Investigating the use of PCM on the performance of solar water heaters in cloudy and sunny weather by using nanoparticles in their structure to reduce energy consumption in buildings

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Abstract:

Phase change materials in the structure of buildings reduce energy consumption and increase the storage of renewable energies .In this study, in order to investigate the effect of phase change materials on the performance of a solar collector in unstable weather conditions (cloudy weather) in Tehran, numerical simulation of the collector was carried out using Ansys Fluent software. For this purpose, four scenarios were examined and numerically simulated. In the first scenario, the performance of the solar collector was investigated in the stable weather conditions of Tehran city without the use of phase change material. The results showed that the desired solar collector can raise the water temperature to 38 degrees Celsius. In the second scenario, to investigate the effect of air instability and cloudiness on the performance of the collector, it was assumed that the solar radiation will decrease. The results showed that the temperature of the outlet water of the collector decreases from 38 degrees Celsius to 35 degrees with the reduction of sunlight. In the third scenario, the effect of using phase change materials on the performance of the collector in stable weather conditions was investigated. The results showed that the use of phase change material in the collector causes heat storage and increases the water temperature when the solar radiation decreases to 37 degrees Celsius. Also, the use of phase change materials in unstable weather conditions caused the water temperature to increase to 41 degrees Celsius.

Keywords: PCM , Ansys Fluent , energy , buildings, structure , water heaters, nanoparticle

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Introduction

Phase change materials can be used in building structures, industrial structures, and agricultural structures.Phase change materials are classified into several groups according to their structure. Today, [1] there is a great need for phase change materials to reduce energy consumption, especially in building structures. Today, the security, reliability and availability of energy resources is a necessary thing in the stability and economic development of societies.[2] Phase change materials in the structure of buildings reduce energy consumption and increase the storage of renewable energies Climate changes, the insecurity of energy carriers (mostly non-renewable) as well as the growth of energy consumption have created many challenges in the field of energy and environment.[3] Therefore, creating suitable platforms for providing energy consumption as well as focusing on how to consume productive energy can be considered as an effective solution to overcome these challenges.[4] Obviously, in this process, issues related to the environment are also of special importance. Increasing the efficiency of energy consumption is directly related to reducing the amount of pollution. Also, the use of new and renewable energies or nuclear energy can be effective factors in reducing carbon dioxide. The increase of greenhouse gases on the one hand and the decrease of non-renewable energy sources on the other hand play a decisive role in determining the strategy of countries in the field of energy [1]. The strong dependence of industrial societies on energy sources, especially petroleum fuels, and their excessive use and consumption, drains the huge resources that have been formed in the underground layers of the earth for many centuries.[5] Due to the fact that the underground energy sources are consumed at an extraordinary speed and in the not too distant future there will be nothing left of them, the current generation has the duty to turn to those energy sources that have a long life and power and knowledge Expand yourself to exploit them.[6] The sun is one of the two important sources of energy that should be turned to because it does not require advanced and expensive technologies and can be used as a useful source of energy in most parts of the world. In addition, its use, unlike nuclear energy, does not leave any risk and adverse effects, and for countries that do not have underground energy resources, it is the most suitable way to obtain power and economic growth and development [7]. Despite the fact that Iran is considered one of the oil-rich countries in the world and has huge natural gas resources, fortunately due to the intensity of the sun in most parts of the country, the implementation of mandatory solar projects and the possibility of using solar energy in cities and towns Scattered villages across the country can bring significant savings in oil and gas consumption. Simple technology, not polluting the air and environment, and most importantly saving fossil fuels for future generations, or turning them into valuable materials and artifacts using petrochemical techniques are the main reasons that reveal the need to use solar energy for the country. Makes. In general, solar energy is used and exploited by different systems and for different purposes [8].One of its applications is the use of solar radiation energy to provide the necessary heat in thermal systems such as water softeners, air conditioning systems, solar water heaters, transmission and pumping systems, dryers and solar ovens, power towers. and thermal power plants. In general, solar energy can be used in three different ways, each of which has different efficiency: [4]

Ansys Fluent

CFD simulation can be used in the architectural industry to analyze airflow and temperature distribution in a building. It can be used to optimize building design to ensure that airflow and temperature are within the desired range.CFD simulation can also be used to analyze the impact of external factors such as wind, sunlight (solar radiation) and rain on building performance. Additionally, CFD simulation can be used to analyze a building's energy efficiency, helping architects design more energy-efficient buildings.CFD has been introduced to architectural engineering and the HVAC (Heating, Ventilation and Air Conditioning) industry for decades, and its effectiveness in assisting architects and engineers in the design process is well established.

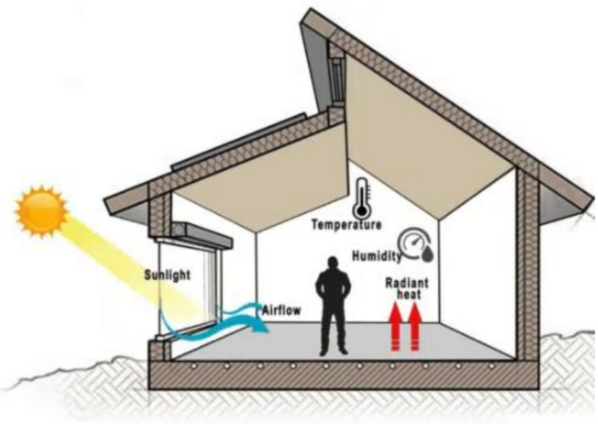

Fig 1 . of solar energy to reduce building fuel consumption

Many researchers used CFD models to predict the indoor thermal environment of atrium buildings, and their results proved that the CFD model is suitable for providing details of the thermal and ventilation performance of the atrium.

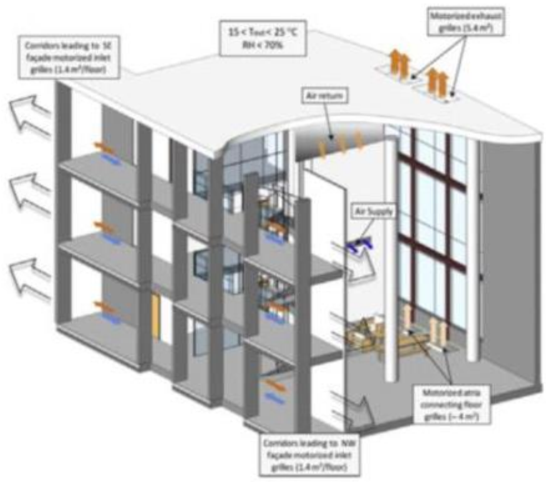

Fig 2. A mode of the atrium and adjacent spaces in the engineering building of Concordia university [48]

Ansys Fluent, the industry standard in computational fluid dynamics (CFD), frees up time for engineers to innovate and improve product results. Simulation performance can be assured with software that has been thoroughly tested in a wide range of applications.

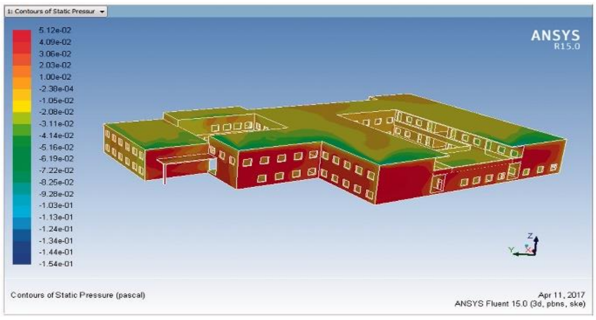

Fig 3 . Using Ansys Fluent in the building

1-1-1- Investigating the methods of increasing the efficiency of flat plate collectors

1- The influence of the position of the absorber plate relative to the pipe:

Investigations show that the least amount of energy is absorbed when the pipes are located on top of the absorber plate. By placing the pipe in the middle of the absorbent plate, the amount of energy received increases due to the fact that more surface of the pipe is exposed to sunlight. Also, by placing the absorber plate under the pipes, more surface of the pipes is exposed to sunlight [9].

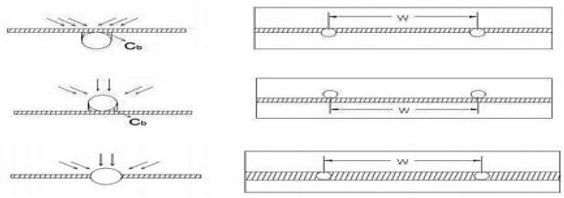

Fig 4. How to place the risers in the absorber plate [9]

2- The effect of the sun's radiation angle on the collector:

Investigations show that by increasing the angle of the collector relative to the horizon, the intensity of radiation applied to the surface of the collector increases until the sun's rays become perpendicular to the collector

3- The effect of the number of collector protective glasses:

Studies show that increasing the number of collector glass covers reduces the heat loss from the top of the collector. Therefore, by increasing the number of these covers, the amount of energy received by the solar collector increases.

4- The effect of the distance between the absorber plate risers on the efficiency of the collector:
As the distance between the risers decreases, the efficiency of the collector increases. Considering that the collector surface is considered fixed, reducing the distance between the risers means that the number of risers should be increased. This causes a greater surface of the fluid to be exposed to solar radiation in each cycle of the fluid circulation in the collector and the received energy increases.

5- The effect of the diffusion coefficient of glass on the efficiency of the collector:
The diffusion coefficient of glass, which is placed as protection on flat plate collectors, is also one of the factors affecting the efficiency of solar collectors. Part of the sunlight that reaches the protective glass passes through it and reaches the absorber plate, and the rest is spread by the open glass. The higher the diffusion coefficient, the less radiation will reach the surface of the absorber plate and the efficiency will decrease.

6- The effect of thermal insulation thickness on collector efficiency:
Thermal insulation reduces heat transfer from under the absorber plate to the outside environment. The results show that by increasing the thickness of the insulation, the heat loss from under the collector decreases, and the efficiency of the collector increases.

7- The effect of gas pressure inside the collector on efficiency:
The gas pressure inside the collector, which is used between the absorbent plate and the glass cover of the collector, can affect the efficiency. The results show that reducing the internal pressure of the collector increases its efficiency. The highest efficiency occurs when a vacuum is created inside the collector. The reason for this is the reduction of the heat transfer coefficient between the absorber plate and the surrounding environment.

8- The effect of the type of working fluid on the efficiency of the collector
One of the methods in which a lot of experimental research has been done in recent years is the use of nanofluids as the working fluid in solar collectors. As it can be seen, the use of fluids with higher heat capacity increases the thermal efficiency in solar collectors.

9-The effect of working fluid flow rate on collector efficiency:
Another way to increase the efficiency of solar collectors is to increase the flow rate of the inlet fluid. So that the higher the flow rate of the inlet fluid, the efficiency increases up to a certain value. And then it will have a steady trend.

10- Using phase change materials under the absorber plate:[9]
One of the technologies that have been widely used in heat storage in thermal systems in recent years is phase change materials that can store thermal energy latently. Using phase change materials under the absorber plate to absorb the heat losses of the collector can increase the efficiency of the collector. Figure below shows a schematic of the placement of phase change materials under the absorbent plate. By placing the phase change material under the absorber plate, the amount of heat loss of the collector is reduced.

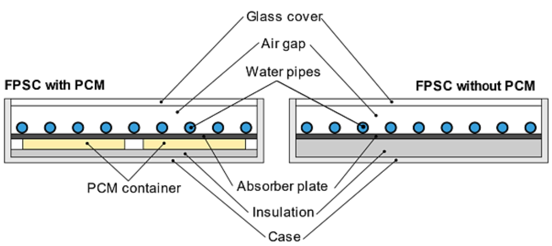

Fig 5. A schematic of the placement of phase change materials under the absorber plates [10]

1-1-2- Introduction of phase change materials

Considering the property of heat storage in PCM materials, the use of these materials in air conditioning systems, especially in solar heating and cooling systems, can reduce energy consumption to a large extent. Phase change materials are materials that absorb or release a large amount of heat when changing their physical state, i.e. from solid to liquid and vice versa. In the heating or cooling process, this phase change takes place as soon as the material reaches its specific phase change temperature. During latent heat absorption or latent heat release, the PCM temperature remains constant. The feature of PCM in absorbing and emitting a large amount of heat in a controlled manner can be used to improve the thermal performance of various products and the latent heat absorbed by PCM can be stored in it. Therefore, PCMs are considered very efficient thermal storage devices [11].

In Figure below, the temperature and heat changes are hidden and shown. As it can be seen, in a constant difference, the phase changer can store thermal energy in itself.

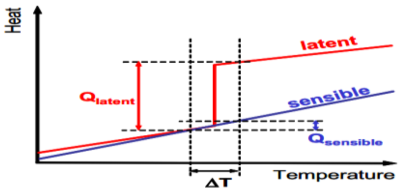

Fig 6. How to store heat latently and openly [12]

In general, phase change materials are divided into three types:

1- Organic (paraffin and non-paraffin),2- Inorganic (salt hydrates and metal alloys), and 3- Eutectic (a mixture of two or more PCM components: organic, inorganic, and both) [13].

.Passive applications include the use of PCM materials in windows, doors, and walls and use in solar panels. Active applications include use in heat pumps, electric heaters, and solar heating.

1-2- The purpose of the research

In this study, the effect of using PCM materials under the absorber plate in a flat plate solar collector is investigated in unstable weather conditions. Sudden weather changes such as cloudiness, local increase in dust concentration, and storms are examples of unstable weather conditions that can affect the amount of solar radiation on the surface of the collector. So far, many studies have been conducted on the use of phase change materials in solar water heaters with flat plate collectors. But so far, no study has investigated the level of reliability and the effect of unstable weather conditions on the performance of solar water heaters.

In this study, the performance of a flat plate solar collector is investigated in unstable weather conditions and the control of the output fluid by using a phase change material in the collector.

1-3- Research method

Numerical simulation is used in order to check the performance of a flat plate solar collector in unstable weather conditions and to control the hot water temperature coming out of the collector by using phase change materials. So that the performance of the desired system is simulated by CFD by Fluent software to determine the effect of phase change materials and their type in controlling the temperature of the water coming out of the collector in unstable weather conditions.

2-2- Investigating the performance of flat plate solar collectors

In flat plate solar collectors, when solar radiation passes through a transparent plate, it collides with a black absorber plate that has a high absorption coefficient. As a result, a large part of the energy is absorbed by the absorbent plate and then transferred to the fluid inside the tube by the intermediate material..

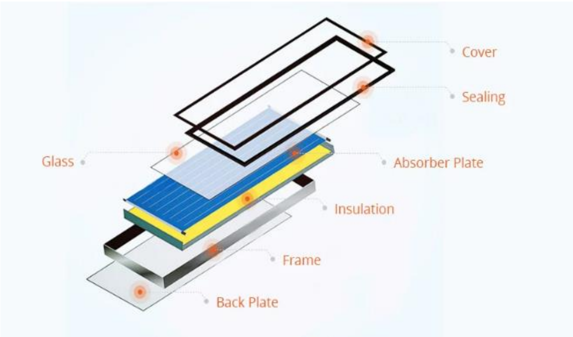

Fig 7. A view of the main components of a flat plate solar collector

The bottom plate of the absorber and its walls are insulated to prevent heat loss. Also, the liquid passing tubes can be welded to the absorber plate or can be as an integral part of the plate. Fluid passing tubes are connected to large-diameter headers at both ends. In order to reduce the heat loss of the absorbent plate, a transparent cover is used on top of it. This is done through the ability of a layer of stagnant air between the absorber plate and the transparent glass cover. Also, the transparent glass screen reduces the radiation loss of the collector through the greenhouse effect. Because glass is a transparent material, and as a result, short-wavelength solar radiation after passing through it and transferring heat with the absorbent plate increases its wavelength and cannot pass through the glass, and as a result, it is stored under the glass cover.

2-3- Equations governing the performance of flat plate solar collectors

The governing equations of the fluid used in flat plate solar collectors are defined as continuity, motion and energy equations as follows.

Continuity equation :

$$\frac{d\rho}{\rho} + \frac{dV}{V} + \frac{dA}{A} = 0 \qquad (1)$$

The equation of motion:

$$\frac{dP}{P} = -\frac{\rho g dZ}{P} - \frac{\rho V^2}{P}\frac{dV}{V} \qquad (2)$$

Energy equation:

$$C_p dT + V dV + g dZ = dq \qquad (3)$$

In the above equations , ،V ، T ، P ، A ، g ، Z ،q ، C_p و ρ , Speed, temperature, pressure, area, acceleration of gravity, coordinate axis along the collector, heat flux, specific heat capacity and density are respectively. By defining the speed of sound and Mach number for an ideal gas, the momentum equation is rewritten as below. Mach number and sound speed are defined in the following equation [12].

$$a = \sqrt{\gamma RT} \qquad (4)$$

Based on the balance of heat transfer for the surface of the ground, under the roof of the collector and the roof of the collector, the temperature is approximated. Three mechanisms of heat transfer, conduction, displacement and radiation are used to calculate the temperature of the desired surfaces. In reality, the roof of the collector absorbs a small part of the incoming radiation and passes the other part. This amount of transmitted radiation reaches the fluid inside the collector of other components and the surface of the ground under the collector.

Also, the conduction heat transfer in the collector is assumed to be negligible due to its small thickness, the temperature of the ground surface under the collector and the collector roof is assumed to be higher than the temperature of the fluid inside the collector, and the heat transfer between the ground surface under the collector, the collector roof, the fluid inside the collector and Ambient air is investigated [12]. As a result, to balance the heat transfer in the roof of the collector, the radiation absorbed by the roof, the exchange of ambient radiation with the fluid inside the collector, and the exchange of heat transfer between the surface of the roof of the collector and the fluid inside the collector, and the exchange of heat transfer between the surface of the collector roof and the ambient air is considered As a result, we can write:

$$(1-\tau)s = -h_c(T_f - T_C) - h_1(T_1 - T_c) + \varepsilon\sigma T_c^4 - \varepsilon\sigma T_e^4 + \varepsilon\sigma(T_f^4 - T_1^4)$$
(5)

In the above relation , σ ، T_C ، T_f ، h_1 ، T_1 ، T_e وh_c ,respectively,Boltzmann's constant, the temperature of the collector roof, the fluid temperature at the outlet of the collector, the heat transfer coefficient of the transfer between the collector roof and the ambient air, the ambient temperature, the surface temperature of the ground under the culture and the heat transfer coefficient of the transfer between the collector roof and the fluid inside the collector. to be To balance heat transfer on the surface of the ground below the collector, radiation absorbed by the surface of the ground, exchange of radiation between two surfaces of the ground and the roof of the collector, transfer of heat transfer between the surface of the ground and the fluid inside the collector and heat loss in the form of constant conduction heat transfer to the depth Land is included.

In the above relation, h_e and respectively are the heat transfer coefficient of the movement between the surface of the ground under the collector and the fluid inside the collector and the depth of the ground. To calculate the displacement heat transfer coefficient between the roof of the collector and the surrounding fluid, the speed of the surrounding fluid is effective and we will have the result [13].

To calculate the displacement heat transfer coefficient between the roof of the collector and the fluid inside the collector, as well as to calculate the displacement heat transfer coefficient between the ground surface under the collector and the fluid inside the collector, the Nusselt number of the forced flow and the Nusselt number of the natural flow are considered, and for the surface with temperature T and the fluid inside the collector with the coefficient of fluid conduction and viscosity, which these properties are included in the average temperature of the desired surface and the temperature of the fluid inside the collector, the displacement coefficient h for the desired surface is equal to:

$$h = \left(\left(Nu_{force}\frac{K_f}{2h_r}\right)^4 + \left(Nu_{nat}\frac{K_f}{h_r}\right)^4\right)^{\frac{1}{4}} \quad (6)$$

For the Nusselt number of the natural flow, which is dependent on the Grashof number (Gr) and the Parantel number, it is defined as follows.

$$Nu_{nat} = 0.115(GrPr)^{\frac{1}{3}} \quad (7)$$

And also for Grashof's number we have:

$$Gr = \frac{g\beta(T-T_f)h_r^3}{\nu^2} \quad (8)$$

For the Reynolds number at a distance r from the center of the collector, we have:

$$Re = \frac{m}{\rho_f \pi \nu}\frac{1}{r} \quad (9)$$

4-2- Examining the equations governing the performance of phase change materials

Phase change materials are ideal for use in any application where the storage and release of thermal energy is desired. PCMs act like a battery for thermal energy because they absorb thermal energy as they melt and can be recharged by cooling until they crystallize and release the stored energy back into the environment. They can store and release thermal energy thousands of times without changing the thermal properties [14].

5-2- Types of phase change materials

There are many types of phase change materials available, but there are three main types: organic (paraffin and non-paraffin), inorganic (salt hydrates and metal alloys), and eutectic (a mixture of two or more PCM components: organic, inorganic, and both). [15]

Reviewing and reviewing the research done

In today's advanced societies, the use of renewable energy sources to meet energy needs is the main priority. The efforts of many countries and companies are focused in this direction. However, green energy production alone cannot solve energy management and pollution issues. Exploiting wasted forms of energy is a good solution for this problem, which requires a lot of energy storage when not needed. Additional energy that can be done in different ways such as electric batteries, thermal storage, dams, wind turbines, etc. [19 , 20]. Among them, thermal energy storage has a wide range of applications [21]. Thermal energy storage can be classified into short-term and long-term (or seasonal) forms, and storage devices act as "thermal batteries". Long-term thermal storage is used to store energy for long periods, for example from summer to winter, is not very common because it is difficult and usually requires the use of large solid or liquid underground areas as storage medium [22]. On the other hand, most research and commercial efforts have focused on short-term thermal energy storage, where the storage space can usually be kept charged for up to two days. Short-term thermal energy storage can be done mainly in three ways. gave The simplest method is to create a large temperature difference between the storage environment and the outside environment, so the sensible heat mechanism is used [23,24]. Materials used as storage media in latent heat storage mechanisms are known as phase change materials (PCM). PCMs are materials that release/absorb energy during phase transition (for example, from solid to liquid). The phase transitions most commonly used for heating, cooling, and hot water applications are: solid-to-liquid and solid-to-solid, while solid-to-gas and liquid-to-gas transitions have high energy transfers and are often due to volume changes. They are not used much during the phase. [25]. According to the chemical characteristics, PCMs can be divided into three main categories: organic, inorganic and eutectic organic and inorganic compounds. Organic PCMs mainly include paraffins and other non-paraffin substances such as esters, fatty acids, alcohols and glycols. The category of inorganic PCMs includes salt hydrates and metals, and finally eutectics can be a mixture of organic-organic, inorganic-mineral and inorganic-organic PCMs [26].Each of the mentioned types of PCMs has its own application according to the temperature range. There are generally four different temperature ranges that PCMs can operate. In the first temperature range (-20 to 5 °C), PCMs are commonly used for domestic or commercial refrigeration and indoor cooling [27]. The second temperature range (5–40°C) is where PCMs are commonly used for heating and cooling applications in buildings [28]. In the third temperature range, PCMs (40–80 °C) are commonly used for solar-based heating, hot water generation [29,30] and electronic applications. Finally, in the last temperature range (80 °C to 1200 °C), PCMs are used for cooling absorption, waste heat recovery, and concentrating solar applications [31].It can be said that the most important weakness of PCMs is their low thermal conductivity. In order to improve the performance and increase the efficiency of PCM, various methods of increasing LHS-TES systems have been studied [31,33]. The first method to improve the heat transfer of PCMs and subsequently the performance of systems using them is to increase the heat transfer area. In recent years, many heat exchangers and geometry of finned tubes of different sizes have been studied [34,35]. Another way to achieve a similar result is to encapsulate PCMs in the form of stable macro, micro or nano structures [36,37]. In this way, the heat transfer area increases and also a more uniform phase change occurs. A different way to improve the performance of PCMs is to add nanoparticles such as graphene to increase the thermal conductivity [38,39]. All of these technologies can work in conjunction with each other to increase both thermal conductivity and heat transfer levels.[40]

Condensing collectors are used in applications that require higher temperatures than those required by flat plate and vacuum tube collectors, for example in steam generation, power generation or metal smelting. Solar radiation is directed to the receiver, while a tracking mechanism is required to maximize performance. In this type of collector, the PCM is placed next to the receiver. Gurayche et al. [41] investigated computationally and experimentally the performance of a parabolic solar concentrator, equipped with an absorber tube with PCM, to keep the energy output constant, even when the solar radiation fluctuates. They compared their proposed receiver with a receiver without PCM and found that the water outlet temperature was about 15% higher for the receiver with PCM.

Abuska et al. [42] have experimentally investigated a new solar air collector with aluminum honeycomb layer filled with PCM. For comparison, three collectors were tested:

- one with honeycomb and 26 kg PCM,
- One without honeycomb and with 26 kg PCM
- One without honeycomb and without PCM

Tests showed that energy production increased for type II collector for 469 minutes and for type III for 539 minutes, compared to collector with honeycomb and PCM. The addition of aluminum honeycomb shortens the charging and discharging time and also makes a significant difference in the storage of sensible heat during midday.Palacio and Caramano [46] experimentally analyzed the effect of temperature stabilization in the operation of a flat plate solar collector integrated with PCM reservoirs under the absorber plate.

Koka et al. [44] performed an energy and exergy analysis of a unit consisting of a solar collector and a storage tank in a T-shaped cavity. They used Mobilterm 605 as HTF in a 10mm diameter copper coil tube. 30 kg of CaCl2. 6H2O was added as PCM and KNO3 was added to crystallize PCM. The PCM was placed in the cavity inside the collector. They found that the exergy efficiency of latent heat storage systems with PCM is very low. Mote et al. [45] have investigated the use of 1 meter long modular solar collectors placed in a vacuum tube, both experimentally and numerically. The two-dimensional internal node approach was used for numerical investigation, and the efficiency of HE was evaluated by the e-NTU method. The configuration of the collectors is the same as the flat plate collectors, and part of the insulating layer is replaced by PCM, forming a monolithic configuration. Different PCMs were investigated and muriatic acid 51 was selected as the most suitable. With the addition of PCM, it was observed that the working temperature of the collector was reduced, as well as the flow rate was reduced for optimal performance (45 instead of 50 L/h). The authors concluded that for the specific application, the additional cost and complexity of PCM cannot be justified by the minor improvements in performance.

Research Methods

The structure of the phase change material can be different. According to the place where the phase change material is used, the appropriate structure and its type are selected for use. Choosing the right phase change material is very important for use in the structure of buildings or anywhere it is used .Overall, PCM application because of their aforementioned intrinsic characteristics ranges from the hand warmer to green buildings; however, for most applications, PCMs with a narrow phase change temperature range with a corresponding high latent heat value, along with robust chemical stability, are preferred because they can store and release higher amounts of energy cycles..In the present study, the effect of using phase change materials in flat plate solar collectors was investigated in the unstable weather conditions of Tehran city in order to control the working fluid outlet temperature performance in the collector. Unstable weather conditions mean sudden changes in solar radiation caused by cloudiness. For this purpose, the geometry of a flat plate solar collector was first designed, and after generating a suitable computing network and verifying the results of the numerical solution, four different scenarios were investigated. In the first scenario, the numerical simulation of a flat plate solar collector in normal weather conditions of Tehran city is done in order to determine the performance of the collector in the basic state. In the second scenario, the numerical simulation of the desired solar collector in unstable weather conditions has been done to determine the effect of unstable weather conditions on the performance of the collector and outlet water temperature.

In the third scenario, with the use of phase change material in the solar collector, first its performance was investigated in stable conditions for the city of Tehran, and then in the fourth scenario, the performance of the solar collector with the use of phase change material was investigated in unstable weather conditions. To determine the effect of using phase change materials on the performance control of the collector. Also, in order to investigate the effect of different types of phase change materials on the thermal performance of the solar collector in unstable atmospheric conditions, three types of phase change materials with different characteristics were investigated. In the following, the climatic condition and the potential of solar radiation in Tehran will be investigated, and then the geometric model of the desired collector and the quality of the generated computing network will be examined, and the governing equations of flat plate solar collectors and the mathematical models used in Numerical simulation is introduced. The country of Iran is located between 25 and 40 degrees north latitudes and is located in one of the regions of the earth with suitable solar radiation. The amount of solar radiation intensity in Iran is on average higher than the world average and more than 280 sunny days have been recorded in more than ninety percent of Iran [45].

The amount of solar radiation on the horizontal surface has a great impact on the output power of solar systems, so the more the amount of solar radiation on the horizon in a region, the greater the potential of using solar systems in that region. As it can be seen, the central, southern and southeastern parts have the highest amount of horizontal solar radiation and there is a good potential for building a solar power plant in these areas. In general, to calculate the amount of solar energy received for a specific area, the standard of sunny hours during the day is used. According to the announcement of the New Energy Organization of Iran, the average annual solar radiation (PSH) in Tehran is 4.5-2.5 hours. In other words, if the desired solar collector absorbs 10 kilowatts of energy, it means that 520 to 540 kilowatts of energy is transferred to the fluid every hour, regardless of losses.

The figure below shows the average solar radiation throughout the year for the city of Tehran in each month. As it can be seen, the maximum amount of solar radiation for the city of Tehran in June is around 200 kilowatt hours per square meter and the lowest amount of solar radiation is in November which is around 120 kilowatt hours per square meter. Also, the annual average direct solar radiation for Tehran is 1900 kilowatt hours per square meter.

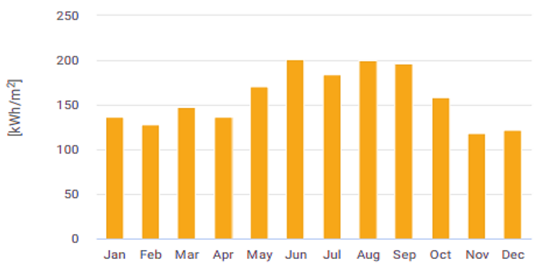

Fig 8 . Average monthly solar radiation for Tehran [46]

Investigating the geometric dimensions and calculation scope of the solar collector

The following table shows the geometric dimensions of the desired collector. As you can see, the length of the pipe and the entire collector is 800 mm and its diameter is 10 mm. Also, the thickness of the tube and absorber plate is considered to be 1 mm, and the thickness of the thermal insulation and glass cover is also considered to be 3.5 mm. In addition, the length of the distance between the glass plate and the absorbent plate is also equal to 25 mm.

- Pipe length 800
- Pipe diameter 10
- Pipe thickness 1
- Thickness of absorbent plate 1
- Thermal insulation thickness 3.5
- The thickness of the glass cover is 3.5
- The length of the distance between the glass cover and the absorbent plate 25

Table 1- thermophysical characteristics of PCM materials

PCM-3 [100]	PCM-2 [99]	PCM-1[98]	
29-36	42-44	35.4-36.4	Melting/freezing temperature (C)
1.6×10^5	1.68×10^5	2.4×10^5	Latent heat of fusion (J/kg)
880	844	910	Solid state density (kg/m3)
760	760	769	Density of the liquid state (kg/m3)
1800	2052	1926	Specific heat of the solid state (J/kg.k)
2400	2411	2400	Specific heat of the liquid (J/kg.k) state
0.2	0.4	0.423	Solid thermal conductivity (w/m.k) coefficient
0.1	0.15	0.146	Liquid thermal conductivity (w/m.k) coefficient
4×10^{-3}	4.9×10^{-3}	4.9×10^{-3}	(Pa.s)
7×10^{-4}	8.3×10^{-4}	8.1161×10^{-4}	Coefficient of thermal (1/k) expansion

After determining the geometry of the collector and its boundary conditions, it is possible to check the temperature balance in the desired collector. Assuming that the heat from solar radiation is divided only in the part below the radiation plane, the water inside the pipe and the space under the pipe. will have:

$$\dot{Q}_{radiation}\left(\frac{j}{s}\right) = Q_{air}(j) + \dot{Q}_{water}\left(\frac{j}{s}\right) + Q_{air\ or\ PCM}(j) + loss \qquad (10)$$

Q˙_radiation is solar radiation in watts per square meter, which is calculated by multiplying by the surface area of the collector and considering one hour of solar radiation on the surface of the collector according to the shape of the collector, finally the desired unit is calculated in joules. Also, T_e is the equilibrium temperature and T_i is the initial temperature of each region. It should be noted that one hour of solar radiation on the surface of the collector is also considered to calculate the heat absorbed by the water.

Check the density

To get the density of the nanofluid, the mass of the nanofluid must be divided by its volume, and by writing the mass and volume of the nanofluid in terms of the mass and volume of the nanoparticles and the base fluid, the following relationship can be obtained.

$$\rho_{nf} = \frac{\rho_{bf} V_{bf} + \rho_p V_p}{V_{bf} + V_p} \qquad (11)$$

m, V, and ρ represent mass, volume, and density, respectively. Also, the subscripts nf, bf and p show the relationship of each property with nanofluid, base fluid and nanoparticles.

The above relationship shows that the specific heat capacity of nanofluid is related to the specific heat capacity and density of the base fluid and nanoparticles as well as the volume percentage of nanoparticles. In the current research, this relationship has been used to calculate the specific heat of nanofluids.

Heat conduction

To calculate the thermal conductivity of nanofluid as stated in the previous chapter, several models have been developed. In the current research, Maxwell's model has been used so that the effects of the nano layer formed around the particle and its role in thermal conductivity are considered.

$$k_{nf} = \frac{[2(1-\alpha)+(1+\beta)^3(1+2\alpha)]\alpha}{-(1-\alpha)+(1+\beta)^3(1+2\alpha)} k_p \qquad (12)$$

$$\alpha = k_{layer}/k_p$$

$$\beta = w/r_p$$

In the presented model, w, k_{layer}, r_p are respectively the thickness of the nanolayer, the radius of the particle and the thermal conductivity of the nanolayer. The above model has the advantage of establishing a relationship between the thermal conductivity of the nanofluid and the diameter of the nanoparticles and considers the effects of the diameter on the thermal behavior of the fluid [47].

Investigating the independence of the computing network

In the figure below, the curve of temperature changes of the outlet water in the collector is shown. As it can be seen, with the increase in the number of elements to 890156, the outlet water temperature has not changed. Also, the comparison of water temperature changes in the number of elements 890156 and 879812 shows that the water temperature does not change much with the increase of elements. Therefore, the desired collector with the number of 879812 elements can be used in the simulation.

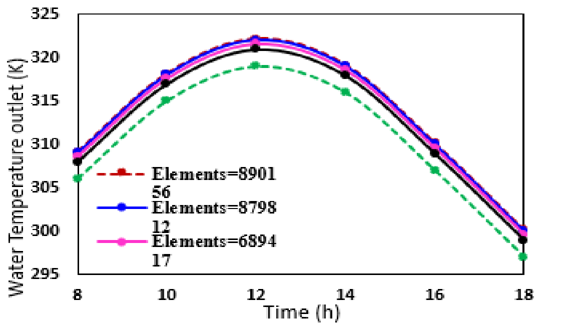

Fig 9. the curve of changes in outlet water temperature with the number of different elements

Examining the results without using phase change materials in the stable atmospheric conditions of Tehran

In this section, the results of the numerical simulation of the desired collector have been investigated, without using phase-changing materials in it, and also in stable weather conditions and without reducing solar radiation during the day.

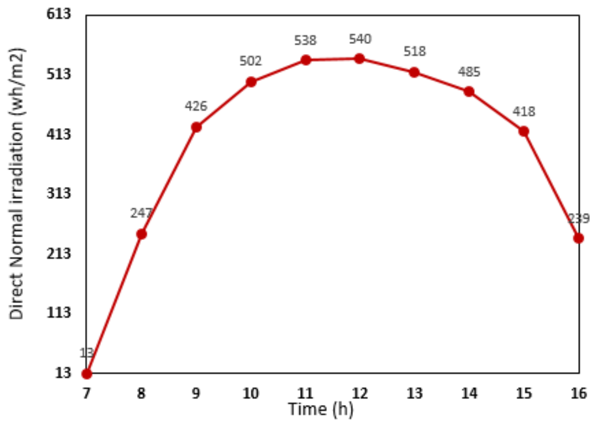

Fig 10 . Hourly solar radiation changes curve in December in Tehran city

In the figure below, the position of the temperature distribution contour in the middle plate of the collector is shown in the condition that the solar radiation on the surface of the collector is 13 watt hours per square meter.

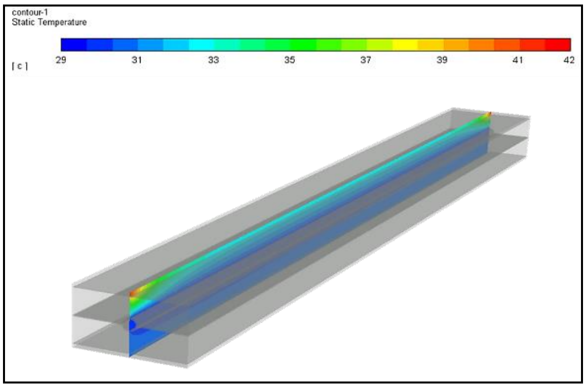

Fig 11. The position of the temperature distribution contour in the middle plate of the solar collector at 7-6 hours without use of phase change materials

In the figure below, the curve of temperature changes of the water coming out of the collector during a day for stable weather conditions and without PCM is shown. As it can be seen, with the increase in the intensity of solar radiation up to 540 Wh/m2 on the surface of the collector, the temperature of the water coming out from it reaches 38.02 degrees Celsius at 12 noon in December. Therefore, the desired collector increases the water temperature by 30 degrees to 38 degrees Celsius in December.

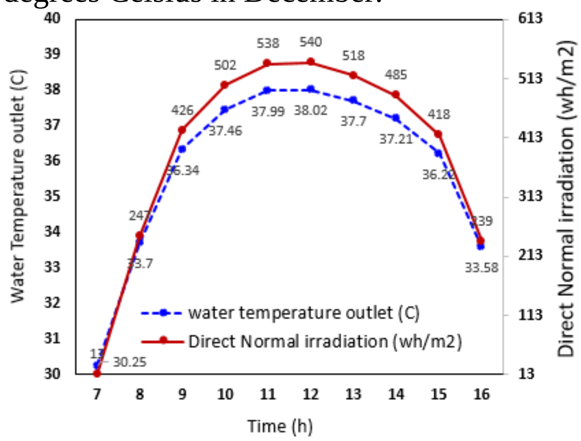

Fig 12 . the curve of changes in the temperature of the water coming out of the collector and solar radiation during a day for stable weather conditions and without the use of phase change materials

To investigate the effect of using phase change materials on the thermal performance of the desired solar collector, three types of phase change materials with different thermophysical characteristics were investigated.

Examining the results using phase change materials in stable atmospheric conditions

- **The effect of using the first type of phase change material (PCM-1)**

So that during charging, the phase changing material absorbs heat from the high temperature area in the collector until its temperature reaches 36.4 degrees Celsius, and then at this temperature it changes phase by absorbing heat and its temperature increases.

In the figure below, the curve of the output water temperature changes in the case of using without phase change material and in the case of using PCM-1 and the average volume fraction of the desired phase change material per hour is shown. As it can be seen, the phase change material The donor has started to melt when the temperature of the water coming out of the collector has reached 35.84 degrees when using the phase change agent, which according to the melting temperature of the desired substance is 36.4 degrees Celsius, it can be concluded that the melting of the change agent The phase changer has been done correctly, because the use of the phase changer has caused the temperature of the water coming out of the collector to be lower than when the phase changer was not used. This trend is due to the higher heat capacity of the phase change material compared to air. Considering that the freezing temperature of the desired phase changer is equal to 35.4 degrees Celsius, the results show that the temperature of the outlet water of the collector has reached 34.08 degrees Celsius at 16:00 and the phase changer is in the solid phase at this time. has taken.

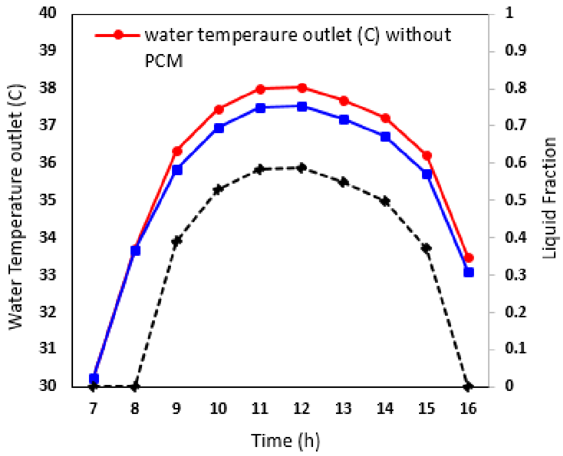

Fig 13 .hourly changes curve of volume fraction of phase change material and temperature of outlet water with PCM-1 material

Examining the results shows that at the end of 16 hours, the heat stored in the PCM is equal to 981612 joules. Considering that there is no solar radiation after 16:00, so the stored heat is transferred to the water. The calculation results show that the water temperature increases from 33°C to 37.42°C. To further investigate the effect of the melting and freezing temperature of the phase change material on the temperature of the water coming out of the collector, a phase change material (PCM-2) with a melting temperature of 44 degrees Celsius was investigated.

The effect of using second type phase change material (PDM-2)

The melting temperature of the phase changing material is equal to 44 degrees Celsius, which is higher than the maximum temperature of the outlet water of the collector. The use of phase change materials with a melting temperature higher than the maximum temperature of the outlet water of the collector has caused the desired PCM to be solid during the operation of the collector. It should be noted that non-melting of PCM does not mean non-absorption of heat. In other words, in this scenario, the desired phase change material has obviously absorbed heat

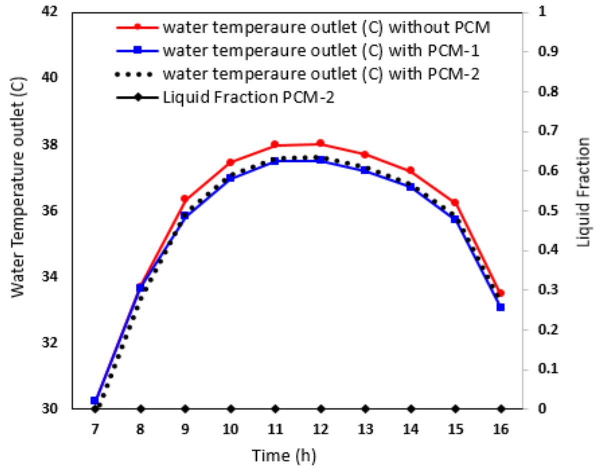

Fig 14 . hourly change curve of outlet water temperature using PCM-2 material

The effect of using the third type of phase change material (PCM-3)

The melting temperature of the desired phase change material is 35 degrees Celsius. Also, the heat capacity of PCM-3 in liquid state is equal to 2400 J/kg Kelvin, which is equal to the heat capacity of PCM-1.

In the figure below, the curve of temperature changes of the outlet water in the collector is shown. As it can be seen, the use of the desired phase change material has reduced the temperature of the outlet water by about 0.5 degrees compared to the state without the use of the phase change material. Also, the heat stored in PCM-3 is equal to 981612 joules. Therefore, the results showed that one of the important parameters in the amount of heat storage of phase change materials is their heat capacity, so that the higher the heat capacity of a material, the more heat it can store.

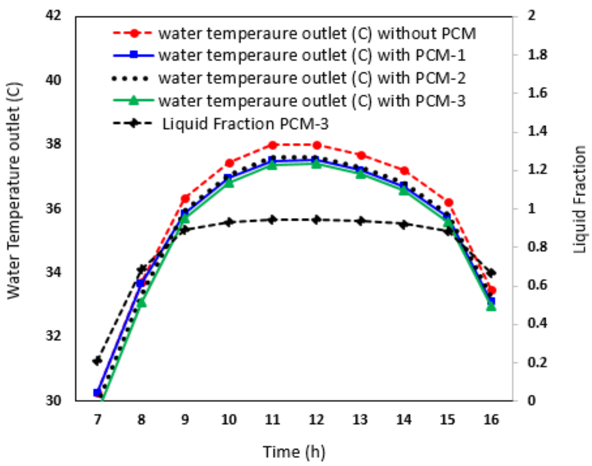

Fig 15 . hourly change curve - outlet water temperature using PCM-1-2-3 material

Therefore, this property can be used to compensate for the decrease in the temperature of the water coming out of the collector when the solar radiation decreases. For this purpose, in order to investigate the effect of using phase change materials in solar collectors when there is instability of solar radiation (such as cloudiness of the air), it is assumed that the air suddenly becomes cloudy after the sun shines at 1:00 p.m. In the following, the effect of using a phase changer in unstable weather conditions will be investigated.

Examining the results by using phase change materials in unstable atmospheric conditions

- **The effect of using the first and third type of phase change material**

Figure below shows the curve of temperature changes of the water coming out of the collector. As the results show, the water temperature decreases up to 35 degrees Celsius by reducing the instantaneous radiation. By using the first type of phase change material in the collector, about 909210 joules of heat is stored in the PCM until 11 o'clock, which increases its temperature to 41.6 degrees Celsius by transferring the stored heat to the 37-degree water. Also, the heat stored in PCM-3 is equal to 898627 joules, which increases its temperature to 41.3 degrees Celsius by transferring heat to water. The results show that the use of the phase change material in the collector during instability with the heat stored in it has been able to increase the water temperature up to 41 degrees Celsius and prevent the water temperature from decreasing.

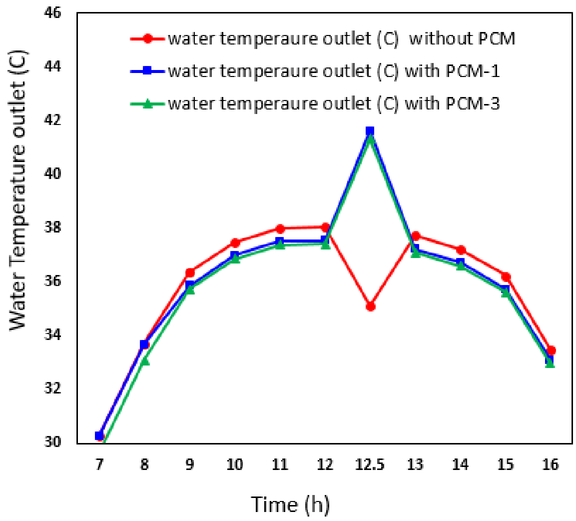

Fig 16 . curve of hourly changes, outlet water temperature using PCM-3,1 material

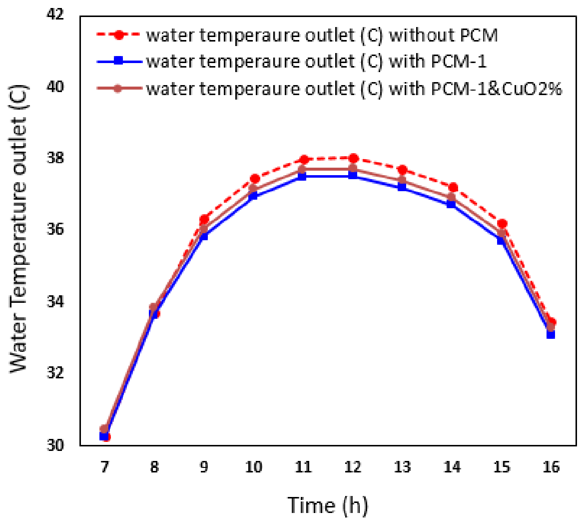

Fig 17 . hourly change curve of outlet water temperature using pure PCM-1 material and nanofluid

The results show that the use of the phase change material in the collector during instability with the heat stored in it has been able to increase the water temperature up to 41 degrees Celsius and prevent the water temperature from decreasing.

Examining the results of using nanoparticles in phase change material

To investigate the effect of adding nanoparticles to the phase change material, copper oxide nanoparticles with a volume fraction of 2% were selected. Calculations show that the specific heat of the desired nanofluid is equal to 2084 kJ/kg degrees Kelvin and its density is equal to 832.2 kg/m3. In the figure below, the curve of the output water temperature changes is shown. As it can be seen, with the reduction of the heat capacity of nanofluid compared to the pure phase change material, the temperature of the water coming out of the collector has decreased to a lesser extent than the base state. Also, due to the decrease in density compared to the pure phase change material, less material can be used in the collector.

Conclusion

In this article, Ansys Fluent software was used to analyze the collector installed in the building If phase change materials are used in the building and its structure, it will reduce the consumption of fossil energy. The structure of phase change materials can be different at the same time, it will reduce the cost. Phase change materials are very important for the future of energy and renewable energy consumption in buildings and the structure of the agricultural and manufacturing industry. In this article, we investigated the effect of using phase change materials in flat plate culture used in buildings, for more energy efficiency.
Supplying heat load in air conditioning systems requires a lot of energy consumption, which in Iran is generally supplied through gas and fossil fuels. One of the energy sources that can replace fossil fuels is solar energy. Solar energy is a sustainable alternative to fossil fuels. One of the methods of using solar energy in supplying the required heat for air conditioning systems is to use flat plate solar water heaters to supply the required hot water. It was determined by the investigations that the thermal efficiency of flat plate solar collectors is around 30-35%. This thermal efficiency is ideal in conditions where there is sunlight on the surface of the collector throughout the day. Therefore, when the weather becomes cloudy, the thermal

efficiency of the collector also decreases, which causes a decrease in the temperature of the water coming out of it. Therefore, according to the fluctuations of solar radiation, heat storage plays an important role in the performance of solar thermal systems. In order to store thermal energy, heat can be stored latently, manifestly or thermochemically in different materials. According to the cases stated in the present study, numerically investigate the effect of using phase change materials for thermal energy storage latently in a The flat solar spa was paid. In order to numerically investigate the thermal behavior of the collector, first a geometric model of the solar collector was produced, and after producing a suitable computing network, the performance of the collector in four scenarios for the month of December was numerically simulated by Fluent software. In the first scenario, the performance of the solar collector was investigated in the stable weather conditions of Tehran city without the use of phase change material. The results showed that the desired solar collector can increase the water temperature of 30 degrees Celsius to 38 degrees Celsius at 12 noon when there is the most solar radiation on the surface of the collector. In the second scenario, to investigate the effect of air instability and cloudiness on the performance of the collector, it was assumed that the solar radiation will decrease. The results showed that with the reduction of solar radiation, the temperature of the water coming out of the collector without the phase change material decreases from 38 degrees Celsius to 35 degrees. In the third scenario, the effect of using phase change materials on the performance of the collector in stable weather conditions was investigated. For this purpose, three types of phase change materials with different melting and freezing temperatures as well as different latent heat of melting were investigated in the collector.. This process is due to the same heat capacity as the first phase change material. In the third scenario, PCM-1 and PCM-3 were checked in the collector for unstable mode. The results showed that by reducing the instantaneous radiation, the water temperature reaches from 37 degrees Celsius to 41 degrees Celsius and prevents the instantaneous water temperature from dropping. Therefore, the use of phase change material in the collector can increase the temperature and compensate for the decrease in water temperature when the solar radiation decreases. Finally, by adding copper oxide to the phase change material, its effect on the amount of heat transfer in the collector was investigated. The results showed that by reducing the heat capacity of the nanofluid compared to the pure phase changer, the temperature of the water coming out of the collector has decreased to a lesser extent than the base state.

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