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AL-FURAT AL-AWSAT TECHNICAL UNIVERSITY ENGINEERING TECHNICAL COLLEGE NAJAF

Controlled Vibration System to Enhance the Performance of Heat pipe Evacuated Tube solar collector with and without PCM: Experimental Study

A Thesis
Submitted to the Engineering Technical College of Najaf/ AL-Furat AL-Awsat Technical University in Partial Fulfillment of the Requirements for the Degree of Master of Technical in Mechanical Engineering

By
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(B.Tch. in Automobile Eng.)

2020

بسم الله الرحمن الرحيم

إلا أَ ن يَشَاء اللَّه نَرفع دَرَجَا ت مَن نَشَاء وَفَوقَ كُل ذِي عِلم عَلِيم

يوسف﴿ 76﴾

DEDICATION

To… My Beloved Parents, My Sisters and My Brothers

DISCLAIMER

I confirm that the work submitted in this thesis is my own work and has not been submitted to other organization or for any other degree

Dr. Adel A. Eidan	**Dr. Assaad Al Sahlani**
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ACKNOWLEDGEMENT

All Praise to ALLAH for his uncountable blessings, assistance during the preparation of this work. I would like to submit my deep respects and sincere gratitude to my supervisors; Asst. Prof. Dr. Adel A. Eidan and Asst. Prof. Dr. Assaad Al Sahlani for their support during the research period and guidance to accomplish this work. Special thanks to the head and members of the Mechanical Power Techniques Engineering department for their assistance to me. Sincere and deep appreciation goes to the office of dean of the Engineering Technical College- Najaf for the continuous support. I would like to thank all lovely, helpful people who support me directly and indirectly to conduct this work. Special thanks to my colleagues for their great assistant and great encouragement. My deepest thanks and gratitude are due to each member of my family, especially my dearest parents, brothers and sisters for their patience, support and encouragement throughout my life.

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SUPERVISION CERTIFICATE

We certify that thesis entitled "**Controlled Vibration System to Enhance the Performance of Heat pipe Evacuated Tube solar collector with and without PCM: Experimental Study** "Submitted by **Sarah Hassan Ali** has been prepared under our supervision at Department of Mechanical Engineering Technical of power, College of Technical Engineering - Najaf, Al-Furat Al-Awsat Technical University, as a partial fulfillment of the requirements for master of thermal technologies degree.

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Nomenclature

HPET-SC	heat pipe evacuated tube Solar collector
PCM	Phase change material
ET	Evacuate tube
ETSC	Evacuated tube solar collector
FR	Filling ratio (%)
R_{exp}	Thermal resistance
$\overline{T_C}$	Condenser average wall temperatures °C
$\overline{T_E}$	Evaporator average wall temperatures, °C
SDHW	Solar Domestic hot water
HDPE	Polyethylene
Al	Aluminum
MS	Mild steel
GI	Galvanized iron
DSC	Differential Scanning Calorimeter
OHP	Oscillatory heat pipe
LHP	Looping heat pipe
LHTES	Latent heat thermal energy storage

Committee Report

We certify that we have read this thesis titled"**Controlled Vibration System to Enhance the Performance of Heat pipe Evacuated Tube solar collector with and without PCM : Experimental Study** "which is being submitted by **Sarah Hassan Ali** and as Examining Committee, examined the student in it is contents. In our opinion, the thesis is adequate for an award of degree of Master of Technical in Thermal Engineering.

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Abstract

An experimental work for a solar collector with paraffin wax as phase change material (PCM). The use of a thermosyphon was studied with solar collector type evacuated glass tube, with a tank for storing water, and containers of paraffin wax which represent the internal surface of the tank as water is in contact with the surface of the containers. The PCM can be benefitted for heat storage and using this heat to obtain water with moderate temperatures even during the absence of the heat source or during the night.

The experimental categories can be classified into three main parts. The first one is studying the effect of the phase change material on the performance of the Evacuated Tube Heat Pipe Solar Collector. The second part are investigated the effect of vibration on thermal performance and efficiency of the Evacuated Tube Heat Pipe Solar Collector. While, the third part is studying the effect of the radius of mass that fixed on the disc which connected with motor to generate the vibration in the Thermosyphon Evacuated Tube Solar Collector. five different vibration frequencies، (21.1, 28.33, 35.55, 42.77, and 50)Hz were applied. The experiments were carried at outdoor conditions (actual solar radiation), tilted angle 45°, filling ratio FR=70%, with paraffin wax mass of 7.2 kg. The work continued from September 2019 to April 2020. In order to achieve the experimental work, four identical rigs have been constructed (with and without PCM and vibration). The rig consists of the first part which is an evacuated glass tube as a solar collector with external diameter 50 mm and internal diameter 45 mm, the second part is a thermosyphon which is used to transfer the heat, it is a copper tube with a diameter of 16 mm consisting of two sections: the evaporator, which is inserted into the evacuated glass tube and the condenser which is inserted into the water tank which is the third part.

Variable solar radiation flux was used based on the available solar radiation in Iraq within the period January to April . The heat flux incident on the evacuated tube is collected and transferred to the thermosyphon and then the heat is transferred to the water in the tank. Finally, the heat is given to the paraffin wax in the containers by using acetone as working fluid. Due to heat applied the paraffin wax changes from the solid phase to the liquid phase. The melting temperature of the paraffin wax is 38-43 °C. The period of falling heat lasts for 9 hours and is called the charge period. this period is called the discharge period during which the stored heat in the PCM transfers into the water. Therefore, water with high temperatures can be obtained overnight.

Generally, the efficiency increased when using the PCM, but the difference between the two cases (with and without PCM) is not exceeded 5 %. The values of the efficiency increased when the vibration frequency increased as well. Where, the maximum values of the efficiency occurred at time 13:00 (1 pm). The efficiency of the system when using PCM increased from 60% to 78% at 1 pm when the influence of vibration frequency changed from (0V to 14 V). While the efficiency of the system without PCM increased from 57% to 76% at 1 pm when the influence of vibration frequency changed from (0V to 14 V).

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CHAPTER ONE
INTRODUCTION

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Introduction

1.1 Introduction

Many common uses in the world certainly needs energy as a basic component. Consequently, energy will be utilized in different applications (like electric power production, manufacturing, transportation, and so forth…). Fossil fuels have helped to cater for all different human needs of energy. This huge utilization of fossil fuels in energy production results in a lot of damage in the atmosphere and the occurring of danger due to the melting of snow in the Northern and Southern Poles of the earth. Therefore, new sources to produce energy should be looked for.

Renewable energy is needed a complementary or alternative element of energy supply sooner or later.

Clean environment needs clean energy production, so we do not effect on human. Renewable energy may be of different kinds: solar energy, wind energy, geothermal energy, biomass energy and hydropower energy (see Figure 1.1). solar energy is considering the backbone for all other kinds of renewable energy. The solar energy is available all around the year but it is not continuous. Because of this limitation, researches are required to solve this problem.

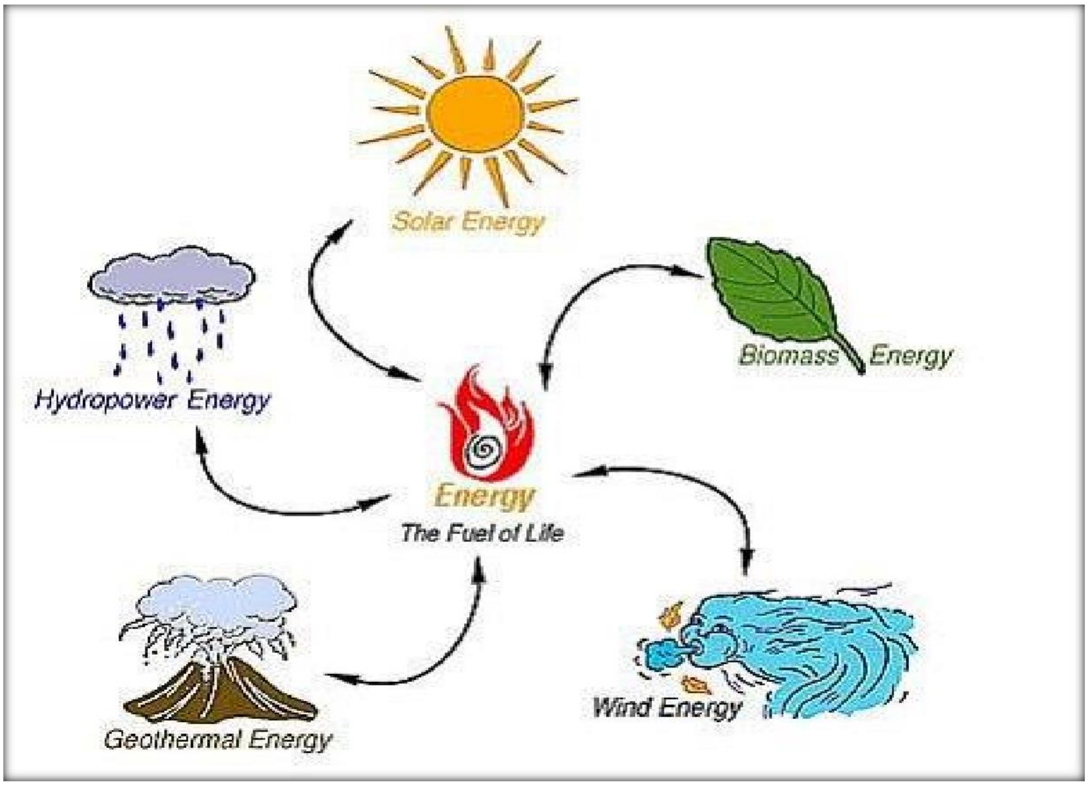


Figure 1. 1 Different kinds of renewable energy[1].

1.2 Solar Energy

Solar energy is a dominant source of renewable energy sources. The sun emits heat energy to the earth, which forms 60% of its whole energy and the rest of this energy is reflected and absorbed by the atmosphere. solar energy is considered the basis of all known energy sources like, wind energy, fossil fuels, and others. The solar energy can be transformed into: electric energy and thermal energy, the electric energy by photovoltaic and thermal energy by solar collector. In the use of renewable energy there are two problems: first the high initial cost of production, secondly low efficiency[1]. The first problem can be solved through an increase of the instruments which produce this energy. The second problem can be solved by using a large amount of the solar energy as its available and free. The major problem of solar energy is that it’s not always continuous, and this particular problem can be solved by using thermal storage. This energy can be stored during sunshine, and used during sunset or during its obliteration (eclipse). Thus, the energy can be available at any time all along the year so that this energy will be in accordance with engineering and trade designs.

1.3 Energy Storage for Solar Energy

Management of energy has been a crucial issue that needs to be addressed thoroughly via alternative sources. many researchers concerned with it, besides humans use different types of energy. This process (management) categorized in different ways; production energy, efficient energy production, storage for future use. The more efficient energy use incorporating by the corresponding efficient energy storage. The proper energy storage utilization is very important, Renewable energy as an alternative energy source plays as an important solution, achieved by many researchers for pollution of environment and prices change and shortage of continuity. Solar energy, wind energy, hydrogen technology are the most common used energy sources. Renewable energy like traditional energy source also has some disadvantage as they are not continuous energy source. This matter can be solved by using a suitable energy system. Energy storage aims at saving energy during its availability and using surplus for storage. The stored energy can be used during its absence later on. At the end of the day, the stored energy is used to balance consume energy and the supply energy. The stored energy can be in variant forms like storage electric energy, storage mechanical energy, and storage thermal energy. Thermal energy may be put in different kinds: sensible heat, latent heat, or both sensible and latent heat.

Many of researches work on efficient energy storage system using phase change material, supported by optimal design, analysis and theory work have been done thoroughly in the literature [2–11]. The phase change criteria will be classified phase change material in four kinds: solid-solid (Solid-solid phase change materials (SS- PCMs) absorbs and releases heat by reversible phase transitions between a (solid) crystalline or semi-crystalline phase, and another (solid) amorphous, semi- crystalline, or crystalline phase) , solid-liquid, solid-gas and liquid-gas [12]. Solid phase to liquid phase, phase change material are the most suitable types of thermal energy storage of these available for kinds, and they can be found as organic PCMs, inorganic PCMs and eutectics, as seen in Figure 1.2 [13].

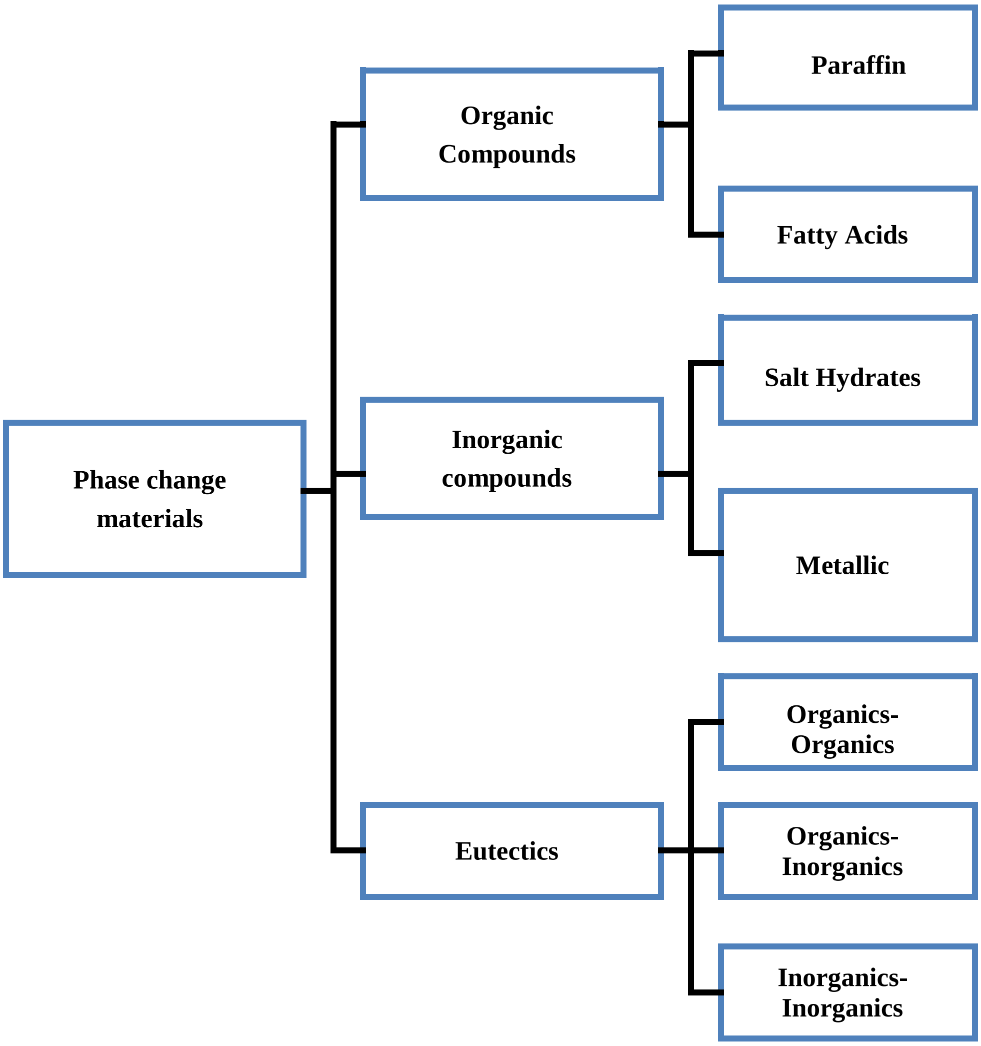


Figure 1. 2 Phase change materials (PCMs) classification [13].

Due to its large heat of fusion and phase change temperature range, paraffin wax is considered as one of the optimal phase change storage material. Paraffin wax is more cost effective, availibity, and widely used because undergoing freezing point without passing supercooling regime. Many active works were done on these topics by the authors [14-17]. The molecular structure of the organic fatty acids is $CH_3(CH_2)_{2n}COOH$ with high value fusion heat as compared with paraffin wax and $CH_3(CH_2)_{2n}COOH$ can achieve melting and freezing point zone with little or without supercooling. One of the restricted points of application of $CH_3(CH_2)_{2n}COOH$ is the cost that is more than 2-2.5 time of paraffin wax [18,19]. phase change materials have some disadvantages like, long time for return cost investment [20]. If any reuse of these phase change material is needed, impossible to do that without system damage and also the phenomena of supercooling will be led to low efficiency process and energy recovery. When it has a good information data on thermal, physical properties, melting point, fusion heat, mass density, conductivity, stability with phase change, these data will be led to a good PCM selection for given application. Figure 1.3 demonstrates schematic representation of phase change materials depended on fusion point temperature and the corresponding melting point temperature.[21]. The figure shows the low melting materials; like paraffin wax, fatty acids, salt hydrates, and their eutectic mixture, beside the corresponding high melting point temperature. Application of these materials have a wide range of uses based on given parameters like fusion and melting temperature.

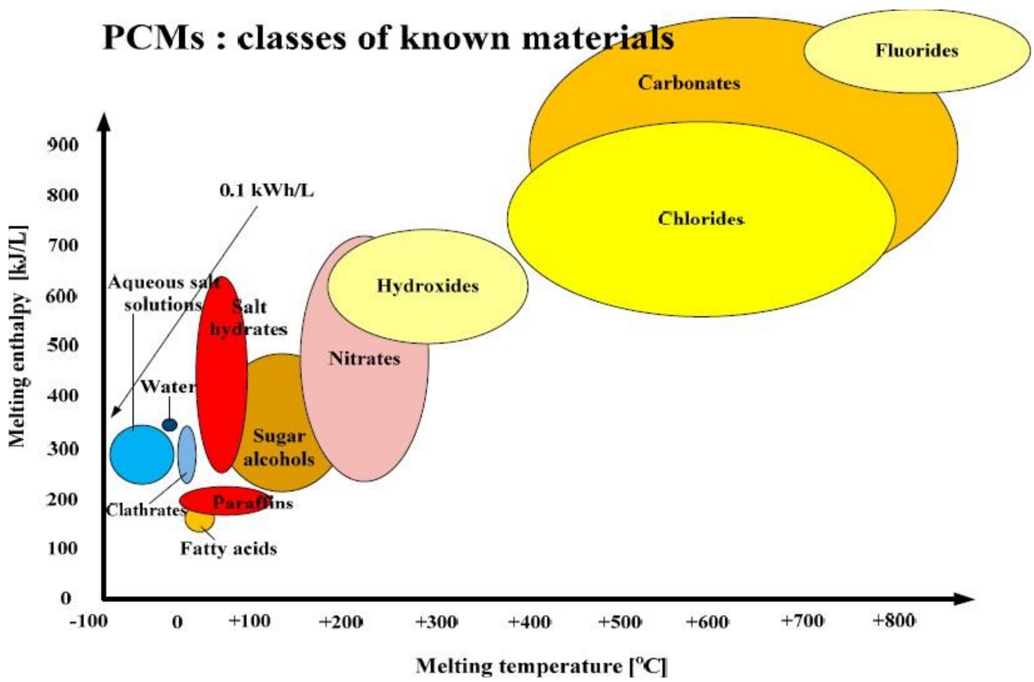


Figure 1. 3 Classes of existing PCMs [21].

For different ways for thermal heat storage systems, solid-liquid pcm, gives these maters important attention [22-27]. There is a large variety of these materials (e.g. water, salt hydrates, certain hydrocarbons, metal alloys, and paraffin) that phase change (melt and solidify) at a wide temperature ranges, giving them a good attention for use of energy conservation in a such applications.

1.4 Solar Collectors

A solar collector is a thermal device used to utilize solar energy via collecting and concentrating solar radiation. The collected solar thermal energy is transferred by a flowing fluid that can be used in various thermal applications such as water heating, building heating, and other industrial applications [28]. Solar collectors generally are classified into two main categories, namely, non-tracking and tracking solar collectors as shown in Figure 1.4. The non-tracking solar collectors are kept stationary at a prespecified orientation according to the location. The commonly used non-tracking solar collectors are flat plate, evacuated tube, and compound parabolic collectors. Here in, the commonly used solar collectors will be briefly discussed

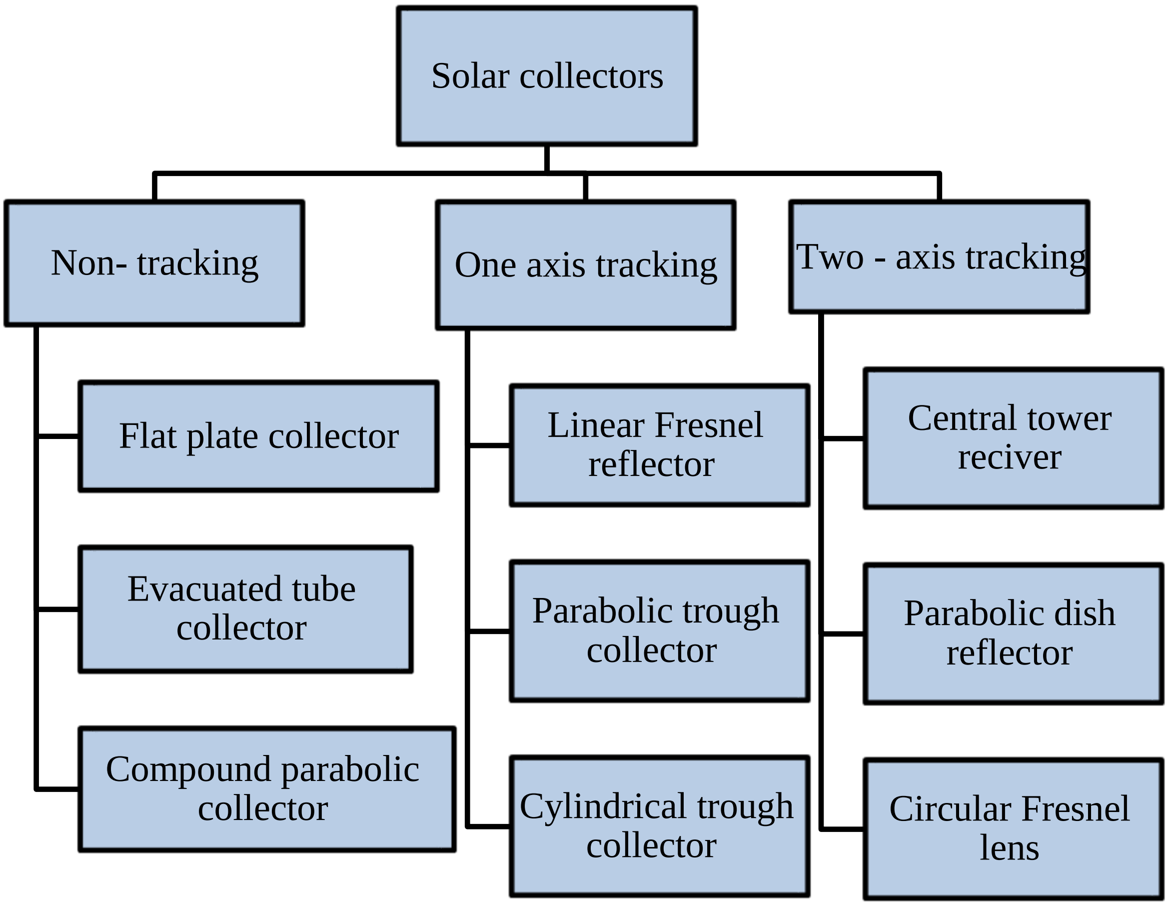


Figure 1. 4 Solar collectors' classifications [28]

1) The performance of a *flat-plate collector:* is not so complicated; it is just based on radiation passing a transparent layer and then set on an absorber layer that absorbs it as heat. As this collector is fixed in its position and don't track the sun it must be made to face south in the northern hemisphere and north in the southern. The best tilt angle of the collector depends on the latitude of the location with angle ranges of 45° [29] (see Figure 1.5a).
2) Evacuated tube solar collector: An evacuated tube collector is a thermal device used to absorb solar energy by capturing the solar insolation through a fluid such which flows inside a heat pipe

enclosed in a glass enclosure for minimizing the heat loss. This fluid absorbs solar radiation which heats it up and then it is undergo evaporation-condensation cycles. These cycles occur due to heating of the fluid by the solar insolation which results in phase change from liquid to vapour under vacuum pressure. The generated vapour rises in the upper direction under the effect of buoyancy force then the vapour reject heat to another working fluid using a heat exchanger, which results in change its phase from vapour to liquid and flows back to the bottom direction of heat pipe under the effect of gravity force. The evacuated tube solar collector may consist of single tube or multiple integrated tubes in Figure 1.5b.[29]

3) Compound parabolic collectors: are designed by Winston [30]. These kinds of collectors have the ability to absorb virtually all the light emitted to the mouth of them. These collectors are to accept a large part of diffuse radiation incident on their apertures and concentrate it without tracking the sun [31]. Schematic diagram of the collectors is illustrated in Figure 1.5c.
4) parabolic dish collector, consist of a parabolic dish coupled with two-axes tracking system. The sun rays are reflected and concentrated at the focus of the parabolic dish where the receiver is placed. A heat exchanger is putt in the acceptor to transfer the absorbed heat to working fluid. Throughout the day, the solar parabolic dish automatically follows the sun movements using tracking control system, as in Figure 1.5d[28].

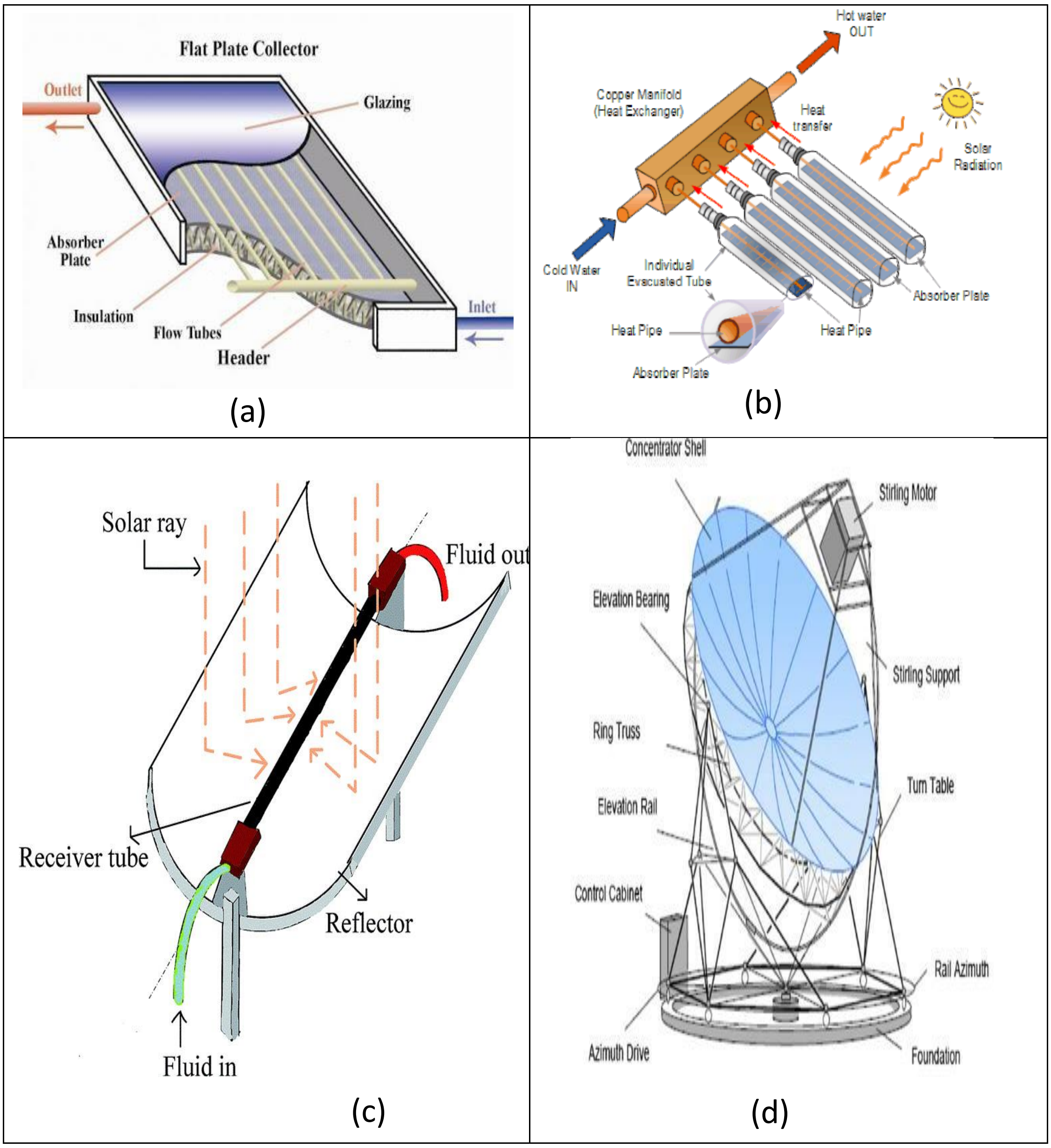


Figure 1. 5 Commonly used solar collector: (a) Flat plate, (b) evacuated tube (c) compound parabolic, (d) parabolic dish [28].

1.5 Enhancement with vibration heat transfer rate

In spite of that many works had been done on enrichment of heat transfer mechanism; it is important to have an idea about a new method of enhancement of heat transfer exchange rates [32]. Many active works carried out to increase values of heat transfer coefficients and mechanisms arranged using nano-fluid, geometry [33,34] of surface incorporated with vibrations, according to some previous work, vibration resulted an important output on exchange heat transfer rates. This fact was available in using a hot wire [35], and the actual geometries of heat exchangers were neglected. So, it is worth considering that one of the up normal geometries is tubular, and a basic orientation of the tubes is vertical [36]. The performances are important due to the role in actual situations, like as cooling devices in electronic items, air refrigeration, and fuel power plant [37]. For some applications are concerning in heat pipes [38], A very little works are available on thermosyphons phenomena and cooling devices. So it is important to make a complete analysis in real cases for heat transfer exchanges by design a system of vibrated cylindrical heat source. Vibration in low rates (10- 20 Hz) that can be available naturally (like in car motors or refrigerators). This study aims at finding a solution to substitute for this weakness, that’s by finding the suitable method for energy storage with time of solar energy availability, that is by employing phase change material for process of energy storage, i.e., during the day time and using this energy during the absence of solar energy.

1.6 Aims and Objectives

1.6.1 Aims

The study aims on improving the thermal solar energy conversion efficiency of heat pipe evacuated tube solar collector through experimental measurements, at outdoor conditions. Enhancement of the proposed system efficiency will be done through using different controllable vibration rates integrated paraffin wax as phase change material.

1.6.2 Objectives

The study objectives will be done by summarizing the following steps as follows:

1- Reviewing main challenges encountered heat pipe evacuated tube solar system and addressing the significance and the optimum conditions for the vibration rate and paraffin wax characteristics.

2- Manufacture four thermosyphon-evacuate tube solar collector systems at the optimal filling ratio and tilt angle according the previous experimental study at the same climatic conditions to study the effect of PCM on the thermal performance of thermosyphon as well as the solar collector.

3- Manufacture controlling vibration system to improve both two phase flow phenomena (boiling and condensation) and acceleration the melting-solidification processes for PCM.

CHAPTER TWO
LITERATURE REVIEW

Chapter Two

Literature review

2.1 Introduction

The continuous demand on the energy led to extensive research efforts to utilize the solar energy as an alternative source of energy. Many different researches have been conducted on the thermal applications relying on the solar energy. Solar water heating is the first and most common application of solar thermal systems [39]. Nonetheless, **Singh et al.** [40] explained such difficulties that related to some storages and the collections of the solar power pose specific limitations to its application as show fig 2.1. **Daghigh et al.** [41] shows that the most critical item of the all solar heated system are the solar collectors.

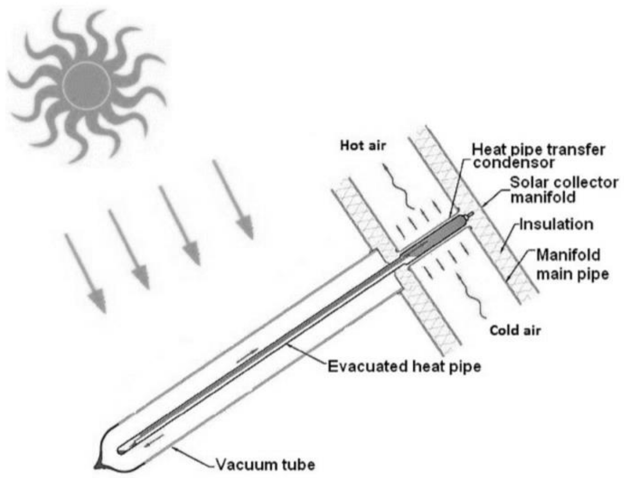


Figure 2. 1 Daghigh et al. experimental

Mazman et al., Malvi et al., and Saman et al. [42,43and 44] worked on some arrangements of the solar water heater systems incorporated with a phase change material. It was formed as energy storage (latent heat thermal), where they made a detail analyses of the theoretical part with the corresponding experimental ones in current years as show in fig 2.2.

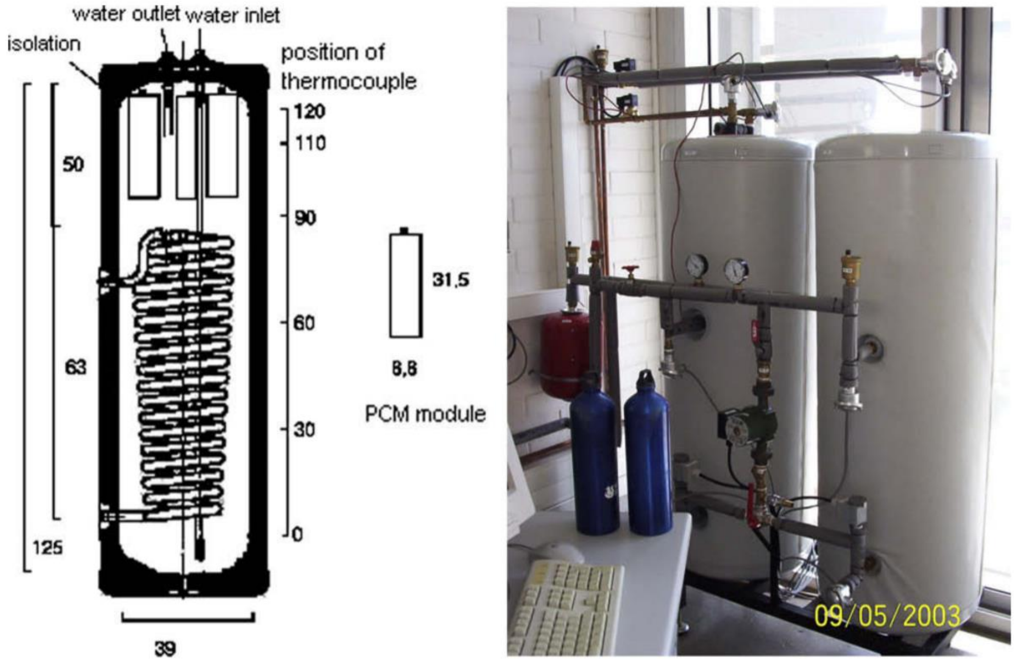


Figure 2. 2 Mazman experimental

Many designs such that presented by [45,46]. It was putted PCM in water storage tank (where the high temperature occurred) as a spherical or cylindrical shape. In most theoretical and experimental work with a given conditions, like system arrangements, PCM type, in and out water flow-rate, these conditions led to an efficiency improvement of SWH-PCM systems. Design of storage tank, outdoor temperature, type of collector were the most active parameters that used in studies. There are many researches proved that the thermal performance of flat plate collectors is lower than thermal performance of evacuated tube heat pipe solar collectors [47,48].

The phase change material suggested like paraffin's matters, acids like fatty and salt hydrates. Many types of PCMs and its properties were studied by **Canbazoglu et al. and Zalba et al**. [49,50]. They found that high LHTES density values of thermal energy storage made it suitable for efficient storage devices, in spite of weakness point of low thermal conductivity of PCMs that led to active effect on system efficiency. This point will be effect. in strong values of heat exchange processes during the storage of heat. It was found that the rate value for the phenomena of phase change is lower than the acceptable level. Consequently, the LHTES system stays in limited applications. So, it is important to discover a method to enhance the rate of charging and discharging operations that related with the PCM.

2.2 Studies about Thermosyphon and PCM

Li and Wang [51] made an experimental work on heat and temperature characteristic performance for two types of evacuated parabolic trough solar collectors with heating working fluids nitrogen and water. The measured data shows that both evacuated tubes gives acceptable heat transfer rate with water as heating fluid. Where the heating efficiency ranges from 70-80%, but the water fast boiling at a rate is lower than 0.0046 kg/s. Furthermore, 40% efficiency value of heating for nitrogen, that's achieved at gas temperature range 320-460ºC. More accurate results (with an accuracy of 5.2%) obtained by designing a model of solar trough evacuated tube.

Riffat et al. [52] performed an experimental study on cylindrical evacuated solar collector system, using water and paraffin wax in different percent's as PCM in order to know the thermal behavior in this system. It was found that water in a partial filling of 25.28% in the system gave a greater overall thermal efficiency compared with other cases: water with 100%, PCM with 22.43%, and PCM 56.7%. This is during the charging and discharging period when no energy input as shown in fig 2.4.

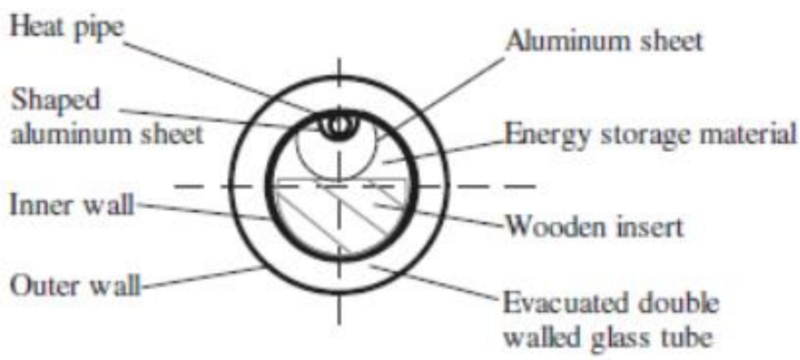


Figure 2. 3 Riffat et al. experimental

Shukla et al. [53], tested the activity of PCM heat storage incorporated with solar heater collector. They classified the proposed studies according to heat transfer mechanism (natural and latent heat storage) and collector type.

Experimental work was done by **Joudi et al. [54]** of heating water system. The evacuated tube with different heat pipes, many types of evaporator length, filling ratio, different flow-rate of water, many types of working fluid all of that work was done at solar irradiance 120-2000 W/m^2. The results proved that increasing evaporator length with the corresponding diameter led to increase surface temperature of the pipe, and consequently, in opposite behavior pipe surface temperature decreases with increased values of filling-ratio for the inclined angle 45^o and 50% charging ratio. Optimum efficiency and performance were achieved, with load values 14-55% as compared with other works.

Suman et al. and Mahbubul et al. [55,56] showed that low values of thermal performance of HPSC-based systems have a good uses and application of solar industry. So, **Tian et al. [57]** demonstrated more studies have been achieved in last decade to find a new mechanism to improve the performance of these systems.

Haillot D. et al. [58] followed new approach of improving thermal heat transfer of domestic hot water (SDHW) by using phase change material (PCM), which studied in different methods. These approaches go on different categories, one in place with storage material in tank, while other in solar thermal collector directly. These two methods gave excellent results. It adopted a new mechanism by setting PCM in the working fluid heat transfer of domestic hot water. This arrangement was studied at different environment conditions and system variables. These preceding results focused on the dramatic enhancement in thermal performance of the system when integrated PCM.

Fazilati, and Alemrajabi [59] studied experimentally the enhancement of performance in the solar water heater with integrated the phase change material. The system consists of a tank containing spherical capsules which are filled with paraffin wax. The intensity of solar radiation was investigated as well. The outlet-results showed that the amount of energy storage increased by 39%. It was enriched the exergy efficiency to approximately 16 % compared with system has not integrated with PCM. Moreover, it was found that the supply of hot water extended with approximately 25% when used PCM with system.

Reddy et al. [60] studied experimentally the effect of the capsule material which contains the PCM on the thermal energy storage. The PCM used was paraffin wax. PCM was used with flat plate solar collector. The water represents heat transfer fluid (HTF). The capsule had same diameter with three types of metals: high density polyethylene (HDPE), aluminum (Al), and mild steel (MS). The results presented that the processes of discharging and charging of the storage energy with fewer affect with change of the metals used. The rate of time improvement was 5%. Aluminum has only little effect in spite of its high thermal conductivity because the high thermal resistance of the spherical capsule containing

PCM.

Razali et al. [61] made an experimental work on thermosyphon solar collector enhanced with PCM (paraffin wax) in storage unit. This unit provide rural areas with hotted water along the day. The output explained that hot water would be available during the day till to 8:00 pm with set temperature range 40-50^{o}C, with performance efficiency 36.6% without PCM, consequently higher efficiency values by adding PCM.

Kavitha, and Arumugam [62] carried out an experimental study of paraffin wax put in galvanized iron (GI) and arrange in criss cross foam in solar collector. The tubes were put in the solar collector water tank. The thermo-physical properties of the paraffin wax were obtained from the analysis of Differential Scanning Calorimeter DSC. Non dimensional numbers Rayleigh and Nusselt were computed. It was found that natural convection between the melted PCM and solid PCM improve the process of melting. The overall efficiency was 43%.

Eidan et al. [63] made an investigation based on the measured data to evaluate the efficiency for the evacuated tube solar collector (ETSC) with wickless heat pipe under environment conditions of Iraq. The results show optimal filling ratio and inclination angles are 70% and 45^{o}, it is recommended to implement, respectively when compared with other values during. At these conditions, the optimal thermal performance was achieved in Najaf city.

Shafieian et al. **[64]** reported the earlier studies on many domestic and industrial uses of HPSC, and also summarized the expected future works in this field.

AL-Haris [65] made an experimental work for a solar collector with wax as phase change material (PCM). The use of the thermosyphon was studied with a solar collector type evacuated glass tube, with a tank for storing water, and containers of paraffin wax which represent the internal surface of the tank as water is in contact with the surface of the containers. The PCM can be benefitted for heat storage and using this heat to obtain water with high temperatures even during the absence of the heat source or during the night.

Shafieian et al. **[66]** made a detail study on real hot-water consumption in cold day (up normal climatic condition) of Perth, Western Australia, that’s done through efficiency characteristic of solar heating system of water heat pipe. The best number of glass tube of solar collector is achieved by developed mathematical model. It was built a test rig that contained 25 tubes, and test with a range of various temperature. The output result summarized a good efficiency performance of the system with increasing rate of the adsorbed radiated solar energy. the good pattern analysis and design of this system is hot water consumption. The parts of the operation time of 19 min e system play an active role during the operation period in the early morning was 19 minutes, and also during other circumstances such as cloudy or overcast, where the operation time is 8 minutes. **Shuang et al. [67]** made an experimental basic structure supported by natural circulation to improve heat transfer in heat of evaporation (latent heat) storage devices for thermosyphon two phase closed loop. The measured data and theoretical work were incorporated to estimate characteristic efficiency performance of heat transfer. Effect of several effective parameters such as height difference, filling ratio, temperature of condenser was studied with corresponding changes in pressure and evaporation temperature variation values. Lower condenser temperature and higher height difference supported performance of heat transfer. Consequently, 44.5% and 49.9% give a best result for performance of heat transfer as show in fig 2.4.

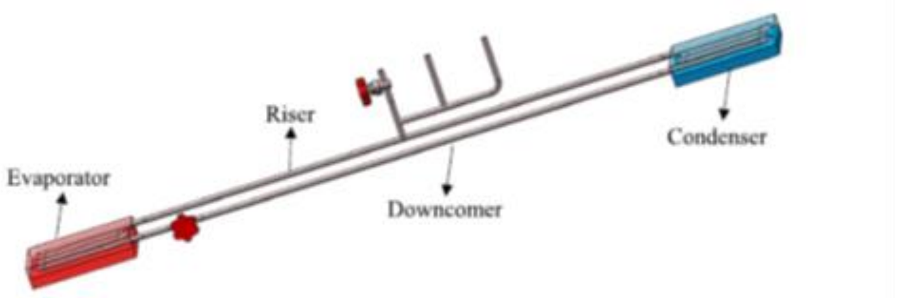


Figure 2. 4 Shuang et al experimental

2.3 Studies about Vibration Works

A very limited work had been done on vibration effect on the process of transfer of heat. Within low frequency values of 10,30, and 50Hz used.

Wong and Chon [68] presented the experiment approach to explain the influence of the ultrasonic vibrations on the rate if heat transfer using electric heated wires. It was noticed the enhancement in the heat transfer coefficients (natural convection).

Chou et al. [69] searched the influence of applying vibration on heat transfer in a cylindrical container. The results showed that the rate heat transfer raised with 65% when applied the vibration compared with static case.

Hsu et al. **[70]** investigated experimentally the effect of the vibration and shock on the overall thermal efficiency of the heat pipes that made from sintered copper (L=0.15m). The applications of such kind of pipes are in the cooling units of the computers and notebooks. The measured value of shock was 40g through 2.5 ms (1^{st} half of the sine wave function) where the range of the frequency was between 5 and 100 Hz with acceleration that equal to 1 to 1.5g. It was vibrated all entire length of the heat pipe in order to obtain the best results. It was found that when increased the value of the acceleration from 1g to 1.5g, the level of pressure decreased this leaded to increase the thermal resistance between 5–30%. Unfortunately, the results were not proved the influence of the shock on the thermal behavior of the pipes.

Amir Alaei et al. [71] used the experimental work to study the influence of the low range of vibration frequencies on the response of gravity-assisted heat pipe. It was found that the vibration has a positive influence on the efficiency of the system, where the highest efficiency (33.83%) occurred when the value of the applying frequency is 30 Hz. The same results were obtained by **Amir Alaei [72]**, where in this research, it used the same concept on the oscillatory heat pipe (OHP). Also, this researcher improved the thermal efficiency of the system (OHP) using the approach. Studied the influence of low range of vibrating (starting from 0 to 30 Hz) with a constant value of the amplitude which is equal to 2 mm. The heat pipe was placed in the horizontal position during the experimental tests. It was found that the excited vibration has a large positive effect on the thermal efficiency. The magnitude of the thermal resistance decreased to 0.05 K/W when applied vibration with frequency 25 Hz.

Rong-Horng et al. [73] examined the influence of the vibration (longitudinal type) and the zone of compensated temperature on the behavior of heat transfer of the cylindrical copper heat pipe that has grooved. It was applied different values of frequencies (3, 4, 5, 6, and 9 Hz) that corresponding to values of amplitudes (2.8, 5, 10, 15, 20, and 25 mm). As a result of these conditions, the range of accelerations is between 0.1–1.01 g. It was found an increase in heat transfer rate for an input vibration rate (horizontally in the longitudinal direction) less than 500 mm^2 Hz^2. For vibration values more than 500 mm^2 Hz^2 the heat transfer performance/ unit of vibration power lowered suddenly. When reducing in the zone of temperature condensation continues, the mean temperature of the heated zone reduced. The effecting of the temperature for the condensation zone on the highest values of the heat transfer is greater than the effect of vibration as show in fig 2.5.

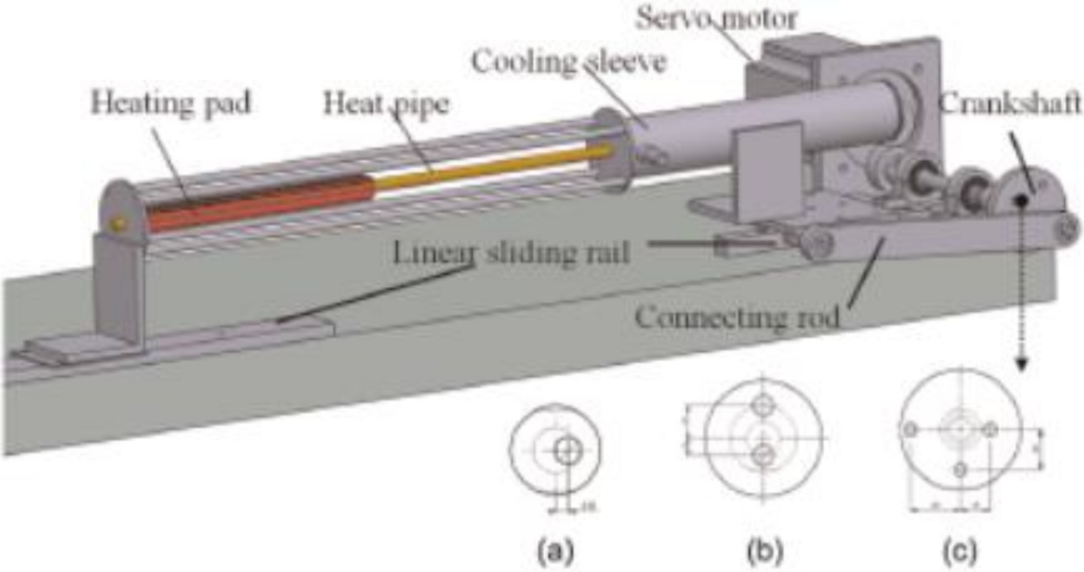


Figure 2. 5 Rong-Horng et al. experimental

Al Sahlani et al. [74] studied experimentally the effect of using vibrating unit to improve the thermal behavior of the evacuated tube solar collector heat pipe. It was used a wide range of the frequencies of vibration (from 2 to 10 Hz). It was investigated that the influence of the rate for water flow on the performance of the system as well. Resultant outlet showed that increasing of heat transfer coefficient of both evaporation and condensation. These values are proportional with vibrating frequency. Vibrating frequency activity is proportional with water flow rate and working fluid. Finally, it was found that the percentage increment of heat transfer coefficients for evaporation and condensation sections are 40% and 20%, respectively. While the percentage increment of the water temperature 22%. These facts can be enhanced the thermal efficiency by integrated PCM with the evacuated tube heat pipe solar collector.

2.4 Summary

Table 2.1 shows the summary for this chapter:

Table 2. 1: Literature review summary.

Researcher Name	Year	Ref.	Research type	Results summary
Riffat et al	2006	52	experimental	●It was found that water in a partial filling of 25.28% in the system gave a greater thermal efficiency compared with other cases.
Razaliet al.	2014	61	experimental	● Their results showed that the hot water was supplied for a long time until 8:00 pm with a range of 40-45 °C. ● also, the efficiency of the solar collector increases and reaches to 36.6% without PCM while with PCM it was higher.
Eidan et al	2015	63	experimental	●The results show optimal filling ratio and inclination angles are 70% and 45°.
AL-Haris	2018	65	experimental	● The PCM can be benefitted for heat storage and using this heat to water with high temperatures.
Amir Alaei et al.	2013	71	experimental	● The highest efficiency (33.83%) occurred when the value of the applying frequency is 30 Hz.
Amir Alaei et al.	2014	72	experimental	●The thermal resistancedecreased to 0.05K/W when applied vibration with frequency 25 Hz.
Rong-Horng et al	2015	73	experimental	●It was found an increase in heat transfer rate for an input vibration rate less than 500 mm^2Hz^2 the excitation energy.
Al Sahlani et al.	2018	74	experimental	●The percentage increment of heat transfer coefficients for evaporation and condensation sections are 40% and 20%.

By surveying the literature on solar applications, one can notice the increased tendency in the implementation of PCM material to enhance the thermal performance of the water heating systems. Moreover, the utilization of mechanical vibration in solar application is rare. In this experimental study, we implemented vibration excitation and usage of paraffin wax as a PCM in an evacuated tube solar collector for water heating purposes. The effect of different parameters such as filling ratios, heat flux, type of working fluid, and angle of inclination was tested. In order to achieve a fair comparison, two identical systems were built to observe the effect of vibration/no vibration on the thermal performance of the solar collector.

CHAPTER THREE
EXPERIMENTAL WORK

Chapter Three
Experimental Work

3.1 Introduction

The experimental work was carried out to study parameters that affect the performance of the solar collector in steady-state conditions, and also to make comparisons of the experimental work results for different cases and parameters; solar radiation flux, thermal performance for therosyphon as well as the hot solar collector with/without phase change materials (PCM) and with/without vibration effect. The experimental study was performed in Al-Furat Al-Awsat Technical University - Engineering Technical College of Al-Najaf/ Department of Power Mechanics. The work starts in September 2019 to April 2020. This period covers the manufacturing of the rig and the experimental measurements.

3.2 Experimental Rig Setup

Experimental procedure included the heat pipe evacuated tube solar collector, vibrating actuation, and measured data systems, with the control system integrated with the control equipment and amusement systems. The schematic representation and picture of the experimental rig setup with auxiliary's equipment are given in Fig.3.1. The experimental rig consists of a new structure that contains the iron stand, evacuated glass tube, thermosyphon, water storage tank, containers of PCM, and other accessories. Figure 3.2 represents the experimental rig setup system with integrated equipment.

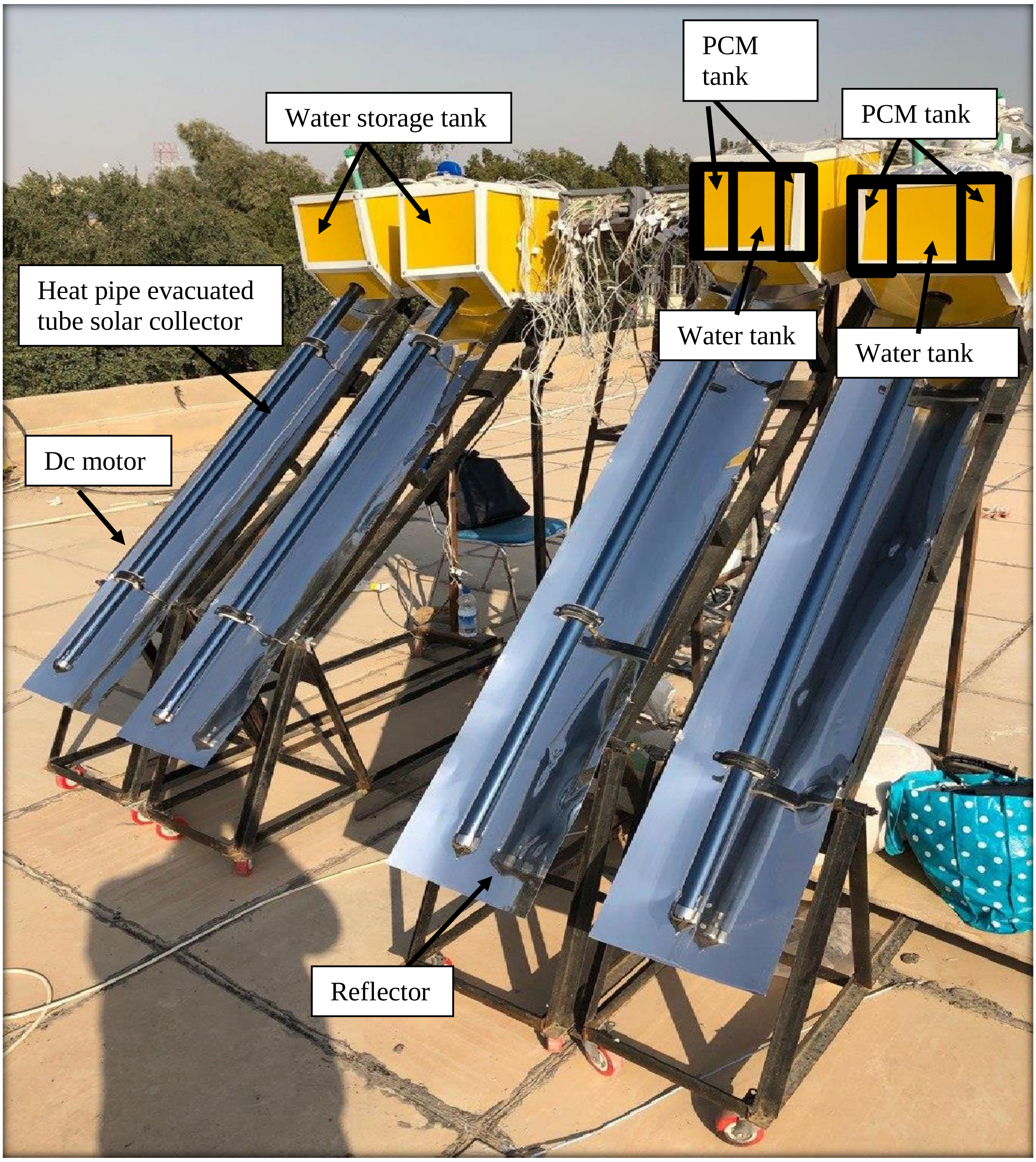


Figure 3. 1 The experimental rig for Thermosyphon with/without PCM containers and vibration system.

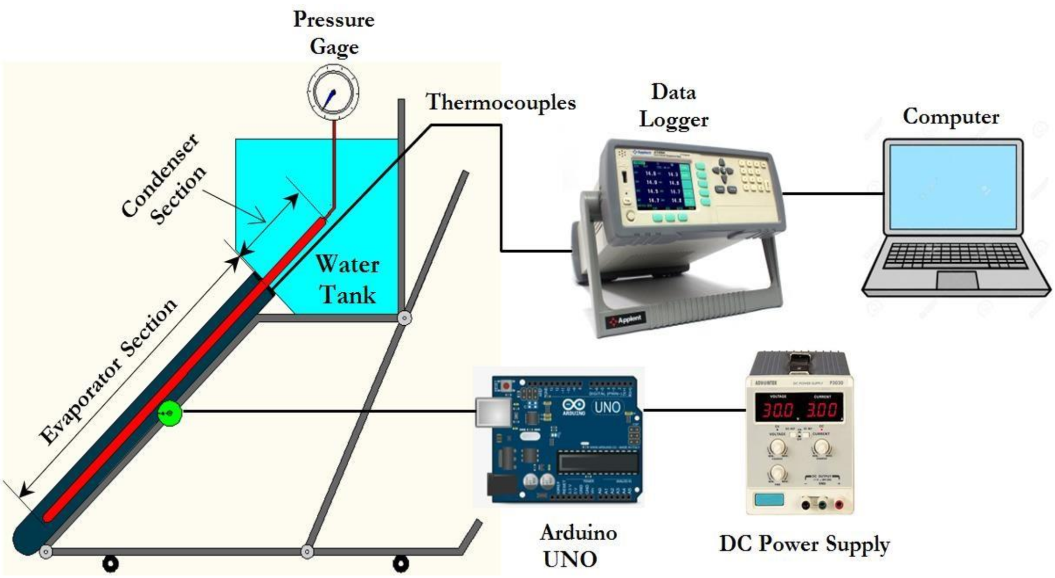


Figure 3. 2 Experimental rig setup system with integrated equipment.

3.2.1 Evacuated Tube Solar Collector

At high temperature application more than 80°C and due to the corresponding increase in heat loss coefficient, flat-plate collectors are not preferred at these high temperatures. If it is urgent to use collector at these conditions, it must to reduce heat loss to outdoor environment. That can be done by two procedures: evacuation and concentration, either singly or in combination. The natural configuration for an evacuated collector is the glass tube.

Many methods solved this problem one of these using glassed-envelope for process of radiation transmitted and choose such coats on absorber to reduce of thermal radiated heat at temperatures more than 80°C. Borosilicate-glass, silica, and boron oxide materials are used to manufacturing evacuate tube. These mixed materials have low thermal expansion coeff. (< $33*10^{-7}$ m/m.°C is required for ET), so it has more flexibility to resist thermal process and shocking [75]. Some other additives can be added like coating, composites (metal-ceramic) lead to more efficient process for heat loss and stability at high temperatures.

For more absorber performance, multi-layer cermet's are sandwiched between the two layers anti-reflection and thermal infrared reflector (see Fig.3.3). More composites of materials are listed in Ref. [75]. The reflector (stainless steel sheet foil) 1250*300mm can added to experimental rig to increase the performance of the system [65, 74]. The reflector is made from stainless steel curved sheet which is 1mm thickness and has a parabolic curve of function foucse = $\frac{x^2}{4y}$. It is fixed behind the evacuated tube.

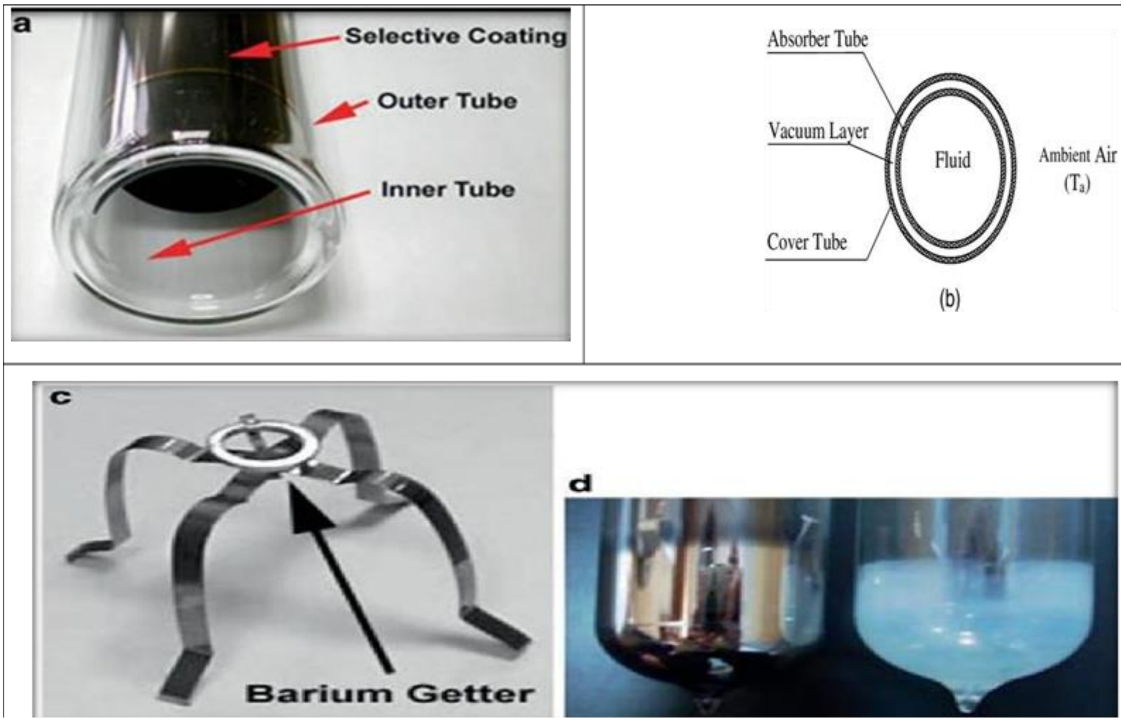


Figure 3. 3 (a) Open end of all-glass evacuated tube, (b) cross section of evacuated tube (c) bracket with barium getter, (d) left: gas absorbing coating deposited on the sealed end; right: gas absorbing coating after tube being filled with air

3.2.2 Thermosyphon Heat Pipe

The standardized copper tubes of external diameter (16mm), and internal diameter (14 mm) diameter and 1350 mm length has been chosen. These dimensions were selected since they are commonly specified by commercial manufacturers and have been selected by several investigators [63, 65, 74 and 79]. So, they were chosen in the proposed work to summarized for comparisons with the similar work.

Th evaporator section of thermosyphon (1150mm) was inserted in evacuated glass tube, while the condenser section of thermosyphon (200mm) was put inside water tank in Figures (3.4&3.5) [65,74 and 79]. The end of the thermosyphon contacted it to the valve device for the service in the event of problems to change the working fluid and the second end of the pipe is welding centrally with a tube 2 mm diameter and joined with pressure gage.

Eight thermocouples were fixed on the surface of thermosyphon and isolated with insulating material to measure the normal temperature of the surface and five thermocouples were planted inside the tube through the tube hole and using a 2mm capillary tube closed its end and put inside the hole and welded with the heat pipe and put the thermocouple and closed by thermal glue to measure the temperatures of working fluid (see Fig. 3.6).

The owins-illinois evacuated glass tube, display 34-46-1350-ycf, supplied by Oriental Incorporated Trading co., ltd., China. This tube (borosilicate) has thickness 2.5mm, supported by glass safeguard with inside diameter 45mm and outside diameter 50mm.This benefit property will by valid up to 150 ^{o}C, the outlet tube is cool by contact(touch). To obey standard condition of operation (vacuum conditions) external glass tubes, a barium getter is used. It makes at high temperature. The Barium layer with vacuum will be ensure out-gassed (CO, CO_2, N_2, O_2, H_2O and H_2) during operation. The silver -hued barium layer will change into white if the vacuum is lost. This makes it simple to see regardless of whether a tube is in great condition.

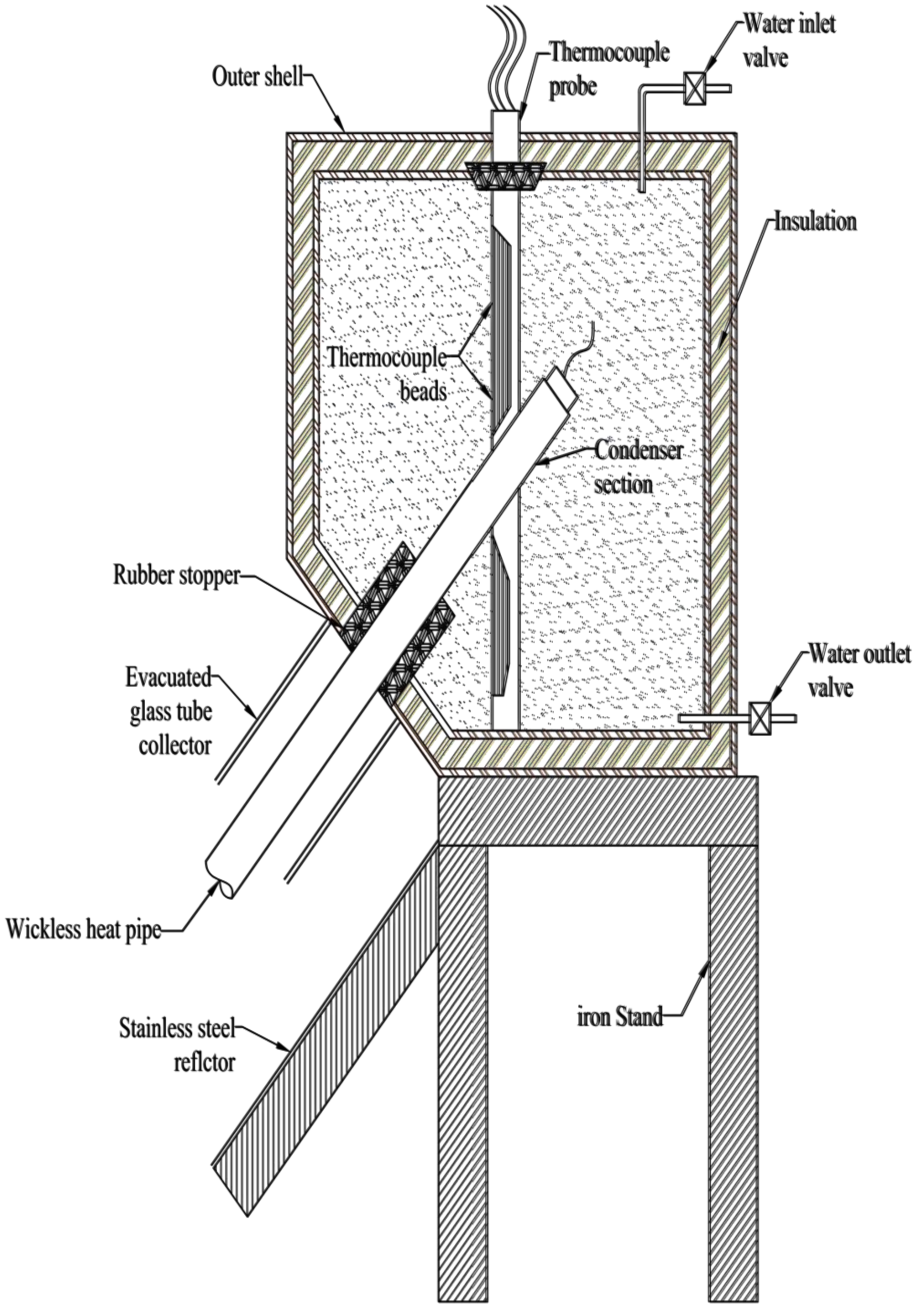


Figure 3. 4 Cross sectional view of the thermosyphon storage tank arrangement

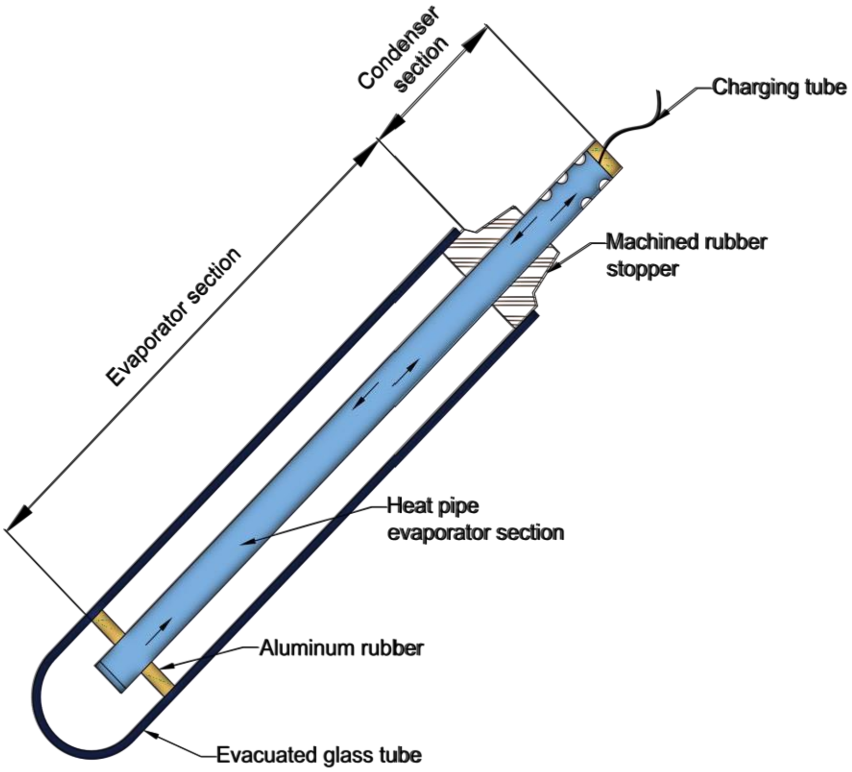
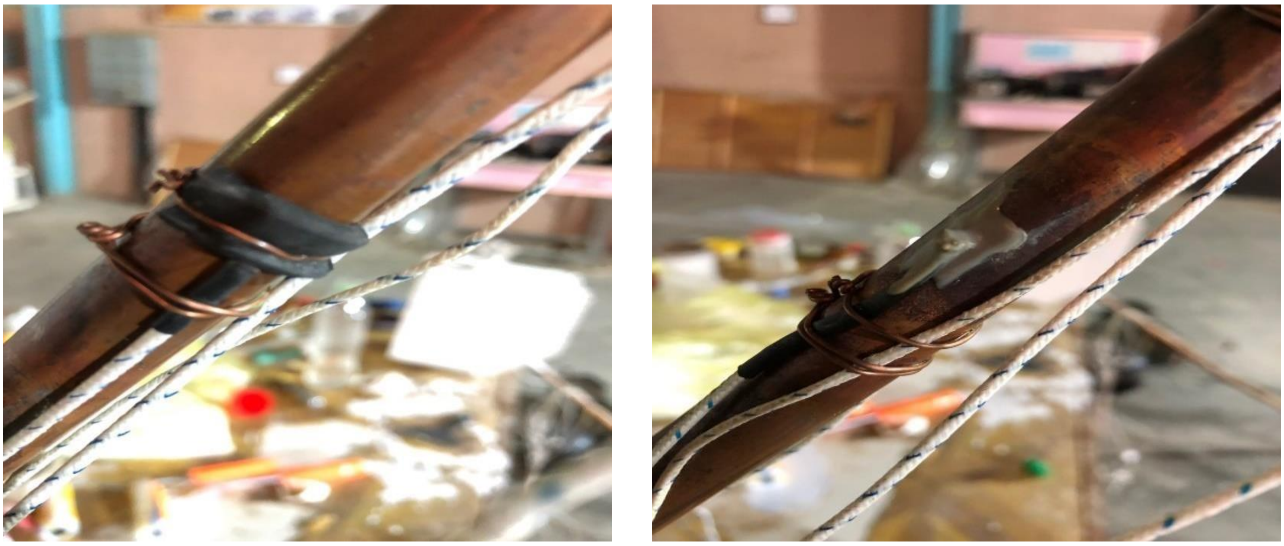


Figure 3. 5 Assembly of the evacuated tube thermosyphon solar collector



Thermocuple on the heat pipe surface Thermocouple inside heat pipe

Figure 3. 6 Thermocouple lie out on Thermosyphon.

3.2.3 Vacuum and charging process

Theromsyphon heat pipe items has been cleaned as follows:

- Cleaning with a bristle brush and carbon tetrachloride.
- Rinsing with carbon tetrachloride.
- Drying with a blower.
- Re-cleaning with acetone and a soft cloth.
- Drying.
- Soaking and washing with a detergent within time period.
- Flushing with tap water thoroughly.
- Drying by using oven for 1h.

The previous procedure can be repeated for several times for efficient cleaning. Gloves must be used to protect your skin. In the present work, acetone was utilized.

The thermosyphon is charged with working fluid by a burette associated safely to the thermosyphon by the filling tubes as shown in Fig. 3.7. Now the thermocouples are distributed all along the surface of the thermosyphon and its core to measure the temperatures in different spots of the thermosyphon.

Evacuating of Theromsyphon heat pipe is an important process to gas-out gases because it undesired noncondensable, or may be made side reactions with the working fluid to form corroded materials. Ensure that must be for 48h for leak considerations.

The working fluid is flashed in a small amount and repeating vacuum process at pressure of 75.5cm Hg for a 3h. This process(vacuum) is accomplished by special pump type (ROBINAIR, 1hp, 250 L/min.; Model 231672; USA). thermosyphon will be operated normally after finalized evacuation. Measurements process was done with filling ratio 70% [63,74].

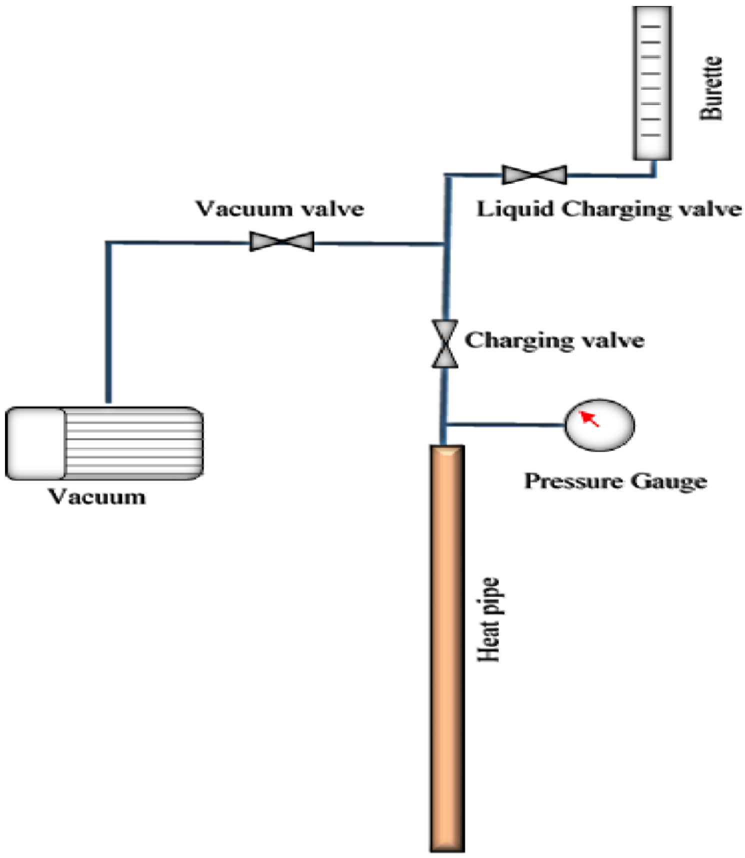


Figure 3. 7 Thermosyphon vacuum and charging apparatus

3.2.4 The Storage Tank

In this study a water storage tank was used. The capacity of the water storage tank was 5.25 L, the dimensions are 27.5 cm*27.5 cm*7 cm [65] . It was made of Aluminum sheet with 1 mm thickness as shown in Figure 3.8. Aluminum has been used in the reservoir industry because of its low cost and high thermal conductivity, as well as its high wear resistance. It was glued with a thermal substance and put five thermocouples inside the tank to calculate the temperature of the water in different levels and contains an opening on the top to add water and open it at the bottom to extract the water in the event of a problem and isolation by glass wool and the use of Alecapon to increase the insulation. One of the lower corners of the tank was cut down with 45° to facilitate the process of assembling of thermosyphon. Figure 3.9 demonstrates the shape of the storage tank.

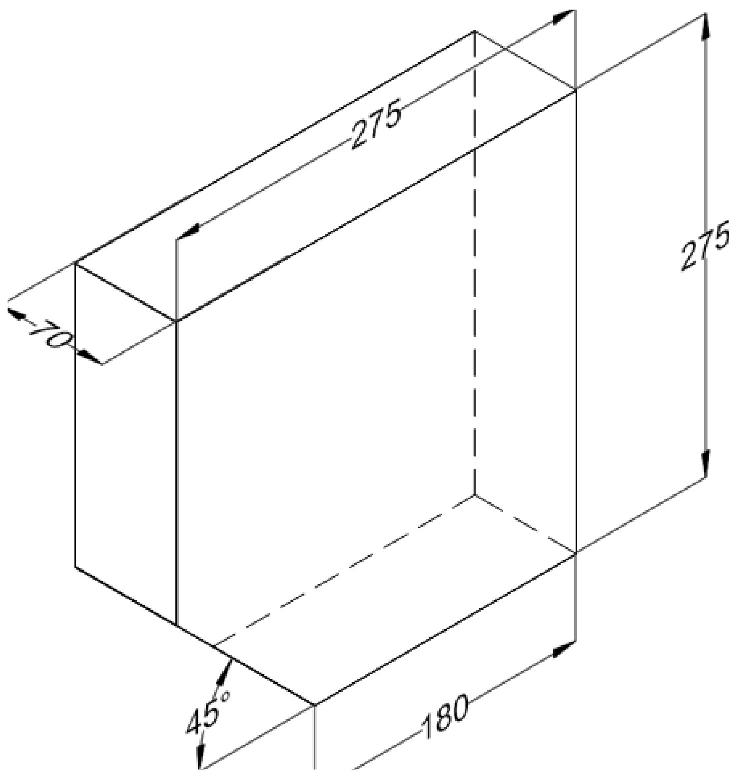


Figure 3. 8 Storage water tank

Figure 3. 9 Storage tank

3.2.5 Phase Change Material Storage Tank

The internal walls of the water storage tank are containers which content the PCM. These containers were put in both, left and right sides of the tank. Each container has the dimension: 275 mm*275 mm*30 mm [65] as in Fig. 3.10. The tank made of aluminum also put on the inner surface of the water tank and put five thermo cables inside the tank contains a hole from the top to add the PCM that was melted by an electric heater and we mention the specifications of the pcm.

The PCM used was paraffin wax. The weight of the PCM in each container was 1.8 kg. In order to reduce the heat losses, the tank and containers were insulated by glass wool with thickness 50 mm. The isolation process was performed by pasting the isolator on the outer walls of the tank. The storage system was folded with Alecapon sheet with the thickness 3 mm. Figure 3.11 shows phase change material storage tank.

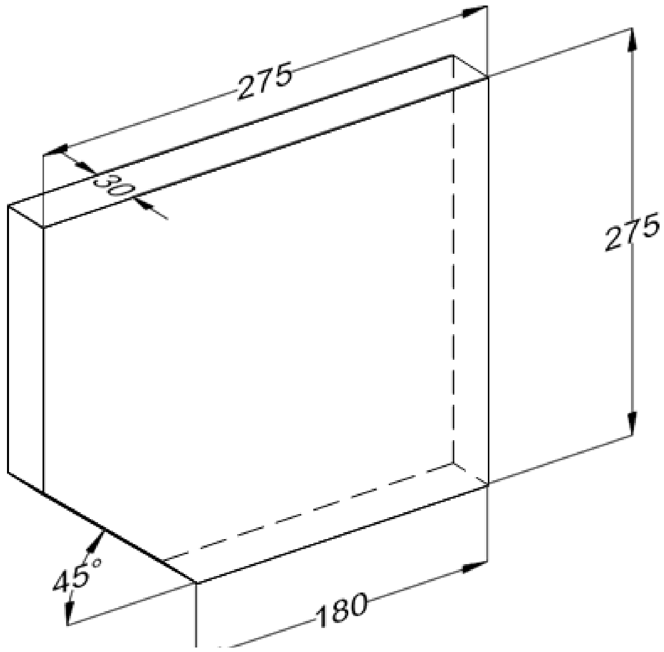


Figure 3. 10 Phase change material (PCM) containers.

Figure 3. 11 Phase change storage material tank

3.2.6 Vibration System

Several vibration frequencies in form of pulses with fix time value in the measurements work are used. These vibration frequencies must be controlled in manufactured control system design as follows:

3.2.6.1 DC Motor

A small DC motor has been used to produce the vibration with an unbalanced load, as illustrated in Fig. 3.12. Where different radii and mass values can be defined by using the eccentric mass. An aluminum disc is produced to hold a screw (eccentric mass) with a constant mass of 15 grams. The DC motor shall be mounted to the structure of the thermosyphon to produce excitation through the control circuit with various amplitudes and frequencies. The motor's base is shielded by an elastic sheet, which smooth out the generated vibration in the heat pipe evacuated tube solar collector. The supplied signal to the vibrating motor has been controlled by using a system includes DC power supply and an Arduino UNO system where the Arduino is a programmable instrument capable of delivering the required output using software code.

The variable resistor regulates the variable voltage delivered to the motor, and as a consequence, the frequency is controlled. The diagram of the circuit of control is illustrated in Fig. 3.13.

Figure 3. 12 DC motor

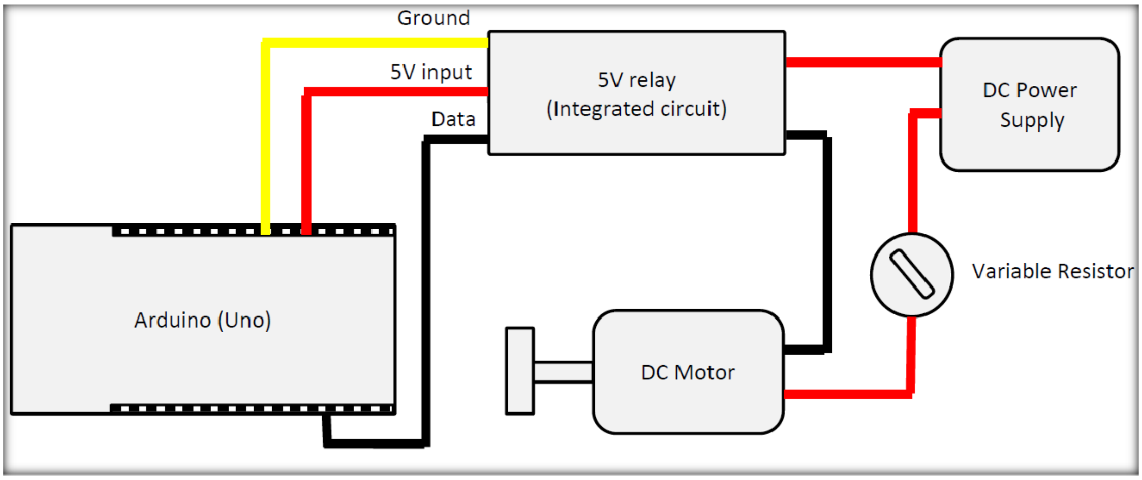


Figure 3. 13 The circuit Control System

A control system with its components, voltage power supply and Arduino UNO system responsible on vibrating of thermosyphon. The DC motor will be work at 0-5V signal and 5V(controlled by variable resister) provided by the Arduino, the Arduino and relay are given in Fig. 3.14. Consequently, the control circuit scheme is given in Fig. 3.13.

Figure 3. 14 The Arduino and Relay

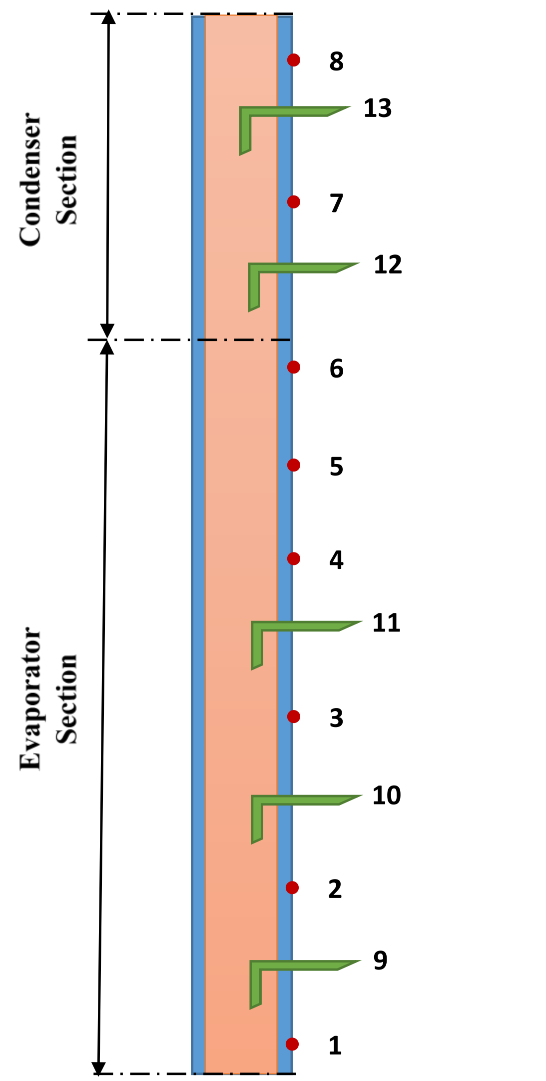
3.3 Measurement and Instrument

3.3.1 Temperature

The thermocouples are of type K, (which are considered suitable for both high temperatures and low temperatures -200 to 1350 °C(Thermo couples are calibrated according standard procedure, see Appendix A).

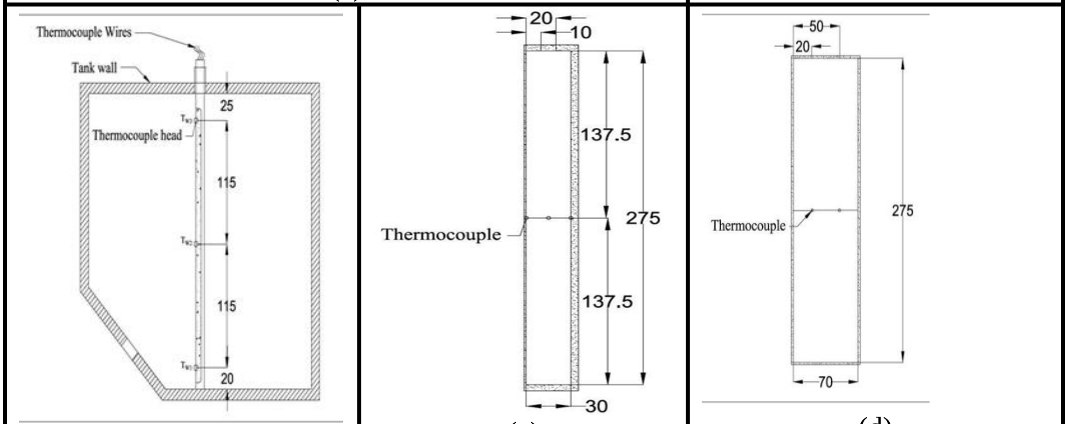
They are cheap, accurate, can work under all environmental in natural and chemical conditions. and made of Nickel- Chrome and they were used to measure the temperatures. Figure 3.15 shows installing method of thermocouples inside water and paraffin wax tanks. Eight thermocouples were fixed on the surface of thermosyphon and isolated with insulating material and five thermocouples inside the tube through the tube hole and using a 2mm tube closed its end and put inside the hole and welded with the heat pipe and put the thermocouple and closed by thermal glue to measure the normal temperature of the surface; five thermocouples were planted in the core of the thermosyphon to measure the temperatures of working fluid as indicated in Fig. 3.16a. five thermocouples in the water tank as shown in Fig. 3.16b, and five thermocouples in the PCM containers as shown in Fig. 3.16c, as the two containers are similar; the thermocouples were planted in one of them. Figure 3.16d shows thermocouples arrangements in storage tank.

Figure 3. 15 Installing method of thermocouples inside water and paraffin wax tanks



(a)

Thermo. No.	Position (mm)
1	10
2	250
3	500
4	750
5	1000
6	1160
7	1230
8	1280
9	30
10	565
11	1100
12	1230
13	1280



(b) (c) (d)

Figure 3. 16 (a) thermosyphon thermocouples positions (core and wall surface), (b) Thermocouple inside water tank and pcm, (c) Thermocouple inside pcm tank, (d)Thermocouple inside water tank

3.3.2 Data logger Device

AT4532 is in a simple way can be fixed at the module. AT4532 has multi- communication via RS-232C, so it can be control by computer. The AT4532 show easy portability along with applent\'s built-in signal conditioning and Universal Input Module as shown in Fig. 3.17.

AT4532 is examined to withstands shock and vibration and electromagnetic interference. AT4532 has high accuracy, especially on low signals. Table 3.1 summarizes data logger AT4532 characteristic properties. Figure 3.18 shows DC power supply YH-305D used in the experimental work.

Table 3. 1 Data logger characteristic properties

Graduation	Thermocouple: J/K/T/E/S/N/B
Accuracy	0.2℃ ± 2 digits (not include accuracy of thermocouples)
Ranges	-200ºC~1300ºC(Varying depend on graduation)
Re-solution	0.1ºC
Channels	32 channel; Can be expanded to 128 channel
Speeds	100ms
Correction	Error correct for each channel

Figure 3. 17Data logger type AT4532

Figure 3. 18 DC power supply YH-305D

3.3.3 Irradiance Measurements

The solar irradiance on the sun-based collector including normal part and diffuse part, the normal part was measured with sun powered power meter display TENMARS TM-207 Taiwan made(it is calibrated according standard procedure see Appendix A). This instrument has resolution ± 1% up to the solar irradiance of 1000W/m^2, within operating temperature range of –20-60°C. The cosine reaction was treated to not exactly ± 5% for edge under 60 °C, the photo image. Figure 3.19 shows the instrument and the orientation sensing of this instrument was mounted on the divider surface of solar orienting collector.

Figure 3. 19 Solar power meter.

3.4 Accessories

3.4.1 Phase Change Material PCM

The paraffin wax was used as PCM, the present study as shown in Fig 3.20. The properties of this material are illustrated in Table 3.2.

Table 3. 2 Properties of PCM paraffin wax[65]

T_m ^oC	C_p KJ/Kg.K	k-solid W/K	k-liquid W/m.K	ρ-solid Kg/m³	ρ-liquid Kg/m³	h KJ/Kg
38-43	2	0.2	0.2	880	770	165

Before melting **After melting**

Figure 3. 20 PCM before and after melting

3.4.2 Working Fluid

Pure acetone was used as working fluid which represents part of the thermosyphon. The volume used was 124 cc (i.e. the volume division FR=70%) [63,79]. A burette tube was used to measure the volume of acetone entering the thermosyphon.

Table 3. 3 Thermal and fluid properties of acetone at T=40°C

Vapor pressure (Pa)	Liquid density (g/m^3)	Vapor density (g/m^3)	Liquid viscosity (g/m s)	Vapor viscosity (g/m s)	Surface tension (N/m)	Latent heat (J/g)
6.0×10^{4}	768	1.05	2.69×10^{-4}	0.86×10^{-5}	0.0212	536×10^{3}

3.4.3 Insulation Material

The glass wool with a thickness of 50 mm was used in the study to isolate the water tank as well as the paraffin wax containers. The isolation process was applied with all side to prevent heat transfer.

3.5 Experimental Procedure:

Four similar thermosyphon rigs were conducted to determine the performance of each one at the same conditions with a presence and an absence of the vibration. the optimal working conditions for the thermosyphon were reached by a filling ratio of 70% and a tilted angle of 45° [63,74]. As two of four thermosyphon systems operates with the absence of vibration effect, it has been considered to be a reference. The other thermosyphon was exposed to a vibrational effect that is expressed as regularly periodic on-off pulses (20 seconds on – 120 seconds off) throughout the course of the experiment. The voltage ranges used to generate vibration frequency are 6, 8, 10 ,12 and 14 volts. Using a 45 ° angle of inclination to achieve the highest performance for the single-gravity assist of thermosyphon system. The procedural steps of the experiment are:

1. The thermosyphon in both four rigs has been supplied with pure acetone at a filling ratio of 70% from the evaporator portion.
2. The control system is adjusted to provide a 20-second vibrating pulse and repeated for every 120 seconds.
3. Throughout 8 AM to 10 PM, the surface and core temperatures were estimated and reported in every five seconds.
4. Change the value of the frequency and repeat steps 2-3.
5. Change the radius of mass in the rotating disc and repeat steps 2-

3.6 Theory relevant

3.6.1 Thermosyphon heat pipe performance calculations

Input solar power (I in W/m^2) transfers from the evaporator thermosyphon to the condenser then to be dissipated through the water tank. To estimate the overall thermal resistance (R_{exp}) for the solar collector, the following correlation used to calculate R_{exp} [63, 74,79]:

$$R_{exp} = \frac{(\overline{T_E} - \overline{T_C})}{2\pi r_0 l_E I} \qquad \text{............(3.1)}$$

Where $\overline{T_E}$ and $\overline{T_C}$ are the average wall temperatures at the evaporator and condenser regions which are measured by surface sensors, Where : r_o and l_E are the outer radius and the length of evaporator thermosyphon in m, respectively.

Consequently, the heat transfer coefficients (EHTC) and condensation and evaporation (CHTC) for both thermosyphon sections are estimated as follows [74,79].

$$He = \frac{I}{\overline{T_E} - \overline{T_v}} \qquad \text{............(3.2)}$$

$$Hc = \frac{I(l_E/l_C)}{(\overline{T_v} - \overline{T_C})} \qquad \text{............(3.3)}$$

Where l_E evaporator length and l_C condenser length in m respectively. T_v is the mean saturated temperature measured by core temperature sensors at the center of the thermosyphon.

3.6.2 Efficiency calculations

Filling ratio, solar radiation flux, tilt angle, inlet temperature, environment conditions, and working fluid are the basic factors of interfere of operation thermosyphon heat pipe [63,79]. From the measured recorded data for the sunny day in January within the time period; 8 AM – 10 PM thermosyphon heat pipe efficiency is studied. The calculation of the efficiency shows a noticeable fluctuating value since many factors affect the efficiency as it was mentioned before. However, the efficiency can be calculated using the following relation [74,79]:

$$\eta = \frac{Q_u}{Q_{in}} = \frac{mC_P(T_{wo} - T_{wi})}{A_c I} \qquad \text{...........(3.4)}$$

CHAPTER FOUR
RESULT AND DISCUSSIONS

Chapter Four

Results and Discussions

4.1 Introduction

In this chapter, the experimental results will present with details. All obtained results were based on the new test rig built to achieve all necessary tasks. It can be classified as the experimental results into three main parts. The first part is studying the effect of the phase change material on the performance of the evacuated tube heat pipe solar collector. The second part of the results is investigated the effect of vibration on the thermal performance and the efficiency of the evacuated tube heat pipe solar collector. While, the third part is studying the effect of the radius of mass that is fixed on the disc which is connected with the motor to generate the vibration in the evacuated tube heat pipe solar collector.

It was applied to a wide range of frequencies (6-14 Volt) to study the effect of vibration on the performance of the system. It was achieved all the experimental work in Najaf Governorate in Iraq that located with latitude 31 ^{o}N and longitude 44 ^{o}E. The daily period to achieve the experimental work is started from eight in the morning to ten in the night during the winter months (January, February, March, and April). where all the experiments were performed in sunny weather.

Figure 4.1 shows the average temperatures along the thermosyphon in the case of absence of the vibration. It can be seen that the values of temperature increased with time, where the minimum values occurred at 8 AM and the maximum values occurred at 13 PM.

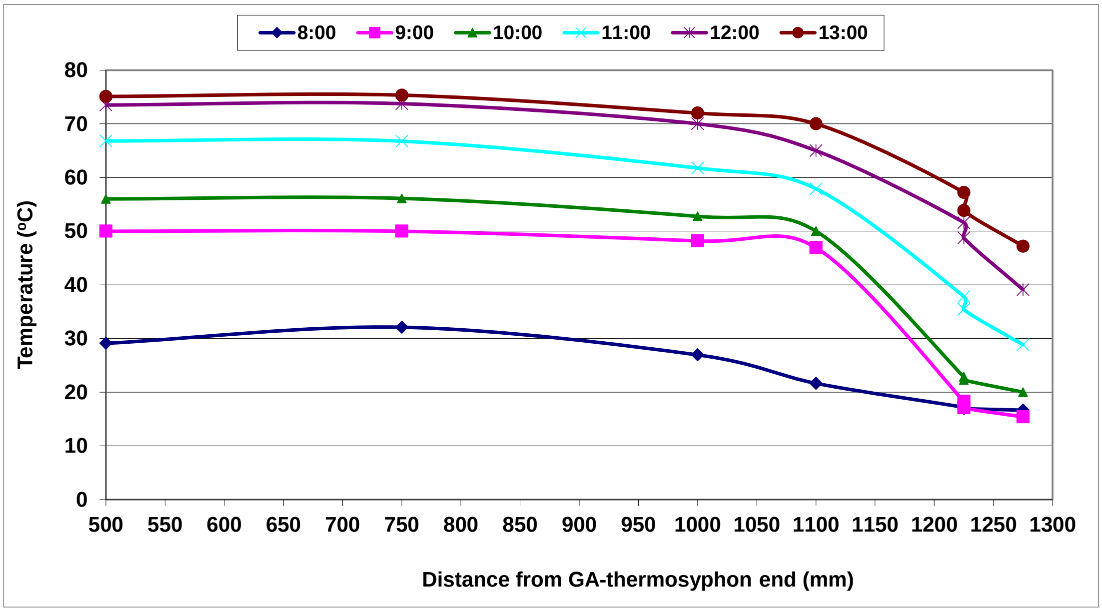


Figure 4. 1 Temperature distribution along thermosyphon without vibration

4.2 Effect of PCM

The experimental tests were performed to study deeply the effect of phase change material (PCM) on the thermal behavior of the evacuated tube heat pipe solar collector under Iraqi climatic conditions. It two different cases was considered, the first one when using PCM and the second case without PCM.

Figure 4.2 shows the variation of water temperature in the storage tank for both cases (with and without PCM). It can be seen that there is no significant difference in the temperature for both cases until 5 pm (17:00). After that, it can be noticed that the fast drop in the temperature for the case without PCM. While, for the other case, the temperature decreased very slowly. This means that the temperatures will be useful during the whole day, especially when the solar intensity is not available. It was found that the lowest value of the temperature is over 35 °C. Where, the maximum temperature is approximately 54 °C for both cases at 4 pm (16:00). The reason for such results is using the PCM that can storage the heat and then will be available later for different kinds of use.

Figure 4.3 demonstrates the variation of thermal resistance with time for both cases. It can be noticed that the thermal resistance decreased when increasing the time of solar radiation for both cases. The maximum values of the thermal resistance for both cases occurred at 8 AM. While the minimum value of the thermal resistance occurred approximately at 2 PM. It can be seen that the difference between the values of thermal resistance for both cases is very small. Generally, it was found that the values of thermal resistance with PCM are lower than those without PCM.

Figure 4.4 shows the variation of the evaporator heat transfer coefficient (EHTC) with time. It can be seen that both cases have the same behavior approximately during the operation time and the difference between them is small and not exceeded 70 $W/m^2\ {}^oC$. The maximum value of the EHTC occurred at time 12:00. While, the minimum values of the evaporator heat transfer coefficient occurred at 8 AM. The reason behind these results is the variation of magnitude of solar radiation with time.

Figure 4.5 shows the variation of condenser heat transfer coefficient (CHTC) with time for the same two cases (with and without PCM). Also, it can be seen that the behavior of both cases is similar during all time, but the values of the condenser heat transfer coefficient when using PCM is higher than those without PCM. However, the difference between them is not large, and the maximum difference between them did not exceeded 100 $W/m^2\ {}^oC$. The maximum value of the EHTC occurred at time 12:00. While, the minimum values of the CHTC occurred at time 8:00 am, the reason behind these results is the variation of magnitude of solar radiation with time.

It can be considered that enhancement of the condensation process is an essential point for all types of the heat pipe to increase the amount of transferred heat via converting the fluid that used as working fluid vapor to liquid status and then the film flow back to the section of evaporator via capillary influence of gravitational effect. Based on the available literature review, it was found that the most effective mode to transfer the heat in the section of condensation is the dropwise mode. Where, this mode provided rates for condensation higher than film wise condensation [76,77]. It was used commonly in the industry sector, where it was made the surface like the non- wetting via the promoters. Where it may be coated with the long-chain fatty acids. Later on, the droplets will be formed and it grows very quickly, the larger ones will be removed by gravity and the process will be resumed.

Figure 4.6 exhibits the efficiency of the system thermosyphon during the day of the experimental work for two cases (with and without PCM). the most stable data was selected as the total period of the experiments. It can be seen that the minimum value of efficiency appeared early in the morning.

The reason for such results is the minimum value for solar radiation that occurred at this period of time. The maximum value of the efficiency occurred at noontime during the whole period of the experimental work, where the peak value of the solar radiation occurred at this time. This will lead to fast increasing in the absorbed heat by the evaporator section compared with any other time during the experiment. Generally, the efficiency increased when using the PCM, but the difference between the two cases (with and without PCM) is not exceeded by 5 %.

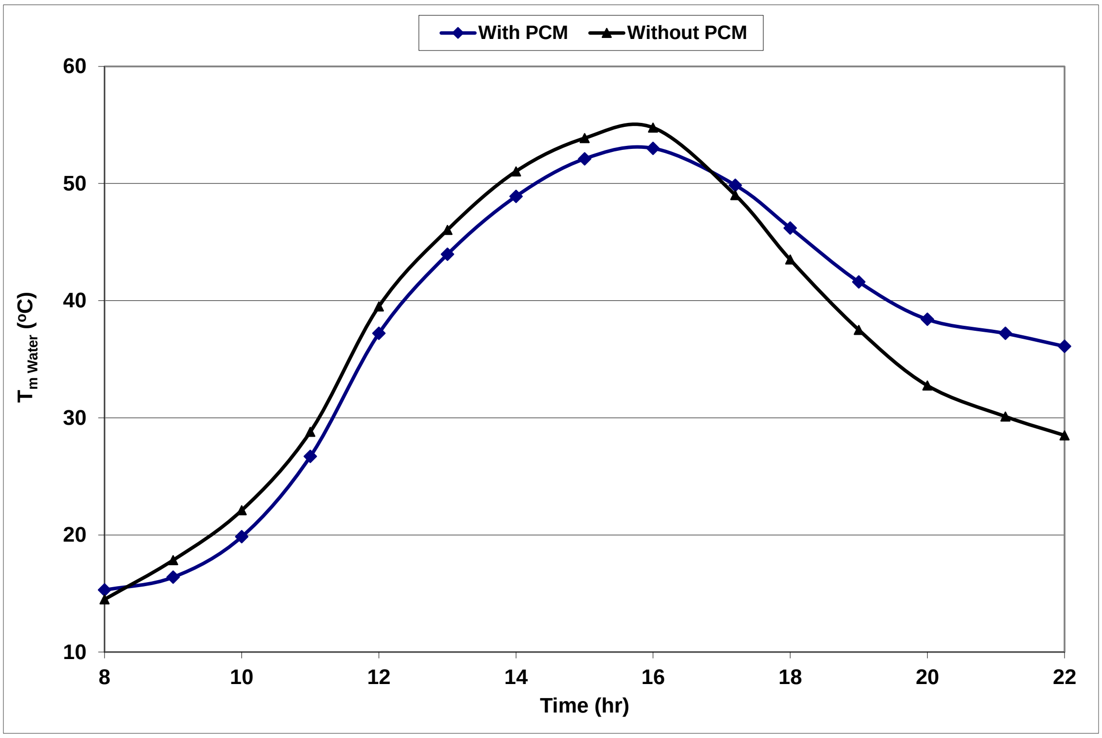


Figure 4. 2 The mean water temperature.

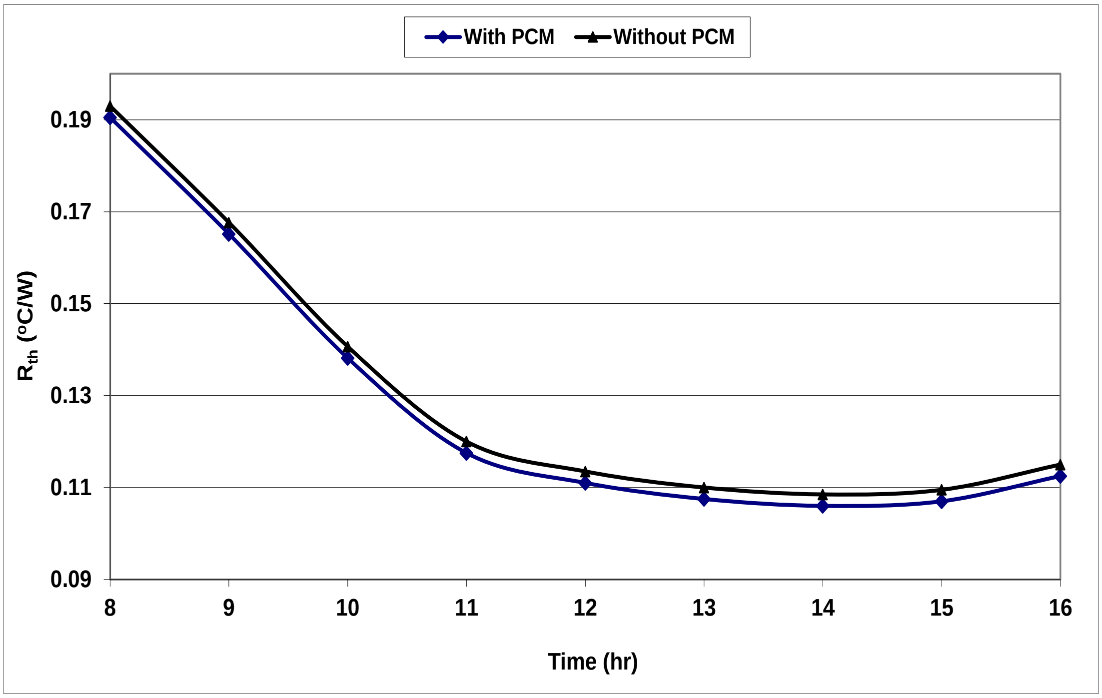


Figure 4. 3 Variation of thermal resistance with time.

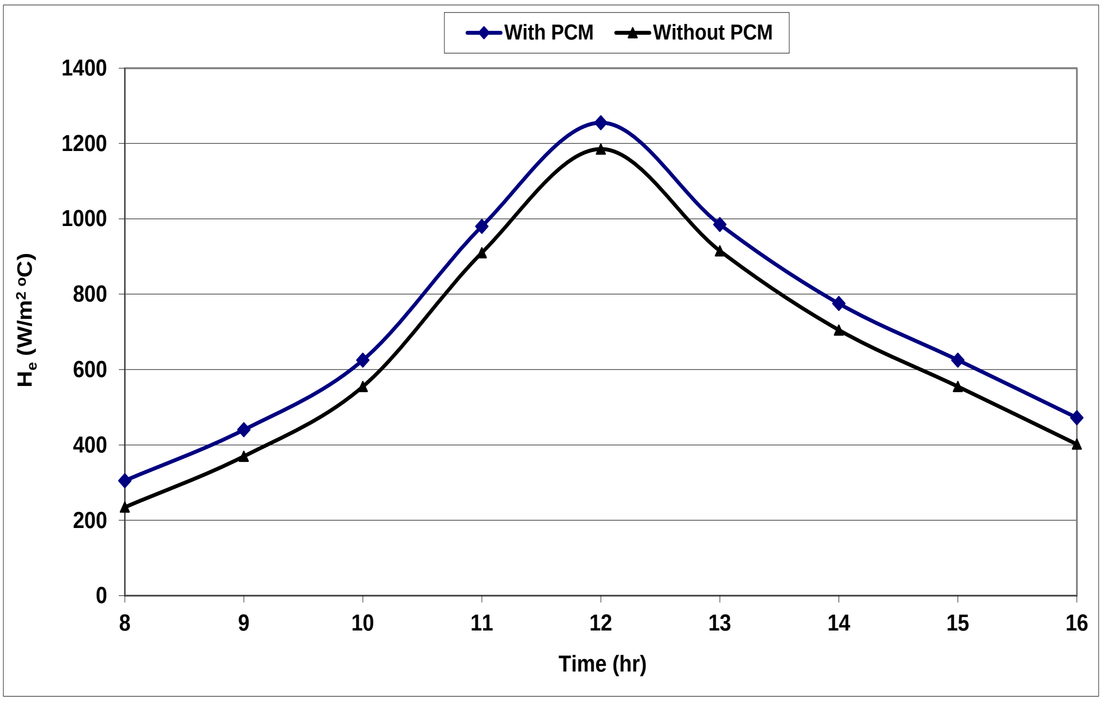


Figure 4. 4 Variation of evaporator heat transfer coefficient with time.

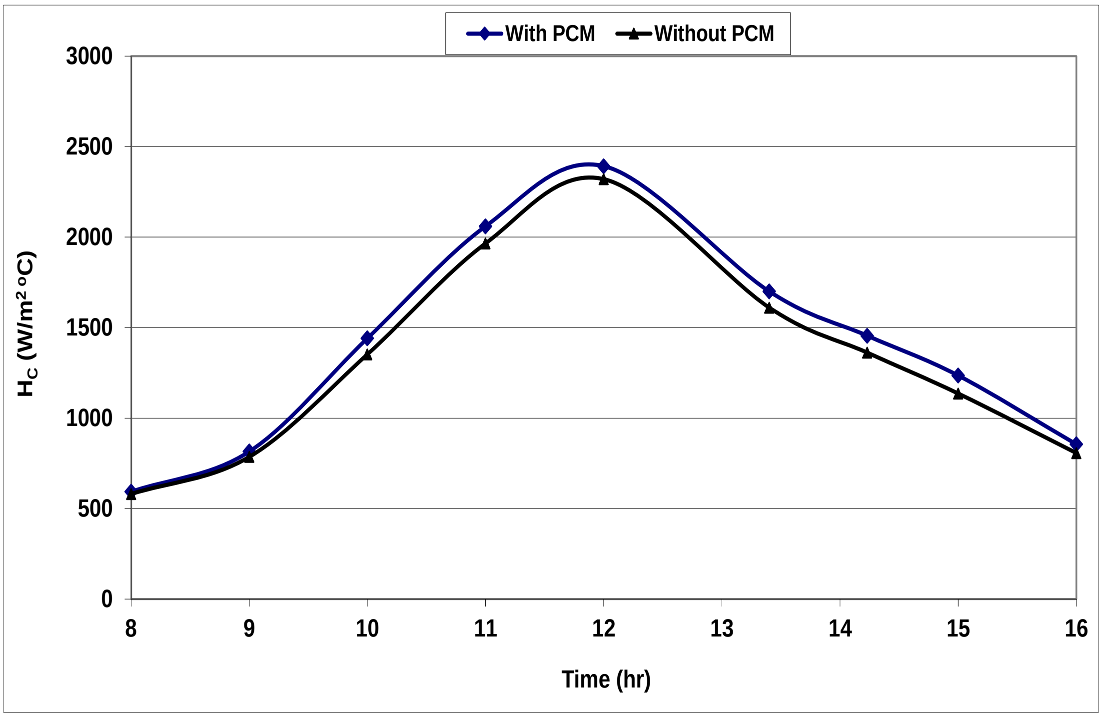


Figure 4. 5 Variation of condenser heat transfer coefficient with time.

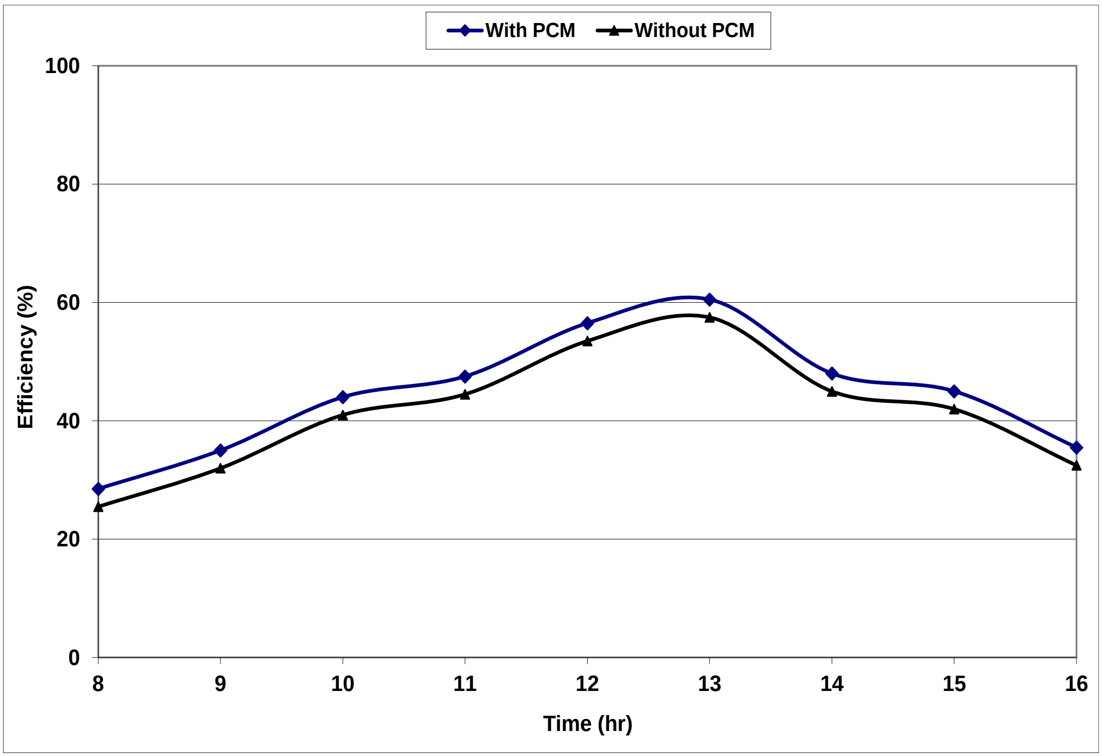


Figure 4. 6 The efficiency of the thermosyphon.

4.3 Effect of Vibration

In this section, the thermal performance will be presented and thermal efficiency of thermosyphon and thermosyphon under the effect of different vibration frequencies. Thethermosyphon thermal resistance for sunny days (from sunrise to sunset) has initially been analyzed with solar radiation. For all results in this section, the radius of mass (15 grams) that fixed on the disc which connected with motor to generate the vibration in the system is equal to 4 cm. It was applied five different vibration frequencies, which are:

1. 21.1 Hz (6 V).
2. 28.33 Hz (8 V).
3. 35.55 Hz (10 V).
4. 42.77 Hz (12 V).
5. 50 Hz (14 V).

It was calculated the applied frequencies based on the following equation,

$$Frequency = \frac{Rotational\ speed\ (rpm)}{60} = \frac{2600}{12*60}\ V \tag{4.1}$$

As a result of applying different vibration frequencies, the surface evaporator temperature decreased with the increasing of the vibration frequency, as shown in Fig. 4.7. The peaks temperature occurred approximately at 13:00 (1 PM). And the minimum value occurred early in the morning 8:00 AM. The maximum difference is 10 ℃ which occurred at 1 PM when changing the applied vibration from 0 V to 12 V.

Also, for the same reason, it can be seen the same behavior, that when increased the vibration frequency, the surface condenser temperature decreased as illustrated in Fig. 4.8. It can be seen that the temperatures decreased gradually when the vibration influence increases compared with the static condition.

It can be considered that the temperature of the tank in solar water heater systems as thermosyphon is the main parameter that will affect the performance of the system. In these experiments, one of the important goals is to find a way to enhance the internal energy of the evacuated tube heat pipe solar collector system, based on the temperature of the water tank to improve the performance of thermosyphon. It can improve the performance of the system based on the temperature of the cooling fluid in the condenser section. In other words, it can be said that when the cooling fluid temperature in the condenser section decreases, the thermal resistance will decrease as well [77].

Five K-type thermocouples are mounted inside the tank in different levels (right, left, top, bottom and center) to determine the values of water tank temperature. A highest tank temperature leads to highest collector efficiency of thermosyphon. Two factors are responsible to obtain the optimal output with similar solar radiation input. The first factor is the quantity of useful two-phase heat transmitted through GAHP which equivalent to the input radiation, which is the optimal working fluid that has smallest values of the thermal resistance. The second factor is the distribution of temperature in a water tank if it is homogenous. Then by reduction of viscosity of water due to rising of temperature and due to the influence of the alter in values of density for warmed water on the thermosyphon over the surface of thermosyphon condenser section.

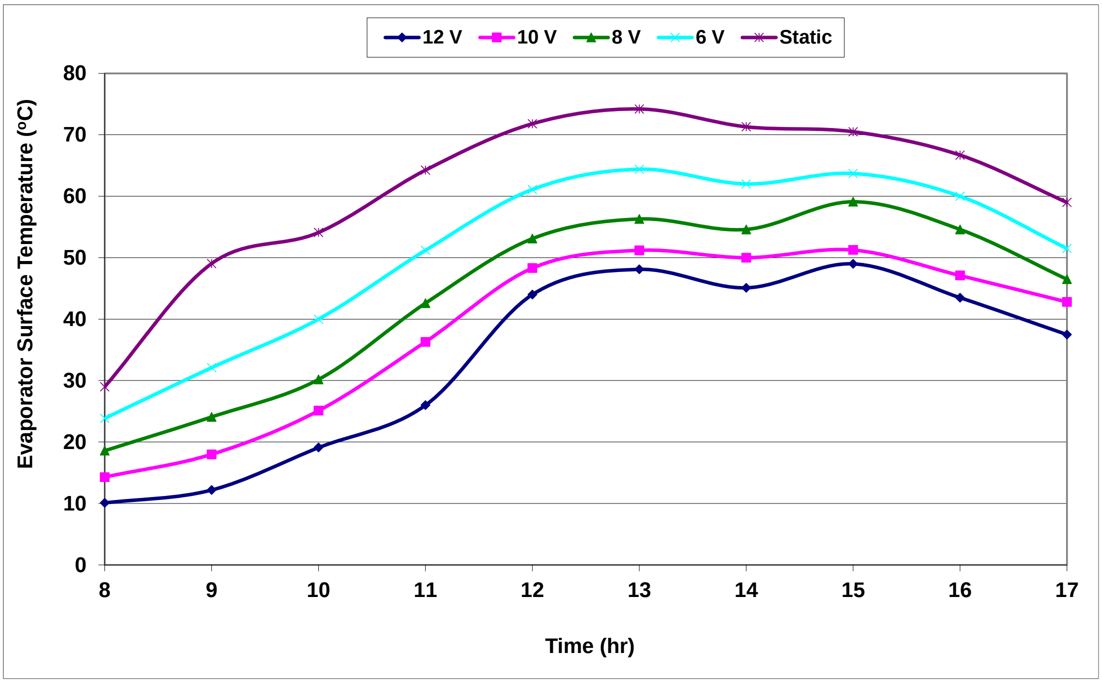


Figure 4. 7 Mean surface temperature of evaporator section of thermosyphon when applying various voltages

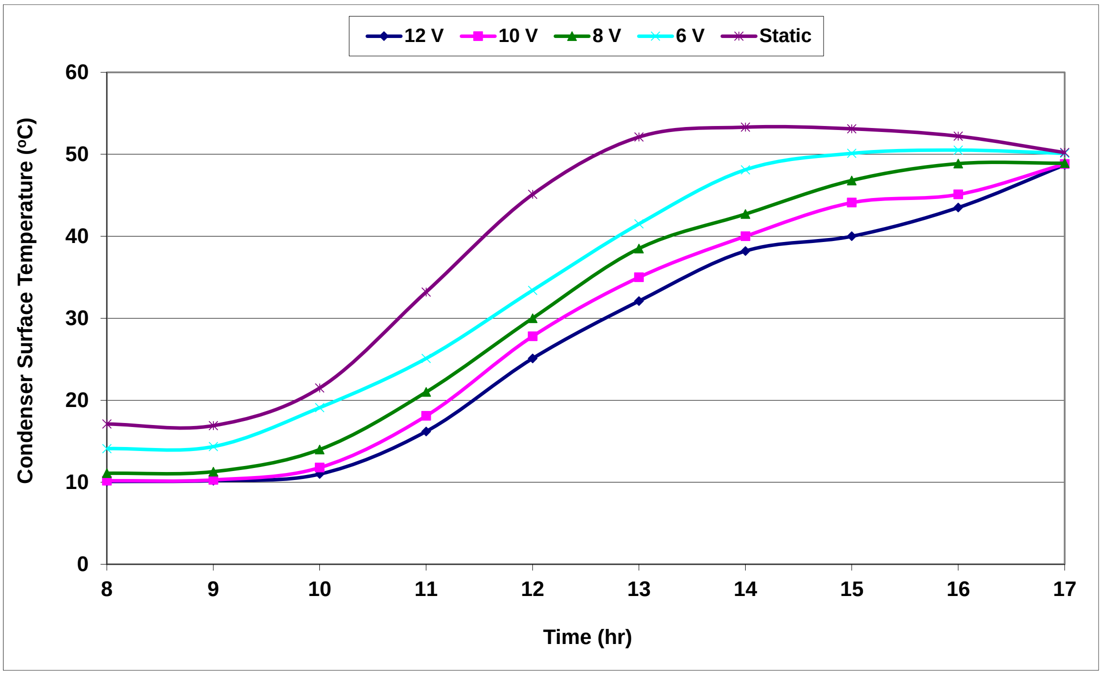


Figure 4. 8 Mean surface temperature of condenser section of thermosyphon when applying various voltages

4.3.1 Effect of Vibration on Mean Water Temperature

The variations of the mean water temperature in the tank with time when applying five different values of vibration (6, 8, 10, 12 and 14 V) are investigated.

Four different cases were studied in details which are: without PCM (without vibration), without PCM (vibration), with PCM (without vibration), and with PCM (with vibration).

Figure 4.9 shows the variation of water temperature in the storage tank for the four cases that explained previously. It can be seen that there is small difference in the values of temperature among all cases until 5 PM (17:00). After that, it can be noticed that the fast drop in the temperature for two cases (without PCM). While, the other two cases (with PCM), the temperature decreased very slowly. Therefore, it can be used this water with such temperature in different useful applications, especially when solar intensity is not available. Where, the lowest value of the temperature is over 35 °C. The maximum temperatures for all cases appeared at 15:00

(3 PM).

Figures 4.10-4.13 illustrate the variation of water temperature in the storage tank for same four cases (with and without PCM and with and without vibration) when applied different magnitude of frequencies (8, 10, 12 and 14 V). It can be seen the same behavior approximately with the previous results (Fig. 4.8). However, it can be recognized the increment in the values of temperature when the frequency increased. The highest values of temperature appeared when applied 14 V. Generally, it was observed that the mean temperature of the tank increased when the frequency of the vibration increased too.

Figures 4.14 and 4.15 give a clear picture of the vibration effect on the behavior and performance of the evacuated tube heat pipe solar collector system when integrated and not integrated the PCM.

It can be found that the values of temperatures are proportional with magnitude of frequency when using PCM or not. The reason for increasing the values of temperature with increasing the magnitude of frequency is the increasing in the amount of heat exchange with time between water tank and the surface of condenser.

When the vibration increased from 0 V (static condition) to 14 V, the average percentage increases in temperature is approximately 13% for time after 1 PM for cases that not used PCM. While for the cases that used PCM, the average percentage increases in temperature is approximately 16% for time after 1 PM when change the frequency from 0 to 14 V.

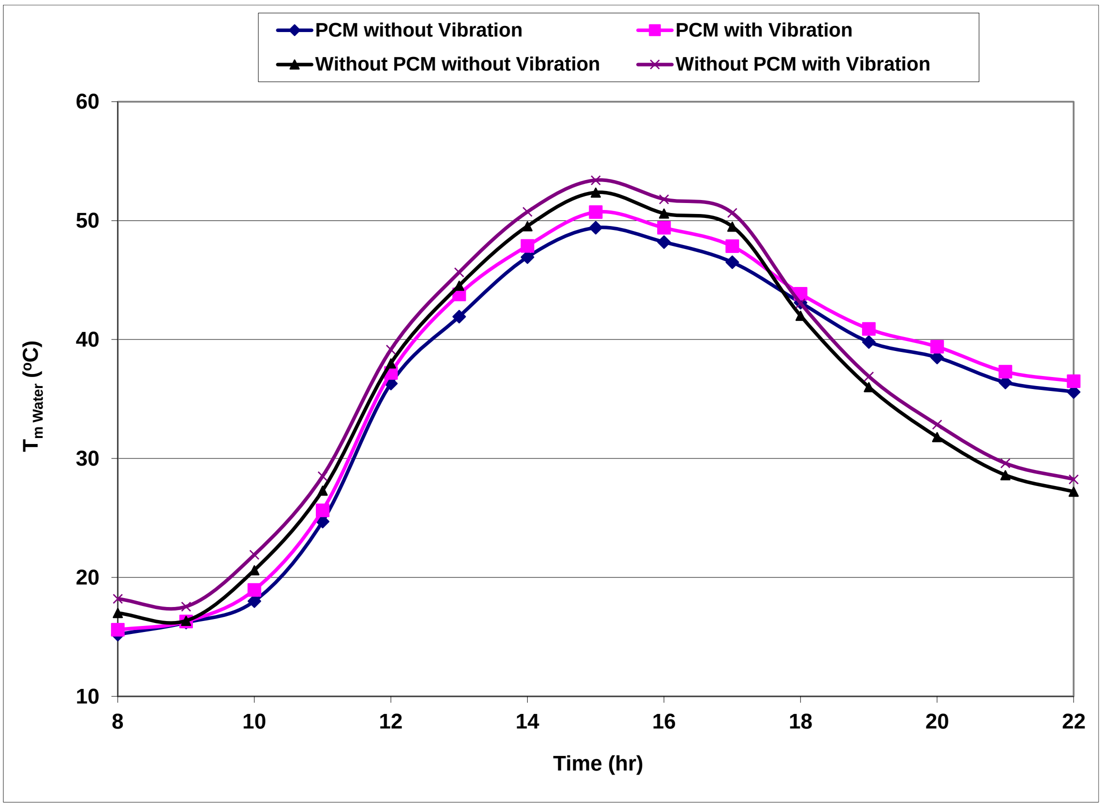


Figure 4. 9 The mean water temperature (applying 6 voltage)

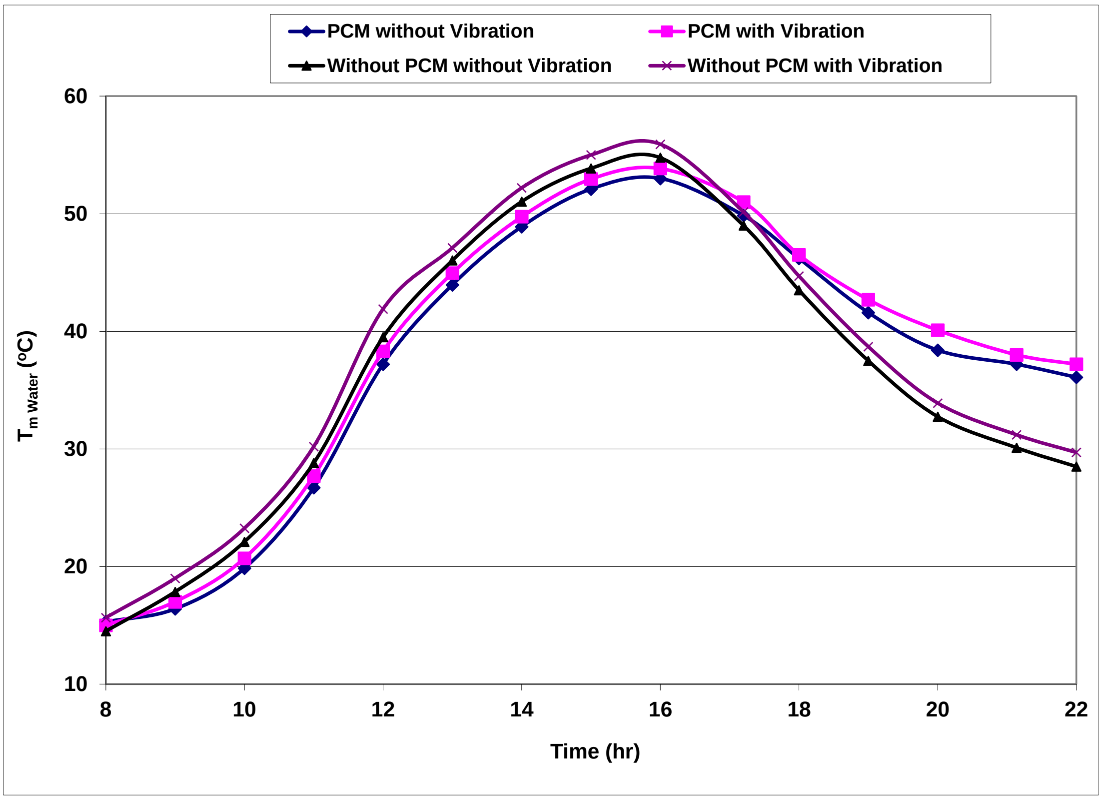


Figure 4. 10 The mean water temperature (applying 8 voltage)

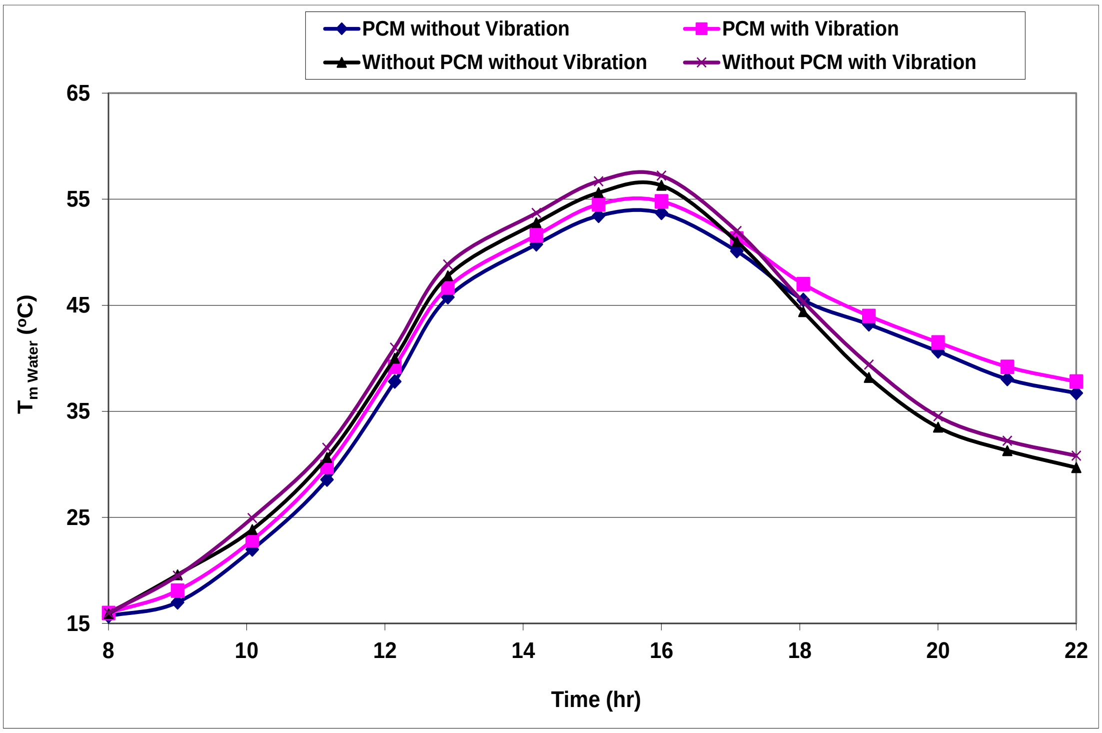


Figure 4. 11 The mean water temperature (applying 10 voltage)

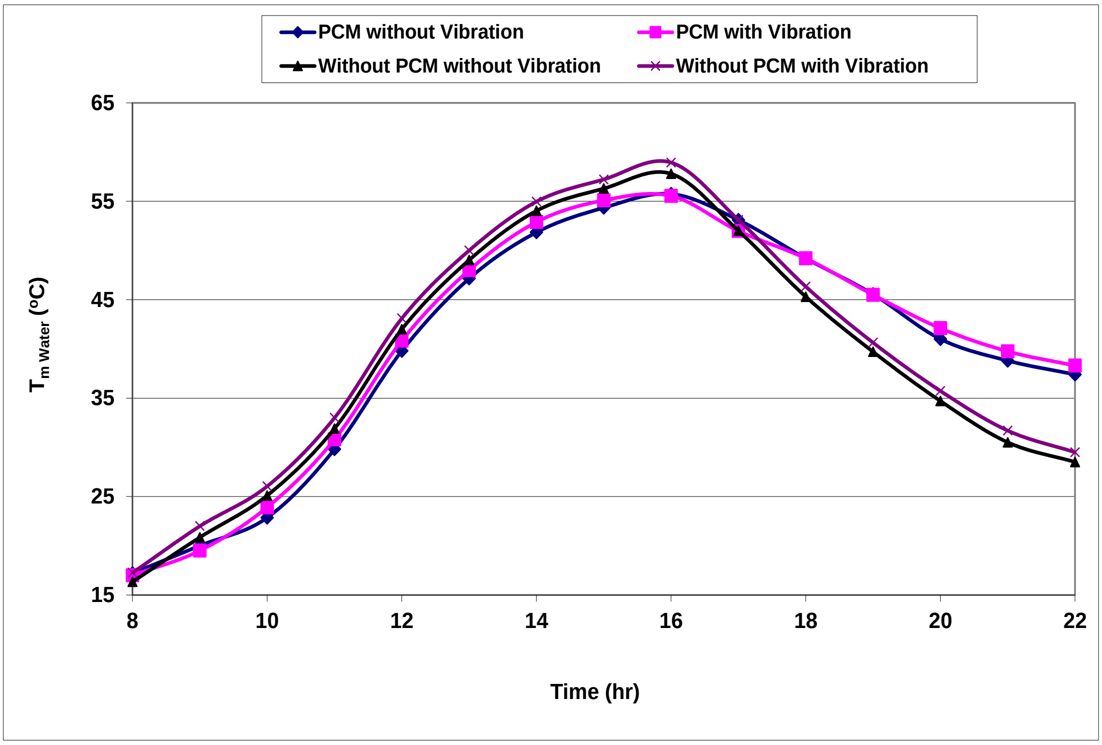


Figure 4. 12The mean water temperature (applying 12 voltage)

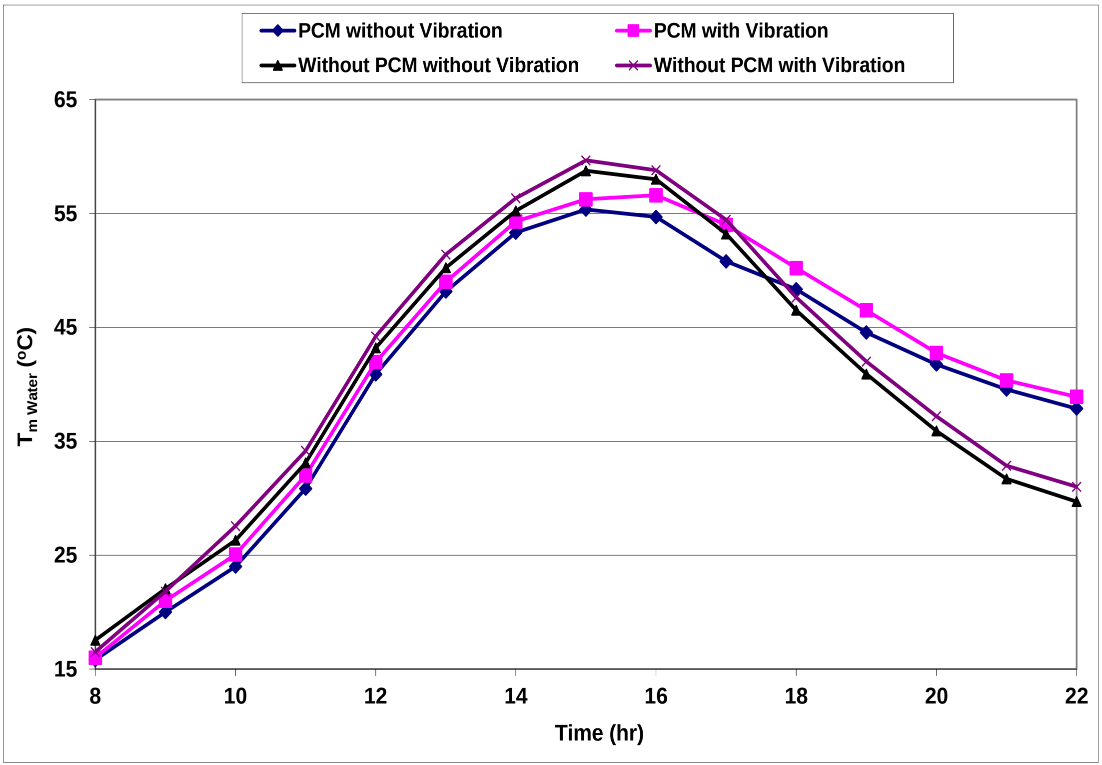


Figure 4. 13 The mean water temperature (applying 14 voltage)

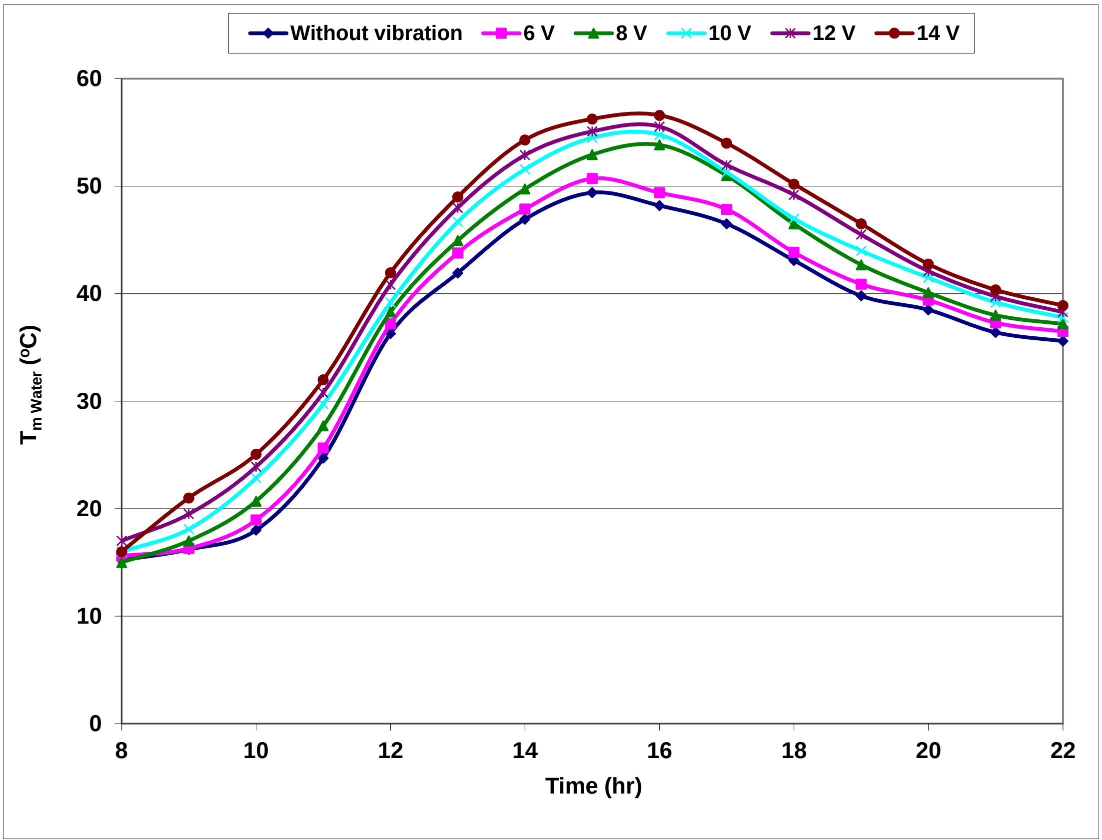


Figure 4. 14 The mean water temperature (with PCM)

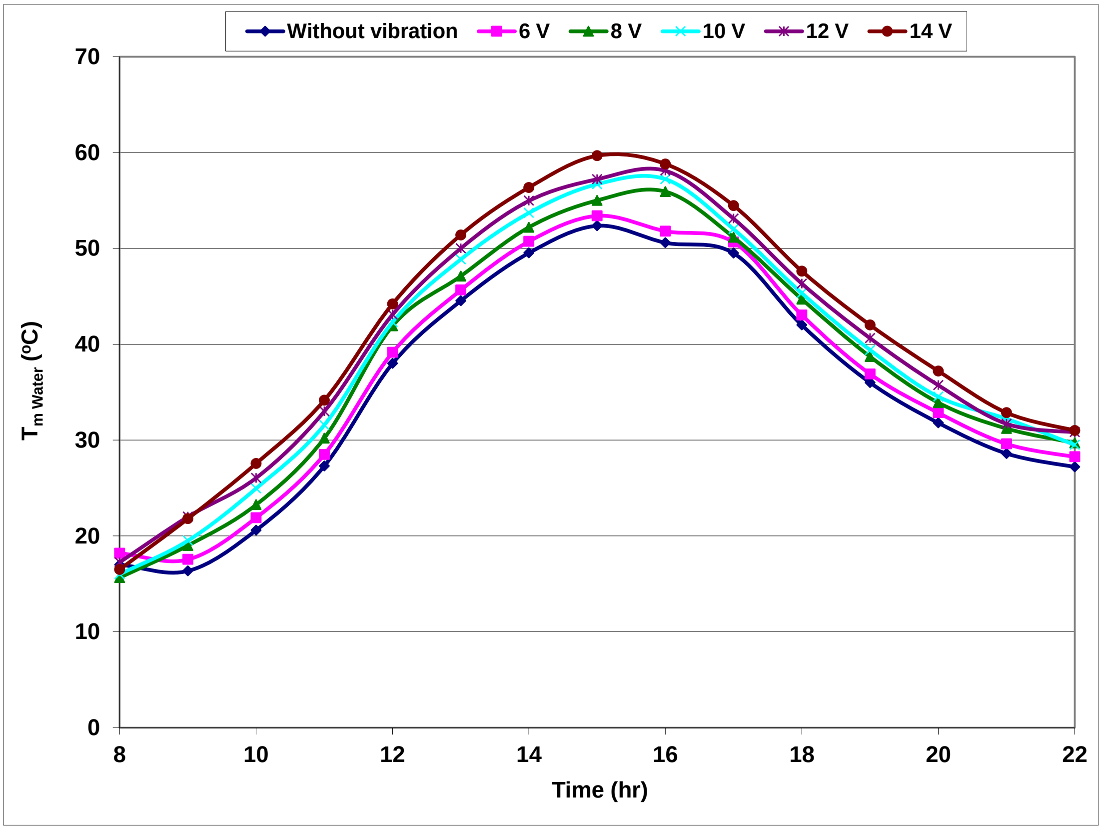


Figure 4. 15 The mean water temperature (without PCM)

4.3.2 Effect of Vibration on Thermosyphon Thermal Resistance

Figure 4.16-4.20 show the variation of the thermal resistance of the thermosyphon applying different values of vibration frequencies (from 6 V to 14 V). It can be seen for all cases that the thermal resistance decreased with the increasing of the solar radiation. Also, it can be observed that the thermal resistance decreased with increasing the magnitude of the vibration frequency. There are many advantages of applying the vibration on such system. The first advantage is to improve the boiling ball in the section of evaporator by exciting to generate the bubbles in the bottom and enclosement the surface of internal wall. This will lead to decrease the mean temperature of evaporator, where the value of evaporation heat transfer coefficient will increase [78]. The second advantage is breaking in the film layer that enclosement the surface of internal wall of the condenser section. Where the kind of condensation phenomena is changed from film wise to dropwise that yields to improve the operation of heat transfer that occurred between the water of tank and the fluid that used as working fluid, where the process will be continued the flowing of the fluid back to the section of evaporation that came from the section of condensation [76,77]. Furthermore, the applied vibration caused to change the distribution of temperature to be more uniform for the water inside tank via exfoliation layers that covered the condensation section of thermosyphon.

In order to show the effect of magnitude of vibration frequency on the thermal resistance of the evacuated tube heat pipe solar collector, it was made a comparison between all cases. Figure 4.21 shows the variation of thermal resistance with time when integrating PCM with the system. While Fig. 4.22 shows the variation of thermal resistance with time when not integrating PCM with the system. It can be noticed that the values of the thermal resistance decreased when the vibration frequency increased for both cases (with and without PCM). The average percentage reduction in the thermal resistance for cases (without PCM and with PCM), when the vibration frequency change from (0 V to 14 V) found (17% and 27%), respectively.

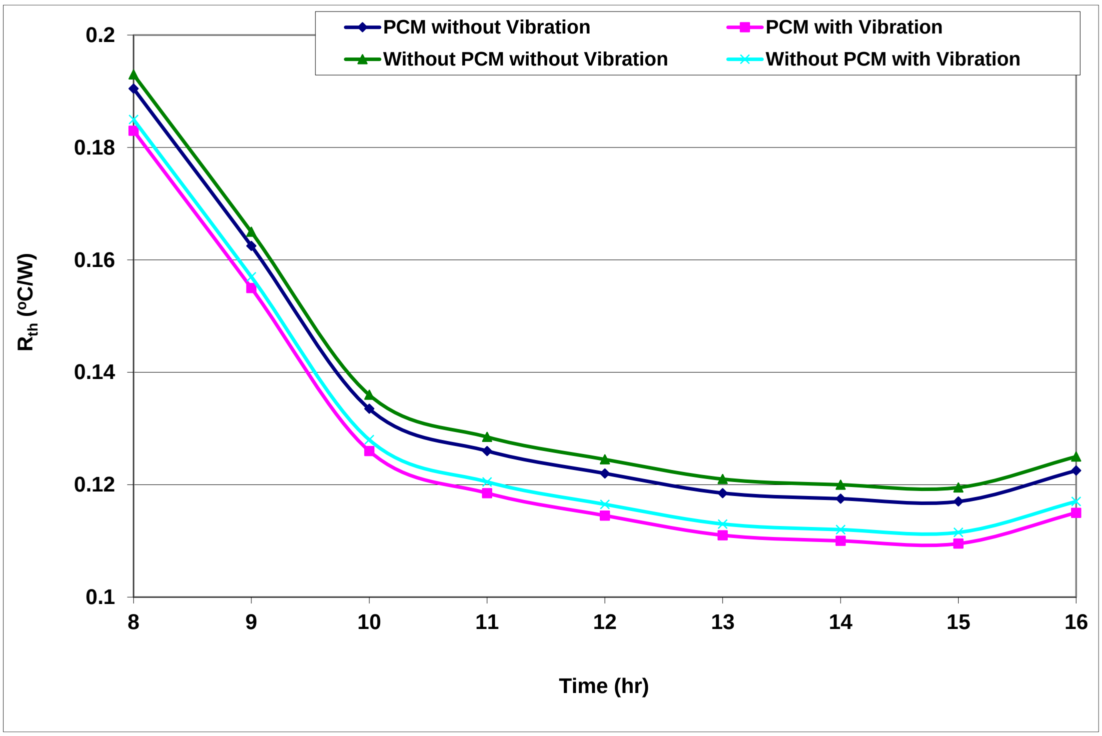


Figure 4. 16 The thermosyphon thermal resistance with time (applying 6V)

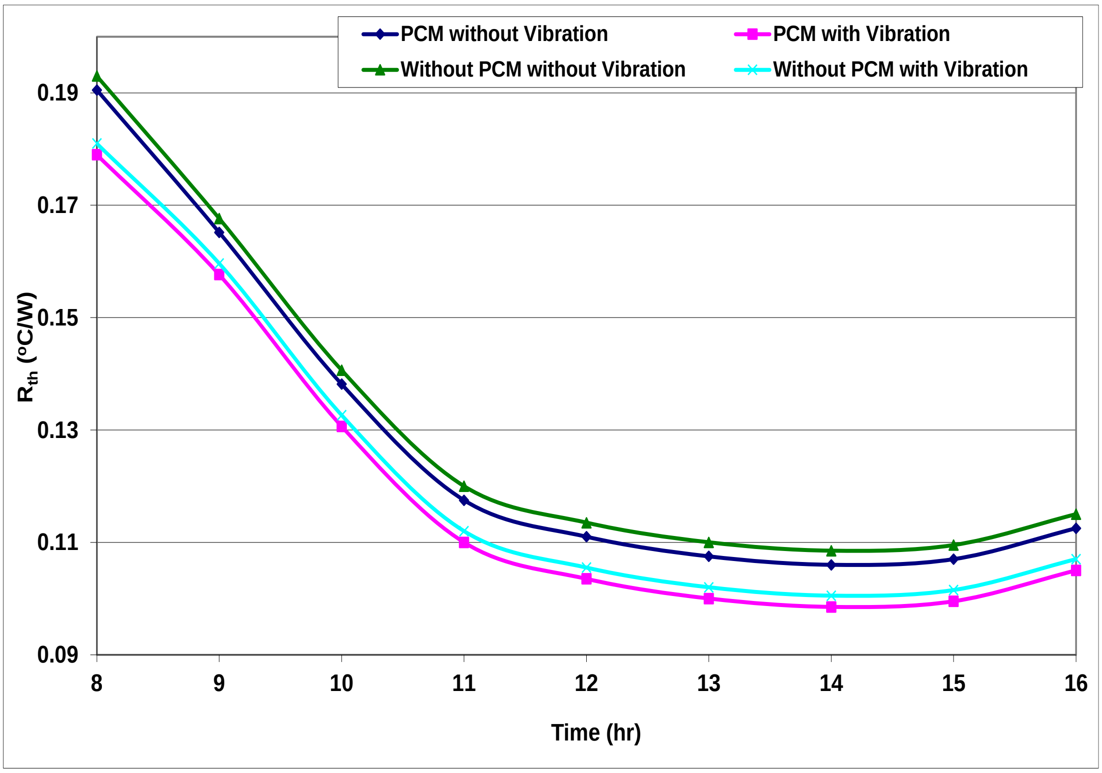


Figure 4. 17 The thermosyphon thermal resistance with time (applying 8V)

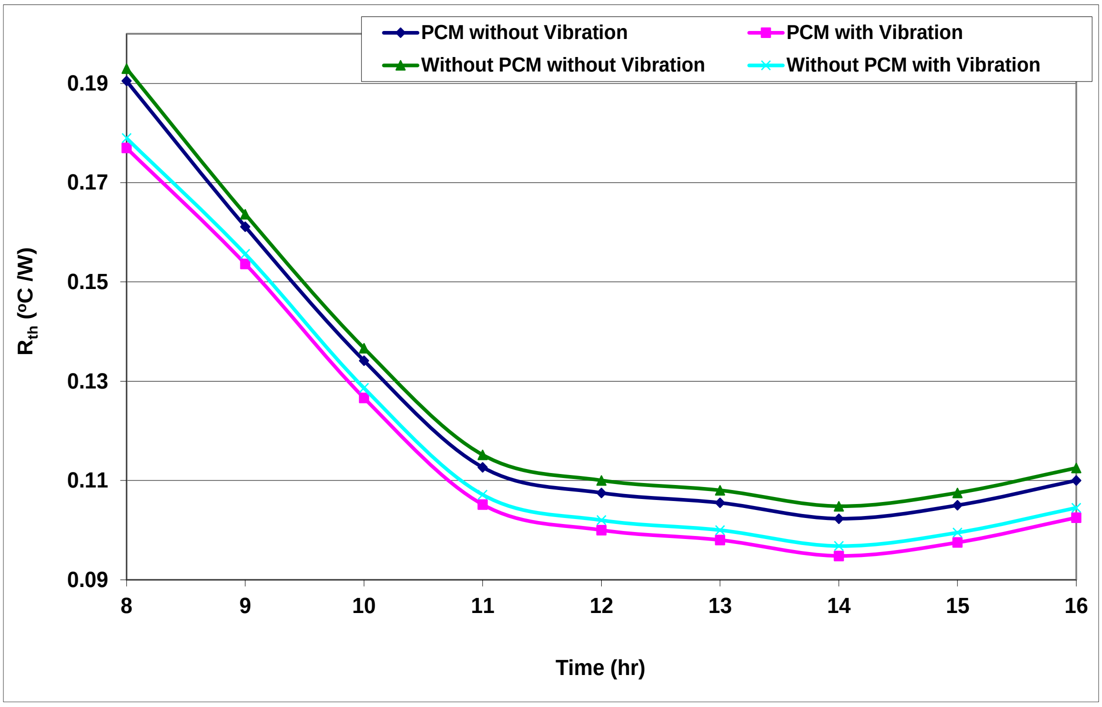


Figure 4. 18The thermosyphon thermal resistance with time(applying 10V)

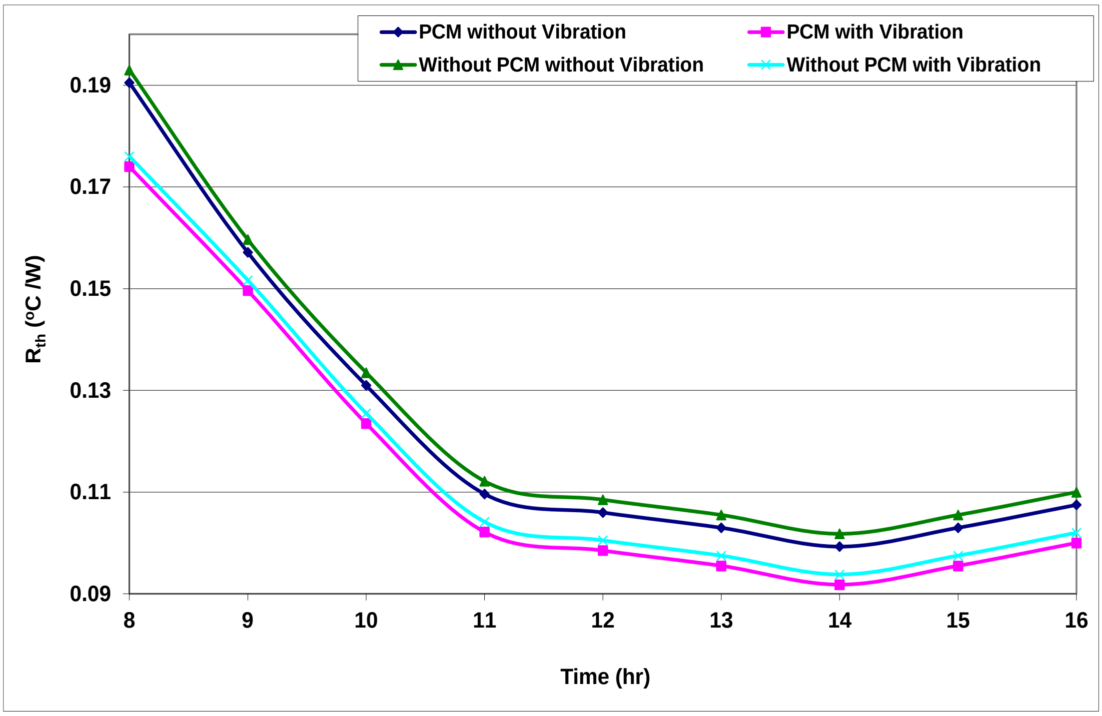


Figure 4. 19 The thermosyphon thermal resistance with time (applying 12V)

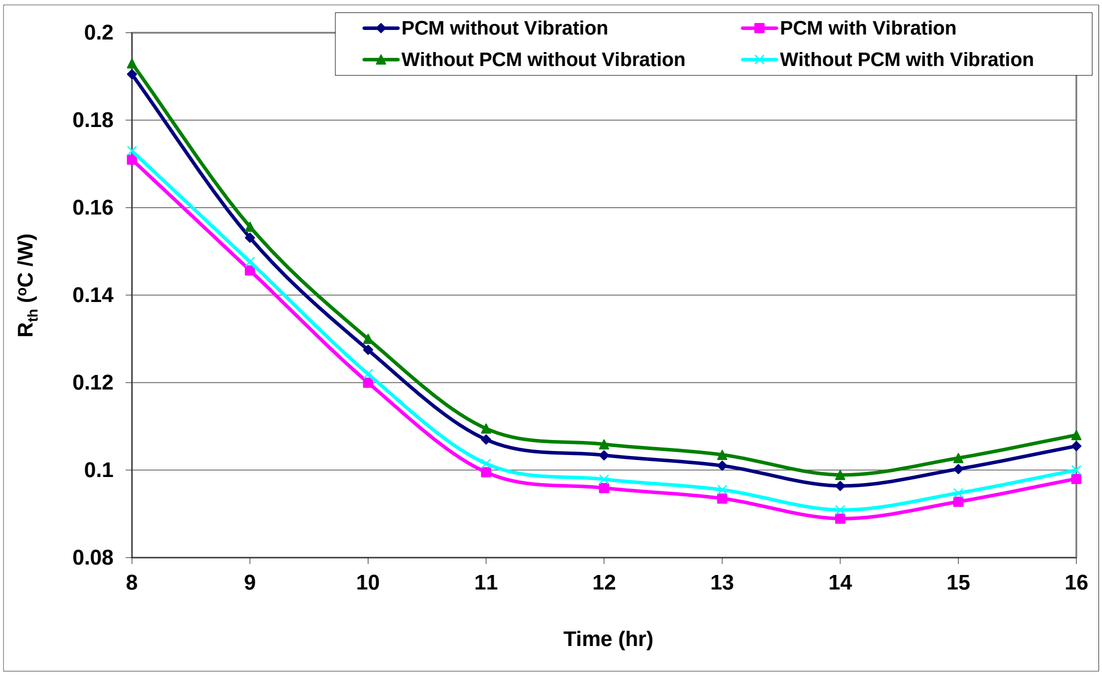


Figure 4. 20 The Thermosyphon thermal resistance with time (applying 14V)

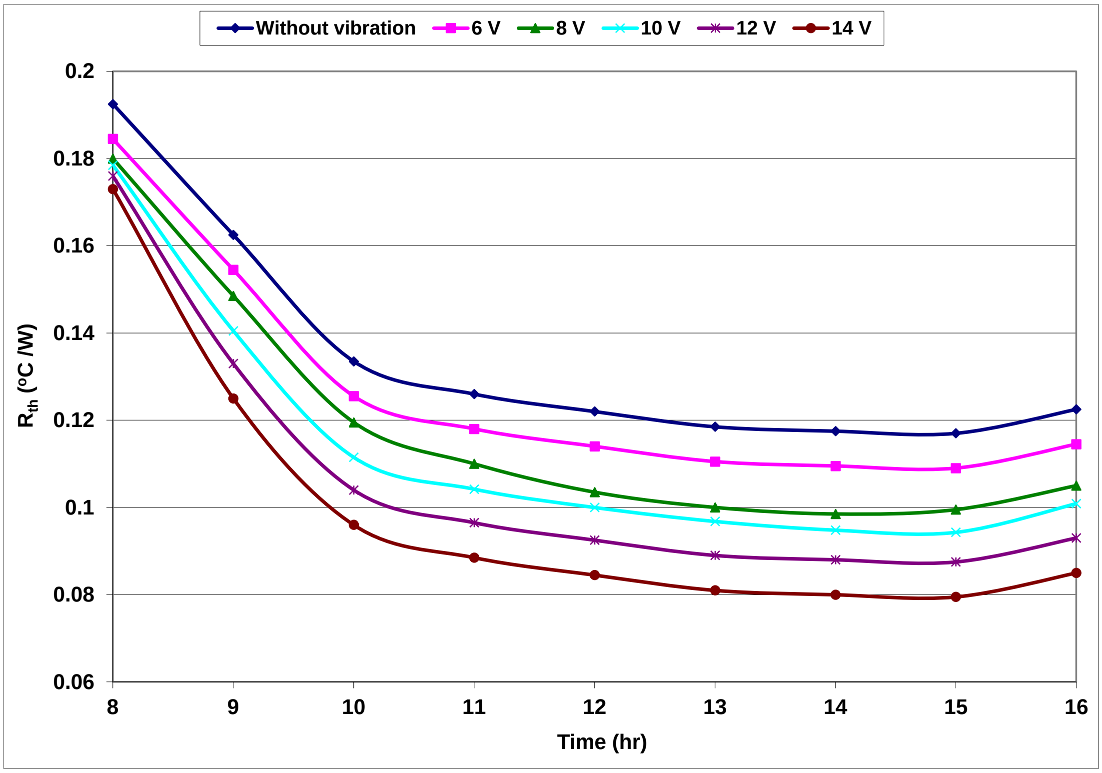


Figure 4. 21 Variation of Thermosyphon thermal resistance with time when applied different vibrational frequencies (without PCM)

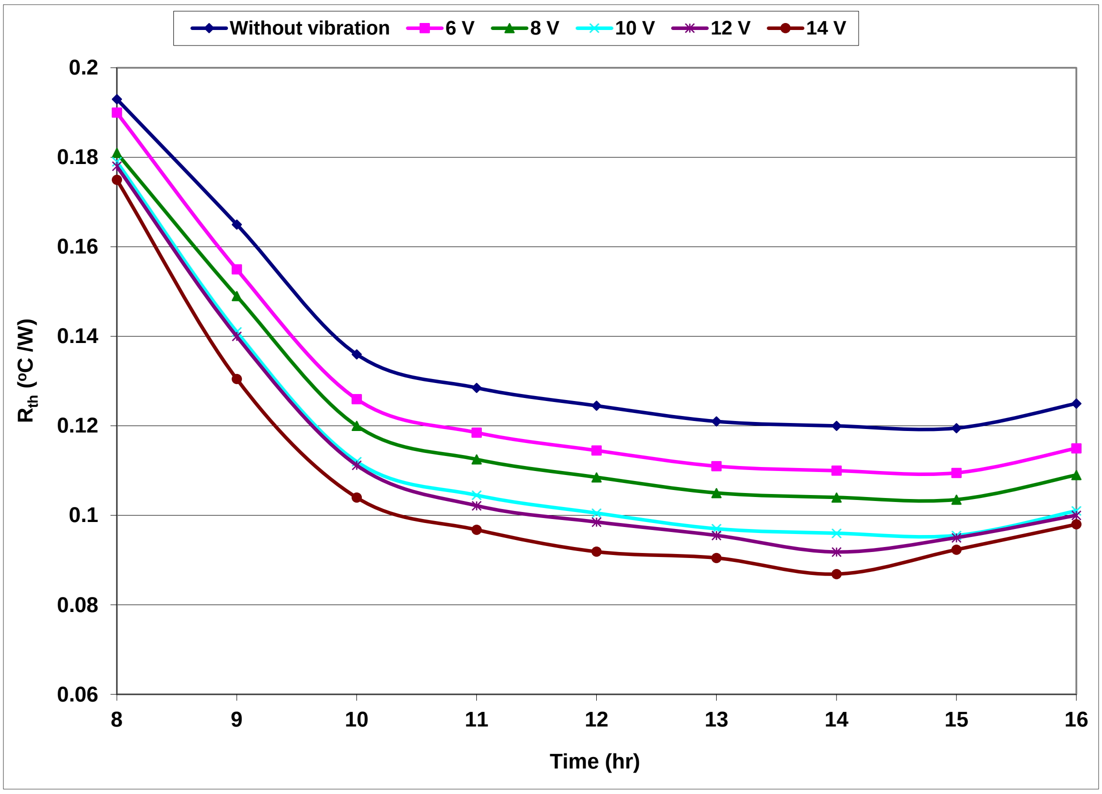


Figure 4. 22 Variation of the thermal resistance when applied different vibrational frequencies (with PCM)

4.3.3 Effect of Vibration on Evaporator Heat Transfer Coefficient

It can be divided the evaporation heat transfer coefficient (EHTC) into two kinds of the internal liquids. The first one is the region of pool liquid that located at bottom side in the evaporator section. While, the other one is the continuous film liquid that flow back from the condenser section. Where, this flowing expands from the surface of liquid pool to the lower end of condenser [77,78]. The sum of the two coefficients is equal to the evaporation heat transfer coefficient (EHTC).

Figure 4.23-4.27 show the variation of evaporator heat transfer coefficient (EHTC) with time when applied different values of the vibration frequencies. It can be seen that all cases have the same behavior during the operation time and the difference between them is small under the same condition (same frequency). These differences increased dramatically when the values of the vibration frequency increased. In the other words, it can be said that the values of evaporator heat transfer coefficient increased when the vibration frequency increased too.

Figure 4.28 and 4.29 illustrate the variation of the evaporator heat transfer coefficient (EHTC) with time when integrating and not integrating PCM with the system. It can be noticed that the values of the evaporator heat transfer coefficient increased when the vibration frequency increased for both cases (with and without PCM). The average percentage increment in the evaporator heat transfer coefficients for cases (with PCM and without PCM), when the vibration frequency changed from (0 to 14V) are found approximately 30% for both cases when the peak value occurred (12:00).

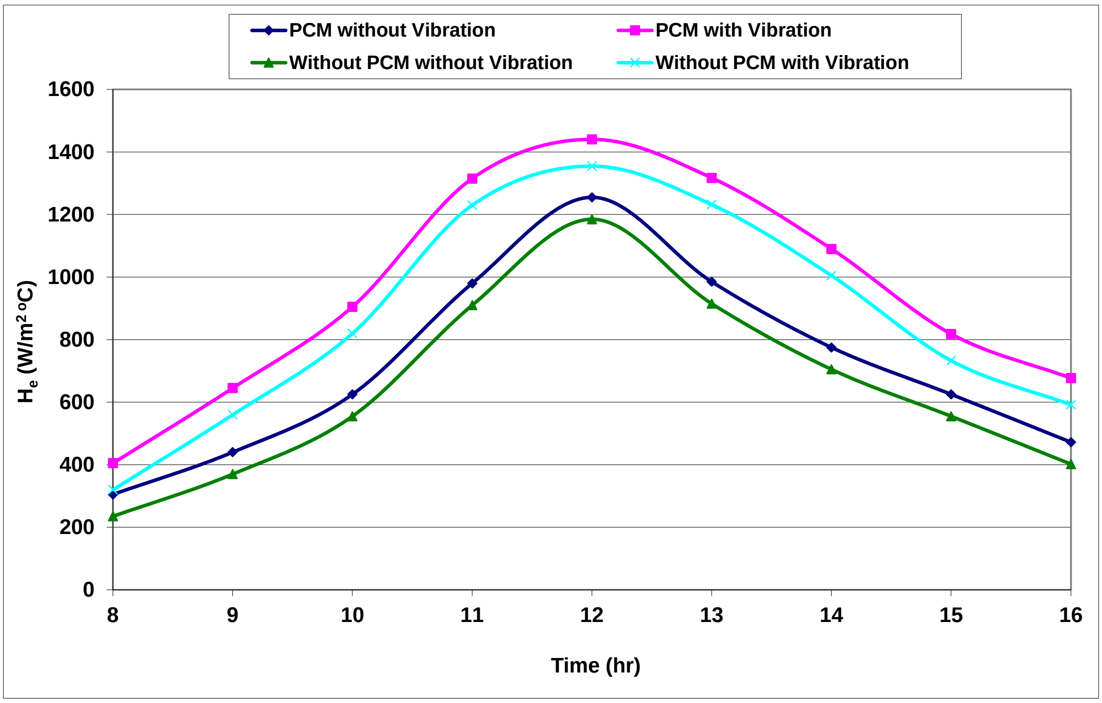


Figure 4. 23 Variation of evaporator heat transfer coefficient with time. (applying 6 V)

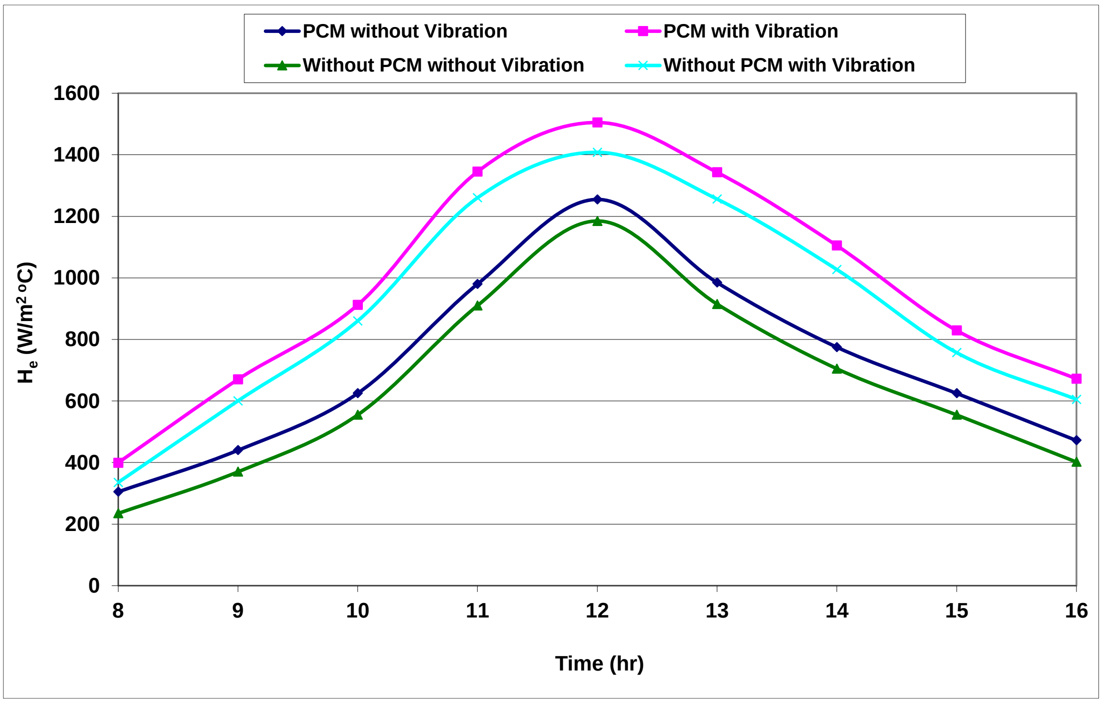


Figure 4. 24 Variation of evaporator heat transfer coefficient with time. (applying 8 V)

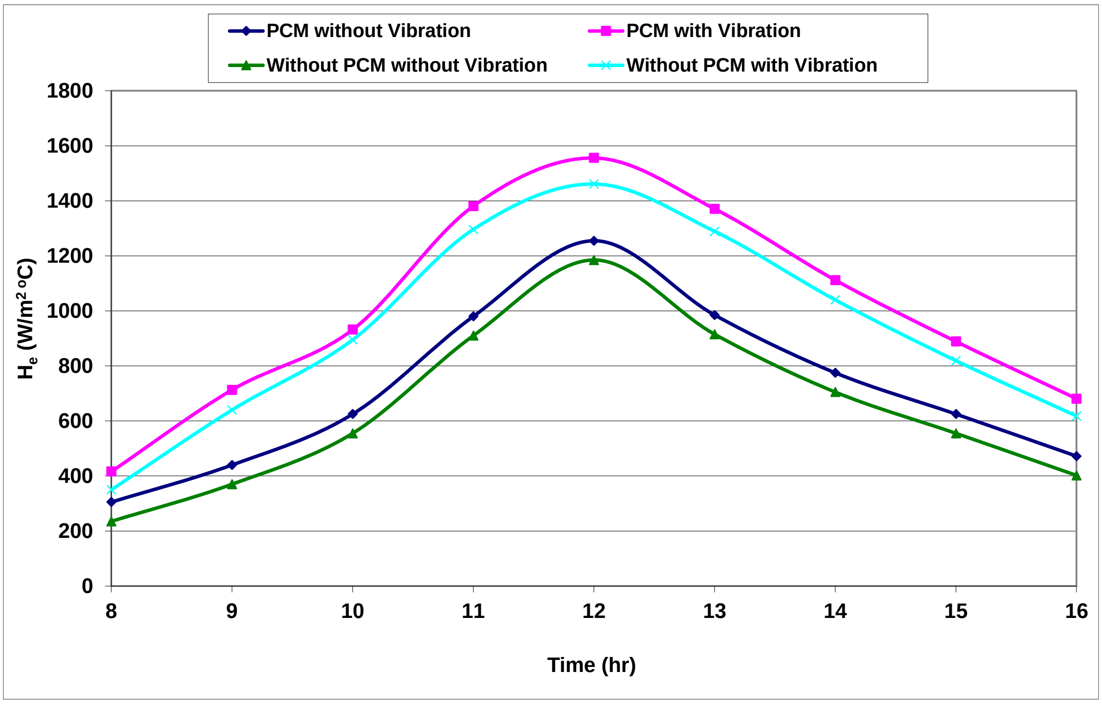


Figure 4. 25 Variation of evaporator heat transfer coefficient with time. (applying 10 V)

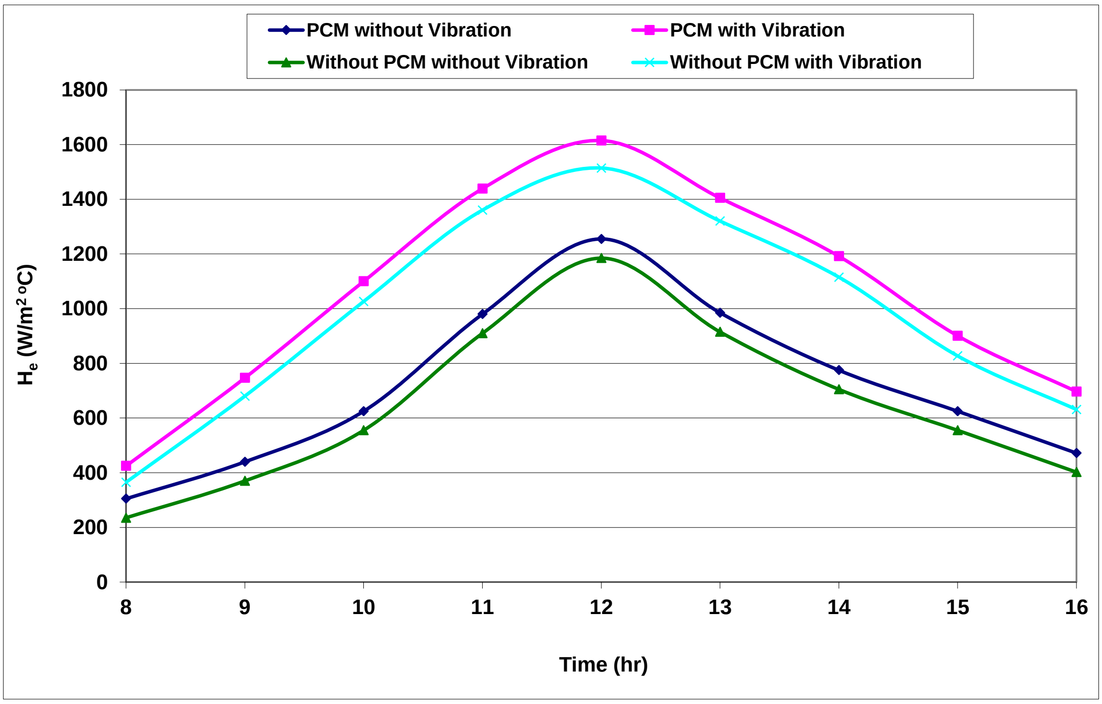


Figure 4. 26 Variation of evaporator heat transfer coefficient with time. (applying 12 V)

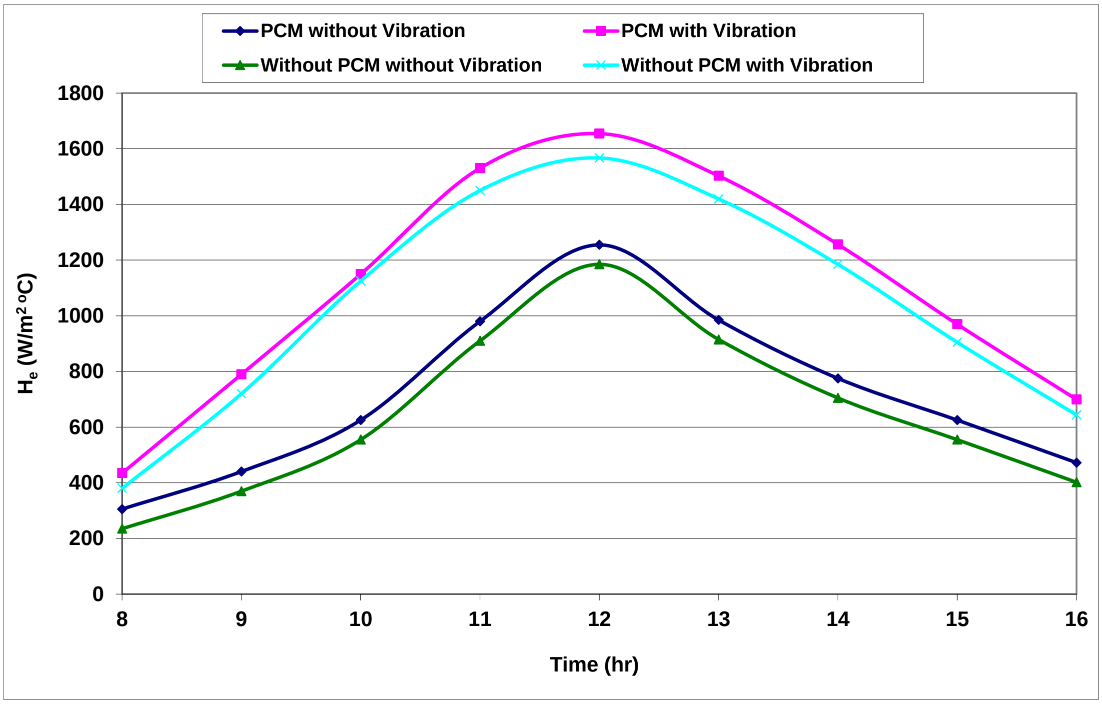


Figure 4. 27 Variation of evaporator heat transfer coefficient with time. (applying 14 V)

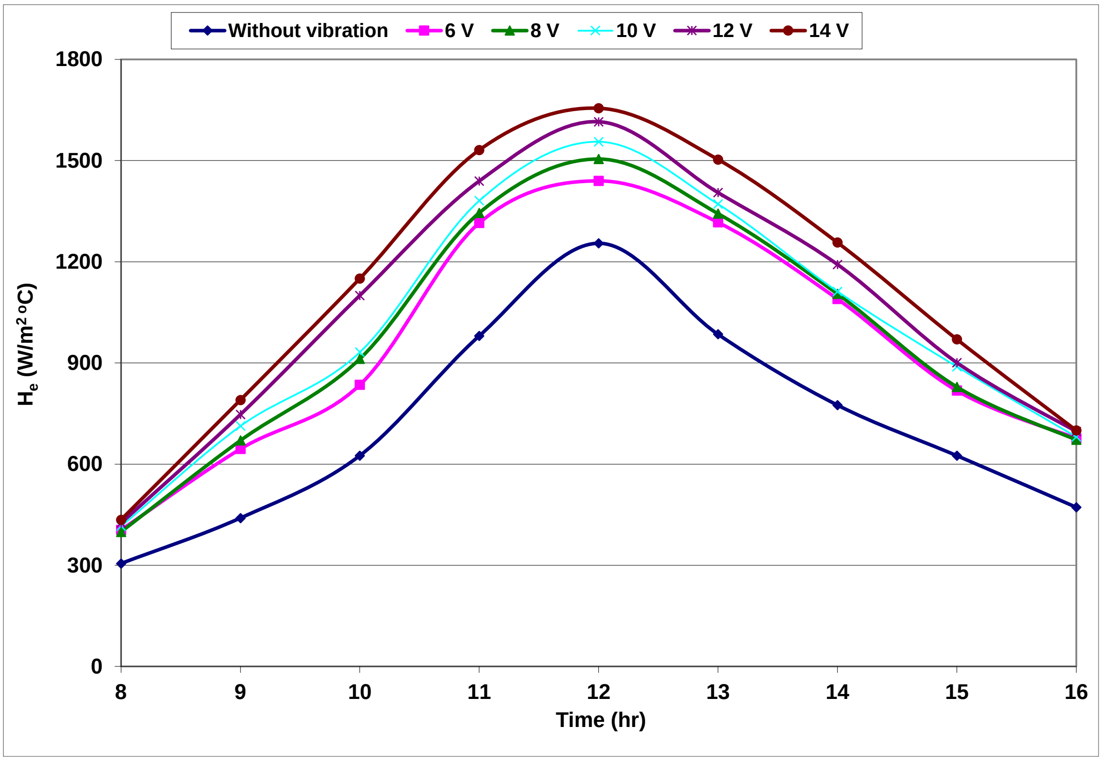


Figure 4. 28 Variation of evaporator heat transfer coefficient with time when applied different vibrational frequencies (with PCM)

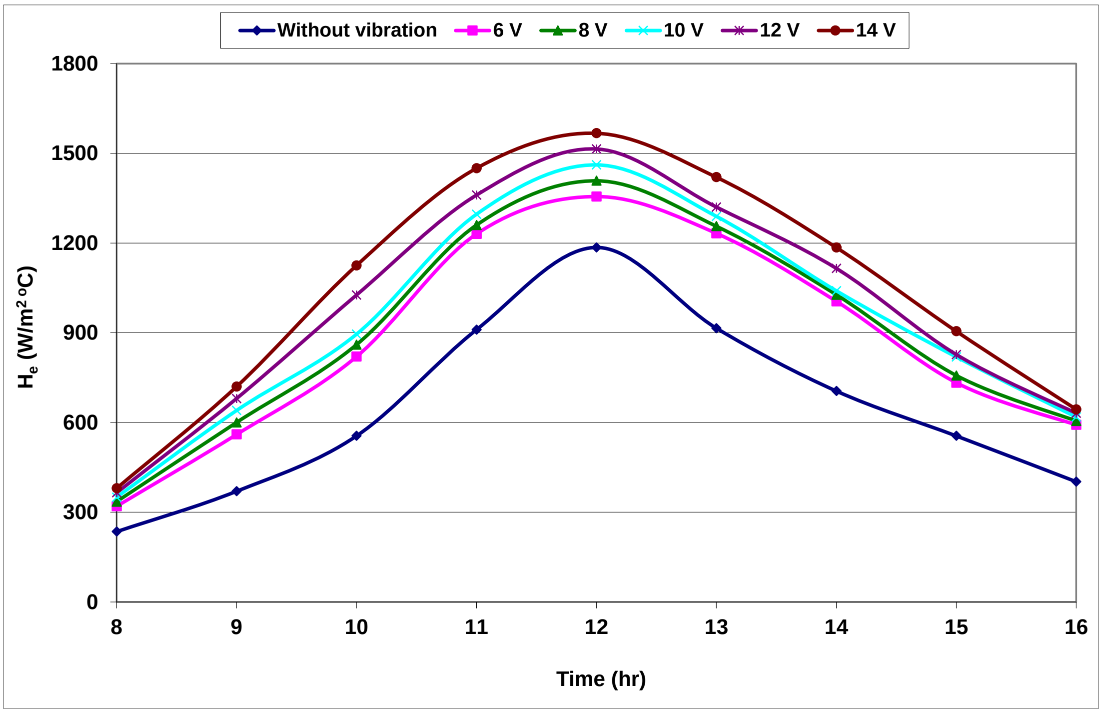


Figure 4. 29 Variation of evaporator heat transfer coefficient with time when applied different vibrational frequencies (without PCM)

4.3.4 Effect of Vibration on Condenser Heat Transfer Coefficient

It can be considered the growth in the heat transfer coefficients is the main key to enhance the performance of the all types of heat pipe systems. Therefore, it should be used an approach to achieve the aim such as applying vibration on the system.

Figure 4.30-4.34 show the variation of the condenser heat transfer coefficient with time for the same cases and under the same conditions (the system with and without PCM). Based on the results, it can be seen that the behavior for all cases are similar during the experiment time. Where, the values of the condenser heat transfer coefficient when using PCM is higher than those without PCM, but the difference between them is not large.

However, it can be seen a significant difference when applied the vibration on the system as shown in Figs. 4.35 and 4.36. Where the values of the condenser heat transfer coefficient (CHTC) increased when the vibration frequency increased as well. The maximum values of the CHTC occurred at time 12:00. The average percentage increment in the condenser heat transfer coefficients for cases (with PCM and without PCM), when the vibration frequency changed from (0 v to 14v) are found approximately 25% for both cases when the peak value occurred (12:00).

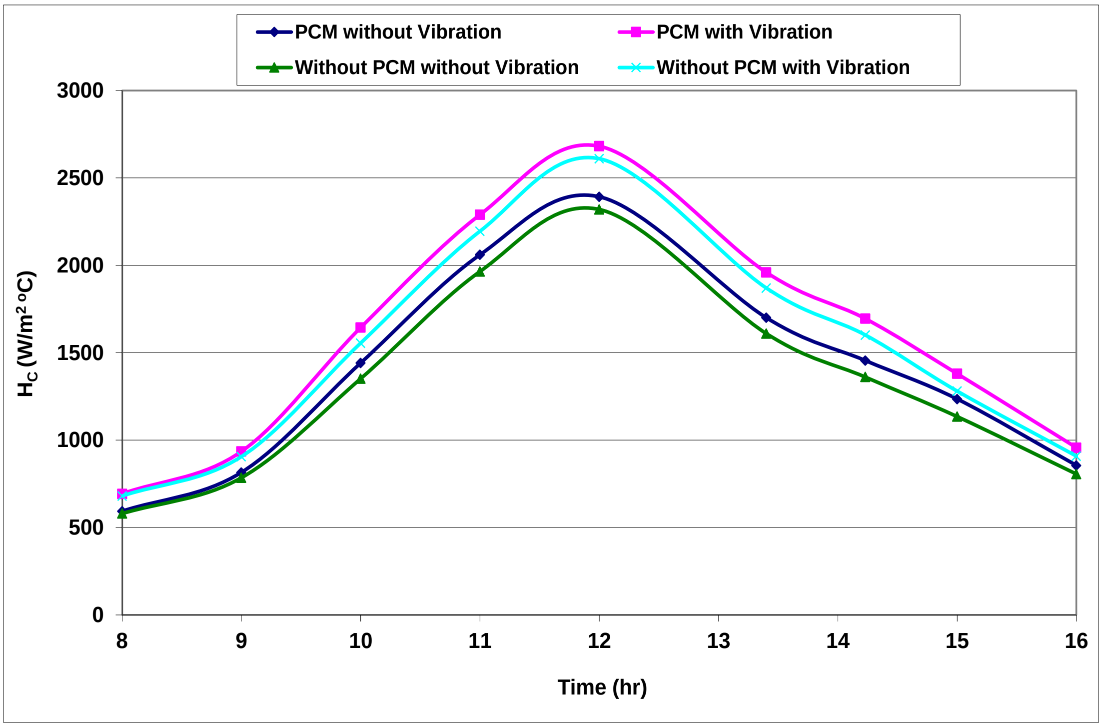


Figure 4. 30 Variation of condenser heat transfer coefficient with time. (applying 6 V)

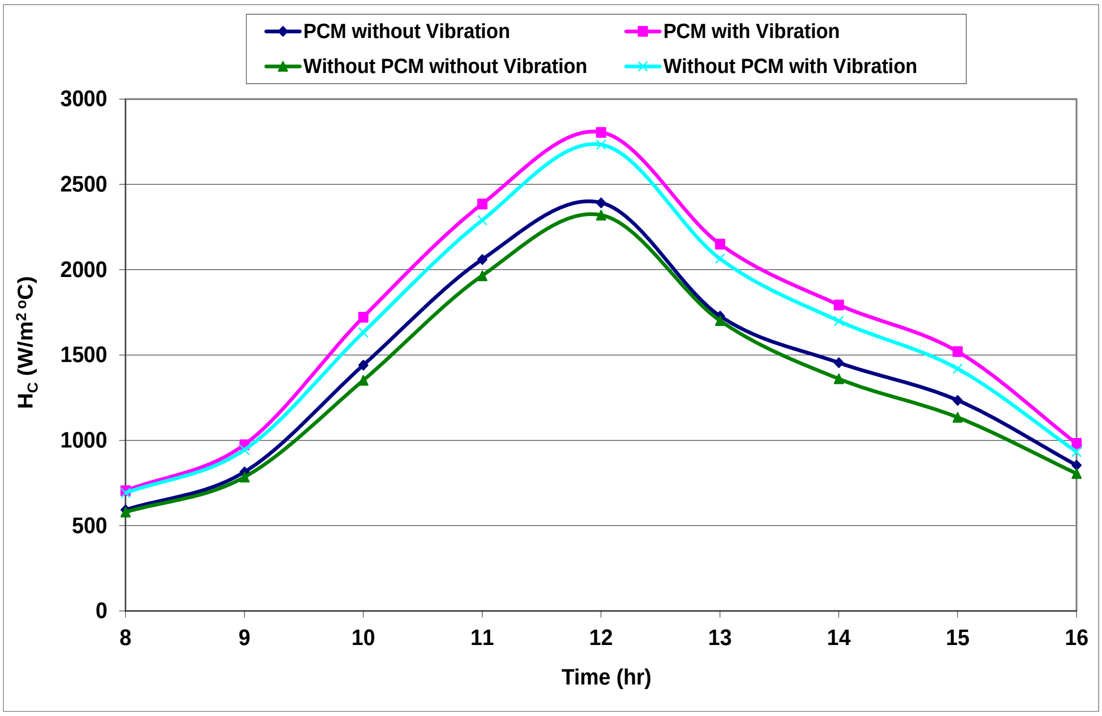


Figure 4. 31 Variation of condenser heat transfer coefficient with time. (applying 8V)

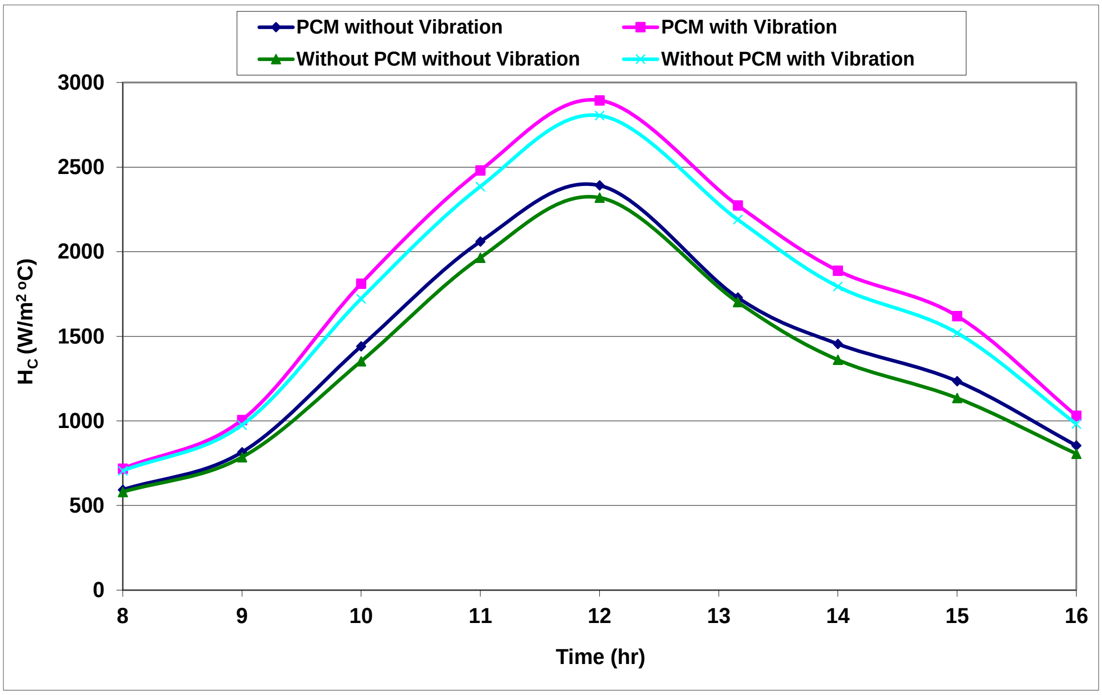


Figure 4. 32 Variation of condenser heat transfer coefficient with time. (applying 10 voltage)

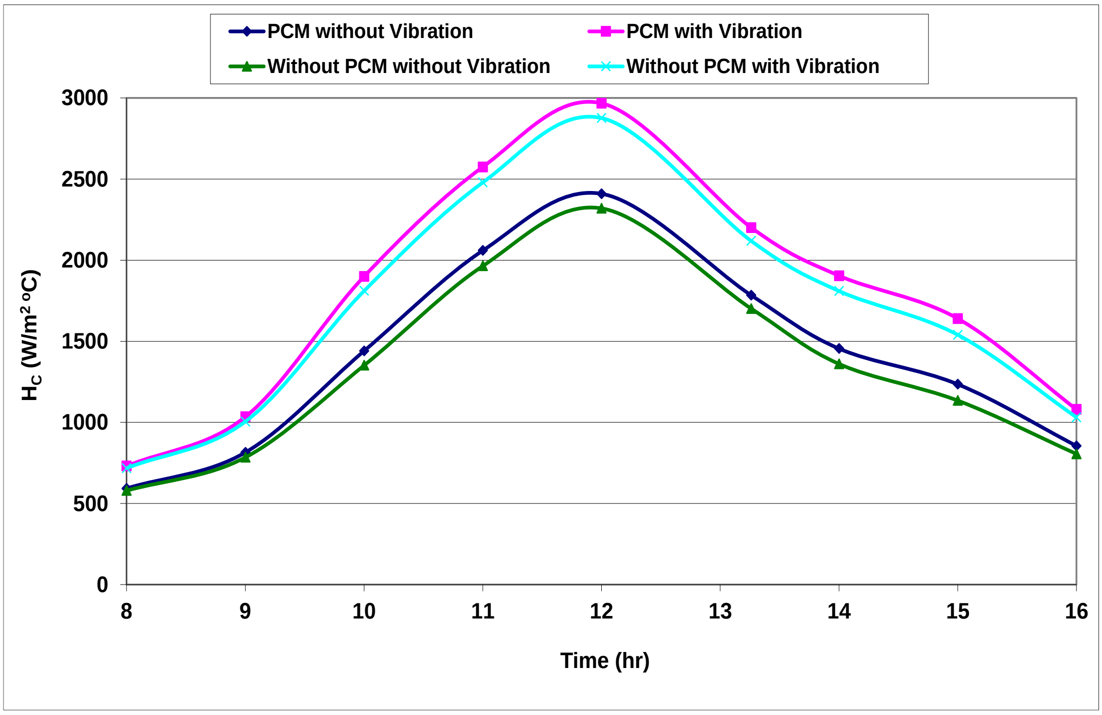


Figure 4. 33 Variation of condenser heat transfer coefficient with time. (applying 12 V)

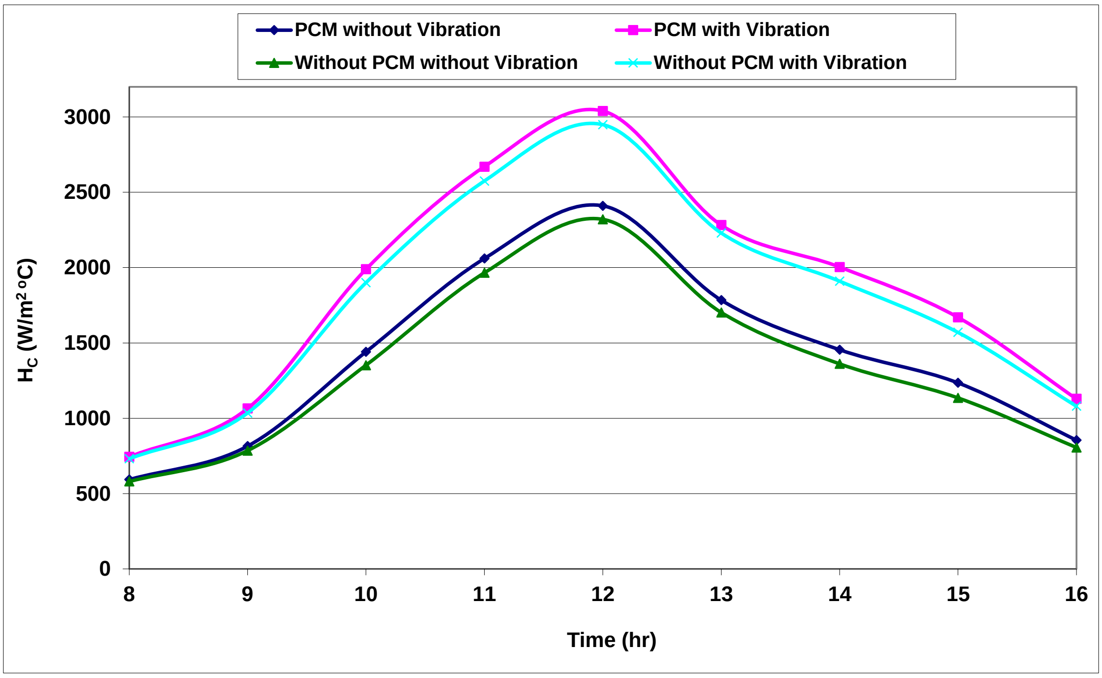


Figure 4. 34 Variation of condenser heat transfer coefficient with time. (applying 14 V)

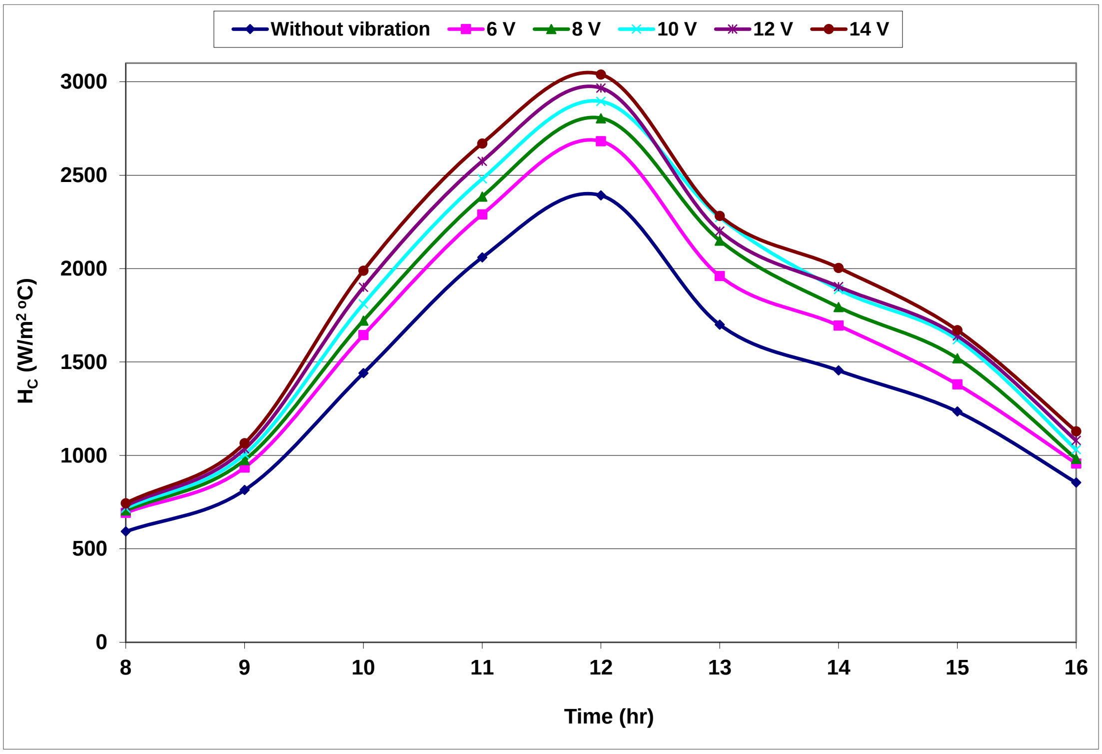


Figure 4. 35 Variation of condenser heat transfer coefficient with time when applied different vibrational frequencies (with PCM)

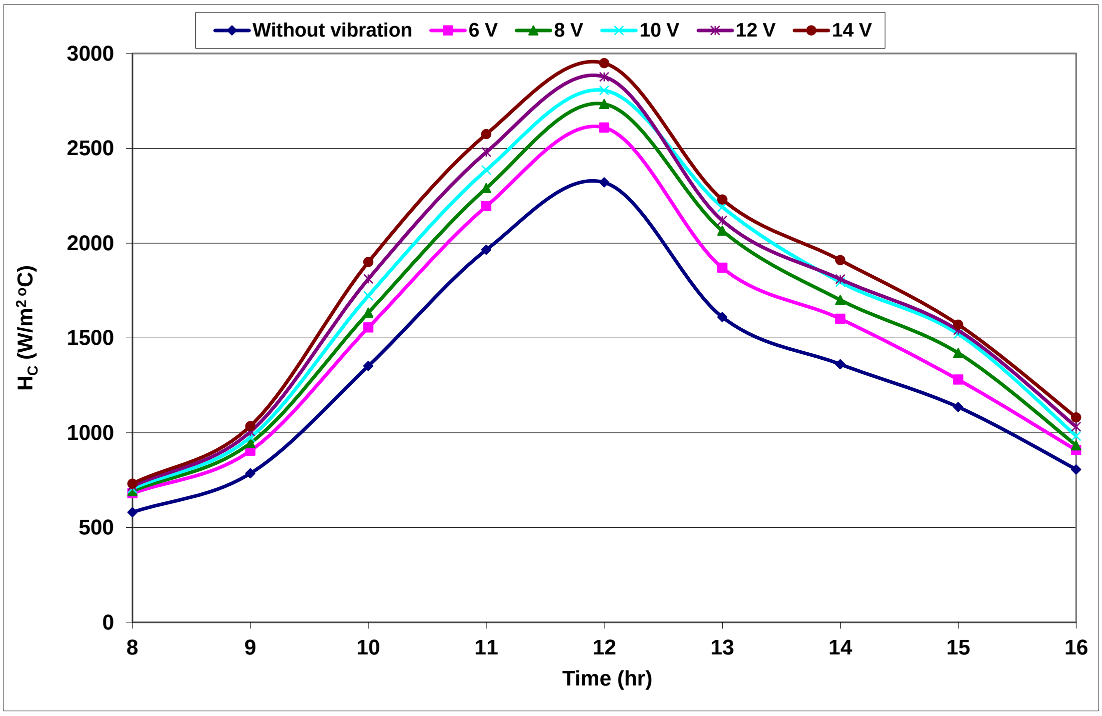


Figure 4. 36 Variation of condenser heat transfer coefficient with time when applied different vibrational frequencies (without PCM)

4.3.5 Effect of Vibration on Efficiency

This section spotlights on the effect of vibration frequency on the efficiency of the evacuated tube heat pipe solar collector during the whole period of the experimental work. Figures 4.37-4.41 exhibit the variation of efficiency of the system during the day of the experimental work when applied five different values of vibration frequencies (6, 8, 10, 12 and 14 v). It was studied the same four different cases that are without PCM (without vibration), without PCM (vibration), with PCM (without vibration), and with PCM (with vibration). It can be seen from the results, which the lowest values of efficiency occurred morning early where the lowest values of the overall solar are occurred. The highest values of the efficiency occurred at the noontime during the whole test period. The reason behind such results is the peak values of the solar radiation occurred at this time. Where, this will lead to increase the amount of absorbed heat in the section of evaporation compared with the remaining time of the test.

Generally, it can be observed an enhancement in the values of efficiency when applied the vibration on the system as shown in Figs. 4.42 and 4.43. Where, the values of efficiency increased when vibration frequency increased as well. Where, the maximum values of efficiency occurred at time 13:00 (1 PM). The efficiency of the system when using PCM increased from 60% to 78% at 1 PM when the influence of vibration frequency changed from (0 to 14 V). While the efficiency of the system without PCM increased from 57% to 76% at 1 PM when the influence of vibration frequency changed from (0 to 14 V). Generally, the efficiency increased when using the PCM without vibration, but the change in the values of efficiency is small and not exceeds 5 %.

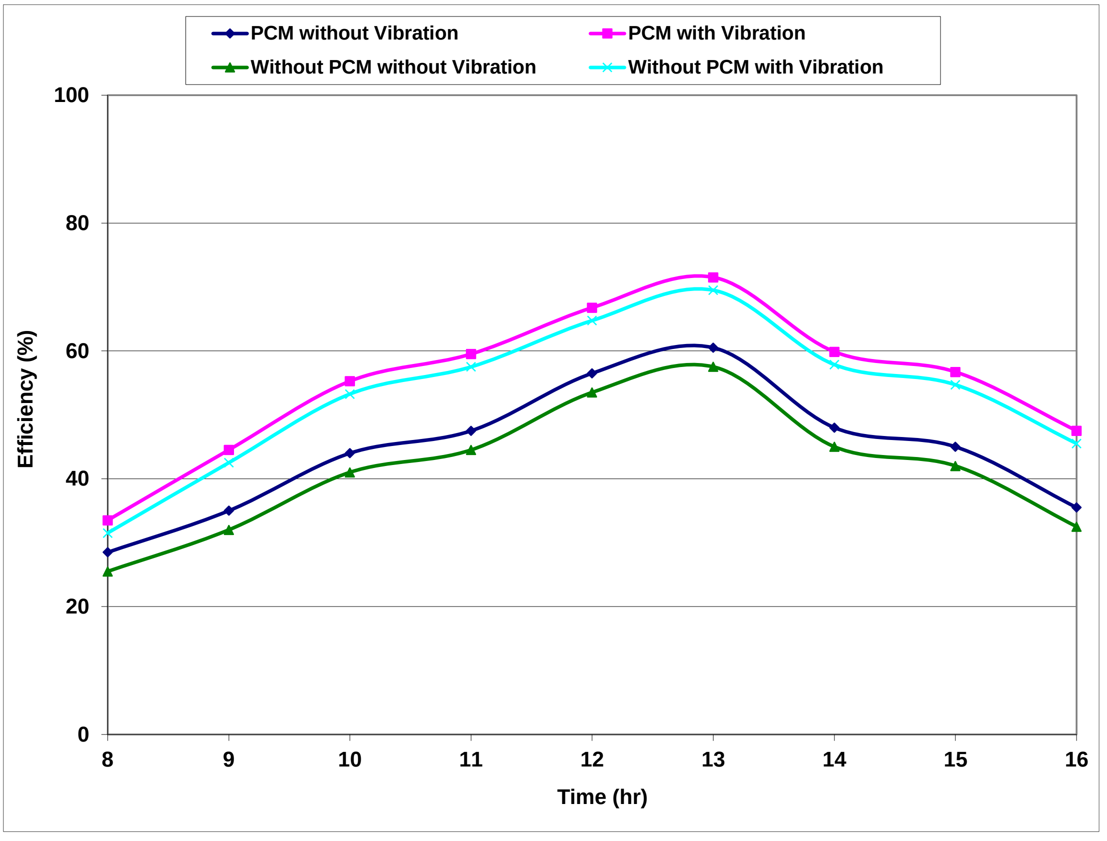


Figure 4. 37 Variation of efficiency with time. (applying 6 V)

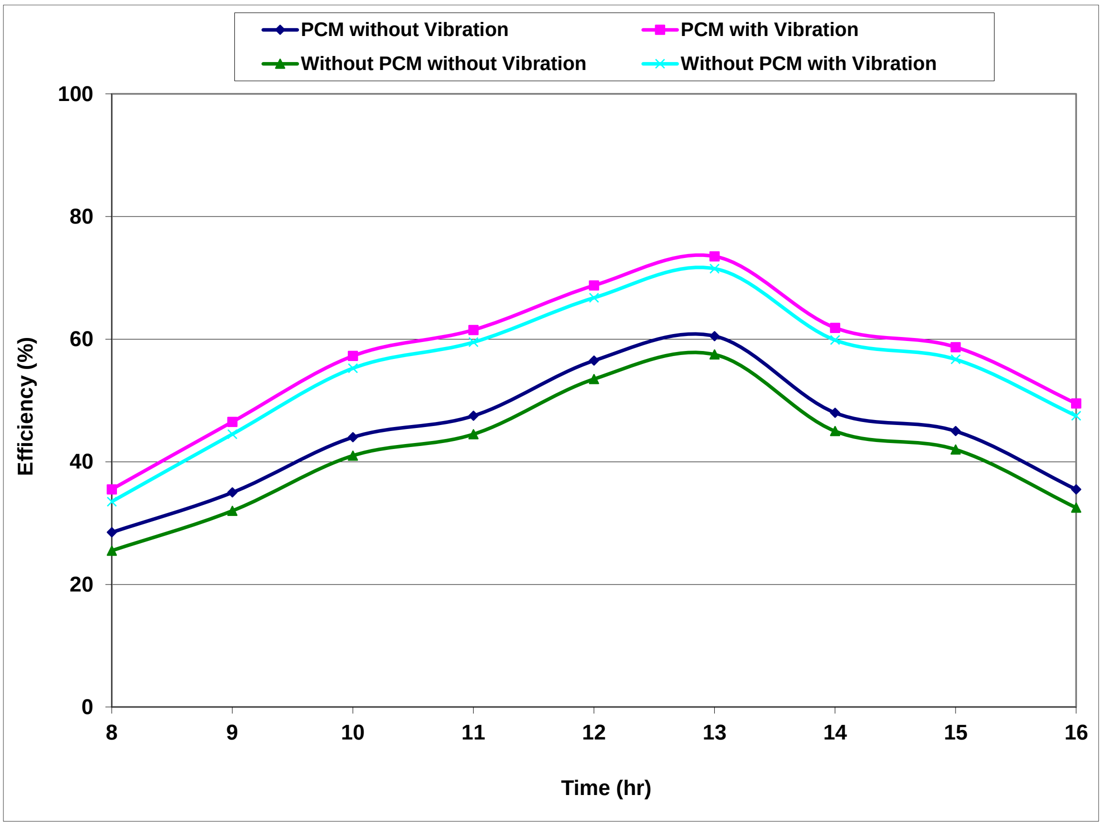


Figure 4. 38 Variation of efficiency with time. (applying 8 V)

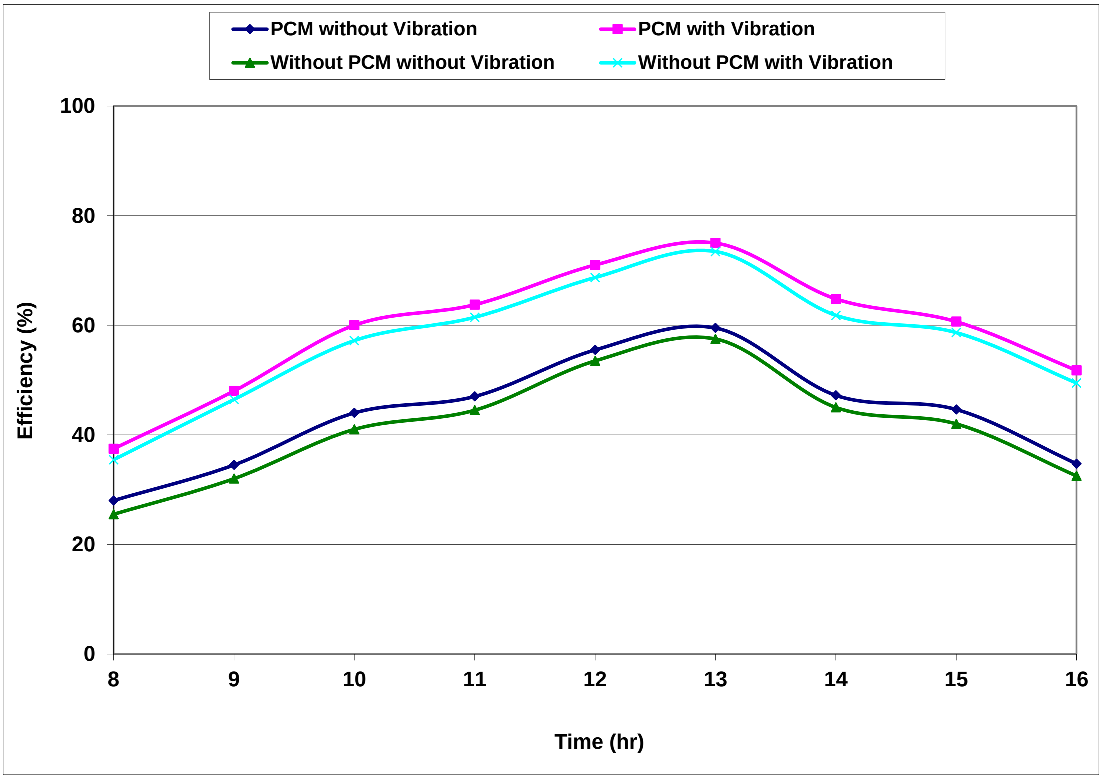


Figure 4. 39 Variation of efficiency with time. (applying 10 V)

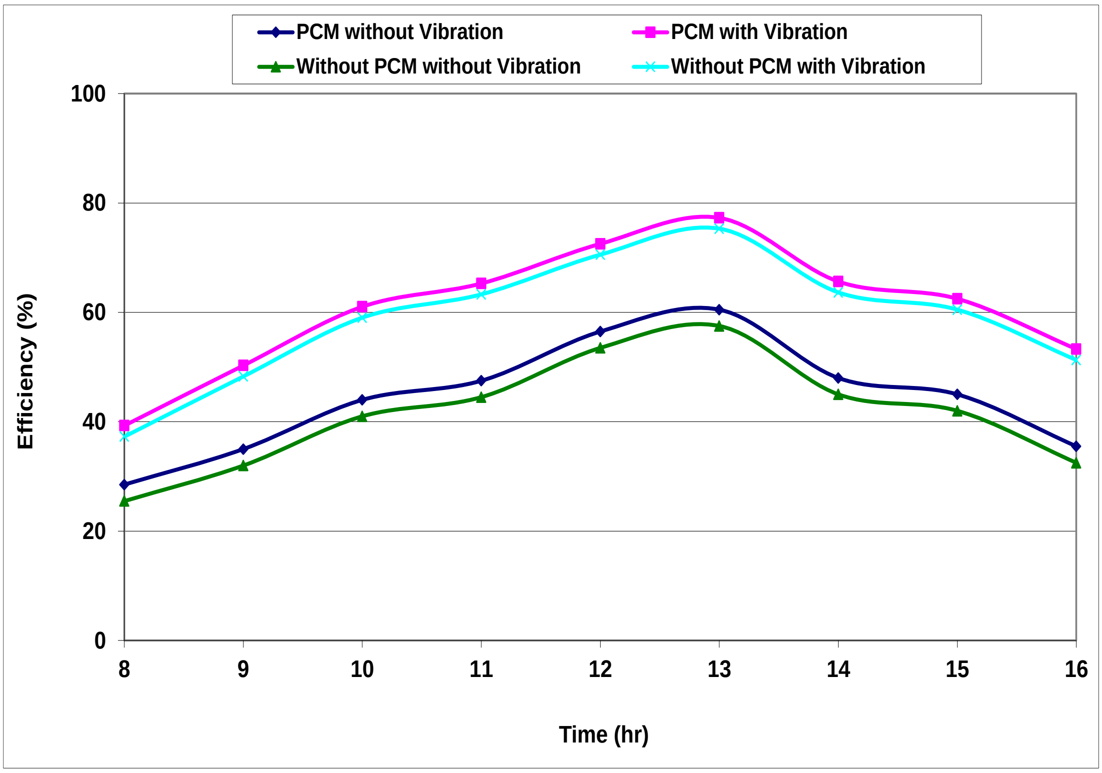


Figure 4. 40 Variation of efficiency with time. (applying 12 V)

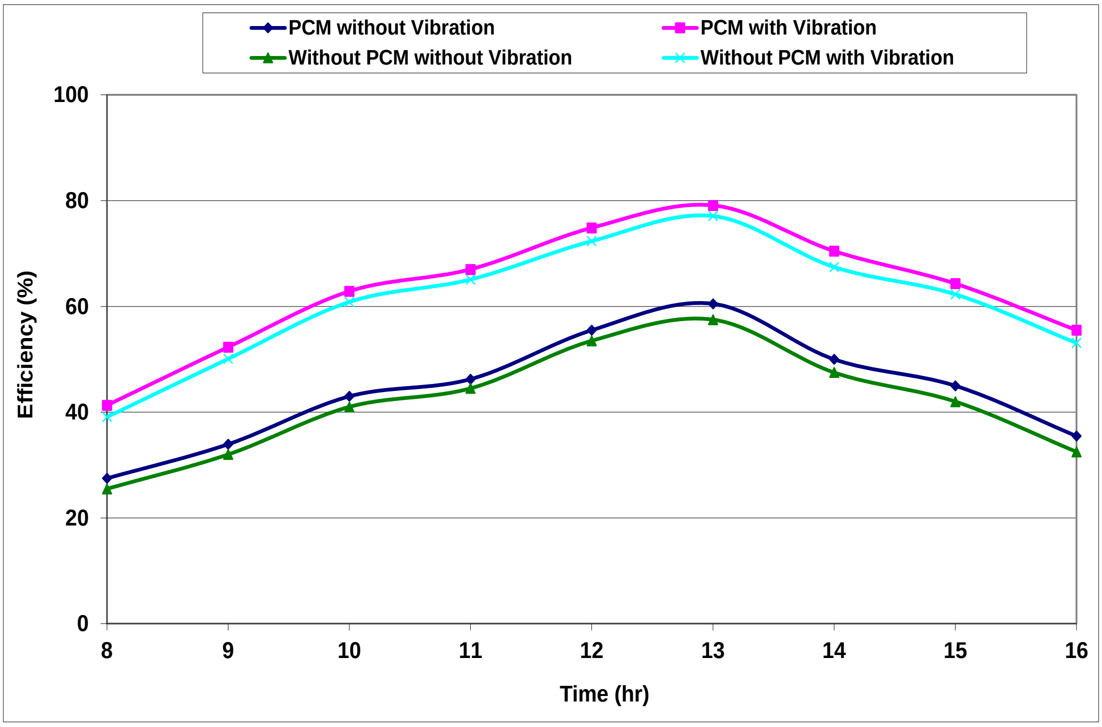


Figure 4. 41 Variation of efficiency with time. (applying 14 V)

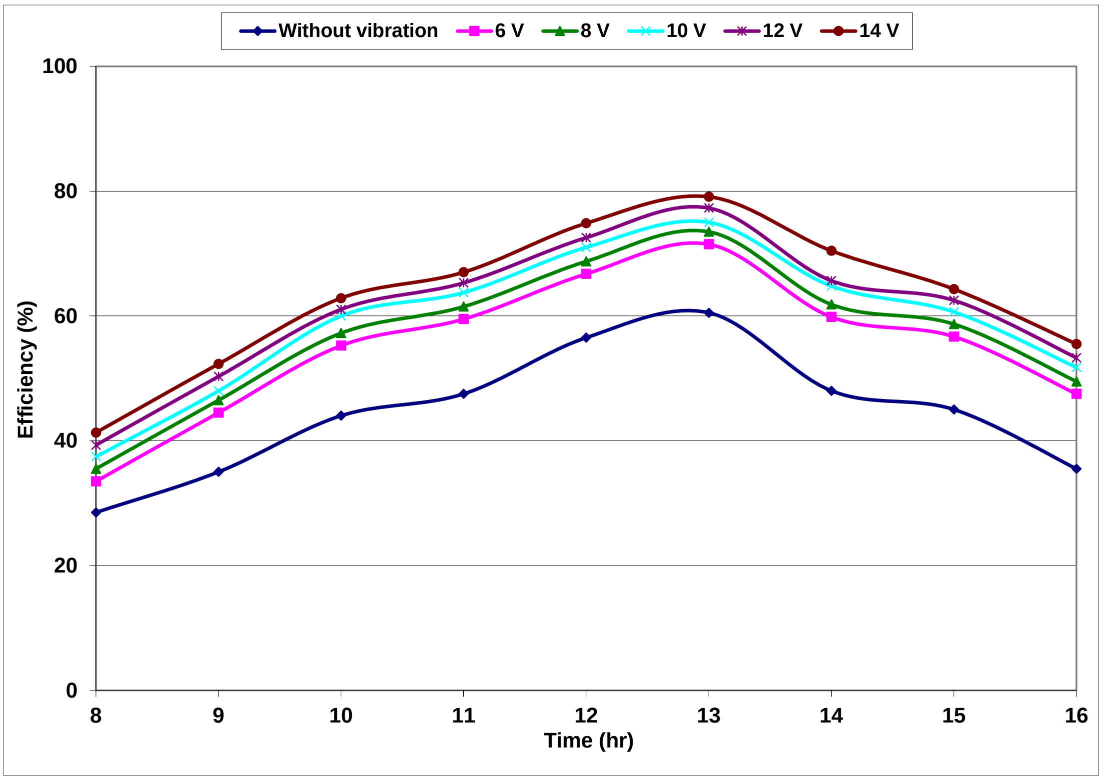


Figure 4. 42 Effect of the vibrational frequencies on efficiency with time (with PCM)

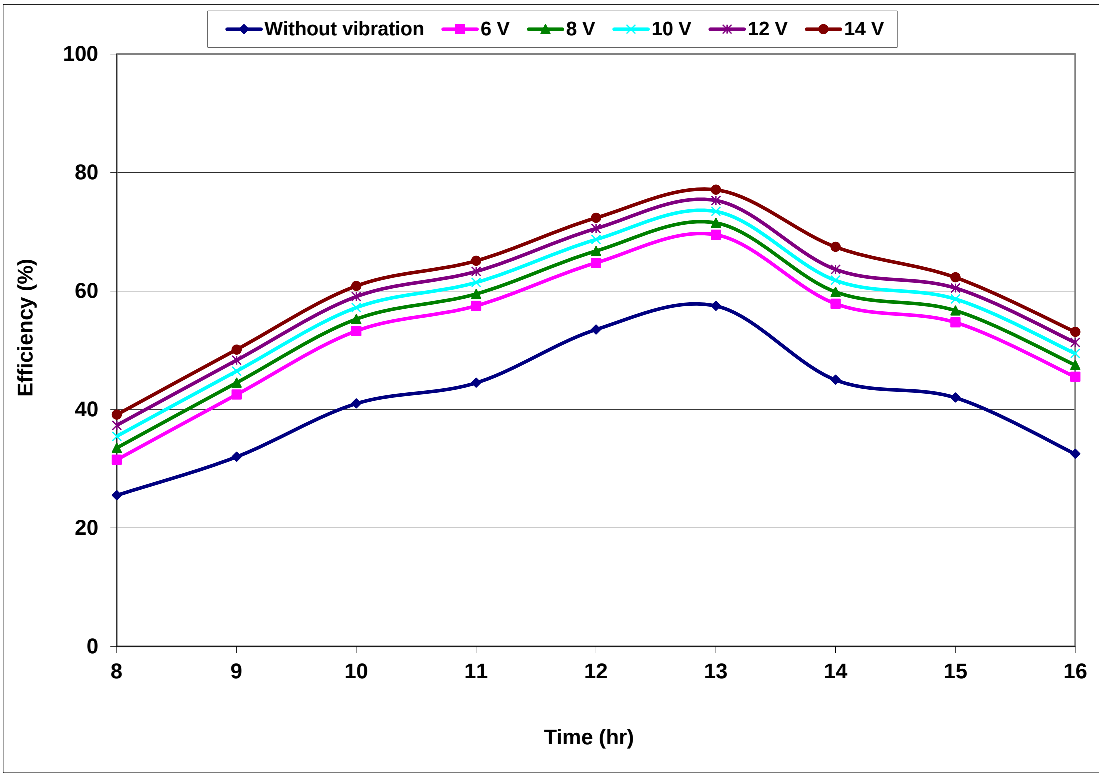


Figure 4. 43 Effect of the vibrational frequencies on efficiency with time (without PCM)

4.4 Effect of Excitation Vibration Force

In this section, the effect of the excitation vibration force on the thermal performance and thermal efficiency of Thermosyphon and thermosyphon when applied different vibration frequencies. It was used the same mass (15 grams) but it fixed on the disc with 2 cm (r) distance from the center, where the disc is connected with motor to generate the vibration. The excitation vibration force is a function of mass, rotating speed and the distance of the mass to the center of disc. In this work, the same five different values of vibration frequencies (6, 8, 10, 12 and 14 v) have been applied using both radius 2cm and 4 cm.

The results in this section will present a comparison among four different cases which are:

1. The system without PCM (distance =2 cm).
2. The system without PCM (distance =4 cm).
3. The system with PCM (distance =2 cm).
4. The system with PCM (distance =4 cm).

Also, it can be classified these four cases into two groups based on the excitation vibration force which are first group is when r= 4 cm, and the second group is when r= 2 cm.

Figures 4.44-4.48 present the effect of excitation vibration force effect on the thermal behavior and performance of the evacuated tube heat pipe solar collector system when integrated and not integrated the PCM. It can be found that the values of temperatures are proportional with magnitude of frequency for when using PCM or not. The reason for increasing the values of temperature with increasing the magnitude of frequency is the increasing the amount of heat that exchanged between the water tank and the surface of condenser. It was applied increased the vibration frequencies from 6 to 14 V. It can be seen the same behavior between two group of cases (distances are equal to 2cm and 4cm). Also, there are very small differences between cases, the reason for that is the small value of excitation vibration force (very small mass = 15 grams).

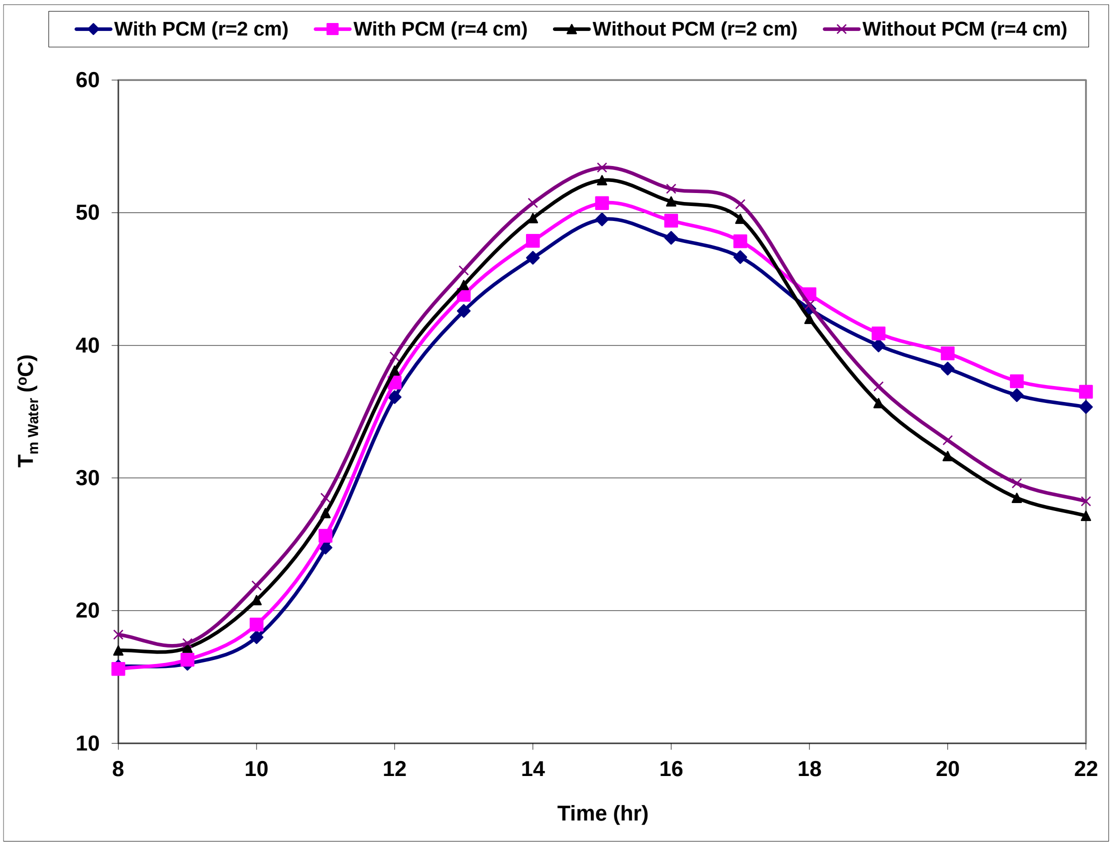


Figure 4. 44 The mean water temperature (applying 6 V)

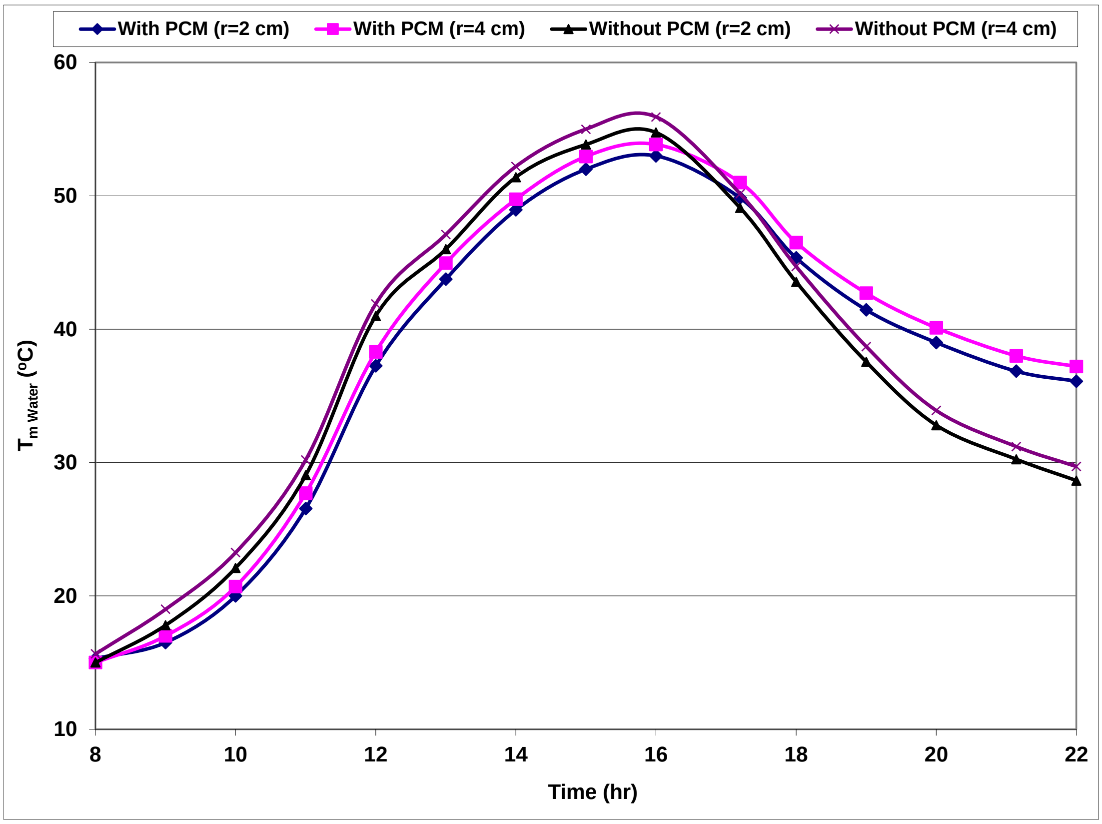


Figure 4. 45 The mean water temperature (applying 8 V)

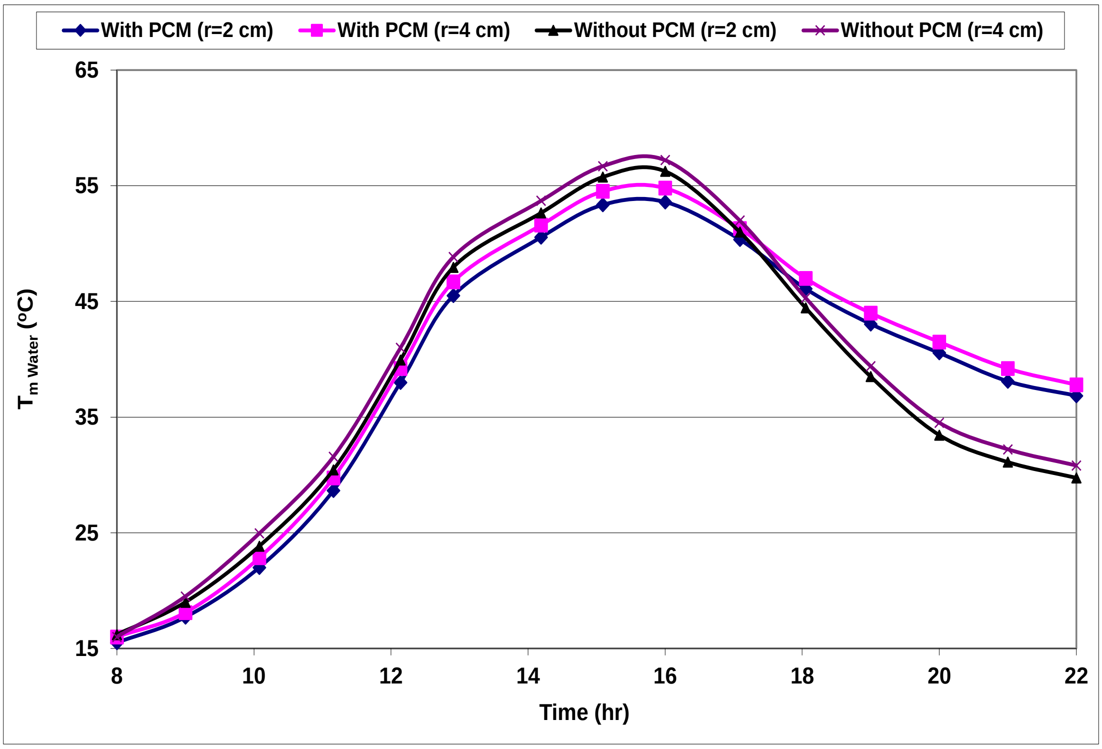


Figure 4. 46 The mean water temperature (applying 10 V)

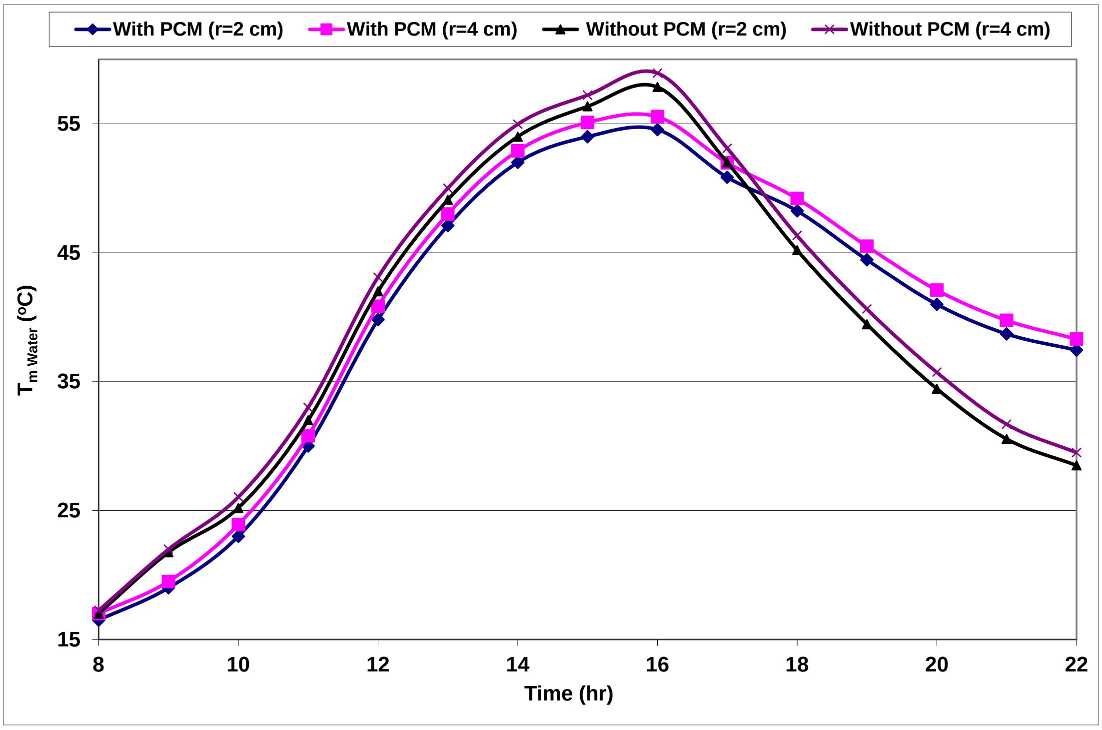


Figure 4. 47 The mean water temperature (applying 12 V)

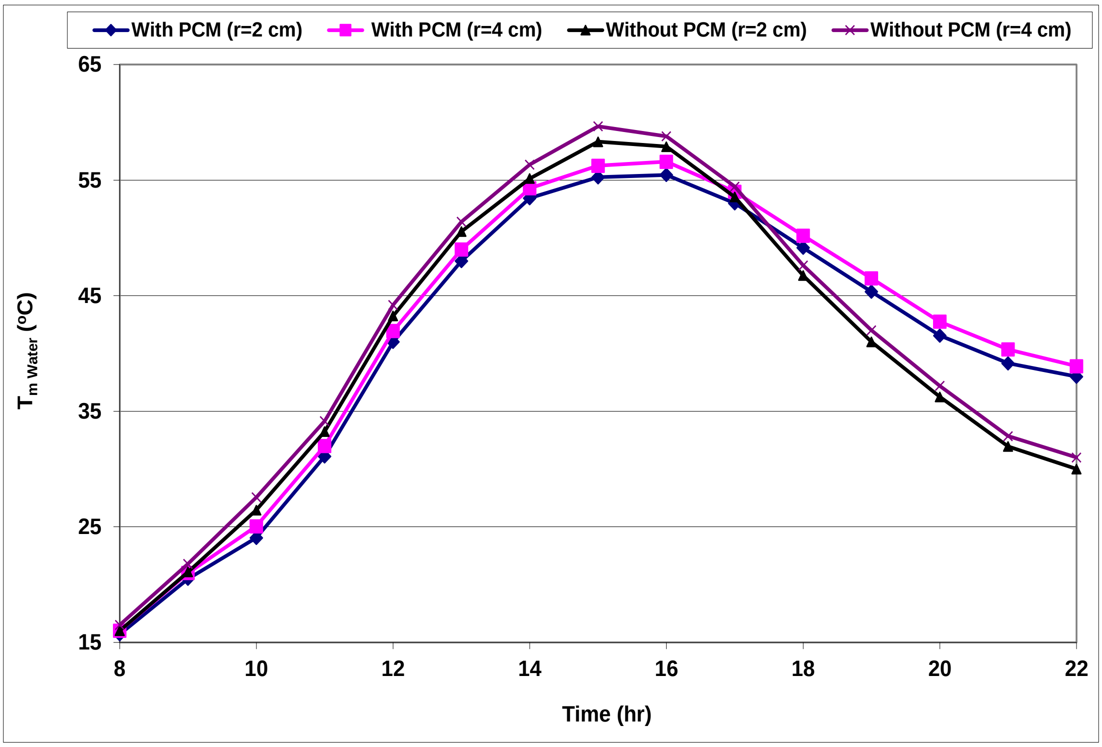


Figure 4. 48 The mean water temperature (applying 14 V)

Figure 4.49-4.53 show the variation of the thermal resistance of the thermosyphon applying different values of vibration frequencies and excitation force (6-14 V). It can be seen for all cases that the thermal resistance decreased with the increasing of the solar radiation. Also, it can be observed that the thermal resistance decreased with increasing the magnitude of the vibration frequency. Also, it can be observed that the difference between the results when applied different values of excitation vibration force is very small and can be neglecting due to the small change in value of excitation force. Where, the behavior for all cases are similar during the whole time of experiments for all cases.

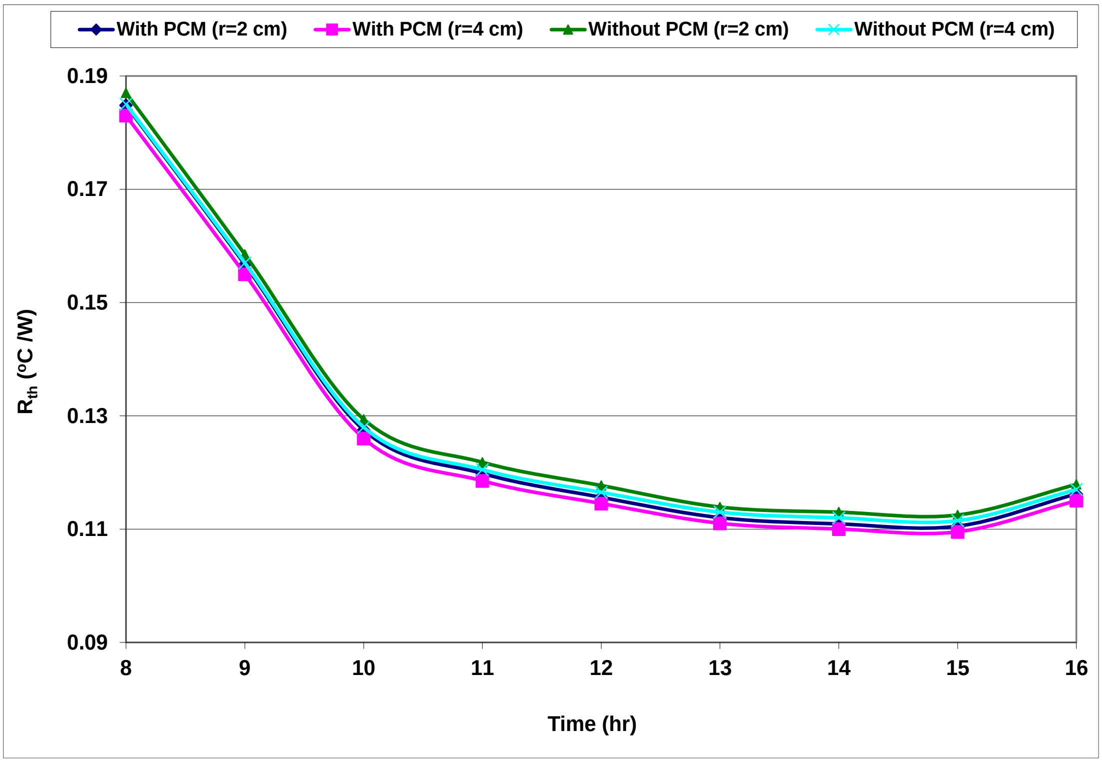


Figure 4. 49 The Thermosyphon thermal resistance with time (applying 6V)

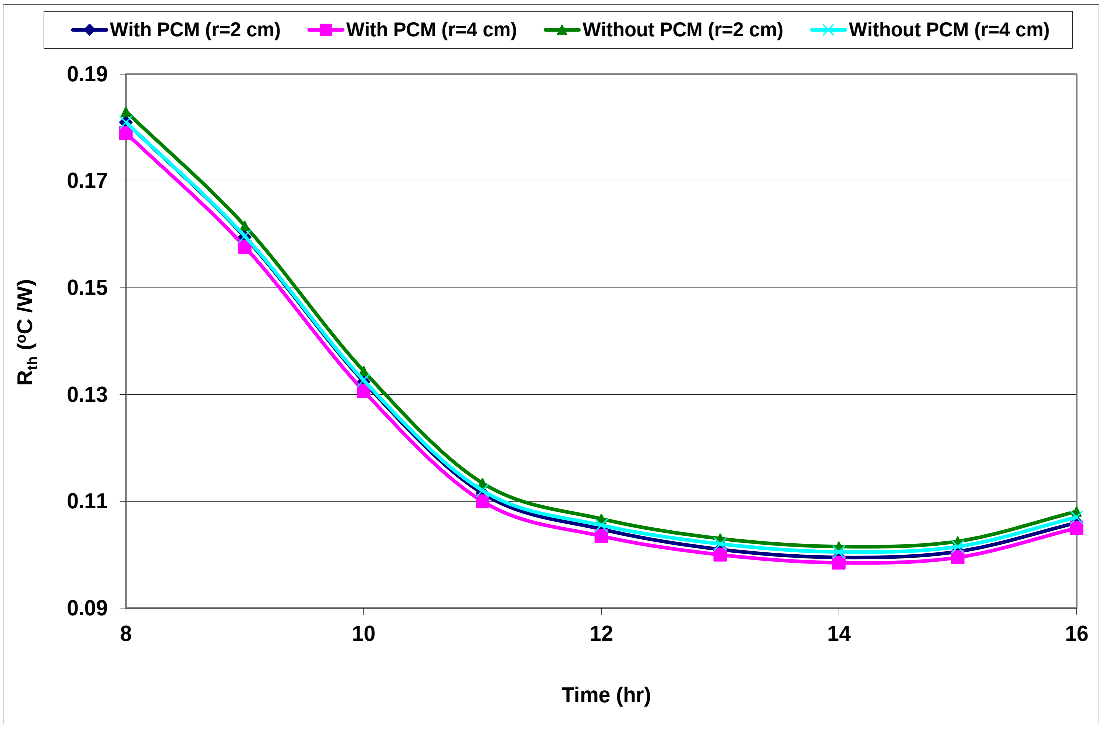


Figure 4. 50 The Thermosyphon thermal resistance with time (applying 8 V)

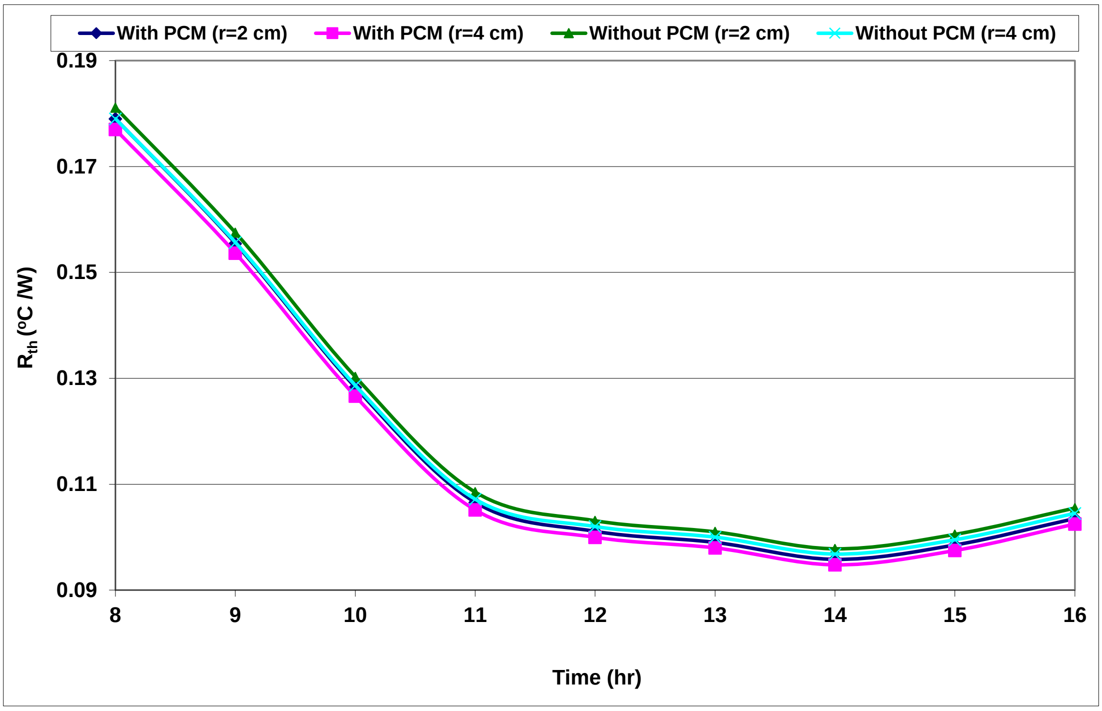


Figure 4. 51 The Thermosyphon thermal resistance with time (applying 10 V)

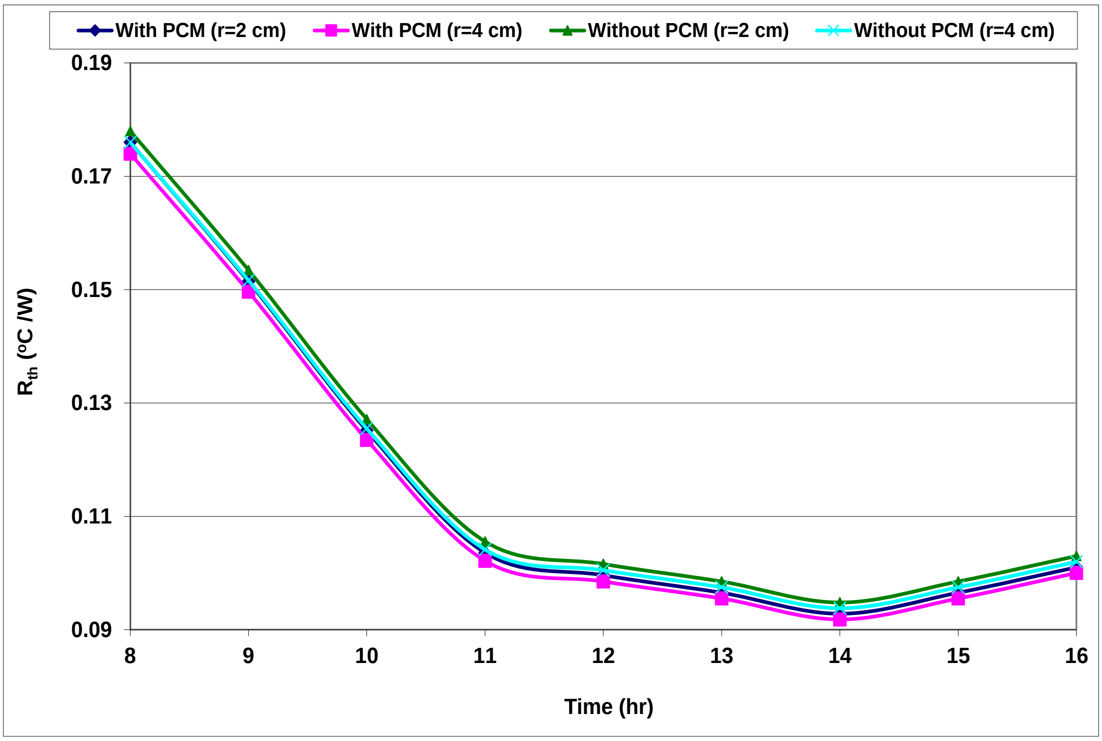


Figure 4. 52 The Thermosyphon thermal resistance with time (applying 12 V)

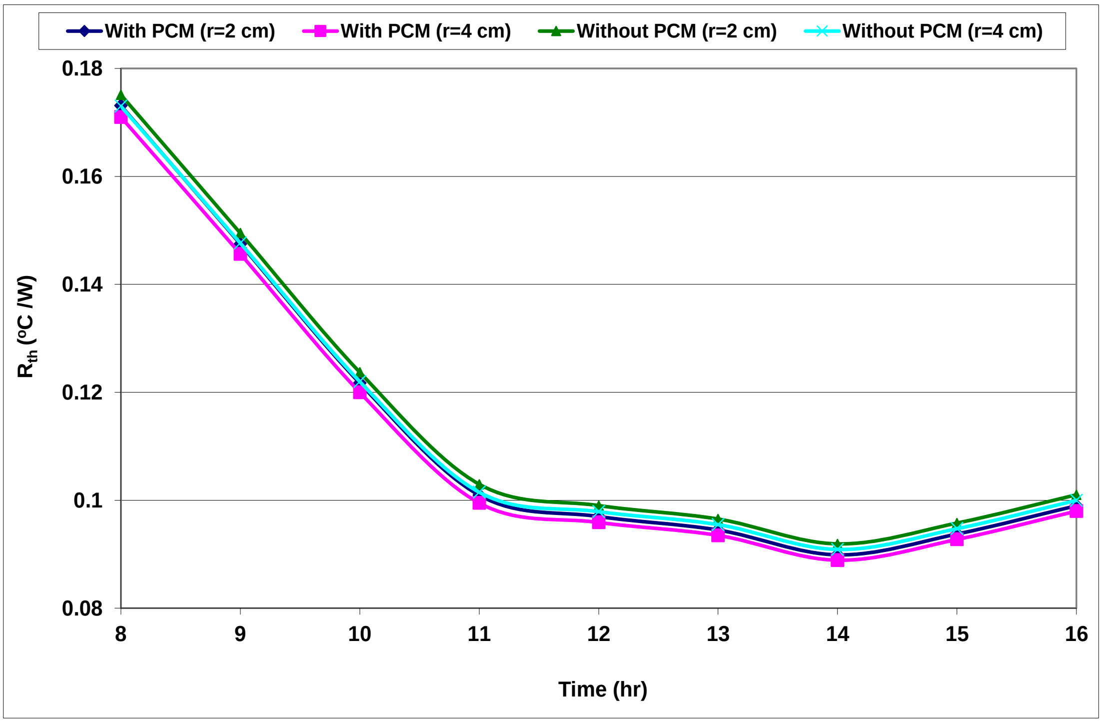


Figure 4. 53 The Thermosyphon thermal resistance with time (applying 14 V)

Figure 4.54-4.58 show the variation of evaporator heat transfer coefficient (EHTC) with time when applied different values of the vibration frequencies and the vibration excitation force. It can be seen that all cases have the same behavior during the operation time and the difference between them is small under the same condition (same frequency and force). These differences increased dramatically when the values of the vibration frequency increased only. In the other words, it can be said that the values of evaporator heat transfer coefficient increased when the vibration frequency increased too. In the other side, when the vibration excitation force increased (from r =2 cm to r= 4cm), very small change in the results was appeared.

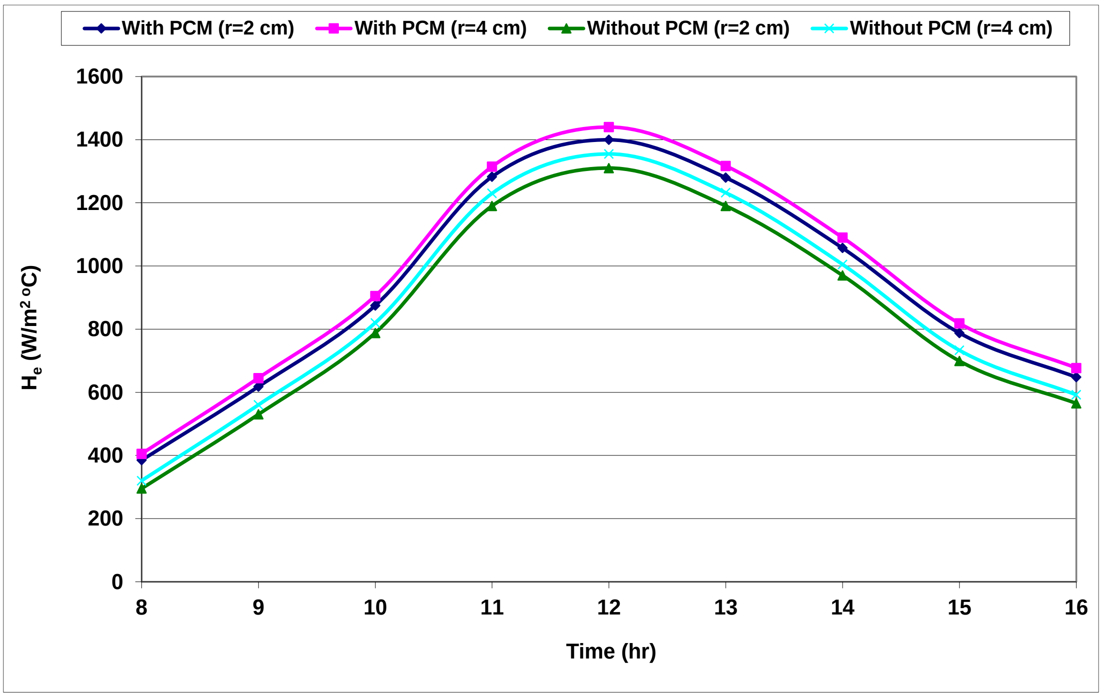


Figure 4. 54 Variation of evaporator heat transfer coefficient with time. (applying 6 V)

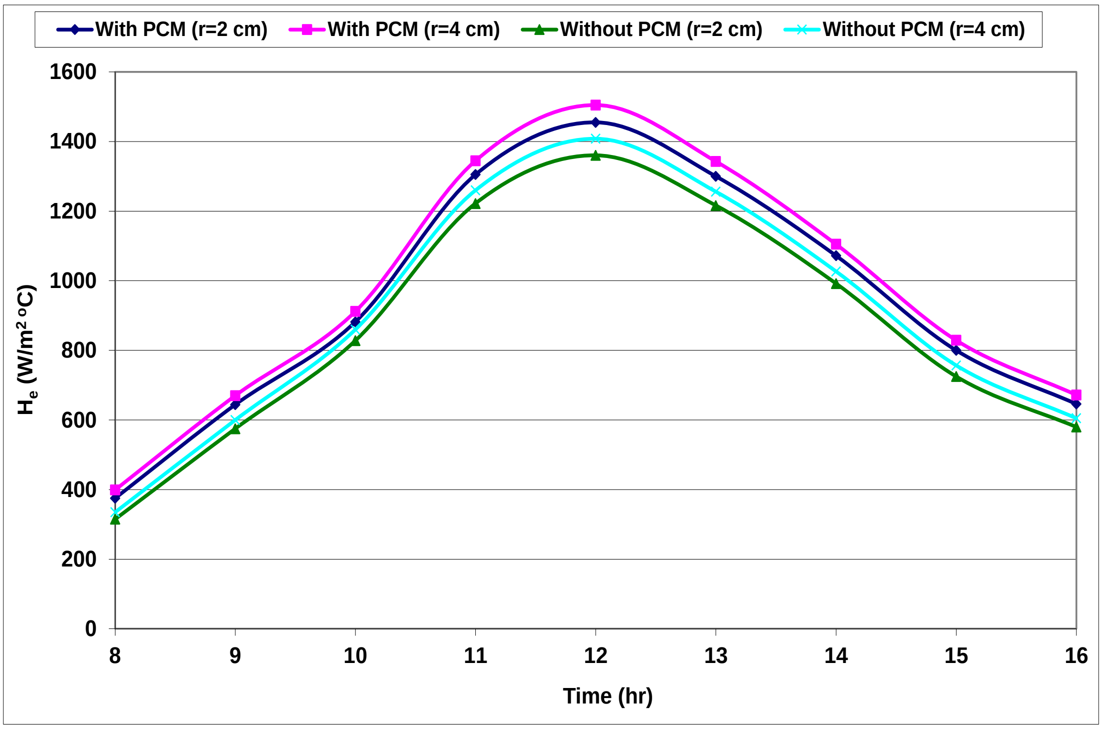


Figure 4. 55 Variation of evaporator heat transfer coefficient with time. (applying 8V)

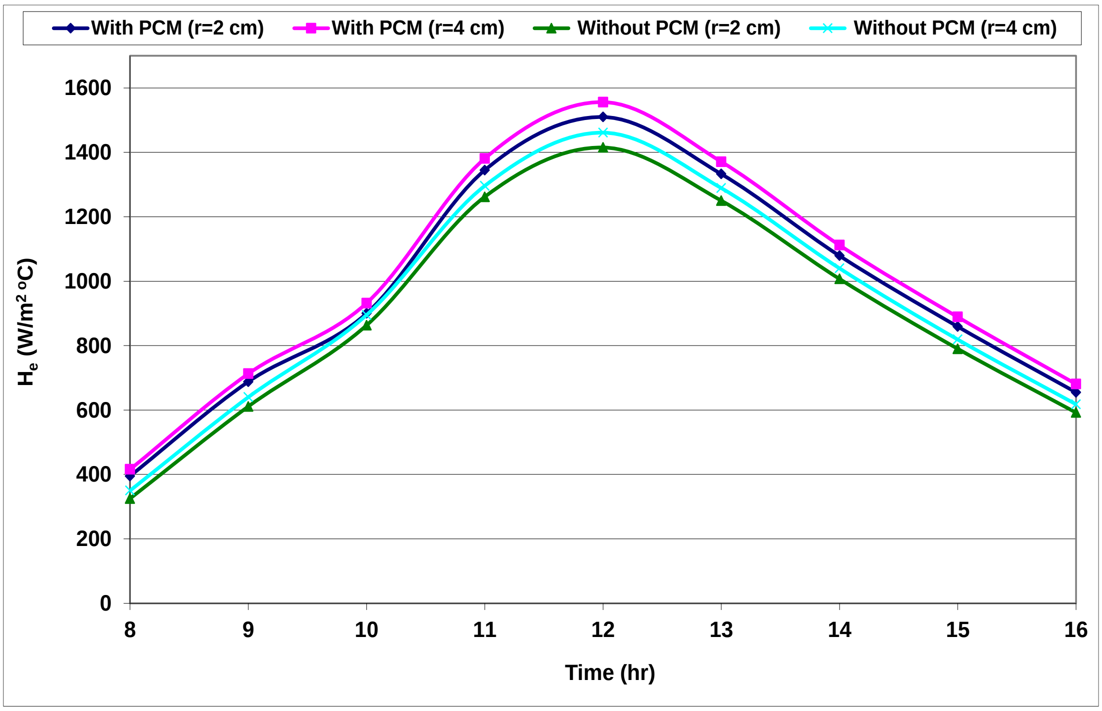


Figure 4. 56 Variation of evaporator heat transfer coefficient with time. (applying 10 V)

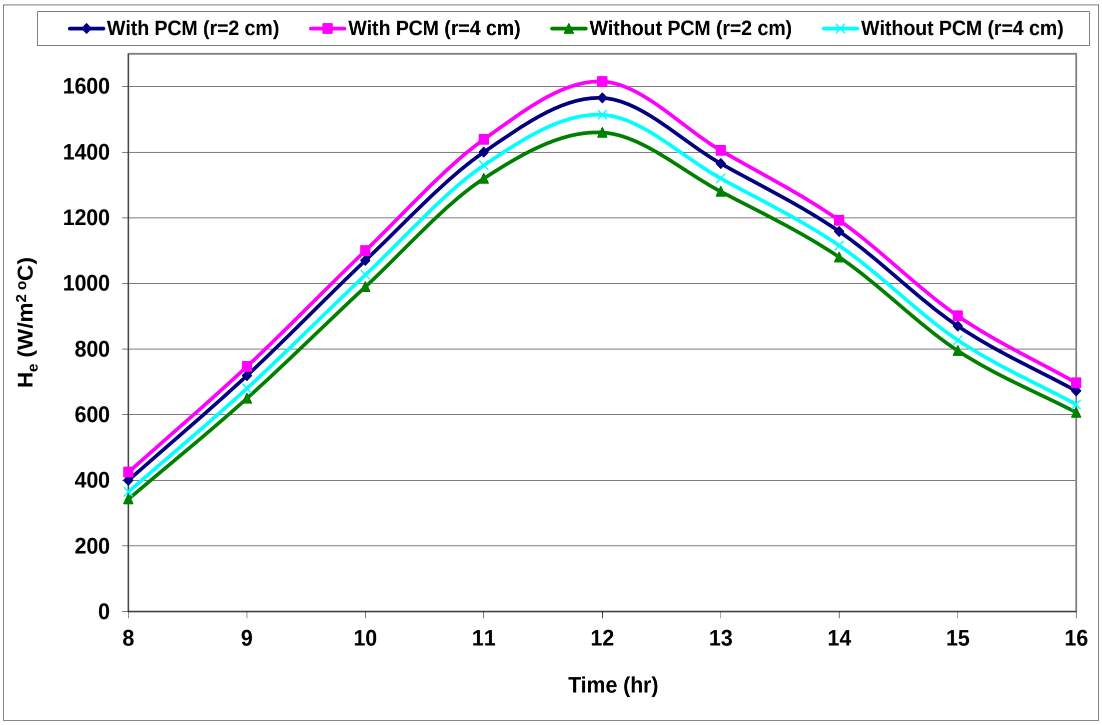


Figure 4. 57 Variation of evaporator heat transfer coefficient with time. (applying 12 V)

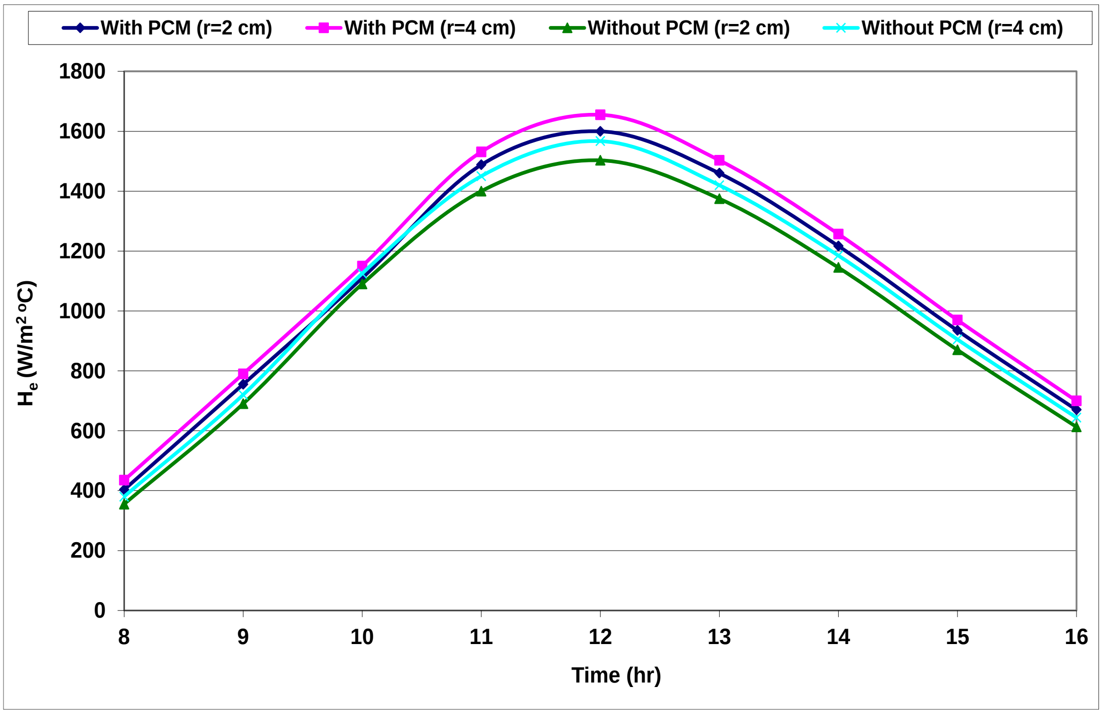


Figure 4. 58 Variation of evaporator heat transfer coefficient with time. (applying 14 V)

Figure 4.59-4.63 demonstrate the variation of the condenser heat transfer coefficient with time for the same cases and under the same conditions (the system with and without PCM). Based on the results, it can be seen that the behavior for all cases are similar during the experiment time. Where, the values of the condenser heat transfer coefficient when using PCM is higher than those without PCM, but the difference between them is not large. However, it can be seen a small difference between results when applied different values of the vibration excitation force, because the value of vibration excitation force is very small relatively.

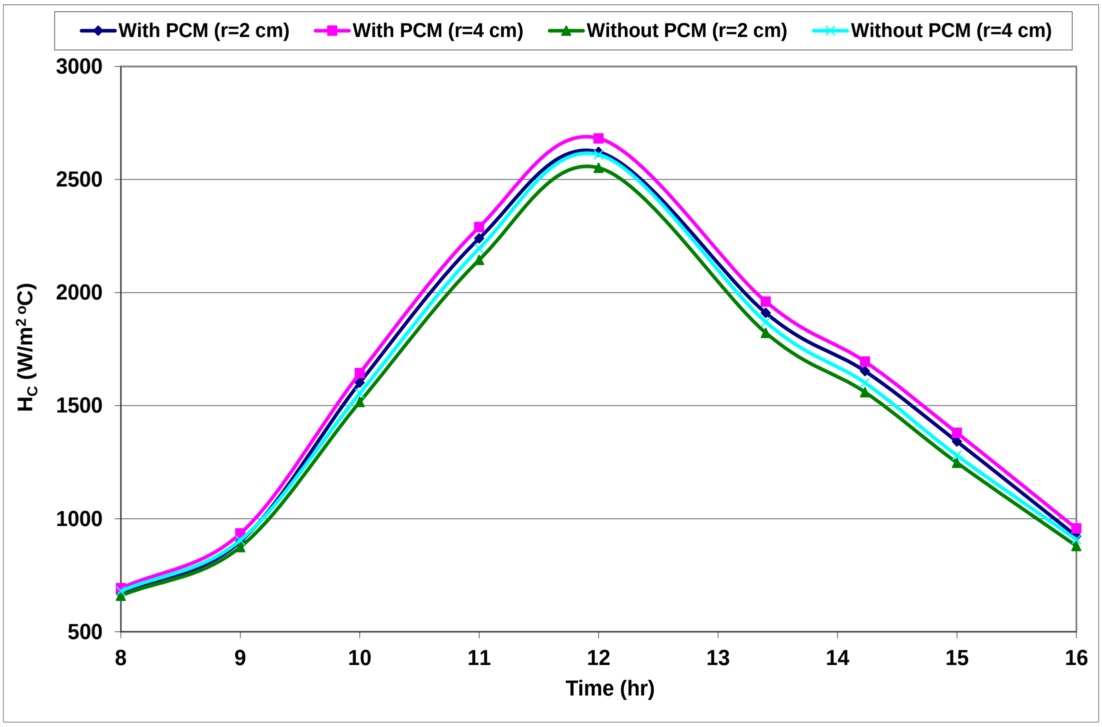


Figure 4. 59 Variation of condenser heat transfer coefficient with time. (applying 6 V)

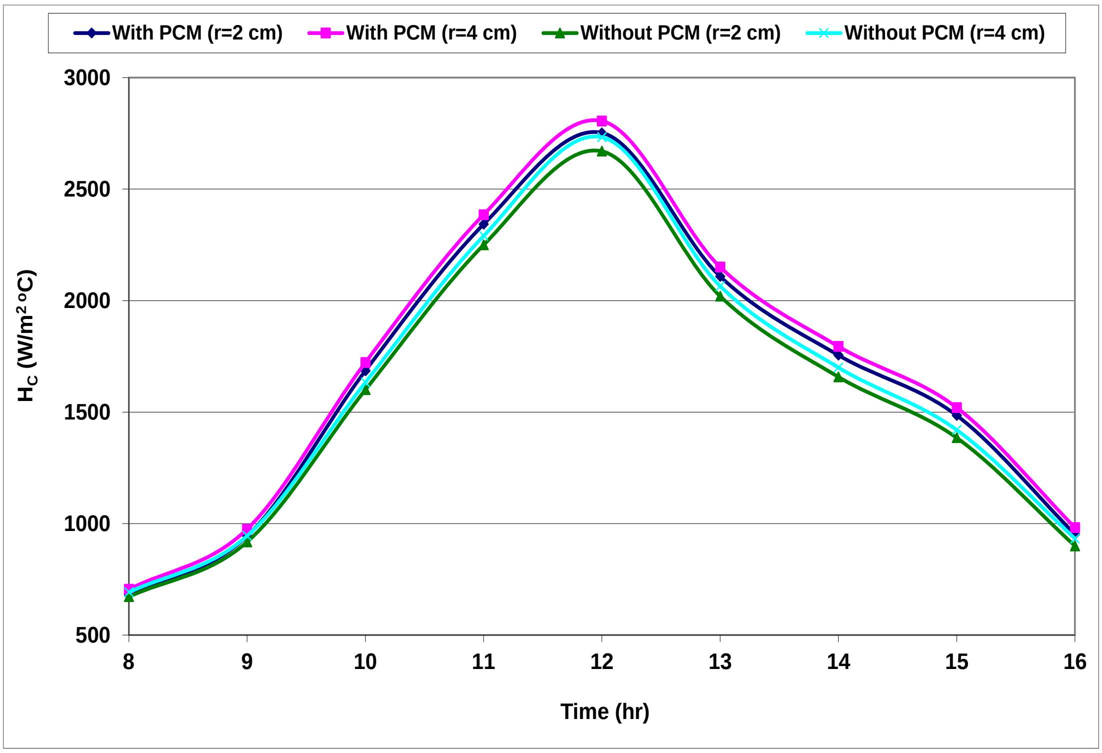


Figure 4. 60 Variation of condenser heat transfer coefficient with time. (applying 8 V)

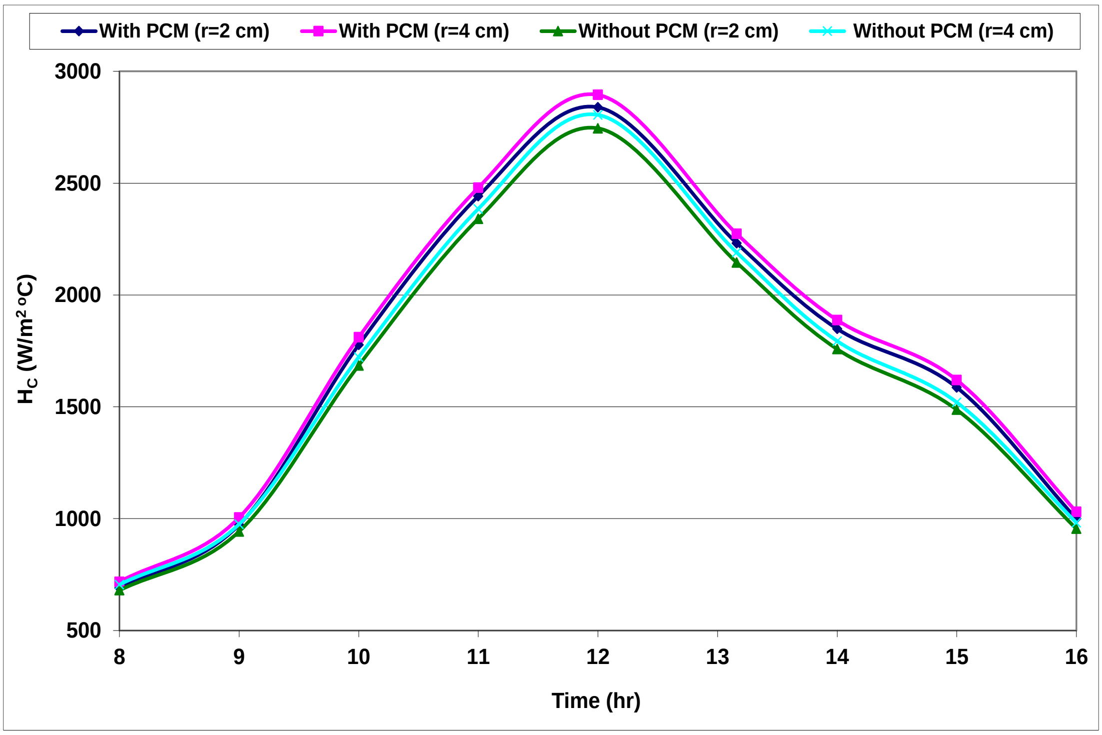


Figure 4. 61 Variation of condenser heat transfer coefficient with time. (applying 10 V)

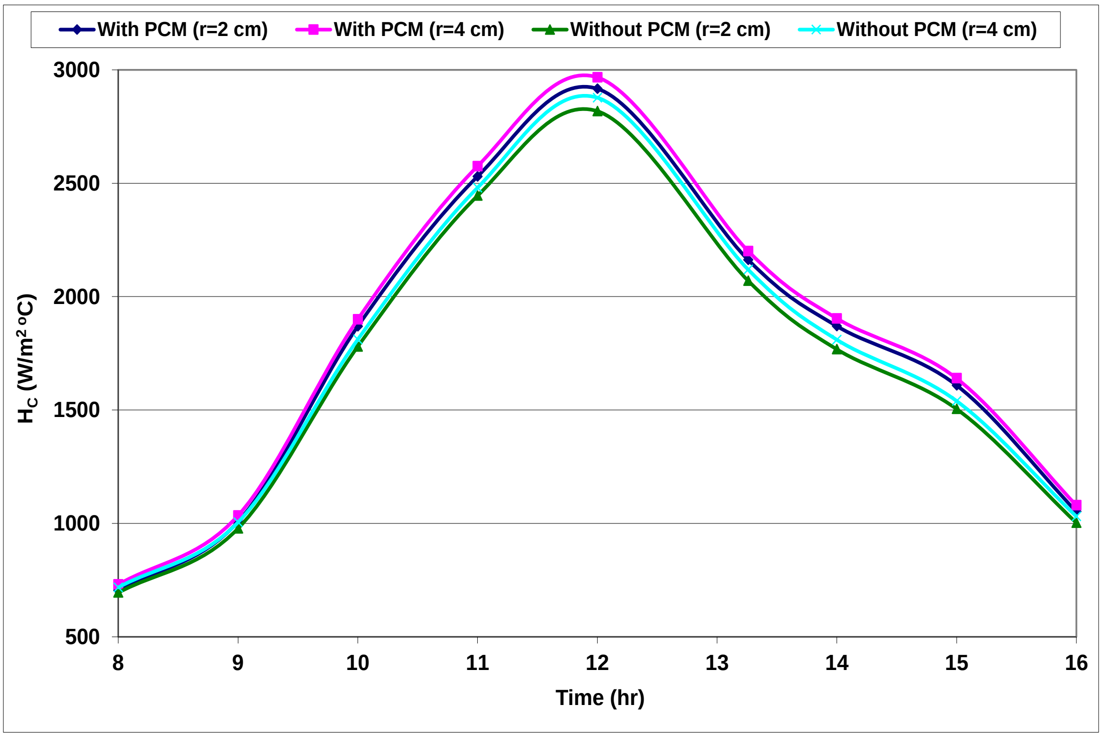


Figure 4. 62Variation of condenser heat transfer coefficient with time. (applying 12 V)

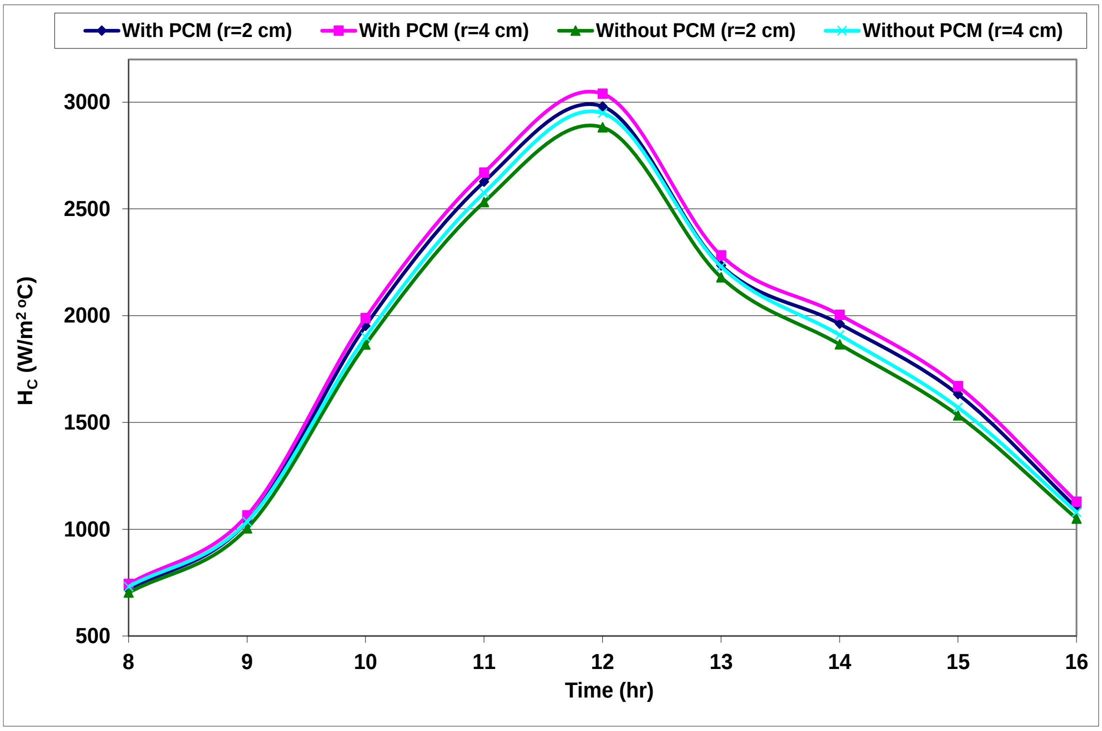


Figure 4. 63 Variation of condenser heat transfer coefficient with time. (applying 14 V)

Figures 4.64-4.68 display the variation of efficiency of the system during the day of the experimental work when applied five different values of vibration frequencies (6, 8, 10, 12 and 14 V) and two values of the vibration excitation force. It can be seen from the results, which the lowest values of efficiency occurred early in the early time (morning) where the lowest values of the global solar are occurred. While, the highest values of the efficiency occurred at the noontime during the whole test period. The reason behind such results is the peak values of the solar radiation occurred at this time. Where, this will lead to increase the amount of absorbed heat via the section of evaporation (GAHP) compared with the remaining time of the test.

Generally, it can be observed a very small enhancement in the values of efficiency when increased the value of the vibration excitation force (radius increased from 2 cm to 4 cm) but this increment in the efficiency not exceeding 2% for all cases.

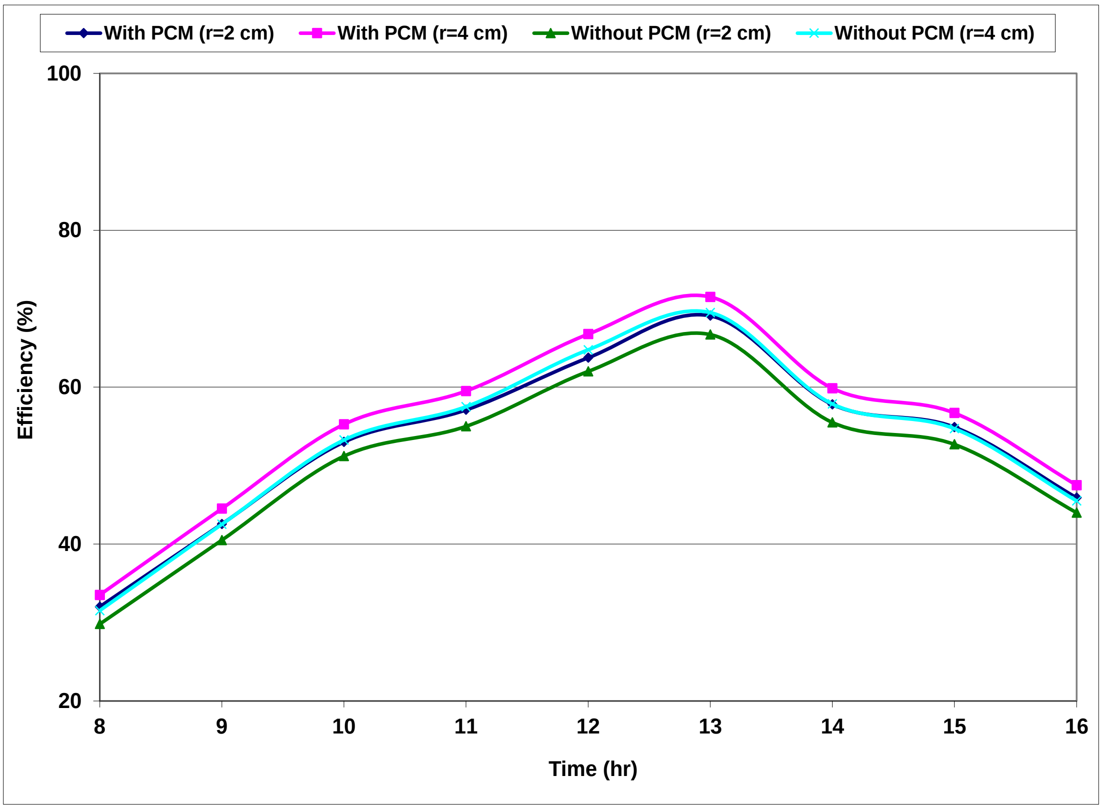


Figure 4. 64 Variation of efficiency with time. (applying 6 V)

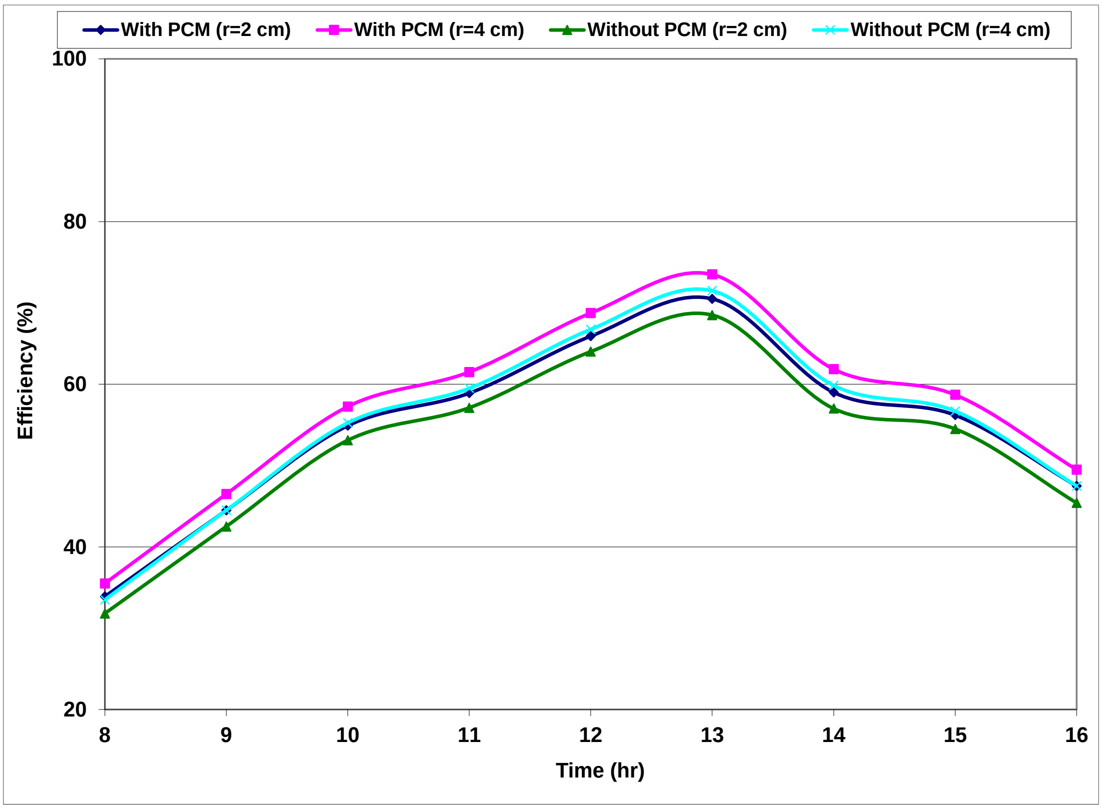


Figure 4. 65 Variation of efficiency with time. (applying 8 V)

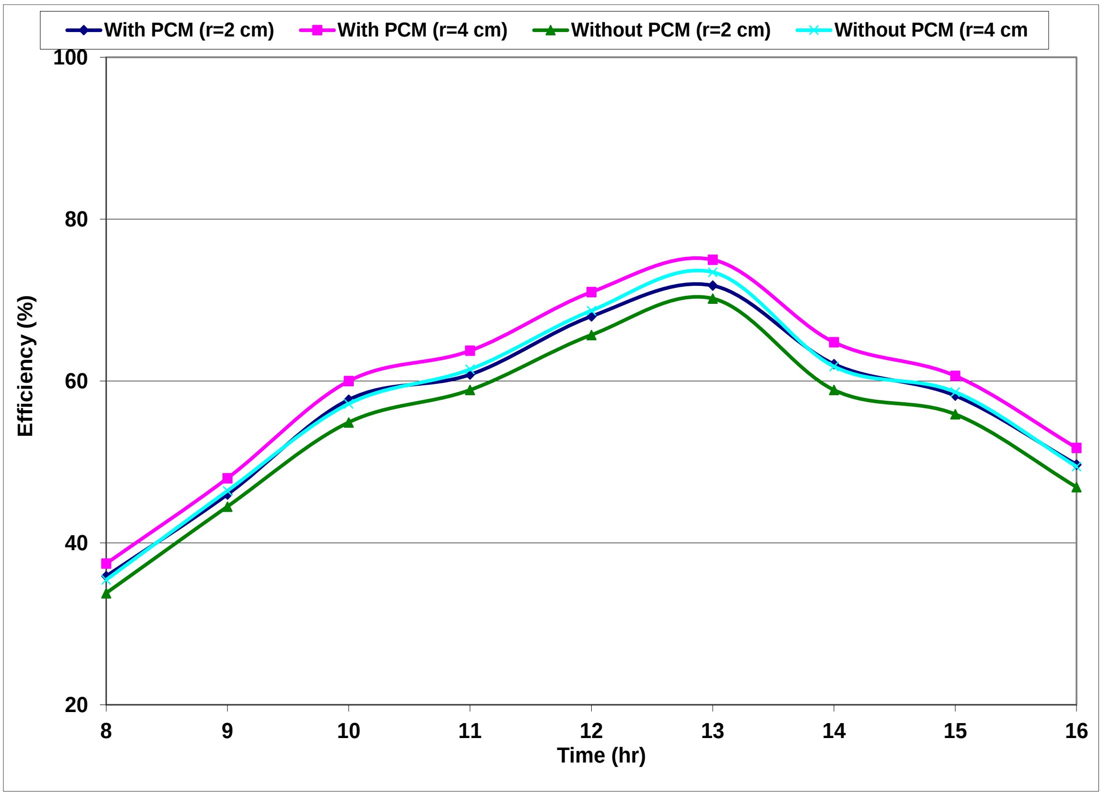


Figure 4. 66 Variation of efficiency with time. (applying 10 V)

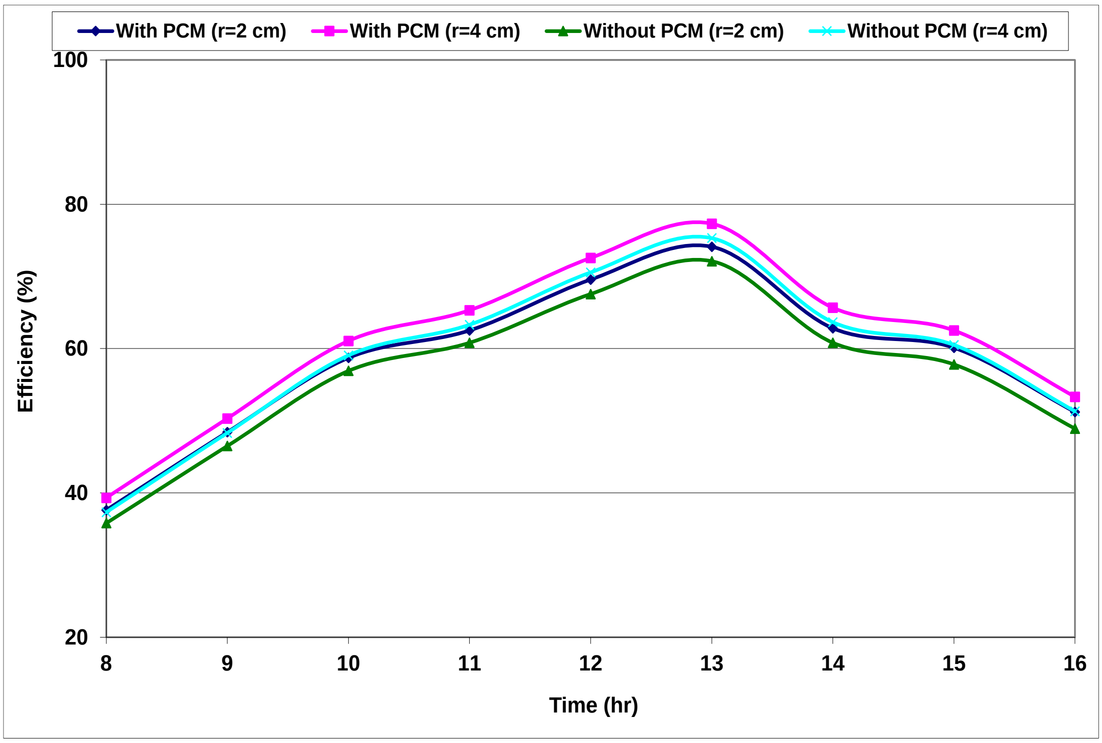


Figure 4. 67 Variation of efficiency with time. (applying 12 V)

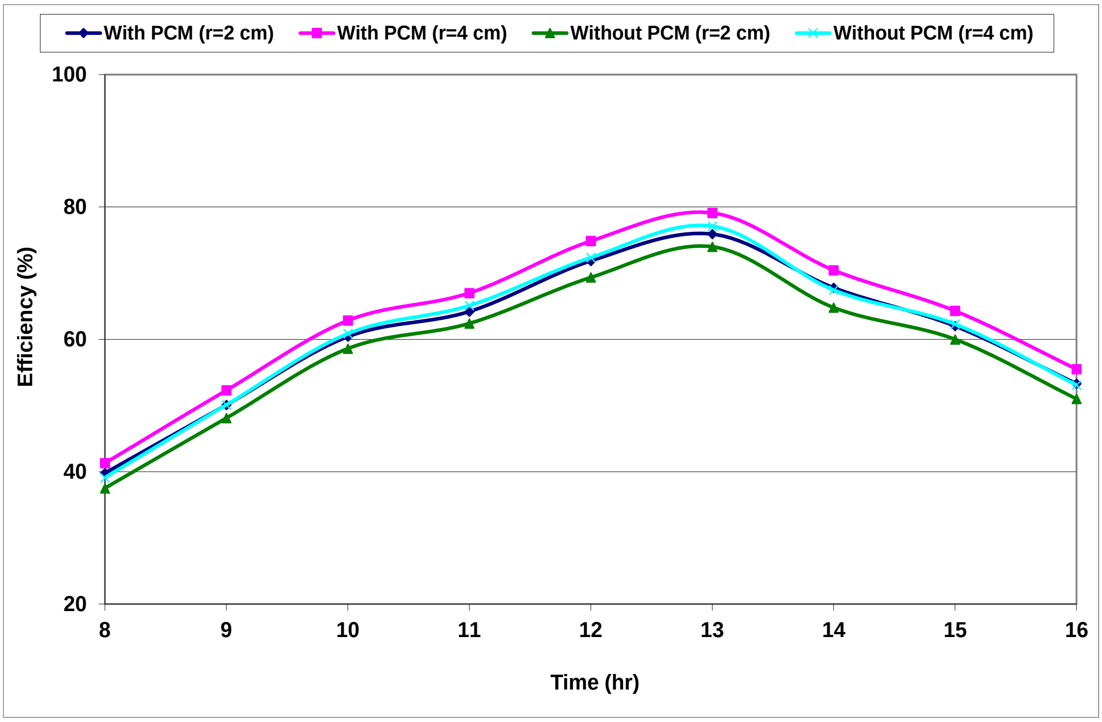


Figure 4. 68 Variation of efficiency with time. (applying 14 V)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK

Chapter Five
Conclusions and Recommendation for Future Work

5.1 Conclusions

It can be summarized the obtained conclusions based on the present work as following:

1) The vibration has a positive significant influence on the thermal behavior and performance for both developed systems (with and without PCM). Where the mean water temperature, evaporator and condenser heat transfer coefficients and efficiency increased when applied the vibration. While the thermal resistance decreased when applied the vibration.

2) A significant effect of the frequency value has been observed. As the frequency increases, the thermal behavior and performance will be enhanced. Where the optimal results were obtained for both developed systems (with and without PCM) when applied frequency (50 Hz).

3) It was concluded that the effect of distance of mass on the disc to generate excitation vibration force on the thermal performance evacuated tube heat pipe solar collector is very small. Where it was seen a small enhancement in the behavior of the system when changed the distance of mass from 2 cm to 4 cm. The reasons for such results are the small value of excitation vibration force (very small mass = 15 grams) and small distance for the radii (2 and 4 cm).

4) The thermal performance of thermosyphon system was enhanced when using PCM. Where, the heat capacity of the system was increased with relatively small volume. Where its possible to keep the useful temperature (relatively hot above 35 °C) of water during the night time. The efficiency of the system was increased with 3-5%.

5) The temperatures of PCM during the charging period are higher in the layer closer to the water of the tank, but during the discharging period it is observed that the remote layers solidify late due to latent heat of PCM.

6) The temperatures distribution in the water tank is approximately uniform.

5.2 Recommendations

For future work, the following recommendation are suggested

1) Using other types of PCM with additives.
2) Using nano technology to enhance energy storage system through forward and backward heat transfer process.
3) More study to be done on filling ratio in the thermosyphon with vibration condition.
4) Using phase change material in different location in ETSC.
5) Using thermal resistance to reduce longitudinal heat transfer effect.

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Appendix A

Calibration of thermocouple and solar power meter

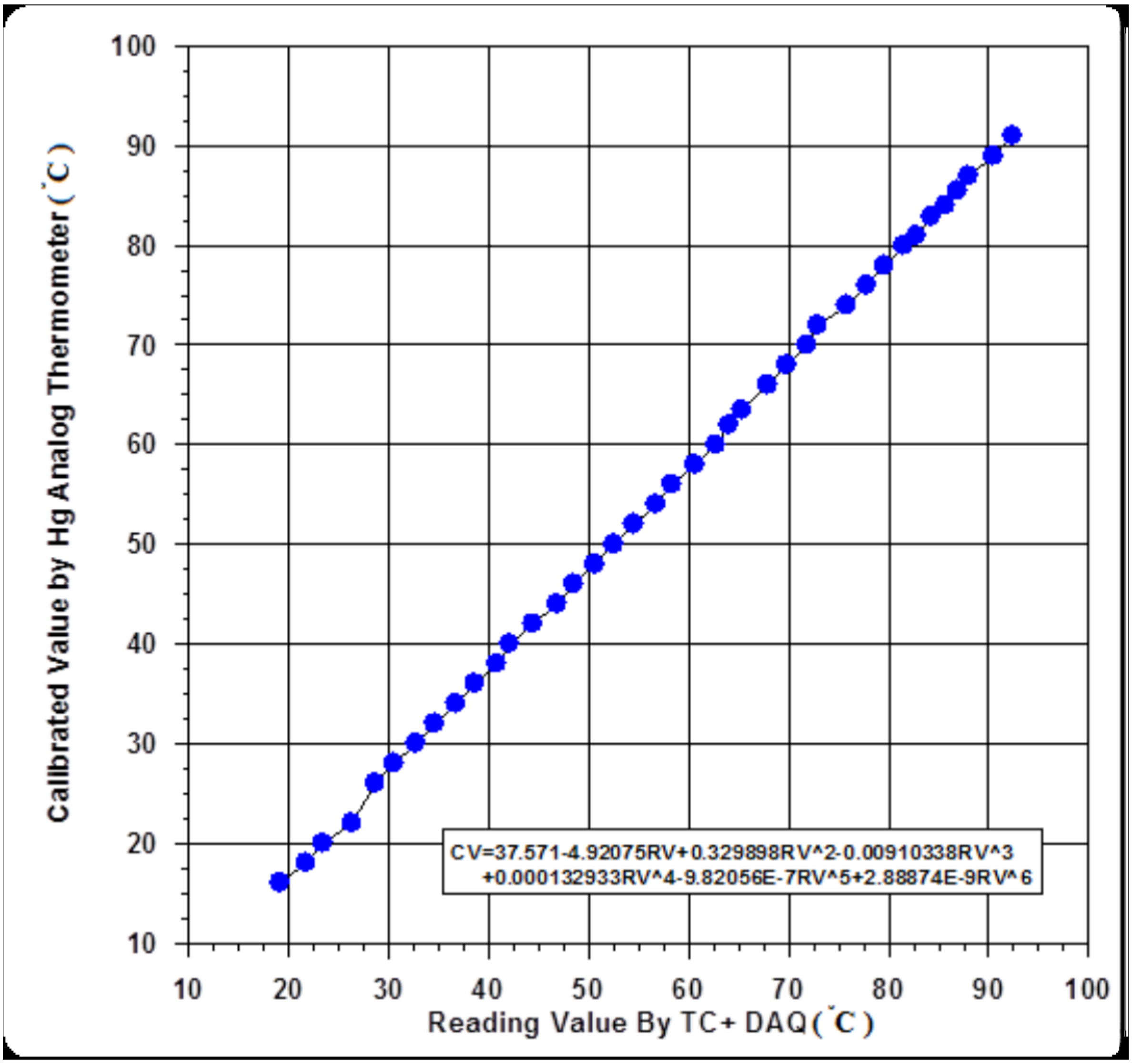

Figure A-1 Calibration for thermocouples

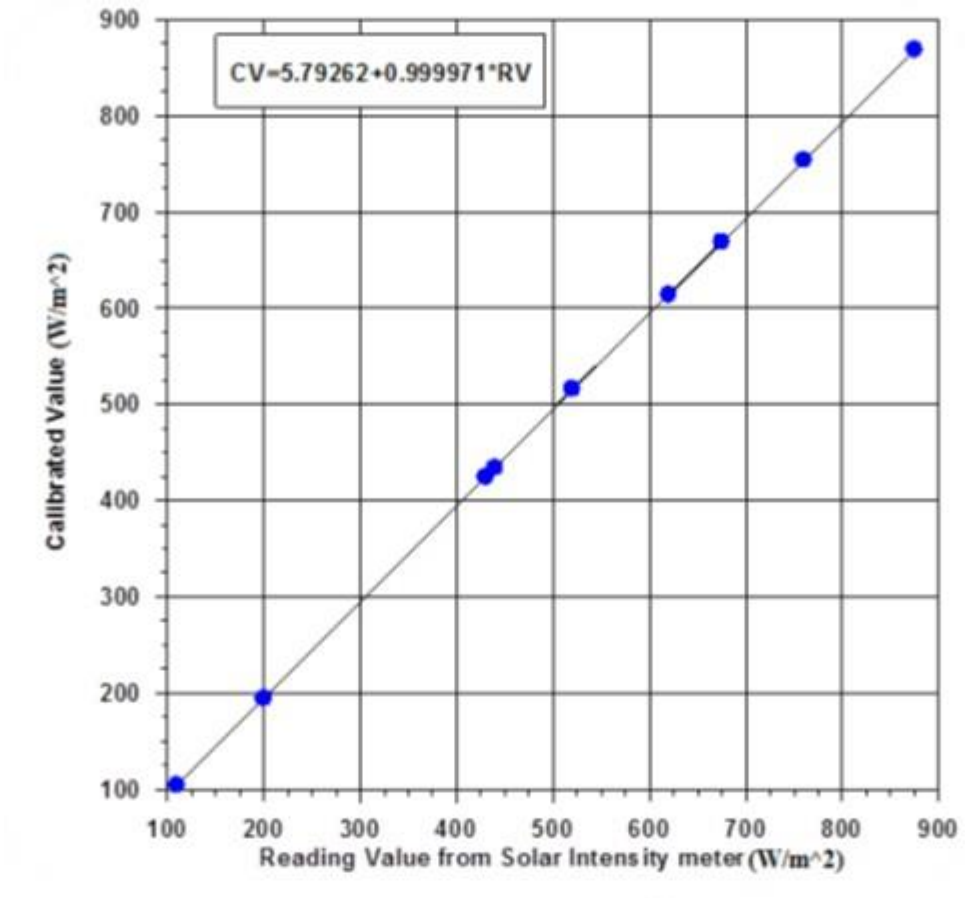

Figure A-2 Calibration of solar power meter

Appendix B List of Publications

1. Ali S., Eidan A., Al-Sahlani A., Alshukri M., and Ahmad A., 2020, "The Effect of Vibration Pulses on the Thermal Performance of Evacuated Tube Heat Pipe Solar Collector" Journal of Mechanical Engineering Research and Developments. 43(4) 340.

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The Effect of Vibration Pulses on the Thermal Performance of Evacuated Tube Heat Pipe Solar Collector

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ABSTRACT: An experimental research has been performed to investigate and elicit a heat pipe evacuated tube solar collector (HPET-SC) that subjected to mechanical vibration. The voltage ranges used to generate vibration frequency are 6, 8, 10 and 12 Volts. For comparison, two HPET-SC's were built identically. This comparison has been made based on the solar collector effectiveness of in a presence and an absence of the vibration under Iraq's winter climatic conditions. In this study, a liquid of an Acetone was used as a working fluid inside the heat tube with 0.7 filling ratio. One of the outlet investigation results indicates that heat transfer coefficients of the evaporation and condensation increased with increasing of the vibrational frequencies. Another result, using the controllable vibration system led to increasing the two coefficients of heat transfer, the temperature of hot water and the total collector effectiveness by (25%), (15%), and (20%) respectively throughout the test conditions.

KEYWORDS: Vibration energy, Evacuated tube solar collector, Thermosyphone, Gravity-assisted heat pipe, ETHPSC

INTRODUCTION

The study of vibration in structures and systems was useful because the effect of vibration plays a crucial role in engineering applications. In the industrial applications, the bulk of the movements and oscillations are practically unfavourable because repetitive or cyclic movement leads mechanical components to a malfunction or severe damages [1-5]. Nonetheless, controlled vibration or induced excitation generation allows meeting the design target for specific applications. For example, kidney stones can disintegrate with shock wave excitation in a medical application. On the other side, in many engineering applications such as thermal systems, regulated vibration is commonly employed.

In a study on a grooved cylindrical copper heat pipe with horizontal longitudinal vibrations to increase efficiency with various condensation section's temperatures, Rong-Horng Chen et al.[6,7] reported that the longitudinal direction vibrator induced the thermal resistance of the heat pipe reduction which was directly related to the input vibration energy. The temperature of the condensation area has a significant impact on thermal efficiency than the vibrations. Bowman and Huber [8] proposed research into the use of the bench-top shaker to excite the heat pipe with a wrapped glass wick at different frequencies and amplitudes. Huber and Bowman have shown that longitudinal vibration decreases the capillary limits of the copper water heat pipe that wrapped screen wick, and consequently, further studies were suggested on various heat pipe types since the subject of (heat pipe vibration) is seldom discussed within the literature[7].

Amir Alaei et al. [9] experimentally researched the effect of the use of low-frequency vibration on a gravitational support heat pipe. They demonstrated that thermal efficiency is highly responsible for the vibration (33.83%); the optimum value of efficiency was achieved at frequency 30 Hz. Amir Alei [10] reported a similar experiment in which he put the same concept into action on an oscillating heat pipe, and the results show a similar trend in thermal efficiency enhancement in the oscillating heat pipe. Furthermore, the "dry-out" at the lower filling rate and the maximum heat transfer rate are eliminated by vibration. To our best knowledge, there is very little research on the use of vibration with evacuated solar heat pipe collector's. The main aim of the current work is to establish a vibration system that will trigger the heat pipe evacuated tube solar collector structure to study thermal efficiency, where the vibration to be delivered as pulses with different frequencies over some time. The experiment is carried out by a fully controlled vibration system, and descriptions of the designed control system are shown in section 2. Section 3 presents the construction of the solar collector system. The test model is shown in section 4.

EXPERIMENTAL RIG SETUP

الخلاصة

عمل تجريبي لمجمع شمسي مع شمع البارافين كمادة متغيرة الطور (PCM). تمت دراسة استخدام الثيرموسيفون مع أنبوب زجاجي مفرغ من نوع جامع الطاقة الشمسية، مع خزان لتخزين المياه ، وحاويات من شمع البارافين والتي تمثل السطح الداخلي للخزان حيث أن الماء ملامس لسطح الحاويات. يمكن الاستفادة من PCM لتخزين الحرارة واستخدام هذه الحرارة للحصول على مياه ذات درجات حرارة عالية حتى أثناء عدم وجود مصدر الحرارة أو أثناء الليل.

يمكن تصنيف الفئات التجريبية إلى ثلاثة أجزاء رئيسية. الأول هو دراسة تأثير مادة تغيير الطور على أداء مجمع الطاقة الشمسية للأنابيب الحرارية ذات الأنبوب المفرغ. الجزء الثاني من النتائج يدرس تأثير الاهتزاز على الأداء الحراري وكفاءة مجمع الأنبوب الشمسي للأنبوب المفرغ. بينما يدرس الجزء الثالث تأثير نصف قطر الكتلة المثبت على القرص المتصل بالمحرك لتوليد الاهتزاز في مجمّع الطاقة الشمسية للأنبوب الحراري. تم تطبيق خمسة ترددات اهتزاز مختلفة ؛ 21.1 و 28.33 و 35.55 و 42.77 و 50. أجريت التجارب في ظروف خارجية (الإشعاع الشمسي الفعلي) ، زاوية السقوط (θ=90درجة) ، نسبة الملء FR = 70٪ ، مع كتلة شمع البارافين 1.8 كغم. استمر العمل من سبتمبر 2019 إلى أبريل 2020. ولتحقيق العمل التجريبي ، تم إنشاء اربع هياكل متطابقه (مع وبدون PCMوالاهتزاز). تتكون الهيكل من الجزء الأول وهو عبارة عن أنبوب زجاجي مفرغ كمجمع شمسي بقطر خارجي 50 مم وقطر داخلي 45 مم ؛ الجزء الثاني عبارة عن أنبوب حراري يستخدم لنقل الحرارة وهو عبارة عن أنبوب نحاسي بقطر 16 مم يتكون من قسمين: المبخر الذي يتم إدخاله في الأنبوب الزجاجي المفرغ والمكثف الذي يتم إدخاله في ماء الخزان وهو الجزء الثالث. تم استخدام تدفق متغير للإشعاع الشمسي. يتم جمع تدفق الحرارة المتساقط على الأنبوب المفرغ ونقله إلى الثرموسيفون ثم يتم نقل الحرارة إلى الماء في الخزان وأخيراً يتم إعطاء الحرارة لشمع البارافين في الحاويات باستخدام الأسيتون كسائل عامل. هنا ، يتغير شمع البارافين من الحالة الصلبة إلى الحالة السائلة. درجة حرارة انصهار شمع البارافين هي 38-43 درجة مئوية. تستمر فترة سقوط الحرارة لمدة 9 ساعات وتسمى فترة الشحن. وتسمى هذه الفترة بفترة التفريغ التي تنتقل خلالها الحرارة المخزنة في PCM إلى الماء. لذلك ، يمكن الحصول على المياه ذات درجات الحرارة العالية بين عشية وضحاها. بشكل عام ، زادت الكفاءة عند استخدام PCM ، لكن الفرق بين الحالتين (مع وبدون PCM) لا يتجاوز 5٪. زادت قيم الكفاءة عند زيادة تردد الاهتزاز أيضًا. حيث حدثت القيم القصوى للكفاءة في الساعة 13:00 (1 بعد الظهر). زادت كفاءة النظام عند استخدام PCM من 60٪ إلى 78٪ في الساعة 1 بعد الظهر عندما تغير تأثير تردد الاهتزاز من (0فولت إلى 14 فولت). بينما زادت كفاءة النظام بدون PCM من 57٪ إلى 76٪ في الساعة 1 بعد الظهر عندما تغير تأثير تردد الاهتزاز من (0فولت إلى 14 فولت).

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الاوسط التقنية

الكلية التقنية الهندسية – نجف

نظام التحكم بالاهتزازات لتحسين أداء المجمع الشمسي ذو الانبوب الزجاجي المفرغ مع الانبوب الحراري بأستخدام الشمع: دراسة تجريبية

رسالة

مقدمة الى الكلية التقنية الهندسية – النجف / جامعة الفرات الاوسط كجزء من متطلبات نيل درجة الماجستير التقني في الهندسة الميكانيكية– تخصص حراريات

من قبل

سارة حسن علي

اشراف

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2020