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مساهمة في دراسة العوامل المؤثرة على التبادل الحراري للاقط شمسي مسطح

CONTRIBUTION TO THE STUDY OF PARAMETERS AFFECTING HEAT EXCHANGES IN A FLAT-PLATE SOLAR COLLECTOR

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شكر و عرفان

الشكر والحمد لله الذي بفضله تتم الصالحات. أما بعد

شكرا لوالدي العظيمين على كل ما منحاني.

شكرا لكل أستاذ حظيت به في مشواري الدراسي ليجزهم الله عني كل خير على رأسهم من شرفوني بقبول مناقشة مذكرتي

الأستاذ المحترم والحازم في الحق. الأستاذ بوغالي سليمان.

الأستاذ الذي علمنا عن الحياة وعن الفيزياء معا. الأستاذ بشكي جمال.

شكر خاص لأستاذي المؤطر. على دعمه وجهده و احترافيته العالية. الأستاذ بوقطاية حمزة.

شكرا لعمال المكتبة. لأعضاء نادي ابن الهيثم للفيزياء ولكل من كان جزءا من خريطة حياتنا الجامعية.

Dedication

To my great parents

LANABI Salim, HACHANI Nadia

To the young mother and the great sister

LANABI Yamina

TO my brother and sisters

To every teacher I had

I dedicate this work.

Summary

CHAPTER ONE: GENERAL NOTION OF HEAT TRANSFER

CHAPTER TWO: SOLAR COLLECTORS

CHAPTER THREE: THERMAL ANALYSIS AND PERFORMANCE

CHAPTER FOUR: PERFORMANCE IMPROVEMENTS

Nomenclature

Q	*heat flow*	W
K	*thermal conductivity*	$W/m.K$
A	*surface*	m^2
ρ	density	kg/m^3
C	specific heat capacity	J/kg K
h	convective heat transfer coefficient	W/m^2.K
σ	Stefan-Boltzmann constant	W/$m^2.K^4$
ε	emissivity	
f_{12}	view factor	
δ	declination	degree
h	hour angle	degree
z	Azimuth angle	degree
G_{on}	extraterrestrial radiation	W/m^2
G_{sc}	solar constant	W/m^2
I	solar radiation intensity	W/m^2
τ	transmition rate	
α	absorption rate	
U_L	overall heat loss coefficient	W/m^2.K
T_p	plate temperature	K
T_a	ambiant temperature	K
m	mass	kg
F_R	heat removal factor	
η	collector efficiency	

INTRODUCTION

Introduction

The expansion in global output and prosperity drives the growth in energy demand, with growth in energy consumption led by fast-growing developing economies [15]. Air pollution is a major public health crisis, with many of its root causes and cures to be found in the energy sector. Around 6.5 million deaths are attributed each year to poor air quality, making this the world's fourth-largest threat to human health. Without changes to the way that the world produces and uses energy, the ruinous toll from air pollution on human life is set to rise [16]. Health crisis, energy crisis and global warming are all results of the unreasonable use of fossil energy.

Energy systems around the world are undergoing substantial changes. Many of these shifts are being driven by purposeful government policies, whether to put a country on a low-carbon transition path, reduce air pollution, secure energy independence and security, or reduce costs and improve efficiencies. Other changes are being driven by external forces, including broader movements in energy markets or by deep societal transformations such as the increased use of information and communication technologies in every wake of life [17]. Renewable energy is the fastest growing energy source, accounting for 40 % of the increase in energy. The energy mix by 2040 is the most diversified ever seen [15].

Solar energy, the power derived from the rays of the sun, is considered to be one of renewable energy; it is an important alternative source of energy. It is relatively preferred to other sources because it is free, endless, clean and available abundantly, and inexhaustible and non-pollutant in nature compared with higher prices and shortage of fossil fuels [12].

One of the most potential applications of solar energy is the supply of hot air for drying of agricultural and heating of buildings to maintain a comfortable environment especially in the winter season. Several designs of solar air heaters have been proposed and discussed in literature [9]. Due to the poor thermal conductivity and low heat capacity of air, the convective heat transfer rate inside the air flow channel is low [9]. Efforts have been made to increase this rate and enhance the performance of the solar air heaters [8,9].

This dissertation presents a modest contribution to the study of parameters affecting the heat exchanges in flat-plate solar air collectors and reviews some of the recent studies aiming to a better controlling of the heat losses and the heat transfer rate and thus enhances the performance of the solar air collector.

The presentation of this dissertation is resumed as follows:

In the first chapter, we briefly described the heat transfer phenomenon and its three modes: conduction, convection and radiation, and gave the necessary background of the environmental characteristics and the sun-earth motion, also given are the basic solar angles and a presentation of the thermal and the extraterrestrial solar radiation.

The second chapter presents all the solar collectors available today and their advantages and disadvantages over each other.

The thermal analysis of a flat-plate collector and the thermal performance equations and description are given in the third chapter.

Finally, in the fourth chapter we presented the modifications that have been made to improve the thermal performance of the flat-plate collector, giving and reviewing some recent works around the world concerning that goal.

CHAPTER ONE:

GENERAL NOTION

1-1 Heat transfer

Thermal energy is related to the temperature of matter. For a given material or mass, the higher the temperature is, the greater its thermal energy. Heat transfer is a study of the exchange of thermal energy through a body or between bodies which occurs when there is a temperature difference. When two bodies are at different temperatures, thermal energy transfers from the one with higher temperature to the other one with lower temperature.

Heat always transfers from hot to cold. [1]

1-2 Modes of Heat Transfer

Heat, by definition; is the energy in transit due to temperature difference. Whenever exists a temperature difference in a medium or between media, heat flow must occur. Different types of heat transfer processes are called modes. These modes are shown in Figure 1.1. When a temperature gradient exists in a stationary medium, which may be a solid or a fluid, heat flows under the law of conduction heat transfer. On the other hand if the temperature gradient exists between a surface and a moving fluid we use the term Convection. The third mode of heat transfer is termed Radiation and it needs no medium to transfer through since it is driven by electromagnetic waves emitted from all surfaces of finite temperature, so there is a net heat transfer by radiation between two surfaces at different temperatures. [2]

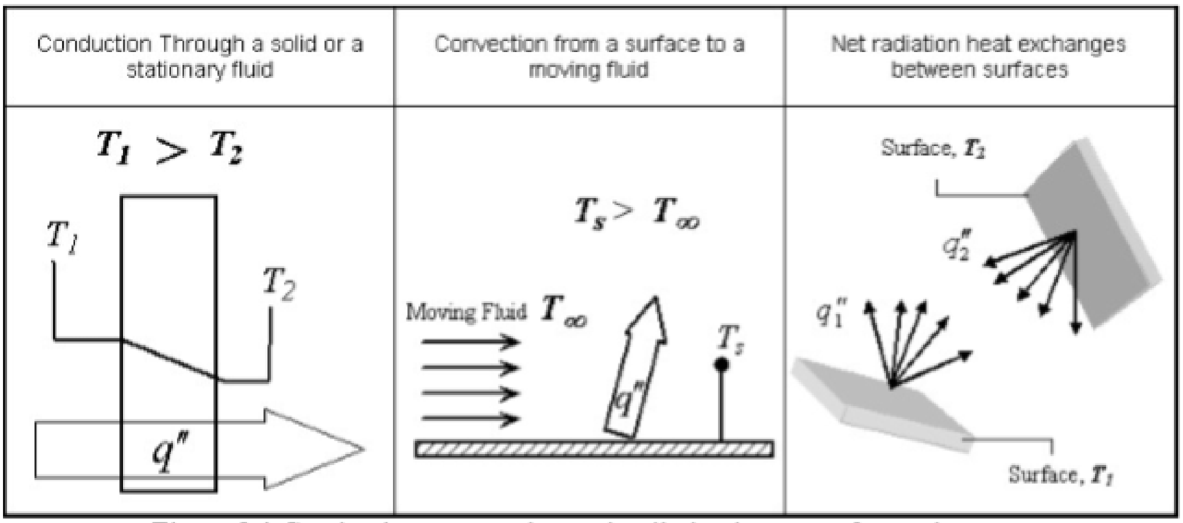


Figure 1.1[2]: Conduction, convection and radiation heat transfer modes

In most of the practical cases under investigations, these three mechanisms combine to generate the total energy flow, but it is convenient to consider them separately. We need to describe each process symbolically in an equation of reasonably simple form.

1-2-1 Conduction

Fourier's law:

Joseph Fourier published his remarkable book "*Théorie Analytique de la Chaleur*" in 1822. In it he formulated a very complete exposition of the theory of heat conduction.

He began his treatise by stating the empirical law that bears his name: the heat flux:[3]

$$Q = -k\,A\,\frac{dT}{dx} \qquad (1.1)$$

Figure1.2 shows, in schematic form, a process of conductive heat transfer and identifies the key quantities to be considered:

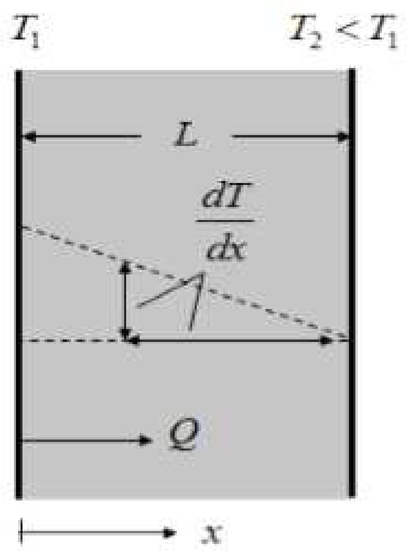


Figure.1.2: One dimensional conduction

Q: the heat flow by conduction in the x- direction (W).

A: the area through which the heat flows, normal to the x- direction (m^2).

$\frac{dT}{dx}$: The temperature gradient in the x- direction (K/m).

A significant feature of this equation is the negative sign. This recognizes that the natural direction for the flow of heat is from high temperature to low temperature, and hence down the temperature gradient.

The additional quantity that appears in this relationship is k, the thermal conductivity (W/m K) of the material through which heat flows. This is a property of the particular heat-conducting substance and, like other properties, depends on the state of the material, which is usually specified by its temperature and pressure. The dependence on temperature is of a particular importance.

Table 1-1 gives the values of thermal conductivity of some representative solid materials, for conditions of normal temperature and pressure. Also shown are values of another property characterizing the flow of heat through materials, thermal diffusivity, which is related to the conductivity by:

$$\alpha = k/\rho.C \qquad (1.2)$$

where ρ: the density of the material (kg/m^3).

C: the specific heat capacity of the material (J/kg K).

The thermal diffusivity indicates the ability of a material to transfer thermal energy relative to its ability to store it. The diffusivity plays an important role in unsteady conduction.

Material	k W/m K	α mm2/s	Material	k W/m K	α mm2/s
Copper	350	115	Medium concrete block	0.5	0.35
Aluminium	236	85	Dense plaster	0.5	0.40
Mild steel	50	13	Stainless steel	14	4
Polyethylene	0.5	0.15	Nylon, Rubber	0.25	0.10
Face Brick	1.0	0.75	Aerated concrete	0.15	0.40
Glass	0.9	0.60	Wood, Plywood	0.15	0.2
Fireclay brick	1.7	0.7	Wood-wool slab	0.10	0.2
Dense concrete	1.4	0.8	Mineral wool expanded	0.04	1.2
Common brick	0.6	0.45	Expanded polystyrene	0.035	1.0

Table 1.1: Thermal conductivity and diffusivity for typical solid materials at room temperature. *[4]*

For gases the thermal conductivities can vary significantly with both temperature and pressure.

1-2-2 Convection

Convection heat transfer occurs both due to molecular motion and bulk fluid motion. Convective heat transfer may be categorized into two forms according to the nature of the flow: natural convection and forced convection.

In natural or 'free' convection, the fluid motion is driven by density differences associated with temperature changes generated by heating or cooling. In other words, fluid flow is induced by buoyancy forces. Thus the heat transfer itself generates the flow which conveys away from the point at which the transfer occurs.

In forced convection, the fluid motion is driven by some external influence. Examples are the flows of air induced by a fan, by the wind, or by the motion of a vehicle, and the flows of water within heating, cooling, supply and drainage systems.

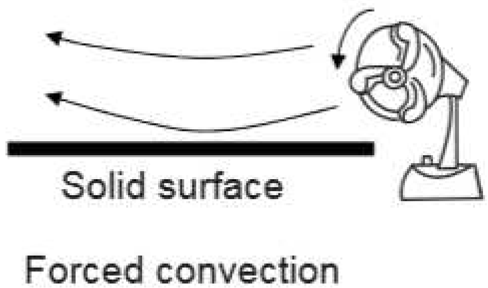


Figure1.3: forced convection.

The Figure 1.3 illustrates a process of forced convection. Air is forced by a fan carrying with it heat from the wall if the temperature of the wall is greater or giving heat to the wall if the temperature is lower than the air temperature.

If T_1 is the temperature of the surface receiving or giving heat, and T_f is the average temperature of the stream of fluid adjacent to the surface, then the convective heat transfer Q is governed by **Newton's law**:

$$Q = h.A(T_f - T_1) \qquad (1.3)$$

Another empirical quantity has been introduced to characterize the convective transfer mechanism. This is h, the convective heat transfer coefficient, which has unit [W/m^2K].

This quantity is also known as the convective conductance and as the film coefficient. The term film coefficient arises from a simple, but not entirely unrealistic, picture of the process of convective heat transfer at a surface. Heat is imagined to be conducted through a thin stagnant film of fluid at the surface, and then to be convected away by the moving fluid beyond. Since the fluid right against the wall must be actually at rest, this is a fairly reasonable model, and it explains why convective coefficient often depend quite strongly on the conductivity of the fluid.

The film coefficient is not a property of the fluid, although it does depend on a number of fluid properties: thermal conductivity, density, specific heat and viscosity. This single quantity subsumes a variety of features of flow. Generally speaking, the convective coefficient increases as the velocity increases.

A great deal of work has been done in measuring and predicting heat transfer coefficient. Nevertheless, for all but the simplest situations we must rely upon empirical data.

1-2-3 Radiation

While both conductive and convective transfers involve the flow of energy through a solid or fluid substance, no medium is required to achieve heat transfer by radiation. Indeed, electromagnetic radiation travels most efficiently through a vacuum, though it is able to pass quite effectively through many gases, liquids and through some solids, in particular, relatively thin layers of glass and transparent plastics.

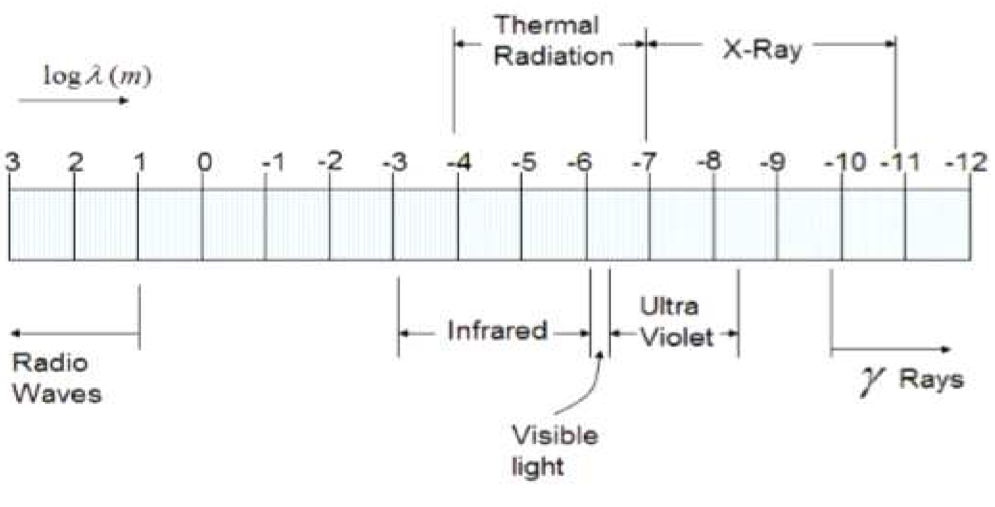


Figure 1.4: Illustration of electromagnetic spectrum.

Thermal radiation is of the same family as visible light and behaves in the same general fashion, being reflected, refracted and absorbed. These phenomena are of particular importance in the calculation of solar gains, every body, unless at the absolute zero temperature, both emits and absorbs energy by radiation. In many circumstances the inwards and outwards transfers nearly cancel out, because the body is at about the same temperature as its surroundings.

In 1884 Boltzmann put forward an expression for the net transfer from an idealized body (Black body) with surface area A_1 at absolute temperature T_1 to surroundings at uniform absolute temperature T_2:

$$Q = \sigma A_1(T_1^4 - T_2^4) \quad \text{or} \quad q = \sigma(T_1^4 - T_2^4) \qquad (1.4)$$

With $\sigma =$ the Stefan-Boltzman constant=5.67× 10^{-8} W/$m^2.K^4$.

The bodies considered above are idealized, in that they perfectly absorb and emit radiation of all wave-lengths; the situation is also idealized in that each of the bodies that exchange radiation has a uniform surface temperature. A development of Boltzmann's law which allows for deviations from this pattern is:

$$Q = \sigma \varepsilon f_{12} A(T_1^4 - T_2^4) \qquad (1.5)$$

With:

$\varepsilon =$ Emissivity of the surface which provide of how efficiently a surface emits energy relative to a black body (no reflection) and it ranges $0 \leq \varepsilon \leq 1$

f_{12}= is the view factor, or the angle factor, giving the fraction of the radiation from A_1 that falls on the area A_2 at temperature T_1, and therefore also in the range 0 to 1 .

The case of solar radiation provides an interesting application of this equation. The view factor for the sun, as seen from Earth, is very small; despite this; the very high temperature (raised to the power 4) ensure that the radiative transfer is substantial.

1-3 Environmental Characteristics

The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39× 10^9m. The sun is about 1.5× 10^8 km away from earth, so, because thermal radiation travels with the speed of light in a vacuum (3000 km/s), after leaving the sun solar energy reaches our planet in 8 min and 20 s. As observed from the earth, the sun disk forms an angle of 32 min of a degree. This is important in many applications, especially in concentrator optics. The sun has an effective black-body temperature of 5760 K. The temperature in the central region is much higher. In fact, the sun is a continuous fusion in which hydrogen is turned into helium. The sun's total energy output is 3.8× 20 MW, which is equal to 63 MW/1m^2 of the sun's surface. This energy radiates outward in all directions. The earth receives only a tiny fraction of the total radiation emitted, equal to 1.7×10^{14} kW; however, even with this small fraction, it is estimated that 84 min of solar falling on earth is equal to the world energy demand for one year (about 900 MJ). As seen from the earth, the sun rotates around its axis about once every four weeks.

Knowledge of the sun's path through the sky is necessary to calculate the solar radiation falling on a surface, the solar heat gain, the proper orientation of solar collectors, the placement of collectors to avoid shading, and many more factors that are not of direct interest.

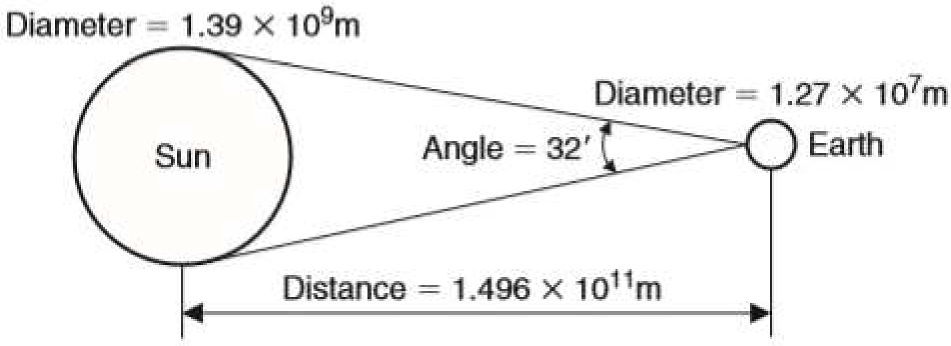


Figure 1.5: Sun-earth relationship.

1-4 Solar Angles:

The earth makes one rotation about its axis every 24h and completes a revolution about the sun is a period of approximately 365.25 days. This revolution is not circular but follows an ellipse with the sun at one of the foci, as shown in Figure1.6. The eccentricity, e, of the earth's orbit is very small, equal to 0.01673. Therefore, the orbit of the earth around the sun is almost circular. The sun-earth distance, R, at perihelion (shortest distance, at January 3) and aphelion (longest distance, at July 4) is given by:

$$R=a(1\pm e)$$

Where a = mean sun-earth distance = 149.5985*10^6km.

The relative motion of the sun and earth are not simple, but systematic and thus predictable.

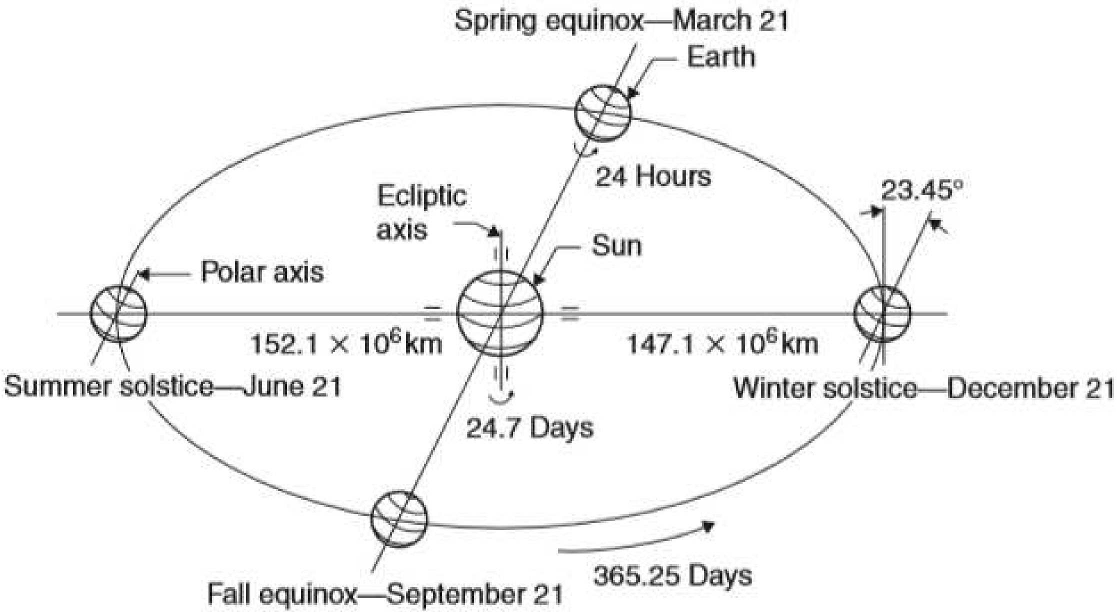


Figure1.6: Annual motion of the earth about the sun.

The most obvious apparent motion of the sun is that it moves daily in an arc across the sky, reaching its highest point at midday. As winter becomes spring and then summer, the sunrise and sunset points move gradually northward along the horizon. In the Northern Hemisphere, the days get longer as the sun rises earlier and sets later each day and the sun's path gets higher in the sky. On June 21 the sun is at its most northerly position with respect to the earth. This is called the summer solstice and during this day the daytime is at a maximum. Six months later, on December 21, the winter solstice, the reverse is true and the sun is at its most southerly position. In the middle of the six-month range, on March 21 and September 21, the length of the day is equal to the length of the night. These are called spring and fall equinoxes, respectively. The summer and winter solstices are opposite in the Southern Hemisphere; that is, summer solstice is on December 21 and winter solstice is on Jun e21. It should be noted that all these dates are approximate and that there are small variations (difference of few days) from year to year.

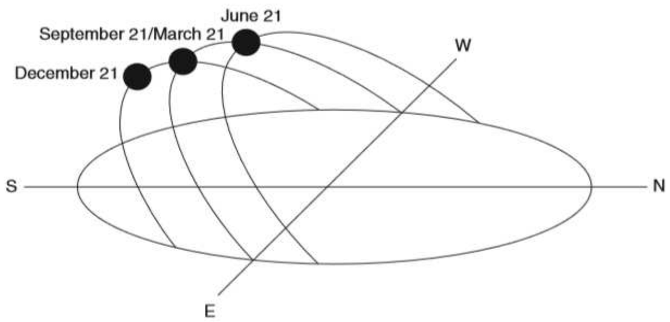


Figure1.7: Annual changes in the sun's position in the sky (Northern Hemisphere).

For most solar energy applications, one needs reasonably accurate predictions of where the sun will be in the sky at a given time of day and year. In the Ptolemaic sense, the sun is constrained to move with 2 degrees of freedom on the celestial sphere; therefore, its position with respect to an observer on earth can be fully described by means of two astronomical angles, the solar altitude (α) and the azimuth (z). The following is a description of each angle, together with the associated formulation.

Before giving the equations of solar altitude and azimuth angles, the solar declination and hour angle need to be defined. These are required in all other solar angle formulations.

1-4-1 Declination δ:

As shown in Figure1.8 the declination is the angle between the sun-earth center line and the projection of this line on the equatorial plan. Declinations north of the equator are positive, and those south are negative.

The declination, δ, in degrees for any day of the year (N) can be calculated approximately by the equation:[5]

$$\delta = 23.45 sin\left[\frac{360}{365}(284 + N)\right] \qquad (1.6)$$

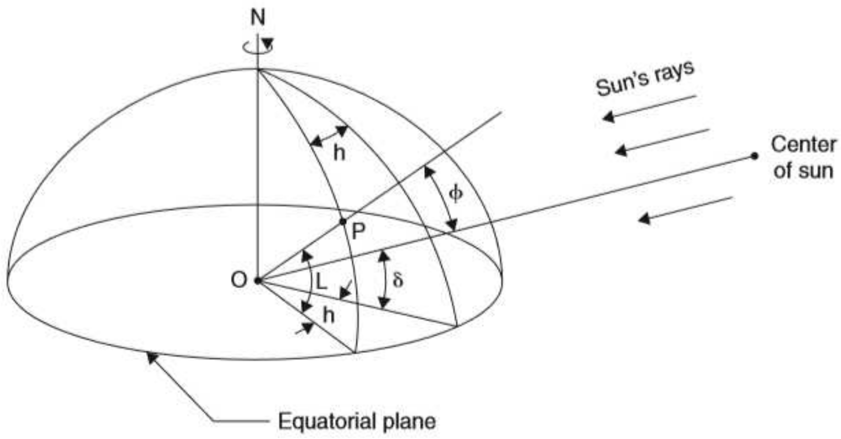


Figure1.8: Definition of latitude, hour angle, and solar declination.

1-4-2 Hour Angle, h:

Figure1.8 shows the hour angle of a point P as the angle measured on the earth's equatorial plane between the projection of OP and the projection of the sun-earth center to center line.

1-4-3 Solar Altitude Angle α:

The solar altitude angle is the angle between the sun's rays and a horizontal plane, as shown in Figure 1.8. It is related to the solar zenith angle ϕ, which is the angle between the sun's rays and the vertical. Therefore,[5]

$$\phi + \alpha = \frac{\pi}{2} = 90^{\circ} \qquad (1.7)$$

The mathematical expression for the solar altitude angle is

$$\sin(\alpha) = \cos(\phi) = \sin(L)\sin(\delta) + \cos(L)\cos(\delta)\cos(h) \quad (1.8)$$

Where, L= local altitude, defined as the angle between a line from the center of earth to the site of interest and the equatorial plane. Values north of the equator are positive and those south are negative.

1-4-4 Solar Azimuth Angle, z:

The solar azimuth angle, z, is the angle of the sun's rays measured in the horizontal plane from due south (true south) for the Northern Hemisphere or due north for Southern Hemisphere; westward is designated as positive. The mathematical expression for the solar azimuth angle is[5]

$$\sin(z) = \frac{\cos(\delta)\sin(h)}{\cos(\alpha)} \qquad (1.9)$$

1-5 Thermal Radiation

When a beam of thermal radiation is incident on the surface of a body, part of it is reflected away from the surface, part is absorbed by the body, and part is transmitted through the body. The various properties associated with this phenomenon are the fraction of radiation reflected, called reflectivity (ρ); the fraction of radiation absorbed called absoptivity (α); and the fraction of radiation transmitted, called transmissivity (τ). The three quantities are related by the following equation:

$$\rho + \alpha + \tau = 1 \qquad (1.10)$$

1-6 Extraterrestrial Solar Radiation:

The amount of solar energy per unit time, at the mean distance of the earth from the sun, received on a unit area of a surface normal to the sun (perpendicular to the direction of propagation of the radiation) outside the atmosphere is called the "solar constant", G_{sc}. This quantity is difficult to measure from the surface of the earth because of the effect of the atmosphere.

Throughout the year, the extraterrestrial radiation measured on the plane normal to the radiation on the Nth day of the year, G_{on}, can calculated by:[5]

$$G_{on} = G_{sc}\left[1 + 0.033cos\left(\frac{36.N}{365}\right)\right] \qquad (1.11)$$

Where

G_{on}= extraterrestrial radiation measured on the plane normal to the radiation on the Nth day of the year (W/m^2).

G_{sc}= solar constant (W/m^2).

1-7 Atmospheric Attenuation:

The solar heat reaching the earth's surface is reduced below G_{on} because a large part of it is scattered, reflected back out into space, and absorbed by the atmosphere. As a result of the atmospheric interaction with the solar radiation, a portion of the originally collimated rays becomes scattered or non-directional. Some of this scattered radiation reaches the earth's surface from the entire sky vault. This is called the "diffuse radiation". The solar heat that comes directly through the atmosphere is termed "direct" or "beam radiation". The insolation received by a surface on earth is the sum of diffuse radiation and the normal component of beam radiation. The solar heat at any point on earth depends on:

1. The ozone layer thickness
2. The distance traveled through the atmosphere to reach that point
3. The amount of haze in the air (dust particles, water vapor, etc.)
4. The extent of the cloud cover

The degree of attenuation of solar radiation traveling through the earth's atmosphere depends on the length of the path and the characteristics of the medium traversed. In solar radiation calculations, one standard "air mass" is defined as the length of the path traversed in reaching the sea level when the sun is at its zenith angle, ϕ, without considering the earth's curvature, by the equation:

$$m = \frac{AB}{BC} = \frac{1}{COS(\phi)} \qquad (1.12)$$

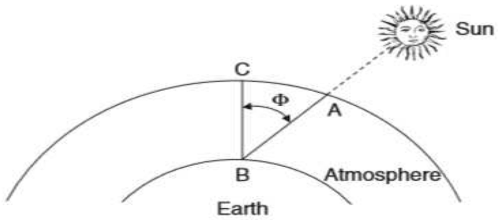


Figure 1.9: Air mass definition.

CHAPTER TWO:

SOLAR COLLECTORS

Introduction

Solar energy collectors are special kinds of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device that absorbs the incoming solar radiation, converts it into heat, and transfers the heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy collected is carried from the circulating fluid either directly to the hot water or space conditioning equipement or to a thermal energy storage tank, from which it can be drawn for use at night or on cloudy days.

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun’s beam radiation to a smaller receiving area, thereby increasing the radiation flux. Concentrating collectors are suitable for high-temperature applications. Solar collectors can also be distinguished by the type of heat transfer liquid used (water, non-freezing liquid, air or heat transfer oil) and whether they are covered or uncovered. A large number of solar collectors are available on the market. A comprehensive list is shown in Table 2.1

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat-plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking			5–15	60–300
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Cylindrical trough collector (CTC)	Tubular	15–50	60–300
	Parabolic trough collector (PTC)	Tubular	10–85	60–400
Two-axis tracking	Parabolic dish reflector (PDR)	Point	600–2000	100–1500
	Heliostat field collector (HFC)	Point	300–1500	150–2000

Note: Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.

Table2.1: Solar energy collectors.

2-1Stationary Collectors

Solar energy collectors are basically distinguished by their motion-stationary, single-axis tracking, and two-axis tracking and the operating temperature. First, we'll examine the stationary solar collectors. These collectors are permanently fixed in position and do not track the sun. Three main types of collectors fall into this category:

1- Flat-plate collectors (FPCs)
2- Stationary compound parabolic collectors (CPCs)
3- Evacuated tube collectors (ETCs)

2-1-1Flat-plate Collectors (FPCs)

A typical flat-plate solar collector is shown in Figure 3.1. When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and transferred to the transport medium in the fluid tubes, to be carried away for storage or use. The underside of the absorber plate and two sides are well insulated to reduce conduction losses.

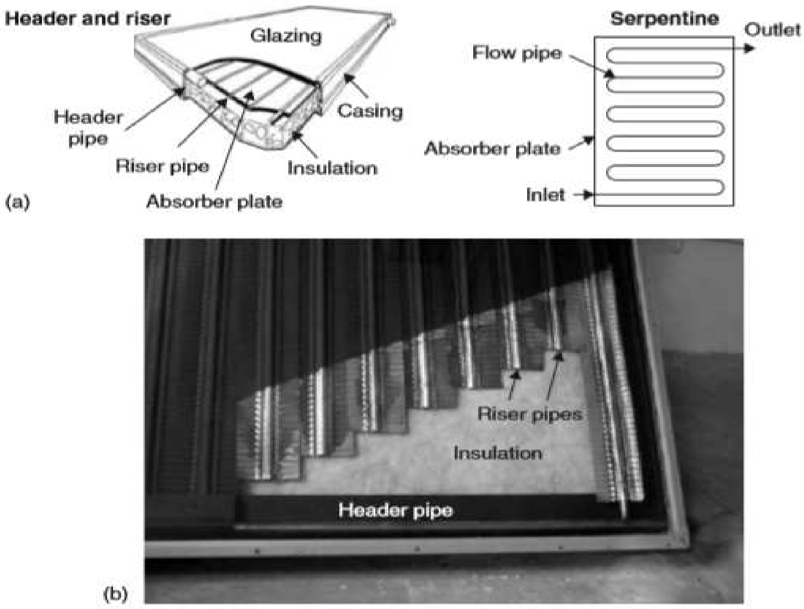


Figure 2.1: Typical flat-plate collector. (a) Pictorial view of a flat-plate collector. (b) Photograph of a cut header and riser flat-plate collector.

The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector because the glass is transparent to the shortwave radiation received by the sun, but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect).

The main components of a flat plate collector, as shown in Figure 2.1, are the following:

- **Cover**. One or more sheets of glass or other radiation-transmitting material.
- **Heat removal fluid passageways**. Tubes, fins, or passages that conduct or direct the heat transfer fluid from the inlet to the outlet.
- **Absorber plate**. Flat, corrugated, or grooved plates, to which the tubes, fines, or passages are attached. The plate is usually coated with a high- absorptance, low emittance layer.
- **Headers or manifolds**. Pipes and ducts to admit and discharge the fluid.
- **Insulation**. Used to minimize the heat loss from the back and sides of the collector.
- **Container**. The casing surroundings the aforementioned components and protects them from dust, moisture, and any other material.

The advantages of flat-plate collectors are that they are inexpensive to manufacture, they collect both beam and diffuse radiation, and they are permanently fixed in position, so no tracking of the sun is required. The collectors should be oriented directly toward the equator, facing south in the Northern Hemisphere.

Flat plate collectors have been built in a wide variety of designs and from many different materials. They have been used to heat fluids such as water, water plus antifreeze additive, or air.

2-1-2 Compound Parabolic Collectors (CPCs)

Compound parabolic collectors (CPCs) are non-imaging concentrators. They have the capability of reflecting to the absorber all of the incident radiation within wide limits. The necessity of moving the concentrator to accommodate the changing solar orientation can be reduced by using a through with two sections of a parabola facing each other, as shown in figure 2.3

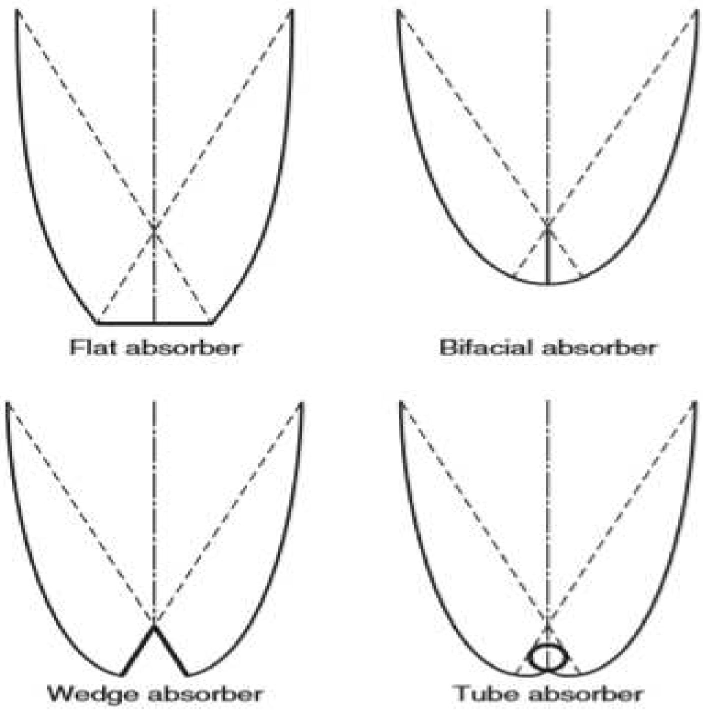


Figure 2.3: Various absorber types of CPCs

Compound parabolic concentrators can accept incoming radiation over a relatively wide range of angles. By using multiple internal reflections, any radiation entering the aperture within the collector acceptance angle finds its way to the absorber surface located at the bottom of the collector. The absorber can take a variety of configurations. It can be flat, bifacial, wedge, or cylindrical, as shown in figure 2.3.

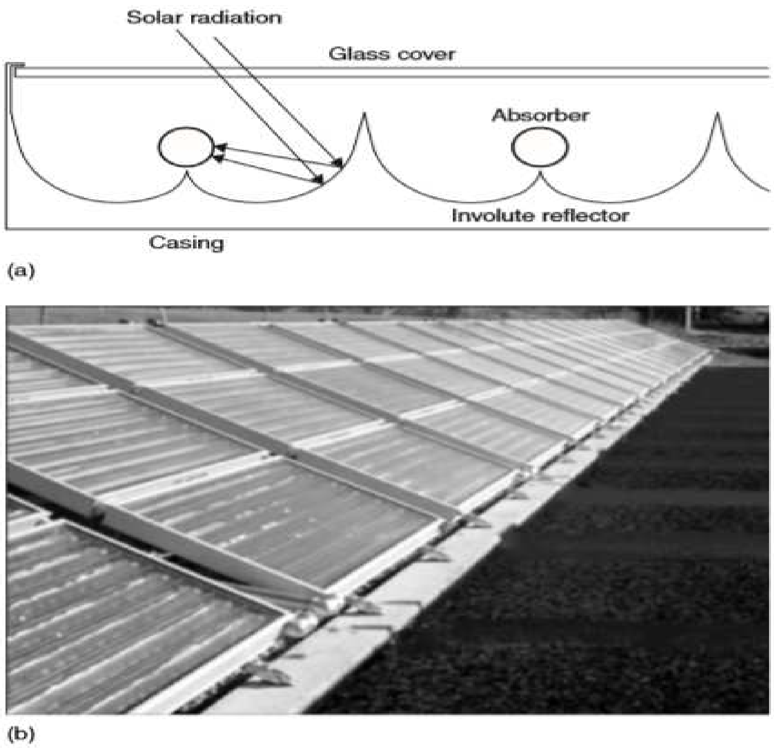


Figure 2.4: Panel CPC with cylindrical absorbers. (a) Schematic diagram. (b) Photo of a CPC panel collector installation.

Compound parabolic collectors can be manufactured either as one unit with one opening and one receiver, Figure 2.3 or as a panel, Figure 2.4 a. When constructed as a panel, the collector looks like a flat-plate collector, as shown in Figure 2.4b.

2-1-3 Evacuated Tube Collectors (ETCs)

Conventional simple flat-plate solar collectors were developed for use in sunny, warm climate. Their benefits, however, are greatly reduced when conditions become unfavorable during cold, cloudy, and windy days. Furthermore, weathering influences, such as

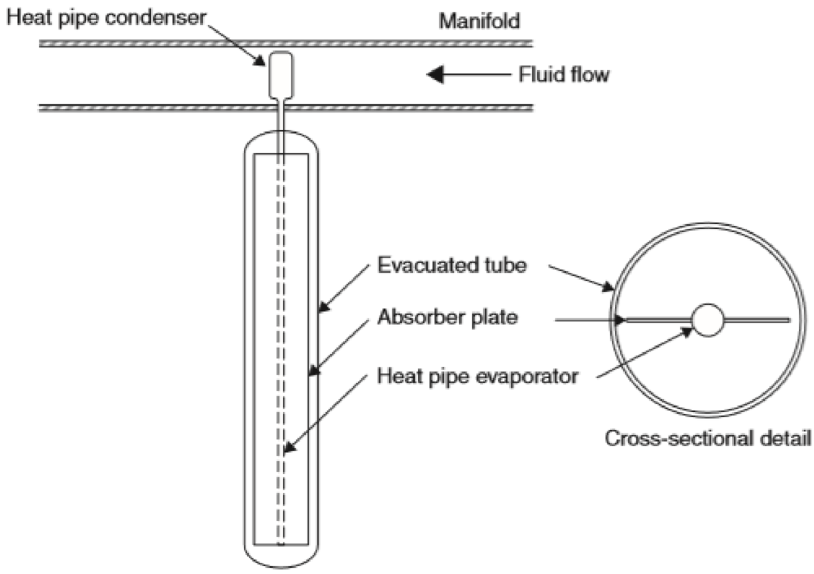


Figure 2.5: Schematic diagram of an evacuated tube collector.

Condensation and moisture, cause early deterioration of internal materials, resulting in reduced performance and system failure. Evacuated heat pipe solar collectors (tubes) operate differently than the other collectors available on the market. These solar collectors consist of a heat pipe inside a vacuum-sealed tube. As shown in Figure 2.5. In an actual installation, many tubes are connected to the same manifold as shown in Figure 2.6.

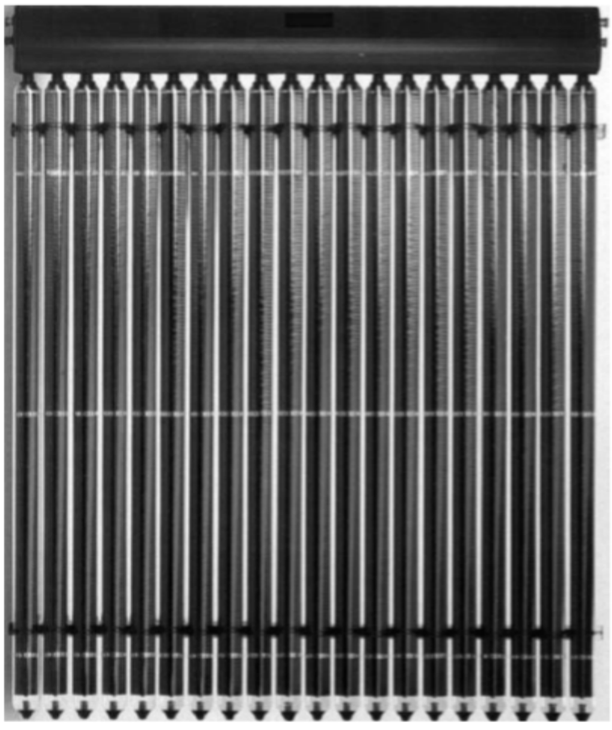


Figure 2.6: Actual ETC installation.

The vacuum envelop reduces conduction and convection losses, so the collectors can operate at higher temperatures than flat-plate collectors, they collect both direct and diffuse radiation. However, their efficiency is higher at low incidence angles. This effect tends to give evacuated tube collectors an advantage over flat-plate collectors in terms of daylong performance.

Evacuated tube collectors use liquid-vapor phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate). Producting from the top of each tube is a metal tip attached to the sealed pipe (condenser). The heat pipe contains a small amount of fluid (e.g., methanol) that undergoes an evaporating-condensing cycle. In this cycle, solar heat evaporates the liquid and the vapor travels to the heat sink region, where it condenses and releases its latent heat. The condensed liquid returns to the solar collector and the process is repeated. When these tubes are mounted the metal tips project into a heat exchanger (manifold), as shown in Figure2.6. Water or glycol flows through the manifold and picks up the heat from the tubes. The heated liquid circulates through another heat exchanger and gives off its heat to a process or water stored in a solar storage tank. Another possibility is to use the ETC connected directly to a hot water storage tank.

2-2 Sun-Tracking Concentrating Collectors.

Energy delivery temperatures can be increased by decreasing the area from which the heat losses occurs. Temperatures far above those attainable by flat-plate collectors can be reached if a large amount of solar radiation is concentrated on a relatively small collection area. This is done by interposing an optical device between the source of radiation and the energy - absorbing surface. Concentrating collectors exhibit certain advantages over the conventional flat-plate type. The main advantages are as follows:

1. The working fluid can achieve higher temperatures in a concentrator system than a flat-plate system of the same solar energy-collecting surface. This means that a higher thermodynamic efficiency can be achieved.
2. The thermal efficiency is greater because of the small heat loss area relative to the receiver area.

3. Reflecting surfaces requires less material and are structurally simpler than flat-plate collectors. For a concentrating collector, the cost per unit area of the solar-collecting surfaces is therefore less than that of a flat-plate collector.
4. Owing to the relatively small area of receiver per unit of collected solar energy, selective surface treatment and vacuum insulation to reduce heat losses and improve the collector efficiency are economically viable.

Their disadvantages are:

1. Concentrator systems collect little diffuse radiation, depending on the concentration ratio.
2. Some form of tracking system is required to enable the collector to follow the sun.
3. Solar reflecting surfaces may lose reflectance with time and may require periodic cleaning and refurbishing.

Because of the apparent movement of the sun across the sky, conventional concentrating collectors must follow the sun's daily motion. The sun's motion can be readily tracked by two methods. The first is the altitude and azimuth, i.e., when performed properly, this method enables the concentrator to follow the sun exactly. Paraboloidal solar collectors generally use this system. The second one is one-axis tracking, in which the collector tracks the sun in only one direction, either from east to west or north to south. Parabolic trough collectors generally use this system. These systems require continuous and accurate adjustment to compensate for the changes in the sun's orientation.

The first type of solar concentrators, shown in Figure 2.7 is effectively a flat-plate collector fitted with simple flat reflectors, which can markedly increase the amount of direct radiation reaching the collector. This is, in fact, a concentrator because the aperture is bigger than the absorber but the system is stationary.

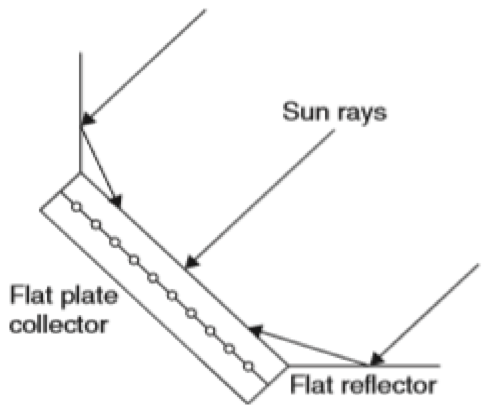


Figure 2.7: Flat-plate collector with flat reflectors.

2-2-1Parabolic trough collectors (PTC)

To deliver high temperature with good efficiency a high-performance solar collector is required. Systems with light structures and low-cost technology for process heat applications up to 400 ‘c could be obtained with parabolic trough collectors (PTCs). PTCs can effectively produce heat at temperatures between 50’c and 400’c.

Parabolic trough collectors are made by bending a sheet of reflective material into a parabolic shape. A black metal tube, covered with a glass to reduce heat losses, is placed along the focal line of the receiver. When the parabola is pointed toward the sun, parallel rays incident on the reflector are reflected on the receiver tube. The concentrated radiation reaching the receiver tube heats the fluid that circulates through it, thus transforming the solar radiation into useful heat. It is sufficient to use a single-axis tracking of the sun; therefore, long collector modules are produced. The collector can be oriented in an east-west direction, tracking the sun from north to south, or in a north-south direction, tracking the sun from east to west. Photograph of PTC collectors are shown in Figure 2.8

Figure 2.8: An industrial solar technology collector(PTC).

A glass cover tube is usually placed around the receiver, thereby further reducing the heat loss coefficient. A disadvantage of the glass cover tube is that the reflected light from the concentrator must pass through the glass to reach the absorber, adding a transmittance loss of about 0.9, when the glass is clean. The glass envelope usually has an antireflective coating to improve tranmissivity. One way to further reduce convective heat loss from the receiver tube and thereby increase the performance of the collector, particularly for high-temperature applications, is to evacuate the space between the glass cover tube and the receiver. The total receiver tube length of PTCs is usually from 25m to 150m.

2-2-2 Fresnel Collectors

Fresnel collectors have two variations: the Fresnel lens collector and the linear Fresnel reflector, whereas the latter relies on an array of linear mirror strips that concentrate light onto a linear receiver. The linear Fresnel collector can be imagined as a broken-up parabolic trough reflector but unlike parabolic troughs, the individual strips need not to be of parabolic shape.

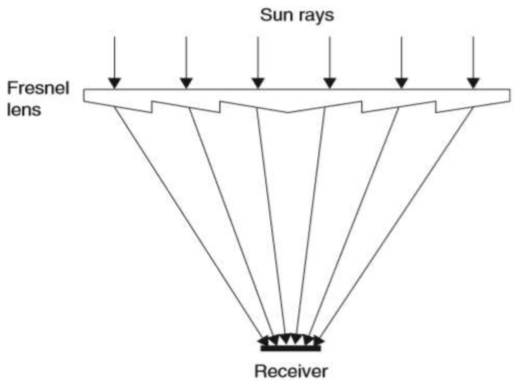


Figure2.9: Fresnel lens collector.

2-2-3 Parabolic dish reflectors (PFRs)

A parabolic dish reflector (PDR), shown is Figure2.9, is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must fully track the sun to reflect the beam into the thermal receiver. For this purpose, tracking mechanisms are used. A photograph of a collector is shown in fIgure2.10. Parabolic dish systems can achieve temperatures in excess of 1500 □. Because the receivers are distributed throughout a collector field, like parabolic troughs, they are often called distributed receiver systems. Parabolic dishes have several important advantages:

1. Because they are always pointing at the sun, they are the most efficient of all collector systems.
2. They typically have concentration ratios in the range of 600 to 2000 and thus are highly efficient at thermal energy absorption and power conversion systems.
3. They are modular collector and receiver units that can function either independently or as part of a large system dishes.

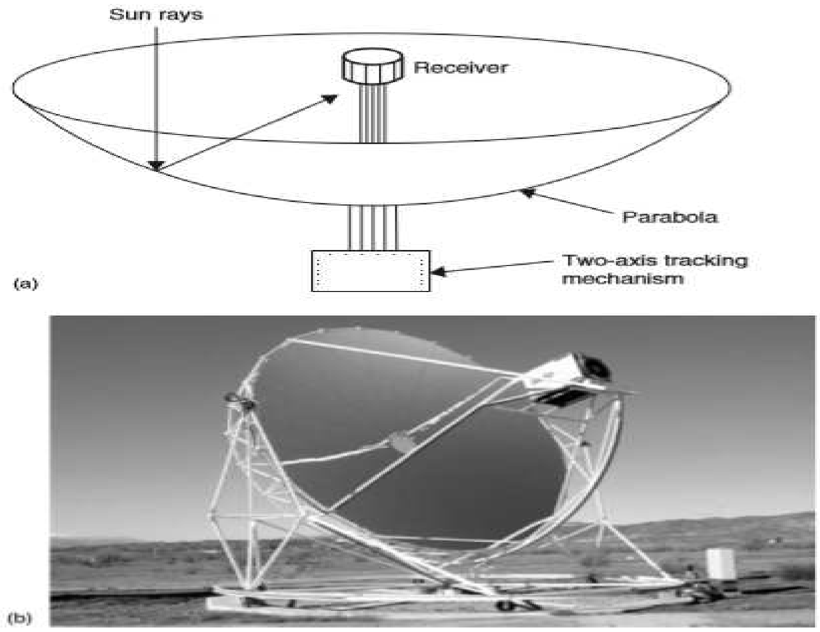


Figure2.10: (a) a schematic diagram and (b) a photograph of a Parabolic dish collector.

The main use of this type of concentrator is for parabolic dish engines. A parabolic dish engine system is an electric generator that uses sunlight instead of crude oil or coal to produce electricity. The major parts of a system are the solar dish concentrator and the power conversion unit.

2-2-4 Heliostat Field Collectors (HFCs)

For extremely high inputs of radiant energy, a multiplicity of flat mirrors, or heliostats, using altazimuth mounts can be used to reflect their incident direct solar radiation onto a common target, as shown in Figure2.12. This is called the heliostat field or central receiver collector. By using slightly concave mirror segments on the heliostats, large amounts of thermal energy can be directed into the cavity of steam generator to produce steam at high temperature and pressure.

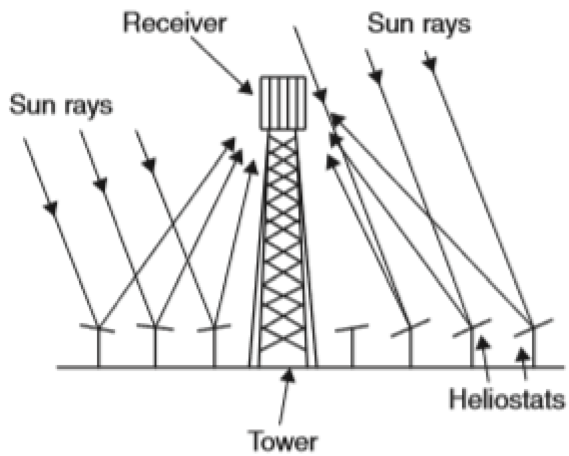


Figure2.11: Schematic of central receiver system.

The concentrated heat energy absorbed by the receiver is transferred to a circulating fluid that can be stored and later used to produce power.

The collector and receiver systems come in three general configurations. In the first, heliostats completely surround the receiver tower, and the receiver, which is cylindrical, has an exterior heat transfer surface. In the second, the heliostats are located north of the receiver tower (in the Northern Hemisphere) and the receiver has an enclosed heat transfer surface. In the third, the heliostats are located north of the receiver tower, and the receiver, which is a vertical plane, has a north-facing heat transfer surface.

CHAPTER THREE:

THERMAL ANALYSIS

AND

PERFORMANCE

A precise and detailed analysis of a solar flat plate collector is quite complicated because of the many factors involved. Efforts have been made to combine a number of the most important factors into a single equation and thus formulate a mathematical model which will describe the thermal performance of the collector in a computationally efficient manner. [6]

3-1 Thermal Analysis

Figure 3.1 shows a schematic drawing of the heat flow through a collector. To measure its thermal performance, i.e. the useful energy gain or the collector efficiency it is necessary to define step by step the singular heat flow equations in order to find the governing equations of the collector system.

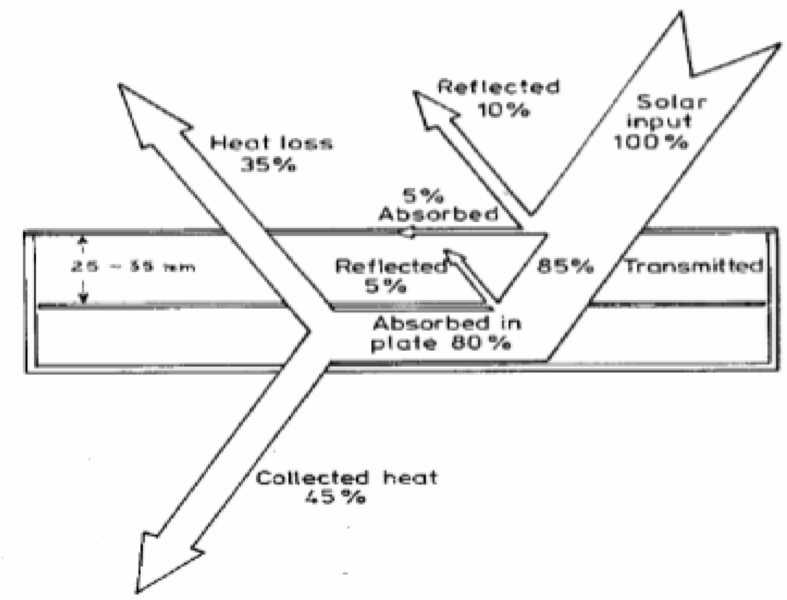


Figure 3.1 [6]: Heat flow through a Flat Plate solar collector

To model the collector shown in Figure 3.1, a number of assumptions, which simplify the problem, need to be made. These assumptions are not against the basic physical principals and are as follows:

1. The collector is in a steady state.
2. Flow through the back insulation is one dimensional.
3. Properties of materials are independent of temperature.
4. Heat flow through the cover is one dimensional.
5. Covers are opaque to infrared radiation.

If ‘I’ is the intensity of solar radiation, in W/m^2, incident on the aperture of the solar collector having a collector surface area of A,m^2, then the amount of solar radiation received by the collector is :

$$Q_i = I.A \qquad (3.1)$$

However as it is shown in Figure 3.1, a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation.

Therefore the conversion factor indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed.

Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.

Thus,

$$Q_{in} = I(\tau\alpha).A \qquad (3.2)$$

As the collector absorbs heat its temperature is getting higher than the surrounding and heat is lost to the atmosphere. The rate of heat loss (Q_{out}) from the collector to the surroundings by conduction, convection, and infrared radiation is represented by the product of the overall heat loss coefficient, U_L, times the difference between the plate temperature , T_p, and the ambiant temperature, T_a.

$$Q_{out} = U_L A(T_p - T_a) \qquad (3.3)$$

Thus, under steady-state conditions, the rate of useful heat delivered by a solar collector is equal to the rate of energy absorbed by the heat transfer fluid minus the direct or indirect heat losses from the surface to the surroundings.

This is expressed as follows:

$$Q_{us} = Q_{in} - Q_{out} = I\tau\alpha.A - U_L A(T_p - T_a) \qquad (3.4)$$

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried in the fluid passed through it, that is:

$$Q_{us} = mC_p(T_o - T_i) \qquad (3.5)$$

Equation (3.4) proves to be inconvenient because of the difficulty in defining the collector average temperature. It is convenient to define a quantity that relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity is known as « the collector heat removal factor (F_R) » and is expressed as:

$$F_R = \frac{mc_p(T_0 - T_i)}{A[I\tau\alpha - U_L(T_i - T_a)]} \qquad (3.6)$$

The maximum possible useful energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature. The actual useful energy gain Q_{us}, is found by multiplying the collector heat removal factor F_R by the maximum possible useful energy gain. This allows the rewriting of equation (3.3)

$$Q_{us} = F_R A[I\tau\alpha - U_L(T_i - T_a)] \qquad (3.7)$$

Equation (3.7) is a widely used relationship for measuring collector energy and is generally known as the « ***Hottel-Whillier-Bliss equation*** ».

3-2 Thermal Losses in a Flat-plate Collector:

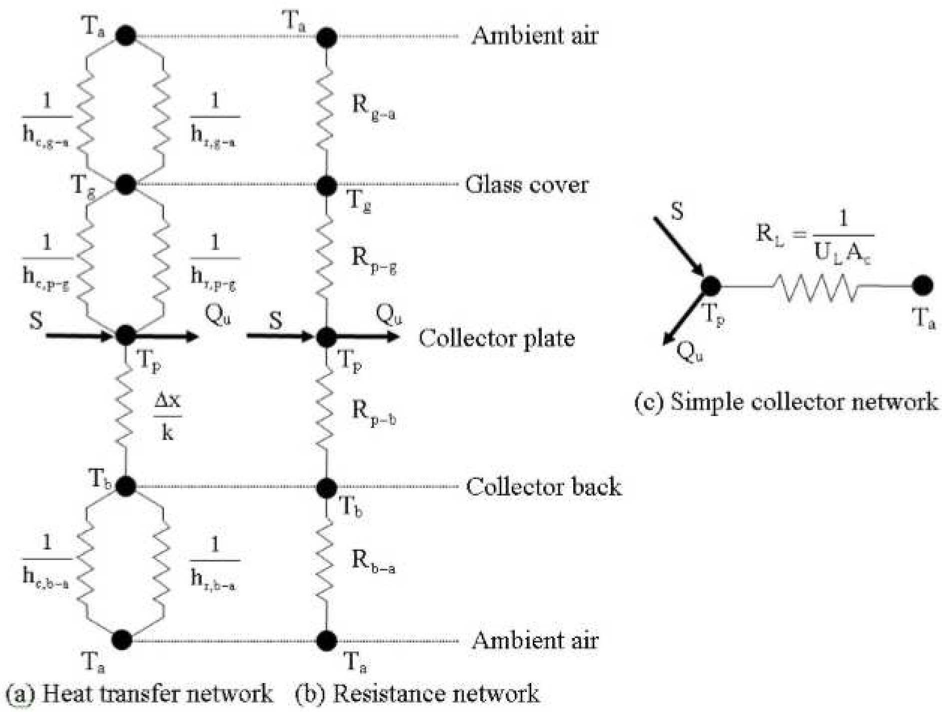


Figure 3.2: Flat plate collector thermal losses

The heat losses from the transparent cover to the ambient air are due to radiative and convective exchanges which are affected by the wind velocity, ground, surrounding condition and by long wave radiation from the sky. The overall effect is the reduction of the global emissivity coefficient, ε_g which relates the absorber plate emissivity, ε_p and the transparent cover emissivity, ε_c as follows: [7]

$$\varepsilon_g = \frac{1}{\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_g}-1} \qquad (3.8)$$

The collector overall heat loss coefficient is the sum of the top, edge and the bottom loss coefficient.

$$U_L = U_T + U_B + U_E \qquad (3.9)$$

But for a well designed collector having a very small collector perimeter to area ratio, the edge losses are almost negligible. The bottom loss coefficient, U_B derives from the thermal conductivity, K and the thikness, Δx of the bottom insulator as: [7]

$$U_B = \frac{\Delta x}{K} \qquad (3.10)$$

Thus,

$$U_L = U_T + U_B \qquad (3.11)$$

As shown in figure 3.2, under steady-state conditions, the heat transfer upward from the absorber plate to the glass cover and from the glass cover to ambient is by convection and infrared radiation. Therefore, the heat loss from absorber plate to glass cover is given by:

$$Q_{p,g} = Ah_{p,g}\left(T_p - T_a\right) + \frac{A\sigma\left(T_p^4 - T_g^4\right)}{\left(1/\varepsilon_p\right)+\left(1/\varepsilon_g\right)-1} \qquad (3.12)$$

Where

A = collector area (m^2).

$h_{p,g}$ = convection heat transfer coefficient between the absorber plate and glass cover (W/$m^2 - K$).

There are empirical equations for the top loss coefficient, U_T, a recent analysis gives the overall loss coefficient in terms of gap spacing, L and reflects the effect of the collector tilt angle: [7]

$$U_L = \left[\frac{N}{\left\{\frac{204.429}{T_p}\right\} \frac{\left\{L^3 \cos\beta\left[T_p - T_a\right]\right\}^{0.252}}{N+f} /L} + \frac{1}{h_w} \right]^{-1} + \frac{\sigma\left(T_p^2 + T_a^2\right)\left(T_p + T_a\right)}{\left[\left\{\varepsilon_p + 0.0425N\left(1-\varepsilon_p\right)\right\}\right]^{-1} + \frac{2N+f-1}{\varepsilon_g} - N} \qquad (3.13)$$

Where

$$f = \left(\frac{9}{h_w} - \frac{30}{h_w^2}\right)\left(\frac{T_s}{316.9}\right)(1 + 0.091N) \qquad (3\text{-}14)$$

3-3 Thermal Performance

A measure of a flat plate collector performance is the collector efficiency (η) defined as the ratio of the useful energy gain (Q_u) to the incident solar energy over a particular period:

$$\eta = \frac{\int Q_{us} dt}{A \int I dt} \qquad (3\text{-}15)$$

The instantaneous thermal efficiency of the collector is:

$$\eta = \frac{Q_{us}}{AI} \qquad (3\text{-}16)$$

$$\eta = \frac{F_R A[I\tau\alpha - U_L(T_i - T_a)]}{AI} \qquad (3\text{-}17)$$

$$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right) \qquad (3\text{-}17)$$

If it is assumed that F_R, τ, α, U_L are constants for a given collector and flow rate, then the efficiency is a linear function of the three parameters defining the operating condition:

Solar irradiance (I), Fluid inlet temperature (T_i) and Ambient air temperature (T_a).

Thus, the performance of a Flat-Plate collector can be approximated by measuring these three parameters in experiments. The result is a single line ($^{\Delta T}/_{I}$ - Curve) shown in Figure 3.3

It should be noted that the resulting plot will be a straight line only if conditions are such that F_R, U_L and ($\tau\alpha$) are constants. In practice, U_L is not a constant as heat losses will increase as the temperature of the collector rises further above ambient temperature (thermal conductivity of materials varies with temperature).

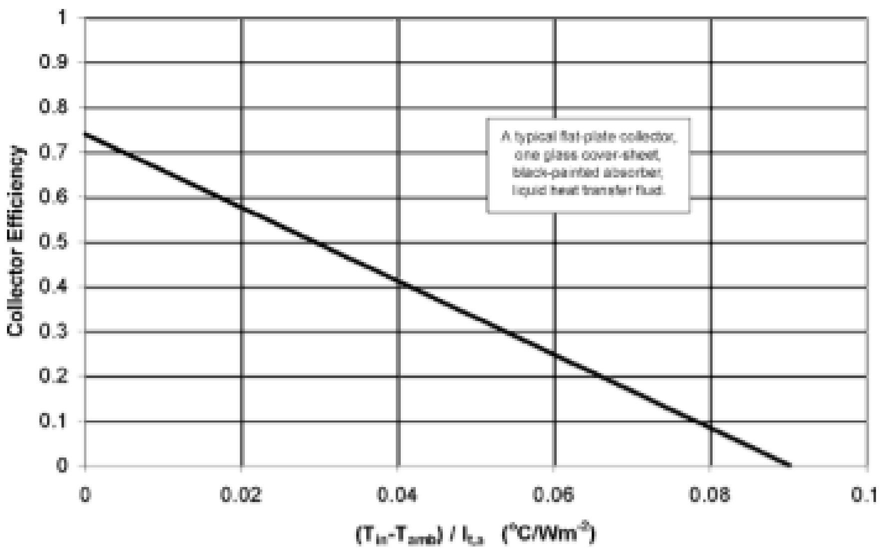


Figure 3.3: Performance of a typical flat plate collector (ambient temperature 25 C).

The collector efficiency η is plotted against$(T_i - T_a)/I$. The slope of this line $(-F_R U_L)$ represents the rate of heat loss from the collector.

There are two interesting operating points on Figure 3.3:

1) The first is the maximum collector efficiency, called the *optical efficiency*. This occurs when the fluid inlet temperature equals ambient temperature $(T_i = T_a)$. For this condition, the $\Delta T/I$ value is zero and the intercept is $F_R(\tau\alpha)$.
2) The other point of interest is the intercept with the $\Delta T/I$ axis. This point of operation can be reached when useful energy is no longer removed from the collector, a condition that can be happen if fluid flow through the collector stops (power failure). In this case, the optical energy coming in must equal the heat loss, requiring that the temperature of the absorber increases until this balance occurs. This maximum temperature difference or “stagnation temperature” is defined by this point. For well-insulated collectors or concentrating collectors the stagnation temperature can reach very high levels causing fluid boiling and, in the case of concentrating collectors, the absorber surface can melt.

CHAPTER FOUR:

PERFORMANCE IMPROVEMENTS

4-1 Introduction :

A solar air heater is a simple device to heat air by utilizing solar energy, which has many applications in drying agricultural products, such as seeds, fruits and vegetables. Also, solar air heaters are utilized for heating buildings with auxiliary heaters to save energy in winter time. Conventional solar air heaters mainly consist of glazing with an absorber plate or glazing with a duct of two parallel plates forming a passage for air flow with top plate acting as an absorber. This arrangement is insulated thermally from the back and the sides [8].

To enhance the performance of solar air heaters, efforts have been made to reduce top heat losses from absorber, increase heat transfer coefficient and increase contact area between the absorber plate and the air stream. Different modifications such as multi-pass air passage, longitudinal fins in the air passage, roughened surface of absorber plate, V-shaped corrugated absorber plate and obstacles on absorber plate, have been suggested to achieve this [8]. In this chapter we introduce some of the studies and experiments that have been done in the last ten years:

4-2 Ebru Kavak Akpinar and Fatih Koçyiğit (2010) : [10]

This study investigates experimentally the performance of a new flat plate solar air heater with several obstacles (Type1, Type 2, and Type 3) and without obstacles (Type 4).

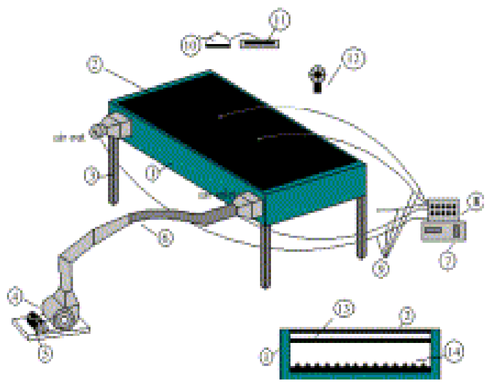


Figure4.1: Schematic view of experimental set-up.

Description of the experimental set-up:

The absorbers were made of stainless steel with black chrome selective coating. Dimension and plate thickness for all four collectors were (1.20 m× 0.7 m×0.12 m), respectively. The absorber surface (Type1, 4) which is the most important component of the collector which absorbs the sun radiation has been plated with copper plated that's been painted black. Normal window glass of 5 mm thickness was used as glazing. Single cover glass was used in all four collectors. Thermal losses through the back of the collector are mainly due to the conduction across the insulation (thickness 3 cm) and those caused by the wind and the thermal radiation of the insulation is assumed negligible.

Type 1: the triangular obstacles of 5×5 cm dimension were manufactured and the obstacles were situated on the absorber plate at 10 cm intervals with 3.5 cm distance between successive lines

Type 2: the leaf obstacles shaped of 5×5 cm dimension were situated on the absorber plate at 10 cm intervals with 3.5 cm distance between successive lines.

Type 3: the rectangular obstacles of 10×10 cm dimensions were situated at 2.5 cm intervals at a 45 □ angle on the absorber plate.

Type 4: there were no obstacles on the absorber surface.

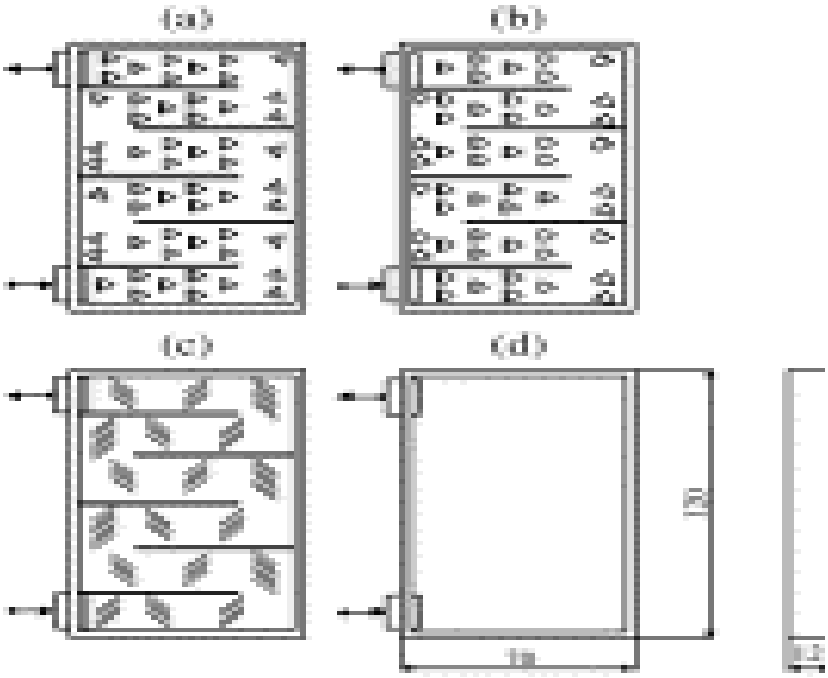


Figure4. 2: Schematic views of absorber plate: (a) with the triangular type obstacles (b) with the leaf type obstacles (c) with rectangular type obstacles (d) without obstacles.

Results and conclusions:

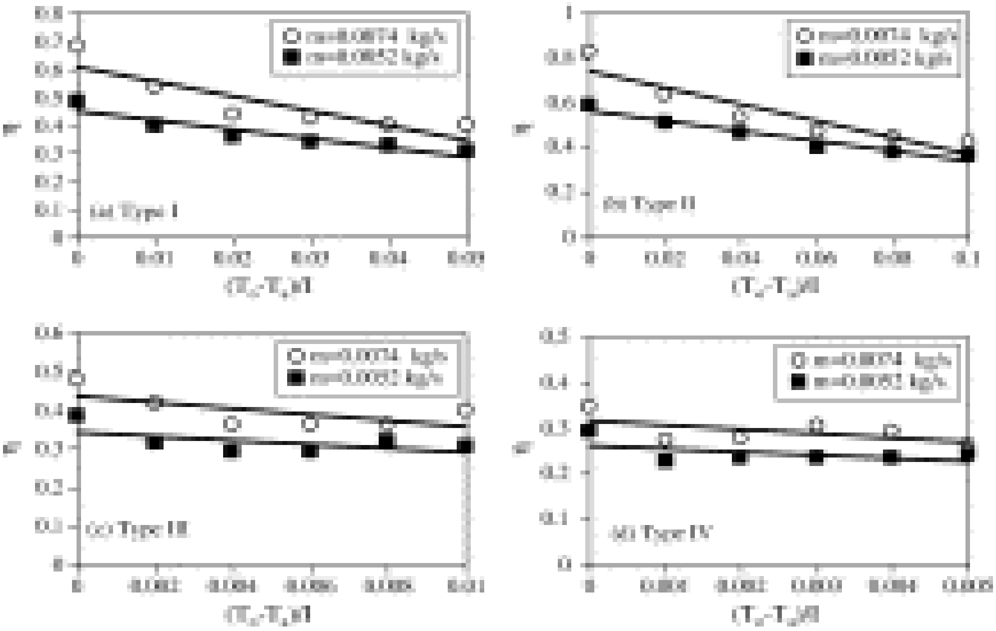


Figure 4.3: Variation of collector efficiency with the temperature parameters $(T_o - T_a)/I$ at different mass flow rates.

The following conclusions have been be derived:

The highest collector efficiency and air temperature rise were achieved by SAHs with leaf obstacles (Type 2), whereas the lowest values were obtained for the SAH without obstacles (Type 4), i.e. flat plate collector. In addition, this study has allowed showing that the use of obstacles in the air flow duct of the collector is an efficient method of adapting in air exchanger according to used needs. Test results always yield higher efficiency values for Type 2 than for Type 4 (without obstacles) flat plate collector. The obstacles ensure a good air flow over and under the absorber plates, create the turbulence, and reduce the dead zones in the collector.

4-3L.B.Y. Aldabbagh et al. (2010): [11]

This experimental study investigates the thermal performance of a single and double pass solar air heaters with steel wire mesh layers used instead of a flat absorber plate.

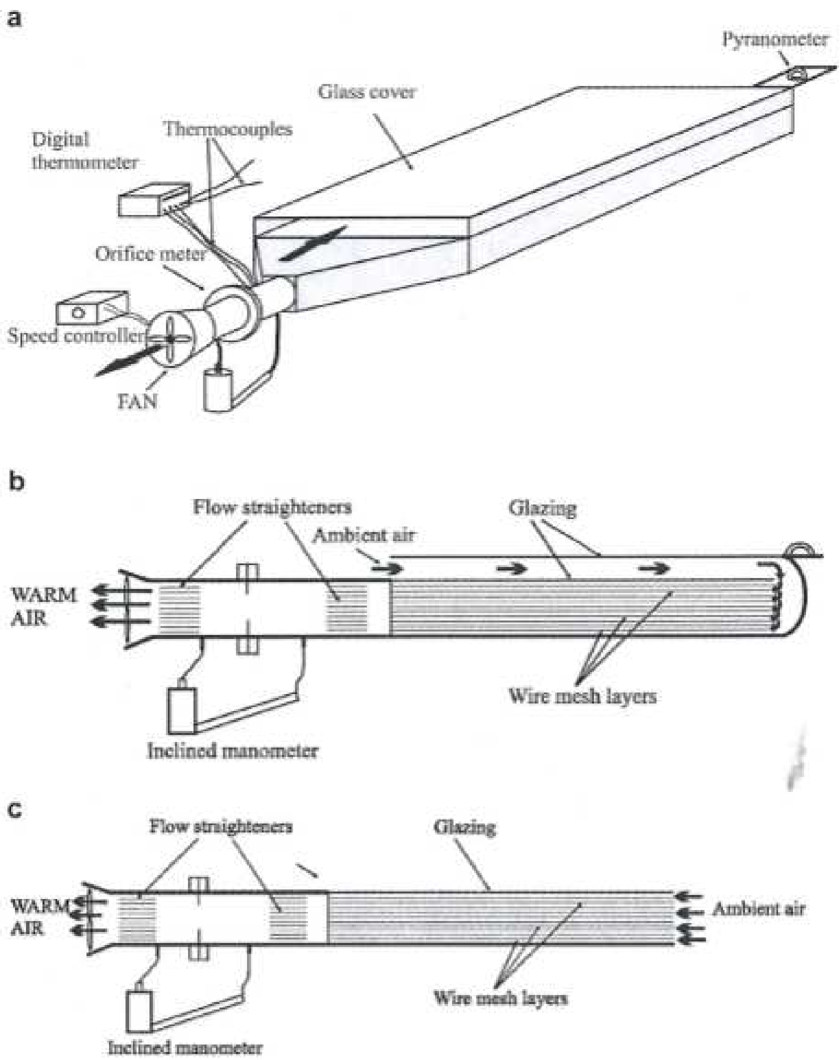


Figure 4.4: Schematic assembly of the (a) double pass SAH, (b) side view of the double SAH and (c) side view of the single pass SAH.

Description of the experimental set-up:

The length and the width of each collector were 1.5 m and 1.0 m respectively. The distance between the first glass and the second glass, h, was 5cm, whereas the distance between the second glass and the bottom of the collector was 10 cm. The single pass air collector could be achieved by removing the first glass at the top of the collector. Normal window glass of 4 mm thickness was used as glazing. Ten steel wire mesh layers, 0.2×0.2 cm in cross section opening, were fixed in the second pass duct parallel to the glazing.

The distance between each wire mesh layers were 1 cm. The wire mesh layers were painted with black before being installed into the second pass. The solar intensity of the sun does not penetrate to the bottom of the second pass of the collector due to ten wire mesh layers. In this arrangement, the tenth wire mesh layer acts as an absorber plate and therefore, no absorber plate was installed at the bottom of the collector. The porosity of the wire mesh is very high (more than 0.85). In order to get a uniform flow through the orifice meter, two flow strengtheners were made and installed inside the pipe.

Results and conclusions:

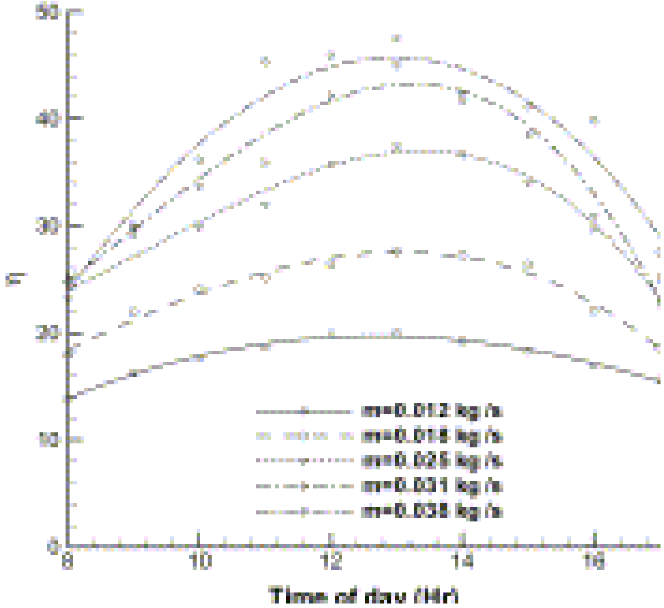


Figure4.5: Efficiency versus time for different mass flow rates-single pass collector.

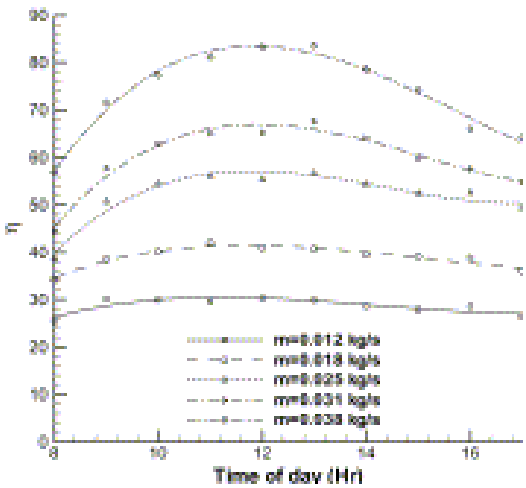


Figure4.6: Efficiency versus time for different mass flow retes-double pass collector.

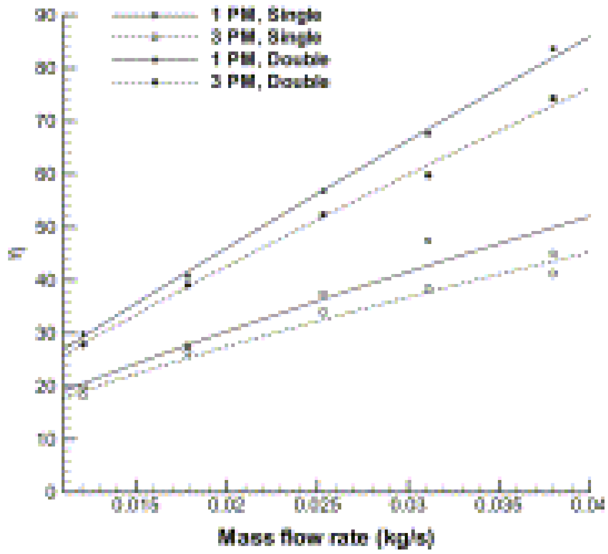


Figure 4.7: Variation of thermal efficiency for different mass flow rates.

-The results showed that a maximum efficiency of 83.65% can be obtained by using a porous media instead of an absorber plate in the double pass model proposed in this study

-For the single pass the maximum efficiency obtained was 45.93% for air mass flow rate of 0.038 kg/s.

The efficiencies were found to increase with increasing mass flow rate of the air in both cases.

4-4M.R.I. Ramadan et al. (2011): [9]

Double pass flat and v-corrugated plate air heaters were designed and investigated theoretically and experimentally in this study.

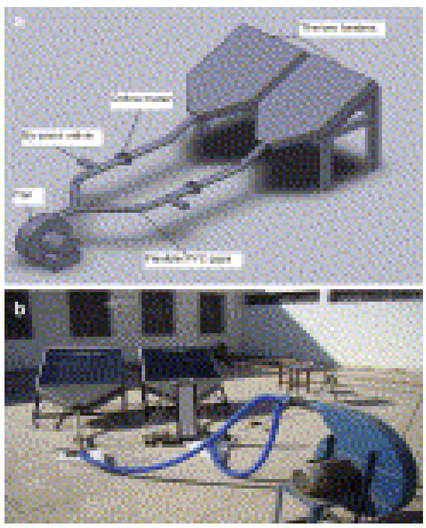
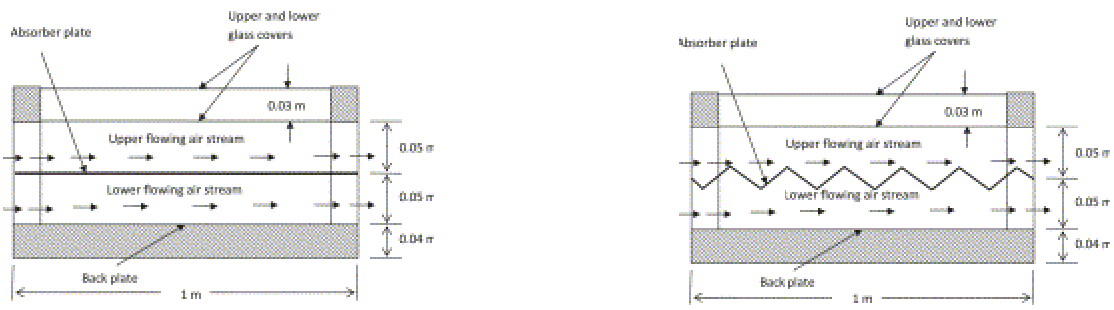


Figure4.8: (a) A schematic diagram of the experimental set-up; (b) Photograph of the experimental set-up.

Description of the constructed solar air heaters:

For the double pass flat plate solar air heater (DPFPSAH), a sheet of copper with thickness 0.001 m and $1m^2$ area was used as the absorber plate. Two sheets of ordinary glass (0.003 m thick) were used to cover the heater on order to minimize the heat losses from the top of the air heater. The gap between the two glass covers equals 0.03 m. Another sheet of galvanized iron, with thickness 0.001 m, was used as a back plate. The heater was insulated from the back and sides using foam as an insulating material with thickness 0.04 m. The absorber plate divides the gap between the lower glass cover and the back plate into two channels of 0.025 m depth.

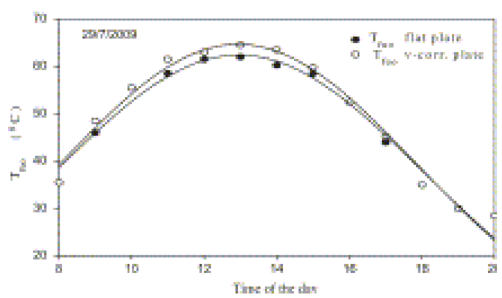
The (double pass v-corrugated plate solar air heater) DPVCPSAH was constructed with the same materials and dimensions that were used in the construction of the DPFPSAH. The only difference is that, the flat plate absorber used in the DPVCSAH was replaced by a v-corrugated plate in the PDVCSAH. The v-shape half-height e and pitch are 0.01 and 0.025m, respectively, while its angle equals 60 degree.

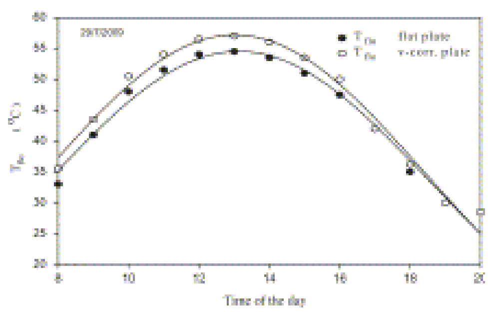


(a) (b)

Figure4.9: A schematic diagram of the double pass (a) flat plate solar air heater, (b) v-corrugated plate solar air heater.

Results and conclusions:





(a) (b)

Figure 4.10: Comparison between the measured outlet temperatures of the air flowing in the channel of the PDFPSAH and DPVCSAH on a typical day of July 2009 when m=0.0203 kg/s.

(a) Upper channel, (b) lower channel.

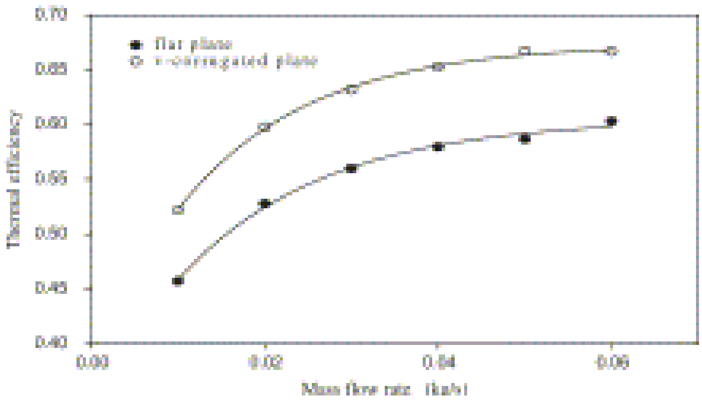


Figure4.11: Effect of mass flow rates of air on the thermal efficiency of the PDFPSAH and PDVCSAH on a typical day of July 2009.

Based on the results obtained from the experiments and theoretical models, the following conclusions have been drawn:

a) The outlet temperature of the PDVCSAH was 5% higher than that of the DPFPSAH.
b) The DPVCSAH was 11-14% more efficient than the DPFPSAH.
c) The thermal efficiencies of both systems increases with increasing mass flow until a typical value of 0.04 kg/s, beyond that, the increase in thermal efficiencies of the two systems are insignificant.

4-5S.S.Krishnananth et al. (2012) : [13]

In this work, a double pass solar air heater was fabricated and tested with energy storage system. Paraffin wax in cylindrical capsules was used as phase change energy storing material.

Experiments were conducted and performances were compared for different configurations. In each configuration, the paraffin capsules were placed in different locations.

Figure 4.12: Photograph of double pass solar air heater.

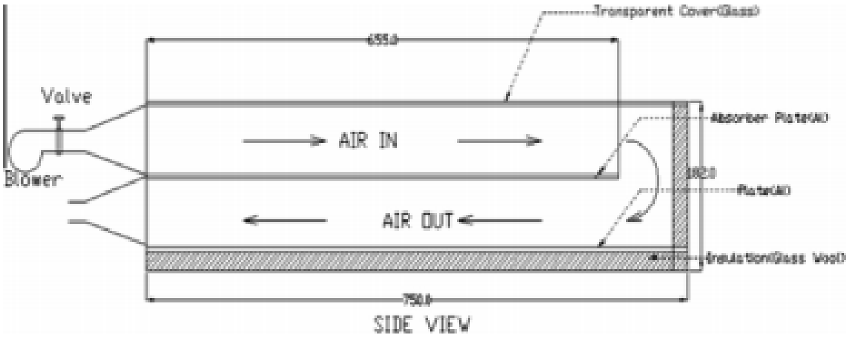


Figure 4.13: Schematic diagram for double pass solar air heater.

Description of the experimental set-up:

A double pass solar air heater of 750 mm length, 500 mm width and 182 mm height was fabricated using mild steel plate, to reduce the heat losses to the atmosphere; the collector bottom and lateral sides were insulated with 20 mm thick glass wool and to reduce convective losses, the collector top side was covered with a 4 mm glass plate. Using a blower, the air was forced through the upper channel in the double pass collector between the top glass cover and the absorber plate and then recirculated in opposite direction through the lower channel between the absorber plate and back plate.

To improve the system performance, the thermal storage system i.e. phase change material was integrated with double pass solar air heater. Paraffin waxes in the six aluminum capsules(each 4 cm diameter and 60 cm length) were used to store the excess thermal energy. The absorber plate and aluminum capsules are painted with black color to absorb maximum solar radiation. The capsules were arranged in different configurations on the absorber plate and on the back plate.

Different configurations:

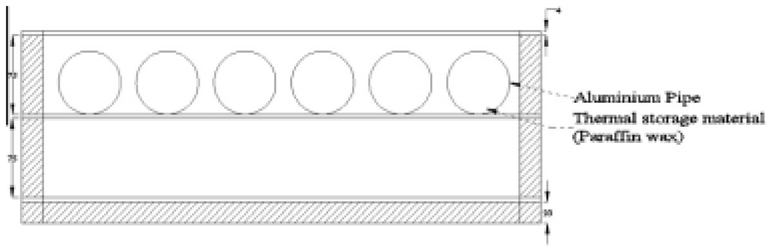


Figure 4.14: Configuration 2, capsules above the absorber plate.

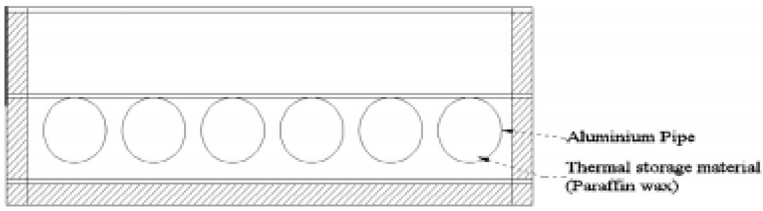


Figure 4.15: Configuration 3, capsules below the absorber plate.

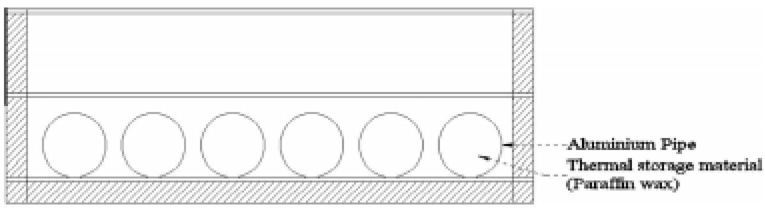


Figure 4.16: Configuration 4, capsules above the back plate.

Results and conclusions:

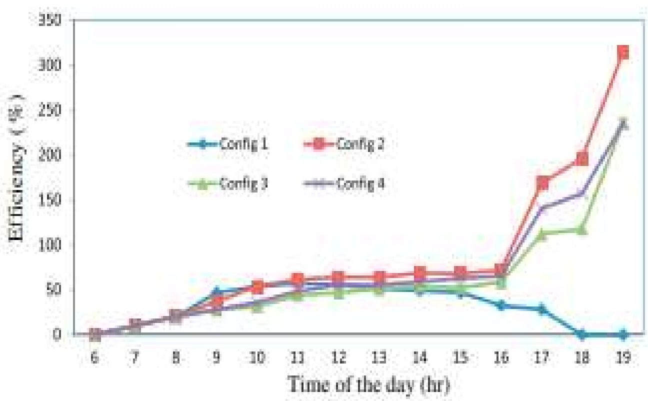


Figure 4.17: Efficiency variation.

-The solar air heater with paraffin wax as energy storage material delivers comparatively high temperature air throughout the day. The efficiency was also higher during evening hours.

- The double pass solar air heater with capsules placed on the absorber plate was the efficient one.

4-6Moukhtar Lati et al. (2015): [12]

This team fabricated a flat plate solar air collector integrated with thermal storage system; a layer of sand was used as a thermal storage system.

Description of the used collector:

The collector is of 2.5 m length, 1 m width and 0.18 m height as showed the figure 4.14, to reduce the heat losses to the atmosphere, the collector bottom and lateral sides were insulated with 0.06 m thick glass wool and to reduce convective losses, the collector top side was covered with a 0.004 m glass plate. Sand (El-Oued) was washed with distilled water then hydrochloric HCL and again with distilled water, the sand then was dried and fixed on the absorber with a matte black paint.

Figure 4.18: Photograph of the solar collector.

Results and conclusions:

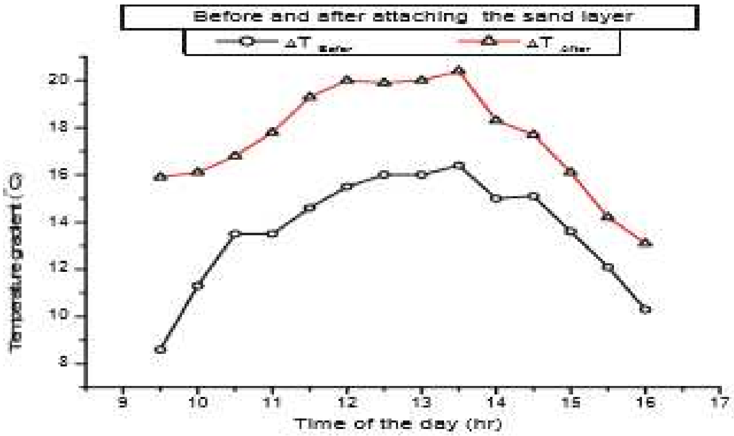


Figure4.19: Temperature gradient variation on 20 and 24 May 2014.

-The flat plate solar air collector with sand layer as energy storage material delivers comparatively high temperature air throughout the day.

4-7 Atilla G.Devecioglu et al. (2017): [14]

In this study, thermal performance of a new solar air collector with porous absorber plate was investigated. The porous surface was accomplished by laying out the copper meshing on the absorbing plate, the experimental data was obtained using two different types of collectors with smooth surface absorber plate (Type 1) and porous surface absorber plate –Type 2).

Figure 4.20: The experimental system and measuring devices.

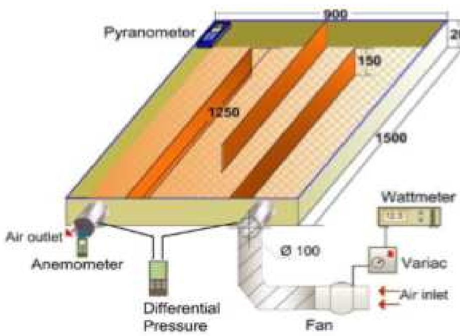


Figure4.21: A schematic view of the experimental set-up.

Description of the experimental set-up:

The dimensions of the collector are 900 × 1500 × 200 mm (width × length × height). The absorber plate is composed of copper material with a thickness of 0.30 mm. The case of the collector is manufactured with aluminum composite material. The collector was insulated with glass-wool with 50 mm thick so that the heat losses from the bottom surface of absorber plate could be reduced.

A classic single-layer glass having a thickness of 5 mm was used as glazing for the collector. There were three labyrinth-shaped guiding plates inside the collector in order to lengthen the distance of flowing air. These guiding elements were composed of copper sheets with a thickness, height and length of 0.50 m, 150 mm and 1250 mm, respectively. The inlet and outlet air ducts are circular having a diameter of 100 mm. The copper meshing wire having a width of 220 mm was laid out on the absorbing plate to obtain a porous surface. The thickness of copper wire was 0.24 mm while the dimensions of meshing were 3×3 mm.

Results and conclusions:

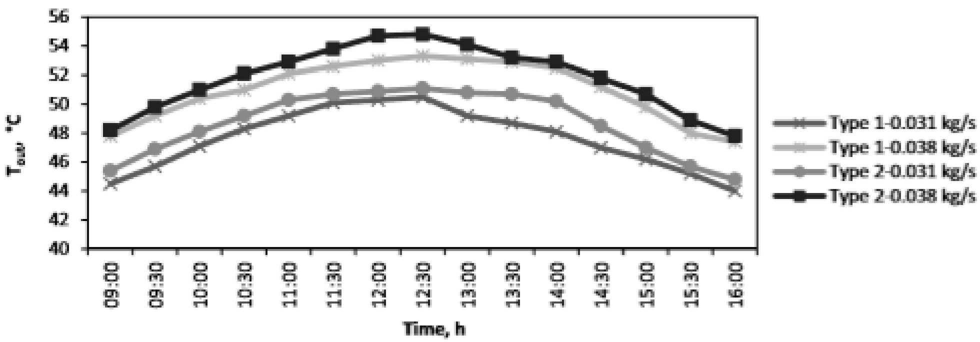


Figure4.22: The variation of temperature at the collector outlet versus time.

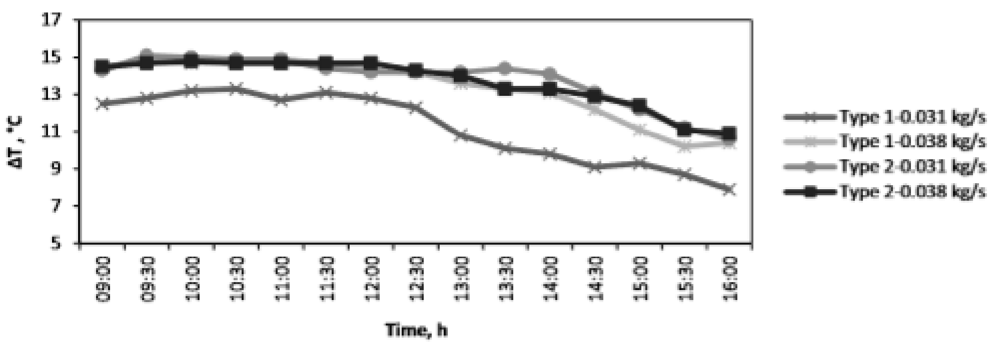


Figure 4.23: The variation of temperature difference between outlet and inlet of the collector with time.

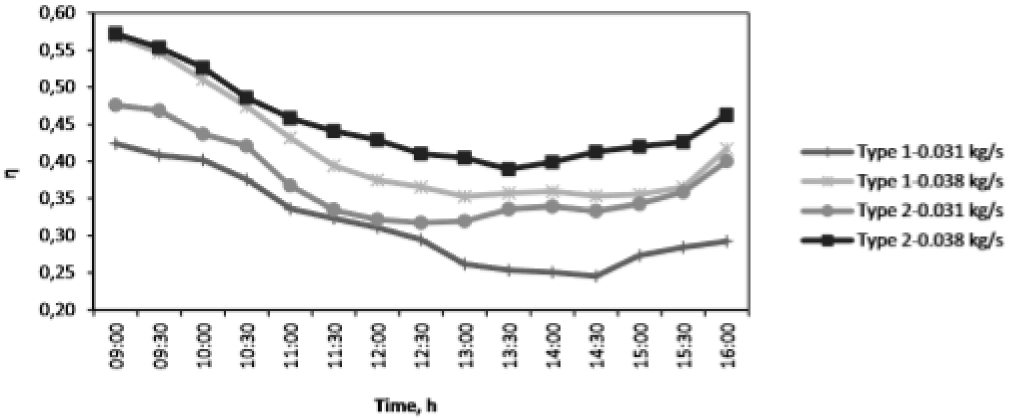


Figure 4.24: The variation of thermal efficiency of the collector with time.

Some important results can be remarked as:

- The efficiency of collector with porous surface absorber plate was determined higher compared to that with smooth surface.
- The thermal efficiency and thermo-hydraulic efficiency values were obtained as 25 % to 57% and 14% to 44%, respectively for the covered cases
- Thermal efficiency values have been increased as mass flow rate was increased. These values were also enhanced using Type-2 collector which caused the heat absorbing surface to expand;
- The increase in mass flow rate caused pressure loss through the collector to rise by 35% approximately.

CONCLUSION

Conclusion

One of the most potential applications of solar energy is the supply of hot air for drying of agricultural and heating of buildings to maintain a comfortable environment especially in the winter season. Several designs of solar air heaters have been proposed and discussed

This dissertation presents a modest contribution to the study of parameters affecting the heat exchanges in flat-plate solar air collectors and reviews some of the recent studies aiming to a better controlling of the heat losses and the heat transfer rate and thus improving the collector efficiency. Performance improvement can be achieved using diverse materials, various shapes and different dimensions and layouts. The modifications include the use of an absorber with fins attached, corrugated absorber, matrix type absorber, with packed bed, thermal energy storage systems, and different configurations, or on the hole design of the collector like double pass and double glass collectors.

All the above mentioned configurations proved to have a noticeable impact on the collector performance, thus we suggest for further constructions of collectors to apply more than one configuration at once in the same collector to maximize the efficiency.

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Abstract

Solar air heaters are extensively used in low temperature energy technology; increasing importance of renewable energy and the low thermal efficiency of conventional flat-plate solar air heaters continue to attract researchers to design more efficient solar air heaters, this dissertation is a contribution to the study of parameters affecting the heat exchanges in a flat-plate collector in which we present and review some of the recent works that aims to improve the collector efficiency. Performance improvement can be achieved using diverse materials, various shapes and different dimensions and layouts. The modifications include the use of an absorber with fins attached, corrugated absorber, matrix type absorber, with packed bed, and different configurations.

Key words: solar air heater, flat-plate collector, thermal efficiency, heat exchanges.

ملخص

تستعمل المسخنات الشمسية الهوائية بكثرة في تقنيات الطاقات ذات درجات الحرارة المنخفضة. الأهمية المتزايدة للطاقات المتجددة والفعالية المنخفضة للوا قط الشمسية الاعتيادية تواصل جذب المزيد من الباحثين لتصميم مسخن هوائي شمسي أكثر كفاءة. تمثل هذه المذكرة مساهمة في دراسة العوامل المؤثرة في التبادلات الحرارية للاقط شمسي مسطح، أين تم استعراض بعض الأعمال الحديثة التي هدفت لتحسين كفاءة اللاقط. يمكن الحصول على أداء أفضل للاقط باستعمال مواد متنوعة، أشكال و أبعاد و تركيبات مختلفة. تشمل هذه التغييرات استعمال لوح ماص موصول بزعانف، امتدادات في اللوح الماص، لوح ماص على شكل مصفوفة أسلاك، الأسرة وأنظمة تخزين الحرارة و أشكال أخرى مختلفة.

الكلمات المفتاحية :ـــ مسخن شمسي هوائي، لاقط شمسي مسطح، الكفاءة الحرارية، التبادلات الحرارية.