Mathematical Modelling of Engineering Problems
Vol. 10, No. 3, June, 2023, pp. 852-860
Journal homepage: http://iieta.org/journals/mmep

Nanomaterials and Phase-Changing Materials in a U Vacuum Tube Solar Collector

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https://doi.org/10.18280/mmep.100315

Received: 19 September 2022
Accepted: 1 February 2023

Keywords:
phase change materials, solar collector, U vacuum tube, melting and solidification

ABSTRACT

Solar Water Heating (SWH) systems provide an environmentally friendly means of generating hot water for domestic or commercial applications by harnessing solar radiation throughout the year. Despite their benefits, SWH systems can be limited by inconsistent solar energy density, often necessitating the use of auxiliary booster units. Recent research has demonstrated that incorporating phase change materials (PCMs) as energy storage media in SWH systems can mitigate the need for booster units. In this study, a novel SWH system was designed with a PCM-based storage unit integrated into a U-shaped vacuum tube solar collector, incorporating Al_2O_3 nanoparticles to enhance thermal performance. Mathematical simulations were conducted to analyze the melting and solidification processes of the PCM over 3600 s daytime and nighttime intervals. Results indicated that the addition of nanoparticles led to a significant improvement in daily thermal efficiency, despite minor variations in outlet temperature. It was observed that the heat transfer mechanism was accelerated in the morning due to solar energy, with optimal fluid solidification achieved at 0.5 wt percent nanoparticle concentration. In the absence of sunlight, the thermal discharge process commenced, transferring heat from the PCM to the evacuated tube and gradually solidifying the material. This study highlights the potential of nanomaterial-enhanced PCM integration for optimizing SWH system performance and reducing the reliance on auxiliary booster units.

1. INTRODUCTION

Solar water heating (SWH) systems have been recognized as an environmentally sustainable alternative for providing hot water for domestic or commercial applications by harnessing the abundant solar radiation energy available throughout the year. Nevertheless, the effectiveness of this technique is hampered by variations in solar intensity, often necessitating the use of backup booster units to maintain the performance of the SWH systems [1]. Recent research has indicated that the reliance on booster units can be mitigated by employing phase change materials (PCMs) as energy storage media. However, in traditional SWH technology, the PCM-based storage unit operates as a separate medium from the solar collectors. The novelty of the present study lies in the development of a new SWH system that integrates heat transfer and storage into a single device while exploring the potential of PCM as a heat transfer fluid (HTF).

The global adoption of SWH technology in countries such as China, India, Brazil, and the Middle East highlights its significance [2]. In fact, access to affordable solar water heaters can provide substantial benefits to individuals in underdeveloped regions. The reliance on wood, gas, or electricity for water heating could be substantially reduced or eliminated in numerous households, thereby decreasing fuel expenses. By replacing traditional fuel sources, solar energy has the potential to considerably reduce carbon emissions. For instance, it has been estimated that residential solar water heating systems in Australia can yield net greenhouse gas savings within 2.5 to 5 years. Furthermore, diminished biomass consumption could alleviate pressures on dwindling forest resources.

Solar water heating systems harness sunlight, an entirely renewable energy source, to heat water. Achieving a temperature range of 60-80℃ is relatively straightforward, making these systems suitable for various applications. For domestic use, SWHs with capacities between 100 and 300 liters are appropriate, whereas larger systems can be employed in restaurants, canteens, guest houses, hotels, hospitals, and other similar facilities. A 100-liter SWH can potentially replace an electric geyser for home use, saving approximately 1500 units of electricity annually. The deployment of 1000 SWHs, each with a 100-liter capacity, could reduce peak demand by about 1 MW. Additionally, a 100-liter SWH can prevent the emission of 1.5 tons of carbon dioxide per year [2].

2. LITERATURE REVIEW AND PROBLEM STATEMENT

Solar-based water heating (SWH) systems present a highly practical and environmentally friendly method for generating hot water for domestic or commercial applications. A novel SWH system has been developed that integrates energy storage and heat transfer into a single unit, employing phase change materials (PCM) as heat transfer fluids (HTF). Tritricontane paraffin (C33H68) was incorporated within the dual PCM energy storage unit for enhanced energy storage and direct power transfer to the system [3]. The impacts of solar energy and PCM on energy savings in a desiccant-assisted air conditioning system have been numerically investigated. Three air conditioning system designs (Type A, Type B, and Type C) were analyzed under similar ambient conditions to determine their energy-saving potential. The results reveal average electrical energy savings of approximately 20.85% for Type B and 75.82% for Type C compared to Type A [4]. The utilization of fossil fuels in various applications has led to rapid depletion and significant climate changes due to global warming. Access to environmentally friendly energy resources has become essential to meet the growing demand for clean energy. Solar energy has proven to be an effective, alternative, and clean energy source for sustainable development worldwide [5].

A solar-driven cooling system based on a desiccant-coated heat exchanger (DCHE) is considered an alternative to vapor compression cooling systems (VCCS) because of its energy-saving and eco-friendly properties. N_2 isotherm adsorption-desorption characteristics of MOF were investigated. The findings indicate that MOF possesses a combination of micropores and mesopores with a relatively large specific surface area and pore volume. A unique numerical model of this system was developed. The results suggest that the solar collector can provide heated water at 52.5-80.4°C from 9:00 to 19:00 under summer and August conditions [6]. The environmental impacts of an experimental Solar Absorption Air-Conditioning System based on a Lifecycle Assessment were assessed for the first time in Mexico. A commercial air conditioning system powered by fossil fuel-derived electricity was also evaluated. The solar cooling system achieved an overall emission reduction of approximately 80% in terms of global warming potential and carbon footprint. For fossil fuel depletion and ecotoxicity impact categories, reductions of 85% and 20% were attained, respectively [7].

Cooling systems represent the largest electricity consumer in residential, commercial, and industrial buildings. This study presents an economic analysis considering technical aspects associated with the integrated use of solar photovoltaic and cooling systems connected to the utility grid. Two distinct systems, variable refrigerant flow and chillers, were examined in two Brazilian cities with varying levels of solar radiation and temperature [8]. The addition of 5 vol% single-walled carbon nanotubes (SWCNT) to R407c refrigerant at temperatures between 283 and 308 K led to an improvement in the coefficient of performance (COP) for nanorefrigerants. The SWCNT/R-407c nanorefrigerant demonstrated a considerable enhancement in thermal conductivity and specific heat, resulting in an approximate COP improvement of 17.02% and 10.06%, respectively. In comparison to the conventional cooling system, the proposed configuration reduces compressor work by 34% and increases COP by 4.59% [9]. A review on solar-powered solid desiccant-vapor compression hybrid cooling systems has been conducted. The use of renewable solar energy can be an excellent source of regeneration heat provided to reactivate the desiccant dehumidifier used in alternative cooling systems. The review aims to enhance the utilization of solar energy as a renewable regeneration heat source in heat-driven solid desiccant-based hybrid cooling systems and guide future researchers to explore research opportunities in this area. It has been determined that solid desiccant-integrated hybrid cooling systems are more advantageous than conventional vapor compression cooling due to their cost-effectiveness and cleaner cooling [10].

In Ghana, 60-80% of electricity consumed in public and commercial buildings is for cooling. Many hot climates, including Ghana, experience high solar irradiation. The need for office space cooling largely results from high solar radiation levels. Studies have been conducted on the performance of a hybrid solar PV-system-powered air conditioner for daytime office cooling in hot and humid climates [11]. Absorption chillers are a widely used technology due to their ability to utilize low-grade thermal energy sources, such as solar thermal energy and waste heat. The efficiencies of these cycles were calculated with LiBr-water-ammonia working pairs in the context of air-cooled solar cooling [12]. The behavior of phase change materials (PCMs) has been investigated using both experimental and computational methods [13]. In these experiments, 100 g of PCMs (wax, pure $Ca(NO_3)_2 \cdot 4H_2O$, and a composite of $Ca(NO_3)_2 \cdot 4H_2O:Mg(NO_3)_2 \cdot 6H_2O$) were placed in a 100 ml glass beaker and heated to a temperature above their melting points using a hot plate and a water bath. The thermal performance of a solar latent heat storage unit was examined in an experimental study [14], which employed external measurements of an evacuated solar collector integrated with built-in porous media. Numerical simulation was utilized to investigate forced convection heat transfer in a horizontal pipe with or without twisted tape-inserts [15].

Inherent fluctuations in the energy supply from renewable sources, particularly solar energy, have been a major obstacle to their global adoption [16]. Phase change materials (PCMs), capable of storing energy for later use, could serve as a potential solution. A challenge encountered in previous studies has been the development of techniques to enhance the absorption and release of heat by manipulating the phase-changing properties of the material.

A research gap exists in understanding the application of nanomaterials in the melting of phase change materials used in solar collectors. This study aims to address this gap, as the importance of incorporating phase change materials in obtaining thermal energy has been underestimated in prior research.

The primary advantage and motivation behind this research paper is to achieve greater thermal efficiency that can be harnessed from solar collectors capable of high thermal processing through the implementation of nanomaterials in these applications.

3. THE AIM AND OBJECTIVES OF THE STUDY

The aim of this work is to enhance heat transfer by adding nanomaterials on phase-changing materials in a solar collector with a U vacuum tube. To achieve this aim, the following objectives are accomplished:

- study the effect of nanomaterial concentrations on temperature,
- study the effect of nanomaterial concentrations on mass fraction,
- study the effect of nanomaterial concentrations on outlet temperature,
- validate the study.

4. MATERIALS AND METHODS

- Object of research

Solar water heating (SWH) systems have been around for a while and are a proven, eco-friendly way to heat water for home or commercial usage by harnessing the abundant solar radiation that is present all through the year. However, there are limitations to this method, particularly during periods of variable solar energy density. When this happens, it's necessary to use a booster unit as a backup to keep the SWH system running.

- The main hypothesis of the study

That the effect of the promoter unit might be diminished while using a phase change material (PCM) for energy storage in a solar water heating system. A U-molded cylinder and stage change materials are used to store additional nuclear power in the present SWH innovation; be that as it may, this is an alternate medium from sunlight-based collectors. Both the dissolving and cementing of the stage change materials were mimicked mathematically, with the previous requiring 3600 s during the day and the last option requiring 3600 s during the evening.

- Assumptions made in the work

The reproduction of the warm improvement model by constrained heat move requires a plan-designing project. The model is planned utilizing Solidworks programming with aspects 47 mm external glass tube and 37 mm internal glass tube 6 mm U-formed tube, tube thickness 2 mm, collector length (L) 500 mm segment from the channel, as displayed in the accompanying Figure 1 and Table 1.

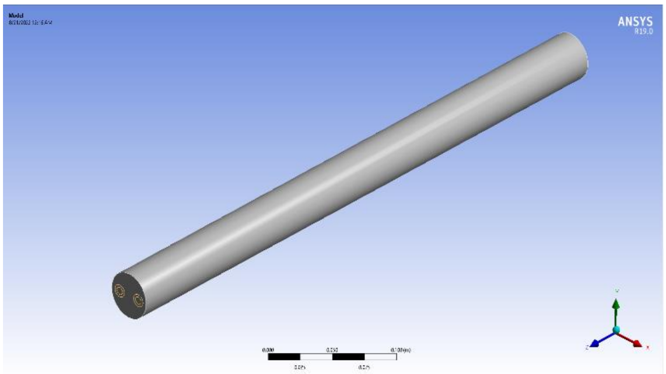


Figure 1. Geometry

Table 1. Details on the proposed system's dimensions [1]

Parameter	Value (m)
Collector's Length	5
Diameter of outer tube	0.047
Diameter of inner tube	0.037
U-shaped tube's diameter	0.006
U-shaped tube's thickness	0.002

Subsequent to finishing the model plan cycle and beginning the reenactment utilizing ANSYS CFD program [17], it is a designing project that reproduces intensity and liquid stream frameworks. Where a reasonable organization should be made to get precise outcomes that can measure up to useful applications, where the organization unwavering quality is expanded and the organization is expanded until a steady outcome is reached. A tetrahedral grid was utilized with various components up to 3254158 since the temperature for this situation was steady and its worth was 305.945 K as shown in Figure 2 and Table 2.

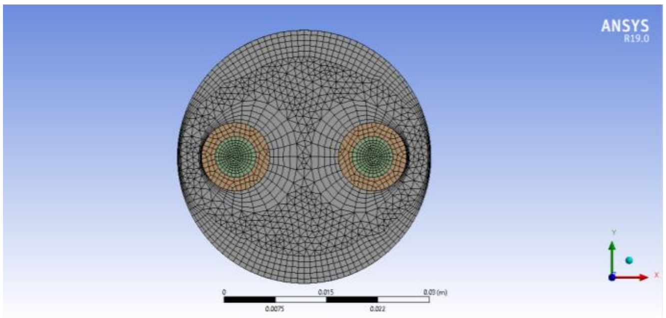


Figure 1. Geometry mesh

Table 2. Mesh independency

Case	Nodes	Element	Outlet temperature [K]
1	625432	724331	311.980
2	925441	1342566	308.875
3	1063456	2234352	306.121
4	1342220	3254158	305.945

The simulation was carried out using ANSYS19.1 CFD program, which is a program dedicated to studying fluids and their kinetic and thermal effects [17]. The k-ε standard model was used, which proved its effectiveness in simulating fluid flow and its compatibility with reality. Where all the ruling conditions and materials used from the previous research were used, with the addition of nanomaterial concentrations to them, as shown in Tables 3 and 4.

Table 3. Comparison of PCM and HTF thermophysical properties [1]

Property	PCM	HTF	Nanoparticle
Model	Paraffin (54 or 57°C)	Water	Al_2O_3
K [W/m.K]	0.21	0.6	30
Fusion heat [kJ/kg]	189	-	-
ρ [kg/m^3]	795 or 920	998.2	3600
Cp [kJ/kg.K]	2 or 2.15	4.182	0.8
μ [kg/m.s]	0.023	0.001003	-
α [1/K]	0.0003085	-	-

Table 4. All possible charge and discharge process boundary conditions [1]

Boundary conditions	Melt	Solidification
V, [m/sec]	0.04	0.04
Temperature of Inlet, [°C]	30	30
Solar Intensity, [W/m^2]	$G(t)=23.3\ t^2+604\ t - 3010$	0
Initialize PCM temperature, [°C]	-	80

4.1 Governing equations

The current investigation is based on a three-tiered model in which the enthalpy-porosity method is used to replicate the transitional phases of PCM. The following are citations for the presumptions of the problem that are necessary for the mathematical recreation:

- There is no compression in the liquid flow, and the stream is Laminar.

- Thermo-actual properties of PCM are assumed to be constant with the exception of thickness.

The regular convection on the PCM fluid period is expected to be shown by employing Bossiness estimation.

- The HTF maintains its original characteristics.

- We ignore the effect of thick scattering.

The adiabatic nature of the exterior mass of mathematics is generally recognized in the reenactment's sanding and cementing processes.

Intake of sunlight-based lighting is accepted uniformly across all pieces of exterior cylinder due to the presence of reflector.

If you want to use solar power to illuminate an outside wall, you may try applying a shaky intensity transition on the wall.

By taking into account above supposition, the administering conditions for mathematical examination for continuity, Navier-Stokes and energy in the Cartesian direction:

Equation of continuity [17]:

$$\nabla \cdot \vec{V} = 0 \tag{1}$$

Equation of momentum [17]:

$$\frac{\partial \vec{V}}{\partial t} + \vec{V} \cdot \nabla \vec{V} = \frac{1}{\rho}\left(-\nabla P + \mu \nabla^2 \vec{V} + \rho \vec{g} \beta (T - T_{ref})\right) + S_m \tag{2}$$

Equation of energy [17]:

$$\frac{\partial h_{sens}}{\partial t} + \frac{\partial h_{lat}}{\partial t} + \nabla \cdot \left(\vec{V} h_{sens}\right) = \nabla \cdot \left(\frac{k}{\rho c_p} \nabla h_{sens}\right) \tag{3}$$

Sensible heat was added to latent heat to get the overall enthalpy [17]:

$$h_{tot} = h_{sens} + h_{lat} \tag{4}$$

The enthalpy porosity strategy was utilized to mimic the freezing system of water. The reasonable and inactive intensity [17].

$$h_{sens} = h_{ref} + \int_{T_{ref}}^{T} c_p dT = h_{ref} + c_p \int_{T_{ref}}^{T} dT \qquad h_{lat} = \sum_{i=1}^{n} \lambda_i h_{sf} \tag{5}$$

where, ρ, V and P are representing density, velocity and pressure of fluid flow, respectively. The equation for density variation is presented as $\rho = \rho_l / (\beta (T - T_l) + 1)$, Boussinesq assumption. Also, μ, β and T_{ref} are shown consistency, warm development and reference temperature, separately. Moreover, S_m is energy source that add to force condition and characterize as [17]:

$$S_m = -A_m \frac{(1-\gamma)^2}{(\gamma^3 + \epsilon)} \left(u - v_p\right) \tag{6}$$

The transition between PCM's fluid and solid phases is determined by the aforementioned condition in light of the enthalpy-porosity strategy. The coefficient A_m for the soft zone typically ranges from 10^4 to 10^7 in its sum. As a result of solids extraction, v_p has a high velocity, and has a low density.

Consistent modest number of 0.001 for forestall zero division. Additionally, γ characterized as fluid portion and portrayed as [17]:

$$S_m = -A_m \frac{(1-\gamma)^2}{(\gamma^3 + \epsilon)} \left(u - v_p\right) \tag{7}$$

The corrugated tube hydraulic diameter defined as [17]:

$$D_h = (D_b + D_{en})/2 \tag{8}$$

The diameters of the bore and the envelope of the corrugated tube are denoted by D_b and D_{en}. In addition, here is the equation used to derive the Reynolds number [17]:

$$D_h = (D_b + D_{en})/2 \tag{9}$$

The definition of the usable heat rate delivered to HTF is [17]:

$$\dot{Q}_{us} = \dot{m}_p (T_{out} - T_{in}) \tag{10}$$

Total daytime usable heat is defined as [17]:

$$Q_{us} = \sum_{i=1}^{n} \dot{Q}_{us} \Delta T \tag{11}$$

Total amount of energy passed through the collection is [17]:

$$Q_{coll} = A \sum_{t_{sunrise}}^{t_{sunnset}} G(t) \Delta t \tag{12}$$

The following equation was used to compute the system's daily thermal efficiency [17]:

$$\eta = \frac{Q_{us}}{Q_{coll}} \tag{13}$$

- Simplifications adopted in the work

The process of adding nanomaterials to paraffin wax and phase-changing materials is one of the important factors in improving the heat transfer of the evacuated tube in the solar collector. The point of origin here lies in the addition of nanomaterials with different concentrations to know their effect on the liquefaction process and the hardness of the PCM.

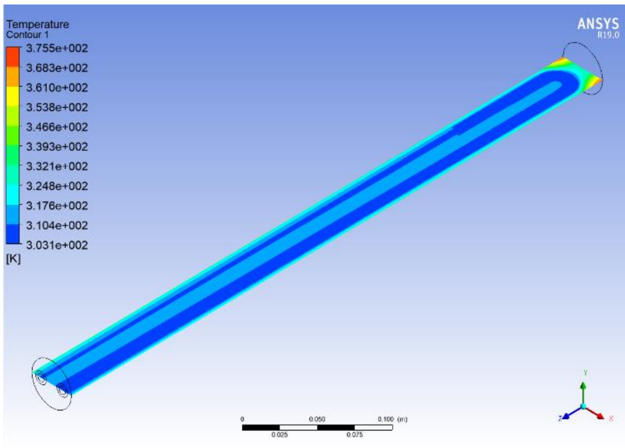
5. RESULTS AND DISCUSSION

In this section, the results obtained from the simulation program will be graded and compared by adding nanomaterials with different concentrations.

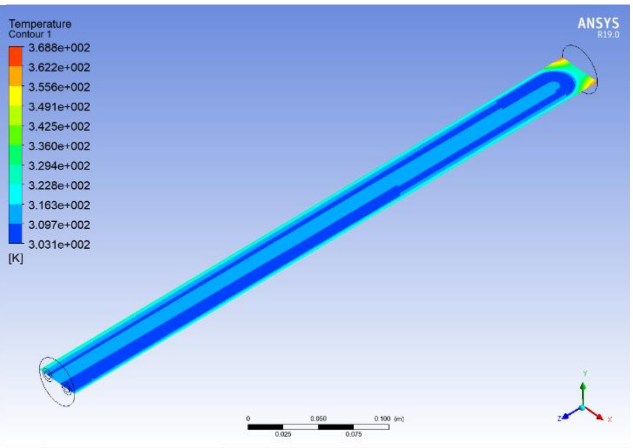
5.1 Effect of nanomaterial concentrations on temperature

Forced convection is the primary heat transfer mechanism in PCM toughening process as displayed in Figure 3. Where the intensity move component was quicker in the first part of the day with the presence of energy and sun based and by adding Al_2O_3 nanoparticles in PCM and its job is significant in the efficiency of solar energy systems. During the discharge process, the maximum level of temperature at outlet is the fundamental model for examination of collector with PCM. This need is connected to the coefficient of liquid fraction during operation. Use a simple tube. Tube effect on the discharge procedure is taken into account. Finally, the beneficial heat absorption of the system was compared, where in the morning the process proved to be fast heat discharge due to the increase of Al_2O_3 nanoparticles.

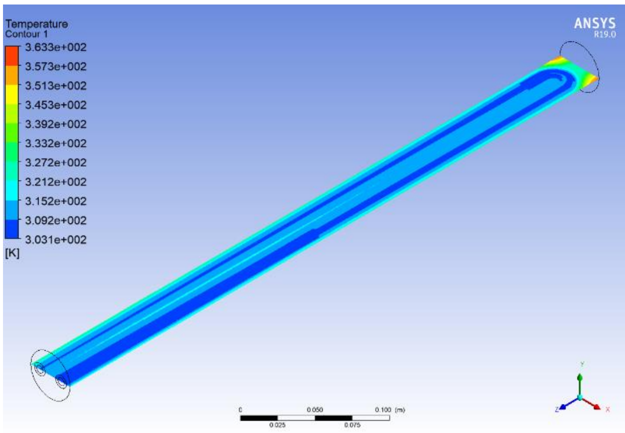
The PCM solidification process in Figure 4 relies mostly on forced convection as its means of heat transmission (4). A nighttime PCM presence is crucial to the effectiveness of solar power systems. The primary criteria for investigating PCM-containing solar collectors is whether or not the output temperature is optimized during the discharge operation. It has been shown that this criterion correlates strongly with the coefficient of liquid fraction when in operation. Take advantage of the humble tube. Today, we take into account how the tube itself affects the discharge procedure. The process in the evening proved to be quick heat discharge owing to the rise of Al_2O_3 nanoparticles, prompting a comparison to be made between the system's favorable heat absorption and the nighttime process.



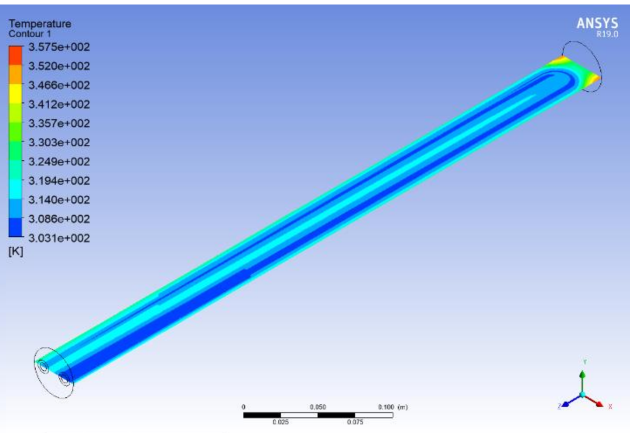
(a)



(b)

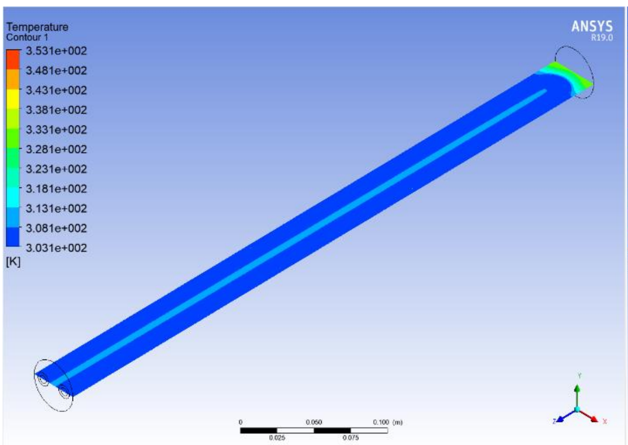


(c)

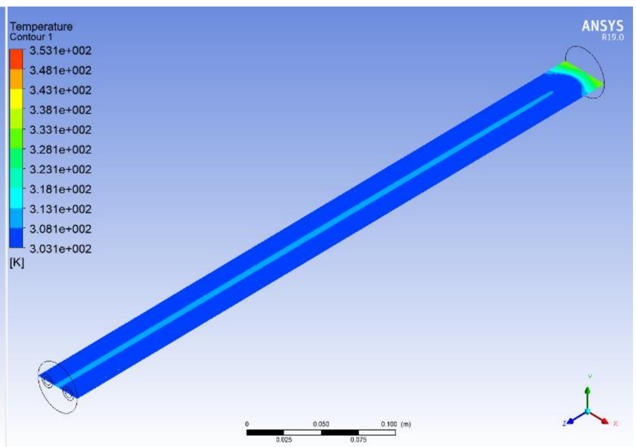


(d)

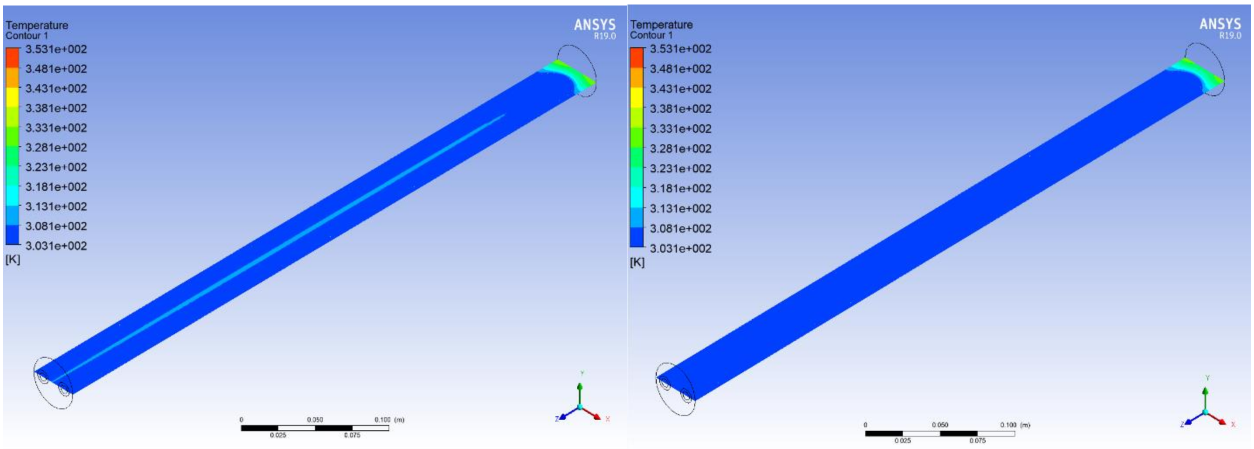
Figure 3. Temperature contour at 3600 s morning of, (a) PCM without nano, (b) PCM with 0.1 wt% Al_2O_3, (c) PCM with 0.3 wt% Al_2O_3, (d) PCM with 0.5 wt% Al_2O_3



(a)



(b)



(c) (d)

Figure 4. Temperature contour at 3600 s night of, (a) PCM without nano, (b) PCM with 0.1 wt% Al_2O_3, (c) PCM with 0.3 wt% Al_2O_3, (d) PCM with 0.5 wt% Al_2O_3

5.2 Effect of nanomaterial concentrations on mass fraction

The test process will be for 3600 s in the first part of the day within the sight of daylight. The presence of Al_2O_3 nanoparticles in the first part of the day assumes a significant part in the PCM melt process and the efficiency of solar systems. Where it is seen while adding Al_2O_3 progressively concentrations of 0.1, 0.3 and 0.5 wt%, which was the best aftereffect of dissolving the liquid is 0.5 wt% in Table 5. Moreover, that the collector can keep up with the HTF at the maximum level of the solar collectors during process of discharge, is the principal standard for examination of collectors with PCM in Table 6. This need is connected to the intraoperative fluid fraction modulus.

The test cycle is for 3600 s at night during dusk. The presence of Al_2O_3 nanoparticles at night assumes a significant part in the PCM solidification process and the effectiveness of solar systems. Where it is seen while adding Al_2O_3 bit by bit in centralizations of 0.1, 0.3 and 0.5 wt%, which was the best outcome for the solidification of the fluid. It is 0.5 wt% and Al_2O_3 nanoparticles help to rapidly let heat out of the PCM and subsequently the collector can keep up with the HTF at the maximum level of the outlet temperature during process of discharge, is the primary rule for examination of solar collectors with PCM. This need is connected to the intraoperative fluid fraction modulus.

Table 5. Mass fraction contour at morning

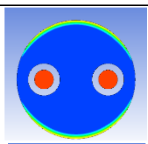
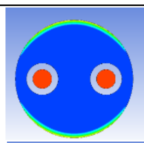
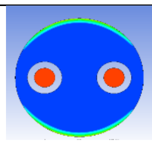
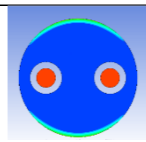
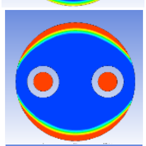
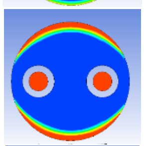
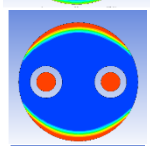
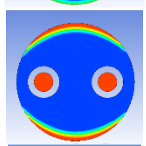
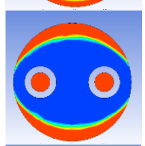
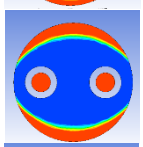
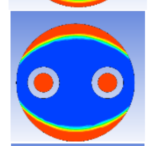
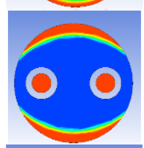
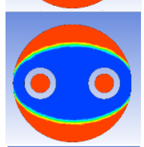
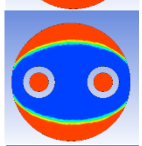
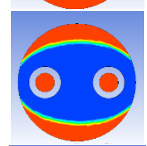
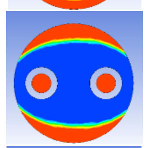
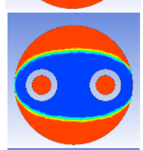
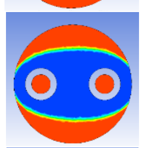
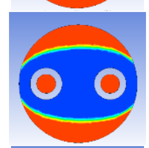
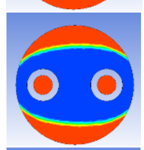
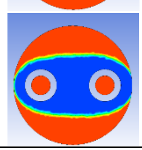
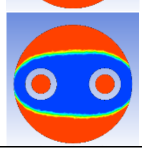
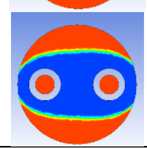
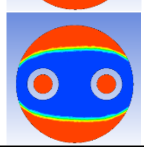
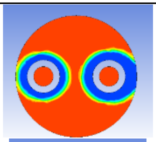
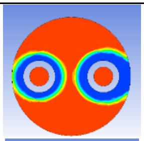
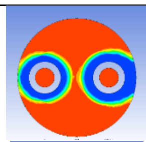
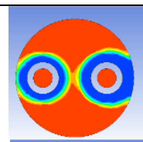
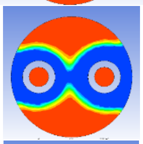
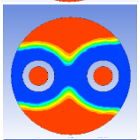
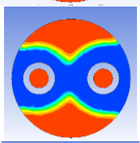
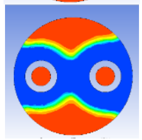
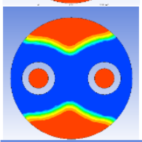
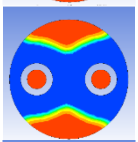
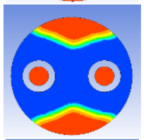
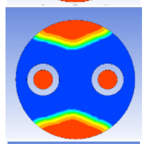
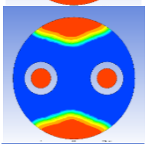
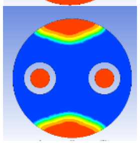
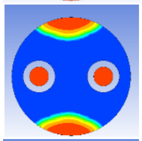
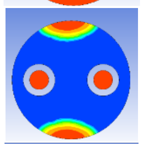
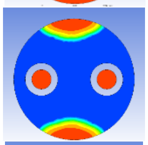
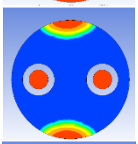
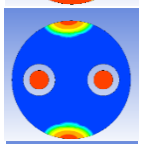
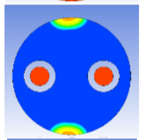
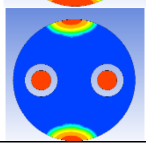
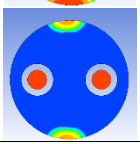
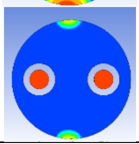
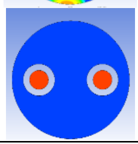
Time	PCM	PCM +0.1 wt% Al_2O_3	PCM +0.3 wt% Al_2O_3	PCM +0.5 wt% Al_2O_3
600 s				
1200 s				
1800 s				
2400 s				
3000 s				
3600 s				

Table 6. Mass fraction contour at night

Time	PCM	PCM +0.1 wt% Al_2O_3	PCM +0.3 wt% Al_2O_3	PCM +0.5 wt% Al_2O_3
600 s				
1200 s				
1800 s				
2400 s				
3000 s				
3600 s				

5.3 Effect of nanomaterial concentrations on outlet temperature

In Figure 5, the thermal improvement by the nanomaterial and its effect on the outlet temperature is observed. The reason for this is due to the increase in the specific heat value in the presence of the nanomaterial and the ability of the PCM to transfer thermal energy to the tube, where the temperatures when adding 0.5 wt% Al_2O_3 concentration reached 312 K, which is the maximum temperature reached by the fluid during the tests.

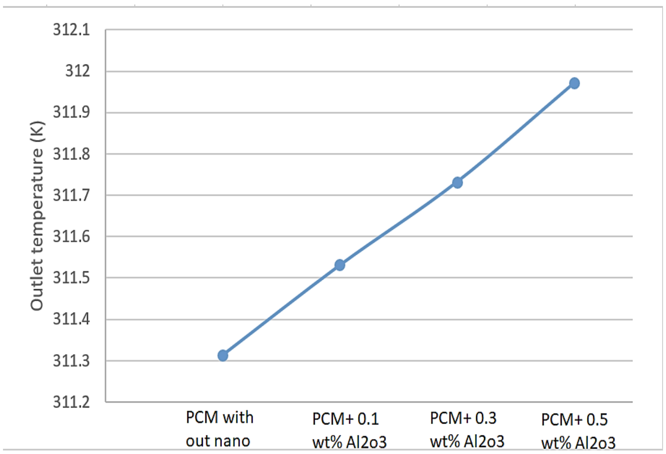


Figure 5. Outlet temperature with adding Al_2O_3 concentrations at morning

As for the time when there is no sunlight, the thermal discharge process begins through the PCM to the evacuated tube, and the PCM material gradually hardens. It can be seen from Figure 6 that the discharging process is significantly lower than the outlet temperatures of the fluid used in the evacuated tube, as the water temperature reached 305.6 K while adding nanomaterials at a concentration of 0.5 wt% Al_2O_3 which is the lowest temperature reached.

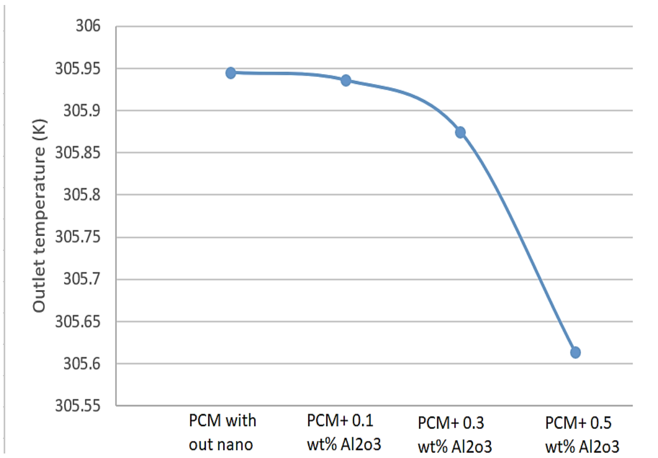


Figure 6. Outlet temperature with adding Al_2O_3 concentrations at night

5.4 Validation study

The comparison process was done on the basic case of the previous research, from which the concept of improvement started by adding nanomaterials. Where a case compared with the previous research [3] was made with the same existing data, dimensions and conditions governing the case from 9:00 am until 15:00 pm extracting the value of the mass fraction and comparing it with the previous research paper as in Figure 7.

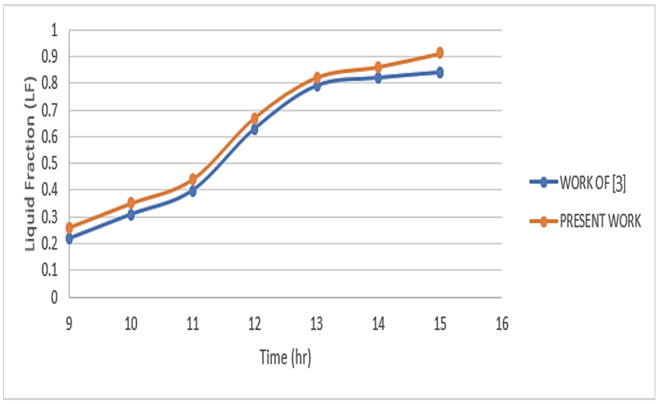


Figure 7. Liquid fraction with time between studies

Through the previous figure shows the percentage of convergence between the previous research paper and the work that was done. The error rate was 6%, which is very acceptable.

6. CONCLUSIONS

1. The key model for examining the collector with PCM is the ideal amount of output temperature during the discharge operation. The heat transfer mechanism was quicker in the first part of the day with the presence of the energy and by adding Al_2O_3 nanoparticles in PCM and its job is significant in efficiency of solar energy systems.

2. Al_2O_3 nanoparticles assume a significant part in the PCM liquefy process and the solar system efficiency. The best consequence of dissolving the liquid is 0.5 wt% and that the collector can keep up with the ideal level of the outlet temperature at the time of discharge, is the principal rule for examination of collectors with PCM. This model is straightforwardly connected with the fluid fraction modulus. The essential models for exploration of solar collectors including PCM is the capacity of Al_2O_3 nanoparticles to quickly let heat out of the PCM, permitting the authority to keep the HTF at the maximum level of the outlet temperature at the time of discharge. The modulus of intraoperative fluid fraction is firmly associated with this measure. The best outcome for fluid solidification in this analysis was 0.5 wt% percent. The sunset testing methodology goes on for 3600 seconds.

3. Thermal improvement by the nanomaterial and its effect on the outlet temperature is observed. The PCM can transfer thermal energy to the tube, where the temperatures when adding 0.5 wt% Al_2O_3 concentration reached 312 K, which is the maximum temperature reached by the fluid during the tests. When there is no sunlight, the thermal discharge process begins through the PCM to the evacuated tube, and the material gradually hardens. The water temperature reached 305.6 K while adding nanomaterials at a concentration of 0.5 wt% Al_2O_3 which is the lowest temperature reached. That the discharging process is significantly lower than the outlet temperatures of the fluid used in an evacuated tube.

4. The comparison process was done on the basic case of the previous research [1] where a case compared with the same existing data, dimensions and conditions governing the case. The percentage of convergence between the previous research paper and the work that was done.

5. This article contributes to knowing the best cases in which energy can be obtained through solar collectors using phase change materials. Where it adds an amount of information that can be taken in the case of designing these solar collectors.

6. The difference between this paper and previous papers lies in the useful knowledge of the use of nanomaterials in the melting of phase change materials used in solar collectors. This article enriches the study of this stream as previous researches have underestimated the importance of adding phase change materials in obtaining thermal energy.

ACKNOWLEDGMENT

The authors would like to thanks Al-Mustaqbal University College, 51001 Hillah, Babylon, Iraq for the assistance in completing this work.

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