computation methods to obtain solutions.

In engineering and other technical fields, optimization is integral to the design process. Given the open-ended nature of design problems, the aim is to find the best solution under certain conditions. This involves trade-offs between costs and benefits, as finding optimal solutions often involves navigating nonlinear relationships between performance and cost. This research Provides an overview of the current state of SWHS and TESS, discussing optimizing techniques used in experiments and analyzing related studies.PCM Materials Process Analysis: Examines the role of PCM materials in SWHS and TESS, analyzing performance and results.

Computational Fluid Dynamics (CFD) Analysis: Details experimental studies and analyzes results. Experimental Work: Discusses the design of Solar and Thermal power storage systems, demonstrating the efficacy of a multi-level PCM Materials approach. Comparative Analysis: Compares methods proposed in this study with previous research. Summarizes the research work, highlights key findings, and suggests avenues for future research.

This study emphasizes the importance of energy storage systems for managing energy supply and utilization across different timeframes. Various methods of thermal energy storage are discussed, including Sensible heat, Latent heat, and Thermo-Chemical or Artificial heat sources, tailored for different latent heat timeframes.

2. LITERATURE SURVEY

This study will concentrate on optimizing the thermo siphon. Researchers in Solar Water Heating Systems (SWHS) have focused on evaluating performance under various operating variables in Solar Thermal Systems (STS). The literature reviews examine designs and aspects of SWH systems to enhance thermal heating systems. These reviews provide an overview of studies on solar collectors applicable to various heat pump systems, covering design characteristics, different passive and active techniques, and heat enhancement methods for Inside flat-plate solar water heating systems (FPSWH).

In this study, we investigate and experimentally analyze the effects of passive and active heat using different enhancement methods such as twisted strips and baffles, and collectors across a range of flow rates.

Thamaraikannn et al. (2017) reviewed methods to improve Phase Change Material (PCM) heat transfer efficiency, including active methods like agitators, vibrators, scrapers, microencapsulation, nano-encapsulation, imbibing PCM with high conductivity particles, assorting PCM with graphite composite materials, and improving contact surface with fins and honeycombs.

Joseph et al. (2015) studied the real-time performance of phase-change material (dodecanoic acid) for solar thermal energy storage. Their results supported previous findings on high energy storage densities in PCMs, highlighting their potential for solar thermal storage. The study also demonstrated the influence of the geometry of the tank’s coil heat exchanger on heat transfer quality.

Solar thermal systems are predominantly used in industries for commercial applications, and this study also evaluates Solar Water Systems (SWS). SWS, based on energy systems, predominantly analyze storage systems, particularly Advanced Latent Heat Storage Systems, for environmentally friendly technological applications. These systems contribute domestically and economically to enhancing the heat fraction of renewable energy sources, integrating with conventional energy systems. PCM materials sustainability is emphasized, especially in cascade solar cooling or heating applications. The study reviews common collectors to enhance performance across various applications and orientations, particularly focusing on minimal latent heat temperatures in solar water heating systems, akin to commercial appliances.

This survey collects data for behavior analysis in SWHS, examining effects on storage tank stratifications and collectors under different weather conditions, analyzing outcomes of solar energy and variations in hot water flow. The study delineates latent heat designs within SWHS under different flow variations, predicting thermal behavior and performance concerning solar radiation. The introduction discusses operating variables in SWHS, as illustrated in Figure 1.

3. EXPERIMENTAL WORK

The solar desalination system utilized in this study is depicted in Figures 1 and 2, comprising five key components: a solar basin, double glass cover, focusing lens, and tubes filled with PCM tray. The basin is oriented towards the south and inclined at a 35º angle, constructed from mild steel and coated black to enhance solar energy absorption. With a square bottom measuring 1 m^2, its front height is 0.16 m while the back is 0.92m. Saltwater is placed at a specific level in the basin. The double glass cover consists of two glass layers spaced 1 cm apart, with coolant water circulating through it to reduce the inner glass temperature. This reduction promotes vapor condensation, enhancing the driving force between evaporation and condensation processes within the chamber. Condensate accumulates on the inner glass surface, flows into an inclined tray attached to it, and then enters a collection tube to be withdrawn as fresh water. Water supply to the basin is regulated by a 20 L adjustment tank, ensuring consistent water levels via a float mechanism. Additionally, a water level indicator and various temperature sensors in the basin, including those for PCM temperatures, aid in monitoring and control. An additional drainage tray is attached to the basin to collect purified water, measuring 1.5 m in length, 0.15 m in width, 0.003 m in thickness, and 0.02 m in height.

The double glass cover, made of brittle silicon material, spans an area of 1.5 m^2 and features 10 parallel copper tubes (8 mm in diameter) arranged on its bottom surface. These tubes are spaced 10 cm apart and covered with 4 mm specular glass. The collector operates under a maximum pressure of 6 bars and maintains a steady temperature of 110ºC at 1000 W/m^2 and 30ºC. Water circulates through the solar collector tubes and the basin's heat exchanger in a closed loop, driven by natural convection or a pump. A stainless-steel tub containing distilled water and plastic tubes filled with PCM material (Sodium Thiosulfate penta hydrate - STSPH) is attached to the bottom of the solar still. STSPH was chosen for its high latent heat of fusion, minimal volume change at the melting point, availability, and cost-effectiveness compared to other PCM materials. Additionally, inorganic salt PCMs like STSPH exhibit superior thermal conductivity compared to organic PCMs. Thermal properties of STSPH are detailed in Table 1, with further information on PCM material selection criteria provided in (Al-Zghoul, 2016).

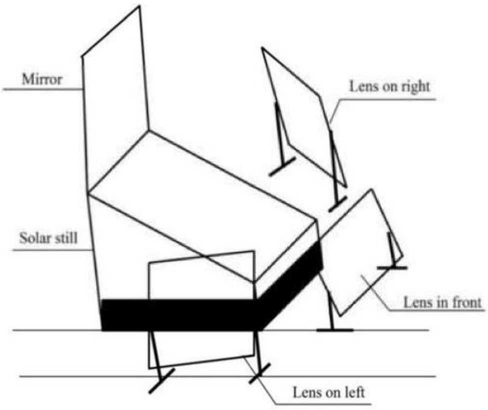

Fig.1

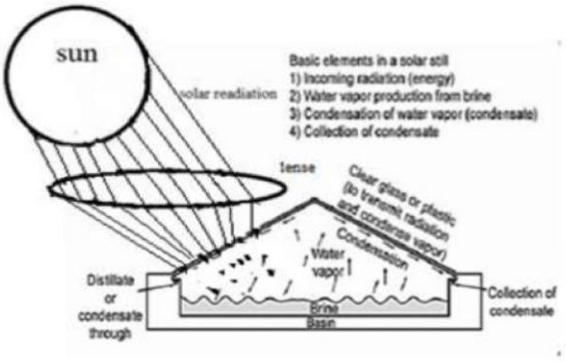

Fig.2

Table 1: Thermal properties of STSPH

Year	Month	Date	Hour	Min	light	humidity	level	Ph1 (sea)	Ph2 (wat)	temp4 (pcm)	temp3 (wat)	temp2 (pcm)	temp1 (pcm)
2018	2	4	2	6	1426	11	35	8.6	7.8	62	58	68	65
2018	2	4	3	2	1331	11.7	36	8.6	7.8	71	67	70	69
2018	2	4	3	30	1289	12	38	8.6	7.8	73	71	71	72
2018	2	4	4	5	1212	12.3	40	8.6	7.8	65	73	68	67
2018	2	4	5	11	1173	13	41	8.6	7.8	59	56	61	59
2018	2	4	6	23	1090	13.8	43	8.6	7.8	46	48	45	47
2018	2	4	7	10	1038	14	46	8.6	7.8	40	37	38	38

4. RESULTS AND DISCUSSIONS

The experiments detailed in this study were conducted in the year 2015 and comprised two main components. Firstly, a parametric study aimed to identify optimal conditions within a specified suitable range for each parameter. This phase involved conducting experiments from 9:30 to 16:30 solar time. The outcomes were utilized to assess system performance and productivity during 24-hour operation (part two). Multiple experiments were carried out on days exhibiting similar total solar radiation and ambient temperatures to ensure reproducibility and to investigate the impact of operational parameters.

Figure 2 illustrates the variations in solar irradiation and temperatures of ambient (Ta), basin water (Tb), and PCM for a typical summer day (May 15, 2015). The peak solar irradiation value (830 W/m2) occurred at 13:00, coinciding with a maximum ambient temperature of 33.5 ºC. However, the peak basin temperature of 65.2ºC was attained 90 minutes later, owing to the thermal capacity of water, PCM, and basin walls.

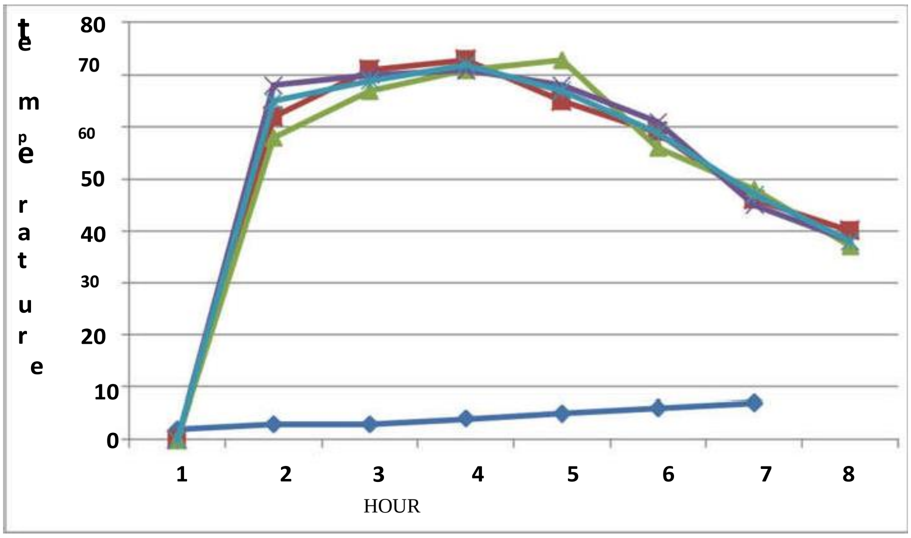

Fig. 3. Various temperature of PCM for corresponding hours

In this graph shows the various PCM temperature and it’s how to react depending upon thetime, in this three PCM s are BBCL wax, red wax, copper brown Wax.

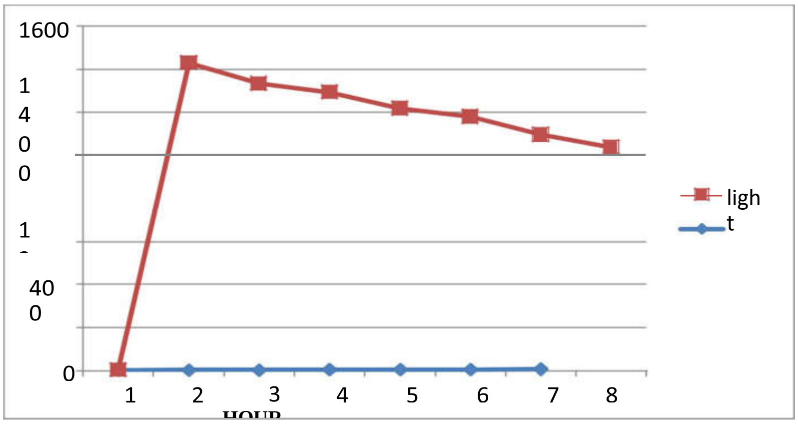

Fig. 4. Various lighting for corresponding hours

In this graph shows the light inside the profile and it's how to change depending upon the time

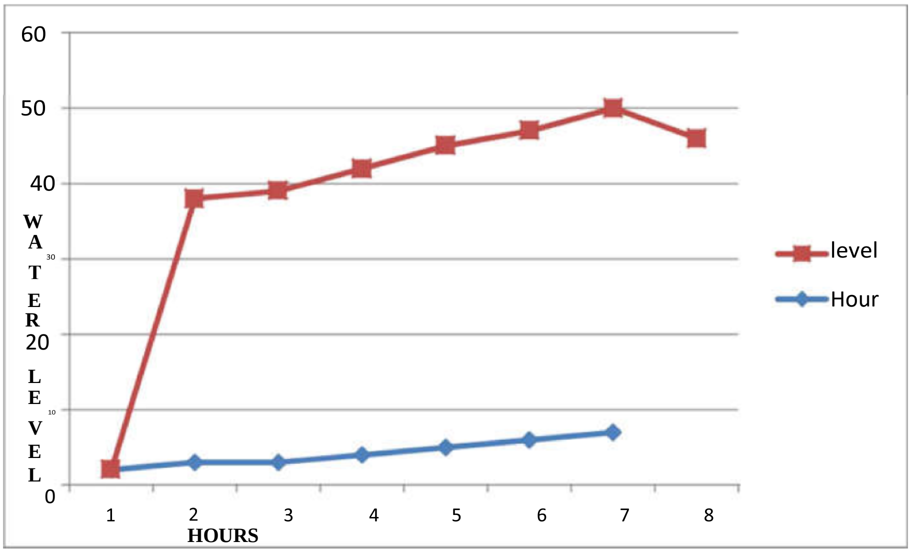

Fig. 5. Various Water level for corresponding hours

In this graph shows the water level inside the profile and it's how to change depending uponthe time

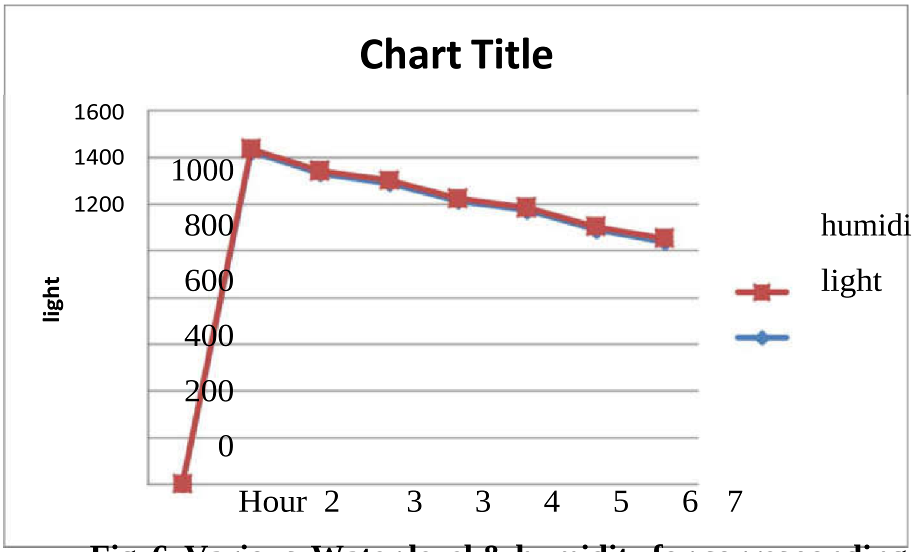

Fig. 6. Various Water level & humidity for corresponding hours

In this graph shows the light inside the profile and it's how to react with humidity level

5. CONCLUSIONS:

The experimental investigation of a solar still incorporating Wax as PCM and linked to an external solar collector concluded that the chosen PCM effectively stored energy during nighttime periods without altering its thermal behavior. Increasing the flow rate of cooling water supply from 6 to 10 cc/s enhanced productivity, whereas further increasing it to 1 ml/s slightly reduced productivity, resulting in a negative impact. Productivity of the unit increased with higher circulation flow rates of hot water, tripling when flow rates escalated from 2 to 30 ml/s. The PCM exhibited greater efficacy when the water level in the wash basin was lower. Altering the water level from 10 to 5 cm doubled the unit's productivity. The highest daily productivity observed experimentally was 5300 ml per twenty-four-hour period.

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