Sudan University of Science and Technology
College of Engineering
Mechanical Engineering
Power Department

Design of Solar heater integrated with phase change material

تصميم سخان شمسي مع دمج مادة متغيرة الطور

Project submitted in partial fulfillments for the degree of
B.Eg. (Honors) in Mechanical Engineering (power)

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الاية

بسم الله الرحمن الرحيم

(هو الذي جعل الشمس ضياء والقمر نورا وقدره منازل لتعلموا عدد السنين والحساب ما خلق الله ذلك الا بالحق يفصل الايات لقوم يعلمون)

صدق الله العظيم

Dedication

To my mother and father, who have educated me and stood by my side throughout my educational career

This is the harvest of your seed and fruit

To my brothers and sisters

And to my dear colleagues who stood beside us

Thanks and appreciation

Thanks to Allah before and after

We extend our appreciation to our supervisor who was behind this project

Distinguished by his wisdom, we have all respect and appreciation

Dr: A.A.A.Abuelnuor

We also give thanks and appreciation

For all those who worked on welding workshops and cars, from whom we found all the moral and technical support in

Project success

You are all our thanks and appreciation

Abstract

The world is suffering from the depletion of fossil energy sources which are commonly used in our time as well as the world. Environment is suffering from the negative effects that still affect due to the use of this energy such as global warming. Renewable and alternative energies are new technologies to solve these problems. The solar energy is a suitable to use in Sudan. Thermal energy storage is one of methods to save energy such as phase change materials (PCM) .An experimentally study to heating water and save it hot at long time by using lab scale solar heater integrated with phase change material. Experimental results show that the water was heated until 65 °C during charge by using PCM. In addition it was investigate experimentally the water still hot until 7 hours with PCM compare 3 hours without PCM.

التجريدة

يعاني العالم من استنفاذ مصادر الطاقة الأحفورية التي تستخدم عادة في عصرنا وفي العالم. وتعاني البيئة من الآثار السلبية التي لا تزال تؤثر بسبب استخدام هذه الطاقة مثل الاحتباس الحراري. الطاقات المتجددة والبديلة هي تكنولوجيات جديدة لحل هذه المشاكل.والطاقة الشمسية هي طاقة مناسبة للاستخدام في السودان. تخزين الطاقة الحرارية هي واحدة من الطرق لتوفير الطاقة مثل المواد متغيرة الطور. وهذه دراسة تجريبية لتسخين المياه وحفظها ساخنة لوقت طويل عن طريق تصميم مجمع شمسي مع المواد متغيرة الطور. أظهرت النتائج التجريبية أن الماء تم تسخينه حتى 65 درجة مئوية أثناء الشحن. وبالإضافة إلى ذلك كان التحقق تجريبيا ان المياه تظل ساخنة حتى سبعة ساعات بوجود مواد متغيرة الطور في حين ظلت المياه ساخنة لمدة ثلاثة ساعات بدون هذه المواد.

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Ic	Solar radiation on the surface of the collector
Ts	Efficient emissivity of the lid or covers of the collector
άs,c	Solar absorption of the absorbent collector surface
qloss	Rate of heat flow or loss of absorbent to the ambient
$\frac{dec}{dt}$	The rate of internal energy storage in the collector
M	Flow rate of fluid mass during the collector
c_p	Specific temperature when pressure is constant for operating fluid
U_b	Coefficient of heat loss from below
K	Thermal conductivity of insulation
X	Insulation thickness
U_t	Coefficient of heat loss from above
N	Number of transparent covers
U_e	Coefficient of heat loss
B	Solar angle of the collector
E_g	Emission of the transparent board
$?_p$	Emission of the absorbent board
T_a	Ambient temperature
T_{pm}	Average temperature of the absorbent board
h_ω	Heat transfer coefficient of air
V	Wind velocity
D	Outer diameter of tube
W	Spaces between tubes rate
δ_p	Absorbent board thickness
H	Heat transfer coefficient of liquid
T_f	Liquid average temperature
L	The length
R_e	Renold's number

V	Liquid viscosity
P	Liquid density
p_r	Brandelt's number
c_p	Specific heat
D_i	Inner diameter of tube
G	Liquid flow rate per square meter of the collector
A_c	Collector area
I	Total Falling Solar Radiation
T	Transparent panel permeability
ά	Absorption of absorbent board
T_{f_m}	Liquid temperature rate
N	Number of tubes inside the collector

CHAPTER ONE
INTRODUCTION

1.1introduction:

Recently, the demand for alternative energy sources has been observed in various daily and industrial activities Rather than the fossil fuels caused by environmental damage, non-permanence and high prices, which led many companies and engineers to invent ways and machines that work on renewable energy from wind, water, solar radiation and others and exploit them in various ways possible. Solar energy is one of the most suitable types of energy to use in order to provide radiation intensity where it is received .earth has 174 watt of radiation coming into it at the upper atmosphere layer and is reflected nearly 30% Of these radiation return to space while the rest is absorbed by clouds and oceans and mass of the earth and the technology is based on solar energy in general, either to be negative or positive according to the way that the exploitation and conversion and distribution of sunlight through them, and to highlight the positive solar energy They are divided into electric generation and thermal applications . Techniques that use the heat of the sun can be used to heat water, heat and cool places and generate energy. Solar heating systems use sunlight to heat water. In geospatial depths (under 40 degrees) , Can be supplied as ranges 60 to 70 percent of household hot water and most types of water heaters with temperatures up to 60 degrees Celsius can be supplied with solar energy Polished flat complexes are generally used to heat water in homes.

1.2Problem statement:

Energy supply is the basic request of humankind, for cooking, manufacturing, electricity generation, transportation and heating. Nowadays the fossil fuel has emerged as one of the most important topics in combustion science and technology since the1970s. Today heating water is important due to use it in several applications. There are many methods to solve this problem such as the solar energy integrated with PCM is the one of the methods to solve this problem.

1.3 objectives:

The objective of this study are:

1- To design and fabricate solar water heater integrated with phase change material.

2-To investigate experimentally the performance of PCM-incorporated thermosyphon solar water heating system using flat plate collector as a heat source.

1.4 significance of study project:

This project gives importance to industrial products especially (solar collectors) that used for domestic purposes and commercialization, thus saving energy from conventional fuels. Resulting in a reduction Percentage of pollution from electrical stations. This project is one of the projects that can be the nucleus of industries that can be in Sudan as one of the ideal areas in the amount of sunshine in most of the year in addition to that of projects that depend On the modern concepts to preserve the environment from pollution in addition to the availability of raw materials needed for production and availability of employment and ease of training.

1.5 Project scope:

The main use of this technique is in residential buildings where demand for hot water has a significant impact on energy bills or in a situation where demand for hot water is increasing or excessive, commercial applications that need this technique include (laundries, car wash, military laundry facilities and food establishments). This technique can also be used for heating if the building is outside the grid or if it is energy usage is subject to frequent interruptions.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction:

The development and deployment of renewable energy technologies are important components for the future of a balanced global energy economy. Renewables can make major contributions to the diversity and security of energy supply, to economic development, and to addressing local

Environmental pollution. In addition, considerable attention has been attracted to their potential to address global warming through zero or near zero net greenhouse gas emissions. Therefore, the world aims to use alternative energies to replace the traditional energies that have had a negative impact on the natural environment and the health of living organisms. Studies have confirmed that these energies will be implemented after several years such as oil.

2.2 some of alternative energies :

2.2.1 wind energy :

Wind energy is produced using wind turbines for the production of electric power, windmills for mechanical energy and wind pumps for water pumping .

Wind movement is transformed into another form of energy that is easy to use.

The energy of the wind starts first from the sun. When the sun warms a certain area of the earth, the air around that area absorbs some of that heat. At a certain temperature, the warm air starts to rise very quickly because the volume of warm air is lighter than the volume of the coldest air. The faster, warmer, the faster the pressure is exerted than the slower moving particles, so it takes less time to keep the normal air pressure at the allowed height and when the warmer air suddenly rises, colder air streams flow quickly to fill the vacuum left by the hot air behind it [13].

Figure (2.1) demonstrates shape of windmills

2.2.2 Hydro energy:

Hydro Electric power (HEP) is a major renewable energy source used all over the world today to produce electricity. It utilizes the basic laws of Physics. Falling water under high pressure has high kinetic energy. In an HEP station, the falling water turns the turbines. Through magnetic induction, the generator converts the mechanical energy of the turbines to electricity [13].

Figure (2-2) hydro power plant

2.2.3 Geothermal energy:

Geothermal energy refers to heat energy stored under the ground for millions of years through the earth formation. It utilizes a rich storage of unutilized thermal energy that exists under the earth's crust. The earth's crust has immense heat (thermal) energy stored over millions of years. There exists a huge temperature difference between the earth's crust and the surface. The temperature difference is known as **geothermal gradient**. This energy is sufficient to melt rock. The molten rock, called magma, at times erupts through cracks on earth surface as volcanoes. Geothermal energy is converted to produce to electricity [13].

Figure (2-3) mechanism of action of geothermal energy

2.2.4 Solar energy:

Solar energy is the energy obtained by capturing heat and light from the Sun. Energy from the Sun is referred to as solar energy. Technology has provided a number of ways to utilize this abundant resource. It is considered a green technology because it does not emit greenhouse gases. Solar energy is abundantly available and has been utilized since long both as electricity and as a source of heat [13].

2.3 Earth's location of the sun:

It is known that one of the important sources of energy for Earth is solar energy and we see that the sun pours a huge amount from its light on the space surrounding it and as the planet revolves around the sun in a specific orbit of the master of this universe Almighty. We find that there are varying amounts of this energy landing on the surface of the earth every day; these quantities can be determined by the position of the Earth from the sun or the four seasons of the year.

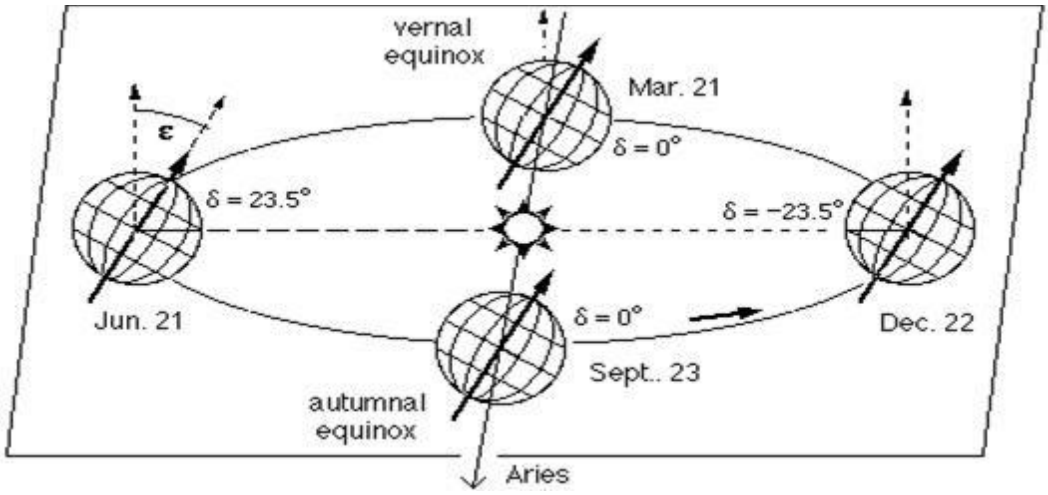


Figure (2-4) the location of the earth from the sun during the year

As it clear from the previous figure, the countries that are located on the equator are the countries that have one season Almost throughout the year - the summer, that is, the sun's rays on these countries throughout the year Countries near the equator have this weather, and it is usually difficult for residents of these areas to feel another seasons. The northern and southern regions of the Equator and near the poles of the Earth, the residents of these regions are aware of the four seasons of the year. The purpose of this introduction is to determine the places where solar energy is concentrated on the planet as it circulates around the sun. The Arab countries enjoy a great of this energy every day. The intensity of solar radiation reaching the earth's surface varies due to changing weather conditions and the changing position of the Earth for the sun. During the day and throughout the year, clouds are one of the main factors determining the amount of solar radiation reaching the Earth. Thus, areas with a cloudy climate receive less solar radiation than Areas with a desert climate.

Generally, the highest intensity of solar radiation received by the Earth is at the time of the afternoon when the sunlight is vertical on the surface of the Earth other than the sunrise and sunset while receiving the least amount of radiation throughout the day for each day.

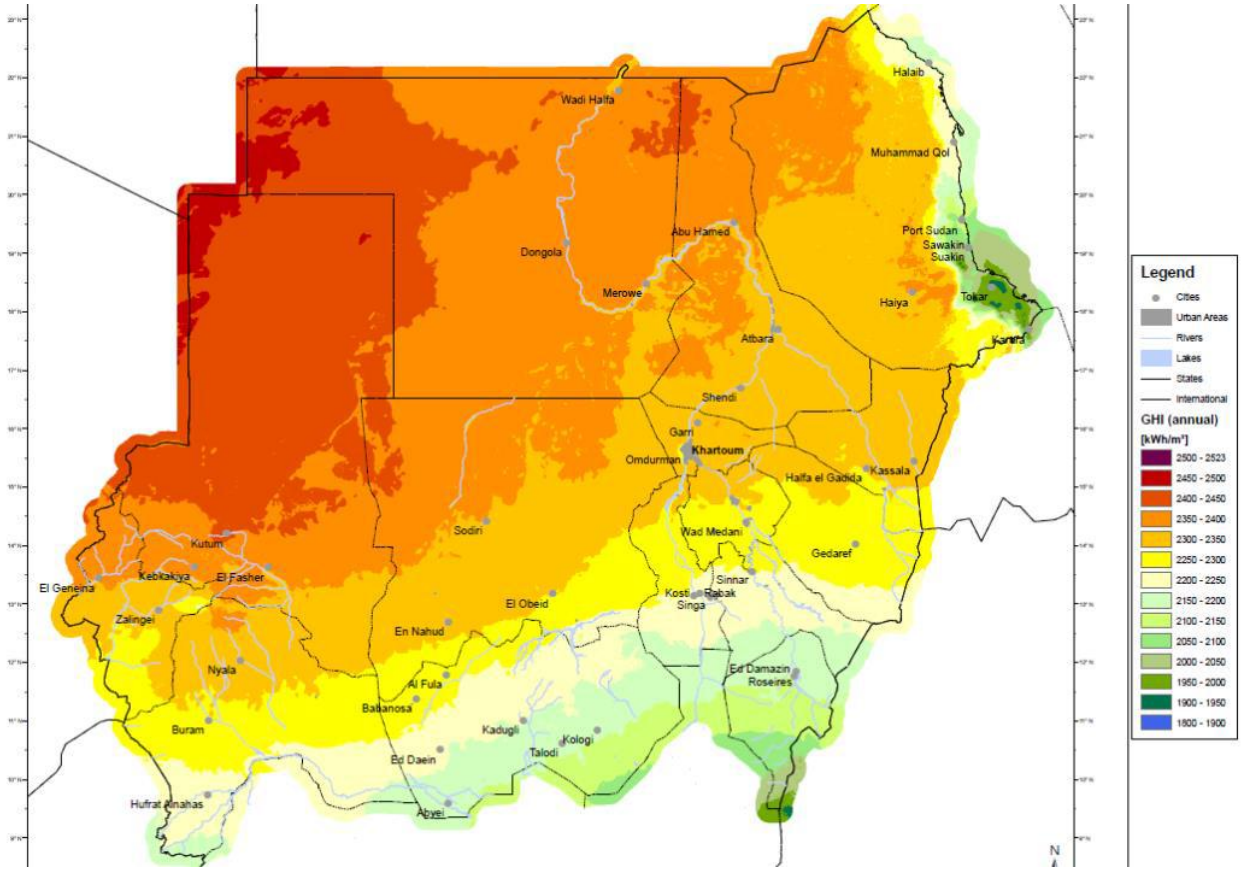


Figure (2-5) demonstrate intensity solar radiation in Sudan

2.4 solar collectors:

Is an integrated system consisting of several parts used in the collection of solar radiation falling on them and converted to heat energy is used to heat water during the hours of sunlight, where hot water is stored in a thermal tank insulated in preparation for use during the day.

Solar heaters generally consist of the surface of solar absorption, the flow paths of the heat transfer fluid and thermal insulators to prevent the transfer of heat obtained in the heating medium to the surrounding medium. The project deals with these components very extensively, as follows:

2.4.1 absorption surface:

The absorption surface is mostly made of dark black metal to increase the absorption rate. The black color is characterized by a high absorption rate of solar radiation up to 98%. In addition to a glass panel with concentrated lenses of solar radiation on the flow paths [1].

2.4.2 flow paths of transfer fluid:

These paths are usually made of metals such as copper and steel and vary from one application to another Depending on the type of medium and the different absorbent surface material, there are rectangular channels with large areas (10-15 cm), and there are circular channels with small diameters (pipes that are about 1 cm in diameter)

2.4.3 Thermal insulation:

When the temperature inside the solar collector and the tank increases compared to the surrounding environment, there is a possibility of losing this heat through the sides of the solar collector and the reservoir. Therefore, special materials and methods can be used to reduce these losses according to the type of loss.

2.4.3.1 Loss by conduction:

It can be reduced by enclosing the sides and bottom of the absorbent and heating pipes with special materials with low thermal conductivity such as thermal insulation such as glass wool, fiberglass and polystyrene.

2.4.3.2 loss by convection:

It can be reduced by blowing the air between the glass covers or by placing the heating pipes with the absorbent surface inside hollow glass tubes of air (discharge).

2.4.3.3 loss by radiation :

It can be reduced by using glass covers that are applied to short rays of the sun and at the same time dark enough to prevent Reflection of long wavelength radiation from the absorbent surface [1] .

2.5 Phase change materials:

The storage of thermal energy in the form of sensible and latent heat has become an important aspect of energy management with the emphasis on efficient use and conservation of the waste heat and solar energy in industry and buildings. Latent heat storage is one of the most efficient ways of storing thermal energy. Solar energy is a renewable energy source that can generate electricity, provide hot water, heat and cool a house, and provide lighting for buildings. Paraffin waxes are cheap and have moderate thermal energy storage density but low thermal conductivity and, hence, require a large surface area.

(PCMs) are materials that store energy in the process of changing the aggregate state from solid to liquid. PCMs are latent heat thermal storage materials. They use chemical bonds to store and release heat [14].

When PCMs reach the temperature at which they change phase (their melting point), they absorb large amounts of heat without getting hotter. When the ambient temperature in the space around the PCM material drops, the PCM solidifies, releasing its stored latent heat.

Figure (2-6) paraffin wax

2.6 Classification of PCM:

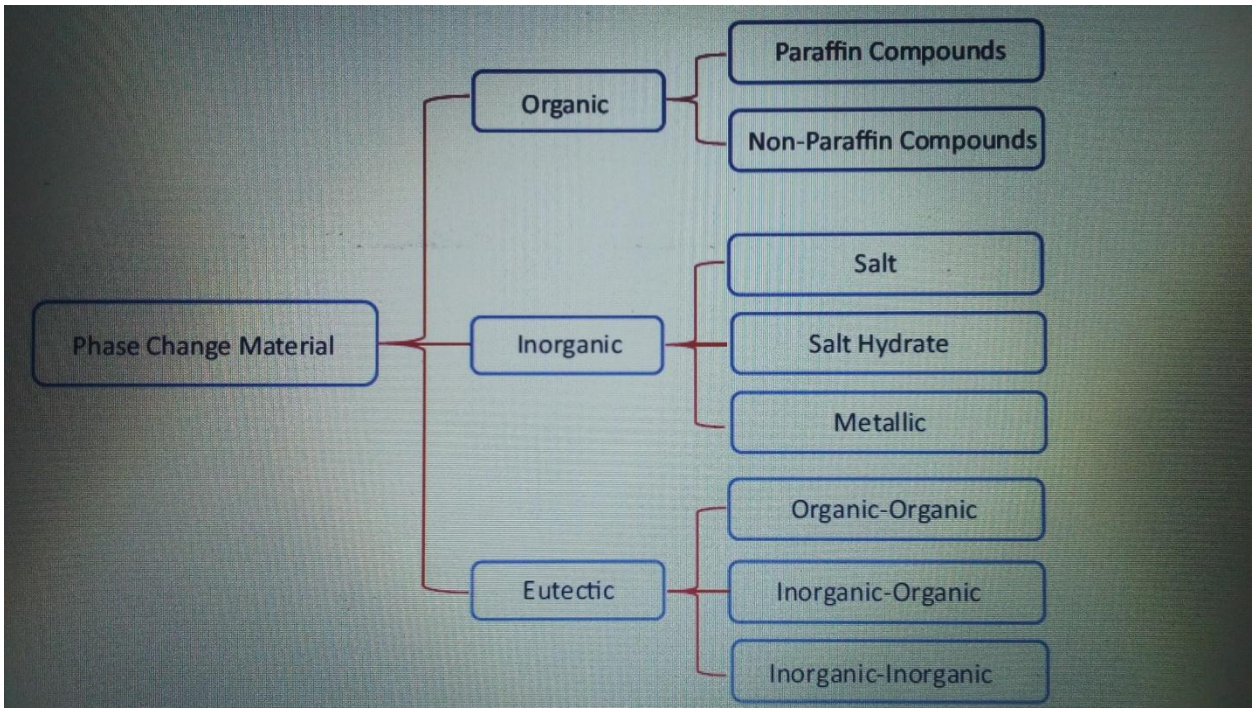


Figure (2-7) Classification of PCMs

2.7 Applications of PCMs:

Phase Change Material (PCM) is a useful remedy when there is a Mismatch between the supply and demand of energy. Some of the potential Applications of PCM shown below [14]:

- Thermal protection of flight data and cockpit voice recorders.
- Hot and cold medical therapy.
- Transportation and storage of perishable foods, medicine and pharmaceuticals products.
- Thermal management systems.
- Solar power plants to store thermal energy during day time and reuse it During the later part of the day.
- Electronic chips to prevent operation at extreme temperatures.
- Photovoltaic cells and solar collectors to avoid hot spots.

2.8 Main components of solar heater system:

1- Solar collector.

2- The tank.

3- Installation structure and connection pipes.

4- Containing cylinder.

5- Phase change material (PCM).

Solar heaters are divided into two main types:

2.8.1 Traditional type:

This type is divided into two parts:

2.8.1.1 Open circuit heaters (direct heating):

In this system passes the water to be heated directly through the solar collector and from it to the reservoir and fall under this section two types of systems:

a- Natural recycling system (without pump):

This system relies on gravity and inclination for natural water circulation because this system does not contain electrical equipment's and are more dependent than coercive system.

b- Forced recycling system (with pump): -

Dependency on hydraulic pumps and heat exchangers.

2.8.1.2 Closed circuit heaters (indirect heating):

These heaters are similar to open-circuit heaters except that the water consumed is not directly leaked to the collectors but heated inside the tank through a heat exchanger immersed in the water to be heated.

This system is divided into:

a- Natural Recycling System.

b- Forced recycling system.

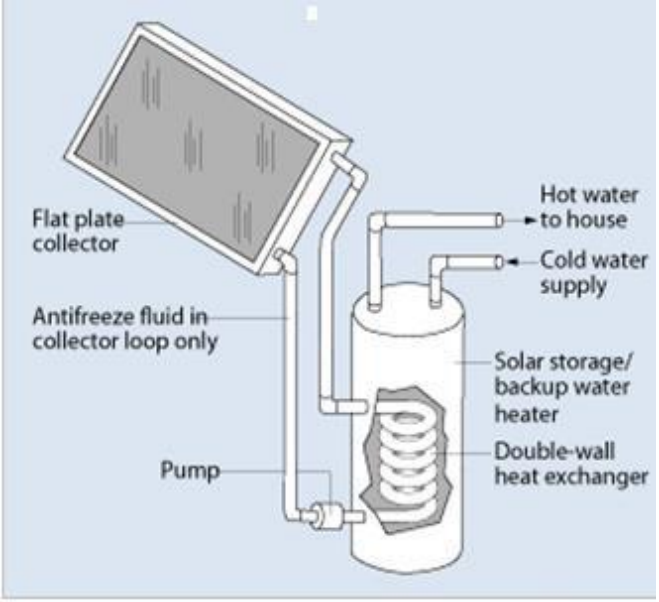


Figure (2-8) forced recycling process

2.8.2 **integrated type:**

This type of single pot consists of a complete function of the solar collector and the reservoir at the same time without any External connections between the collector and the reservoir, and depends on the principle of its work on absorption of radiation and stored directly by Although there is a limited amount of commercially available water available in different forms, techniques and techniques, there is a wide range of scientific and technical research currently underway at the level of the world to improve its performance and improve its production efficiency, which will help to spread it more widely.

2.9 types of solar collectors:

Solar collectors are the main component of solar heating systems. The solar collector collects sunlight and transforms it into a heat that travels to the working fluid (water or air) for use in the desired place. Advanced solar collectors designed for water heating consist of frame panels with black copper tubes covered with glass to hold the heat inside the board and thereby increase its heat efficiency. The process of water heating does not necessarily require the conversion of electric energy into thermal energy. This can be accomplished by using the solar absorbers with a tubular absorbent surface made of galvanized steel or copper with a steel and aluminum pipette. Most of these devices operate in an open cycle.

There are three types of solar collectors:

1- Flat solar collectors.

2- Hollow tubular collectors.

3- Integrated Storage Collector Systems.

2.9.1 Flat solar collectors:

They are the most common collectors among other systems, it is a metal box insulated with a lid Plastic or glass with a heat-absorbing metal plate and a HTF that conveys heat either liquid or gas.

Types of flat collectors:

2.9.1.1 Flat solar collector with liquid HTF:

Where the liquid transporting heat (often cold water) flows into the absorbent sheet to warm and exit from the other end.

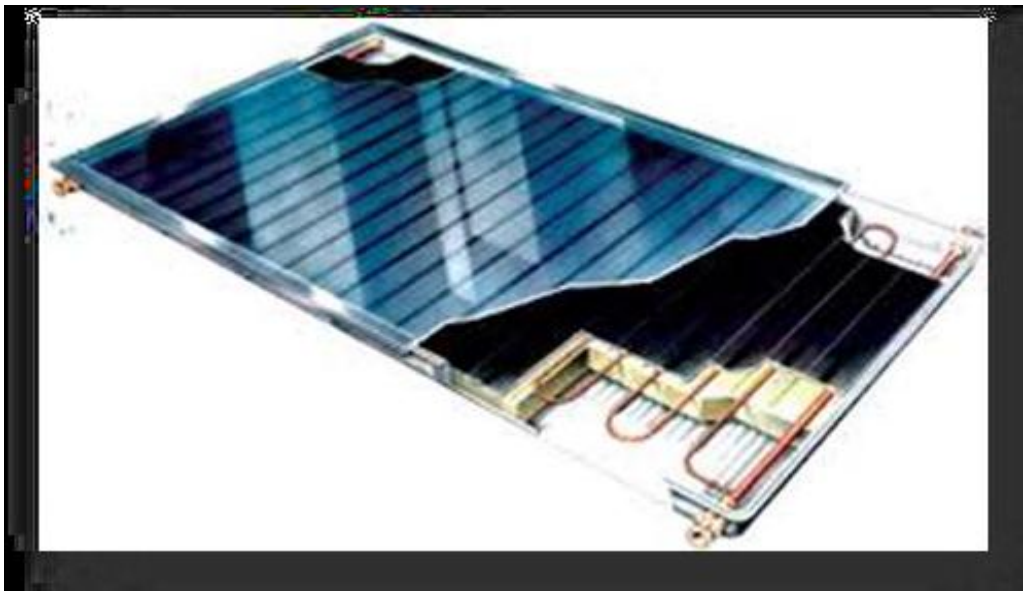


Figure (2-9) flat solar collector with a liquid HTF

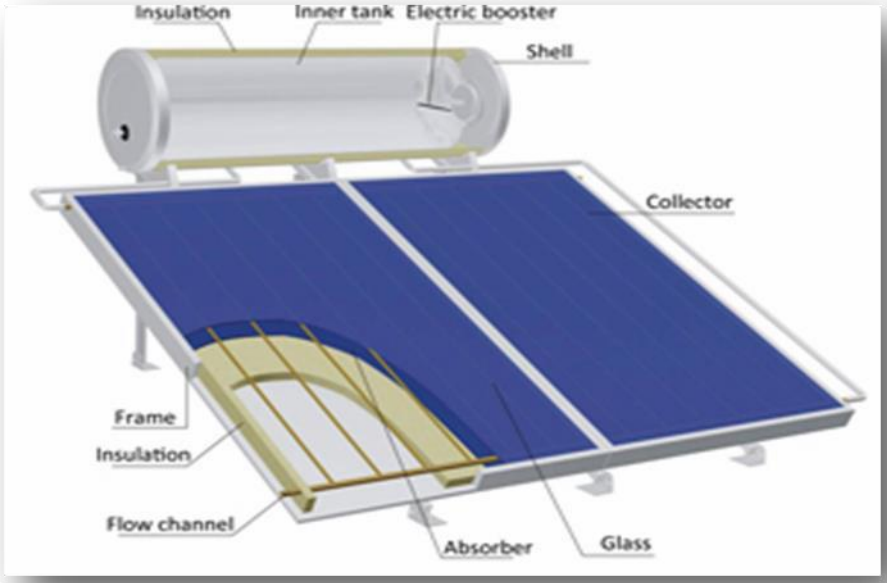


Figure (2-10) shows the components of the solar collector of the flat type (heating unit + tank)

2.9.1.2 Aerobic flat collectors:

They are mainly used to heat the air indoors or for other purposes where air flows into a plate Absorption either naturally or using a fan to heat up and out of use, and these collectors are less efficient than liquid-HTF collectors.

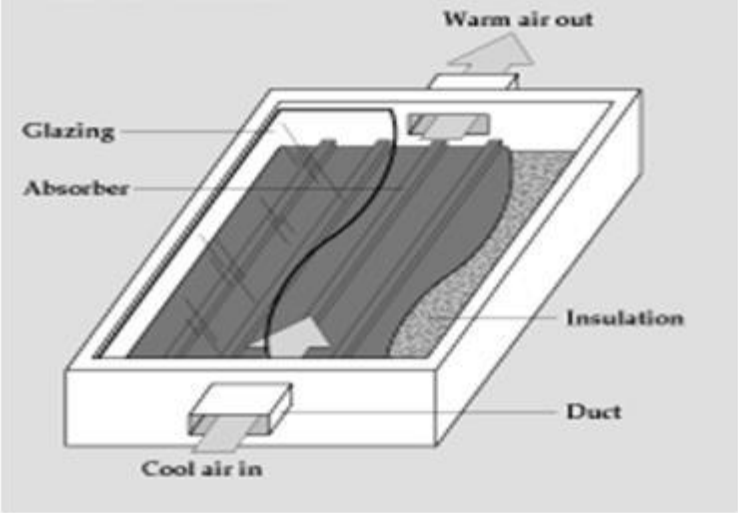


Figure (2-11) detailed section for heating the air in a flat solar collector

2.9.2 Vacuum tube collectors:

The vacuum tubular collectors can produce very high temperatures ranging from (170 to 350) Fahrenheit, making them more suitable for cooling applications and industrial steam applications. On the other hand, tubular collectors are more expensive than flat collectors, each costing the cost of constructing two flat collectors. These collectors are usually made up of parallel rows of glass tubes and each tube contains a glass tube External, transparent and inside a heat-absorbing metal tube covered with a material that absorbs the solar heat well and is advantageous This type of compound is characterized by high yield and the reason is that the air between the two overlapping tubes removes the thing that prevents the loss of heat by conduction [4] .

Figure (2-12) vacuum tubular collector

2.9.3 Integrated Collectors Systems:

Consists of one or more tanks where each tank is coated with a dark material and is well insulated. This collector plays the role of the solar collector and the tank’s role at the same time, known as the "integrated collectors"

2.10 Technical considerations to be considered in the selection and installation of the solar heater:

There are several technical considerations in light of which choose and install the appropriate solar heater, including:

1- Type of solar water system, which is determined based on the nature of consumption and the quality and quantity of available water - Water required for daily use.

2- The volume of the tank, which represents the amount of water required for use, which depends primarily on the number of individuals

Home.

3- The slope angle of the solar collector should be proportional to the geographical location of the house.

4- Install the solar heater tightly to the south as far as possible while avoiding the occurrence of shadows on the surface of the collector -

Of neighboring buildings.

5- Cover the roofs of solar collectors whenever needed.

6- Service maintenance and follow-up.

2.11 Applications of solar collectors:

Solar heaters can be manufactured in several sizes to meet the needs of solar energy according to temperature required for water, whether warm (less than 50 ° C) for swimming pools or hot (from 60 to 80 ° C) for domestic use or boiling for steam to generate electricity and this depends on the capacity of the heater and its design [4] .

The simplest of these heaters is the solar heater (FLAT-PLATE SOLAR HEATER COLLECTOR):

It is a metal insulated box with a cover of ordinary glass or transparent plastic, and inside it is a black-painted heat-treated panel and pipes that are drained by water or air to be heated. And the absorbent board is made of copper, aluminum or alloy, because they have a great ability to deliver heat quickly and efficiently. Copper is corrosion-resistant though it is more expensive. The box is insulated to prevent heat leakage and to keep the water temperature at night. Hot water is stored in insulated tanks thermally the outer cover will be from of glass or fiberglass.

2.11.1 Solar air heater:

Which are used to dry agricultural crops and heat houses with hot air, are cheaper, easier to operate but less heat than solar heaters that heat water. The absorbent panel, whether metal or non-metallic, is airborne by a fan to heat it.

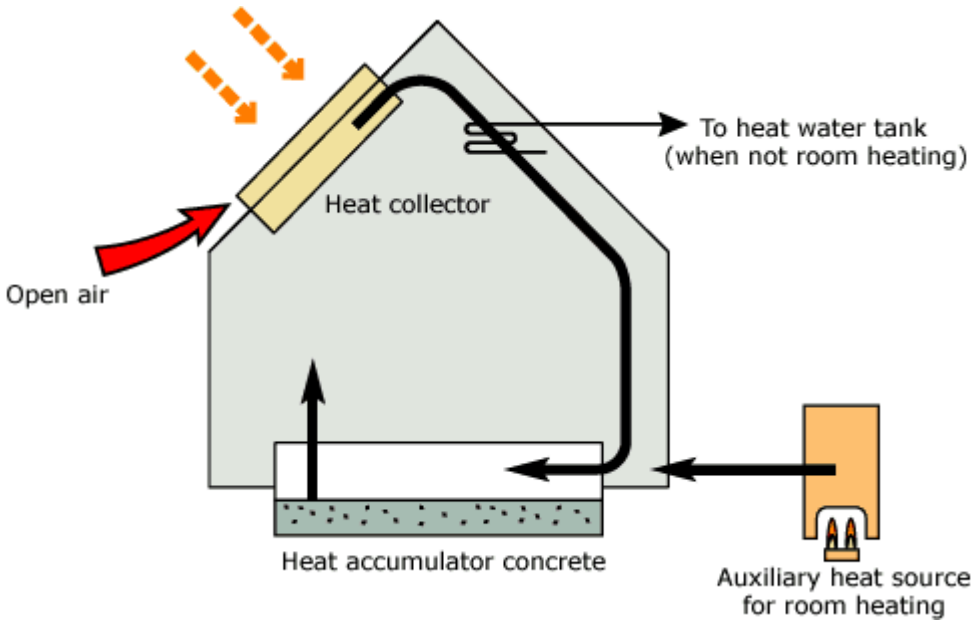


Figure (2-13) solar air heater

2.11.2 Concentrating collector:

Which uses bright mirrors (concave) to reflect the concentrated rays of the sun above the absorbent board to a gathering point of the sun over the receiver to pass through the water to be heated. These heaters give water temperatures much higher than the normal solar heaters as it goes with the direction of the sun, Water is milled or used in Saline distillation and desalination by attaching a condenser to get the distilled water.

Figure (2-14) concentrating collector

2.11.3 Solar cooker:

This method can be used to cook food in black receptacles called the solar oven and consists of bright mirrors dominated by the sun to reflect over the wall of these vessels and may reach 200 degrees Celsius, this means through which bacteria can be killed and water sterilized. It is not expensive if these solar complexes are designed with the construction of the building the size of the power collector depends on usage and the daily need. The person can consume 50 liters per day. Hot water in the degree of 55 to 60 degrees Celsius [3].

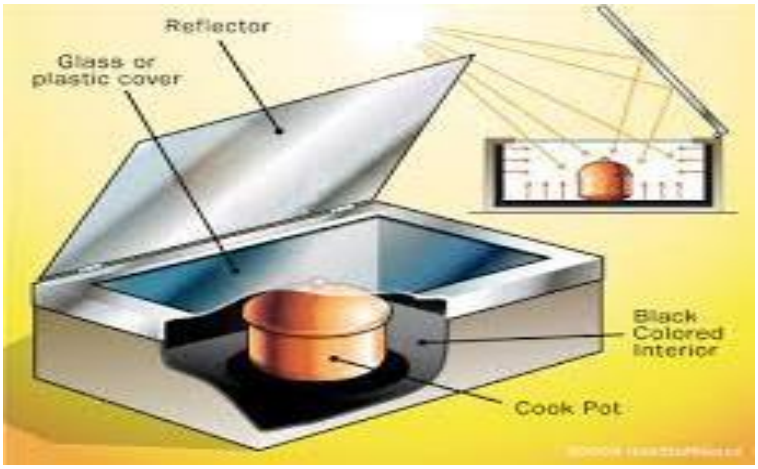


Figure (2-15) solar cooker

2.11.4 Solar-heated swimming pools:

Solar water heaters can also be used to heat pools water, where solar collectors heat water to slightly above ambient temperature and use cheap solar collectors which are usually made of plastic materials specially prepared for this purpose. Glasses solar collectors are not a model for use in pool water heating applications except for pools Interior. The heating of pool water using solar energy requires a solar pool of equal area (50-150 m^2).

In general, when the area of the pools increase, the more the pool can be used in cold weather, and the pool cover and insulation significantly reduces the loss of heat and thus conserves the pool water warm for a larger period.

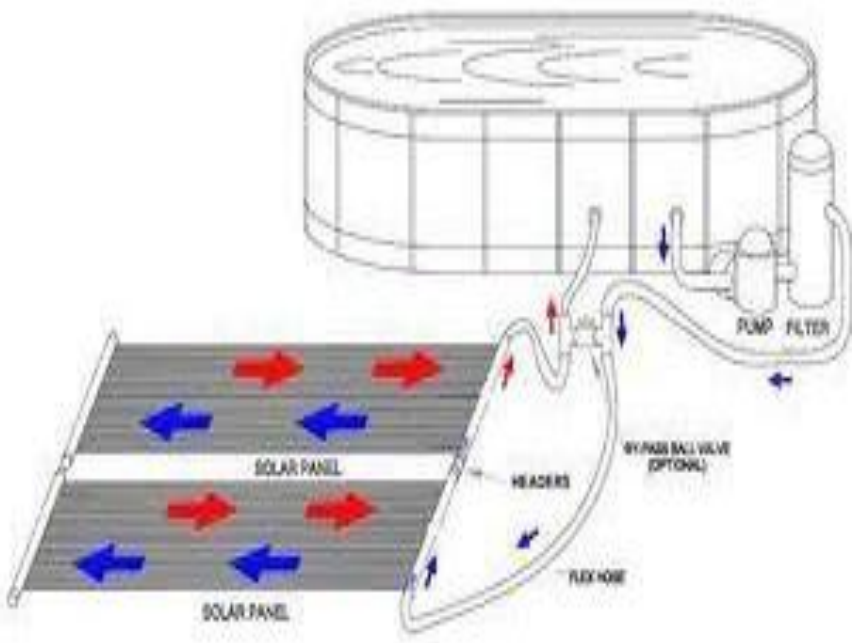


Figure (2-16) Swimming pools heated by solar collector

2.11.5 Solar farm plant:

To use such a method, solar plant farms are designed and built

In these farms mirrors are installed (manufactured in the form of equivalent pieces - the reception system) in parallel so that the concentrated sunlight is focused on it and suction tubes are placed in the middle of these dishes where the gathering point of solar radiation falls, and water or thermal oil is passed in this tube, as is done. The absorption tubes are placed in a vacuumed glass casing of the air and part of the energy produced is used as a catalyst to help improve steam temperature [2].

Figure (2-17) solar farm plant

2.12 current studies to improve the performance of the flat solar collector:

Most of the experiments were conducted to improve the performance and thermal efficiency of the flat collector, which uses air as a HTF and a few experiments for water use as a HTF, and review some of the studies carried out to increase the efficiency of a solar collector with design additions:

1- A study conducted at the Cartagena University of Technology in Spain by Herrera and Martin Garcia Pinar and Perez Garcia - The Experiment of Heat Transfer of an Improved Flat Solar Collector. The study was a comparison between an ordinary flat collector and another with the same dimensions but improved with design additives such as spiral valves for control and drainage valves, the heating and heat exchanger between entry and exit complex have led to these improvements to increase efficiency from 66.7% to 72.5% [11].

2-A study conducted at the Faculty of Engineering, University of Baghdad in Iraq by Saad Mohsen Al-Mashat and Omar Khalil Jubouri - Ahmed Hassan entitled "Study of the performance of the effective use of solar energy using the porous brush where it was in this study is designed as a solar collector that uses a porous brush (stone) as an absorbent surface and a heat-resistant material with an air pump. The highest current efficiency of the complex is about 20% [12].

The primary purpose of our study is to examine the performance of PCM-incorporated thermosyphon solar water heating system using flat plate collector as a heat source and clear how our study differs from the previous studies are using thermal energy storage tank without PCM.

2.13 Solar investments in the Arab world:

Energy workers realize that Arab land is one of the world's richest areas of solar power Compared with some other countries in the world. It is also obvious that our oil capacity will be depleted after 100 years at the most, which is the best source of energy and in the absence

The presence of large quantities of uranium in our Arab countries in addition to the cost of energy devices and technology over the past fifty years and the possibility of not catching up, which made us short to invest and hope not to miss the opportunity to create Arab technologies to exploit solar energy is still at the beginning of development. Most of the field and laboratory experiments to exploit solar energy in the Arab world are still in their early stages and should be activated and many of them and if we reviewed what the world's countries in this area, especially developed countries industrialization, which does not have a fifth of the Arab countries' own solar energy, we find that Britain alone spends on solar energy projects are equivalent to all the Arab countries combined. This applies to the number of workers in the renewable energy fields, where twice as many people work in all Arab countries in these fields [2].

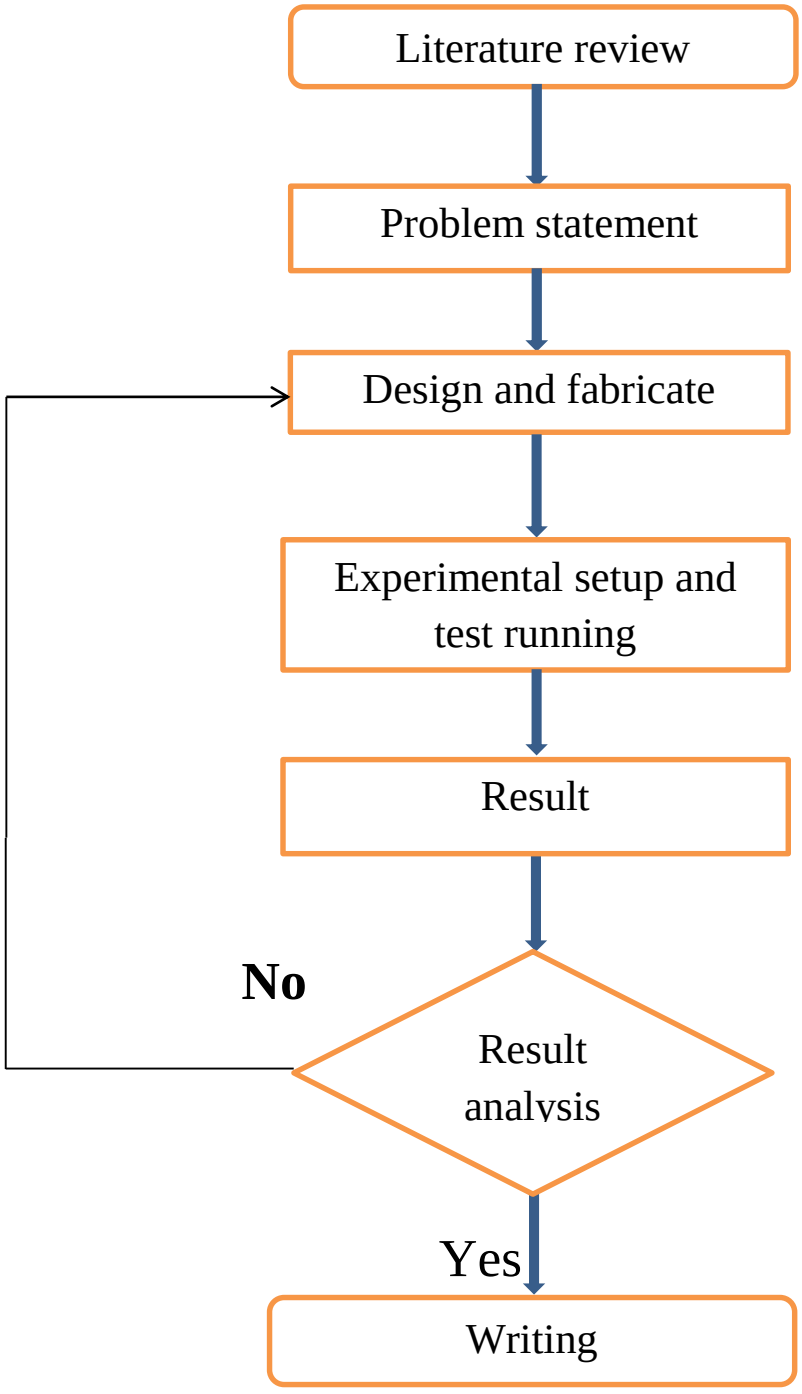
CHAPTER THREE
METHODOLOGY

3.1 Introduction:

Solar energy has been identified as one of the excellent and sustainable Alternate energy sources for the future. However, the effective use of solar radiation is hindered by the intermittent nature of its availability, limiting its use and effectiveness in domestic applications, notably water heating. Water heating is One of the qualities of the direct use of solar energy, and it is an alternate thermal application from an economic viewpoint.

It is necessary to develop an efficient solar water heating system for economical usage. Nowadays researchers are focusing their attention on innovative design changes in order to improve the performance of solar water heating system. Latent heat thermal energy storage (LHTES) systems using phase change materials (PCM) as a storage medium offer advantages such as high heat storage capacity, small unit, and isothermal behavior during charging and discharging. PCMs can be integrated with solar water heater tanks to improve stratification. The behavior of PCM in real conditions has been studied by adding a PCM module at the top of a hot water storage tank with stratification.

3.2 Flow chart:



3.3 design and fabricate:

The solar water heater is a solar absorption and heating unit of thermal radiation and replaced by water that moves inside the suction unit. Its temperature is increased and hot water is maintained in an insulated tank well then the solar heater is used. And the solar heater consists of:

1- Solar Collector.

2- Thermal tank.

3- pcm (paraffin wax).

4-pcm container.

3.3.1 Solar collector:

It is the most important part of the solar heating system, which collects the required heat energy from the sun directly, in this case, any project must know the intensity of the incoming radiation and the energy required to operate. The system and thus determine the type of solar collector and assess its performance, and consists of the solar collector of the following parts: Surface absorption, heating channels, glass cover, external thermal leakage barriers, metal holder and box.

a- Surface Absorption:

The absorptive surface is mostly made of pure black metal to increase the absorption rate. The dark colors are characterized by high absorption rate of solar radiation an average of (98%).

b- Flow channels heating medium:

These channels are usually made of metals such as copper, steel or rubber and vary from one application to another the type of medium as well as the different surface absorption material. There are circular channels with different small diameters to heat liquids.

c- Glass cover:

The basic function of the transparent cover is to allow the solar radiation to reach the heat absorber and to prevent energy the thermal loss through vertical loss also prevents water and air from leaking into the collector.

Table (3-1) illustrates the characteristics of glass

Cover w/m.C	**Thickness** mm	**Weigh** kg/m^2	**Thermal conductivity**
Standard glass	4	10	0.84
Standard glass, Heat processor	4	10	0.84
Glass free of Iron	4	10	0.91
Non-reflective glass	4	10	0.95

d- Thermal Insulation:

When the temperature in the heaters increases as compared to the surrounding atmosphere, there is a possibility of losing this heat through the sides of the heater and the underside of it, and the load, and radiation through the glass envelope, and therefore can be used special materials and methods to reduce these losses according to the type of loss.

Table (3-2) showing the characteristics of thermal insulators [10]:

Insulation material	**Highest temperature allowed**	**Density**	**Thermal conductivity**
Metal wool	200	60-200	0.04
Glass wool	200	30-200	0.04
Glass wool	200	130–150	0.048
Polyurethane foam	130	30 – 80	0.03
Foam polystyrene	80	30 – 50	0.034

e- Outer cover:

The outer cover is used to prevent air and moisture from leaking into the collector as these factors increase heat loss. The outer box can be manufactured from light galvanized steel sheets, wood, aluminum or any other materials.

Table (3-3) demonstrate the thermal conductivity for some materials [10]:

Metal	Thermal conductivity
Cooper	385
Aluminum	205
Steel	79.5

* According to the specifications provided, the type of thermal insulation used in the solar collector and the tank is Polyurethane and the materials of manufacture; the selection was very accurate to take advantage of the maximum available solar energy and therefore was selected copper and steel as two good Thermal conductivity in the tubes.

Table (3-4) specifications flat solar collector

Collector area	51*51 cm^2
Collector cover material	Single tempered glass
Glass cover absorptivity	0.85
Length of cooper tubes	4 m
Length of steel tubes	4 m
Material of the absorber plate	Cooper
Material of the absorber plate	Steel
Thermal conductivity of cooper	385 W/m k
Thermal conductivity of steel	79.5 W/m k
Plate thickness	2 mm
Diameter of cooper tubes	13 mm
Diameter of steel tubes	20 mm
Number of cooper tubes used	6
Number of steel tubes used	6
Collector angle	30

3.3.2 Thermal Tank:

The tank is made of plastic (40L) and is completely insulated with Polyurethane and is attached to the container of pcm (paraffin wax).

3.3.3 Phase change material:

the phase change material used in this study is paraffin wax and the quantity of it is 2 kg.

Table (3-5) shows the properties of paraffin wax:

Properties	Solid phase	Liquid phase
Melting point	56	56
Latent heat	142.7	142.7
Thermal conductivity	0.4	0.2
Density	670	640
Specific heat	2.4	1.6

3.3.4 PCM container:

Made of light steel and volume of cylinder is 0.006 m^3.

3.4 equations energy of solar collector [7]:

$$Q_u = m * c_p * (Tf, out - Tf, in) \dots\dots\dots (3-1)$$

Since:

m = Flow rate of fluid mass during collector.

c_p = Specific temperature when pressure is confirmed for operating fluid.

(, $out - Tf, in$) = The rise in operating fluid temperature passes through the collector.

The amount of energy benefited from the solar collector of the square meter and the amount of flow (Q) depend on the collector form.

There are design considerations as follows:
First : Heat the absorbent board (Tpm) Equal to the temperature of the liquid inside(Tfi).
Second: Calculation of the thermal loss coefficient of the collector U_L .

$$U_L = U_b + U_e + U_t \dots\dots\dots (3-2)$$

$\frac{k}{x} = U_b(\frac{w}{m^2.^\circ c})$ = loss heat factor from bottom

k= thermal conductivity factor for insulation

X= thickness insulation

U_e = loss heat factor passing

U_t = loss heat factor from upper

* Calculation the efficiency factor for solar collector (F'):

$$F' = \frac{1}{\frac{W+U_l}{\pi D_i h}+\frac{W}{D-(W-D)F}} \quad \text{…….. (3-3)}$$

H =heat transfer coefficient for liquid.

K =thermal conductivity factor.

D_i =Inner diameter for the tube.

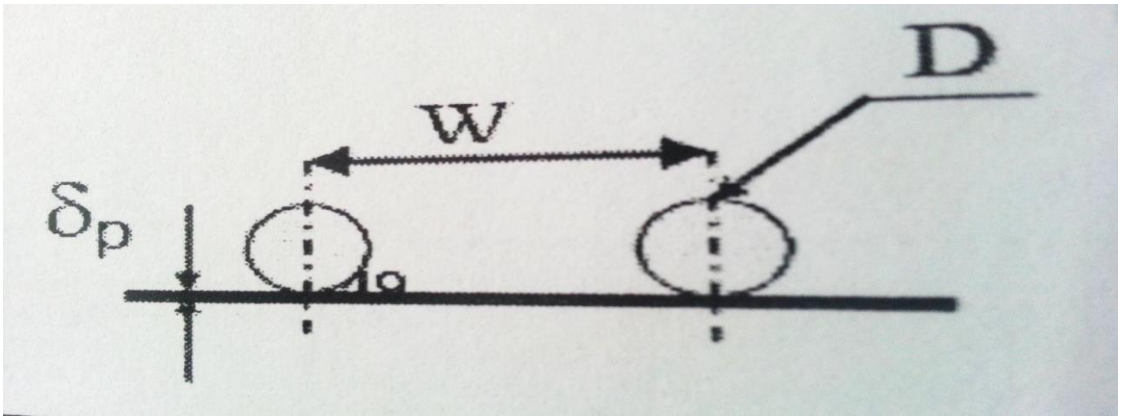


Figure (3-1) shows the tubes under the absorber surface [7]

*Calculation of heat removal coefficient (F_R):

$$F_R = \frac{G\ C_p}{A_c\ U_l}[1 - exp - \left(\frac{A_C\ U_l\ F'}{G\ C_p}\right)] \ldots\ldots\ldots\ldots (3\text{-}4)$$

G = liquid flow rate per square meter of the collector

$A_{c\,=}\ collector\ area\ (m^2)$

*calculation the useful energy gained by the collector using:

$$Q_u = A_c F_R [I(t\alpha) - U_l(T_{F_i} - T_a)] \ldots\ldots\ldots \text{(3-5)}$$

Since:

I = total solar radiation fallen.

t = permeability of the surface.

$\alpha =$ Absorptivity of the absorbent surface.

T_{f_i} = Temperature of inlet liquid.

*calculation the efficiency of solar collector:

$$□ = \frac{Q_u}{A_c\, I}$$

3.5 solar angels:

The solar angles are divided into:

3.5.1 Solar deflection angle (δ):

Is the angle between the equatorial plane and the line between the center of the earth and the center of the sun. The value of this angle ranges between 23.45 + and -23.45.

This angle differs from day to day and calculated from the relationship [7]

$$\Delta = 23.45 \sin \frac{360}{365}(284 + N) \ldots\ldots \text{(3-6)}$$

N = number of day in the year

3.5.2 Solar elevation angle(α):

Is the angular height of the sun in the sky measured from the horizon this angle is equal to zero at sunrise and sunset, and 90 when the sun is directly above the Observatory [7].

3.5.3 The hour angle (ω):

Is the number of degrees the sun moves in its daily path across the sky. By definition, the angle of the hour is zero at noon. Since the Earth rotates 15° per hour, the time clock from noon corresponds to the movement of a corner of the sun in the sky of 15° negative angle in the morning and afternoon.

3.5.4 Elevation of the maximal height:

Is the maximum height of the sun in the sky at a certain time of the year, and this maximum angle occurs at noon and follow the latitude and angle of deviation.

3.6 design steps:

All materials have been purchased(Glass, Lenses, Copper Pipes, steel pipes, Thermal Insulation, Paint Black ,Sheet steel and Base steel of collector) from Khartoum Segana Market.

The design manufactured and assembled in the university with the help of university technicians in various workshops.

3.6.1 Manufacturing of the solar collector:

Figure (3-2)The collector designed in this project

a- Production of external frame:

Operation steps	Machines and tools
- production of external frame - operation -cutting of slices	Measurement Scissor Multi-drifly
-Bends the collector sides	Bending machine "crochet machine"
-Assembling the frame	Welding machine
-Assembling the frame and the base -Manual assembly -Welding	Welding machine Drill

The thickness sheet (1.5) mm was cut by an electric shearing machine then the four pieces were assembled and the welding was done by welding machine.

b- The absorbent surface:

It is a 4 mm thickness standard glass plate and its thermal conductivity equal 0.84.

c- Base of collector:

It has length 6m has been cut into 10 parts. 6 pieces to make base, 4 pieces to make the frame to carry the solar collector .The parts were welded together by a welding machine

Figure (3-3) base of the collector

d- Cooper & steel tubes:

Copper and steel pipes that contains water were wound into the solar collector U- Shaped by a pipe-winding machine.

e- PCM container:

Its cylindrical steel sheet has welded by cold welding on its sides (avoid leakage) to contains the paraffin wax.

Figure (3-4) PCM container

f- The tank:

Its capacity equal 32L and it contains the water and the pcm Container.

Figure (3-5) water tank

CHAPTER FOUR

RESULTS & DISCUSSION

4.1 Introduction:

This chapter shows the results of study and discuss the performance of solar water heater with PCM, all this results was taken as the average for several experiments.

4.2 experimental results and discussion:

The test rig was designed and fabricated according to the specifications and standards required as shown in figure (4-1).

Figure (4-1) solar water heater integrated with PCM

Table (4-1) average temperature variations during Charging with PCM Cylinder for September month

Time	Water temperature	Cooper tubes temperature	Steel tubes temperature	Ambient temperature
10	26	26	26	35
10:30	28	29	28	36
11	30	31	31	37
11:30	33	39	37	39
12	37	45	42	40
12:30	41	50	48	42
13	45	53	50	44
13:30	50	56	52	43
14	53	57	54	43
14:30	57	60	57	42
15	59	64	61	42
15:30	62	60	56	40
16	63	58	55	38
16:30	64	57	54	36
17	65	50	47	35

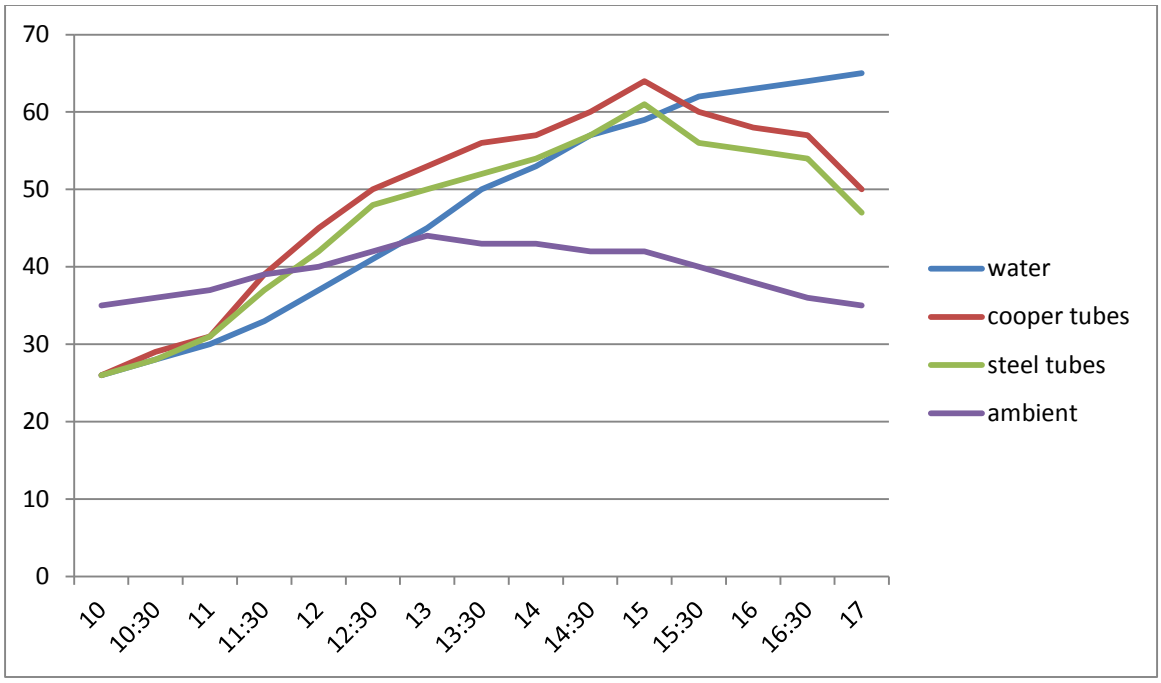


Figure (4-2) average temperature variations during Charging with PCM Cylinder for September month

Figure (4.2) show in x axis the time per hour and y axis temperature by degree calicoes. From this figure, the water temperature in the tank increases with time increasing until arrived 65°C at the end of charging process.

Table (4-2) average temperature variations during Charging

With PCM cylinder for October month

Time	Water temperature	Cooper tubes temperature	Steel tubes temperature	Ambient temperature
10	26	26	26	36
10:30	28	29	28	37
11	30	31	31	38
11:30	32	36	34	39
12	34	44	42	40
12:30	37	50	47	42
13	40	53	50	43
13:30	43	57	53	43
14	48	58	55	44
14:30	52	61	58	44
15	56	65	62	42
15:30	59	62	59	40
16	61	58	55	38
16:30	63	54	50	37
17	64	50	47	35

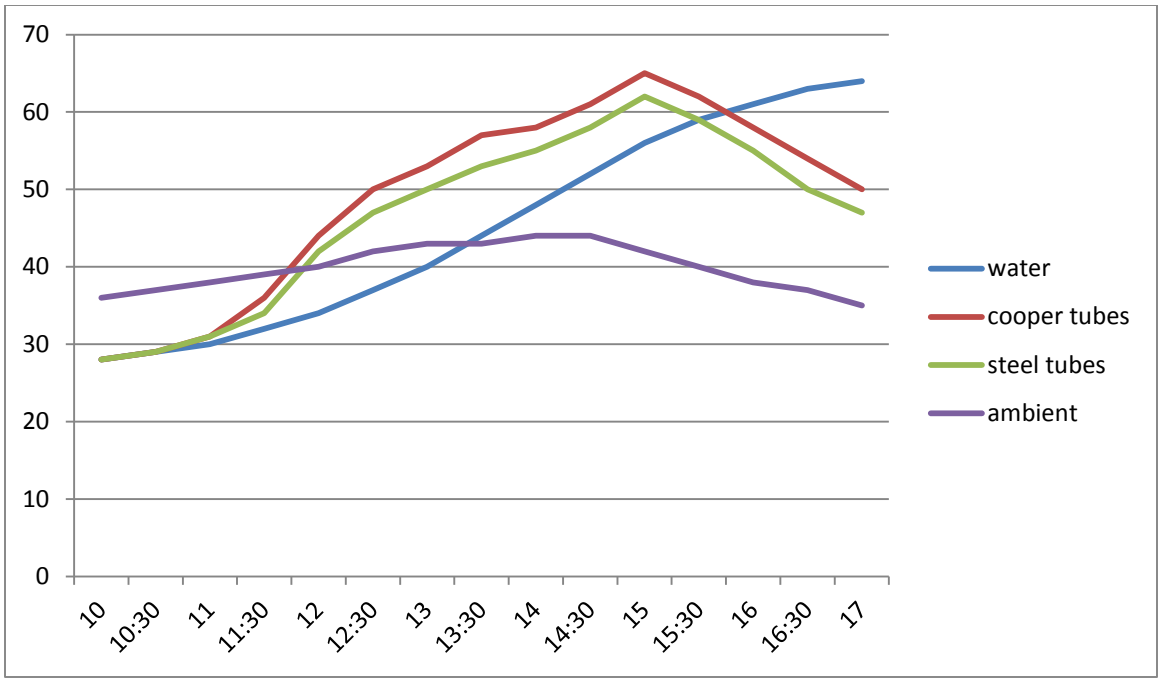


FIGURE (4-3) average temperature variations during Charging With PCM cylinder for October month

Figure (4.3) show in x axis the time per hour and y axis temperature by degree calicoes. From this figure, the water temperature in the tank increases with time increasing until arrived 65°C at the end of charging process.

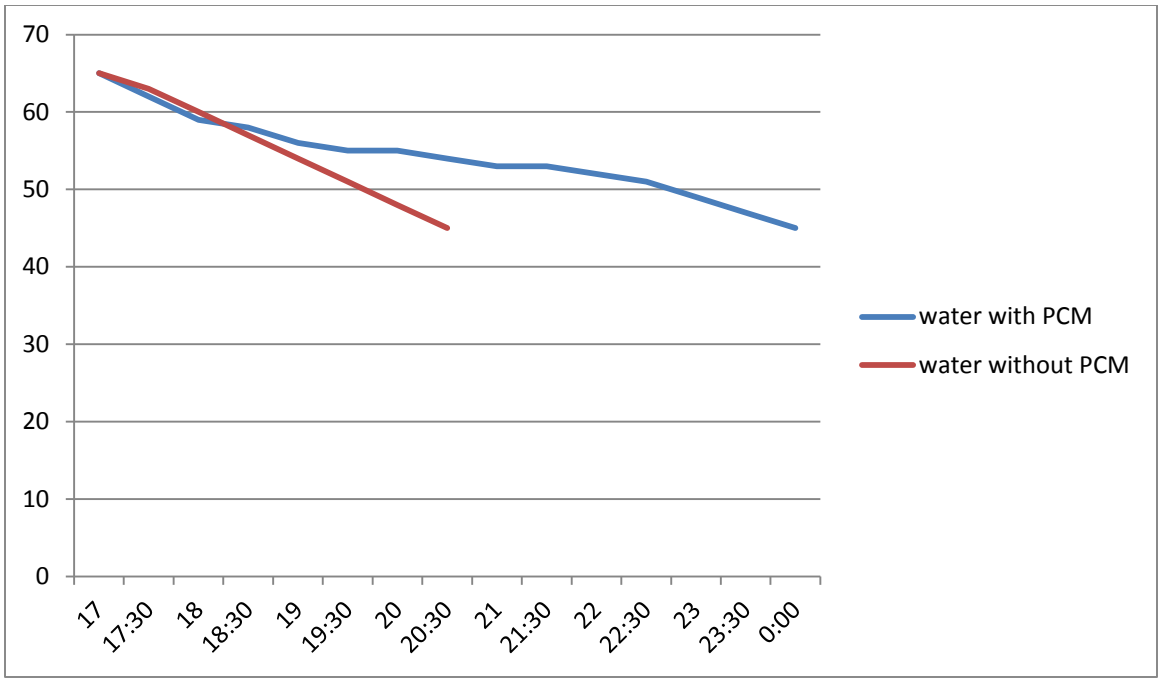


Figure (4-4) average temperature for discharging process with PCM & without PCM

From Figure (4-4) above, discharging in the presence of PCM takes longer period of time than discharging without PCM.

All this results agrees with the previous studies.

CHAPTER FIVE

CONCLUSION

5.1 Conclusion:

Finally the design and fabricate of the solar water heater integrated with phase change material was done and experimental results show that the PCM can make as solar water heater in evening after the sunset.

5.2 Recommendations:

1- The continuity of this research project for more studies.
2- Implement this solar water heater with PCM in industrial and domestic applications.

3- It is preferred to discharge the collector from the air and thus reduce heat loss through convection.

4- Establish a data bank on the intensity of solar radiation, temperature, wind intensity, dust volume, of periodic information necessary for the use of solar energy.

5-The importance of the role of the State through material and moral support and the activation of the research movement in the fields of solar energy.

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