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An Investigation Of a Solar Water Heater Using a Double-Walled Absorbent Spherical Tank and Solar Gravity For Thermal Operation

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دراسة سخان مياه بالطاقة الشمسية باستخدام خزان كروي ماص مزدوج الجدار والجاذبية الشمسية للتشغيل الحراري

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Abstract:
This study explores innovations in solar water heating systems through two key approaches. In the first stage, a spherical, double-walled thermal storage tank integrated with phase change materials (PCM) was designed to enhance both solar energy capture and thermal insulation, achieving a maximum temperature of 80.3°C and 74% thermal efficiency, sufficient for 8.43 individuals. In the second stage, the use of graphene/water nanofluids was investigated to improve the efficiency of solar gravity heat pipes. Results showed that incorporating 0.05 wt% graphene nanofluids reduced startup times by 15.1% and 10.7%, indicating enhanced thermal performance and efficiency in solar energy collection.

Keywords: Solar Water Heater, Absorbent Spherical Tank, Solar Gravity, Thermal Operation

الملخص
تستكشف هذه الدراسة الابتكارات في أنظمة تسخين المياه بالطاقة الشمسية من خلال منهجين رئيسيين. في المرحلة الأولى، تم تصميم خزان تخزين حراري كروي مزدوج الجدران متكامل مع مواد تغيير الطور (*PCM*) لتعزيز كل من جمع الطاقة الشمسية والعزل الحراري، حيث تم تحقيق درجة حرارة قصوى بلغت 80.3 درجة مئوية وكفاءة حرارية بنسبة 74%، مما يكفي لتلبية احتياجات 8.43 فردًا. في المرحلة الثانية، تم التحقيق في استخدام سوائل نانوية مكونة من الجرافين/الماء لتحسين كفاءة أنابيب الحرارة بالجاذبية الشمسية. وأظهرت النتائج أن استخدام سوائل نانوية بتركيز 0.05% وزنًا من الجرافين قلل من أوقات بدء التشغيل بنسبة 15.1% و10.7%، مما يشير إلى تحسين الأداء الحراري وزيادة كفاءة جمع الطاقة الشمسية.

الكلمات المفتاحية: سخان المياه بالطاقة الشمسية، خزان كروي ماص، الجاذبية الشمسية، التشغيل الحراري

1. Introduction

The foundation of sustainable development is an affordable and environmentally friendly energy source. Development should consider both future and existing requirements, and it should view environmental concerns as a challenge. The utilization of solar energy, which is environmentally beneficial, offers hope for reducing greenhouse gas emissions. In addition to its benefits for the environment, renewable energy also enhances human happiness and health while contributing to global socioeconomic development. Constant energy service provision contributes to energy security. Renewable energy sources, particularly solar energy, are dynamic and intermittent, which causes energy production to fluctuate and affect system effectiveness [1]. As a result, it is believed that the absence of ideal storage devices is the primary and most significant obstacle to solar energy development and advancement. We can use energy storage technology to harvest the load during peak times, thereby addressing the issues. One method to store solar energy is through thermal energy storage (TES) technology. TES increases the total efficiency and dependability of solar systems by providing thermal assistance during low or no radiation hours [2]

Technology for storing solar thermal energy (STES) is based on solar water heaters (SWH). In reality, the collector converts solar energy into thermal energy, which the solar water heater tank then stores. The design of the water storage tank poses a significant challenge to solar energy procedures. Through computational fluid dynamics (CFD) parametric calculations, [3] looked into the properties and best design of horizontal solar storage tanks. Research uses both dynamic and static modes to observe the operation of the water tank. Heat charges or drains the tank, a process known as the dynamic mode. As a result, the water in the tank enters a dynamic mode during its consumption. In contrast, when it is not in use, the tank is in static mode. Because heat loss from the tank transfers energy to the surrounding air during a natural cooling process, the static mode is sometimes referred to as the cooling process in some writing. This thermal categorization affects both the tank's storage capacity and system efficiency [4].

The studies include a mathematical model-based investigation of the charge and discharge modes of a solar water heater tank operating under dynamic conditions in accordance with typical weather conditions. In a numerical analysis using CFD, [3] looked into the hydraulic characteristics of a coil-heating water tank. Research on hot water storage tanks typically ignores the tank's shape, instead focusing on the charge and discharge modes of cylindrical tanks in both horizontal and vertical positions. There has been no specific research on different kinds of tanks. In contrast to the ambient temperature, which varies throughout a normal day in a cold area, solar radiation is not static and has a dynamic feature. Because solar energy fluctuates and is unstable, the storage tank size should be large enough to hold enough heat. Furthermore, study [5] used a phase change material-based latent heat storage system (LHS) to make solar water heaters (SWH) smaller in size and improve their performance and dependability by making the system work for longer. In the form of latent heat energy and sensible heat energy with little temperature change, PCMs are able to store a high density of thermal energy. By storing high amounts of latent heat in a relatively small volume of the PCM, we decrease the volume of the heat storage tank. This resolution resolves the issue of a mismatch in the supply and demand of solar energy during the day and night.

However, since a solid PCM layer is developing around the coil, conduction is the primary reported heat transmission mechanism in the tank discharge process. Some researchers have used nanofillers in solar water heaters to integrate PCMs with nanoparticles. By improving the thermal conductivity of the PCM, nanofillers significantly assisted heat storage for a longer period of time. The water temperature rises by 33% compared to traditional water heaters [4]. Researcher who tested how a thermal storage system with nanoparticles charged and discharged found that the system's average energy performance and melting rate went up in a straight line, while the times it took to charge and discharge went down. Researchers examined the impact of CuO nanoparticles on PCM paraffin wax to assess the thermal performance of solar water heaters at night. By increasing the PCM's thermal conductivity, CuO nanoparticles improved the amount of heat exchange from the phase change material to the water and lowered the thermal storage capacity of the PCM paraffin wax. According to this study, using CuO nanoparticles in the PCM proved ineffective at night. According to several researchers in this field, placing fins in PCMs is a better option than using nanofillers to increase the quantity of heat exchanged.

Adding nanoparticles to an improved heat transfer technology can significantly improve a base fluid's thermal conductivity. This can also change the flow characteristics and increase the heat transfer coefficients for convection, boiling, and condensation. Regarding heat pipe heat transfer using nanofluids, the majority of earlier studies have found that using various nanofluids as the working fluid can boost the thermal performances of various types of heat pipes. [2], for instance, used experimental evidence to show that charging a heat pipe with MgO/water nanofluid instead of water enhanced its performance by a heat pipe's efficiency by 26% when subjected to 200 W of heating power [6-8]. The addition of nanoparticles, however, may also cause a decline in the thermal performance of the heat pipe, so it is not always advantageous in all working conditions. Researchers discovered that the smooth surface enhanced the nucleate boiling heat transfer of the alumina nanofluid, whereas the rough surface either left it unchanged or even reduced it. The nanoparticles deposited could reduce both the nucleation site density and the roughness of the heated surface [9].

A gravity heat pipe does not have a separate liquid and vapor flow line, unlike a loop heat pipe. Moreover, the gravity heat pipe used in solar collectors has a short condensing part for heat release and a long evaporation section housed in a hoover tube or flat-plate solar absorber. As a result, the heat pipe solar collector operates differently from the typical heat pipe heat exchanger. Several literary works have discussed the use of nanofluid in solar thermal collectors. An open thermosyphon employing nanofluid for high-temperature evacuated tubular solar collectors was the subject of research by [10]. In general, the majority of the study in this area concentrated on the improvement in heat transfer that results from the use of nanofluid in heat pipes. The start-up characteristics of the heat pipe under low and unstable heat flux conditions have a major impact on the overall performance of the heat pipe solar collector because solar radiation has a substantial degree of volatility and a relatively low heat flux [11]. However, research on the startup characteristics of solar heat pipes and their impact on the efficiency of solar energy collection remains limited.

2. Materials and Methods

At the first stage of the study, with the capacity to track the sun, the collector and tank are both spherical, symmetrical, and created with these features. The collector is made up of flexible aluminum tubes that wrap around a frame to form a spherical absorber coil. To better understand the spherical structure, researchers placed a transparent, spherical glass cover with 24 pieces of bent glass on top of the frame. The study prepared a graphene/water nanofluid at the second stage. The carbon atoms in graphene exhibit a regular, atomic-scale hexagonal arrangement, tightly packed in a crystalline form. It has drawn a lot of interest due to its outstanding thermal conductivity and potential for thermal management applications. The thermal conductivity of graphene nanoplatelets (GNPs) has been said to range from 1500 to 5000 W/(mK). This is thought to depend on the quality of the graphene and how it was processed. In addition, the GNP and distilled water mixture exhibits a notable improvement in heat conductivity over the basic fluid. Furthermore, researchers anticipate that the two-dimensional structure will influence the material's heat transfer differently from existing nanoparticles and one-dimensional carbon nanotubes.

The GNPs have a surface area of 800-900 m2/g as determined by a chemical analysis method, a particle size of 0.5-2 m, a thickness of 0.8-1.2 nm, a single layer rate of about 80%, and a particle size of 0.5-2 m. Figure 1a depicts a picture of the graphene powder. Figure 1b depicts the GNPs as a TEM (Transmission Electron Microscope) micrograph from FEI Corporation, Hillsboro, OR, USA. The full single-layered structure of the graphene nanoplatelet is clearly visible. Deionized water served as the foundation for the nanofluid created in this study. According to earlier studies, polyvinylpyrrolidone (PVP) has a greater dispensability and a significant affinity with graphite surfaces. This led to the selection of PVP as the dispersant in the current work. Figure 1 illustrates the creation of the graphene/water nanofluid and the graphene power. (A) Graphene powder was used in the experiment. (b) A SEM view of a nanoplatelet ma(c) A graphene/water nano fluid prepared with varying concentrations of GNPs.ous GNP concentrations. Magnetic stirring introduced GNPs to the deionized water over the course of two steps. The graphene/water suspension was then mixed with PVP while being subjected to ultrasonic oscillation. Figure 1c displays the produced mixes of graphene/water nanofluid with various GNP concentrations.

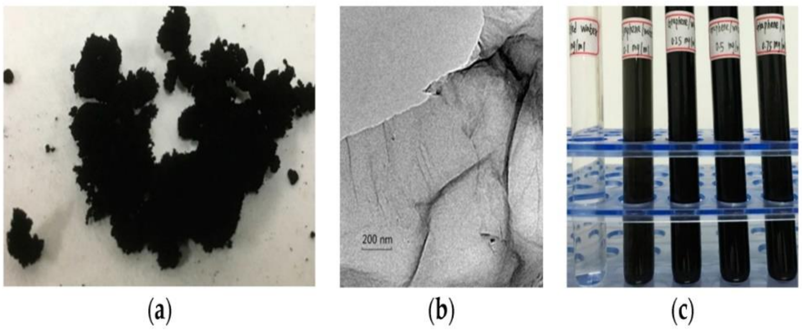

Figure (1): The creation of the graphene/water nanofluid and the graphene power.

An ultraviolet-visible spectrophotometer was used to evaluate the spectrum absorbance of nanofluid with various PVP to GNP mass ratios in order to examine the impact of the addition of PVP on the dispersion stability of the graphene/water nanofluid. Due to the powerful extinction, researcher added seven different PVP to GNP mass ratios: 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, and 7:1 to the same volume of deionized water. According to Eq. (1), there is a linear relationship between the concentration of nanoparticles present in the suspension fluid and the absorbance at a certain wavelength. Eq. (1) states that the less sedimentation and agglomeration occur over a specific standing time, the higher the absorbance. The stability and dispersion are both improved with increased absorbance.

$$A = \lg (I0 /I) = Ebc \quad (1)$$

where A is the absorbance in Abs, I0 and I are the intensity of the incident and transmitted light, respectively, in W/m2, is the molar absorptivity in L·mol−1·cm−1; b is the optical distance in cm and c is the solute molarity in mol·L−1.

Figure 2 displays the observed absorbance of nanofluid with various mass ratios of PVP to GNPs after standing for various lengths of time (i.e., two days, one week, or a month). In this work, the researcher used a 400 nm measurement wavelength. It is clear that absorbance values were highest when the PVP to GNPs mass ratio was 4–5. This means that a graphene/water nanofluid with this amount of PVP dispersion (5 g PVP for every 1 g GNPs) might be able to keep its shape better. For future research, we created a nanofluid with four distinct GNP concentrations: 0.01, 0.025, 0.05, and 0.075 wt%, based on the optimal dispersant addition. Figure 1c displays the synthesized graphene/water nanofluid with various GNP concentrations.

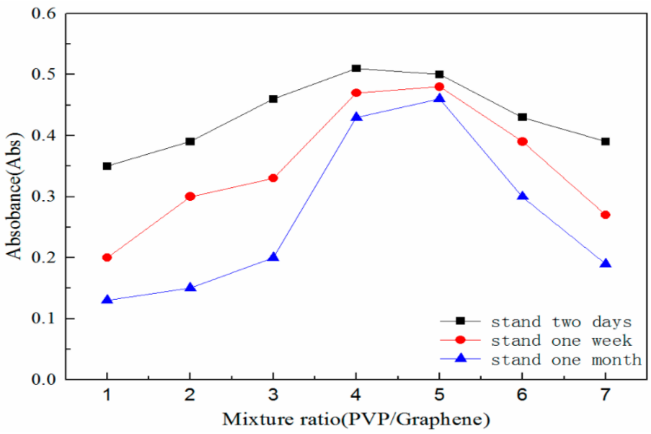

Figure (2): Absorbance of graphene/water nanofluid

The graphene/water the thermal conductivities of nanofluid and deionized water both increase as temperatures rise, as shown in Figure 3. When this is happening, the concentration of GNPs has an impact on the nanofluid's thermal conductivity. Tharail et al. (2017) found that at 20 °C, the nanofluid with 0.075 wt% GNPs has a thermal conductivity of 0.71 W/(mK), which is 18.6% higher than that of deionized water.

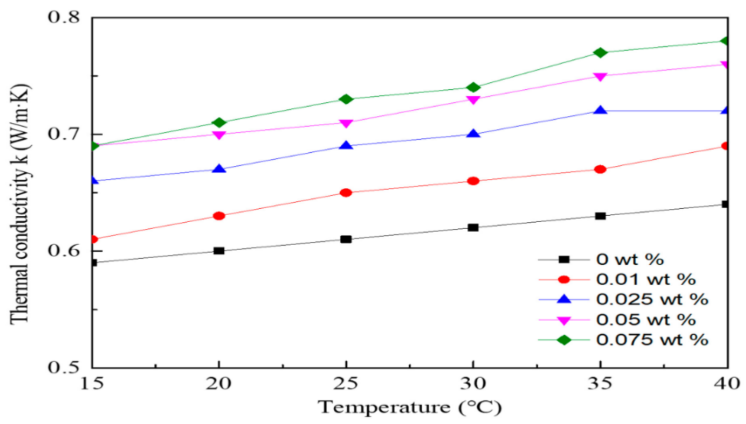

Figure (3): Thermal conductivity of the water/graphene Nano fluid at varied GNP concentrations and temperatures.

Energy calculation for the thermal water tank, Eq (2). is the energy balance equation for the spherical solar water heater. The solar radiation energy (QI) absorbed by the absorber surfaces, the stored energy (Qs), the energy absorbed via the tank body (Qb) and the lost heat (QL) are all included in Eq (2). The entire energy of the thermal storage system, comprising the tank, the water, and the PCM, is expressed as Eq. (3):

$$Q1 = Qs + Qb + QL \quad (2)$$

$$Qs = Q\ PCM + Qt + Qw \quad (3)$$

For forecasting the thermal conductivity of nanofluid, several theoretical models have been proposed for forecasting nanofluid thermal conductivity. A lot of things need to be carefully thought through in theoretical calculations. These include the thermal conductivities of the base fluid and nanoparticles, the volume percentage of the particles, how the particles are moving, and the matrix additive interface contact resistance. Figure 4 shows the graphene nanofluid and water's viscosity. Temperature and viscosity exhibit a strong correlation. With rising temperatures, there is a striking decrease in velocity. Furthermore, it is obvious that adding GNPs would make the graphene/water nanofluid viscous. When the fluid temperature varies between 20 and 60 °C, the viscosity of nanofluid with a concentration of GNPs of 0.075 wt% increased by 19% to 34% in comparison to the base fluid.

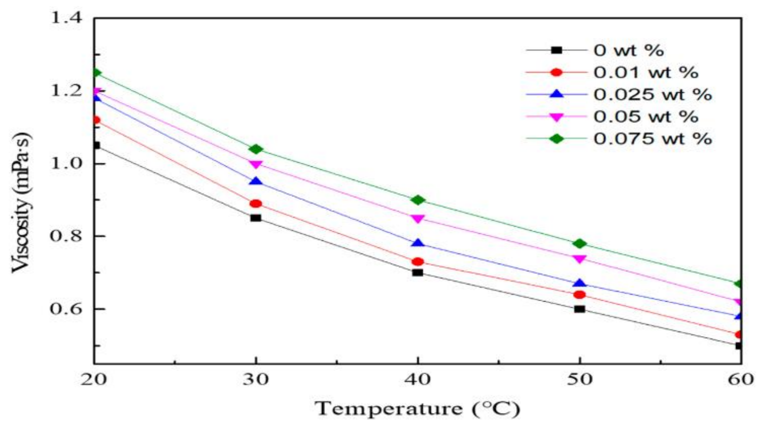

Figure (4): The viscosity of the graphene/water Nanofluid at varied GNP concentrations and temperatures.

Additionally, as the temperature rose, the enhancement ratio in viscosity for a specific concentration of GNPs in a graphene/water Nano fluid remained essentially unchanged or even slightly increased. The rise in the thermal conductivity of the nanofluid enables the improvement of the phase-change heat transfer inside the heat pipe. Therefore, the increased viscosity is not advantageous. The physical characteristics of the nanofluid, the roughness, and the hydrodynamics of the heated surface, among other things, all have an impact on the heat transmission of nanofluids that are boiling. According to numerous studies, the boiling heat transfer coefficient dropped as nanoparticle concentration rose. The deposited nanoparticles settle on the heated surface, reducing the density of nucleation sites. A graphene/water nanofluid concentration range of not more than 0.05 weight percent is chosen in solar gravity heat pipes due to the fact that the stability of the suspension became weaker with greater concentrations at this study.

3. Results and Discussion

A spherical hot water storage tank and the use of a PCM were used to conduct an experimental study on the thermal efficiency of the solar water heater in thermal storage. In order to evaluate the spherical tank's performance in terms of thermal energy storage capacity, thermal classification, mix ability and thermal behavior of the PCM, this research is being conducted. Researcher choose the ideal flow rate to complete the tank efficiency research at its highest level. Variable solar radiation conditions frequently operate the solar gravity heat pipe, negatively impacting its solar thermal collection performance. This study used the graphene/water Nanofluid, whose thermal properties had been evaluated in the preceding part, as the working fluid and concentrated on the complex startup characteristics of a single solar gravity heat pipe. The first experiment used deionized water as the working fluid. This process sought to understand the start-up qualities of the gravity heat pipe and its general evaluation approach.

The gravity heat pipe used for solar collection displays a different geometric structure from a typical gravity heat pipe used for heat exchange. Table 1 displays the design specifications for a solar gravity heat pipe that underwent testing. The solar gravity heat pipe has a non-equal diameter, a long evaporation section for heat absorption that is 1550 mm in length and has an inner diameter of 6 mm and a short condensing section for heat release that is 50 mm in length and has an inner diameter of 12 mm. Because the change from the evaporation to the condensing section is not clear, there is essentially no adiabatic portion. Both the evaporation and condensing sections use capillary-free smooth cooper tubes. Since the condensing part is located above the evaporation section, gravity, rather than a wick, can return the condensed liquid there. As a result, the solar gravity heat pipe acts as a thermal diode to convey the absorber solar heat in one direction (from the bottom to the top), preventing reverse heat transfer loss. In the subsequent trials, Researcher filled the working fluid to 18% of the total pipe capacity for each heat pipe.

Table (1): The specifications of a solar gravity heat pipe used in testing.

Components	Materials	Length (mm)	Inner Diameter (mm)	Outer Diameter (mm)
Single Heat Pipe	Copper	1600	—	—
Evaporation Section	Copper	1550	6	8
Condensing Section	Copper	50	12	14

With solar radiation levels between 200 and 1000 W/m2, a typical heat pipe solar collector can function. Typically, a single heat pipe may collect between 10 and 70 W of solar thermal heat flux. This experiment used a single solar gravity heat pipe and positioned it at a 30° inclination angle. It was tested with various heating powers between 20 and 70 W. In order to accomplish this, the DC power supply's output voltage was changed. The circulating water temperature was held steady at around 10 °C for the duration of the experiment. Initially, the circulating water temperature and the temperature of the heat pipe wall were nearly identical.

Figure 5 displays the results of an experimental investigation into the fluctuations in pipe wall temperatures at various heights following different heating times during the startup period. This supported the heat pipe's aforementioned start-up procedure. Figure 5a depicts the variations in pipe wall temperature when the heat pipe receives a 20 W heating power application. Turning on the heating quickly raises the wall temperatures at various heights. This ensures that the heat input primarily heats the pipe wall and the initial liquid pool height inside the heat pipe. As the heating process progresses, the amount of vaporized steam rises to the condensing portion.

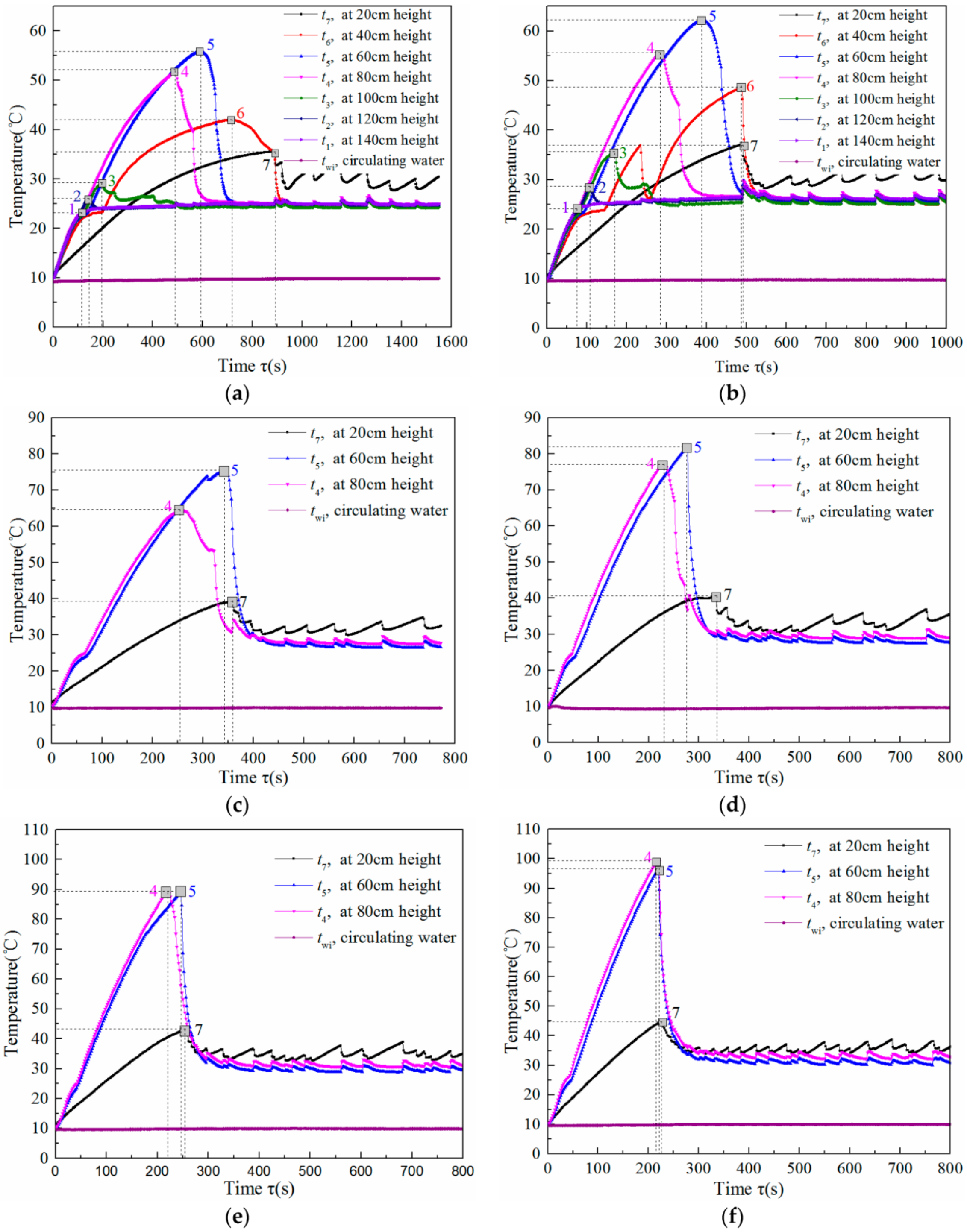

Figure (5): Temperature variations at the pipe walls over the course of operation for various heating powers, including 20 W, 30 W, 40 W, 50 W, 60 W, and 70 W.

The condensate then returns to flowing downward. The temperature at this height (t1), where the condensed reflux liquid is flowing, encounters the inflection point 1 in the diagram, drops abruptly to equal the condensate temperature, and then stays there. After that, the wall temperatures at the evaporation section, measured from top to bottom, represent their corresponding inflection points in the following order: 2, 3, 4, 5, 6, and 7. Before reaching time point 7, the heat pipe completes the startup process and then operates in a steady state. The wall temperature at this height (t7) fluctuates because the liquid pool inside the heat pipe is close to 20 cm. Figure 5–f illustrates the comparable variable tendencies of pipe wall temperatures when the heat pipe operates under various heating power settings.

4. Conclusion

A solar thermal storage tank is created as a double-walled, spherical tank that resembles a heat exchanger as a novel design. The collector heats the water in the inner wall, and the addition of PCM to the outer wall submerges the thermal storage tank in a sea of PCM. The absence of thermal insulation will result in a fixed and symmetrical active surface on the tank's outer wall. Instead of using deionized water as the working fluid, graphene/water nanofluid with varying concentrations was created to improve the thermal performance of a solar gravity heat pipe. Experimental research was done to examine and contrast the thermal start-up performance of solar gravity heat pipes boosted by nanofluids with a standard sun heat pipe. In addition, during the preparation of graphene/water, the ideal amount of dispersant was added. The mass ratio of 5 g PVP to 1 g GNPs demonstrates the best dispersion stability. The addition of GNPs increases deionized water's viscosity and thermal conductivity. At temperatures ranging from 20 to 60 °C, correlations have been provided to assess the impacts of GNP concentration on the thermal conductivity and viscosity of graphene/water Nano fluid. Moreover, the larger the enhancing effect on the thermal start-up process, in the range of 0.01–0.05 wt%, the higher the GNPs concentration. Employing 0.05 wt% grapheme/water nanofluids as the working fluid instead of deionized water could reduce the start-up time of a solar gravity heat pipe by 15.1% and 10.7% under 30 and 60 W input heating settings, respectively. Thus, the thermal efficiency in the solar heat pipe for water heating was significantly lower during startup than it was during steady operation. Therefore, a significant reduction in the start-up time could potentially lead to a higher thermal efficiency for solar gathering.

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