CHAPTER (1)

INTRODUCTION

Introduction

In today's climate of growing energy needs and increasing environmental concern, alternatives of the use of renewable and non-polluting energy sources for the use of fossil fuels have to be investigated. One such alternative is solar energy .Solar energy is quite simply the energy produced directly by the sun and collected elsewhere ,normally the earth .The sun creates it's energy through a thermonuclear process that converts about 650,000,000 tons of hydrogen to helium every second (sizman,1985).The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction(yahoo, solar energy). The electromagnetic radiation (including visible light, infrared light, and ultra-violet radiation) stream out into space in all directions.

Only a very small fraction of the total radiation produced reaches the earth. The radiation that does reach the earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy and nuclear fission and fusion .Even fossil fuels owe their origins to the sun, they were once living plant and animals whose life was dependent upon the sun.

Much of the world's required energy can be supplied directly by solar power .More still can be provided indirectly .The practicality of doing so will be examined, as well as the benefits and drawbacks. In addition the uses solar energy is currently applied to will be noted.

Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone) .The storage unit is required because of the non- constant nature of solar energy; at certain times only a very small amount of radiation will be received . At night or during heavy cloud cover, for example, the amount of energy produced by the collector will be quite small. The storage unit can hold the excess energy produced during the periods of maximum productivity, and release it when the productivity drops. In practice , a back up power supply is usually added ,too, the situations when the amount of energy required is greater than both what is being produced and what is stored in the container.

There are two ways of utilizing solar energy :(A) Photovoltaic, where solar energy is converted directly to electric energy. (B) Thermal, where solar energy is converted into heat.

Since the present study focuses on the thermal method of utilization, no more will be said about photovoltaic, and attention will be directed towards (B) only. These are three main systems of collecting and using solar thermal energy, depending on the intended application: central receiver system, evacuated tubes, and flat plate collector. In the present study attention will be focused on flat plate collectors, and specifically on the effect of surface coating on the performance of a flat-plate collector.

Flat-Plate collectors are the more commonly used type of collectors today. They are arrays of solar panels arranged in a simple manner. They can be of any size , and have an output that is directly related to a few variables including size, facing, and cleanliness . These variables affect the amount of radiation that falls on the collector. Often these collector panels have automated machinery that keeps them facing the sun. The additional energy they take in due, to the correction of facing , more than compensates for the energy needed to drive the extra machinery .

People need energy for many things, but a few general tasks consume most of the energy. These tasks include transportation heating, cooling, and generation of electricity. Solar energy can be applied to all four of these tasks with different levels of success.

A solar collector is a device for extracting and converting the energy of the sun directly into a more usable or storable form. The energy in sunlight, in the form of electromagnetic radiation, lies in from the infrared to the ultraviolet range.

The solar energy striking the earth's surface at any time depends on condition s and location on the surface , but over all it averages about (200 watts per squire meters). A typical solar thermal collector uses water as the storage medium, because it has high thermal capacity and is convenient to handle.

The direct radiation is captured using a black painted surface which absorbs the radiation and conducts it to the storage medium. Metal makes a good heat sink, and copper is best. By coating the surface with black paint or copper oxide the surface has the properties of a blackbody.

Special "selective surface" materials can be chosen to reduce heat loss due to emission. As it heats up the collector will itself start to radiate heat back into space, which reduces its efficiency. This is countered in two ways. First, a glass plate is placed above the collector plate which will trap the radiated heat within the air space below it. This exploits the

so-called green house effect , which is in this case a property of the glass, it readily transmits solar radiation in the visible and ultraviolet spectrum , but does not transmit the lower frequency infrared reradiation very well .The plate is also insulated below to prevent losses by radiation to whatever is below the collector(Sodha,2002) . The second way in which is efficiency improved is by cooling the collector plate this is readily done by ensuring that the water is circulated through it. The water carries away the absorbed heat so cooling the plate. The water, maybe used to heat a building directly. The temperature differential across an efficient solar collector is usually only 10 or 20 degrees °C
a large differential may seem impressive, but is in fact an indication of a less efficient design (Sodha, 2002).

Chapter II

Literature Review

2-1: Solar Radiation Flux (Insolation)

Matter emits incoherent electromagnetic radiation usually referred to as thermal or heat radiation.

In equation (2-1) below M_b depends on temperature and materials properties, In particular on surface properties. However, by laws of thermodynamics there exists an upper limit M_b of radiosity which is independent of the material and dependent solely upon the absolute temperature T,

$$M_b = \sigma T^4 \qquad (2\text{-}1)$$

The universal factor (σ) for emission, the Stefan Boltz'man constant, contains fundamental constants of nature (Sizman.1985).

$$\sigma = \frac{2\pi^5 k^4}{15 c^2 h^3} = 5.6705 \times 10^{-8} Wm^{-2} K^{-4} \qquad (2\text{-}2)$$

Where:

k : Boltz'man constant equals 1.38×10^{-23} (w s/K);

c : vacuum light velocity equals 2.998×10^{8} (m /s);

M_b : Radiation energy (radiosity);

h: Blank's constant equal 6.626×10^{-34} (w s).

Generally, radiosity depends on material properties and hence is lower than the upper limit M_b .

$$M = \varepsilon M_b = \sigma\varepsilon T^4 \qquad (2\text{-}3)$$

Where (ε) is the emittance, averaged over the spectral and angular distribution of emitted radiation of the body at temperature T. the limiting case of maximum emittance, $\varepsilon = 1$, also implies maximum absorbance, $\alpha = 1$ is consequence of Kirschoff's law of equivalence of emittance and absorbance. Hence, a body with highest emittance $\varepsilon = 1$ is at the same time the best absorber possible, $\alpha = 1$; any incident radiation becomes completely absorbed. The body appears to be perfectly black, for that reason radiosity with $\varepsilon = 1$, is labelled black body radiation (Sizman, 1985).

(2-2)Black body radiation:-

The amount of heat radiation emitted by a body depends on three variables:-

(a) The surface area of the body (b) The type of surface, and (c) the temperature of the body. We consider first "the type of surface".

Experience shows that black surfaces are the best emitters and absorbers of radiation at a given temperature, and that a matt black surface is better than a shiny one .An ideal absorber of heat would be one that absorbs all the radiation that falls on it, and from Kirchoff's law also emits the maximum amount of radiation possible for that area at that temperature. Such a body is known as a "black body" and the radiation emitted by it as "black body radiation". Since it comes form a hole it is some times called "cavity radiation", since the hole is a perfect absorber it will emit black body radiation and will emit more energy per second than any other surface of the same area at that temperature.

The standard laboratory black body was designed by Lummer and Pring Sheim in 1899 to define a scale for black body radiation (Sizman, 1985).

The energy emitted by a black body may be measured over a range of different temperatures and in many different regions of the spectrum. The results obtained can be summarized as follows (Keith, 1996). The total energy (E), emitted by a black body per unit area of surface per second is proportional to the fourth power of the body's absolute temperature T. This is known as Stefan's law and can be written as

$$E = \sigma T^{4} \qquad (2\text{-}4)$$

Where (σ) is known as Stefan's constant and can be shown to have a value of $5.7 \times 10^{-8} wm^{2} k^{-4}$.

If the body is surrounding by an enclosure at temperature $T_{\circ}$ there will be an exchange of heat energy between the enclosure and the body, since both will radiate heat .The net loss of energy by the body per unit area will be.

$$E = \sigma (T^{4} - T_{\circ}^{4}) \qquad (2\text{-}5)$$

For a body of surface area (A) the total energy emitted per second will be.

$$E_{t} = \sigma A T^{4} \qquad (2\text{-}6)$$

If the body is not a black body, then the energy it emits at any temperature will be less than emitted by a back body of similar surface area at the same temperature. The emission equation is modified as follows.

$$E_t = \varepsilon\sigma A T^4 \quad (2\text{-}7)$$

Where (**ε**), the emissivity of the body, is always less than unity (Sizman, 1985).

In applying this equation, it is important to realize the difference between its basis and the basis of Newton's law of cooling. Stefan's law applies to loss of energy by radiation, while Newton's applies to loss of energy by convection and conduction. Both laws are found to hold for temperature differences of hundreds of degrees (Voigt, 1988).

(2-3) The Solar constant:-

Assuming the sun to be a spherical black body emitter, its radiation flux is (ϕ_S):

$$\phi_s = 4\pi R_s{}^2 \sigma T_s^4 \quad \text{Or} \quad \phi_s = 4\pi R_s^2 M_s \quad (2\text{-}8)$$

$$R_s = 6.96\times 10^8$$

Where R_s is the sun's radius and T_s its surface temperature (photosphere temperature). By consequence of energy conservation, this flux passes through any imaginary external spherical surface concentric with the sun. In particular ϕ_s passes through a surface of radius D_{ES} , the distance between earth and sun, D_{ES} =1.495 x 10^{11} m. The flux density observed at this distance is called the "Earth's solar constant" E_{SC} .

$$\phi_s = 4\pi Rs^2 M_S = 4\pi D_{ES}^2 E_{SC} \quad (2\text{-}9)$$

The solar constant, E_{SC}, is directly accessible to measurement. Therefore, M_s and T_s can be calculated.

$$M_S = \frac{E_{SC}}{f_S} \quad \text{And} \quad T_s = \left(\frac{E_{SC}}{\sigma f_s}\right)^{\frac{1}{4}} \qquad (2\text{-}10)$$

The ratio $f_s = (\frac{R_S}{D_{Es}})^2 = 1.165 \times 10^{-5}$

Is an important number in sun-earth astronomy. The numerical value of E_{sc}, at present, accepted as most reliable is

$E_{sc} = 1.367 \pm 0.1 wm^{2}$ (Sizman, 1985), Where E_{sc} is a solar constant.

(2-4) Sun-Earth Relation

(2-4-1) Basic Geometry:

The Earth is a part of the solar system, and it is moving around the sun as well as it is rotating about its own axis. The position of different locations on the earth, as a result of these motions, with respect to sun, is changing constantly. This implies that the amount of radiation received at any location on earth is varying continuously.

In order to calculate the solar flux and its nature, it is necessary to understand the motion of the earth around the sun and define the parameters to describe it (Sodha, 2002).

As a result of the revolution of the earth around the sun, and the rotation or spinning of the earth about its axis the apparent position of the sun is constantly changing in the sky .This apparent motion of the sun determines the amount and nature of solar energy incident at any location at different times of the day and on different days of the year. The earth revolves in an elliptical orbit having semi-major of 1.522 x 10^8 *Km*, and semi-minor axes of $1.4968 \times 10^8\ Km$, with the sun at one focus of the ellipse (fig.2.1).

The period of revolution is defined as one year. The earth is nearest to the sun on January, 3rd, (perihelion), and at its greatest distances on July, 5th, (aphelion). The plane containing the earth's elliptical orbit is called the ecliptic plane (Kanpal, 1999).

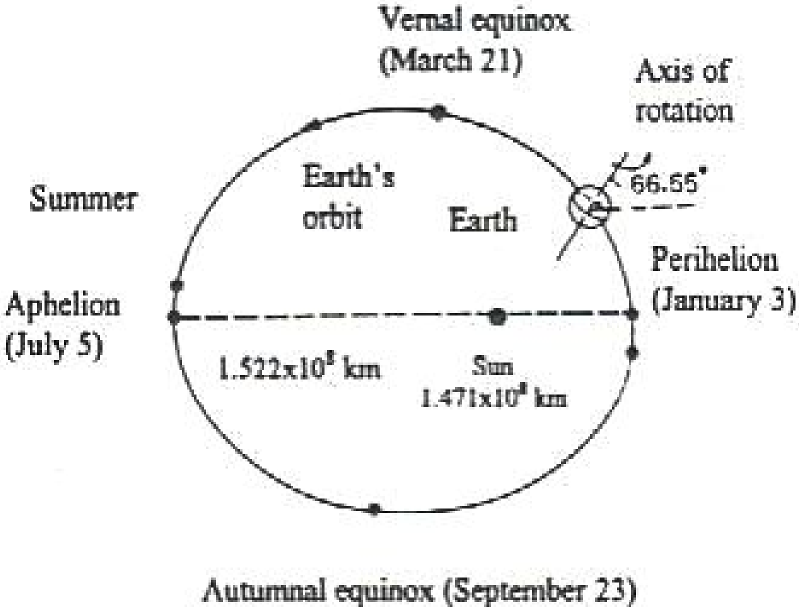


Fig (2-1) sun –earth geometry

The earth is also rotating about its axis which is tilted at 23.45° with respect to its ecliptic plane about the sun, it completes one revolution in about 24 hours. Solar radiation strikes the earth's northern hemisphere more directly near aphelion consign summer condition during that part of the year. At the same time, solar radiations strike the earth's southern hemisphere more obliquely and cause winter there. As a result, major seasons in northern and the southern hemispheres are reversed. The equinoxes are dates on which the earth–sun vector lies in the equatorial plane which is defined as the plane containing the equator. Spring equinox occurs on March 21 and autumn equinox occurs on September 23 (Kanpal, 1999).

(2-4-2) Solar declination:-

The earth sun vector moves in the ecliptic plane; the angle between the earth-sun vector and the equatorial plane is called the solar declination angle, δ . By convention, δ is considered positive when the earth-sun vector points northward relative to the equatorial plane –the declination δ varies from -23.45° on December 22 (the winter solstice in northern hemisphere) to 23.45 on June22 (the summer solstice) the solar declination can be calculated by the relation (Soldha, 2002).

$$\delta = 23.45 \sin\left[360\left(284 + n\right)\right] \Big/ 365 \qquad (2\text{-}11)$$

Where (n) is the day of the year (= 1, for January 1^{st}).

(2-4-3) Solar Azimuth, Altitude and Zenith angels:-

The sun's position is usually specified in terms of the solar azimuth angle, a_{sun}, and the solar altitude angle, α, (fig 2.2) the solar altitude angle measures the sun's angular distance from the horizon, and the azimuth angle measures the sun's angular distance in the horizontal plane from the south. Azimuth angles have a singe convention; it is considered positive to the east of south and negative to the west of south (Kandpal, 1999).

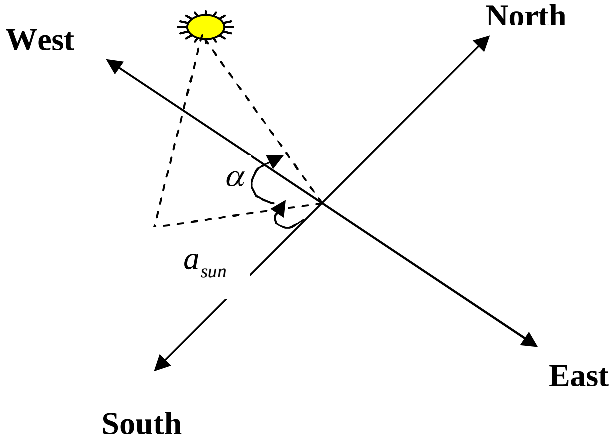


Fig (2-2) Solar Altitude and Azimuth Angles

The solar zenith angle, θ_Z, is the sun's angular distance from the zenith (the point directly over head). Thus, α and θ_Z are complementary angles, i.e.

$$\alpha + \theta_Z = 90° \qquad (2\text{-}12)$$

(2-4-4) Solar Time and Standard Time:

Rotation of the earth about its axis causes the day-night cycle on earth and is also responsible for the apparent diurnal motion of the sun. Solar time is based on the apparent angular motion of the sun across the sky. Solar noon is the time when the sun a crosses the local meridian which is the plane formed by projecting a north–south longitude line through the location out into space from the earth's center. A solar day is defined as the interval of time between two successive occasions when the sun crosses the local meridian. Because of the earth's forward movement in its orbit during this interval, the time required for one full rotation of the earth is less than a solar day by about four minutes (Kandpal, 1999).

The solar day as defined above varies-in length through the year. This variation is due to two factors (i) the earth's axis is titled with respect to the ecliptic plane, and (ii) the sweeps out unequal areas on the ecliptic plane during affixed time and it depends upon the earth's position in its elliptic orbit. Consequently, standard time (which is uniform time and is observed from a clock) and solar time differ. Solar time is related to standard time by (Sodha, 2002).

$$\text{Solar time} = \text{stander time} + 4(L_{St} + L_{loc}) + E \qquad (2\text{-}13)$$

Where (E) the equation of time in minutes and takes into account the minor perturbation in the rotational and orbital motion of earth (L_{st}) is the standard meridian for the local time zone and (L_{loc}) is the longitude of the location. (E) May be calculated from: (Kandpal, 1999),

$$E = 9.87 \sin 2\beta - 7.23 \cos \beta - 1.5 \sin \beta \qquad (2\text{-}14)$$

β = [360(n-81)]/364 (2-15)

Once again (n) is the day of year.

(2-4-5) Solar Hour Angle:

Hour angle (ω) is a measure of the angular displacement of the sun east or west of the local meridian due to relation of the earth on its axis at 15º is per hour. It is used extensively to the express solar time as it is directly related to the sun's position in the sky. The solar hour angle is measured from solar noon and is positive before and negative after solar noon. For example, at 8a.m solar time, the solar hour angle is +60° where for 4p.m solar time it would be -60°.

(2-5) Availability of Solar Radiation on an Inclined Surface:

The total solar radiation incident consists of (i)-beam solar radiation (ii) - diffuse solar radiation and (iii) - solar radiation reflected from the ground and the surroundings normally the beam radian (I_b) and diffuse radiation (I_d) on a horizontal surface are recorded .In the case of non availability of dates for beam and diffuse radiation, the following expression for beam and diffuse radian on the horizontal surface can be used:

$$I_d = \frac{1}{3}\left[I_{ext} - I_N\right] \cos \theta_z \qquad (2\text{-}17)$$

Where;

I_{ext} = The intensity of extraterrestrial radiation.

I_N = The intensity of beam radiation.

After knowing beam and diffuse radiation on horizontal surface, Liu and Jordan (1962) have given a formula to evaluate total radiation on a surface of arbitrary orientation (Sodha, 2002)

$$I_T = I_b R_b + I_d R_d + \rho R_r \left(I_b + I_d \right) \qquad (2\text{-}18)$$

Where R_b , R_d and R_{dr} are known as conversion factors for beam, diffuse and reflected components respectively and ρ is the reflection coefficient of the ground (=0.2and 0.6 for ordinary and snow covered ground respectively) .The expression for these are as follow.

I. R_b it is defined as the ratio of flux of beam radiation incident on an inclined surface to that on horizontal surface (Kandpal, 1999).

The flux of beam radiation incident on horizontal surface (I_b) is given by.

$$I_b = I_N \, \mathrm{Cos}\, \theta_Z \qquad (2\text{-}19)$$

And that on an inclined surface (I_b') is

$$I_b' = I_N \cos \theta_i \qquad (2\text{-}20)$$

Where θ_Z and θ_i are the angles of incidence on the horizontal and inclined surfaces, respectively, and I_N is the intensity of beam radiation. Now, R_b for beam radiation can be obtained as.

$$R_b = \frac{I'_b}{I_b} = \frac{\cos\,\theta_i}{\cos\,\theta_Z} \qquad (2\text{-}21)$$

Depending on the orientation of inclined surface, the expression for cos θ_i and $\cos\theta_Z$ can be written from equation (2-22) and (2-23) respectively (Kandpal, 1999).

$$\begin{aligned}&\cos\theta i = (\cos\phi\cos\beta + \cos\beta\cos\gamma\sin\phi)\cos\delta\cos\omega\\&+\cos\delta\sin\omega\sin\beta\sin\gamma +\\&\sin\delta(\sin\phi\cos\beta - \cos\phi\cos\gamma\sin\beta)\end{aligned}$$

(2-22)

And equation

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\delta\sin\phi \qquad (2\text{-}23)$$

The variation of R_b with nth days of the year for different latitude, inclination hour angles. The convection factor for radiation has significant effect at higher latitudes and low value of (n). Also R_b depends significantly at higher inclination of the plane (β) and becomes less significant at lower value of (β) .The maximum value of R_b is observed at higher β and low value of n as per expectation-similar effect has been observed for hour angle, however R_b tends to minimum value at higher (n) irrespective of any value at ω which is in accordance with motion of sun at an early morning or at late evening (Sodha, 2002).

R_d : It is the ratio of the flux at diffuse radiation falling on the tilted surface to that on the horizontal surface.

This conversion factor depends on the distribution of diffuse radiation over the sky and on the portion of sky seen by surface. But satisfactory method of estimating the distribution of diffuse radiation over the sky is yet to be found. It is, however, widely accepted that sky is an isotropic source of diffuse radiation. If (1+cosβ)/2 be the radiation shape factor for a tilted surface with respect to sky, then (Kandpal, 1999).

$$R_d = \frac{1 + \cos \beta}{2} \tag{2-24}$$

R_r : The reflected component comes mainly from the ground and other surrounding objects. If the considered reflected radiation is opposite to that in the above case.

$$R_r = \rho' \left(\frac{1 - \cos \beta}{2} \right) \tag{2-25}$$

Where ρ' is the reflection coefficient of the ground. (O.2 and o.6 for ordinary and snow covered ground, respectively). (Kandpal, 1999).

(2-6) Heat Transfer: Concepts and Definition:-

The transfer of heat energy occurs as a result of a driving force called temperature difference. Heat Transfer is of great importance in modern technology and therefore the understanding of its basic principles and practical application is of vital importance. In this section, some of elementary fundamentals of heat transfer have been reviewed. Heat is transferred by conduction, convection or thermal radiation. These modes of heat transfer differ profoundly in nature and governed by different laws (Kandpal, 1999).

(2-6-1) Conductive Heat Transfer:-

Heat transfer by conduction takes place between bodies or particles of bodies that are in direct contact and at different temperature. Heat conduction is a molecular process, that is, heat is transferred from molecule to molecule and there occurs negligible movement of particles of the body. Heat conduction may be through solids, liquids and gases. The phenomenon of heat conduction is a process of propagation of energy between the particles of body which are in direct contact and have different temperature (Kandpal, 1999).

Conduction is the mode of heat transfer in which the transfer of energy takes place at a molecular scale. As molecules attain thermal energy, they vibrate at their respective location, but there is no physical movement of the material .Conductive heat transfer through a system describes by Fourier's law for heat conduction, thus,

$$q_X = \frac{-kAdT}{dx} \qquad (2\text{-}26)$$

Where

q_X = rate of heat flow in x direction by conduction;

k = thermal conductivity ($Wm^{-1}K^{\circ -1}$);

A = area through which heat flows (m^2);
T = temperature (k°);
X = length variable (m);

(2-6-2) Fourier's law:-

The basic equation for steady state heat conduction is known as Fourier's equation. According to this, the quantity of heat (dQ), passing through an isothermal surface (dA), per time interval (dt) is proportional to the temperature gradient ($\frac{\partial t}{\partial n}$) and mathematically can be expressed as.

$$dQ = -K \frac{\partial T}{\partial n} dAdt \qquad (2\text{-}27)$$

The proportionality factor (K) in equation (2-27) is a physical property of the substance, which defines the ability of substance to conduct heat and is called the thermal conductivity. The heat flux $q^{\cdot}$, defined as the rate of heat flow per unit area and unit time of the isothermal surface, is given by:

$$q^{\cdot} = -K \frac{\partial T}{\partial n} \quad \text{(w)} \qquad (2\text{-}28)$$

The direction of heat flux $q^{\cdot}$ (w) is normal to the surface and is positive in the direction of decreasing temperature, which explains the negative sign on the right hand side of equation(2-28) (Sodha, 2002).

(2-6-3) Thermal Conductivity:-

As already stated, thermal conductivity is a physical property of a substance. The values of thermal conductivity of a few commonly used materials are given in appendix.

Thermal conductivity of gases, liquids and solids depends on temperature. Experimental studies have shown that for many materials the dependence of thermal conductivity on temperature can be assumed to be linear.

$$K = K_{\circ}[1 + \beta (T - T_{\circ})] \qquad (2\text{-}29)$$

Where:

$K_{\circ}$ = is the thermal conductivity at temperature $T_{\circ}$.

β = is a constant for the material.

In general, an increase in temperature causes the conductivity of a gas to increase ($+\beta$) and conductivity of a solid or liquid to decrease ($-\beta$). However, there are some exceptions of this generalization.

Thermal conductivity is greatly influenced by moisture content of the substance. In general, an increase in temperature causes the conductivity of a gas to increase (positive β)and conductivity of a solid experimental studies have show that the thermal conductivity increases substantially with an increase in moisture content (Kandpal, 1999).

(2-6-4) Convection Heat Transfer:-

Convection is the process in which heat is carried from place to place by the bulk movement of a fluid (Johnson, 1995).Convection is the transfer of heat to or from a moving fluid. The rate of heat transfer is expressed by Newton's law of cooling, which accounts for the over all affect of convection;

$$q = hA(T_p - T_a) \qquad (2\text{-}30)$$

Where

h = convection heat transfer coefficient (w $m^{-2} K^{-1}$°);

A = area of collector (m^2);

T_P = plate surface temperature (°K);

T_a = ambient temperature (°K);

The convective heat transfer coefficient usually calculated from dimension less parameters, Nusselt number, Nu the Raleigh number, R_a the prendtl Number, P_r , Reynolds number Re and the Grashof number,Gr, (Sodha, 2002).

$$\mathrm{Nu}=\frac{h'L}{k} \qquad \text{(2-30a)}$$

$$R_a = gB'\Delta TL^3 \big/ \upsilon\alpha \qquad \text{(2-30b)}$$

$$P_r=\frac{\upsilon}{\alpha} \qquad \text{(2-30c)}$$

$$R_e = P_r L \big/ \upsilon \qquad \text{(2-30d)}$$

$$G_r = gB'\Delta TL^3 / \upsilon^2 \qquad \text{(2-30f)}$$

Where

h= heat transfer coefficient ($wm^{-2}k^{-\circ}$).

L =plate spacing (m).

K= thermal conductivity (w/mk°).

g=gravitational constant ($9.8\ m/s^2$).

β' =volumetric coefficient at expansion (For ideal gas $\beta' = 1/T$)

ΔT=temperature difference between plates (K°);

υ=kinematics viscosity (m^2/s);

α =thermal diffusivity (m^2/s);

$\rho =$ Fluid density (kg/m^3);

Nusselet number for tilt angle from o to 75° can be calculated from the following relation ship (Sodha, 2002).

$$[\, N_u = 1 + [[1 - 1708 \big/ R_a \cos \beta \;]$$

$$1 - (\; \sin 1.8\beta)^{1.6}(1708 \big/ Ra \cos\beta)\} + [(Ra\cos\beta \big/ 5830)^{1/3} - 1]\;] \quad (2\text{-}31)$$

(2-6-5) Radiative Heat transfer:-

Radiation is the process in which energy is transferred by means of electromagnetic waves (Johnson, 1995).

The special distribution of radiation from a black body can be

$$E_\lambda = \frac{C_1}{\lambda^2 (\ell^{C_2 \lambda T} - 1)} \qquad (2\text{-}32)$$

Predicted by using plank's law;

Where

$C_1 = 2\pi h C_\circ^2 = 3.74 * 10^{-16}\, wm^2$;

$C_2 = h\, C_\circ \big/ K = 0.014 \quad mK$;

$C_\circ$ = speed of light in vacuum;

λ =wave length;

$\lambda_{\max}$ =2987.8 by wine's law;

From Planck's law, the total energy emitted by a black body is

$$E_b = \int_0^\infty E_{\lambda b}\, d\lambda = \sigma T^4 \qquad (2\text{-}33)$$

Where σ is Stefan-Boltzman constant and is equal to $(5.6696*10^{-8}(w/m^2K^4))$

Kirchoff reach to important general conclusion about surface properties, namely (Sodha, 2002);

$$\alpha_\lambda = \varepsilon_\lambda$$

Where;

α_λ =monochromatic absorptance and ε_λ is monochromatic emittance.

It follows that the heat flow from aerial body of emittance, ε, area A and absolute temperature T is.

$$Q_t = \varepsilon\sigma AT^4 \qquad (2\text{-}34)$$

For radiation between t finite parallel plates at temperature T_1 and T_2 defined by ε_1 and ε_2 heat transfer is (Sodha, 2002)

$$Q = \sigma A(T_2^4 - T_1^4)/(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2}) - 1 \qquad (2\text{-}35)$$

(2-7) Type of Collectors:-

There are three types of collectors.

(2-7-1)Focusing collectors:-

Focusing collectors are essentially flat plate collectors with optical devices arranged to maximize the radiation falling on the focus of the collectors. These are currently used only in a few scattered areas. Solar furnaces are examples of this type of collectors (Kandpal, 1999). Although they can produce for greater amounts of energy at a single point than the flat- plate collectors can they lose some of the radiation that flat plane panels don't.

Radiation reflected off the ground of the ground will be used by flat-plane panels but usually will be ignored by focusing collectors (in snow covered regions, this reflected radiation can be significant) (Yahoo, solar energy). One other problem with focusing collectors in general is due to temperature. The fragile silicon components that absorb the incoming radiation lose efficiency at light temperature, and if they get too hot they can even be permanently damaged. The focusing collectors by their very nature can create much higher temperatures and need more safeguards to protect their silicon components (Yahoo, solar energy).

(2-7-2) **Passive collectors**: -

Passive collectors are completely different from the other two types of collectors. The passive collectors absorb radiation convert it to heat naturally, without being designed and built, to do so. All objects have this property to some extent, but only some objects (like walls) will be able to produce enough heat to make work while .often their natural ability to convert radiation to heat is enhanced in some way or anther (by being painted) black for example, and a system for transferring the heat to a different location is generally added (Sodha, 2002).

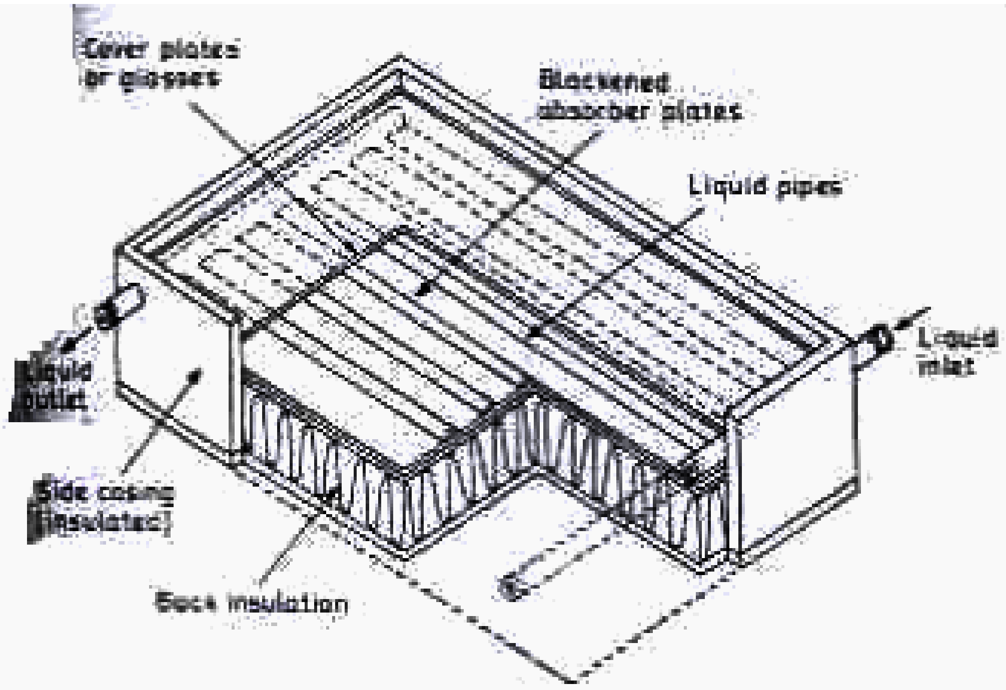
(2-7-3) Flat-Plate Collectors

Flat-Plate Collectors are the more commonly used type of collectors to day. They are arrays of solar panel arranged in a simple plane .

They can be of nearly any size, and have and that is directly related to a few variables including size, facing and clean lines. These variables all affect the amount of radiation that falls on the collector .Often these collector panels have automated machinery that keep them facing the sun. The additional energy they take in due to the correction of facing more than compensates for, the energy needed to drive the extra machinery (Yahoo, solar energy).

The flat plate collector is the heart of any solar energy collection system designed for operation in the low temperature range (ambient 60°c) or in the medium temperature range (ambient 100°c). It is used to absorb solar energy, convert it into heat and then to transfer that heat to a stream of liquid or gas. It absorbs both the direct and the diffuse radiation, and is usually planted on the top of building or other structures .It does not require tracking of the sun and requires little main tenancies .A flat plat collector (Fig2-3b) usually consists of the following components:

Figure 2.3a: A Typical Liquid Flat-plate Collector.



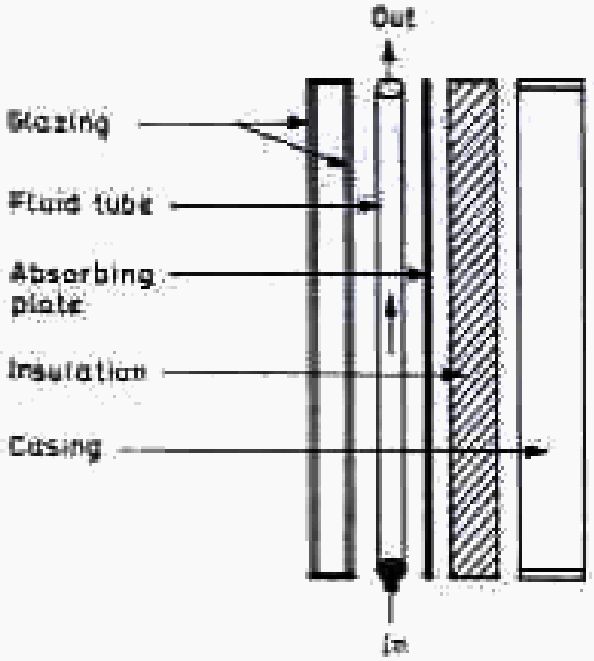


Figure 2.3b: Exposed Cross-section Through
a Glazed Flat-plate Collector.

1- Glazing which may be one or more sheets of glass or some other diathermanous (radiation transmitting) martial (fig-2-3b).

2- Tubes, fins or passages for conducting or directing the heat fluids form the inlet to the outlet.

3- Absorber plate which may be flat, corrugated or grooved with tubes, fins or passages attached to it

4- Header or manifold, to admit and discharge the fluid.

5- Insulation, witch minimizes heat toss form the back and sides of the collector.

6-Container or casing, which surrounds the various Components and protects them from dust, moisture etc,

(Kandpal, 1999).

The complete view of the collector is shown in figure (2-3a).

(2-8)Glazing Materials: -

The role of glazing is to admit the maximum possible radiation and to minimize the upward loss of heat. The most commonly used glazing material is glass as it can transmit up to go percent of the incident short wave radiation while its transmittance to the long wave heat radiation (5.0 to 50 μm), emitted by the absorber plate ,is negligible.

Plastic films and sheets may also be used for the purpose of the glazing as they possess high transmittance to short wave solar radiation , but transmission bands in the middle of thermal radiation spectrum and dimensional changes this temperature range restricts their uses as a good glazing surface (Kandpal, 1999).

(2-8-1) **The Transmittance**:-

The propagation of radiation through one non absorbing cover is shown in figure (2-3b). Considering only the perpendicular component of polarization of incoming radiation, (1-$\rho_\perp$) of incident radiation reaches the second interface, the $\rho_\perp$ part of

(1-$\rho_\perp$)= $\rho_\perp$ (1- $\rho_\perp$) is reflected back to first interface from the second interface and remaining (Sodha, 2002).

$$(1-\rho_\perp)^2 = (1-\rho_\perp) - \rho_\perp(1-\rho_\perp)$$

Passes through the interface and soon summing the transmitted terms we get

$$\tau_\perp = (1-\rho_\perp)^2 \sum_{n=0}^{n=\infty} \rho_\perp^{2n} = \frac{(1-\rho_\perp)^2}{(1-\rho_\perp^2)} = \frac{1-\rho_\perp}{1+\rho_\perp} \quad (2\text{-}36)$$

The same expression can be obtained for the parallel component of polarization of incoming radiation. The $\rho_\perp$ and ρ_{II} are not equal except at normal incident and the transmittance of initially un polarized radiation the average of the two components and it is given by (Sodha, 2002).

$$\tau_\rho = \frac{1}{2}\left[\frac{1-\rho_{II}}{1+\rho_{II}} + \frac{1+\rho_\perp}{1+\rho_\perp}\right] \quad (2\text{-}37)$$

Where the subscripts indicates that only reflection losses has been considered for transmission of radiation (Kandpal, 1999).

Similarly an expression for $\tau_{\rho N}$, for system of N covers, can be derived and can be written as.

$$\tau_{\rho N} = \frac{1}{2}\left[\frac{1-r_{II}}{1+(2N-1)r_{II}} + \frac{1-r_{\perp}}{1+(2N-1)r_{\perp}}\right] \tag{2-38}$$

where,

$$r = \frac{I_{\rho}}{I_i} = \frac{1}{2}(\rho_{\perp} + \rho_{II}) + \left(\frac{n-1}{n+1}\right)^2 \tag{2-38a}$$

Here one medium is air, i.e. a refractive index of nearly unity. The transmittance decreases as number of glass cover increases as per expectation (Sodha, 2002).

(2-8-2) Absorption by glazing: -

According to Bouguer's law, the absorbed radiation proportion to the intensity and the distance traveled (x) in the medium and can be expressed as.

$$dI = -Ikdx \tag{2-39}$$

Where k is proportionality constant (the extinction coefficient which is assumed to be constant in the solar spectrum). The value of k varies from 4 m^{-1} for "water white "glass to 32 m^{-1} for poor glass which appears greenish when viewed on the edge) .Integrating from zero to actual path length $\left(\frac{L}{\cos\theta_2}\right)$ in the medium, we get (Kandpal, 1999).

$$\tau_a = \frac{I_{transmitte\ d}}{I_{incident}} = \left(\frac{-kL}{\cos \theta_2} \right) \qquad (2\text{-}40)$$

The subscript (a) indicates that the transmission is due to absorption only .The absorption of solar collector cover can be written as.

$$\alpha = 1 - \tau_a \qquad (2\text{-}41)$$

The reflectance of a single cover can also be written as

$$\rho = 1 - \alpha - \tau = \tau_a - \tau \qquad (2\text{-}42)$$

Now, transmittance of single becomes

$$\tau = \tau_r \tau_a \qquad (2\text{-}43)$$

The transmission characteristic of a window glass cover has also been in these equations. After transmission it is absorbed by the blackened surface. The blackened surface emits the long wave length radiation (Sodha, 2002).

Due to its properties, the window glass cover behaves as a opaque for long wave length radiation and hence it blocked the emitted long wave length radiation from the blackened surface.

(2-9) Collector Plates:-

The most important part of the collector is the absorber plate along with the pipe or duct to pass liquid or air in thermal contact with the plate to transfer heat from it.

The function of the collector plate is to absorb maximum possible solar radiation incident on it through the glazing, to emit minimum heat, to the atmosphere and down ward, through the back of the casing, and to transfer the retained heat to the fluid. Material generally used for collector plates, in decreasing order of cost and conductance, are copper, aluminum and steel. The surface coating of the plate should be such that it has high absorptivity and poor emissivity for the required temperature range .Selective surfaces is particularly important when the collector surface temperature is much higher than the ambient air temperature (Sodha, 2002).

For domestic water heating System the plate is normally painted black. The energy absorbed by the plate is extracted by circulating a fluid, through a network of tubes in good thermal conductive with the plate or directly in contact with the plate. The bottom and sides of the collector are covered with insulation to reduce the conductive heat loss. The collector is placed in chinned at suitable angle to receive the maximum solar radiation (Sodha, 2002).

(2-10) Classification:-

In steady- state condition, the rate of energy an absorbed by plate per unit area should be equal to the sun of the rate of the useful energy (q'_u) transferred to the fluid and the rate of energy lost (q'_L) per unit area by the plate to the surrounding Thus (Sodha, 2002).

$$\dot{q}_{ab} = \dot{q}_L + \dot{q}_u \qquad (2\text{-}44)$$

Where

$$\dot{q}_{ab} = (\tau_{\circ}\alpha_{\circ})I(t)$$ And

$$\dot{q}_{L} = U_{L}(T_{P} - T_{a}) \qquad (2\text{-}45)$$

Equation (2-36) can be rewritten as

$$\dot{q}_{u} = (\tau_{\circ}\alpha_{\circ})I(t) - U_{L}(T_{P} - T_{a}) \qquad (2\text{-}46)$$

Further, $$\eta_{i} = \frac{\dot{q}_{u}}{I(t)} = \tau_{\circ}\alpha_{\circ} - U_{L}\frac{(T_{P} - T_{a})}{I(t)} \qquad (2\text{-}47)$$

Where $\tau_{\circ}$ and $\alpha_{\circ}$ is the transmissivity and absorptivity, of the glazed surface, respectively. $I(t)$ Is the incident solar radiation in the plane of absorber (wm^{-2}), T_P and T_a are the plate and ambient temperature (C°) respectively and U_L is the heat loss coefficient for collector (wm^{-2}).

The useful energy decreases with increasing temperature difference .The thermal loss to the surroundings is an important factor in the determination performance of collector, the higher losses the lower is the useful energy output and the heat loss depends upon ($T_P - T_a$). Hence, for different ranges of temperature, difference, different types of collectors have been designed to minimize $\dot{q}_L$ and optimize $\dot{q}_u$ as attempts to decrease $\dot{q}_L$ also decrease $\dot{q}_{ab}$ (Sodha, 2002).

The collectors, according to their shape, are divided into two categories, namely, evacuated tubular collector and flat –plate collector.

(2-11) Flat –plate Collectors:-

In the flat plate collectors, the heat loss by convection is more important in the determination of their performance .The convection heat loss may be decreased by using double glazing, but the radiation reaching the absorber is reduced due to double reflection .Hence, at low temperatures where this loss is small, use of single glazing gives a better efficiency than the double one while at higher temperature different the use of double glazing is advisable for better performance(Sodha, 2002).

Flat plate collectors are basically divided into two categories according to their use, (i) water or liquid heaters and (ii) air heaters .The collector meant for these uses are sub-divided as follow (Sodha, 2002).

There are two type of flat plate collector:

1- The first type is water or liquid heater;
  - a- Pipe and fin type.
  - b- Water sandwich type.
  - c- Semi-sandwich type.

2- The second type Air heater is;
  - a- Finned plate.
  - b- Metal matrix.
  - c- Corrugated plate with selective surface.
  - d- Miller LOF type.
  - e- Thermal trap.

The conditions, in which the various types of flat–plate collectors are used for water heating purpose, are:

- Full pipe and fin with comparatively low wetted area and water capacity, should be used with fin of highly conducting material (e.g. copper or aluminum). It is used for high temperature domestic applications.
- Full water sandwich type, where both the wetted area and the water capacity are high. As the thermal condition is only across the skin thickness (short distance), low conductivity material may be employed. Both plastic and steel have been used. It is commonly used for heating swimming pools with plastic paned and semi sandwich type, medium conductivity material such as steel is commonly used, though aluminum may also by used (Kandpal, 1999).

(2-12) Energy Absorbed by the Absorber plate:

The solar radiation incident on a tilted flat plate solar collector (I_T) has three different components direct (beam) Solar radiation, diffuse (sky) radiation and diffuse ground reflected radiation. The amount of solar energy absorbed by the absorber plate can be determined by treating the three components separated as the angle of incidence for each component may be different. The absorbed solar radiation (($\eta_\circ I_T$) where $\eta_\circ$ is defined as optical efficiency of the flat plate solar collector) on an hourly basis can be calculated as follows (Sodha, 2002):

$$\boldsymbol{\eta_o I_T = I_b R_b (\alpha\tau)_b + I_d (\alpha\tau)_d \left[\frac{1+\cos}{2}\right] + \rho_g (I_b + I_d)(\alpha\tau)_g \left[\frac{1-\cos}{2}\right]} \qquad \mathbf{(2-48)}$$

The effective beam incidence angler sky diffuse components and ground reflected diffuse component can be determined by this equation for diffuse sky radiation given the relation (Sodha, 2002) :

$$\theta_i ds = 59.68 - 0.1388\beta + 0.001497\beta^2 \qquad (2\text{-}49)$$

and:

$$\theta_i, d_g = 90 - 0.578\beta + 0.00269\beta^2 \qquad (2\text{-}50)$$

For diffuse ground reflected radiation.

(2-12-1) **The Useful Gain of the Collector**:-

The useful gain of the collector can be written as follows

$$Q_u = A_c\left[S - U_L\left(T_{p,m} - T_a\right)\right] \qquad (2\text{-}51)$$

Where;

Q_u = useful energy (w);

A_C = Collector area (m^2);

S = the solar radiation absorbed by a collector (wm^{-2});

U_L = heat transfer coefficient (w$m^{-2}K^{-1}$);

$T_{p,m}$ = the mean absorber plate temperature (K°);

T_a = the ambient temperature (K°);

It is difficult to measure $T_{p,m}$ because it is a function of collector design, entering fluid conditions, and incident solar radiation, (Sodha, 2002).

(2-12-2) **The Collector Efficiency Factor** F' :-

F' is introduced in calculation to account for the temperature difference between inlet and outlet fluid while the absorbing surface tempera-ture is still higher than fluid temperature. F' may be expressed as :

$$F' = \left[1 + \left(h_r U_t \right) \Big/ \left(h_p + hc\ h_r + h_p h_r + h_c h_p \right) \right]^{-1} \qquad (2\text{-}52)$$

Where:

U_t = top loss coefficient accounting for combined convection and radiation $\left(wm^{-2} k^{\circ -1} \right)$.

h_c = convection heat transfer coefficient from the fluid at T_f to the bottom of the cover at T_c ;

h_p = convection heat transfer coefficient from the plate to the fluid at T_f ;

h_r = radiation heat transfer coefficient between plate and cover.

U_t Calculated from equation (2-55).

(2-12-3) **Collector Heat Removal Factor**; F_R :-

The collector heat removal factor; F_R defined as a quantity that the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature and mathematically is given by : (Sodha, 2002)

$$F_R = \dot{m} C_p \left(T_{f,o} - T_{f,i}\right) \Big/ A_c \left[S - U_L \left(T_{f,i} - T_a\right)\right] \qquad (2\text{-}53)$$

where :

$\dot{m}$ = fluid flow rate;

$T_{f,i}$ = temperature of fluid at inlet;

$T_{f,O}$ = temperature of fluid at outlet;

T_a = ambient temperature;

(2-12-4) **Modified Useful Energy Equation**:-

Instead of equation (2-51) Q_u can be related to fluid inlet temperature, ($T_{f,i}$) and heat removal factor F_R as follow;

$$Q_u = A_c F_R \left[S - U_L \left(T_{f,i} - T_a\right)\right] \qquad (2\text{-}54)$$

(2-12-5) **Heat Transfer Losses of Collector**:-

In evaluating the collector performance, it is necessary to determine the overall heat transfer losses. The major heat losses in the collector top losses,U_t , bottom losses ,U_b, and side or edge losses , U_e, (Sodha, 2002).

(2-12-6) **Top Heat Loss Coefficient**:-

An empirical equation for top heat loss. Coefficient (U_t) developed by some investigator (Sodha, 2002) is given below:

$$U_t = \left[N / \left(C / T_{p,m} \right)^{*} \left\{ (T_{p,m} - T_a) / (N + f) \right\}^{e} \right] + 1/h_w + \sigma (T_{p,m} + T_a)(T_{p,m}^2 + T_a^2) /$$
$$\left[(\varepsilon_p + 0.0059\, N h_w)^{-1} + (2N - f - 1 + 0.133 \varepsilon_p)/\varepsilon_g - N \right] \qquad (2-55)$$

Where:

N = number of glass cover;

f = $(1 + 0.089\, h_W - 0.1166\, h_W \varepsilon_p)(1 + 0.07866 N)$

C = 520($1 - 0.000051 \beta^2$) for $0 < \beta < 70°$ for $70° < \beta < 90°$, use β = 70°

e = $0.43(1 - \frac{100}{T_{p,m}})$;

β = collector tilt (degrees);

ε_g = emittance of glass (0.88);

ε_p = emittance of plate;

T_a = ambient temperature (^{o}K);

$T_{p,m}$ = mean plate temperature (k°);

h_w = wind heat transfer coefficient (w $m^{-2} K^{-1}$°);

(2-12-7) Bottom Heat Loss Coefficient:-

The bottom heat loss coefficient, (U_b) is approximately given by an empirical equation (Sodha, 2002).

$$U_b = \frac{k}{L} \tag{2-56}$$

where:

K=insulation thermal conductivity;

L= plate thickness;

(2-12-8) **Edge (Side) Heat Loss Coefficient**:-

The loss through the edge, (U_e) should be referenced to the collector area, also collector by an empirical equation (Sodha, 2002).

$$U_e = U_b (A)_{edge} / A_C \tag{2-57}$$

Where:

(U_e) = the product of the edge loss coefficient times the area;

(A_C) = Collector area;

(A_{edge}) = edge area;

(2-12-9) **Collector Overall Heat Loss Coefficient:-**

Collector Overall Heat loss coefficient, U_L Is the sum of the top, bottom and edge loss coefficient (Sodha, 2002).

$$U_L = U_t + U_b + U_e \tag{2-58}$$

(2-12-10) **Heat Transfer Due To wind**:-

The heat loss from flat-plates exposed to outside is given by (Sodha, 2002).

$$h_w = 2.8+3.0\, v \qquad (2\text{-}59)$$

Where:

v = wind speed (m/s);

h_w = heat transfer coefficient ($wm^{-2}K^{\circ -1}$);

(2-13-1)**Absorber-Reflector Tandems:**

These surfaces consist of surface layer, usually black, which is highly absorbing in the solar, rang but transparent to radiation in the thermal (IR) range, deposited on a metal surface (Al, Cu, Steel, etc.) of low emittance. The combination of a coating layer of high solar absorptance and a metal base of low thermal emittance results in a spectrally selective surface.

Most of the surfaces described in the literature belong to this category. This includes silver oxide on silver iron oxide on steel, copper oxide on copper and other metals, and nickel-zinc-sulfide (Nickel Black) on nickel and other metals. However, the most important systems in this category of surfaces are of the oxide-type. This includes black copper, black chrome, black zinc, black cobalt and black molybdenum.

The coating layer in these systems is believed to be metal cermets which consist of small metallic particles dispersed in a dielectric matrix. Solar energy absorption occurs through Maxwell-garnet type of absorption, through band-gap transition absorption, or through multiple reflections within the surface features. The guest ion of each one of these mechanisms predominates in a given oxide system is still under investigation (Talballa, 1984).

Except for the Mo-O-Mo which is deposited by CVD, these surfaces are formed mainly by chemical conversion or electro-coating followed by electrolytic conversion. These are relatively simple and cheap techniques compared to other deposition methods.

Since almost all flat-plate solar collectors in use to day employ this type of selective surface, and since the deposition techniques utilized are more likely to meet the requirement of being “low-cost”, the following systems have been selected and studied in other projects (Talballa,1984).

Black Copper on Copper
Black Zinc on Steel
Black Zinc on Copper
Black Zinc on Aluminum
Black Chrome on Ni-plated Steel
Black Cobalt on Steel

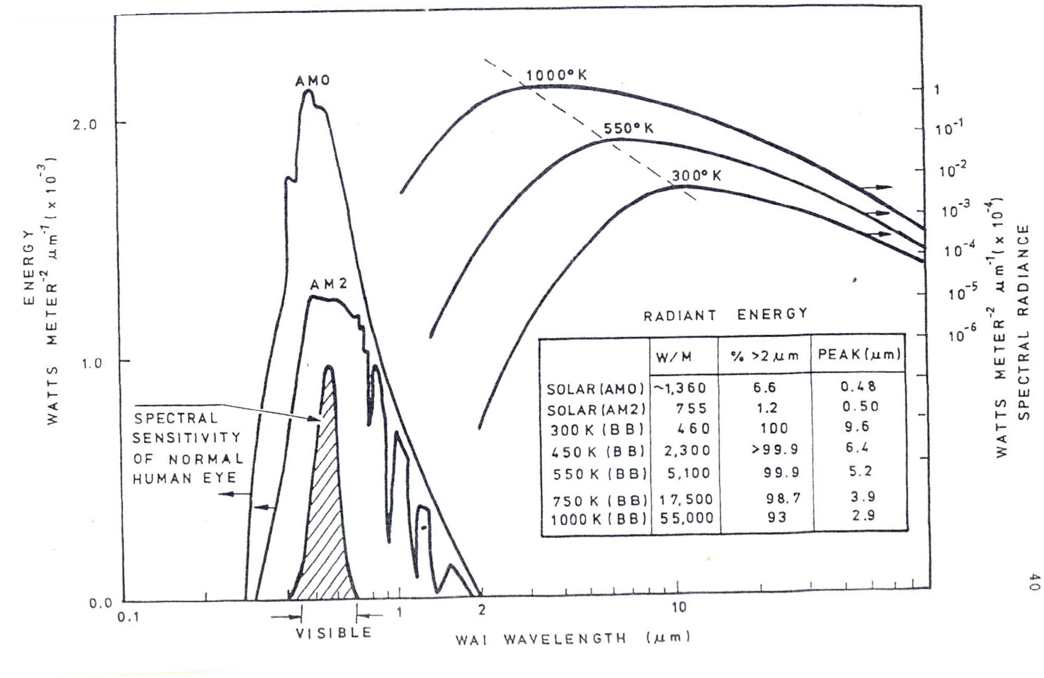
The methods used for the deposition of these coatings are chemical conversation, electro conversation, spray-sinter and, possibly, CVD. These are low-cost deposition methods and, therefore, represent a good start in the direction of cost-effectiveness.

(2-13-2)**Ideal Selective Surface:**

Solar radiation spectrum corresponds fairly closely to that of a black body at a temperature of 6000^{o}k. This gives a peak emission at about 0.55µm (Wine’s equation). Allowing for absorption in the atmosphere, we fined that 98.8% of the solar radiation at the earth’s surface lies in the range 0.3—2.0µm, Fig. (2-4a).at the same time the Wien’s equation shows that at terrestrial temperatures the wavelengths of emitted radiation are much longer than the solar radiation. At room temperature (say 300ºk) a black has its emission peak at 9.7 µm; at the boiling point of the water (373ºk) the peak is 7.8µm and less than 1% of the emitted radiation is at wavelength below 3.9µm. A black body heated to 573ºk has its peak emission at 5.0µm and almost all the emitted radiation is in the rang 2.5—3.0µm. Fig.(2-4a) shows that very little energy falls in overlap area between the solar radiation and that of a heated black body even at 1000ºk. For bodies which are not ideal black bodies, the energy in the overlap region is even less (Talballa, 1984).

The picture out line in the preceding paragraph allows us to contemplate an ideal surface whose characteristics in absorption, reflection and transmission of radiation are different below and above 2.0 µm, i.e. in the solar range and the thermal range. Specifically this means that the surface would have zero reflectance (α=1) in the solar range and 100%

Reflectance in the thermal (IR) range (ε=0) (Talballa, 1984).



RADIANT ENERGY

	W/M	% >2 µm	PEAK (µm)
SOLAR (AMO)	~1,360	6.6	0.48
SOLAR (AM2)	755	1.2	0.50
300 K (BB)	460	100	9.6
450 K (BB)	2,300	>99.9	6.4
550 K (BB)	5,100	99.9	5.2
750 K (BB)	17,500	98.7	3.9
1000 K (BB)	55,000	93	2.9

Fig. (2-4a) Spectral curve

Such a surface is an ideal “spectrally selective surface”.(Talballa, 1984)

It is worth mentioning that although the optical properties of many surfaces vary with wavelength and, therefore, may be described as spectrally selective, they do not fall under the title as used above. In the context of solar energy collection, “spectral selectivity” refers to a type of “band-pass filter “

The optical properties are substantially constant but different over broad bands of wavelengths, i.e. the band of the wavelength below 2.0µm and the band above 2.0µm (see Fig.2-4b below).

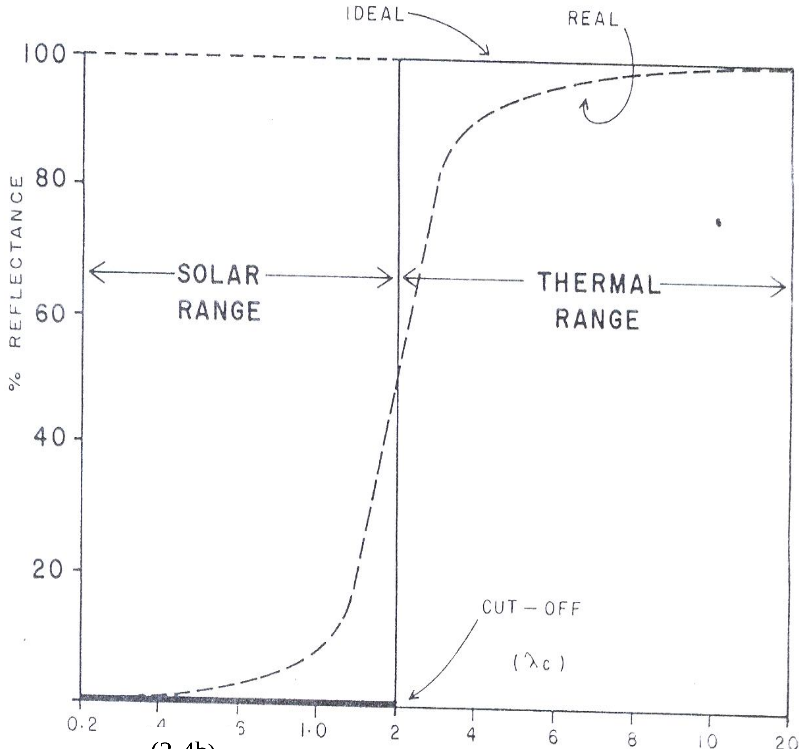


FIG. (2-4b) REFLECTANCE SPECTRUM FOR AN IDEAL SELECTIVE SURFACE.

Fig (2-4b) and the arguments in the paragraphs preceding it form the basis of the search for materials, natural or synthetic which would have spectral selectivity when applied as coatings on the surface/cover of a solar collector. Although the position of the “cut-off” wavelength in important, the way the optical properties vary on each side of the cut-off is of even greater importance. We are usually interested in the value of a given optical property, say reflectance, after summation over all wavelengths in a region of interest. Such properties are termed “total properties” as will be explained (Talballa, 1984).

(2-13-3**) Intrinsic Absorbers**:

Unlike the multilayer of dielectric “sandwiches” these coatings consist of a simple material which is either a transition metal or a semiconductor. These metals have a plasma reflection edge at about 0.3µm which can be shifted toward the longer wave length range (IR) by suitable doping. The main systems reported in the literature are

Mo-doped with Mo O_3 ,Eu_2O_3 ,ReO_3 and LaB_6.

The use of a single material as a selective surface would be ideal; however the development of such a material at reasonable cost is in its early stage (Talballa.1984).

(2-13-4) **Topological Surfaces**:

As early as 1955, it has been suggested that surface-texturing may be used to increase the absorptance of an otherwise low-absorbing surface. This idea has been developed since then by several groups but mainly by the Mont Louis group and the Australian CISRO groups.

In the macro-version, this method consists of corrugating the surface into a series of V's so that any beam of incident radiation within a given range of angles of incidence will undergo multiple reflections before emerging from the V. For a surface with an absorptance of 0.8 and having 90^o V's, the effective absorptance is increase to 0.96 with only two reflections within the V.

In the micro-version the surface roughness has dimensions of the order of a micrometer and may be produced by etching, grating deposition or dendritic growth. The surface may act as an array of adjacent cavity absorbers for short wavelengths (i.e. in the solar range) whilst appearing substantially flat for longer wavelengths (in the IR range). If the surface, such as that of polished metal, has low emittance, the result is selective surface.

The most promising systems in this category of surfaces are:

- Grid or mesh deposition
- Dendritic Tungsten
- Dendritic Nickel

The deposition costs are estimated to be higher than for any other method of deposition.

(2-13-5)Characterization Of Selective Surfaces:

The following characteristics have been given as basic requirements for a practical selective surface for a solar collector:

1. High solar absorptance, α.
2. Low thermal emittance, ε.
3. Long-term stability at the desired operating temperature.
4. Short-term stability towards over heating due to failure to extract heat from the collector.

5. Stability to weathering and resistant to atmospheric corrosion.
6. Adhesion to given substrate materials.
7. Reproducibility.
8. Reasonable coast.

(2-14)**MANGANESE:**

Manganese, symbol Mn, silvery white, brittle metallic element used principally in making alloys. Manganese is one of the transition elements of the periodic table. The atomic number of manganese is 25.

(2-14-1)Properties and Occurrence:

Manganese was first distinguished as an element in 1774 by the Swedish chemist Johan Gottlieb Gahn. Manganese metal corrodes in moist air and dissolves in acid. Manganese melts at about 1245ºC (about2271ºF), boils at about 1962ºC (about 3564ºF), and has a specific gravity of 7.2; the atomic weight of manganese is54.938.

Pure manganese is obtained by igniting pyrolusite (manganese dioxide) with aluminum powder or by electrolyzing manganese sulfate. The metal does not occur in the Free State, except in meteors, but is widely distributed over the world in the form of the ores, such as rhodochrosite, franklinite, psilomelane and manganite. It ranks about 12th in abundance among elements in the earth's crust. The principal ore of manganese is pyrolusite. Ukrania, Georgia, and South Africa is important producer of manganese (Google, manganese).

Manganese used in many areas like dry battery, paint and varnish oils, for coloring glass and ceramics, and preparing chlorine and iodine.

Chapter III

EXPERIMENTAL

In this chapter we outline the materials, equipments and the experimental procedures and techniques employed in this study.

(3-1) Materials:-

The materials used to design flat-plate collectors are described below.

(3-1-1) **Glass Sheet**:-

A glass sheet used in the design, because of its good transparency for visible radiation .The thickness of the glass sheet used was about 3 mm, and the area 1.0 m^2.

(3-1-2) **Insulation**:-

Fiber glass is an effective good thermally insulating material and the thickness about (5 cm) and the area is 1.0 m^2.

(3-1-3) **Paint:-**

Black paint was used to coat the absorber.

(3-1-4) **Galvanized Steel**:-

One sheet from galvanized steel of thickness is (0.2 mm).

(3-1-5) **Copper:-**

Copper tubes of (sp. gr. 8.66), diameter (1.5 cm), and length (11 m) were used. The purity of the copper was about (92 %.) These materials are shown assembled in Fig (3-1).

(3-1-6) Rhodonite:

Table (3-1) below. Properties of manganese used in the second test

minerals	formula	%Mn	Colour/Lustre	Hardness	Crystal system/habit
Rhoddonite	**$MnSiO_3$**	42	**Pink to rose – red to brownish red, rarely yellow-grey; transparent to translucent; vitreous**.	**5fi-6fi**	**Triclinic ;commonly Tabular, massive, cleavable to compact; fine to course granular.**

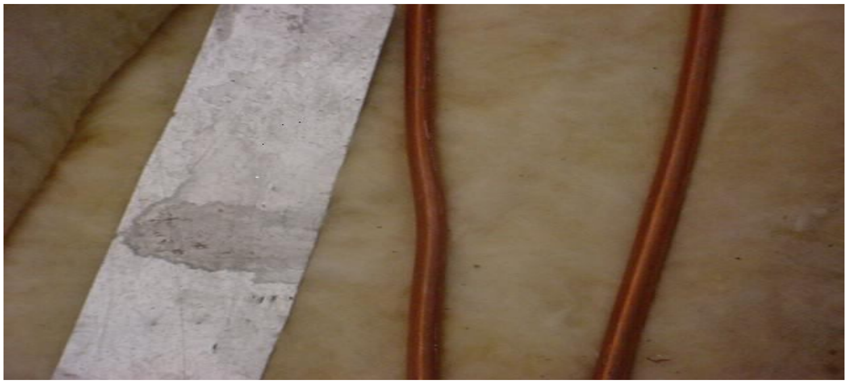


Fig (3-1) Schematic diagram of some materials.

(3-2**) Equipment**:-

The equipment used in this research included the following:

(3-2-1) **Solarimeters:-**

A German SWH volt, type CM10, Nr CM11820059, sensitivity $4.52\times10^{-6} V/wm^2$,world Radiometric Reference, is used to measure the global (beam and diffuse) solar radiation that is falling on the collector. The solarimeters connected by digital Multimeters shown in Fig (3-2).

Fig.3-2. solarimeters and digital Multimeters

(3-2-2) **Thermometers:-**

Three digital thermometers were used during the test to read the temperatures on different locations on collector and the flat plate collector, to check the temperature of the inlet water outlet water and the ambient temperature. One of them is a German digital thermometer 2Hand B reads temperature from -240 to 1200 $^{\circ}C$ .The second and third one French digital temperature [NOVO] reads temperatures from -55to 180 $^{\circ}C$ .These types are shown in Fig (3-3) type one in the left hand and other types in right hand.

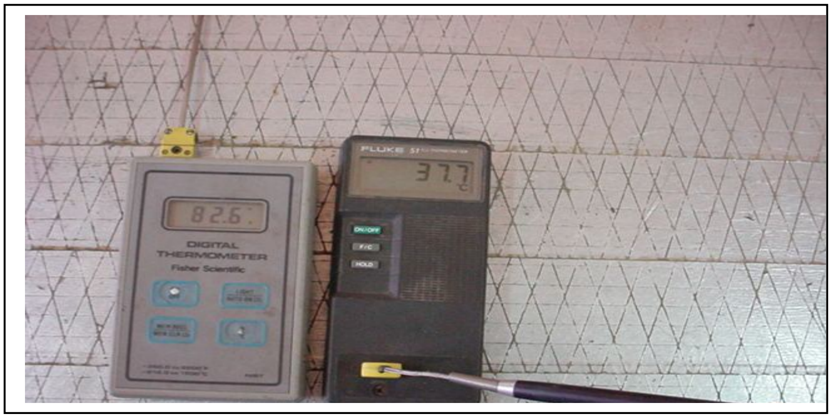


Fig 3-3.Two types of digital thermometers

(3-3**) Methods:-**

(3-3-1**) Preparative Techniques**: Design of flat-plate collectors

Two types of flat-plate collectors have been designed. The first type was uncoated, and the second type was coated with black paint; these are shown in Fig.3-4 and Fig 3-5.

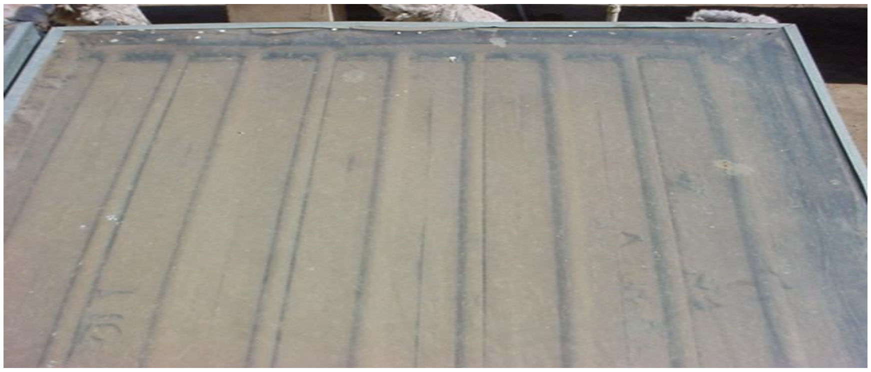


Fig.3-4.Type (A) flat plate collector uncoated

Fig.3-5.Type (B) flat plate collector coated with black paint.

These collectors consist of the absorber plate, one transparent cover, thermal insulation and outer casing.

An absorber plate is a sheet of galvanized steel of high thermal conductivity and the copper tubes are placed on the galvanized steel. One collector was coated with black paint, so that it absorbs the incident solar radiation and minimizes loss of heat by radiation form the collector plate.

A glass sheet which was transparent to the incoming solar radiation was placed 5-cm above the absorber plate .This prevents convective heat loss from the absorber plate and prevents infrared radiation from the plate to escape to the atmosphere. The absorber plate rests on a 5-cm thick bed of fiber glass thermally insulating material. This is also placed along the sides of the collector plate. Insulating material of adequate thickness to cut down heat loss by conduction. Copper tubes were used to extract heat from the collector plate. The cylindrical copper tubes were fixed at a distance of about 10-cm from one another .They were then (spot welded), tied with wires and clamped. The diameter of tubes at the point of connection was narrowed so as to change the velocity of liquid in the pipe. These risers were connected to larger pipes called headers at both ends so that removal fluid can enter from the lower header and leave from the upper header. This, configuration of absorber plate is called the fin and tube type. The heat removal fluid is water, which flows through these tubes to carry away the heat received from the sun.

All parts of the collector were kept in an outer case made of galvanized steel sheet. There was no leakage of air from this case, otherwise, considerable loss of heat from the collector plate to the ambient atmosphere can occur.

The collector is finally placed on a stand so that the absorber plate is correctly inclined to the horizontal, and receives maximum amount of heat from the sun. Two galvanize steel plates were used, one of them was coated with black paint (type B) and the other (type C) was coated with manganese. The two surfaces were then subjected to sun rays. Surface heat was measured for each of the plates from 9:00 am to4:00pm and the data was recorded in table (4-6) to compare their temperature through this period.

(3-3-2) **Exposure Procedure:-**

The flat plate collector was mounted and coupled to an outdoor test loop. Prior to commencement of the test the residence time of water in the collector is determined. The mass flow rate of heat transfer fluid through the collector is set to a value between (0.013and 0.015 kg/s), per square meter of collector aperture. The inlet (T_i) and outlet (T_O), and ambient (Ta) temperatures were then recorded. The tilt angle of plate was 15° at south. These parameters were measured during the day, before and after solar noon, at half hour intervals. During the test the data on four parameters were recorded, these parameters were:

a- total solar radiation incident upon the plate (I (w/m^2)).

b- the surrounding air speed (Vs (m/s)).

c- the ambient temperature (T_a).

d- the temperature of the heat transfer fluid of the collector out let (T_{out}).

e- the temperature of the heat transfer fluid of the collector inlet (T_{in}).

These measurements may then be used to define the efficiency of collector .The measurements should then be collated to produce a set of data points which meet the required test condition, including those for steady operation. In this research two cases are studied : the first case uncoated plate, called type (A), and the second case plate coated with black paint, called type (B).The efficiencies of the two types of plate are then compared.

Chapter IV

RESULTS

4. RESULTS:-

The results obtained on the two types of collector plate (type A uncoated, type B coated with black paint) are presented in Table (1) and Table (2) below. This result it taken in the Energy Research Institute in soba.

Table (1) : Data Obtained on Type (A) Collector

No	Local time t(min)	mean Wind speed V m/s	Ambient Temp. T_a(°C)	inlet temp. T_i (°C)	outlet temp. T_o(°C)	*Insola-tion* wm^{-2} ***I***
1	9:00	9.3	31.6	34.5	47	*417*
2	9:30		31.9	36.2	52.1	*595*
3	10:00		33	39.7	55.3	*614*
4	10:30		34.2	45.3	58.7	*709*
5	11:00		39	46.6	60.3	*780*
6	11:30		40	49.5	65.7	*868*
7	12:00		41	52.1	67.1	*898*
8	2:30		41.3	53.6	72.4	*908*
9	1:00		41.7	56.9	76.5	*915*
10	1:30		42.1	60.2	80.2	*917*
11	2:00		42.6	64.3	79.1	*879*
12	2:30		42.1	61.5	78.7	*754*
13	3:00		42.4	60.9	76.9	*674*
14	3:30		42.2	59.1	75.3	*568*
15	4:00		41.8	57	72.8	*486*
16	4:30		41	56.5	70.4	*464*
17	5:00		40.1	52.7	67.1	*437*
18	5:30		38	50.1	64.3	*408*
19	6:00		36.2	46	61.7	*392*
20	*6:30*		*33*	*41.2*	*58.2*	*369*

Table (2): Data obtained on type (B) collector

No	**Local time t(min)**	**mean Wind speed V (m/s)**	**Ambient Temp. T_a (^oC)**	**inlet fluid temp. T_i (^oC)**	**outlet fluid temp. T_o (^oC)**	***Solar insolation*** wm^{-2} ***I***
1	9:00	4.9	**32.2**	**34.5**	**47**	***420***
2	9:30		32.8	37	52.1	*505*
3	10:00		33.1	38.1	55.3	*612*
4	10:30		34	49.7	71.4	*705*
5	11:00		34.9	51	76.3	*780*
6	11:30		35.7	54.5	79.4	*844*
7	12:00		39.1	60	84	*888*
8	12:30		40	65.2	89.7	*911*
9	1:00		41.2	68.9	91.3	*922*
10	1:30		41.6	70.8	93.8	*926*
11	2:00		42.1	68.2	90.2	*892*
12	2:30		42.3	67.3	87.2	*824*
13	3:00		41.8	65.4	83.6	*715*
14	3:30		40.1	63.7	80	*621*
15	4:00		38.7	61.2	78.3	*513*
16	4:30		38.0	59.8	76.0	*481*
17	5:00		37.2	57.0	74.8	*456*
18	5:30		36.0	55.2	71.3	*418*
19	6:00		33.7	52.6	69.8	*380*
20	*6:30*		*31.9*	*46.2*	*62.3*	*369*

(4-1) Overall Heat Loss Coefficient:

The collector efficiency under the various conditions will be the major quantity to be determined and used for comparison. However, it will be necessary to determine first the overall heat loss coefficient, $U_{L,}$ which is an important parameter for calculating the plate efficiency, as can be seen from equation (2- 47). U_L has been given by equation (2-58) as being a combination of three components:

$$U_L = U_t + U_b + U_e \qquad (2\text{-}58)$$

where :

U_t is the heat loss from the top of the plate, and is given by:

$$U_t = \left(\frac{1}{h_1} + \frac{1}{h_2}\right)^{-1} \qquad (4\text{-}1)$$

Where: $$h_1 = h_{1c} + h_{1r} \qquad (4\text{-}2)$$

h_1 = the heat loss coefficient for radiation and convection from plate to cover:

h_2 = the heat loss from the glass cover to the atmosphere at (T_a)

h_{1c} =heat loss coefficient by convection from plate to cover;

h_{1r} = heat loss coefficient by radiation from plate to cover its equal 1.78 w/m^2K (constant).

The value of h_{1c} is calculated by the equation below:

$$h_{1c} = \frac{NuK}{L}$$

Nu = the Nusselt number (= 7.7)

K =thermal conductivity of air (= 0.0272 w/mK)

L =the spacing between the plate and the cover (= 0.05 m)

Hence:

$h_{1c} = \frac{7.7 \times 0.0272}{0.05} =$ 4.2 w/m^2K is constant, and

$h_1 = h_{1c} + h_{1r}$ = 4.2+ 1.78 = 5.98 w/m^2K (is also constant).

(h_2), coefficient for the heat loss from cover to ambient is given by:

$h_2 = h_{2c} + h_{2r}$ (4-3)

h_{2c} =heat loss coefficient by convection from cover to ambient

(depends on wind speed) is given by :

$h_{2c} = 2.8 + 3v \ w/m^2K$

v = is wind speed, m/s, was approximately constant during exposure, at (9.3 m/s) for type A plate, and at (4.8 m/s) for type B plate . Therefore, the value of h_{2c} for type A plate will be :

h_{2c}(A) = 2.8+3 x 9.3 = 30.7 w/m^2K

and for type B plate will be :

h_{2c}(B) = 2.8 + 3 x 4.9 = 17.5 w/m^2K

h_{2r} The heat loss coefficient by radiation from cover to ambient is constant and equal to (5.8 w/m^2K). Substituting these values in equation (4-6) yields :

for type A : h_2 = 30.7 + 5.8 = **36.5** w/m^2K

for type B : h_2 = 17.5 + 5.8 = **23.3** w/m^2K

Substituting these last values of h_1 and h_2 in equation (4-4) :

for type A :

$$U_t = \left[\frac{1}{5.98} + \frac{1}{36.5}\right]^{-1} = \underline{\mathbf{5.14}} \ w/m^2K$$

for type B :

$$U_t = \left[\frac{1}{5.98} + \frac{1}{23.3}\right]^{-1} \qquad = \quad \underline{\mathbf{4.76}} \;\; w/m^2K$$

The bottom loss coefficient, U_b is given by :

$$U_b = \frac{\mathrm{K}_{\mathrm{ins}}}{\mathrm{L}_{\mathrm{ins}}} \tag{4-4}$$

where :

K = the insulation conductivity it has the fixed value of (0.048 $w/m^{\circ}C$) for fiber glass.

L = back insulation thickness, has the fixed value of (0.05 m)

The suffix (ins) indicates insulation.

Substituting the above values in equation (4-7) yields :

$$U_b = \frac{0.048}{0.05} \qquad = \underline{\mathbf{0.96}} \;\; w/m^2K$$

The Edge-loss coefficient, U_e is given by :

$$\mathrm{U_e} = \quad \mathrm{U_b}\left(\frac{\mathrm{A_e}}{\mathrm{A_c}}\right) \tag{4-5}$$

where :

A_e = edge's area, which is fixed, (≈ 0.4 m^2)

A_c = plate's area, which is fixed, (≈ 1.0 m^2). Hence :

$$U_e \;=\; 0.96\frac{0.4}{1} \qquad = \quad \underline{\mathbf{0.38}}\, w/m^2K$$

The overall heat loss coefficient, U_L, can now be calculated for the two types of plate :

$$U_L = U_t + U_b + U_e$$

For type A, U_L = 5.14 + 0.96 + 0.38 = $\underline{\mathbf{6.48}}$ w/m^2K

For type B,

$U_L = 4.76 + 0.96 + 0.38 \quad = \quad \underline{\mathbf{6.10}} \; w/m^2K$

(4-2) **Collector Efficiency Calculation:-**

The efficiency, η, can be determined mathematically by measuring the ambient, inlet and outlet temperature, the wind speed and the solar insolation (solar intensity upon the plate (w/m^2), using equation .The experimental data are given in Tables (3) and (4). The efficiency, η, may be calculated from (2-47) :

$$\eta = q_u / I = \tau_o\alpha_o - U_L (T_p - T_a) / I \qquad (2\text{-}47)$$

q_u = useful energy
$\tau_o\alpha_o$ = glass transmissivity (0.88), and black paint absorptivity (0.97)
U_L = overall heat loss coefficient ($w / m^2.^oK$)
T_p = plate temperature (°K)
T_a = ambient temperature (°K)
I = insolation (w/m^2)

It is difficult to measure T_p, therefore, this has been approximated by
$T_p \approx T_{av.} = (T_{in} + T_{out})/2.$
$\Delta T_{p/a} = (T_{av.} - T_a)$ (°C);
I = Insolation (solar radiation) (wm^{-2}).

The transmissivity for the glass cover is the same for both types of collector, namely ($\tau_o = 0.88$). However, the absorptivity is different, for Type A it is ($\alpha_{o,A} = 0.77$), while for Type B it is ($\alpha_{o,B} = 0.97$). These values yield:

$$(\tau_o \alpha_o)_{\mathbf{A}} = (0.77x0.88) = \mathbf{0.68}$$

$$(\tau_o\ \alpha_o)_{\mathbf{B}} = (0.97x0.88) = \mathbf{0.85}$$

The various constants that have been determined are utilized in calculating the thermal efficiency, η, and the two ratios $(\Delta T_p - T_a)/I$ and $(\Delta T_{in} - T_a)/I$. The results of the calculated values are shown in Table (3) for Type (A) plate and in Table (4) for Type B plate.

Table (3): Calculated Efficiency on Type (A) Collector

$$\eta = \tau_o\alpha_o - U_L (T_p - T_a) / I$$

$$\tau_o\alpha_o = 0.68; \qquad U_L = 6.48$$

No	I wm^{-2}	T_{av} $(T_{in} + T_o)/2$	T_a	**(Tav –Ta)/I**	η (%)	***(T_{in} –Ta)/I*** ***(x100)***
1	417	39.6	31.6	0.0192	56	*0.40*
2	595	42.7	31.9	0.0182	56	*0.72*
3	614	46.0	33.0	0.0212	54	*1.09*
4	709	52.0	34.2	0.0251	52	*1.56*
5	780	53.5	39.0	0.0186	56	*0.97*
6	868	57.6	40.0	0.0203	55	*1.09*
7	898	59.6	41.0	0.0207	54	*1.23*
8	908	63.0	41.3	0.0239	53	*1.35*
9	915	66.7	41.7	0.0273	50	*1.66*
10	917	70.2	42.1	0.0306	48	*1.97*
11	879	71.7	42.6	0.0331	47	*2.47*
12	754	70.1	42.1	0.0371	44	*2.57*
13	674	68.9	42.4	0.0393	43	*2.74*
14	568	67.2	42.2	0.0440	39	*2.98*
15	486	64.9	41.8	0.0475	37	*3.28*
16	464	63.5	41.0	0.0485	36	*3.34*
17	437	59.9	40.1	0.0453	39	*2.88*

18	408	57.2	38.0	0.0471	37	*2.97*
19	392	53.9	36.2	0.0452	39	*2.50*
20	*369*	*49.7*	*33.0*	*0.0453*	*39*	*2.22*

Table (4): Calculated Efficiency on Type (B) Collector

No	wm^{-2} **I**	T_{av} $(T_{in} + T_o)/2$	T_a	**(Tav –Ta)/I**	η (%)	***(T_{in} –Ta)/I (x 100)***
1	417	40.8	32.2	0.0206	73	*0.55*
2	595	44.6	32.8	0.0208	72	*0.71*
3	614	46.7	33.1	0.0222	71	*0.81*
4	709	60.6	34.0	0.0375	62	*2.2*
5	780	63.7	34.9	0.0370	62	*2.1*
6	868	67.0	35.7	0.0360	63	*2.2*
7	898	72.0	39.1	0.0366	63	*2.3*
8	908	77.5	40.0	0.0413	60	*2.8*
9	915	80.1	41.2	0.0425	59	*3.0*
10	917	82.3	41.6	0.044	58	*3.2*
11	879	79.2	42.1	0.0422	59	*3.0*
12	754	77.3	42.3	0.0464	57	*3.3*
13	674	74.5	41.8	0.0485	55	*3.5*
14	568	71.9	40.1	0.0560	51	*4.1*
15	486	69.8	38.7	0.0640	46	*4.6*
16	464	67.9	38.0	0.0644	46	*4.7*
17	437	65.9	37.2	0.0657	45	*4.5*
18	408	63.3	36.0	0.0670	44	*4.7*
19	392	61.2	33.7	0.0702	42	*4.8*
20	*369*	*54.3*	*31.9*	*0.0607*	*48*	3.9

The relationship between efficiency, (η), and the quantity **($T_{in} – T_{a}$) / I, is implied by the equations:**

$$Q_u = A_cF_Rq_{ab} – A_cF_RU_L (T_i – T_a)] \quad \textbf{(4-6)}$$

$$= A_cF_R(\tau_o\alpha_o)I - A_cF_RU_L (T_i – T_a)$$

$$\eta = Q_u/A_cI = q_u/I = F_R(\tau_o\alpha_o) - F_RU_L (T_i – T_a)/I \quad \textbf{(4-7)}$$

$$\equiv K_1 – K_2 (T_i – T_a)/I$$

Where: $K_1 = F_R(\tau_o\alpha_o)$, and $K_2 = F_RU_L$.

Equation (4-7) gives a linear relationship, i.e. η vs. $(T_i – T_a)/I$ is a straight line, with slope ($-K_2 = -F_RU_L$) and intercept ($K_1 = F_R(\tau_o\alpha_o)$). The plots of equation (4-7), using the data for Type A and Type B plates, are given in Fig. (4-1) below.

(4-3) Calculation of the Useful Energy (Q_u) and Absorptivity (α)

The heat removal factor, F_R, may now be determined from the relation

$$F_R = - \text{slope} / U_L$$

This yields for :

Plate Type A: $F_R = - (- 5.4) / 6.48 = 0.83$

Plate Type B: $F_R = - (-5.8) / 6.10 = 0.95$

Using the average values for (ΔT_{av}) and (I_{av}), the useful energy and the efficiency may be calculated. The various needed quantities are tabulated in Table (4-5).

Table (4-5): Calculated Values Used in Determining (Q_u) and (η)

Plate	ΔT_{av} °C	I_{av} Wm^{-2}	Slope	Intercept $(\tau_o\alpha_o)$	A_c m^2	F_R
Type A	12.5	659	- 5.4	0.59	1.0	0.83
Type B	19.0	659	- 5.8	0.73	1.0	0.95

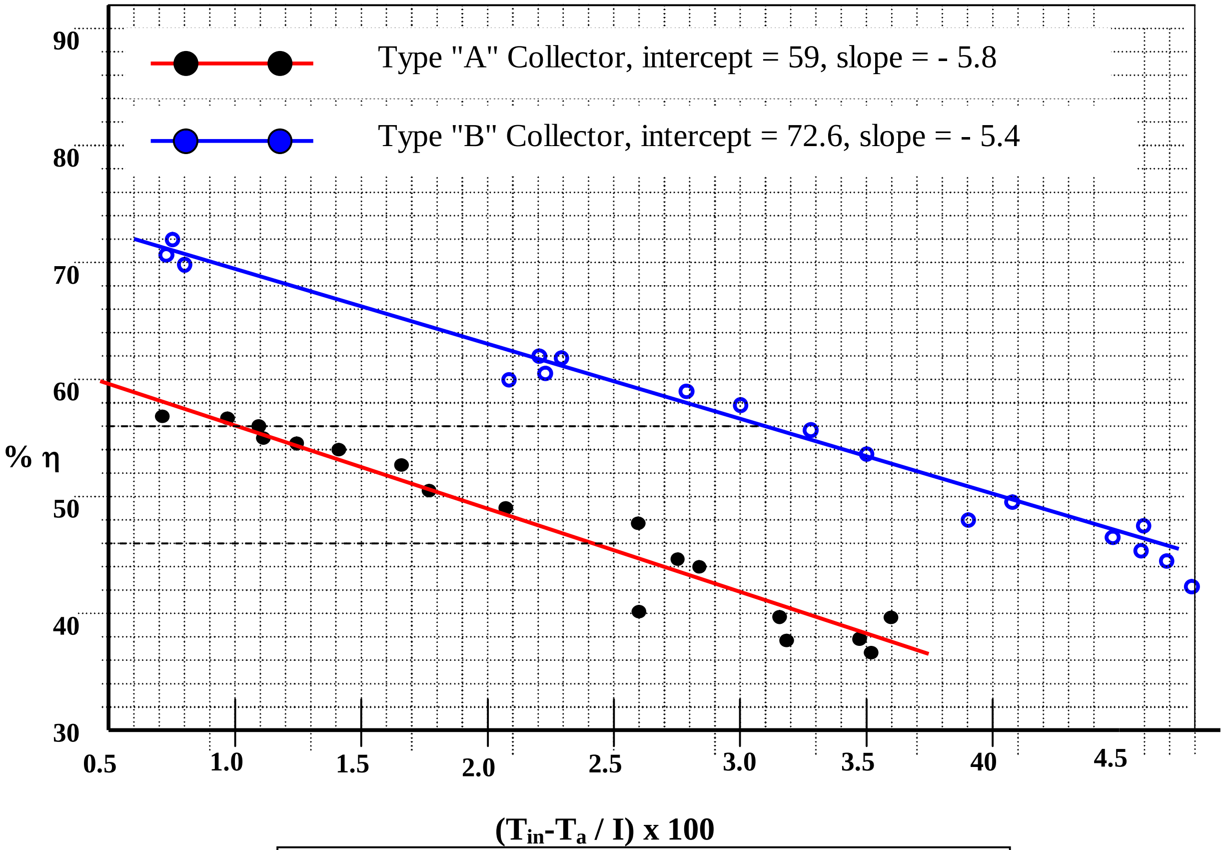


Fig. (4-1) : Plate Efficiency vs. ($\Delta T_{in,\,a}/I$)

The basic equations to be used are (4-6) and (4-7):

$$Q_u = A_c F_R q_{ab} - A_c F_R U_L (T_i - T_a)$$

$$\eta = \frac{Q_u}{A_C I} = F_R(\tau_o\alpha_o) - F_R U_L (\Delta T)_{av}/I_{av}$$

A_C =collector area (m^2); $\Delta T_{av} = \sum (T_i - T_a)/20\,(°C)$; $I_{av} = \frac{\sum I}{20}\,(wm^{-2})$

Substituting values of the various parameters in equation (4-6), for:

Type A plate: Q_u = (1)(0.59)(659) – (1)(5.8)(12.5) = <u>321</u> wm^{-2}

Intercept = $\alpha \tau$ = 0.59, and using (τ = 0.88) gives **α_A = <u>0.67</u>**

Type B plate : Q_u = (1)(0.73)(659) – (1)(5.4)(19) = <u>378</u> wm^{-2}

Intercept = $\alpha \tau$ = 0.73, and using (τ = 0.88) gives **α_B = <u>0.83</u>**

The result obtained on the two types of plate (type B coated with black paint, type C coated with Rhodonite (MnSio3, manganese))are presented in table (4-6) below.

Table (4-6) Data obtained on type (B) and type(C)

Time (hour)	Temperature (ºC) Type (B)	Temperature(ºC) Type (C)
9:00	36	37
10:00	38	39
11:00	40	42
12:00	41	43
1:00	42	44
2:00	45	46
3:00	47	51
4:00	43	48
Average	41.5	43.6

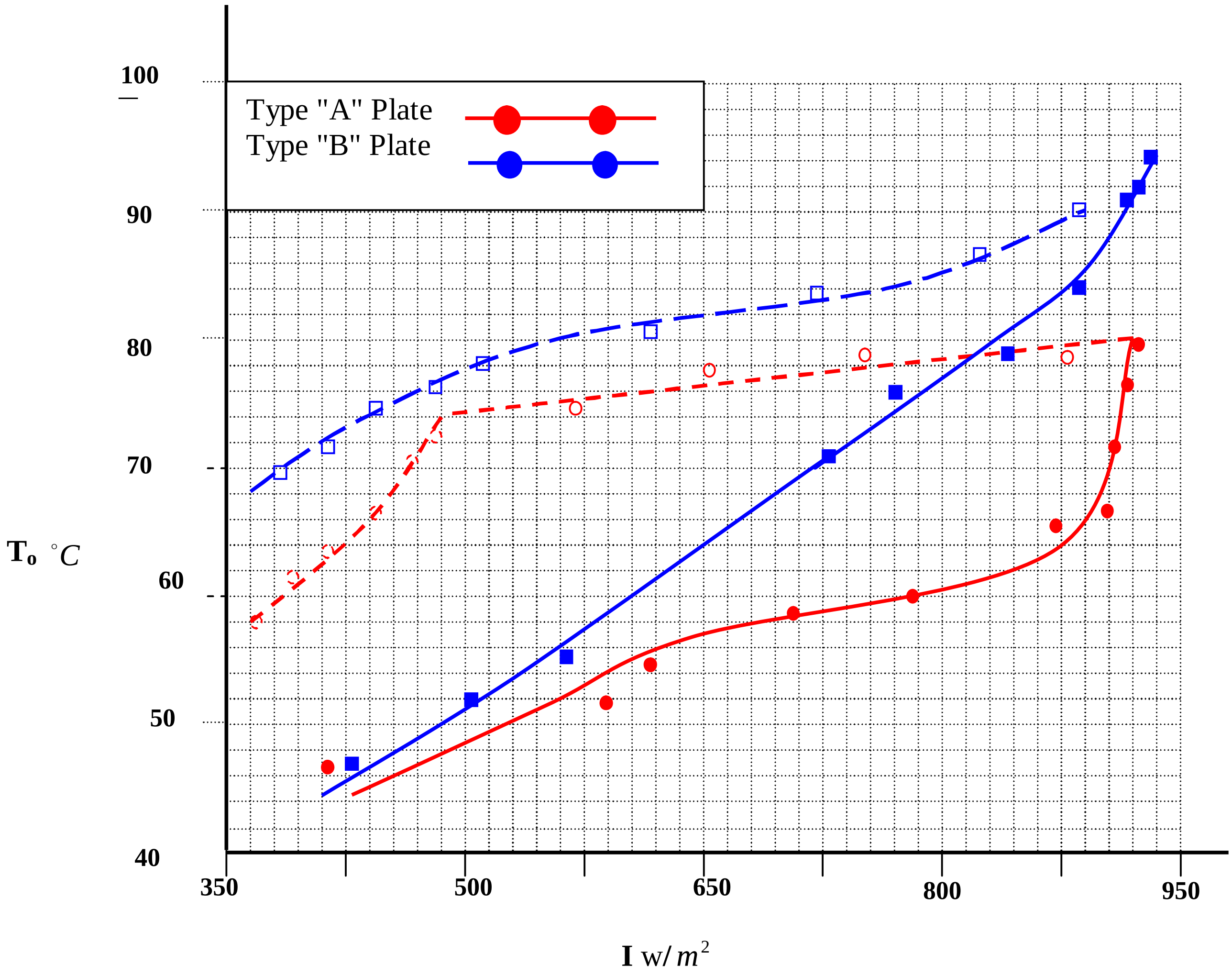


Fig. (4-2) : Variation of Outlet Temperature (T_o) with (I)

Chapter V

DISCUSSION & RECOMMENDATION

(5-1) Discussion:

Tables (1) and (2) show the recorded temperatures for the two types of flat-plate collector (A and B). They also show average wind speed (velocity) during the day and the incident, incoming insolation .It is noticed that the outlet water temperature rises with the incoming solar energy .In type (A) collector maximum outlet water temperature was found to be (80.1 °C) at 1:30 pm, whereas in type (B) the temperature was higher (93.8 °C) which indicates that higher temperatures are attainable when the plate is coated with black paint. Tables (3) and (4) give the calculated values of the collector efficiency (η) and the difference between the ambient temperature and inlet temperature and the received solar energy (I). The relation between these is shown by scatter Fig. (4-1), which shows that the efficiency for Type (A) rises gradually to reach the peak value of (56 %) at mid-day, then starts to fall to approximately a constant value; for Type B the peak value is (73 %). The difference of 23 % in the maximum efficiency is again attributed to the paint coating.

A more fundamental improvement due to the coating is found in the difference in the calculated absorptivity: 0.67 for Type A, and 0.83 for type B, which means an improvement of 19 %.

A plot of (T_o) against the incoming insolation is shown in Fig. (4-2). It shows that two trends exist, one before noon and the other in the afternoon. In all cases the attainable outlet temperature is higher for the coated plate than the uncoated one. Again this demonstrates the definite superiority of the coated plate.

Fig. (4-1) shows that the efficiency for both types of plate decreases continuously with decrease in the ratio (T_{in} – T_a)/I. However, Fig. (4-2) indicates that for equal values of (I), the attainable (T_o) is higher in the afternoon than in the morning-noon interval, an unexpected result!! The opposite has been expected.

Was noticed from table (4-6) that the heat energy of plate surface of type(C) was found to be slightly higher than of type (B).

It is obvious that the rough surface of manganese painted plate is able to absorb more radiation energy and in the same time reduces the loss by reflection .In the case of type (B), the smooth black paint reflects some of the falling rays.

(5-2) Conclusion:

The experimental data provided by this study demonstrates that black greatly improves the performance of flat plate collectors by improving the absorptivity of the surface. An attempt to evaluate the effect of increasing insolation on the efficiency has not been successful; probably, because many parameters intervene in relating these two quantities.

It is also found that the temperature of surface of manganese painted plate (Type C) is higher than that of the surface painted with black paint.

(5-3) Recommendations:

1. In the present study, application of a black paint has improved the efficiency by a factor of about 23 %. This is significant, but not satisfactory. The total design of the collector is involved. Reduction of the heat loss factors (F_R) and (U_L) increases the useful energy (Q_u), and hence the efficiency. Further work to improve the design is recommended.

2. There has been an improvement in the fundamental parameter (α), the absorptivity, up to a maximum of 0.83, an improvement of 19 %. This

implies a large loss of energy. An absorptivity of over 0. 90 is needed to capture most of the solar radiation. This is attainable through the application of "selective surfaces" which provide high (α) and low (ε). Further work to develop techniques of applying such surfaces is highly recommended.

Table (7) constant values

parameter	Miens	value
g	gravitational constant	($9.8\ m/s^2$).
σ	Boltzman constant	$5.67 \times 10^{-8} w/m^2 K^4$
k	Thermal conductivity of fiber glass	$0.048\, w/m^{\circ}C$
$\alpha_{\circ}$	absorptivity of copper	0.77
$\tau_{\circ}$	transmissivity of glass	0.88
$\alpha_{\circ}$	absorptivity of galvanize steel	0.89
$\alpha_{\circ}$	absorptivity of paint	0.97
β	Collector tilt angle	15
k	Thermal conductivity of copper	$383\, w/m^{\circ}C$
D	Diameter of copper	0.015m

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