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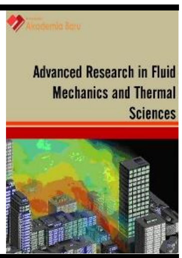


# Performance Enhancement of Solar Air Heater Using Different Phase Change Materials (PCMs)

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**ABSTRACT**

Water is used as a heat storage material in liquid-based systems, such as solar heating systems, and variable phase materials. In order to obtain the maximum period of time for thermal storage using different mixing ratios (70% of water and 30% of the variable phase PCM). The objectives of this work is to find the best mixing ratio between water, and choose the best type of PCM of two materials, to obtain high efficiency for testing and thermal energy storage using PCM, and the possibility of arriving at the optimal design of the system containing the variable phase material at the greatest thermal energy stock during the whole day for the purpose of heating with then to reach the extent of success of using its system in the climatic conditions of the city. (PVP is a powder or white flakes or yellowish white, attractive for moisture, dissolve freely in water and alcohol and PEG is a mark B ether and water-loving, with a few toxicity) so with these specifications we have had a good storage time of up to 44 minutes when mixing (70% of water and (20% PVP, 10% PEG)) and put it in brass tubes inside the box of the closed Sun Fair at an angle of 45.



## 1. Introduction

Solar radiation is still as resource of time-dependent energy, so energy storage is necessary meet energy needs at cloud cover periods or at night or make an important contribution to needs of total energy. Solar energy can be changed into different forms and may be stored such as; chemical, thermal, potential, and kinetic energy. In General, the storage media selection is concerned to the energy deplete. The optimum capacity of storage equipment for a specified solar process based on the solar availability dependence time, the load nature, the auxiliary energy cost, and the process components price. These four factors should be reached the suitable system design (like storage size), which lowers the final delivering energy cost [1-4].

Solar air heaters have been applied in energy saving, and used for solar water desalination, space heating, marine products, textile, and air drying [5–7]. Solar air heaters have good properties such as

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preventing the problems of stagnation or freezing, leaks, risk of hazard from the media of heat transfer. So, they be with low energy consumption costs [8,9].

Kabeel *et al.,* [10] made a literature review for improvement methods and design of different SAHs. Many researches made many researches on SAHs for either theoretical or experimental to enhance their duty. Various types of fins types were used to achieve the performance enhancement such as corrugated and longitudinal fins. There is a good enhancement in the values of friction coefficient and Nusselt number for a high Reynolds number.

Wenye Lin *et al.,* [11] reviewed the performance and development evaluation for solar energy storage using paraffin-based PCMs in the building surrounding. They studied two cases of radiant solar heating with paraffin-based PCM. The systems of paraffin-based PCM TES can rationalize the solar energy utilization for air conditioning at maintenance of indoor environment. Researchers studied different mixtures for solar energy storage and release [12-18]. Farhan *et al.,* [19], Aseel *et al.,* [20] and Naheda [21] used phase change material for solar energy storage and release applications. Farhan *et al.,* studying the effect of using phase change material on production enhancement of solar desalination unit [22]. Mohamad *et al.,* characterized phase change material behaviour like the supercooling degree, phase change temperature and thermal conductivity [23].

The aim of this work is to find the best mixing ratio between water, and choose the best type of PCM of two material, to obtain high efficiency for testing and thermal storage using PCM, and the possibility of arriving at the optimal design of the system containing the variable phase material at the greatest thermal energy stock during the whole day for the purpose of heating with then to reach the extent of success of using its system in the climatic conditions of the city.

## 2. Main Types of Thermal Energy Storage (TES)

Sensible solar energy storage systems save thermal energy by temperature changing of the storage medium, like water, rock, brine, etc. While systems of latent thermal energy storage save solar energy by change of phase, like cold water to ice and heat obtained from paraffin waxes melting. Units of latent solar energy storage are less than sensible thermal energy storage units. Thermal energy storage can be performed based on storages of utilizing chemical reaction. The thermal energy storage during a latent heat process may be calculated as [23,24].

$$Q = m.L \tag{1}$$

where
$m$ = mass to change phases
L = the PCM specific latent heat. The unit of latent heat is J/kg [25].

Collector thermal efficiency (η) can be mathematically defined as [26]

$$\eta = \frac{\dot{m}\, Cp\, (\Delta T)}{Ac\;\, G} \tag{2}$$

where
$\dot{m}$ = fluid mass flow rate (kg/s)
$C_p$ = fluid specific heat (J/kg. K)
$\Delta T = T_o - T_i$
$T_o$, $T_i$ = outlet and inlet fluid temperature of solar collector (°C), respectively
G = radiation intensity ($W/m^2$)
$A_c$ = area of total collector aperture ($m^2$)

## 3. Experimental Setup

In Figure 1, the image of the experimental rig (specifications listed in Table 1) which is designed and manufactured in laboratory of renewable energy. For this rig, radiation of solar energy passes through the glass cover to an absorbent pad and matte black-painted tubes to enhance the short-wave absorption of solar radiation and to reduce long wavelength of radiation loss from surface absorption. This solar radiation turns into the thermal stored, this system consists of the following parts.


**Fig. 1.** Heating system

**Table 1**
The specifications of component project

| Component | Specification | Remarks |
|---|---|---|
| Wooden box | 90 cm, 45 cm, 18 cm | Gross area – 4050 cm$^2$ |
| The glass | 94 cm, 49 cm, 3 mm | Gross area – 4606 cm$^2$ |
| Fan | The speed of out let = 4 m/s | 12 volt and the Dimension of hole = 8 cm |
| Iron base | The angle equal 45$^0$ | The Easter contains a holder to raise the wooden box with an angle of 45, and a width of 22 cm |
| The coating | Rust-oleum painter 97% | The coating black to high absorber |
| Wires | - | - |
| Thermo couple meter | Type k | It is use three couple (Inlet, outlet, surface of box) |
| The battery | SN12002 (12 volt) Small size valve lead acid battery | 12 volts |
| Pipes | 6 with dimension (length 80 cm, diameter 2.5 cm) | Copper |

### 3.1 The Heating Room

Wooden box with dimensions [length 90 cm, width 45 cm, depth 18 cm] is used as a heat insulator and painted with black paint to increase the absorption of sunlight and thus increase the efficiency of the model. It consists of two holes each diameter 8 cm (top, bottom) [the bottom in which the air fan and upper holes, to open and close when take reading].

### 3.2 The Glass

Window glass type of 3 mm thickness and dimensions (94 cm, 49 cm) was used. It has a high transparency degree, week refraction or constant reflection ratio on the wooden box front face.

### 3.3 Coating

We use (the Rust-oleum painter 97%, as shown in Figure 2) as paint to increase the absorption efficiency of sun rays for the coated parts and its absorption rate 97% (We examined the pigment in the laboratory of the college using the source-solar card-within the appropriate laboratory conditions we found that uptake reaches 97%) .


**Fig. 2.** The absorbed paints used

### 3.4 The Battery

We use the SN12002 to operate the fan capacity of the battery 12 volts, as shown in Figure 3.


**Fig. 3.** The battery used

### 3.5 The Pipe

Copper tube shown in Figure 4 is used because of high quality for corrosion resistance and easy to stretch thermally. Available in yellow and red colours. Six pipes with dimensions (length 80 cm, diameter 2.5 cm) were distributed in zigzag to ensure that the greatest sunlight reached them.

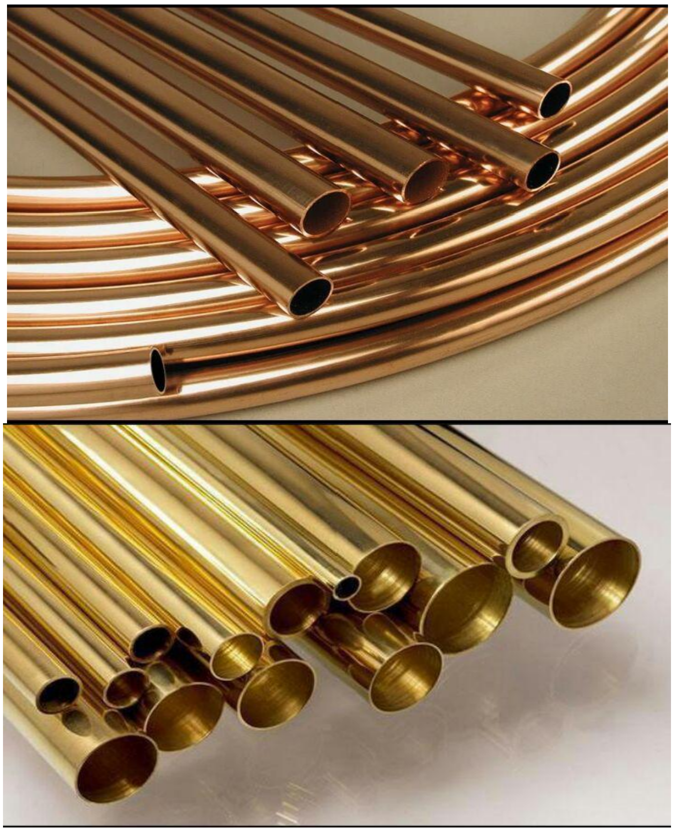

**Fig. 4.** The pipe

### 3.6 The Fan

It is a device that pays the air when the place is closed to increase the speed of heating and get hot air at good speed, as shown in Figure 5.

**Fig. 5.** The fan used

### 3.7 The Measuring Devices
#### 3.7.1 Recorder of temperature

The readings of thermocouples were gathered and stored in a desktop computer through a Make-Lutron-BTM-42085D recorder, as shown in Figure 6.


**Fig. 6.** The temperature recorder

#### 3.7.2 Solar power meter

Figure 7 presents the solar intensity measurement device of A digital solar power meter type, VOLTCRAFT, model TES (1333R). with accuracy of ±10 W/m$^2$; Sampling Rate: 4 times/sec.

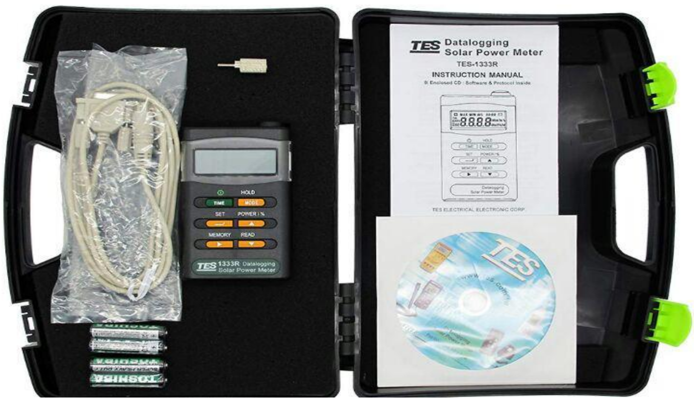


**Fig. 7.** The solar intensity meter

### 3.8 Materials Used
#### 3.8.1 Polyethylene glycol (PEG 6000)

Polyethylene glycol series, as shown in Figure 8, can be used as solvent, active agent surface, is colorless, odorless, viscous. There is a sweet taste, but it is toxic if eaten. Polyethylene glycol is the most commercially available glycol and manufactured in the world. It can be used as an antifreeze for cooling, in hydraulic fluids, and in the manufacture of low-freeze dynamite and resins. Is a polyurethane compound with many applications. Molecular formula: $H-((O-CH_4)-CH_2)-OH$, Melting point 55-65 $^{o}$C. The Molar mass is (20000 g/ mole).

**Fig. 8.** Polyethylene glycol

*3.8.2 Polyvinyl pyridine (PVP)*

Poly Vinyl Pyridine, as shown in Figure 9, is white or yellowish white powder which is freely attracted to the water, alcohol and methanol, and can be stored in normal conditions without collapsing or decomposes, but the powder is active for moisture so it must be stored in sealed packaging to close, in cold places and Dry. Different types of it are characterized by high wives in solutions., Molecular formula: $C_6H_9NO$, the molar mass is (2.500 - 2.500.000g/mole), density (1.2 g/cm$^3$), melting point 150 - 180 °C.

**Fig. 9.** Polyvinyl pyridine

*3.9 Experimental Procedures*

i. We fill the copper pipes with 70% water and a specific percentage of the variable material.
ii. The collector was faced to south with the angle of 45° at 33.2° latitude and 44.3° longitudes.
iii. Put the tubes inside the box and close the opening and open the fan connected to the battery and subject to open the bottom to heat the center.
iv. After a specified period of time we open the aperture to measure the heat of the air we obtained from the experiment.

## 4. Results and Discussion

All tests were carried out on February and March 2019 in Iraqi weather. It can be seen that the solar radiation increases during (10 am - 5 pm) with little fluctuations resulted from the clouds presence from period to another, as in Figure 10-14.

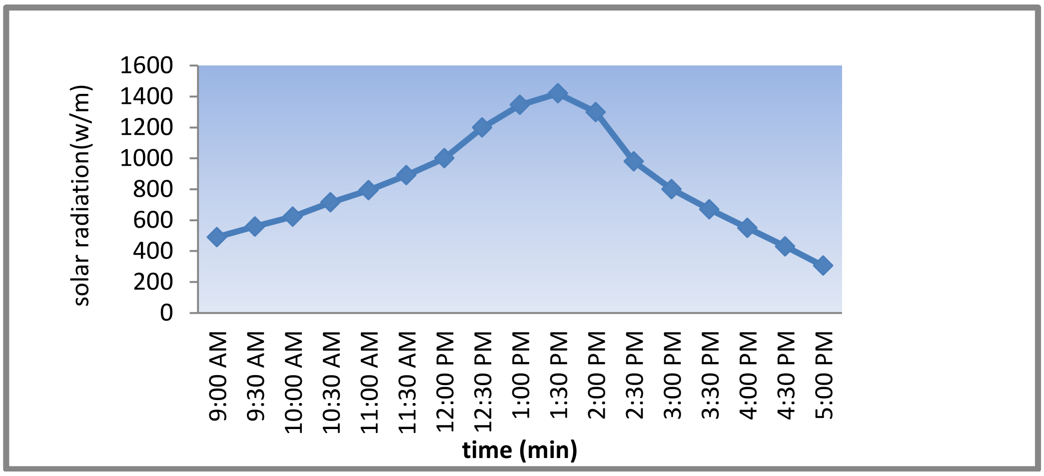


**Fig. 10.** Incident solar radiation vs. time, air of angle 45 ° on February Tuesday 21-2-2019

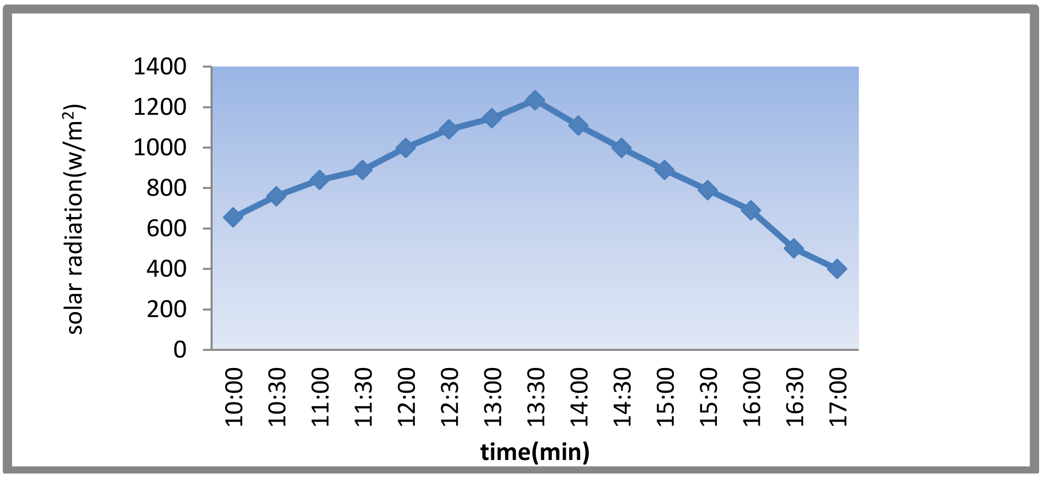


**Fig. 11.** Incident solar radiation vs. time, water of angle 45° on February Tuesday 26-2-2019

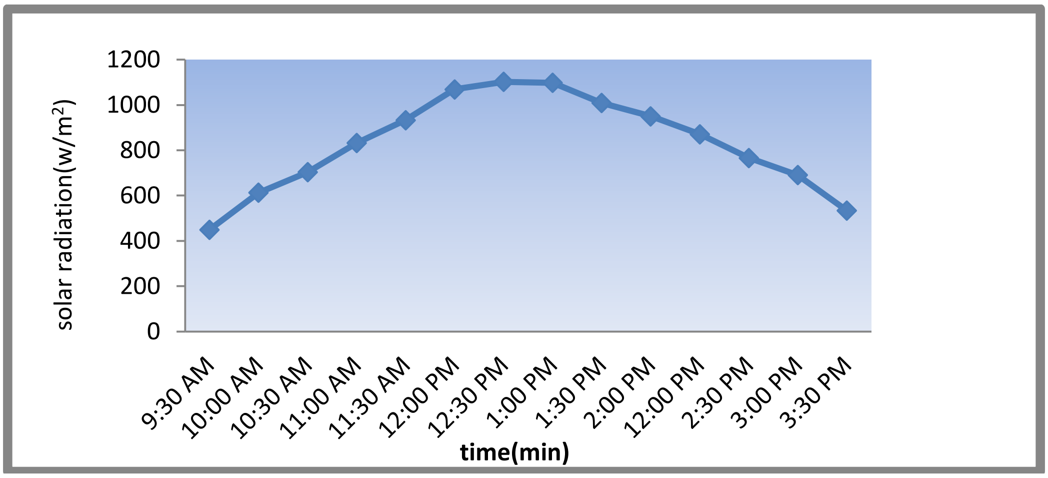


**Fig. 12.** Incident solar radiation vs. time from the phase change material when (PEG 10%, PVP 20%) of angle 45° on February 27-2-2019

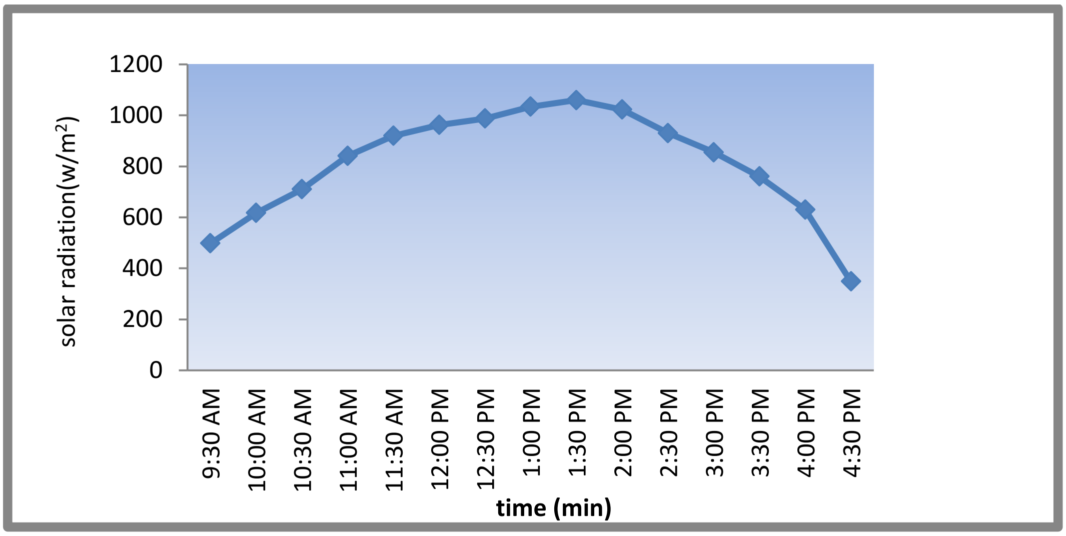


**Fig. 13.** Incident solar radiation vs. time from the phase change material when (PEG 15%, PVP 15%) in angle 45° on March Wednesday 6-3-2019

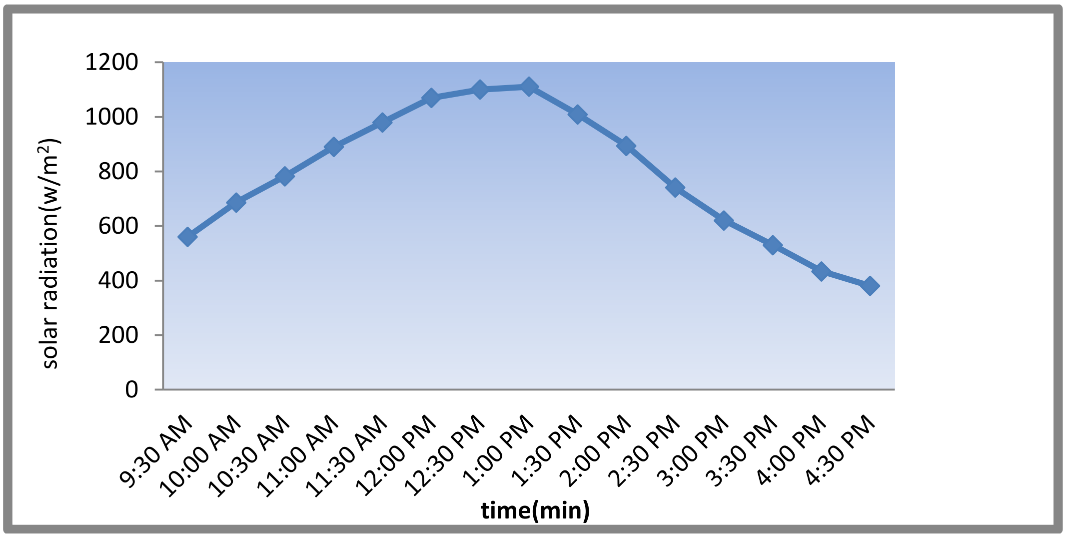


**Fig. 14.** Incident solar radiation vs. time from the phase change material (PEG 20%, PVP 10%) in angle 45° on March Tuesday 12-3-2019

Figure 15 it can be seen that ΔT (The difference between the temperature inside and outside) with time. Gradual increase to the highest value, which ranges from 12 to 3 pm. Then note a gradual decrease in temperatures begin by 3 pm at a specific time we observe the temperature equals any start of the storage phase, this can be listed in the following Table 2.

After the system is turned on and heated, it will reach a certain time where the heat inside and outside and the temperature of the surface means that the system is in storage and although the water is the main reservoir but the use of additional materials with it leads to enhance the system efficiency, when using PEG as a dissolved substance with water will lead to a decrease To absorbency the heating because of the decrease of the polymer viscosity and the replacement of the polymer chains while noting the higher the percentage of PVP increases the absorbency heating and the duration of heat storage increases to give a slow and continuous liberalization of heat.

Table 3 provide the efficiency of the wooden box to know the highest temperature to be obtained. Figure 16 presents the effect of mixing ratio on the solar collector efficiency. It can be seen that solar collector efficiency increases with increase mixing ratio.

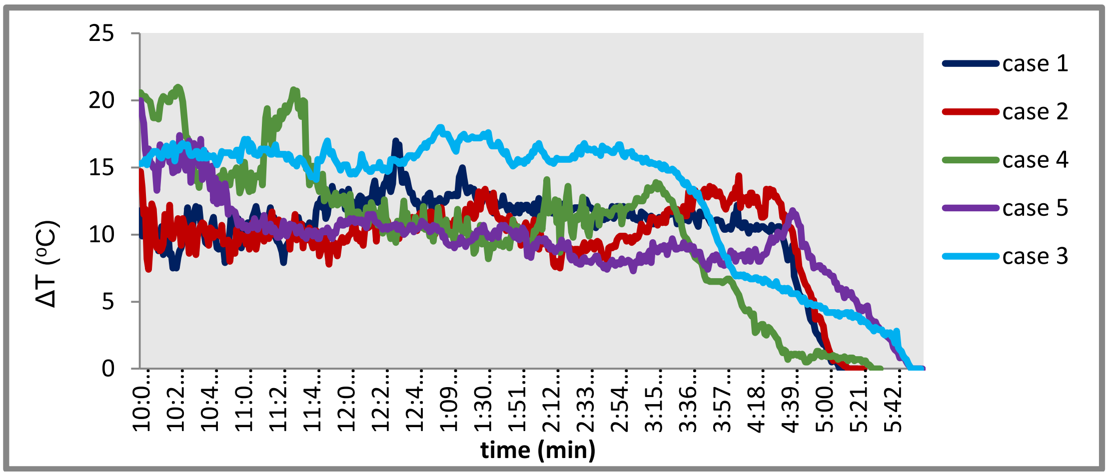


**Fig. 15.** Temperature difference vs. time for different cases

**Table 2**
Time storage energy

| Case | Type of material | Time storage energy |
|---|---|---|
| 1 | The air | 2 min |
| 2 | The water | 5 min |
| 3 | PVP 20 % +PEG 10 % | 44 min |
| 4 | PVP 15% + PEG 15% | 20 min |
| 5 | PVP 10% +PEG 20% | 14 min |

**Table 3**
The solar collector efficiency

| Case | Type of material | Specific | Efficiency |
|---|---|---|---|
| 1 | The air | 4 m/s | 55.8 % |
| 2 | The water | 1100 L | 57.1 % |
| 3 | Polyethylene glycol (peg 6000) | 10 g | 90.1 % |
| | Polyvinyl Pyrrolidone | 20 g | |
| 4 | Polyvinyl Pyrrolidone | 15 g | 64.9 % |
| | Polyethylene glycol (peg 6000) | 15 g | |
| 5 | Polyvinyl pyrrolidone | 10 g | 56.5 % |
| | Polyethylene glycol (peg 6000) | 20 g | |

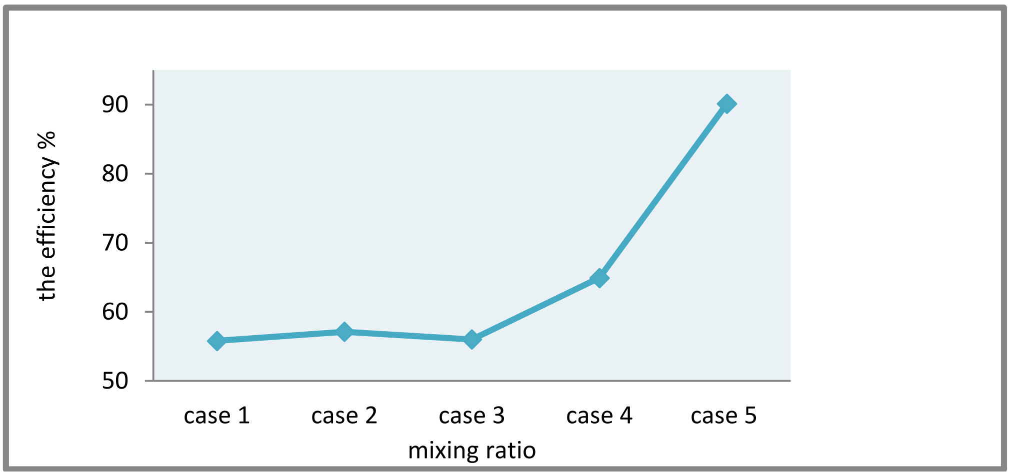


**Fig. 16.** Solar collector vs. mixing ratio

## 5. Conclusion

The thermal storage value can be improved using PCMs (PVP 20%, PEG 10%). The results show that the solubility decreases if the concentration of the volatile substance increases, so in need of a specific amount of solvent. After melting the substance, the viscosity of PVP is reduced due to high temperatures.

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