THERMAL PERFORMANCE ANALYSIS OF SOLAR THERMAL SYSTEM INTEGRATED WITH PHASE CHANGE MATERIAL

FOAD NASOURI

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ABSTRAK

Kebimbangan kajian ini adalah untuk menyiasat dua sistem pemungut parabola silinder berdasarkan undang-undang termodinamik pertama dalam satu ruang dimensi. Perbezaan antara kedua-dua sistem yang telah dipertimbangkan adalah bahawa sistem kedua adalah pemungut parabola silinder seperti yang pertama, tetapi beberapa perubahan yang berlaku dalam penyerap dalam usaha untuk membuat dan reka bentuk ruang untuk memasang bahan perubahan fasa. Sistem pertama belajar di bawah keadaan mantap dan yang kedua di bawah keadaan mantap kerana kewujudan bahan perubahan fasa. Hasil daripada simulasi menunjukkan kesan perubahan fasa pemasangan material, di atas air keluar, Pyrex dan suhu penyerap, kehilangan haba dan kecekapan haba di bawah pelbagai sinaran matahari. Tambahan pula suhu dan fizikal keadaan PCM kira-kira dikira melalui prestasi sistem. Akhirnya, menurut output sistem simulasi dan pemilihan yang sesuai PCM ada kemungkinan pengurangan kehilangan haba dan pengoptimuman sistem.

ABSTRACT

The concern of this study is to investigate two systems of cylindrical parabolic collector based on first thermodynamic law in one dimensional space. The different between these two systems which has been considered is that the second system is a cylindrical parabolic collector like the first one, but some changes are taken place in its absorber in order to create and design a space to install phase change material. First system is studied under steady state and second one under the unsteady state due to the existence of phase change material. The results from simulation exhibit the impact of phase change material installation, on outlet water, Pyrex and absorber temperature, thermal loss and thermal efficiency under various sun radiations. Furthermore the temperature and physical condition of PCM is roughly calculated through the system performance. In the end, according to the output of simulated systems and selection of suitable PCM there is possibility of reduction in thermal loss and system optimization.

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Nomenclatures

PCM Phase Change Material

TES Thermal Energy Storage

HCE Heat Component Element

HTF Heat Transfer Fluid

CHAPTER ONE: INTRODUCTION

1.1 Background of Study

The increasing demand of energy thanks to the high grows rate of population and standards of living which are growing over time on the one hand and, on the other hand, limitation of fossil-fuel sources and pollution of carbon dioxide force governments to utilize other sources of energy like nuclear and renewable energies. Most of the shortage in energy can be supported by nuclear sources of power but the main challenge to use it is its waste. Nowadays, scientists try to find new ways to utilize renewable energy as a main or spare source to overcome the shortage and decrease the pollution. So thermal energy storage has been considered by many scientists that is one the technologies for storage of energy(Dincer & Dost, 1996).

Sun is a source of heat energy. This enormous and endless source is located far from earth, only its radiation can be received by earth. Sun radiations naturally are the waves that take a long distance from their source to earth. Sunlight is defined as two regions of visible and near-visible radiation emission. Main reason of having different regions is wavelength range in the interior the broad-band range of 0.20 to 4.0 µm. Beyond the atmosphere, solar radiation possesses a power 1370 watts per area. However, it loses some of its energy when travelling through the atmosphere, for example for example on a day with no clouds, noontime; the straight ray will be around 1000 watts per m^2 area for many locations. The availability of energy depends on the location (latitude and elevation), season, and time of day.

Solar systems are structures which can help us to use the radiation from the sun as a prime source for other forms of energy like electricity, heat, etc. Usually, a solar system contains two main parts, a collector and a reservoir. The collector collects the radiation transfers the heat to the reservoir by a heat transfer fluid. Many solar devices work in this cycle such as Solar Water Heater.

Solar Water Heater is the developed renewable technology used for energy saving. Therefore several types and models of which the conventional flat plate collectors are a common type. They have been well considered and established. Low prize, simple structure and assembly and low maintenance have led to these systems being extensively used all over the world in low temperature thermal systems. It consists of water pipes that attach to the collecting and water circling (free or forced) convection in it, to transfer the heat from the collector to the reservoir.

The heat storage material and development of heat exchanger are most important factors for quick charging and discharging heat transfer rate in the latent heat storage process. The suitable surface of heat transfer should be large enough that maintain low temperature gradient over these process(Banaszek, Domanski, Rebow, & El-Sagier, 1999).

1.2 Limitation of Study

Energy storage existed in the form of practical heat in a fluid or hard substance used as heat of blend or chemical energy and products in reversible chemical reactions. The detailed classification of Energy storage is hereby presented. However technical and economical questions about its practicality are yet to be answered. All recent studies carried out in this field are done focusing on the practical and latent heat storage organisms. Researches were piloted on making comparison between the phase change and practical heat storages have shown that a major decrease in energy storage volume can be stored by using PCM rather than sensible heat storage. Maybe a remark on the problems related to volume change during phase change, should be added also.

1.3 Objectives of Study

In the latent storage system, selection of PCM and its chosen criteria remain the chief features. The usage of Sodium silicate hydrate as a PCM has been pointed out in some studies as it has great volumetric concealed heat storing capability, sharp melting point, great thermal conductivity, great heat of fusion, and flame resistance. Hence the objectives of the study are as follows:

- To increase the operating hours of collector by adding PCM
- To compare the efficiency of collector by adding PCM
- To carefully assess, through theoretical modeling as well as measurements of PCM TES in real heating applications, the desired properties of the storage in terms of storage capacity

1.4 Scope of Study

In current studies, a novel theoretical strategy is programmed to find the overall heat loss coefficient, temperature differences and efficiency of an individual collector tube that is installed on the focal line of parabolic mirror, one time with Phase Change Material included and without it. It is not a difficult process and the assistance of professional assessment device like vacuum diffusion pump, mass spectrometer or gas analyzer is not essential.

The PCM is installed around the pipe and in side of absorber. The purpose of this study is to approximately assess the general heat loss coefficient and efficiency for every concentrate collector module to observe whether each of them has the same thermal behavior and estimate the amount of heat that is needed for the PCM. The suggested technique is capable of being applied at any interval throughout the functioning lifecycle of parabolic collector in the field. Furthermore, the anonymous heat properties of PCM will be estimated by an analytical method.

A well-organized methodology is always necessary for achieving the best conceptual of work. The outlines are:

- ✓ To have the most comprehensive literature review for beginning of the study
- ✓ To investigate all the boundary condition and thermal properties which are needed for this study
- ✓ To program the sample
- ✓ To characterize and analyze the sample
- ✓ To write reports and documentations

The flowchart below shows (Figure.1) the steps and framework of the study:

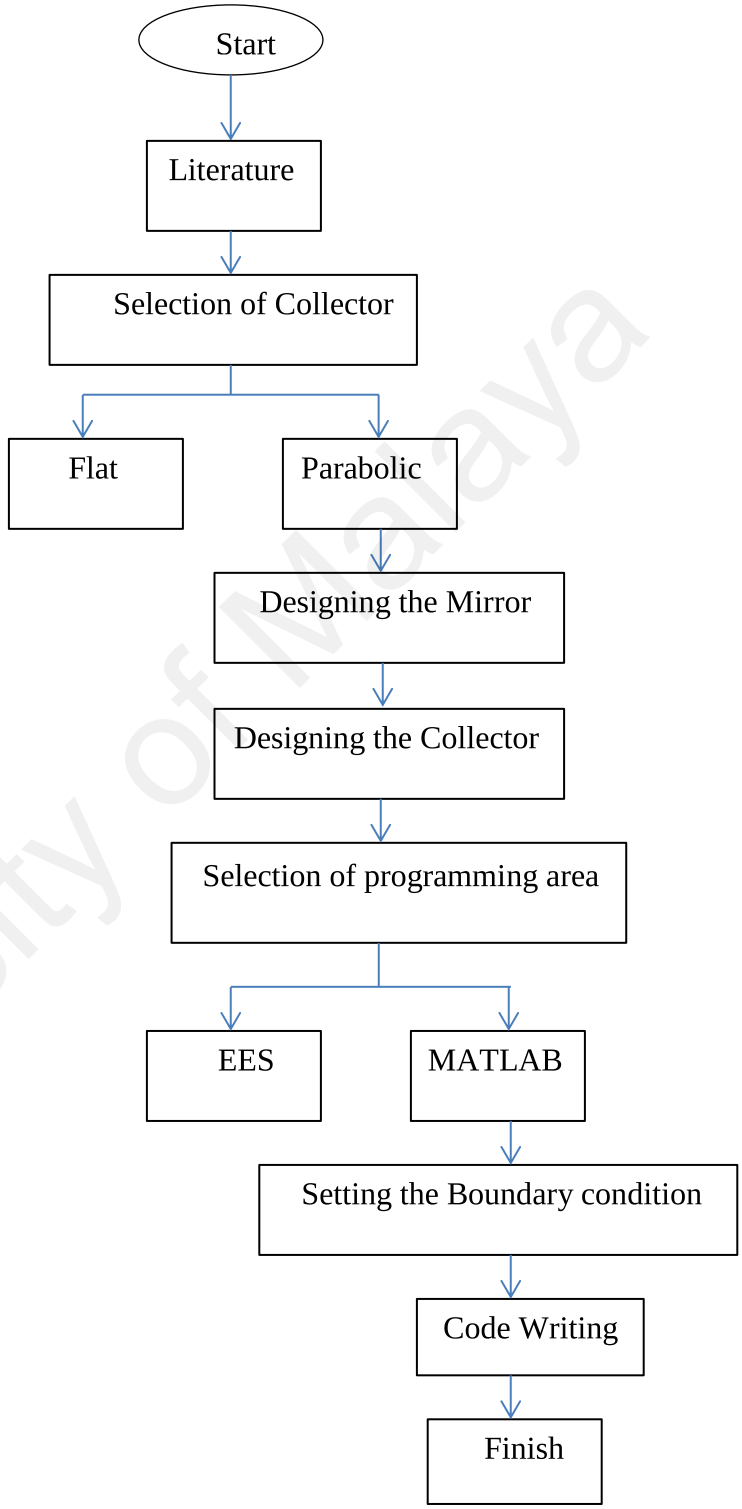

Figure 1.1 Methodology Flowcharts

1.5 Organization of this Study

This chapter describes the background of the study, the objectives, and the importance of the study. It is also shows the conceptual framework of the study in addition to scope and limitation of that.

Chapter two presents literature review on renewable energy, thermal energy storage, PCM, collector type and other materials that are used for the solar water heater.

Chapter three will discusses the method of the thermal modeling, explain the system which is used for the thermal modeling, and procedures which are used for the study.

Chapter four reports the research and thermal modeling findings and data and discuss about the findings.

Chapter five summarizes the conclusion and discuss about further works which are offered and recommended.

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CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

In chapter 1 the background and context of the study was outlined. This chapter reviews the relevant literatures on specific terms in this study. It reviews the literature that is related to thermal energy storage, solar thermal system, PCMs, and the usage of inorganic PCM in a solar thermal system.

For many years solar energy have been under research as a means for thermal structures from a reversible energy source using Phase Change Materials (PCMs). Also uses of Phase change materials for cool and warm appliances have been studied in past decade which a main element of this energy is their storage capacity (Agyenim, Hewitt, Eames, & Smyth, 2010; Baetens, Jelle, & Gustavsen, 2010; Kaygusuz & Ayhan, 1999; Kürklü, 1998; Mehling, Cabeza, Hippeli, & Hiebler, 2003; Sharma, Tyagi, Chen, & Buddhi, 2009; Shukla, Buddhi, & Sawhney, 2009; Szabó; Zalewski, Joulin, Lassue, Dutil, & Rousse, 2012).

An operational way of loading thermal energy and also one of the advantages of high-energy storage density is utilizing of a latent heat storage systems which are using phase change materials. There has been an extensive utilization of PCMs in different industries like: latent heat thermal-storing systems for heat pumps, main solar industries, and also applied in space rockets warm air mechanism. (Agyenim et al., 2010) reviewed the expansion of latent heat thermal energy storing structures and did research on particularizing numerous phase change materials (PCMs) that have been studied during the last thirty years, the heat transmission and augmentation methods applied in PCMs to efficiently charge and discharge latent heat energy and the construction of the problem of phase change substance.

A study was done in 1985 by Kaza and Chen which was concerned with the advantages of utilizing phase-change slurries as improved heat-transmission or storing liquids in solar energy and excess heat consumption structures. It showed that a slurry which contains a PCM as the dispersed phase talented to have much higher heat-transmission factors than conservative single-phase working liquids (Kasza & Chen, 1985). Integrated collector storage (ICS) theory for temperature which is not high and solar heating of water was defined by Robin in 1995. The solar energy was kept in a salt-hydrate PCM that is seized in the collector and was discharged to cold water flowing through a surface heat exchanger which is placed in a layer of secure heat transmission liquid (SHTL), floating over an immiscible layer of PCM(Rabin, Bar-Niv, Korin, & Mikic, 1995).

Hawlader et.all (2002) summarized phase change materials (PCMs) which were utilized for the storing of thermal energy. In their study both trials and simulation were executed to estimate the physical appearances of captured PCMs (Hawlader, Uddin, & Zhu, 2002).

A novel form of parabolic collector was technologically advanced and its short period thermal presentation was studied in Turkey in 2002. The parabolic collector that displayed a net solar gap range of 1.44 m^2, contained two contiguous segments one of them full of water and the other one is filled with a phase change substance with a melting and solidifying rate. The parabolic collector was much profitable against the old-style solar hot water collectors in Turkey in expressions of entire structure mass and the cost in specific(Kürklü, Özmerzi, & Bilgin, 2002)

In 2006, the operating of a dense phase change material (PCM) solar collector based on latent heat storage was examined by Mettawee and Assassa. The trial outcomes displayed that in the charging procedure, the average heat transmission coefficient rises severely with growing of the molten layer thickness, as the natural convection rises strong. In the process of discharging, the suitable heat achievement was originate to increase as the rate of water mass current rises(Mettawee & Assassa, 2006).

This topic also was studied in 2007 by Kenisarin and Mahkamov which is focused on the evaluation of the heat properties of several PCMs, approaches of thermal transmission augmentation and design formations of heat storage facilities to be used as a part of solar passive and active space heating systems, greenhouses and solar cooking (Kenisarin & Mahkamov, 2007).

(Koca, Oztop, Koyun, & Varol, 2008) analyzed energy and exergy that has been performed for a latent heat storage system with phase change material (PCM) for a flat-plate solar collector. There are several studies which were done in 2009. Guerra (2009) also studied on modeling a solar energy collector with an integrated phase-change material. He designed a finite-element computer model in order to pretend a solar air heater by using an integrated-phase change material. The finite-element sets were used to generate the model that captures the fundamental physical processes which are necessary in accurately simulating system. The simulation yielded positive results to its validity and can now be used to test different physical geometries and material before a prototype of the solar air heater is produced(Guerra, 2009).

operation examination of a latent heat storage system with phase change material for innovative planned solar collectors in greenhouse heating and also other heating devices studied recently (Benli & Durmuş, 2009; Mazman et al., 2009).

In 2012, an investigational study of a small-scale Trombe composite solar wall was done by Zalewski et.all. In their investigation, the phase change material was injected into the wall in the form of a brick-shaped package. This substance can collect more heat than the same volume of solid (for the same temperature range), it exposed various thermal behavior under dynamic situations (Zalewski et al., 2012).

Following up the review of past literatures, there are certain keywords and elements which are associated with this study are going to be thoroughly defined and signified in the nest part.

2.2 Thermal Energy Storage

Chemical and sportive heat storage systems which are counted as thermochemical storage systems are relatively new, promising technology approaches with considerable benefits compared to both the sensible and the latent-heat storage structures. Here storage densities can theoretically be up to 10 times above those of the medium water; i.e. these structures are capable of storing far more energy with requiring no greater structure capacity. Storage of thermal energy plays an important role in many engineering applications such as space, water cooling and heating and air conditioning (Dincer & Rosen, 2002).

"Thermal energy storage has the ability of being stored as a shift in internal energy of a substance as sensible heat, latent heat and thermochemical or blend of these. This is a chief method of storing solar thermal energy" (Sharma et al., 2009).

An overview of thermal energy storage is shown in Figure 2.1.

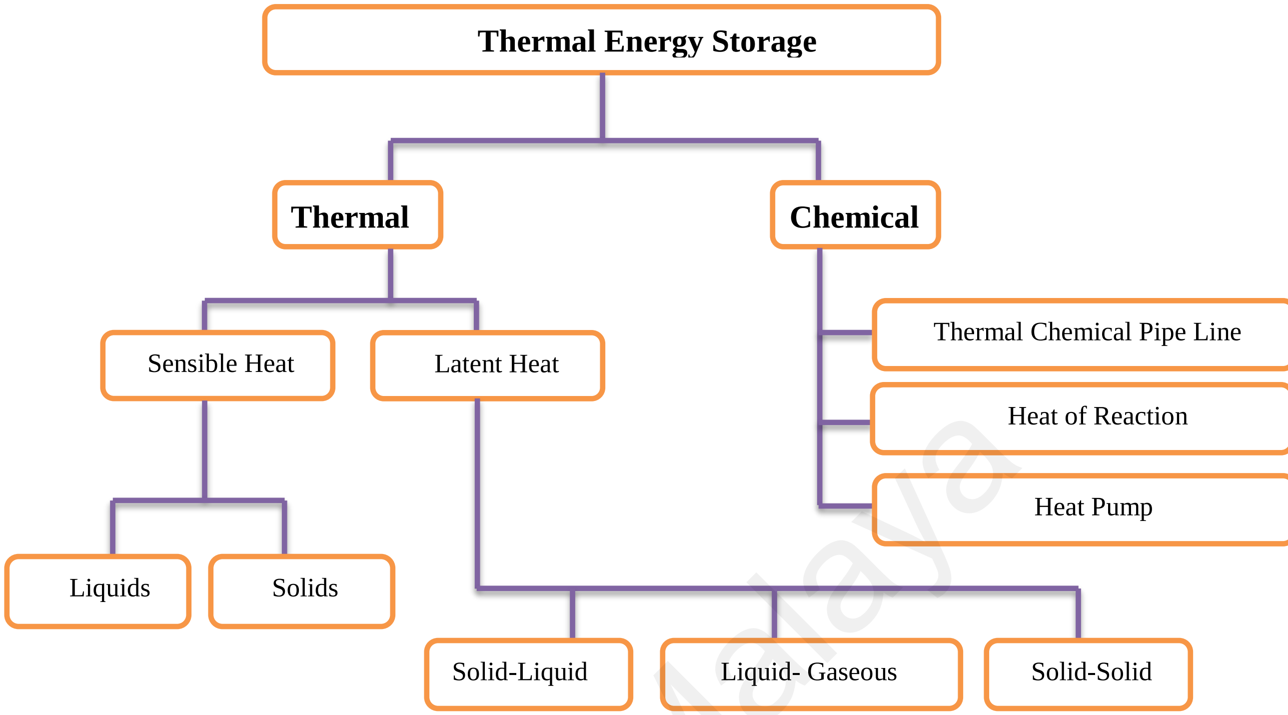

Figure2.1. Different types of thermal storage of solar energy

2.3 Thermal Energy Storage Method

- Sensible heat storage

In sensible heat storage (SHS), thermal energy is kept by levitation the temperature of a solid or liquid. SHS method that employs the heat capability and the alteration in temperature of the material through the process of charging and discharging(Sharma et al., 2009).

- Latent heat storing

Latent heat storage (LHS) is described as the absorbing of thermal energy or discharging it when a storage substance go through a phase change from solid to liquid or liquid to gas or vice versa(Padmaraju, Viginesh, & Nallusamy). The integration of a latent heat storage system in a modern heating system ought to enhance the overall system performance. Therefore a latent heat storage plate design for cooling applications has been adapted to the requirements of a modern heating system. The new storage system can be linked to a heat pump or a thermal solar system supplying a typical residential building, e.g. floor and ceiling heating system.

2.4 PCM (Phase change materials)

A PCM is a material with a high merging heat that is accomplished of storing and discharging huge amounts of energy by melting and hardening at a specific temperature. Most of the phase change materials (eutectic, organic and inorganic) are available in a various desired -temperature range. But it is true that the only criterion which is satisfied by most of these PCM is the melting point in the operating range. Although there isn't any single material having all the required properties of an ideal thermal storage media one should try to compensate for the poor physical properties of the available materials by designing a complete adequate system.(Sharma et al., 2009).

The PCM selected for any application must include some basic requirements such as:

- A temperature of phase change for the application (to reassure storage and also release of heat at the desired temperature) A congruent melting temperature,
- A large melting enthalpy density per unit volume (to achieve high storage density)
- A large density of melting enthalpy for each unit volume (in order to have high-storage density).

2.5 Classification

A useful classification of the materials has been given for TES by Abhhat in1983. Most of literatures have been focused on PCMs and its classifications to various materials, eutectics and combinations (inorganic, organic and fatty acids), that have been investigated by different scholars for their possible consumption as PCMs. Some of their thermo physical features are contained within (thermal conductivity and density, melting point, heat of fusion), however several authors gave more data (congruent/incongruent melting, specific heat, etc.) (Abhat, 1983; Padmaraju et al.).

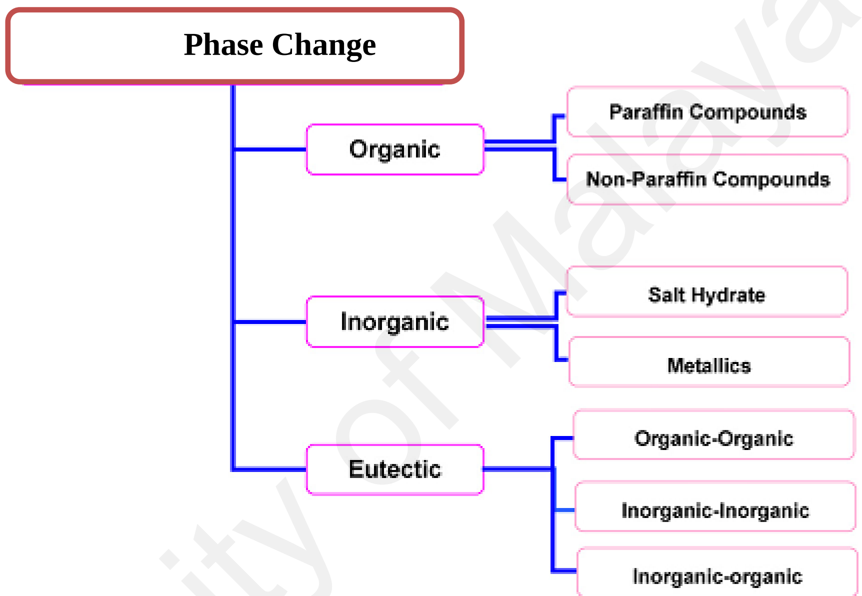

Fig.2.2 Classification of PCMs

	Organic	Inorganic	Eutectic
Pros	• No Phase segregation • Self-nucleating • Low Cost • Recyclable • Chemically inert and stable • Available in large temperature range	• Moderate Cost • Higher thermal conductivity • Low volume change • Non flammable • High volumetric storage density	• Sharpe melting point • High volumetric storage density
Cons	• Low thermal conductivity • Flammable • Low volumetric storage density	• Phase Segregation • Sub cooling • Corrosion of containment material	• Limited availability

Table2.1Advantages and Disadvantages of Organics, Inorganics and Eutectics

Organic Inorganic Eutectic

2.5.1 Inorganic PCM

Mineral substances are later categorized as salt hydrate and metallic. These phase change materials do not supercool noticeably and their heats of fusion do not reduce with cycling.

Commonly inorganic substances have greater volumetric latent heat storage capacity than the organic materials due to their high density. They show sharp phase change, high thermal conductivity and they are non-flammable. Moreover, they are easily available at low cost. The main drawback of these materials is incompatibility with metals because severe corrosion effect is proven for some PCM-metal combinations (Castellon, Martorell, Cabeza, Fernández, & Manich, 2011; Feilchenfeld & Sarig, 1985; Gin, Farid, & Bansal, 2011).

These materials are further classified as (1) salt hydrates (2) salts, and (3) metals.

Name	Melting Point (°C)	Latent Heat (kJ/kg)	Name	Melting Point (°C)	Latent Heat (kJ/kg)
H_2O	0.0	333	BI_3	31.8	10
$POCl_3$	1.0	85	$SO_3(\beta)$	32.3	151
D_2O	3.7	318	$TiBr_4$	38.2	23
$SbCl_5$	4.0	33	$H_4P_2O_6$	55.0	213
H_2SO_4	10.4	100	$SO_3\ (\gamma)$	62.1	331
$IC\ l(\beta)$	13.9	56	$SbCl_3$	73.4	25
MOF_6	17.0	50	$NaNO_3$	307	199
$SO3(\alpha)$	17.0	108	KNO_3	380	266
$IC\ l(\alpha)$	17.2	69	KOH	380	149
P_4O_6	23.7	64	$MgCl_2$	800	492
H_3PO_4	26.0	147	NaCl	802	492
Cs	28.3	15	Na_2CO_3	854	275
Ga	30.0	80	KF	857	452
$AsBr_3$	30.0	38	K_2CO_3	897	235
$SnBr_4$	30.0	28			

Lane, 1983; Abhat, 1983; Garg et al., 1985; Buddhi, 1994; Hale et al., 1971; Sharma, 1999.

Table2.2 List of some Inorganic PCMs

2.5.2 Salt hydrates as PCM

The most significant cluster amongst the PCM which have been comprehensively investigated for their consumption in latent heat thermal energy storage structures are Salt hydrates. Salt hydrates may be considered as mixtures of isolated ratio of inorganic salts and water forming a usual crystalline solid bounded through ion-dipole or hydrogen bonds with the general formula AB·nH 2O. Salt hydrates are available in wide temperature range from 5 to 130 ºC. Generally, they have high volumetric energy density due to their high density. But they can potentially separate into two different phases since the presence of salt and water molecules which have different densities. Actually, the solid-liquid conversion of salt hydrates is a process of dehydration of hydration of the salt, even though this procedure looks like melting or freezing thermodynamically. When a salt hydrate undergoes melting, it gives either salt hydrate with fewer amounts of water molecules (lower hydrate) or the anhydrous form of the salt. When the salt hydrate solidifies it releases water and the released amount of water is not enough to dissolve all the solid phase present and consequently causing the incongruent melting. Since there is density difference between water and salt, the minor hydrate (or anhydrous salt) slow down at the lowest part of the container. Most of salt hydrates melt incongruently which is the main disadvantage of using salt hydrates as PCM.

Advantages: The estimated cost of salt hydrates is very low and they are also easily available, these features make them very ideal for the application of the heat storage. (George Ashel Lane, 1983).Two of the most useful salt hydrates are $CaCl2.6H_2O$ and $Na_2SiO_3.5H_2O$ (George A Lane, 1980). They have a sharp point of melting and their thermal conductivity is very high at the time of comparison with other heat storage PCMs. This will increase transferring of the heat in and also out of the storage unit. Their fusion heat is high which decline the required mass of the storing structure. Salt hydrates' volume change is also lower than other PCMs. This will be helpful for designing a container for accommodation of volume change.

On the other hand the advantages could be:

- ✓ Incongruent melting Phase separation is the main problem due to the salt and water components with different densities. This can cause a reduction in the absorbed heat on melting and also released on crystallization and will increase the enthalpy peak over a broad range of temperature.
- ✓ Due to the phase separation they show problem with the cycling stability.
- ✓ Almost all the salt hydrates show sub cooling.

- ✓ They have low vapor pressure.
- ✓ Many salt hydrates are potentially corrosive.

But some solutions could be helpful to overcome phase separation, sub cooling and incongruent melting, such as, sub cooling can be counteracted by rough surfaces, sub cooling can also be prevented by introduction of crystal seeds, sub cooling can also be overcome by violent motion of the PCM, straight interaction heat transfer among hydrated salts and an immiscible fluid for the solution to sub cooling and other things.

Compound	Melting temperatur e (°C)	Heat of fusion (kJ/kg)	Thermal conductivity (W/m·K)	Density (kg/m^3)
Na2CrO4·10 H2O	18	n.a.	n.a.	n.a.
KF·4 H2O	18.5	231	n.a.	1447 (liquid, 20°C) 1455 (solid, 18°C) 1480
Mn(NO3)2·6 H2O	25.8	125.9	n.a.	1738 (liquid, 20°C) 1728 (liquid, 40°C) 1795 (solid, 5°C)
CaCl2·6 H2O	29 29.2 29.6 29.7 30 29-39	190.8 171 174,4 192	0.540 (liquid, 38.7°C) 0.561 (liquid, 61.2°C) 1.088 (solid, 23°C)	1562 (liquid, 32°C) 1496 (liquid) 1802 (solid, 24°C) 1710 (solid, 25°C) 1634 1620
LiNO3·3 H2O	30	296	n.a.	n.a.
K3PO4·7 H2O	45	n.a.	n.a.	n.a.
Zn(NO3)2·4 H2O	45.5	n.a.	n.a.	n.a.
Ca(NO3)2·4 H2O	42.7 47	n.a.	n.a.	n.a.
Na2HPO4·7 H2O	48	n.a.	n.a.	n.a.
Na2S2O3·5 H2O	48 [48-49	201 209,3 187	n.a.	1600 (solid) 1666
Zn(NO3)2·2 H2O	54	n.a.	n.a.	n.a.
NaOH· H2O	58.0	n.a.	n.a.	n.a.
Na(CH3COO)· 3 H2O	58 58.4	264 226	n.a.	1450
Cd(NO3)2·4 H2O	59.5	n.a.	n.a.	n.a.
Fe(NO3)2·6 H2O	60	n.a.	n.a.	n.a.
NaOH	64.3	227.6	n.a.	1690
Na2B4O7·10 H2O	68.1	n.a.	n.a.	n.a.
Na3PO4·12 H2O	69	n.a.	n.a.	n.a.
Na2P$_2$O7·10 H2O	70	184		n.a.

n.a.: not available or not known at the time of writing

Table2.3 Inorganic substances with potential use as PCM

2.6 Solar Water Heater

Sun's energy has been used ever since as a source for heating water, not lesser than a hundred years ago a huge number of countries started to use black painted water tanks as the primary solar water heaters. SWH has been totally developed through past century. Today the number of the installed solar collectors is more than 30 million m2 all over the world. There are a growing number of contemporary solar water heaters which is utilize in china, India, Germany, Japan, Australia and Greece. Actually in some countries, according to law, solar water heaters must be installed in any new construction projects.

Solar water heating systems transfer heat to the load by using solar collectors and a liquid handling unit. The liquid treatment unit consists of a pump that is used to mix the working fluid from the collectors to the storing tank, switch and protection equipment. If the design done is professional solar water heaters will effort even if the external temperature is beneath freezing.

They can also be protected on hot, sunny days from overheating. Many systems also include a back-up heater in order to warranty consumers' needed hot water supply so long as the sunshine is not sufficient.

Solar water systems are of three kinds based on the operations:

- **Collection:** solar radiation is trapped by a solar collector
- **Transfer:** the energy is transferred by circulating fluids to a storage tank. This circulation can be natural or forced using a low-head pump as a circulator.
- **Storage:** Hot water will be stored pending for a later time when it is needed in a mechanical room or on the roof in thermo siphon system.

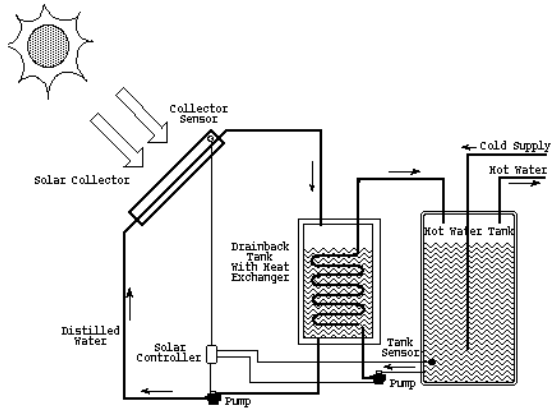

Figure.2.3 Three main part of solar water heater

2.7 Solar collectors

2.7.1 Glazed liquid flat-plate collectors

In glazed liquid flat plate collectors, as shown in Figure.2.5 a flat plate absorber with a selective coating is located inside a frame which is among a single or double layer of glass and a lagging panel in the back.

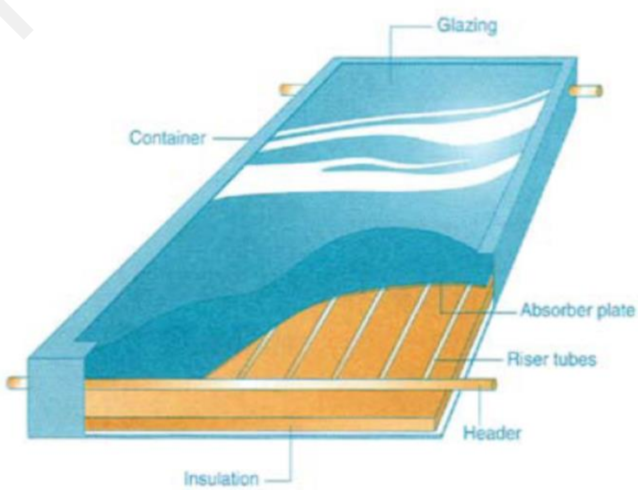

Figure.2.5 Glazed liquid flat-plate collectors

2.7.2 Exiled tube solar collectors

Evacuated tube solar collectors as indicated in Figure.2.6 consist of an absorber with a selective coating inside a sealed glass vacuum tube. Their energy capturing from the sun is very high and also their thermal losses to the environment is very low.

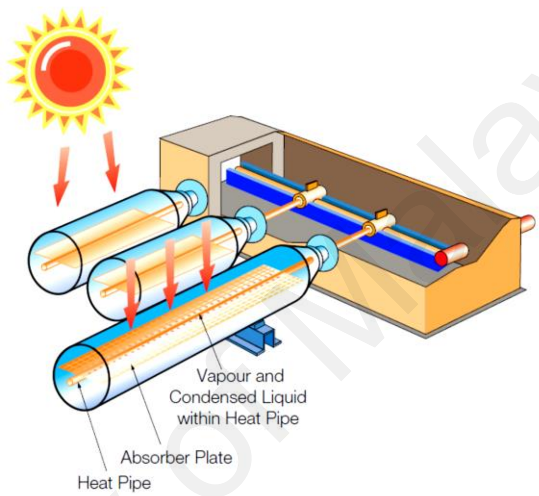

Figure.2.6 Evacuated tube solar collectors

2.7.3 Parabolic Concentrator

A parabolic trough is a kind of solar thermal collector which is straight in one dimension and curved in the other lined by a polished metal mirror. There is a Dewar tube typically runs the length of the trough at the focal line. The mirror is adjusted in a way that the reflected sunlight will be concentrated on the tube, containing a fluid which is going to be heated to a high temperature by the sunlight energy.

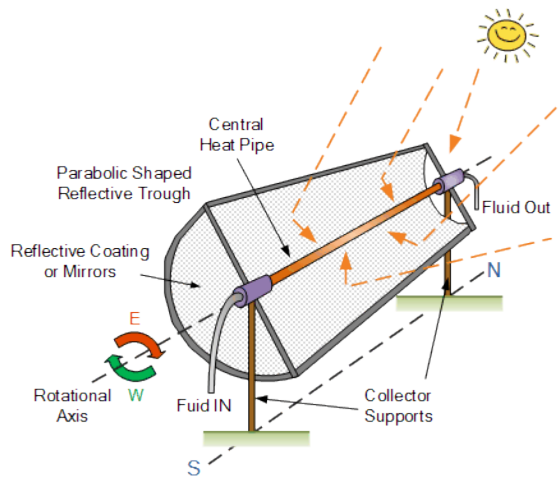

Figure.2.7. Parabolic Concentrator

2.7.4 Unglazed liquid flat-plate collectors

Unglazed liquid flat plate collectors are prepared up of a black polymer without a selective coating excluding an edge and insulation at the back. They are generally merely placed on a roof or a wooden support as shown in Figure 2.4 Their cost is very low and they can capture sun energy very well. But in windy locations thermal losses to the environment will increase fast with water temperature, therefore they have to be used for applications with low temperature energy delivery (pool heating, process heating applications, make-up water in fish farms, etc.). If they are to be used in colder climate they should be operated in summer or warm seasons to avoid thermal losses of the collector.

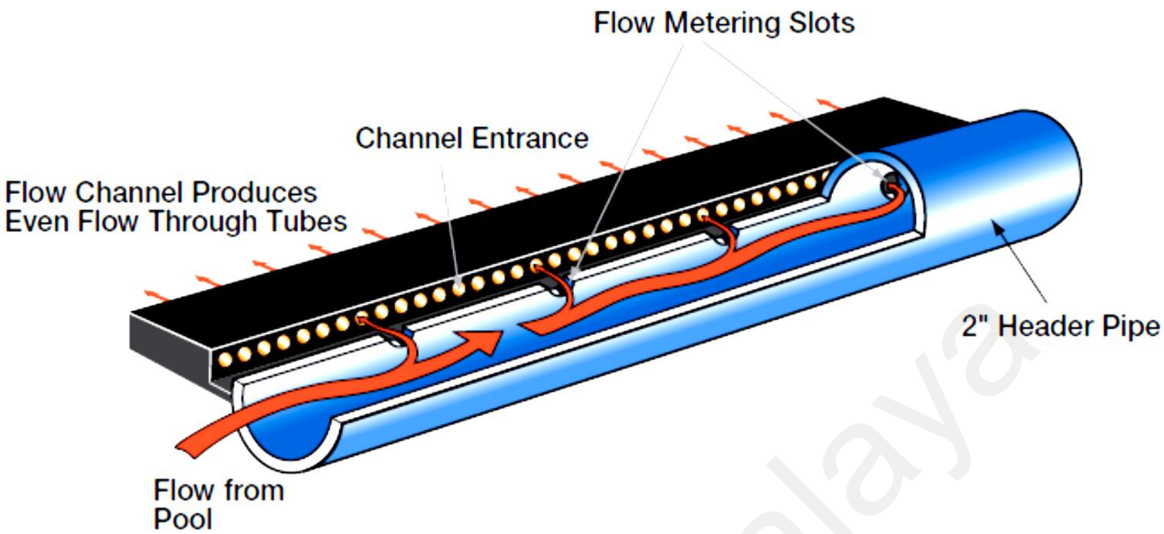

Figure.2.4 Unglazed liquid flat plate collector

CHAPTER THREE: DESIGN, METHODS AND PROCEDURE

3.1 Introduction

This study states the development, validation and application of heat transfer models installed in MATLAB. This model clarifies the operation of a parabolic rack solar collector's linear receiver, named as heat collector element (HCE). Heat transfer and thermo dynamic equations, optical properties and parameters of the model are studied and described in details together with the whole inputs and out puts of the model.

Inputs are: collector and HCE geometry, visual possessions, Heat transfer fluid properties (HTF), HTF inlet temperature, the rate of the flow, solar insolation, phase change material properties, and the ambient temperature.

Outputs are: Heat gains and losses, outlet HTF temperature PCM temperature, absorber temperature, Pyrex envelope temperature and collector efficiency. All of the assumptions and limitations of the model are also discussed besides the model improvement recommendations.

For more accuracy, Tow-dimensional is better than one–dimensional but usually one dimensional has been used for small collector. The MATLAB diagram windows, Function and look up tables for each version of the codes is included in the study. Although the detailed software of MATLAB is not included, the references are available.

3.2 Heat collector element Performance Typical

The HCE performance typical or model is constructed with energy equilibrium to collector and the HCE. The energy equilibrium consists of the straight, ordinary solar contamination instance on the collector, optical fatalities from the collector and HCE, thermal fatalities from HCE, the heat gain in to HFT and the stored heat in PCM. A one-dimensional HCE performance model for two designs is elaborated in the following chapters.

3.3 One-Dimensional Energy Balance Model

The HCE performance typical works with energy equilibrium among the HFT and the atmosphere and in order to fulfill the terms in the energy balance it includes all the necessary equations and correlations which also depend on the type of collector, HCE condition, PCM ambient conditions and the optical properties. One-dimensional will give us a reasonable result if the length of parabolic collector is less than 100 meter.(Forristall, 2003)

Figure 3.3 shows the energy balance of one-dimensional steady-state for a cross section in a HCE including a phase change material and without it. Figure 3.4 indicates a thermal resistance model and the subscript definition . In order to clarify; the received solar energy and visual fatalities were lost from the conflict model. The visual fatalities are because of the collector mirrors' imperfections, tracking errors, mirror and HCE cleanliness and shading. The effective incoming solar energy is trapped by a glass envelope and absorber selective coating.(Forristall, 2003)

Note that the solar absorption in glass envelope and absorber are preserved as heat flux term. This will simplify the terms of solar fascination and conduct the heat inside the absorber pipe and glass envelope linearly.

In fact the solar absorption which exists in the absorber and glass envelope are volumetric singularities. Furthermost of the absorption in the absorber appears very close to the surface. The absorbance is fairly small although solar absorption happens through the thickness of the glass envelope. As a result any errors in handling solar absorption as a surface singularity are moderately small.

3.4 System definition

Two systems are analyzed in this study, a simple parabolic collector and the same parabolic collector but the PCM has been installed inside it in specific circumstance. The Pyrex cover has been fixed in focal line of parabolic mirror with a cylindrical absorber joined to a co axial pipe assembly. Figure.3.1 shows a schematic of design. All the specifications and featured values of the whole relevant parameters and constant used in this study are specified in Table .3.1.

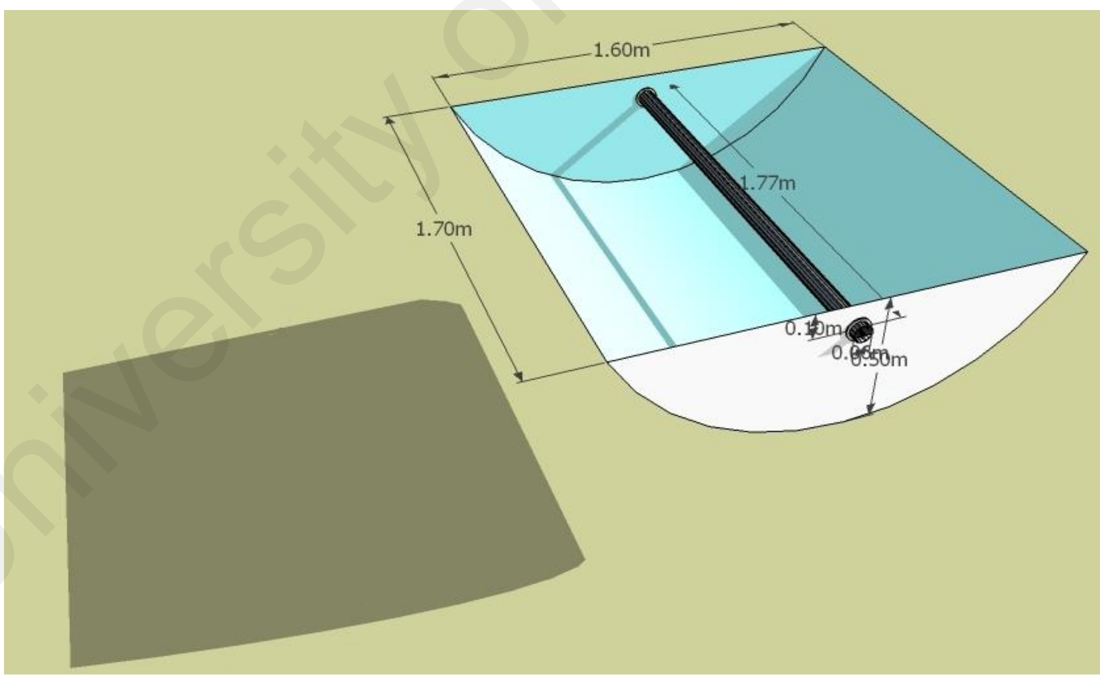

Figure.3.1Overall view of design

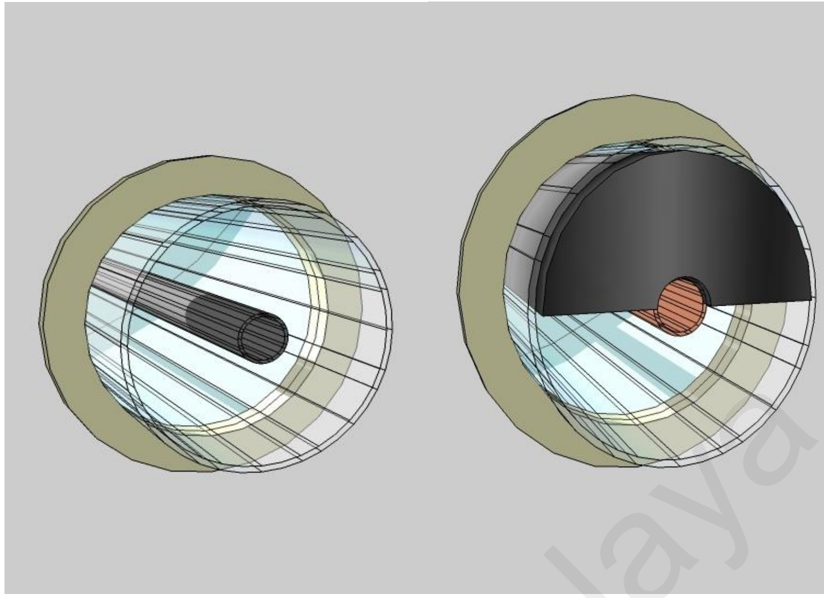

Figure.3.2 Cross Section View of (Left side) Simple Collector (Right side) With PCM Box

Description	Specificatio
Outside diameter of glass cover (mm)	65
Inside diameter of glass cover (mm)	62
Length of glass cover and absorber sheet(mm)	1770
Outside diameter of pipe(mm)	18
Inside diameter of pipe	17.5
Emissivity of glass	0.88
Emissivity of surface coating	0.05
Emissivity of copper	0.03
Specific heat water(KJ/KG.K)	4.187
Mass flow rate Of Water (KG/s)	0.07

Table3.1Dimensions Descriptions

3.5 Phase change material

The material that is going to be used must have certain features as follow:

1. Having high melt temperature (Since the operation temperature is between 60 ºc – 160 ºc)
2. Having high heat capacity
3. Causing minimal corrosion in collector
4. Having the highest heat conductivity

According to those features Sodium Silicates ($Na_2SiO_3{\cdot}5H_2O$) is been chosen as the phase change material in thermal system. Sodium silicate is a soluble white powder which is readily miscible in water, creating an alkaline solution Table.3.2 exhibits the thermal properties of the Sodium Silicates.(Nagano, Mochida, Takeda, Domański, & Rebow, 2003)

Material	Melting Point(ºC)	Heat of fusion (kJ·kg−1)	Heat of fusion (MJ·m−3)	Cp solid (kJ·kg−1·K−1)	Cp liquid (kJ·kg−1·K−1)	ρ solid (kg·m−3)	ρ liquid (kg·m−3)	Ksolid (W·m−1·K−1)
$Na_2SiO_3{\cdot}5H2O$	72.20	267.0	364.5	3.83	4.57	1,450	1,280	0.128

Table3.2.Materials Descriptions(Kalapathy, Proctor, & Shultz, 2003)

3.6 Energy balance of model

The heat-transfer model is necessary to determine the amount heat which needs to charge the phase-change material or estimate the heat losses from the system during the day. For this purpose, we need to use the energy balance equation between the system and surrounding. This equation must be according to collector type, dimension, solar radiation and surrounding condition. The schematic design is shown in Figure.3.3. Picture shows a simple diagram of heat transfer between the heat pipe, glass envelope and atmospheric for upper side.

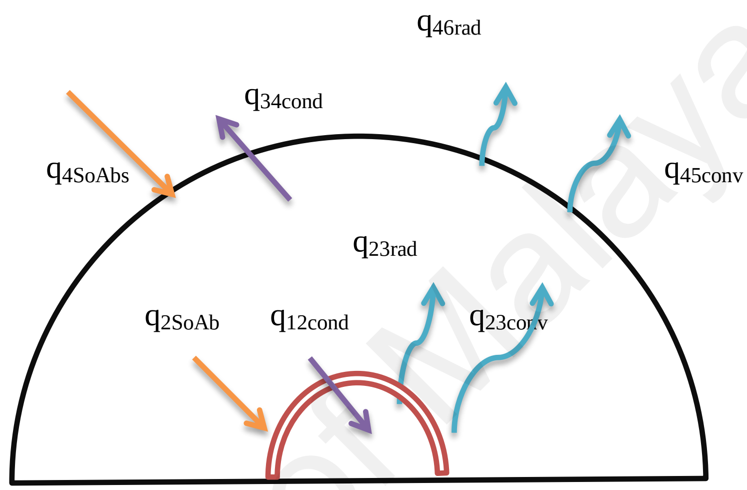

Figure3.3 Figure of upper side of the collector tube

According to the figure.3.3, equation balance of simple collector is:

$q_{water}=q_{12cond}$ (1)

$q_{2SoAbs}=q_{23conv}+q_{23rad}+q_{condabs}$ (2)

$q_{23conv}+q_{23rad}=q_{34cond}$ (3)

$q_{4SoAbs}+q_{34cond}=q_{45conv}+q_{46rad}$ (4)

3.6.1 Thermal resistance model of top and bottom:

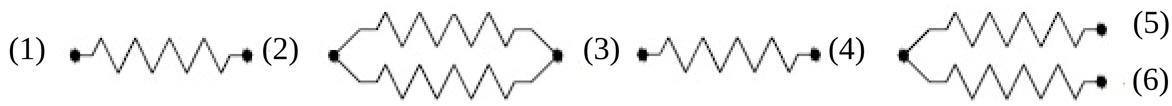

Figure.3.4Thermal Resistance Model (Forristall, 2003)

This thermal model resistance is exist for both side of model (top side & bottom side)

(1) Absorber inner surface Temperature

(2) Absorber outer surface Temperature

(3) Glass envelope inner surface Temperature

(4) Glass envelope outer surface Temperature

(5) Surrounding air Temperature

(6) Sky Temperature

3.6.2 Heat Transfer between the HTF and Absorber Area

Heat transfer of HTF is given by Newton's Law:

$$q_{convwater} = \pi h l D_{ai}(T_1 - T_{water}) \quad (5)$$

$$h = \frac{k_w}{D} Nu_D \quad (5\text{-}1)$$

D_1: Inside Diameter of Absorber

Nu_D: Nusselt Number of absorber pipe with diameter of D

k_w: Conductivity of Water

T_1: Absorber Temperature

T_{water}: Mean Temperature of HTF

L : Length of Absorber

A possibility to make prototype of the current as laminar is contained within in all the one-dimensional versions of the HCE heat transfer codes. Once the laminar preference is selected and the Reynolds number is lower than 2300, the Nusselt number will be persistent. For tube current, the significance will be 4.36(F. D. Incropera).

3.6.3 Conduction heat transfer in the Absorber

Fourier`s law is used to calculate the heat that transfer through the absorber plate(F. P. Incropera & David, 1990).

$$q = 2\pi K_{12}(T_2 - T_1)/\ln(D_2/D_1) \tag{6}$$

K_{12}: Conductance coefficient at the average temperature $(T_1+T_2)/2$

L: Length of absorber and Pyrex envelope

D_2: Outer Diameter of Absorber

D_1: Inner Diameter of Absorber

T_1: Absorber top side surface Temperature

T_2: Absorber bottom side surface Temperature

3.6.4 Convection heat transfer in Annulus

When the pressure inside the Pyrex envelope is more than one torr the convection heat transfer process between the absorber and Pyrex is the natural convection. The correlation of natural convection between the spaces of horizontal cylinders, which used in this case is presented by Raithby and Holland.(Bejan, Tsatsaronis, & Moran, 1995)

$$q_{23} = \frac{2.425 k_{23} l (Pr Ra_{D2}/(0.861+Pr))^{1/4} (T_2 - T_3)}{(1+(D_2/D_3)^{3/5})^{5/4}} \quad (7)$$

$$\beta = 1/T_{23} \quad (7\text{-}1)$$

$$Ra = \frac{\beta g D_2^3 \Delta T_{23}}{\alpha \vartheta} \quad (7\text{-}2)$$

L: Length of absorber plate

W: Width of absorber plate

k_{23}: Heat conductivity of annual gas at T_{23}

T_2: outer absorber surface temperature

T_3: inner glass envelope surface temperature

β : volumetric thermal expansion

Ra: Rayleigh number

g: Acceleration due to gravity

μ: Dynamic viscosity (kg/m s)

ΔT_{23}: Difference temperature (T_2-T_3)

D_3: Inner Diameter of Pyrex

D_2: Outer Diameter of Absorber

Pr : Prandtl Number

3.6.5 Radiation heat transfer

The heat transfer by radiation between the absorber and glass envelope is calculated by the following equation. (De Soto, Klein, & Beckman, 2006):

$$q_{23rad} = \sigma(T_2^4 - T_3^4)/(\frac{1-\varepsilon_2}{\varepsilon_2} + (1-\varepsilon_3)A_{ab}/(\varepsilon_3 A_g)) \quad (8)$$

σ: Stefan-Boltzmann Constance

A_{ab}: Absorber area

A_g: Inner Glass area

T_2: Outer absorber surface temperature

T_3: Inner glass envelope surface temperature

ε_2: $Absorber$ Selective coating emissivity

ε_3: $Glass\ envalope$ Emissivity

Several assumptions are made to simplify the equation:

(1)Non-participating gas in the annulus, (2) gray surface, (3) diffuse reflection and irradiation and (4) long concentric isothermal cylinders(Wamsteker, Kroes, & Fountain, 1974).

3.6.6 Conduction Heat Transfer through the Glass envelope

The heat flow by conduction through the glass envelope can be expressed by the same equation as that for absorber wall but in cylindrical form. The thermal resistance due to the anti-reflective treatment of the surfaces is neglected and therefore, does not affect the emissivity. The temperature distribution is considered to be linear and the conductivity to be constant.(Redfield et al., 2002)

$$q = 2\pi\, k_{34}(T_4 - T_3)/\ln(D_4/D_3) \tag{9}$$

k_{34}: Conductance coefficient at the average temperature $(T_3+T_4)/2$

D_4: Outer diameter of glass envelope

D_3: Inner diameter of glass envelope

T_3: Absorber outer side surface Temperature

T_4: Absorber inner side surface Temperature

3.6.7 Convection heat transfer from glass envelope

More energy is lost by convection from the glass envelope that can be estimated by(F. Incropera & DeWitt):

$$q_{45conv} = \pi D_5 h_{45}(T_4 - T_5)/2 \quad (10)$$

$$h_{45} = \frac{k_{45}}{D_4} Nu_{D4} \quad (10\text{-}1)$$

T_4: Temperature of outer surface`s glass envelope

T_5: Ambient temperature

h_{45}: Convection heat transfer coefficient for air at $(T_4 + T_5)/2$

k_{45}: Thermal conductivity of air at $(T_4 + T_5)/2$

D_5: Glass envelope outer diameter

Nu_{D4}: Average Nusselt number based on the glass envelope outer diameter

No wind condition

Convection heat transfer is divided two cases, one is No wind case and another one is wind case that they have different solution. Two systems are model in no wind condition, so we have free convection from the outer surface of the glass envelope to the environment. In this condition, Nusselt number is obtained by equation.(F. Incropera & DeWitt)

$$Nu_{D4} = \left\{0.60 + \frac{0.387 Ra_{D5}^{1/6}}{[1+(\frac{0.559}{Pr_{45}})^{9/16}]^{8/27}}\right\}^2 \quad (11)$$

$$Ra_{D5}=\frac{g\beta(T_4-T_5)D_4^3}{(\alpha_{45}\vartheta_{45})} \quad (11\text{-}1)$$

$$\beta = 1/T_{45} \quad (11\text{-}2)$$

$$Pr_{45} = \vartheta_{45}/\alpha_{45} \quad (11\text{-}3)$$

Where:

Ra_{D5}: Rayleigh number for air

g: gravitation constant

α_{45}: Thermal diffusivity for air at T_{45}

β : Volumetric thermal expansion coefficient

Pr_{45}: Prandtl number

ϑ_{45}: *kinematic viscosity for at* T_{45}

T_{45}: temperature of film

3.6.8 Radiation Heat transfer

Due to the eight differences between the temperature of the glass envelope and the sky, heat-transfer radiation happens. To approximate the amount of heat transfer; the envelope is assumed to be as a small convex gray object in a large black body cavity (sky).

$$q_{46rad} = \pi\varepsilon_4 D_4 \sigma(T_4^4 - T_6^4) \quad (12)$$

σ: *Stefan − boltzmann* constant

D_4: Glass envelope outer diameter

ε_4: *Emissivity of a glass envalope outer surface*

T_4: Glass envelope outer surface temperature

T_6 : Effective sky temperature

3.7 Optical Properties

All the mentioned visual assets in the HCE performance model are collected after a plenty of sources, some of which were determined by SEGS plant for performance modeling accomplished by NREL and a number of them were regulated by tests directed by SNL, and solei system ltd. of Israel the prime HSE manufacturer.

Table 2.4 indicates term used for estimating the effective optical efficiencies, it was created from the published data of a report done by NREL which was based on field tests and software performance modeling the first three terms, and the last term are totally estimates(Abazajian et al., 2009). The first three terms, ε_1, ε_2, and ε_3, and the last term, ε_6, are strictly estimates. The clean mirror reflectance ρ cl is a well-known value, and the two dirt effect guesses ε_4 and ε_5 are presented by(Gansler, Klein, & Beckman, 1995). The whole data generated in the table are merely valid for solar incidence vertical radiation on the collector aperture. A term for beam angle modifier is added to clarify the incident angle losses. It includes reflection and reflection changes, trough end shading.

ε_1= HCE Shadowing (bellows, shielding supports)	0.932
ε_2= Tracking Error	0.945
ε_3= Geometry Error (mirror alignment)	0.979
ρ_{cl} = Clean Mirror Reflectance	0.925
ε_4= Dirt on Mirrors*	reflectivity/ ρ_{cl}
ε_5= Dirt on HCE	$(1 + \varepsilon_4)/2$
ε_6= Unaccounted	0.92
reflectivity is a user input (typically between 0.88 and 0.93)	

Table3.4 Optical parameter (Forristall, 2003; Price, 2003)

3.8 Solar Radiation Absorption by the Glass Envelope

The solar absorption into the glass is treated as a heat flux. The solar absorption in the glass envelope is a heat generation phenomenon and is a function of the glass thickness. However, this assumption has error a very small since the solar absorption for the glass is small (0.08) and the thickness is small also (1.5mm). So the solar absorption can be determined(Wamsteker et al., 1974):

$$q_{4SoAbs} = \eta env \; q_s \alpha_{env} \tag{13}$$

$$\eta_{env=}\varepsilon_1\varepsilon_2\varepsilon_3\varepsilon_4\varepsilon_5\varepsilon_6\rho_{cl} \tag{13-1}$$

α_{env}: Absorption of glass envelope

q_s: Solar radiation per receiver length (w/m)

η_{env} : Effective optical efficiency

3.9 Solar Radiation Absorption in the Absorption

The solar energy absorption by the absorber happened so near the surface; so, it is assume as a heat flux. The equation give the amount of energy is absorbed by absorber(Wamsteker et al., 1974):

$$q_{2soAbs} = q_s \alpha_{abs} \tau_{env} \eta_{env} \tag{14}$$

α_{abs}: absorptance of absorber (14-1)

τ_{env}: Transmittance of the glass envelope (14-2)

3.10 Temperature of SKY

The corresponding temperature of the clouds, water vapor, and other atmospheric components make the sky to be considerable a surface which can radiate the heat so its temperature is capable of being calculated by current formula.(Cohen, Kearney, & Price, 1999)

$$T_{sky} = T_a(0.711 + 0.0056T_{dew} + 0.000073T_{dew}^2 + 0.013\cos(15h))^{1/4} \tag{15}$$

T_a: Ambient Temperature

T_{dew}: Dew Point Temperature

h: Solar hour

3.11 Energy balance for system with PCM

The energy balance is similar to normal one however the Phase Change Material(PCM) is installed inside of collector, between the heat transfer fluid pipe and absorber, since of the nature of the phase change material that they store the heat as latent heat this equations are given in un steady- state condition.

Equations of energy balance for PCM:

$$q_{2SolAbs}=q_{23conv}+q_{23rad}+q_{12cond}+q_{PCM} \quad (16)$$

$$q_{23conv}+q_{23rad}=q_{34cond} \quad (17)$$

$$q_{4SolAbs}+q_{34cond}=q_{45conv}+q_{46rad} \quad (18)$$

3.12 PCM energy balance

The equation below shows rate of conserve energy by Phase Change Material:

$$q_{PCM}=\rho_{PCM} A_{PCM} C_{PCM} dT_{PCM}/dt$$

3.13 Irradiation from parabola solar collector

For this project we chose the parabolic mirror as collector since this kind of collector concentrate the solar radiation on Focal Line. So the heat flux can be calculated by this formula(Eskin, 1999):

$$q_s = \varphi_r I_b w \quad (20)$$

φ: Interception factor (Figure.3.6)

w : Reflector Aperture $(w = 4f)$

I_b : The irradiance of the incident beam

γ : Rim angle (show in the Figure3.5)

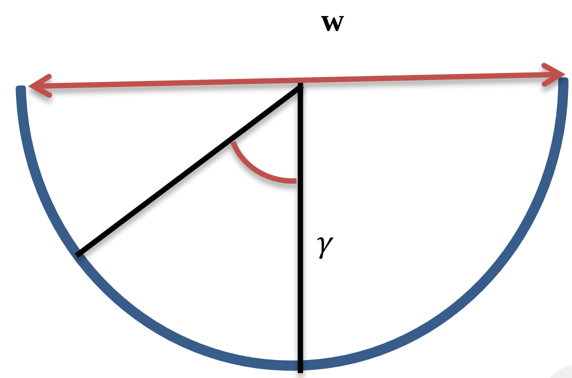

Figure.3.5Geometric shape of Parabola collector

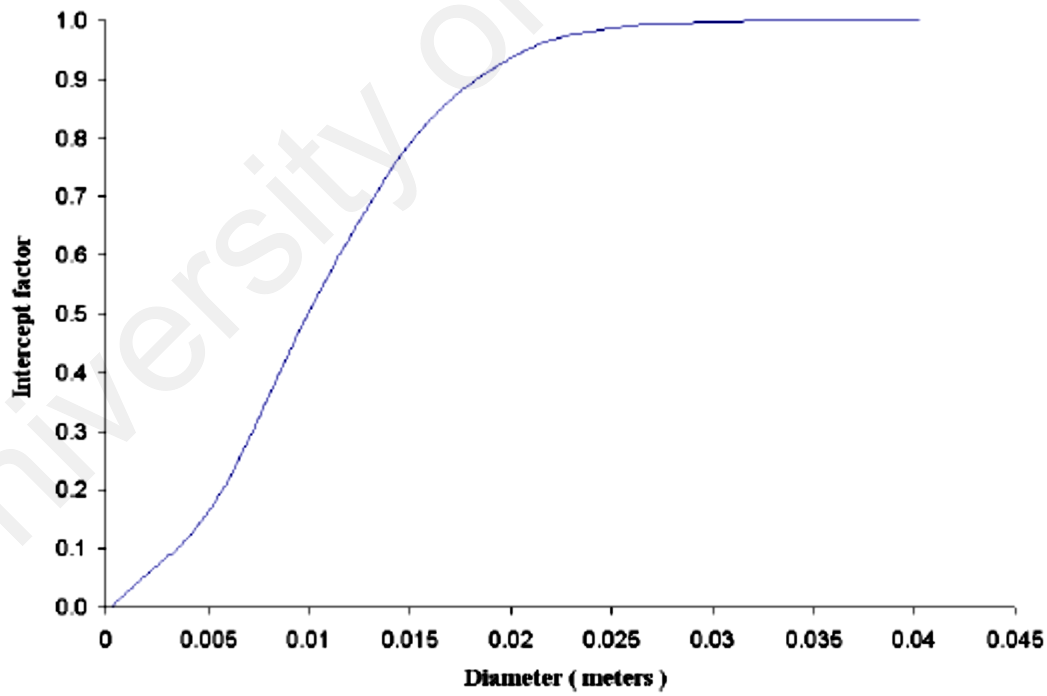

Figure.3.6Graph of interception factor(Lovegrove, Burgess, & Pye, 2011)

3.14 Efficiency of System

The efficiency of system is going to be gained by using formula (21)(Eskin, 1999).

$$\eta_c = E/IA_c \tag{21}$$

$$E \doteq \dot{m}c_w(T_{w,o} - T_{w,i}) \tag{22}$$

η_c: Efficiency of Collector

E: Output of system

m: Mass Flow rate of Water

$T_{w,o}$: Outlet Temperature of Water

$T_{w,i}$: Inlet Temperature of Water

C_w: Mean Capacity of Water

3.15 Solar Radiation Data

To assess and confirm the formulation which stated in this study, the daily operation of the cylindrical concentrator collector was made similar utilizing the set of solar radiation data gather on 18 July. These data are for a sunny and clear day with available insolation and ambient temperature from morning to sunset. They are presented in Table.3.4.

Solar Time	Available insolation(W/m^2)	Ambient Temperature(C)
6	113	24
7	224	24
8	433	25
9	612.5	26
10	750	28
11	835	28.3
12	865	28.7
13	840	29
14	755	28.6
15	605	27.8
16	435	27
17	224	26.4
18	112	25.6
19	10	24

Table.3.4Available Insolation and Ambient Temperatures Measured in a Day(Eskin, 1999)

3.16 Assumptions and Simplifications

Several assumptions and simplifications presented in the simulation of the parabolic solar collector listed in Table.3.5. And the main assumptions to simulate the system are(Forristall, 2003):

1. In this work, the temperatures of the absorber tube and glass cover are assumed to be circumferentially unvarying and the water fully in the liquid phase.

2. In the analysis, the temperature changes through the thickness of the walls of the Pyrex and the absorber are presumed to be negligible.

3. The mass flow rate of the working fluid is assumed to be constant

Model Component	**Assumptions and Simplifications**
Convection heat inside of cylindrical collector	· Inlet temperature is the medium temperature of mass · Constant flow. · For laminar flow and constant flux
Conduction heat transmissions through absorber pipe	· Negligible thermal resistance from absorber coating and glass envelope anti-reflection treatment.
Convection heat transfer Inside of Pyrex envelope	· Constant convection heat coefficient. · Uniform temperatures.
Inside radiation between Pyrex envelope and absorber pipe	· Annulus gas is nonparticipating. · Both surfaces are gray. · Diffuse irradiation and reflections. · Surfaces are formed from long concentric isothermal cylinders. · Pyrex cover is impervious to emission in the infrared domain.
Convection heat transfer	· No wind case are Assumed

	· Long isothermal Cylinder
Radiation heat transmission between Pyrex cover and sky	• Small convex gray object in a large blackbody cavity.
Visual possessions	• Constant possessions. • Negligible degradation with time. • Anti-reflection behavior is too small to assume effect on glass envelope emittance. • Optical properties are autonomous to temperature
SolAbs $q3'$ & and *SolAbs* $q5'$	· Assume as uniform heat fluxes
Irradiance	· Uniform · Neglected heat component element and bracket shadowing.
General	· Heat losses from side to side of cross piping are not involved. ·Thermal belongings of PCM is to be constant · Investigation from head-to-head holders is ignored. · temperatures are unchanging

Table.3.5. Table of Assumption

3.17 Model Limitations

There have been several limitations for HCE performance model. As an example, since the model disregards the no uniformity in the solar radiation round the boundary and length of the Collector Component Element, therefore these properties cannot be assessed. It is also concluded that asymmetric model changes cannot be assessed– such as accumulating a reflective coating to part of the internal surface of the Pyrex to return back to the absorber some of the focused solar flux that failures the absorber and to decrease some of the absorber thermal radiation .(Forristall, 2003)

CHAPTER FOUR: RESULTS AND DISSCUTION

4.1 Introduction

The only way that enables us to change the parameter of system or performance condition is simulation of parabolic solar collector. This ability helps us testing the system and compares it under the same weather condition with deference performance parameter in the simulator without expensive test. Regarding to this benefit the cylindrical parabolic collector can be design with a higher efficiency in order to deduct the waste of energy and cost.

The developed simulation program of a steady state model of parabolic collector is utilized to achieve to the collector efficiency and heat loss of system which run in domestic solar water heater or solar power plan process.

Performance result of two systems are calculated for the constant flow by rate of 0.007Kg/s, water inlet temperature 25^{o}c from sunrise to sunset in order to analyze and compare them in real time of operating hours. All boundary condition and the material component are the same for two systems which are simulated in MATLAB. In the following chapter the output of simulation will be compared and analyzed.

4.2 Absorber Temperature Analysis

Absorber temperature diagrams for two systems are given in Figure 4.1 and Figure 4.2 .The graphs show the comparison of the temperature of absorber within a solar day. Between 6 a.m. and 16 p.m., both diagrams have a similar pattern which show that the temperature of absorber rise steadily to around 380 ^{o}k then decrease moderately to 320 ^{o}k at 16 pm. Therefore system with a PCM keeps its temperature around 320 ^{o}k but the other one drop to 299^{o}k at 19. The output data are presented in Table 4.1for more information.

HOUR	T_a (NORMAL)	T_a (PCM)
6	309.085	308.3268
7	321.0237	319.5195
8	344.4862	341.5783
9	364.6498	360.5459
10	381.4477	376.4211
11	391.0229	385.4177
12	394.5999	388.7965
13	392.4724	386.8208
14	382.4441	377.3924
15	365.8315	361.7668
16	346.4486	343.5439
17	323.4183	321.9143
18	310.4973	320.7543
19	299.0072	319.9462

Table.4.1.Absorber Temperature Data

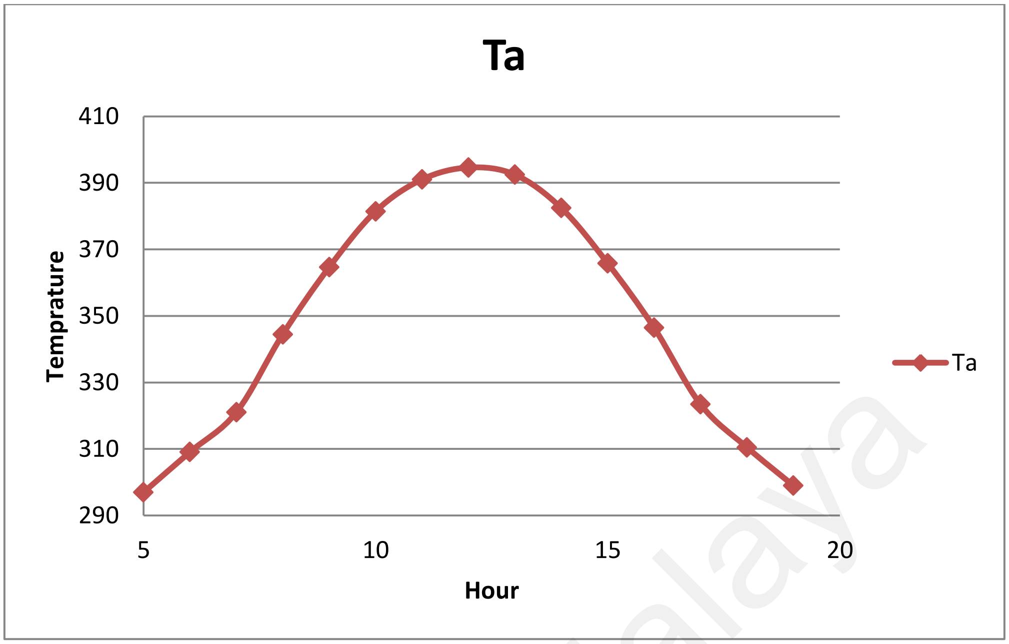

Figure 4.1 Absorber Temperature diagram for parabolic collector without PCM

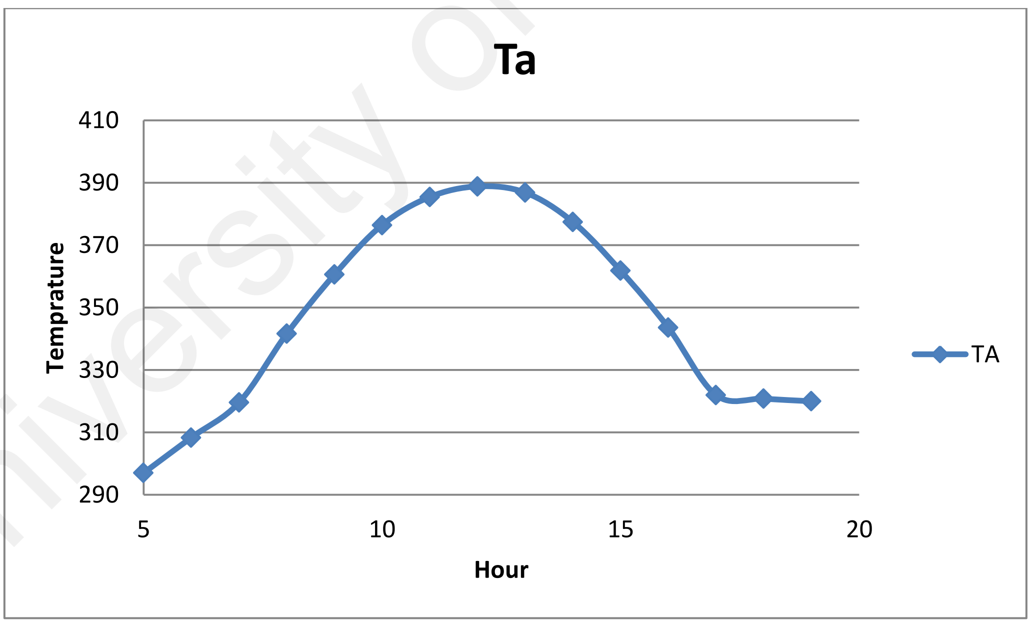

Figure 4.2 Absorber Temperature diagram for parabolic collector with PCM

4.3 Pyrex Temperature Analysis

Impact of installation PCM inside the parabolic solar collector on the Pyrex temperature is too small. According to the given diagrams (Figure 4.3 and Figure 4.4) and output Data table (Table 4.2), Pyrex temperature has a gradual rise to around 327 ^{o}k in solar noon and a sharp fall to ambient temperature after this time.

HOUR	T_p (NORMAL)	T_p(PCM)
6	294.5424	294.2538
7	299.2708	298.6886
8	313.7009	312.1784
9	317.1474	315.4787
10	324.1427	322.2299
11	327.3256	325.179
12	328.3404	326.1272
13	328.4054	326.2804
14	323.5579	321.6567
15	318.0348	316.5099
16	310.6581	309.5663
17	301.0501	300.4852
18	296.9306	296.639
19	288.6017	288.5667

Table.4.2.Pyrex Temperature Data

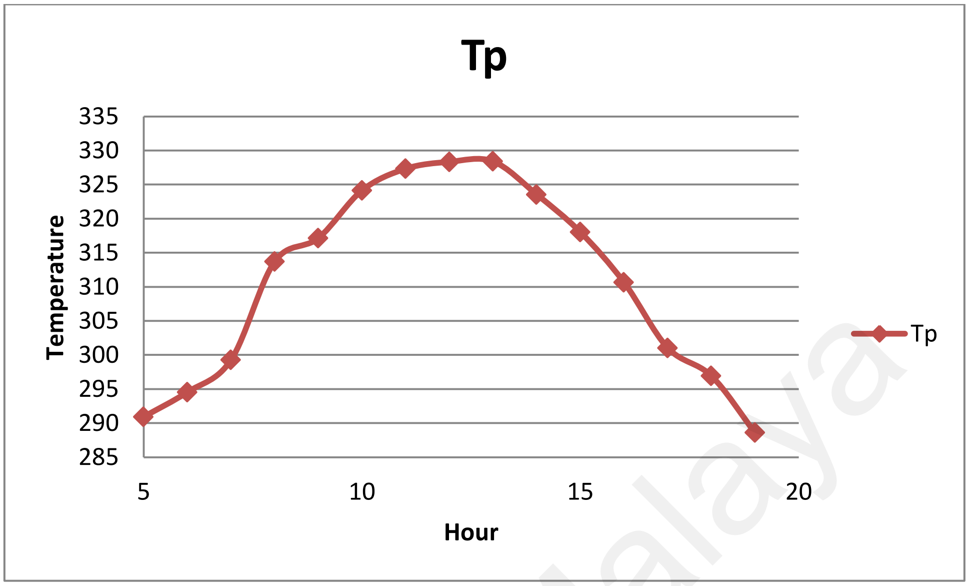

Figure 4.3 Pyrex Temperature diagram for parabolic collector without PCM

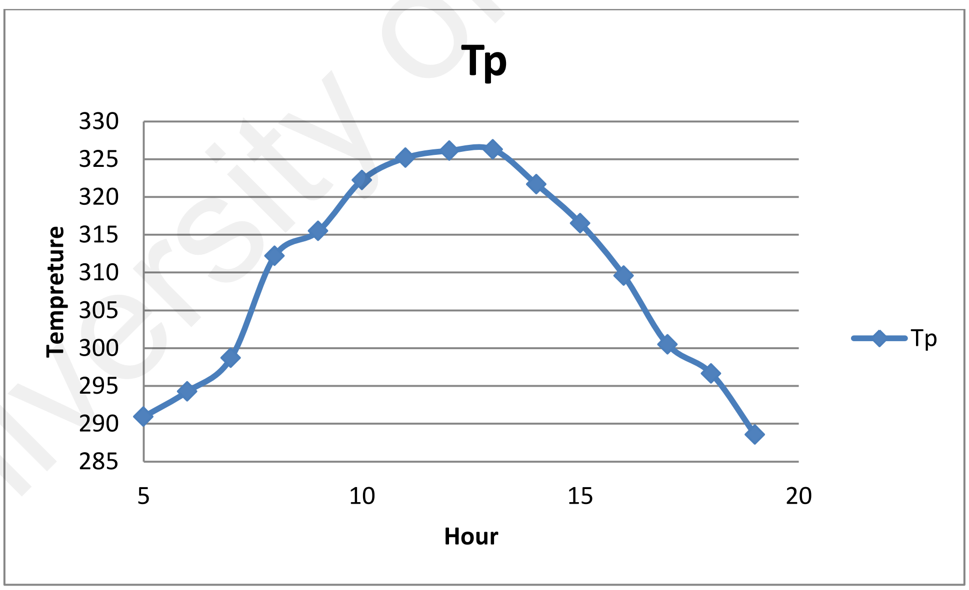

Figure 4.4 Pyrex temperature diagram for parabolic collector with PCM

4.4 Water Temperature Analysis

According to the Figures (4.5) and Figures (4.6), outlet temperature of water has similar pattern like absorber temperature which it is goes up 350^{o}k in 12 pm. It shows that temperature slump to 320 ^{o}k in the system with PCM and 298^{o}k for system without PCM. Since high heat transfer between the absorber and HTF is the main reason that they have similar pattern. For more comparison the data is given in Table 4.3.

HOUR	T_w (NORMAL)	T_w (PCM)
6	303.8965	303.4639
7	310.7078	309.8496
8	324.5225	322.8635
9	336.4578	334.1162
10	346.9013	344.0333
11	352.4939	349.2956
12	354.7069	351.3955
13	353.6216	350.3968
14	347.7279	344.8455
15	337.9052	335.586
16	326.5023	324.8451
17	313.1049	322.2468
18	305.3892	320.9634
19	298.577	319.5386

Table.4.3Outlet temperature of water

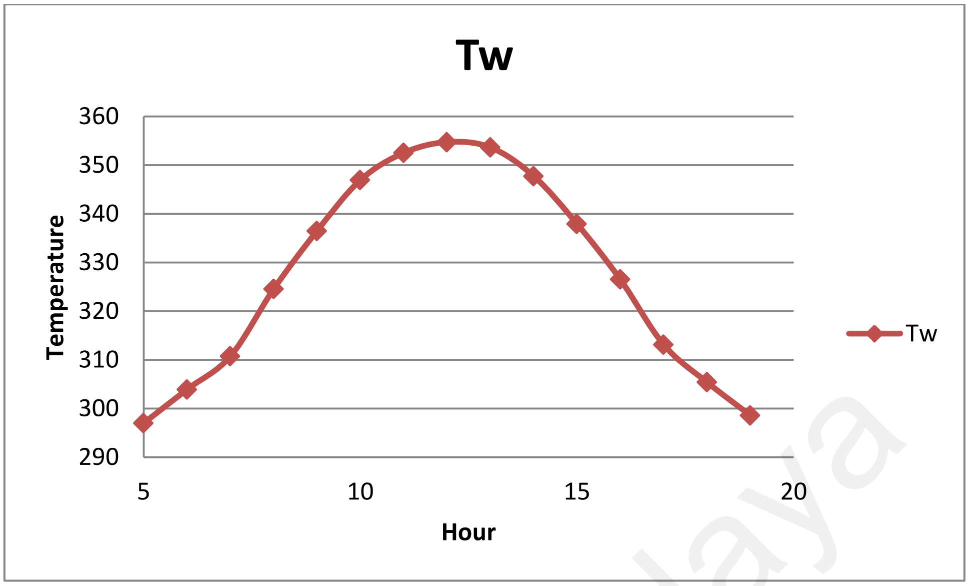

Figure 4.5 Outlet Water Temperature diagram for parabolic collector without PCM

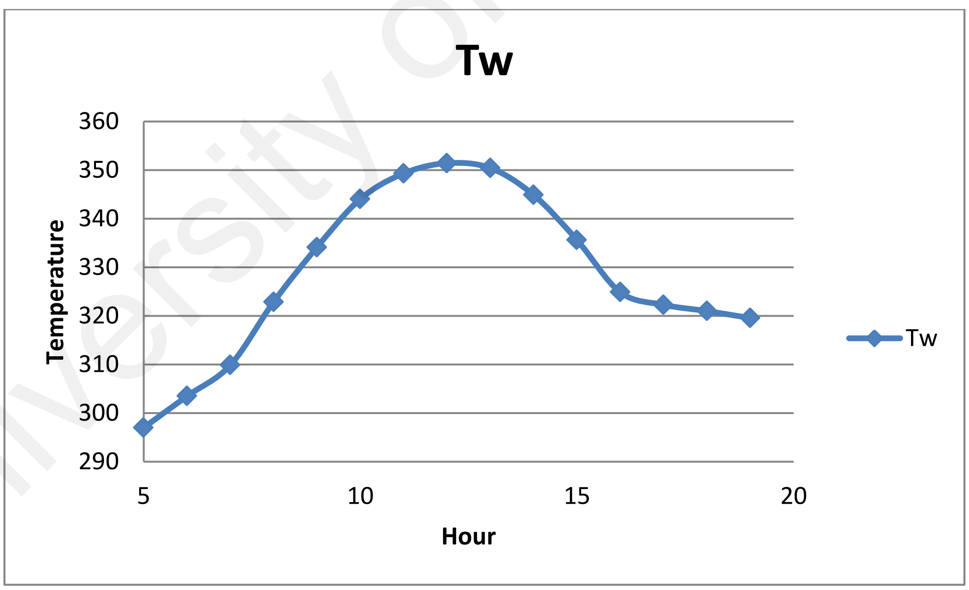

Figure 4.6 Outlet Water Temperature diagram for parabolic collector with PCM

4.5 Efficiency Analysis

In contrast, efficiency diagram for parabolic collector in Figures 4.7 and 4.8 present the different pattern from the other graph. There has been no change in amount or even the change is too small between 8am and 16pm. The efficiency for two systems has a range of 60% to 70%. A sudden dramatic growth of efficiency at the end of day cues by manner of PCM to discharge and support the hut when the radiation is low.

HOUR	Efficiency (NORMAL)	Efficiency (PCM)
6	0.665911	0.62414
7	0.667111	0.625347
8	0.668023	0.626237
9	0.667597	0.625864
10	0.667508	0.6258
11	0.667437	0.62574
12	0.667389	0.625697
13	0.667431	0.625736
14	0.667422	0.625717
15	0.667528	0.625806
16	0.667515	0.625774
17	0.666971	0.625211
18	0.666158	0.625385
19	0.629514	0.6577

Table.4.4.Energic Efficiency

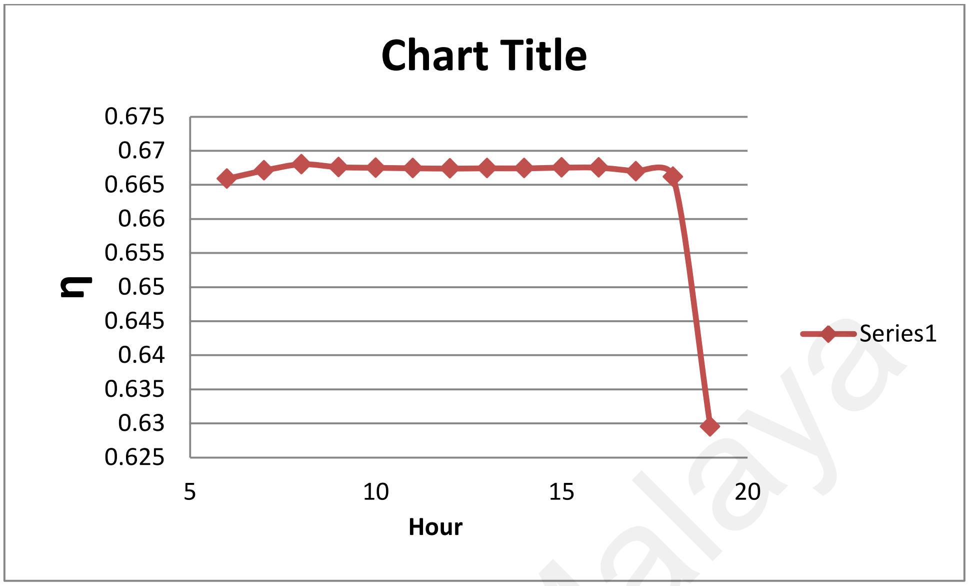

Figure.4.7 Efficiency diagram for parabolic collector without PCM

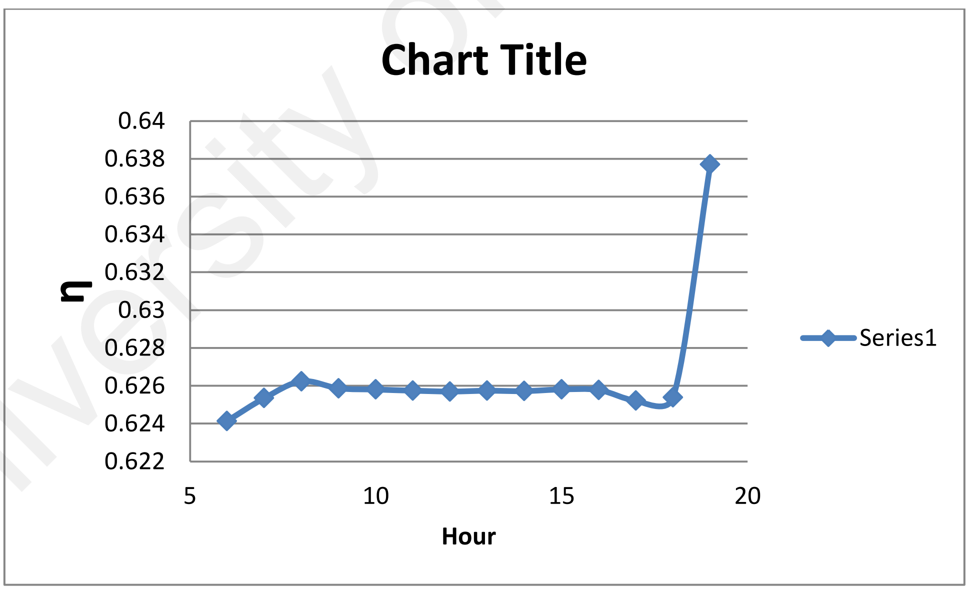

Figure.4.8 Efficiency diagram for parabolic collector with PCM

4.6 Heat Loss

As in Figure 4.9 and 4.10 it is stated that the heat loss in function of the Pyrex has the similar outline in a day. The reason of the difference amount heat loss between two systems is that phase change that material absorbed heat as a sensible and latent heat. The negative value of heat loss says that after sunset, the heat transfer from ambient temperature to system.

HOUR	Q_{LOSS} (NORMAL)	Q_{LOSS} (PCM)
6	6.789897	6.288837
7	13.9967	13.02165
8	39.58587	36.36289
9	46.86429	43.27472
10	56.9328	52.65312
11	64.28462	59.42764
12	66.34208	61.32147
13	64.43294	59.59084
14	56.01493	51.79248
15	44.11855	40.82001
16	30.0204	27.7938
17	13.99421	13.07103
18	6.806937	6.313746
19	-6.25968	-6.33238

Table.4.5.Heat loss data of system

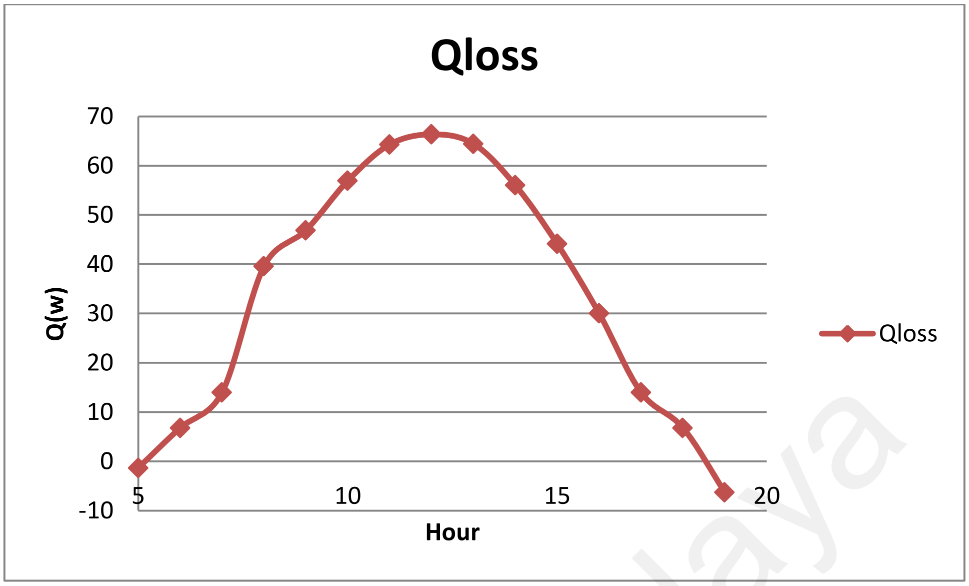

Figure 4.9 Heat loss diagram for parabolic collector without PCM

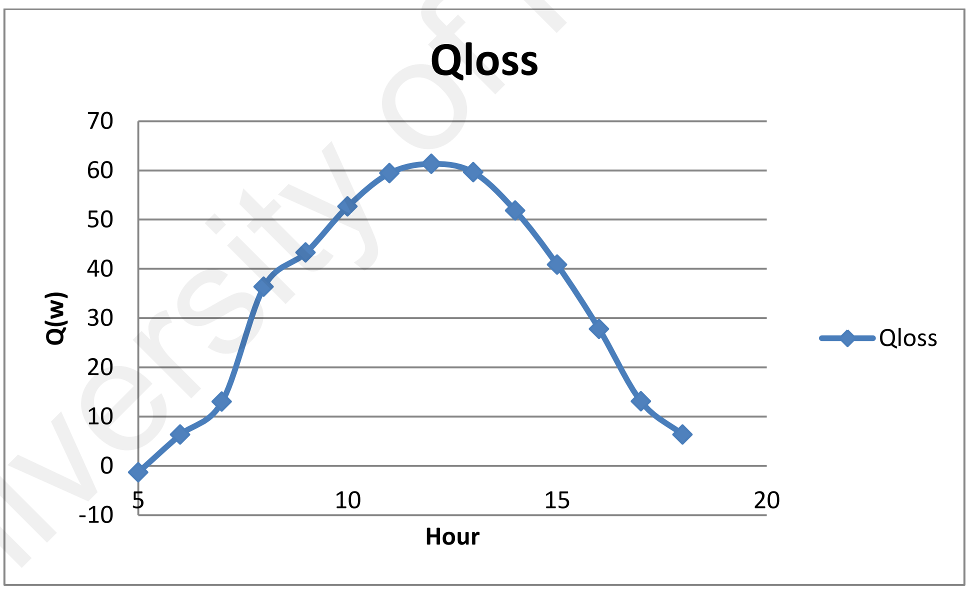

Figure 4.10 Heat loss diagram for parabolic collector with PCM

4.7 Phase Change Material Analysis

According to the line graph 4.11, it shows simulated phase change material charging and discharging process in various insolation values per day in July. The charging process happened between 7 and 16 .The line increases to melting point like a parabolic function then stays stable in peak point until change its phase from solid to liquid. At this time, phase change material gaines thermal energy from the sun and stored it as latent heat.

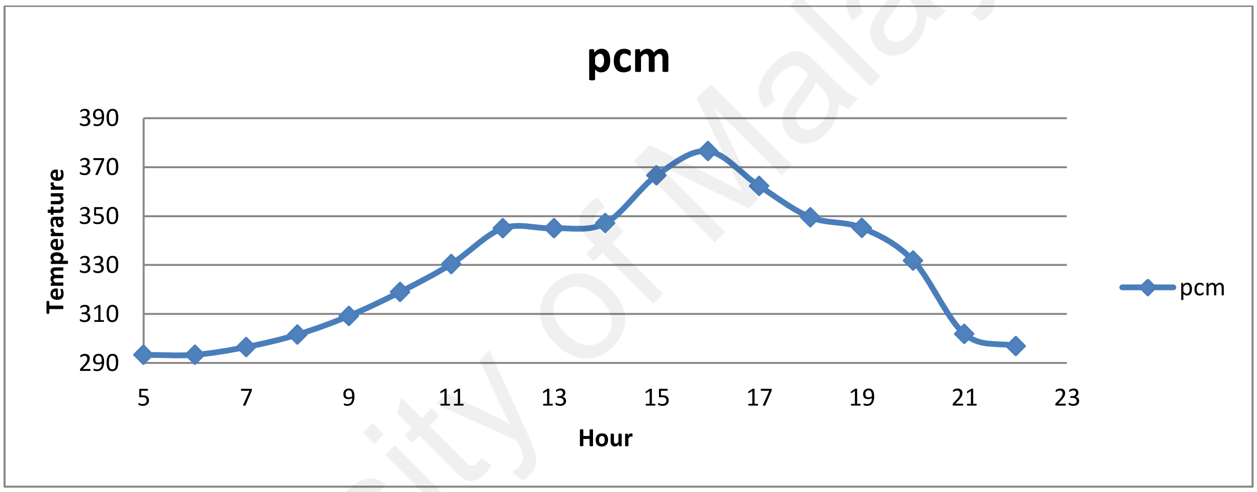

Figure.4.11 Charging and Discharging diagram of PCM per day

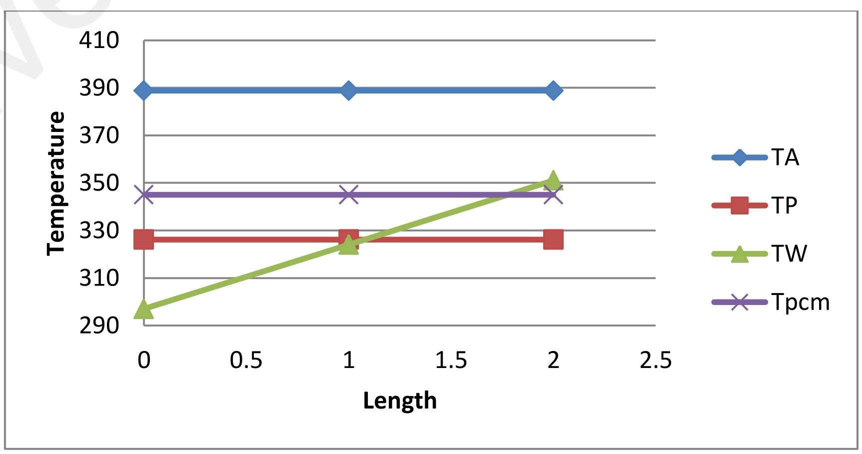

Figure.4.12 Temperature change along the length

CHAPTER FIVE: CONCLUSIONS AND RECOMENDATION

5.1 Conclusion

What has been tried to do in this study is, to deeply and thoroughly analyze the cylindrical parabolic concentrating collector under the various insolations from time to time in a day. Absorber tube, envelope phase change material and collector liquid were investigated individually and logical calculations were planned and created.

The performance of the cylindrical parabolic with phase change material from the perspective of energy was investigated. The outcome of the simulation revealed that PCM is capable of increasing the performance period of collector to one hour, roughly decrease the heat loss and also it has the lowest effect on the outlet water temperature. By means of solar radiation and ambient temperature the energetic efficiency and heat loss of the system were determined. The energy efficiency was found to be mightily dependent on the heat loss. The charging period of PCM is longer in comparison with its discharging Process.

5.2 Recommendation

On the basis of the present simulation carried out and result obtained the following recommendation are suggested for future studies:

Develop the code from one-dimensional to two-dimensional in order to better result for simulation.

The parabolic collector performance model does not do optimization or exergy analysis, both of which would help identify parabolic collector performance with the PCM limitations.

Run the system practically in order to validate the output data of simulation program.

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