Enhancing a Trombe wall charging and discharging processes by adding nano-Al_2O_3 to phase change materials

Miqdam T Chaichan, Ali H. Al-Hamdani, Adeeb M Kasem

Abstract— In this study, two Trombe walls were designed and fabricated to evaluate the effect of enhancing the paraffin wax thermal conductivity on the charging and discharging period of the wall. The nano Al2O3 was added to the paraffin wax of one wall. The study results revealed a faster charging and discharging times due to the improvement in the thermal conductivity of the wall with wax mixed with nano-material. The wall, which uses wax with nano, had higher temperatures and faster charging period than the wall with wax only. The exit air of this wall is hotter that of the other case. Given high thermal conductivity of the wax with nano-material (case 2), the loss of storage energy was faster, depending on the entering outside air temperature and its mass flow rate. The Trombe wall with nano-materials and wax had overall higher temperatures up to 29.08% compared to wax alone. At discharge period, the paraffin wax with nano-material temperatures was higher than that for the wax alone case up to 42.68%. The exit air temperatures from a Trombe wall with the nano-wax compound was higher by about 43.24% compared to the air exited from the other wall with wax only.

Keywords- Trombe wall, thermal conductivity, charging period, discharging time, nano-Al_2O_3.

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1 INTRODUCTION

The greenhouse gas emission levels are increasing continuously, and the fuel prices are jumping highly; these are the two most significant dilemmas which serve as the catalyst behind the efforts to expand the use of effective alternative energies from various renewable energy sources [1]. Direct solar radiation is considered one of the most important future sources of renewable energy, in many parts of the world [2]. The development of energy storage devices is just as important as the development of new energy sources [3]. The suitable energy storage is that system which makes the energy restored and converted properly to the desired form of energy. This system is the best way to expand the use of renewable energies such as solar power [4].

The use of storage system depends on using the latent heat storage material (PCMs) is an efficient way to store thermal energy storage with high energy density [5]. The stored energy potential concept is from the best thermal energy storage technologies, with an energy storage density as high as possible. This type of storage is characteristic by its ability to store heat at constant temperature (which represents the temperature of the phase change either at fusion or freezing) [6].

The employments of phase change materials (PCMs) for thermal storage purpose are widely used in the heat pumps systems, solar energy engineering, and spacecraft technologies [7]. The PCMS uses for heating and cooling buildings have been investigated in many articles. Phase-changing material is a collection of large numbers of materials organic and inorganic. The degrees of melting and freezing for these materials is spreading over a wide range of temperatures, making the possibility of using it in various applications in diverse storage temperature degrees very attractive [8].

Tromp wall provides when used PCMs, better performance than if it used sensible heat storing materials like concrete. The amount of latent heat stored during the stage of transition or the phase change is colossal compared to sensible heat storing materials [9]. So, the choice of PCM material for a particular application must be taught accurately to specify the temperature change of the PCM material which is suitable for the application degree heat, whether it is for heating or cooling application [10]. The substance must be selected to give the highest latent heat possible by volume, to reduce the physical size of the treasurer of the heat storage. Also, high thermal conductivity of the material PCM facilitates and speeds up the processes of charging and discharging the thermal energy stored [11].

Many researchers studied the use Trombe wall in Iraq, and everyone praised the results with confirming on some of the restrictions due to the low thermal conductivity of the used PCMs [12]. The thermal conductivity means the possibility of charging and discharging the thermal reservoir (here PCM) quickly commensurate with the exposed load to give temperatures appropriate to the comfort conditions. Enhancing the thermal conductivity of the PCM is, in fact, the way to improve the effectiveness of thermal energy storage (TES) depends fundamentally on the PCM systems [13].

Several methods have been examined to improve the thermal conductivity of PCM such as adding metal fins of high thermal conductivity material inside the PCM store [14], or using fibers made in various forms to act like flippers [15]. Also, adding honey, wool, and brush was used to enhance the thermal conductivity of PCM [16]. Research results show that these methods cause an increase in the weight and the costs of

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storage systems. The rapid advances in the technology of the Nanomaterials (has usually nominal diameter limits of 10-50 nm) gave clear impetus; especially these materials have become commercially available from various metals and metal oxides. Nanomaterials have been used to develop the heat transfer in fluids to take advantage of the significant increase in thermal conductivity of the resulted fluid [17]. The process of adding nano-materials to PCM has become well contribute to improving the properties of thermal conductivity, latent heat, viscosity, and the PCM super cooling.

The aim of the recent study is to design, fabricate and evaluate the performance of Trombe wall using PCM as a storage medium. The effect of adding nano-materials to PCM of this wall and its influence on the charging-discharging process was investigated, also. In continuous of the previous studies [18]-[33] in the Energy and Renewable Energy Technology Center, we are focusing on the greater use of solar energy as it is a renewable energy in various applications suitable for Iraq climates.

2 Experimental Setup

In the recent study, two simple Trombe walls using Iraqi paraffin wax as a storage media was design and fabricated. The first novel Trombe wall consists of the followings:

1. Wooden Box

The wooden box of 1 m2 was built in a carpentry workshop in the UOT. This box covers the Trombe wall and isolates its central parts from the surroundings. Wood was used as it is a good insulator that prevents the stored energy from outflow.

2. Copper Tubes

Copper is characterized by its high thermal conductivity which helps in transferring heat to the PCM inside it. The copper pipes were located in the eight columns, with 12.5 cm between every tube. The tubes were filled with paraffin wax as a phase change material (PCM). The tubes were closed from both sides by a wooden cover to prevent melting wax from escaping out of the pipes. The tubes were welded to a copper plate (3mm thickness). The tubes and the plate were colored with a nonselective black color to increase the absorbency of the collector

3. The Paraffin Wax

In this study, paraffin wax was used as PCM due to its efficient latent energy storage. Paraffin wax is a thermoplastic material that can be reformed by heat. Paraffin wax is a hydrocarbon substance and one of the components of the oil extracted through the refining process. This hydrocarbon consists of chains consisting of (26-30) carbon atoms each. Paraffin wax thermal melting points range from 25 to 68° C. Its viscosity at 98.9°C is 4.3 -7.2. Table 1 illustrates the used paraffin wax specifications

4. The glass layer

A glass cover was used to allow solar radiation to fall on the PCM pipes in the system. Also, glass layer supplies a greenhouse effect to the system which increases the heating process.

5. The fan

A small fan (8.25 cm radius) was used to withdraw the heated air from the system and sent to the room.

The second Trombe wall was fabricated as the first one, except for adding Al2O3 nano-material to the wax to increase its thermal conductivity. This material was selected depending on Ref. [13] results, as well as, for its availability and cost in the local markets. Table 2 represents the used Al2O3 nano-material specifications.

Table 1
Thermophysical properties of the tested paraffin wax

Material properties	Range
Fusion temperature(°C)	44
Latent heat of fusion (kJ/kg)	190
Solid state density (kg/m3)	930
Liquid state density (kg/m3)	830
Thermal conductivity (W/m °C)	0.21
Solid state specific heat (kJ/kg °C)	2.1
Liquid state specific heat (kJ/kg °C)	2.1

Table 2
The used nano-fillers specifications

Item	Al2O3 specifications
Manufacturer	Yurui (Shanghai) Chemical Co., Ltd
Appearance	White powder
Assay	99.99%
PH value	7.5
Crystal and Type	a
Grain size nm	30-60nm
Bulk density %	0.43
Lose on drying %≤	0.21
Sulfated assay %≤	0.42
Fe ≤ ppm	≤0.005%
Si ≤ ppm	≤0.003%
Mg ≤ ppm	≤0.001%

The nanoparticles were used as received from the manufacturer without any additional purification. The mixing process of wax with this substance conducted by the following steps:

1. The wax was melted individually at a temperature about 60°C and mixed to get rid of any amount of soluble water or air and to confirm its homogeneity. After completion of this process, the molten wax was poured in contains to facilitate handling it in the following steps, and it was left to cool to room temperature
2. The nanomaterial was weighted using a sensitive balance to ensure correct mixing ratio. In this study, we used a ratio of 1 weight% of the nano-material to reduce costs of the Trombe wall, which increases the possibility of accepting it as the product.

3. The paraffin wax was heated to a temperature higher than its melting temperature, and then the measured quantity of the nano-material was added to it. The two substances were mixed using an ultrasonic shaker for about 45 minutes while maintaining the sample temperature above the melting point

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of paraffin wax at 60°C.

4. After ensuring the complete mixing process that clearly appeared when the color of the paraffin wax was changed from its original color into nailed white color. The photographs present in fig. 1 (a & b) show the wax sample before and after it was mixed with nano Al2O3. The mixing process was stopped, and the mixture was poured into a clean pot and was left again to solidify at the room temperature (25oC).

5. After the homogeneity of the mixture and its intransigence, it was heated again to the fusion temperature, and then pouring fixed weights in the copper pipes. The weight of the mixture used in each tube was equal to 15.166 kg.

Fig. 1. (A), A shot for paraffin wax sample

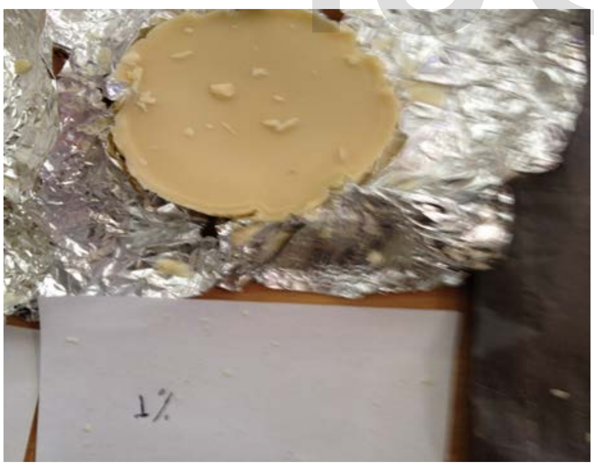

Fig. 1. (B), A shot for paraffin wax with nano-Al_2O_3 sample

2.1. Instruments

In this study we used many devices, as follows:

1. The mold: used to form the required samples needed to measure the thermal conductivity. It was manufactured from copper flakes to enhance heat dissipation to the air after pouring the liquid wax into it.
2. Ultrasonic mixer: an ultrasonic mixer type (EXXX_1000) used to mix the nano-fillers with wax smoothly.
3. Hot Disk Thermal Constants Analyzer was used to measure the thermal conductivity of samples.
4. Several thermocouples type K were used to measure different temperatures. They were distributed various parts of the system.
5. Digital thermometer, used to measure temperatures. It was calibrated in the lab.
6. Selector switch: a selector switch was used to choose the required thermocouple to measure its temperature.

All the data in this study was repeated three times and the average was taken as the reading. It has been found that the uncertainty was less than 2% for the repeated measurements, which means that the readings are within the engineering accepted range (less than 5%).

2.2. Tests procedure

After completing the pipes filling, it was heated to examine whether there is a leak from the closed areas. After this process was completed, the tubes were welded on the copper board, and the collection was painted with a nonselective black paint, and then installed on the wall. A transparent lid (glass sheet) was used to cover the wall. The two walls, then, was installed vertically and facing south. The reading process was conducted at the beginning of each hour, starting from 8:00 pm each day of the test process. At sunset, the glass face of the wall was covered by a wooden gate to prevent leakage of stored heat to the surroundings. The fan was operated, and the exit air temperature was measured every one hour. Two clear days every week were selected throughout the test period, which lasted from 15 Dec. 2015 till 15 Jan. 2016 (this period represents the coldest winter days in the tested area) in the city of Baghdad / Iraq. The average recorded readings were used in the accounts. The first wall with only paraffin wax will be called Case 1 to facilitate the delivery of results, and the second Trombe wall with nano-wax will be called Case 2. The following equations were used in calculations:

The energy stored in the tubes during the tests period (for every one hour) calculated by:

$$Qs = mw\ Cw\ (T_{t+1} - T_t) \quad \text{………. (1)}$$

The total stored energy per day calculated by the equation:

$$QS.\ Total = Q7\text{-}8 + Q8\text{-}9 + \ldots + Q3\text{-}4 \quad \text{…… (2)}$$

For the withdrawn energy by the fan during its operation time calculated by the equation:

$$Qu = ma\ cp\ (Tair_{out} - Tair_{in}) \quad \text{……. (3)}$$

The total drawn energy for one day was calculated by:

$$Qu\ total = Qu\ 4.5\text{-}5.5 + Qu\ 5.5\text{-}6.5 + \ldots \quad \text{…….(4)}$$

The delivered air can be calculated depending on fan diameter

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and air velocity and air density, as follow:

$m_a = A\ Va\ \rho a$ …….. (5)

3 Results and Discussions

Tromp wall stores the heat absorbed from solar radiation, which is represented by the increase in the wall temperature. Fig. 2 shows the temperature distribution of the outside air temperature, paraffin wax, and paraffin wax with nano-materials. The degree of the outside air temperature is low in the winter and be the maximum temperature between 12 AM and 1 PM while the paraffin was temperatures for the two cases were much higher. The wax stores heat and its temperature rose to reach its highest values at 2 PM. The maximum temperatures in Case 2 were significantly higher than the wax only case, and the peak was at 12 AM. The wall copper tubes are gaining heat and transmitted it quickly to the wax. Heat is distributed too quickly due to high thermal conductivity resulted from the addition of nano-materials. The heat distribution in the paraffin wax alone is low due to low thermal conductivity. The addition of nano-materials to wax have caused overall higher temperatures up to 29.08% compared with wax alone. Note that the wax temperature was higher than that for air temperature with about 51.6% for the entire examination period

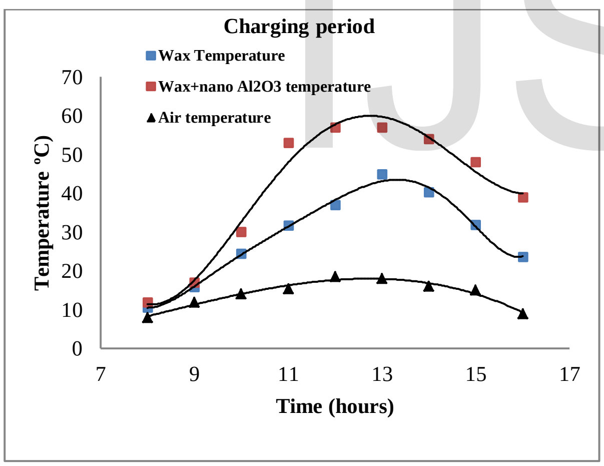

Fig. 2. Temperature variation with daytime through the charging period for the tested cases and outdoor air

Discharge process depends on two important factors thermal inventories in the wall, which is represented by the temperature of the internal wall components, which is here the temperature of the copper pipes and the copper plate. The second factor is the outdoor air temperature as the less this temperature the emptied charged heat of the wall lessons rapidly. To elongate the discharge periods it needs to increase the Trombe wall area, and directed it toward the sun to collect the direct solar radiation. This issue did not materialize here because the fence was fixed perpendicular to the ground surface. Fig. 3 reveals the temperature distribution during the discharge period, which begins at 5 PM and continues until 10 PM, in this study. After sunset, the air temperatures reduced similar to the wax of the two cases, with and without nano-material. The figure declares that because of the highest thermal storage in the Trombe wall that used nano-materials; it has warmer temperatures, as well as, the air flowing out of it at evening, which was too high compared to the other wall. For the wall, which used only wax, the out air temperature went down rapidly to become equal to the degree of external air temperature inside of the wall. For comparison, the temperatures of the paraffin wax with nano-material were higher than the wax alone case for the discharge period up to 42.68%. The difference between the out air from a Trombe wall with the nano-wax compound was higher by about 43.24% compared to the air outside of the Case 1 wall.

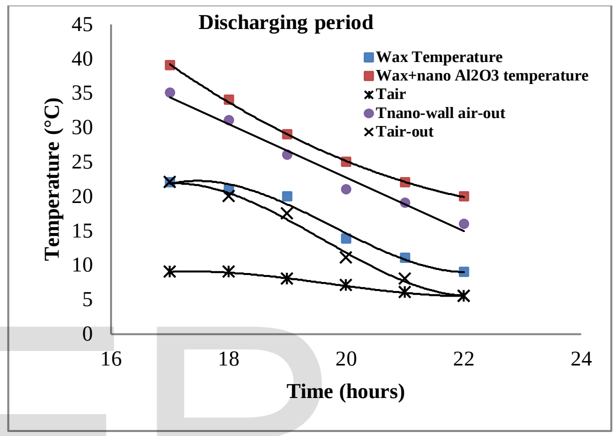

Fig. 3. Temperature variation with daytime through the discharging period for the tested cases, the outdoor air, and the air out from the wall

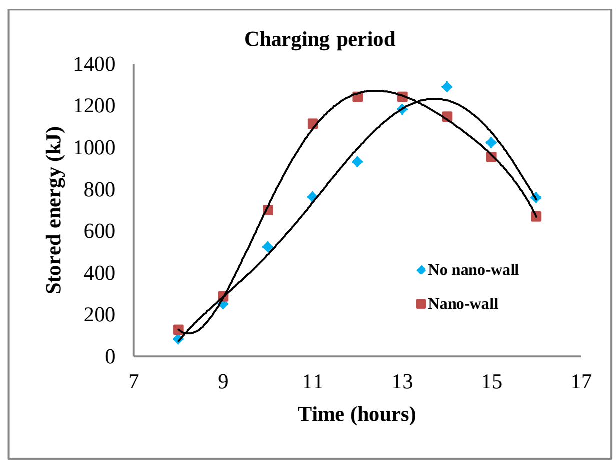

Fig. 4. Stored energy variation with daytime through the charging period for the tested cases

Fig. 4 shows the relationship between the stored energy with the time for the two studied systems. Tromp wall stores heat faster, with the existence of nano-material, and achieved the maximum peak value at 12 AM. Case 1 Trombe wall stored heat slower and delayed its arrival at its peak value until 2 PM. The cause of this variation is the thermal conductivity which is better in the Case 2. The increase in thermal storage

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in Case 2 at 1 PM was about 20.85% compared to the status of the Case 1. As for the period from 1 PM to 4 PM, the thermal storage in the Case 1 wall preceded the energy storage of the Case 2 wall with 9.7%, because Case 2 wall loses heat at the same speed it gains it, because of the superiority acquired by thermal conductivity compared to the other system.

Fig. 5 manifests that the energy stored in Case 1 in discharge period was higher than that in the Case 2 because Case 2 lost thermal energy quickly due to its higher thermal conductivity. The stored energy in Case 1 was greater than that for Case 2 by about 20.6 %.

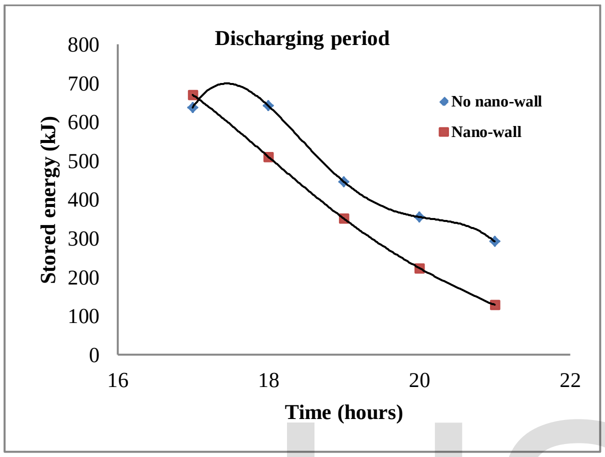

Fig. 5. Stored energy variation with time through the discharging period for the tested cases

4 Conclusions

Trombe wall is one the solar-powered apparatuses used to store thermal energy by absorbing the solar radiation. This stored energy will be used to heat the after sunset. Since Iraq has relatively high solar radiation intensity in the wintertime, so Trombe wall can be considered very appropriate. In this study, the performance of a Trombe wall contains a paraffin wax as a phase change material with the addition of nano-material Al2O3 to improve the thermal conductivity of the wax. The study results showed that the wall, which uses wax with nano had higher temperatures and faster than the wall with wax only. The exit air of this wall is hotter that of the other case. Given high thermal conductivity of the wax with nano-material (case 2), the loss of storage energy was faster, depending on the entering outside air temperature and its mass flow rate.

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NOTATIONS

Qs	the storage energy inside wall pipes (kJ)
m_w	Wax mass in wall pipes (kg)
C_w	Wax specific heat (kJ/ kg. K)
$(T_{t+1} - T_t)$	The increase in wax temperature for each hour of daylight (K).
Q_u	The drawn energy from wax pipes in the wall (kW).
m_a	Drawn air quantity (kg/s).
cp	Air specific heat (kJ/kg.K).
$Tair_{out}$	The fan delivered outer air temperature (K).
$Tair_{in}$	The temperature of the air entering the wall (K).
A	The fan area (7 cm dia.) (m2).
V_a	Outlet air velocity (m/s).
ρ_a	Air density (kg/ m3).