Re-designing of Solar Collector Using Newly Developed Insulations and Materials

by

Mohd Farid bin Md Aris

Dissertation Report in partial fulfillment of
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Universiti Teknologi PETRONAS
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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Farid bin Md Aris

ABSTRACT

A solar collector is a device that utilizes the solar radiation to heat a fluid (usually water or air), which can be used for suitable application. This is done by absorbing the solar radiation on an absorber plate and thus heating it. This heat is then transferred to a circulating fluid for use elsewhere.

In this project, the author has to re-design the existing solar collector using new materials. The main objective of this project is to improve the performance of solar collector by increasing the water temperature inside of the solar collector.

This report consists of five main topics that are introduction, literature review and theory, methodology of project work, result and discussion, lastly conclusion and recommendations. In the chapter 1, introduction part, background of the study in defined along with problem statement and objective of this project. While in the second chapter there are literature reviews and theories involved in this project. For the chapter three, the author discussed about the methodology been used to complete this project. After that there is chapter 4, which is result and discussion of this project. Last chapter of this report is conclusion and recommendation.

In completing this project, lot of research and literature in internet, books and journal has been done by author in order to get the information about this topic throughout this project. The author also used AUTOCAD softwares to design the flat-plate solar collector before work out to make a working model of flat-plate collector. Finding that the author discovered, in a way to increase the efficiency of solar collector, he found a way to increase the heat gain and decreasing the heat loss from solar collector.

ACKNOWLEDGEMENT

In the name of Allah, The Most Merciful and The Most Gracious. First and foremost, I thank to Allah, as with His blessings I was able to complete my Final Year Project (FYP).

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To my beloved parents, thank you for your full support and advice that make my task easier. They are very helpful to me and understanding through out this project. My special thanks also go to my housemate especially Mr Amirul Mukminin bin and Mr Syahril Izwan bin Sulaiman with their help and kindness. Also to all my colleagues who directly and indirectly contributed to this project, thank you for your support and cooperation.

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Nomenclature

A	area, m^2
A_c	cross-sectional area, m^2
c	specific heat, J/kg; speed of radiation
d	diameter, m
E	thermal internal energy, J
Gr	Grashof number
g	gravitational acceleration, m/s^2
h	convection heat transfer coefficient, $W/m^2.K$; Planck's Constant (J/s) 6.625×10^{-34}; height, m
h_c	convective heat transfer coefficient, $W/m^2.K$
k	thermal conductivity, W/m.K
L, *l*	length, m
m	mass, kg
Nu	Nusselt number
Pr	Prandtl number
P	pressure, kPa
Q	energy transfer, J
q	heat transfer rate, W
q'	heat transfer rate per unit length, W/m
q"	heat flux, W/m^2
Ra	Raleigh number
Re	Reynolds number
T	temperature, K
t	thickness
U	overall heat transfer coefficient, W/m^2
V	volume, m^3; fluid velocity, m/s
v	frequency, s^{-1};
w	width, m
α	thermal diffusivity, m^2/s
β	volumetric thermal expansion coefficient, K^{-1}
ε	emissivity
γ	radii, m; kinematic viscosity; m^2/s
λ	spectral
ΔT	temperature difference, K

CHAPTER 1
INTRODUCTION

Background of Study

Solar energy has the potential to be a major alternative to the fossil fuels. The energy density of solar radiation at earth's distance from the sun averages 1353 joules per second per square meter. Some of this energy is deflected and absorbed in earths' atmosphere. On a sunny day at ground level we received about 1000 joules of energy per second (1000 watts of power) per square meter perpendicular to the sun. (reference 4)

Solar energy is becoming a practical source of heat for heating water, homes and commercial buildings. There are already many devices which use solar energy to produce electricity. Solar energy is one of he most promising of the alternative energy sources.

Most of our present energy sources are indirect uses of the sun's energy. The burning of fossil fuels releases solar energy stored millions of years ago. Even though most energy now in use originated from the sun, the term "solar energy" is commonly used to describe the direct control of the sun energy. There are several types of solar collectors used for residences. These are flat-plate, evacuated-tube and concentrating collectors.

Solar collectors transform solar radiation into heat and transfer heat to a medium (water, solar fluid, or air). Then solar heat can be used for heating water, to back up heating systems for heating swimming pools. A typical flat-plate collector is a metal box with a glass or plastic cover (called glazing) on top and dark-colored absorber plate on the bottom. The sides and bottom of the collector are usually insulated to minimize heat loss.

Before the author understands more about solar collector, firstly he must understand the nature of heat and temperature and how heat (thermal energy) moves from one place to another. Heat moves naturally from ward to colder areas. Heat has three ways of moving from one place to another, which are conduction, radiation and convection.

Problem Statement

Problem Identification

Now-a-days a lot of people use solar collectors in their homes. But it is still new technology that we can improve it. The existence of solar collector can only increase the temperature of solar around 30-45^{0}C. But more research and development is needed to make sure solar-produced electricity more economical. In this project the author was assigned a task to improve the performance of the solar collector by increasing the temperature in the solar collector. Besides that the author has to come out with a working model of solar collector.

Significance of the Project

This project gives a better understanding to the author about the working principle of the solar collector and heat transfer. Besides that this project give a opportunity for the author know how to do a research and paper work since this project is an individual project. At the end of this project, the author will come out with a working model that has been developed. Last but not least, improvement of the solar collector can be seen by increase of the temperature of water inside solar collector.

Objectives and Scope of Study

Objectives

The duration of this project is one year and these are the objectives to be accomplished:

- ✓ To increase the temperature of the water inside the solar collector.
- ✓ To study the basic and working of solar collector especially solar flat-plate.
- ✓ To study the mechanism of heat transfer of the solar flat-plate collector
- ✓ To apply knowledge about heat transfer and others in completing this project.
- ✓ To provide the prototype Transparent Insulated Flat-plat Solar Collector

Scope of Study

Within through out a year, this project focused on flat-plate solar collector. The author tried to increase the temperature of flat-plate solar collector from the existence one. The scope of study for this project involving the basic working principle of flat-plate collector. Besides that the heat transfers calculation involving heat loss such as conduction, convection and radiation losses. The author also must know the materials been used in making working model of solar collector to accomplish this project at the end of time duration.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLAR COLLECTOR

Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid or air). Then solar heat can be used for heating water, to back up heating systems or heating swimming pools. The heart of a solar collector is the absorber, which is usually composed of several narrow metal strips. The carrier fluid for heat transfer flows through a heat-carrying pipe, which is connected to the absorber strip.

Absorbers are usually black, as dark surfaces demonstrate a particularly high degree of light absorption. The level of absorption indicates the amount of short-wave solar radiation being absorbed that means not being reflected. As the absorber warms up to a temperature higher than the ambient temperature, it gives off a great part of the accumulated solar energy in form of long-wave heat rays.

The ratio of absorbed energy to emitted heat is indicated by the degree of emission. In order to reduce energy loss through heat emission, the efficient absorbers have a selective surface coating. This coating enables the conversion of a high proportion of the solar radiation into heat, simultaneously reducing the emission of heat.

Solar collectors are usually roof mounted and once installed are difficult to reach for maintenance and repairs. They must firmly attached to the roof in a leak-proof manner and then must withstand everything that nature can throw them –acid rain, sea spray, and hailstones. They also have to be proof against internal corrosion and very large temperature swings.

2.2 MOVEMENT OF HEAT (THERMAL ENERGY)

Before we proceed on solar collector, we first must understand the nature of heat and temperature and how heat been transferred or moved from one place to another. Heat moves naturally from warm to colder areas. It always seeks to balance or "even out" the temperature of objects and substances. For example the air outside your home may be colder than the air inside. In this case, the inside heat will seek every possible route to flow to the outside. When it is hotter outside than inside, heat will attempt to flow into your home.

This movement can be understood as the movement of molecules. The warmer air has faster-moving molecules meet the slower ones; they give the slower-moving some of their speed. All molecules will then move at the same speed, which is the average speed of both sets of molecules. The warm air has given some of its heat (speed of molecules) to the colder air. The result is an in-between temperature. The tendency to balance the temperature by heat flowing from warm to cold always takes place. Heat has three ways of moving from one place to another:

- Conduction
- Radiation
- Convection

2.2.1. Conduction

The movement of heat through a substance is called conduction. It is the way heat travels through an object. Different materials conduct heat as different rates. Metals conduct heat well. Materials that slow down heat flow are called insulators. The denser the material, the more quickly the heat can move through it.

Density refers to how closely the molecules of a substance are packed together. It is the number of molecules in a given volume. For example, concrete permits a quicker passage of heat than wood because it has greater density. Closely packed molecules collide more easily and more often than loosely packed molecules and thus transfer heat energy more quickly.

When an object is heated, it will share its heat energy with everything around it until everything is at the same temperature. If something hot is touching less hot, heat energy will be transferred by conduction.

2.2.2. Radiation

Heat also can move by electromagnetic waves. These heat waves can pass through space and air without being absorbed. This form of heat is called radiation. Through radiation, heat moves from warm objects to cooler ones. It does this with minimum warming of the air in between.

Heat and light travel from the sun through space as radiant energy (electromagnetic waves). These waves do not heat the atmosphere; they just pass through it. When radiant energy hits a dark object such as the earth or an interior wall, the object absorbs the radiant energy and becomes warmer.

The dark object than radiates heat, but at a much longer wavelength than the radiant energy from the sun. The dark object also heats the surrounding air. This is one reason why the air near the ground is warm, and gets colder the higher you go. Air is warmed by the heated surface of the earth rather than directly by the sun.

2.2.3. Convection

A third way that heat may be transferred is by convection. Convection is the moving heat from warmer to colder areas by air, water or other fluids. Heated air or water will always move to colder area. Once there, the fluid will lose its heat.

In convection, a warming and cooling process causes fluid movement. As a fluid warms up, its molecules move faster. The motion pushes the molecules apart and expands the fluid. The fluid now occupies a greater space. Therefore, it is lighter. It has less density.

Warm, light fluid rises. Colder, heavier fluid replaces it. When warm fluid touches a colder object, it transfers heat to that object. The fluid then cools and becomes more dense or heavier. Gravity pulls the cooler fluid down. The fluid heats up again and the cycle repeats.

Air convects heat well only under certain condition. The air must have enough room to set up currents (air movements). On the other hand, air trapped in a small space is a good insulator. Trapped air must transfer heat by conduction. Air molecules are much farther apart than molecules of a solid. Therefore, air will help keep warm objects warm and cool objects cool.

These principles also explain how the air surrounding the earth is warmed and cooled to cause wind. As mentioned in the section on radiation, the radiant energy from the sun warms the earth. The earth in turn warms the air closest to the ground. This air becomes lighter in weight (less dense) and moves up. Colder, heavier air sinks to replace the warm air. This air movement is wind.

2.3 TYPES OF SOLAR COLLECTOR

There are a few types of solar collector now days. The followings are the most common hardness test methods used in today's technology:

1. Flat-plate solar collector
2. Evacuated tube collector
3. Concentrating collector

2.3.1. Flat-plate Solar Collector

Flat-plate collectors are the most common collector for residential water-heating and space-heating installations. A typical flat-plate collector is an insulated metal box with a glass or plastic cover—called the glazing—and a dark-colored absorber plate.

The glazing can be transparent or translucent. Translucent (transmitting light only), low-iron glass is a common glazing material for flat-plate collectors because low-iron glass transmits a high percentage of the total available solar energy.

The glazing allows the light to strike the absorber plate but reduces the amount of heat that can escape. The sides and bottom of the collector are usually insulated, further minimizing heat loss.

The absorber plate is usually black because dark colors absorb more solar energy than light colors. Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar radiation into heat energy.

The heat is transferred to the air or liquid passing through the collector. Absorber plates are commonly covered with "selective coatings," which retain the absorbed sunlight better and are more durable than ordinary black paint.

Absorber plates are often made of metal- usually copper or aluminum—because they are both good heat conductors. Copper is more expensive, but is a better conductor and is less prone to corrosion than aluminum.

Flat-plate collectors fall into two basic categories: liquid and air. And both types can be either glazed or unglazed.

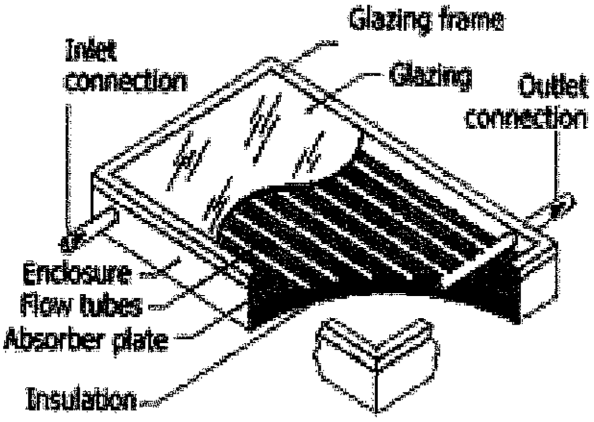


Figure 2.3.1: Flat Plate Collector

2.3.2. Evacuated Tube Collector

Evacuated-tube collectors heat water in residential applications that require higher temperatures. In an evacuated-tube collector, sunlight enters through the outer glass tube, strikes the absorber tube, and changes to heat. The heat is transferred to the liquid flowing through the absorber tube.

The collector consists of rows of parallel transparent glass tubes, each of which contains an absorber tube (in place of the absorber plate in a flat-plate collector) covered with a selective coating. Evacuated-tube collectors are modular—tubes can be added or removed as hot-water needs change.

When evacuated tubes are manufactured, air is evacuated from the space between the two tubes, forming a vacuum. Conductive and convective heat losses are eliminated because there is no air to conduct heat or to circulate and cause convective losses.

There can still be some radiant heat loss (heat energy will move through space from a warmer to a cooler surface, even across a vacuum). However, this loss is small and of little consequence compared with the amount of heat transferred to the liquid in the absorber tube.

Evacuated-tube collectors are available in a number of designs. Some use a third glass tube inside the absorber tube or other configurations of heat-transfer fins and fluid tubes. One commercially available evacuated-tube collector stores 5 gallons (19 liters) of water in each tube, eliminating the need for a separate solar storage tank. Reflectors placed behind the evacuated tubes can help to focus additional sunlight on the collector.

These collectors are more efficient than flat-plate collectors for a couple of reasons. First, they perform well in both direct and diffuse solar radiation. This characteristic, combined with the fact that the vacuum minimizes heat losses to the outdoors, makes these collectors particularly useful in areas with cold, cloudy winters.

Second, because of the circular shape of the evacuated tube, sunlight is perpendicular to the absorber for most of the day. For comparison, in a flat-plate collector that is in a fixed position, the sun is only perpendicular to the collector at noon. While evacuated-tube collectors achieve both higher temperatures and higher efficiencies than flat-plate collectors, they are also more expensive.

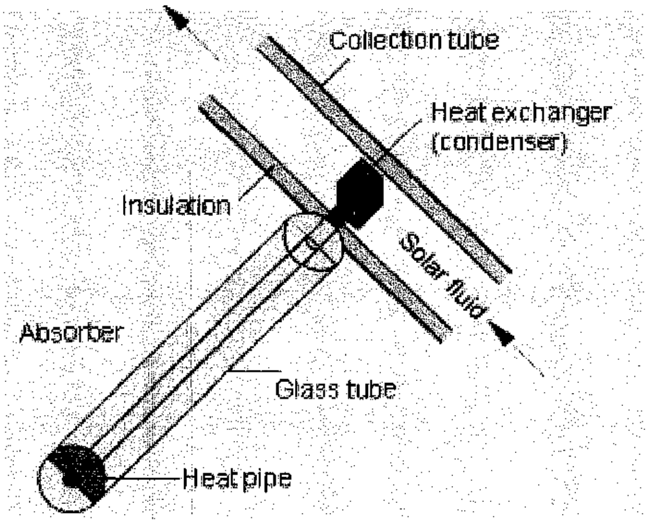


Figure 2.3.2: Evacuated Tube Collector

2.3.3. Concentrating Collector

Concentrating collectors use mirrored surfaces to concentrate the sun's energy on an absorber called a receiver. Concentrating collectors also achieve high temperatures, but unlike evacuated-tube collectors, they can do so only when direct sunlight is available.

The mirrored surface focuses sunlight collected over a large area onto a smaller absorber area to achieve high temperatures. Some designs concentrate solar energy onto a focal point, while others concentrate the sun's rays along a thin line called the focal line. The receiver is located at the focal point or along the focal line. A heat-transfer fluid flows through the receiver and absorbs heat.

These collectors reach much higher temperatures than flat-plate collectors. However, concentrators can only focus direct solar radiation, with the result being that their performance is poor on hazy or cloudy days. Concentrators are most practical in areas of high insolation (exposure to the sun's rays), such as those close to the equator and in the desert southwest United States.

Concentrators perform best when pointed directly at the sun. To do this, these systems use tracking mechanisms to move the collectors during the day to keep them focused on the sun. Single-axis trackers move east to west; dual-axis trackers move east and west and north and south (to follow the sun throughout the year).

In addition to these mechanical trackers, there are passive trackers that use freon to supply the movement. While not widely used, they do provide a low-maintenance alternative to mechanical systems.

Concentrators are used mostly in commercial applications because they are expensive and because the trackers need frequent maintenance. Some residential solar energy systems use parabolic-trough concentrating systems.

These installations can provide hot water, space heating, and water purification. Most residential systems use single-axis trackers, which are less expensive and simpler than dual-axis trackers.

2.4 HONEYCOMB OR TRANSPARENT INSULATION

Honeycomb consists of an array of open cells, formed from very thin sheets of materials attached to each other. Honeycomb closely resembles the bee's honeycomb found in nature, from which it gets its name. It can be made from any thin flat material. The most common cell configuration is the hexagon but there are many other shapes for special applications.

The honeycomb panel can be made to transmit heat right through the panel or act as an insulating panel. The heat is transmitted from one side to the other: heat conduction through the honeycomb cell walls, radiation from one facing to the other, and air convection currents in the cells.

In certain cases, as in some space applications, both facings should be the same temperature to prevent panel thermal bending. If a very flat panel is desired and if one skin is hotter than the other or they have different coefficients of thermal expansions, the panel will bow. The thermal conductivity coefficients (k) of several honeycomb types are given in the Table 2.4.1. Notice that by filling cells with an insulating material such as foam or fiberglass the 'k' value can be approximately half. This is due to the fact that the air convection currents and radiation effects are eliminated. The heat now travels by conduction through the cell walls and insulating filler.

k(BTU.in./(h.ft^2.^{0}F))		
Core Type	Unfilled cells	Filled cells
Fiberglass	0.6	0.35
Nomex	0.5	0.30
Kraft paper	0.7	0.40
Aluminum	75.0	-

Table 2.4.1: Honeycomb Thermal Conductivity Coefficients (reference 6)

Heat transmission through unfilled honeycomb core is the sum of the flow through the cells walls and air spaces. The flow through the cells is by conduction, convection and radiation. The standard honeycomb cell sizes are such that the air convection current effects are significant; the smaller the cell, the more constricted the air current, thus the lower the heat transfer by this mode. The thermal resistance is also influenced by the direction of the heat flow and orientation of the panel. This is due mainly to the fact that warm air rises, thereby carrying heat in an upward direction more easily.

Honeycomb filled with insulating material eliminates the convection and radiation modes of heat transfer, but now transfers the heat by conduction. Generally, the fill materials have better insulating properties than the core materials; consequently a large cell, low density core filled with a good insulating material has a relatively low *k* value. Since the heat seeks the path of least resistance, the fewer cores the better *k* value will be.

For metal honeycomb the conductivity of the web is usually much greater than that of the air within the cells. For example, the thermal conductivity of aluminum is 8750 times that of air. Furthermore, in the case of aluminum core, both convection and radiation are usually negligible compared with heat conduction through the cell walls. The thermal resistance of metallic honeycomb is then approximately that of a solid block of the cell wall material of the same thickness times the ratio of the honeycomb cell wall area to the total area.

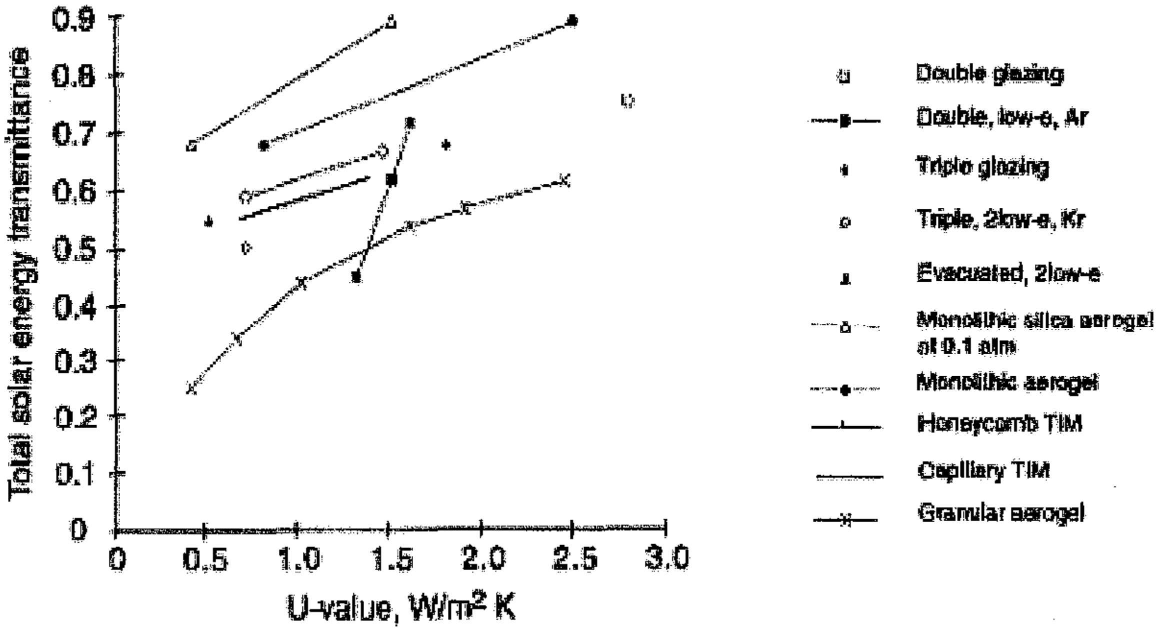


Figure 2.4.1: Solar Energy Transmittance/Heat Loss Coefficient for low U-value Glazing Systems (reference 6)

In nonmetallic cores such as Kraft paper, Nomex and fiberglass reinforced plastics; the method of heat transmission is more involved. Here the thermal conductivity of the web no longer dominant. In fact it is of the same order of magnitude as that of the air for the fiberglass honeycomb and several orders of magnitude less than air in the case of paper honeycomb cores.

For fiberglass core, the cell sizes are usually small enough so that air convection within the cells is relatively negligible and the principal modes of heat transfer are thus conduction and radiation. For Kraft paper honeycomb the cell sizes of interest are such that convection effects are significant. The thermal resistance is therefore influenced by the direction of the heat flow, as well as by the other factors.

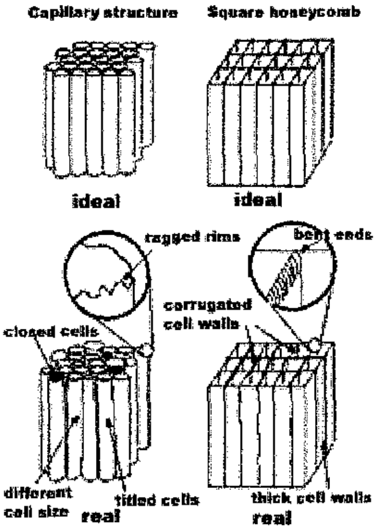


Figure 2.4.2: Honeycomb (reference 6)

CHAPTER 3

METHODOLOGY AND PROJECT WORK

During one whole year working on this project, the author did a lot on research. There are 3 main stages the author describe his project work. First stages are finding information about this project, and any relevant information that related to his topics such as heat transfer, how the working principle of solar collector and calculation on heat loss for flat plate. The author finds all info from internet, books and journals in Recourse Center of UTP. A second stage is the design stage to make a working model. The author uses AUTOCAD to design the flat-plate solar collector. The last stages is making the working model that sizes of surface area, A_c 1.5 M x 1 M

Based on the design using AUTOCAD, the author manages to make a working model. First of all, the author makes the casing or box of flat-plate collector. The author using plywood with thickness 10 mm. Then the author search for copper tube and cooper pipe for header and riser of flat-plate collector. First of all, the author had to straighten the copper tube since it is sold in a roll. After that the author connects both the end all the tube copper with copper pipe. The Gantt chart is in Appendix B.

3.1 EQUIPMENT AND MATERIALS:-

- ✓ Riser - Copper tube inner diameter = 8mm. t= 0.35mm
  Spaces between the risers: 150mm
  Operating Temperature Range: Max. 300^0C (572^0F)
  Fluid: Water
- ✓ Absorber – Copper sheet, t=0.7mm
  Operating Temperature Range: Max. 300^0C (572^0F)
  Solder: 95/5 tin antimony
  Operating Temperature Range For Solder: Min -50^0C (-58^0F); Max. 400^0C (752^0F)
- ✓ Header – Copper pipe inner diameter = 22mm, length = 1.2m
- ✓ Casing – Plywood, t=20mm for side and bottom.
- ✓ Top cover – Single glazing, t=4mm, low iron tempered glass.
  Refractive Index: 1.526

Operating temperature range: Min: below-46^0C (-51^0F); Max: 260^0C (500^0F)

Durability: Glass is chemically inert to most chemical solvent and staining agents, and is resistance to surface weathering, ultraviolet and thermal degradation and moisture damage.

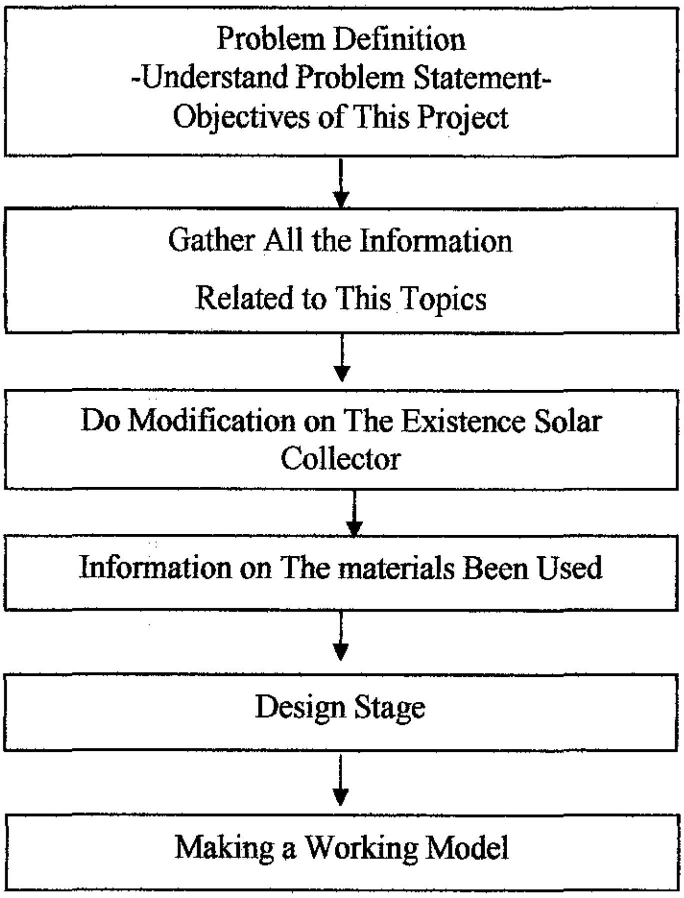
Tensile strength: Design pressure is 2.87kPa (0.416psa) or 1/8 inch glass with a design factor of 2.5. Tensile strength is 152 MPa 22,000psa) with a 2.5 safety factor.

- ✓ Insulation – Fiberglass, k=0.036W/m^0C at 24^0C (75^0F) for both sides and bottom.

  Thermal Resistance: RSI 0.7^0C.m2/W at 24^0C (75^0F)

  Operating Temperature Range: Maximum continuous operating temperature is 232^0C (450^0F)
- ✓ New features installed – transparent insulation, that is using straws
- ✓ Gauge – wire to support a bundle of straws (honeycomb) below the glass
- ✓ Screw and nails.

3.2 PLAN & SCHEMATIC FLOW PROCESS OF THE PROJECT



3.3 ASSEMBLY OF THE FLAT-PLATE SOLAR COLLECTOR

1. Cut the plywood; treat all sawn ends with a good quality timber preservative.
2. Paint the collector panel using as thin a coating as possible of high temperature, black, oil base paint (black car exhaust paint is a good suggestion).
3. Glue and screw the sides together
4. Glue and screw the backing plywood onto the frame.
5. Screw the corner plates into position.
6. Glue and screw (from the back) the cross braces into position.
7. Drill a number of 24 mm drain holes in the lower side, just in front of the insulation.
8. Lay the panel in position within the case marks the position of the pipe entry points on the frame. Remove the absorber and drill the holes for the pipe entries.
9. Cut and fit the insulation between the cross braces and the case.
10. Put the copper sheet at top of the insulator.
11. If not being built in position, this is a good time to position and secure the case.
12. Lay the panel in the case and secure using the holding down blocks on the cross braces.
13. Fit the pipe work between the panel and the rest of the system; fill the gaps around the pipes where they enter the case using a suitable flexible sealant.
14. It's probably best to leave the front cover off until the system has been filled with water and the system checked for leaks.
15. Fit the glazing retaining clips to the lower side of the case.
16. Using putty or glazing tape, fit the front cover and secure by screwing strips to the sides of the case.

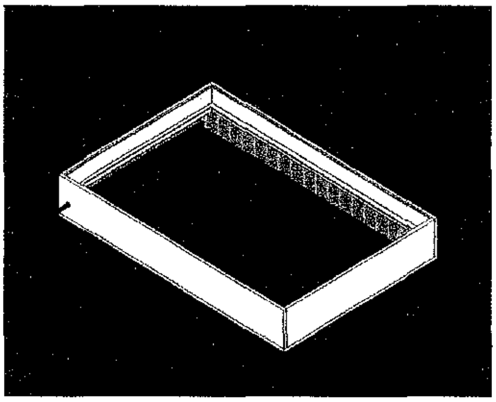


Figure 3.3.1: The Flat-plate Collector

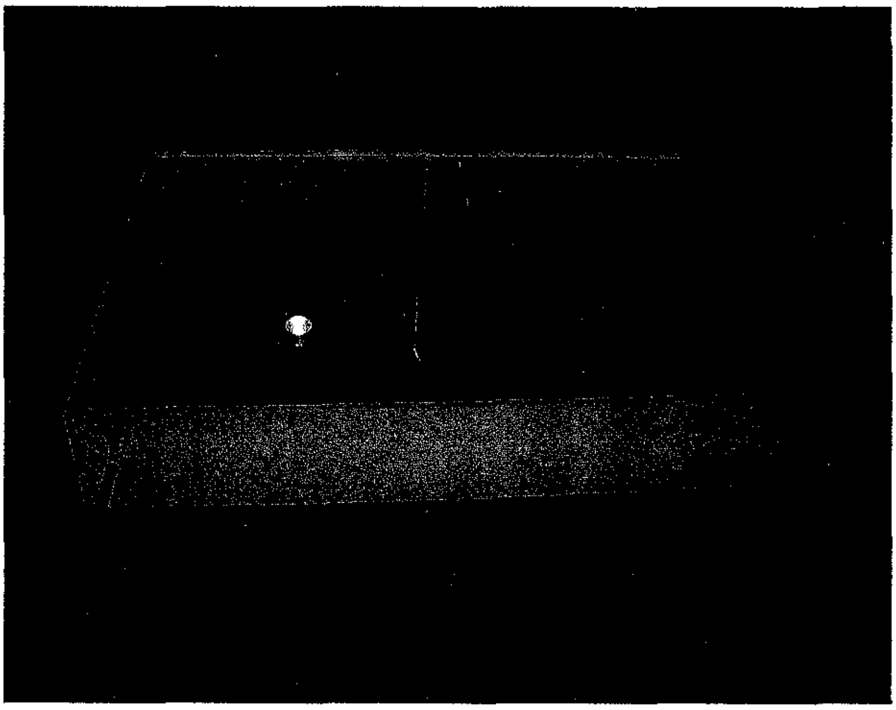


Figure 3.3.2: The Real Model of Flat-plate Collector

3.4 METHODOLOGY ON COLLECTING DATA TESTING MODEL OF FLAT-PLATE COLLECTOR

1. Position the flat-plate collector inclination of 20^0 from the floor.
2. Put the halogen lamp on top of the flat-plate collector.
3. Connect the water inlet to the pipe and water outlet to the container
4. Switch on the halogen lamp and turn on the pipe so that water can go into the water inlet.
5. Take temperature of water inlet and water outlet at the beginning of the experiment

6. The water that been used at the water inlet of collector is not circulating water from the container (water from outlet). So the inlet water of collector is constant.
7. Take the temperature outlet of the collector every 30 minutes.
8. This testing is done two types of condition, which are; flat-plate collector with transparent insulation and flat-plate collector without transparent insulation.
9. After collecting data for both condition, tabulated the data and from the data, the author comes out with a graph for both condition.
10. Analysis the graph and data that has been collected.

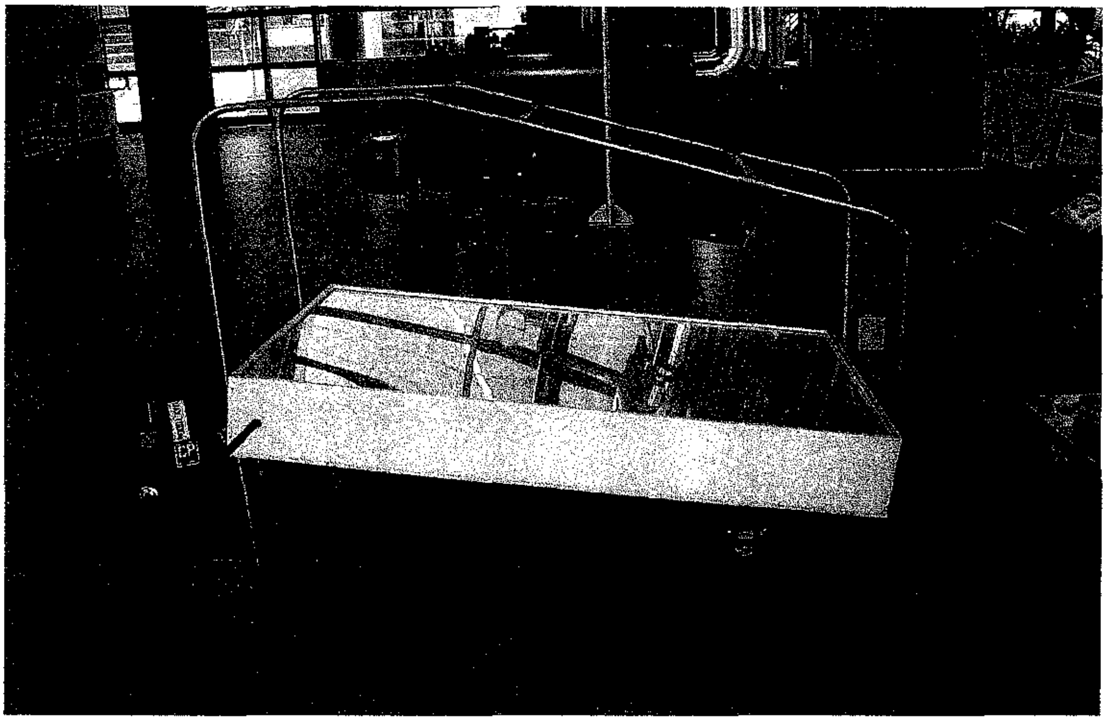


Figure 3.4.1: The Position of Flat-plate Collector and The Halogen Lamp.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 BASIC PRINCIPLE OF OPERATION OF A FLAT SOLAR COLLECTOR

The basic working principle of a flat plate solar collector is explained by the following steps:

A. Consider a rectangular metal plate painted black on its top surface, placed at an angle to the horizontal and exposed to sun's rays. Solar radiation strikes the black surface. A part of the radiation is absorbed and the remaining is reflected (as the plate is opaque, none is transmitted through the plate). Due to absorption, the plate temperature rises above the ambient. The metal plate absorbs solar radiation and hence can be called the absorber.

To attain thermal equilibrium with the surroundings, the plate loses heat by two means; by convection to the air in the vicinity of the plate and by radiation to the sky. The convective heat transfer is mainly due to wind, while the radiative heat transfer takes place at longer wavelength (infra red). The aim is to attain high temperature in the plate.

The plate should have the property to absorb all the radiation falling on it (or at least the major part of the solar spectrum) and reflect no (or a minimum) radiation. This would maximize the input energy to the plate and therefore, requires a study of the absorption capability of the absorber plate.

The losses due to convection and radiation should be minimized as much as possible. The convective loss will be due to wind to the ambient; while the radiation loss will be to the sky. The plate should be oriented in such a manner to receive maximum radiation for achieving maximum output. This requires a study of solar radiation on tilted surfaces and the optimization of the tilt angle.

B. The thermal energy of the plate has to be transferred to a working media for use. This could be done by bonding (welding or clamping) tubes (called riser tubes) on the bottom side (or at the top) of the metal plate along the length of the plate and through which a fluid (say, water) could be circulated. The two ends of the tube are connected to headers (horizontal pipes, which distribute and collect the water flow), which are connected to the storage tank containing the water to be heated.

Due to this arrangement, the absorber plate now transfers a part of its energy to the water in the tube (through the material of the tube and the joints of the tube and plate) and therefore, the water gets heated. This water (heated) becomes lighter and hence rises to the storage tank thus bringing in fresh cold water to the riser tube. This cold water receives heat from the absorber plate and rises and the process continues.

There is conduction heat transfer in the absorber plate and through the riser tube material. The heat transfer through the bond depends on whether the rises tube is welded or just mechanically pressed to the absorber plate.

There is convective heat transfer between the riser tube material and the water in the tube, and the heat transfer also depends on whether water is pumped or the circulation is by natural means.

There are convective and radiative losses as described in A from the absorber plate to the environment, even though the temperature of the plate will be lower (as a part of heat is taken from the plate by the circulated water) than A.

C. To improve the efficiency and reduce the losses, the bottom and the sides of the absorber plate (with riser tube) is insulated. This will reduce the heat loss at the bottom and thus the temperature of plate and, therefore, the temperature of water will rise than at B.

There will be conductive heat transfer through the insulation and convective and radiative heat transfer from the insulation to the surroundings. The convective and radiative losses at the top of the absorber plate remain the same.

D. To suppress the convective and radiative losses from the top, a glass cover is placed on top of the absorber plate. Glass has the property of being transparent in the visible spectrum of solar radiation and is opaque to infra red. Therefore, it allows most of the solar radiation to pass through, while not allowing the long wavelength radiation from the absorber plate to be radiated to the sky. Due to the air gap, the convective heat transfer is also reduced. This increases the efficiency of the system and thus produces a higher temperature lift of the water flowing in the rises tubes.

To know how much radiation passes through glass (to know the radiation incident on absorber plate), the transmittance of solar radiation through glass should be known (and also the reflectance and absorptance. The calculations are complicated by the spectral character of the incident radiation.

Due to the presence of a glass cover, convective currents will be set up between the absorber plate and glass cover and it is necessary to know how much heat transfer taken place between absorber plate and glass cover by convection. There will also be radiative heat transfer between the absorber plate and glass cover.

There will be convective heat transfer from glass to ambient and radiative heat transfer between glass and sky. Reflected radiation form absorber plate will be reflected from glass cover to the plate and also to the sky. Thus, there will multiple absorption & transmittance.

Thus, it can be seen that though the working of a flat plate solar collector is simple, the heat interactions are complex. However, in order to quantitatively assess the solar collector, this simple qualitative analysis will provide the necessary basis. The correlations and other considerations necessary will be discussed in the following sections.

4.1.1 Optical and Heat Transfer Correlations for Flat Plate Collector Analysis

The study of the flat plate collector (FPC) can now be divided into 3 major parts:

i. what is the input to the solar collector systems (SCS)?

ii. how much are the losses from SCS?

iii. what is the useful energy delivered by the SCS?

The details are as follows:

(i) Solar input:

In this section, the quantity of radiation transmitted by the glass (also considering the reflectance and absorptance of glass) as well as the radiation absorbed by the absorber plate will be discussed.

When radiate ion strikes a body, a fraction of it is absorbed, another fraction is reflected and a third fraction is transmitted. The fraction of the incident radiation that is absorbed is known as absorptance (α), the fraction that is reflected is known as reflectance (ρ) and the fraction that is transmitted is known as transmittance (τ).

$$\therefore \alpha + \rho + \tau = 1 \tag{4.1.1}$$

For a transparent material like glass, there exists a value for transmittance, absorptance and reflectance even though the transmittance might be very high. On the other hand, for an opaque surface like a metal plate, the transmittance is zero.

The input to the SCS is the total radiation incident on the glass cover, but it is of interest to know the quantity of radiation absorbed by the absorber plate. Of the total incident radiation on the glass cover,

- only a part (of the incident radiation) is transmitted through the glass, while the remaining is either reflected to atmosphere or absorbed by the glass and
- Of the transmitted radiation striking the absorber plate, a part is absorbed and the remaining is reflected.

To estimate the radiation absorbed by the absorber plate, the following information should be known: the incident global radiation on the collector (glass) surface, the transmittance of the glass to the incident radiation and the absorptance of the absorber plate (of the incident radiation). The methods for calculating transmittance and absorptance are discussed in the following sections.

Estimation of transmittance of the cover

In order to estimate the transmittance of the cover material (glass or plastic), it is necessary to know the reflectance and the absorptance of the cover because these materials possess the ability to reflect as well as absorb the radiation.

Reflectance

If we consider a glass plate and a ray incident on it at an angle θ then the expression for reflectance (ρ) on a single interface, which is the ratio between the reflected component of the beam radiation (I_ρ) and the incident beam radiation (I) is

$$\rho = \frac{I_\rho}{I} \qquad (4.1.2)$$

$$= \frac{1}{2}\left[\frac{Sin^2(\theta_2 - \theta_1)}{Sin^2(\theta_2 + \theta_1)} + \frac{\tan^2(\theta_2 - \theta_1}{\tan^2(\theta_2 + \theta_1)}\right] \qquad (4.1.3)$$

where, θ_1, θ_2 are the angles of incidence and refraction respectively.

These angles are related by Snells' law as

$$\frac{n_1}{n_2} = \frac{Sin\theta_2}{Sin\theta_1} \qquad (4.1.4)$$

where n_1, n_2 are the refractive indices of medium 1 (usually air) and medium 2 (usually glass) respectively.

If the incident radiation is in a direction normal to the surface (ie) θ = 0, then for a single surface,

$$\rho = \left[\frac{n_1 - n_2}{n_1 + n_2}\right]^2 \qquad (4.1.5)$$

⇒ In case of a single glass cover [(n_2 = 1.526) and for air (n_1 = 1)], ρ = 0.44, meaning that about 4.4% of the incident radiation is reflected from one surface. Thus, for single glass plate, the loss due to reflection of the incident radiation will be about 8.8% (4.4 % for each surface - top and bottom).

Normally, a flat plate collector has only one or a maximum of two glass covers.

For a system of N covers of the same material neglecting absorption by the material, the reflectance is given by

$$\rho_n = 1 - \frac{1}{2}\left[\frac{1-\pi_p}{1+(2N-1)\pi_p} + \frac{1-\pi_n}{1+(2N-1)\pi_n}\right] \qquad (4.1.6)$$

where,

$$\pi_p = \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 - \theta_1)} \, and \quad \pi_n = \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)}$$

and, therefore the transmittance through this system of covers (neglecting absorptance) is given by

$$\tau_{Nr} = 1 - \rho_N \qquad (4.1.7)$$

(i). The discussion on reflectance of cover material has been done by not considering absorption by cover material.

(ii). The reflection loss from glass cover can be significantly reduced by adding a surface film to the glass having a refractive index between glass and air. This is done by dipping the glass in a silica saturated fluosilicic acid solution to create a porous silica film on the surface if the glass. This treatment has been found to reduce the reflectance at normal incidence from about 8% to about 1% for ordinary glass.

Absorptance

While considering reflectance, it was assumed that the absorptance of glass of the incident solar radiation is zero. But, in reality, the absorptance is given by Bouguer's law, which states that the absorbed radiation is proportional to the intensity in the medium and the distance the radiation has traveled in the medium. Mathematically, the fraction α that is absorbed over a path length L in a medium of extinction coefficient K is given by,

$$1-\alpha = \exp(-KL) \tag{4.1.8}$$

If θ is the angle between the normal surface and the direction of light ray in a slab of thickness'd' then

$$L = d/\cos\theta$$

and the transmittance through one glass cover taking into account only the absorption cover (neglecting reflection) is given by

$$\tau_a = 1-\alpha = \exp(-KL) \tag{4.1.9}$$

and for a system of N covers, the same expression could be used for the estimation of transmittance with the path length taken for N covers together.

In glass, it is iron oxide that controls the color and the absorptivity of glass. Low iron glass containing about 0.05% iron oxide has an absorptance of about 2.5%, while ordinary window glass has an absorptivity of nearly 15% at normal incidence and these values will be higher at other incidence angles.

(ii) Collector losses:

The losses from the collector have been qualitatively described in the section "Basic principle of operation". Methods for calculating the heat losses in terms of the various heat transfer coefficients will be given in this section.

Heat loss due to conduction

Conduction is the transfer of heat through a material. For a flat plate solar collector, conduction transfer is found at (i) the absorber plate, (ii) heat transfer through the riser tubes (iii) heat losses through the back of the collector and (iv) heat loss from the hot liquid to the ambient through the walls of the pipes (in case of water) and ducts (in case of air).

Consider a plate of thickness 'x' and area of cross section 'A' with the left face at a temperature T_1 and the right face at temperature T_2 ($T_1>T_2$). Assuming that the direction of heat flow will be at right angles to the wall, the rate of heat flow (Q) is given by

$$Q = -R.A.\frac{dT}{dx} \qquad (4.1.27.a)$$

where, R is the thermal conductivity of the wall material and

dT/dx is the temperature gradient

As dT/dx is negative, Q will be positive

In case of composite walls (for example, when an insulator is added to a metal sheet to reduce thermal losses), the rate of heat transfer per unit area between two extreme faces can be estimated from

$$q = \frac{(T_1 - T_4)}{\frac{x_a}{R_a.A_a} + \frac{x_b}{R_b.A_b} + \frac{x_c}{R_c.A_c}} \qquad (4.1.27.b)$$

where, x_a,x_b and x_c are the thickness of the walls having thermal conductivities R_a, R_b and R_c respectively and the areas of the walls being A_a, A_b, & A_c respectively, while T_1 and T_4 are the extreme temperatures.

For pipes (solar thermal water heaters have pipes carrying hot water from collector to storage tank and it is necessary to minimize heat losses) with internal and external radii r_i and r_o and inside and outside wall temperatures T_i and T_o respectively, the rate of heat transfer is given by

$$q = \frac{2\pi RL\ (T_i - T_o)}{l_n (r_o / r_i)} \qquad (4.1.27.c)$$

where, R is the thermal conductivity of the wall material and

L is the length of pipe

For multiple layer cylinder walls (assuming two walls), the expression for heat transfer rate by conduction is

$$q = \frac{T_1 - T_3}{\frac{\ln(\gamma_2/\gamma_1)}{2\pi R_1 L} + \frac{\ln(\gamma_3/\gamma_2)}{2\pi R_2 L}} \qquad (4.1.27.d)$$

where, γ_1, γ_2 and γ_3 are the inside, intermediate and outer radii

L is the length of the pipe

T_1 and T_3 are the inner and outer temperatures and

R_1 and R_2 are the inner and outer wall thermal conductivities

For rectangular ducts (used with solar air heaters) having width w, height h, insulation thickness t and for a length L, the rate of heat transfer is

$$q = RL\left[\frac{2w + 2h}{t} + 2.16\right](T_i - T_o) \qquad (4.1.27.e)$$

where, T_i, T_o are the inner and outer face temperatures respectively and

R is the thermal conductivity of the material

Heat loss due to convection

Heat transfer by convection is due to fluid motion. Cold fluid adjacent to a hot surface receives heat and gives to the bulk of the fluid by mixing with it. For the estimation of heat transfer by convection, the convective heat transfer coefficient is first calculated from the appropriate correlations from which the heat transfer (q) is calculated as

$$q = h_c . \Delta T \tag{4.1.28}$$

where, h_c is the convective heat transfer coefficient (written also as h) and

ΔT is the temperature difference

Convention process in a flat plate solar collector occurs principally in:

(i) A combination of free and forced convection in the inclined riser tube

A study of combined free and forced convection with water in a horizontal tube receiving uniform heat fluxes for Reynolds number ranging from 1000-2000, and Prandtl number from 4 to 9 is given by the following correlation

$$\overline{Nu} = 4.36 + 0.048 \, \mathrm{Pr}^{1/3} . (\mathrm{Re} \, Ra)^{1/5} . \tag{4.1.29.a}$$

where, $\overline{Nu}$, the Nusselt number

Ra, the Raleigh number given by

$$R_a = \frac{g . \beta^1 (\Delta T) . L^3}{\gamma \alpha} \tag{4.1.29.b}$$

where,

L is the plate spacing

k is the thermal conductivity of the separating medium

g is the gravitational constant

β^1 is the volumetric coefficient of expansion $(= \frac{1}{T}$ for ideal gases)

ΔT is the temperature difference between plates

γ is the kinematic viscosity

α is the thermal diffusivity and

(ii) Free convection between the absorber plate and the glass cover

The heat transfer between the absorber surface and the glass plate or between two glass plates due to convection is calculated by assuming that they are long parallel plates for which the following expression could be used for the estimation of convective heat transfer coefficient for tilt angles between 0 and 75°.

$$Nu = 1 + 1.44\left[1 - \frac{1708(\sin 1.88\beta)^{1.6}}{R_a.\cos\beta}\right]\left[1 - \frac{1708}{R_a.\cos\beta}\right]^{+} + \left[\left(\frac{R_a\cos\beta}{5830}\right)^{1/3} - 1\right]^{+} \quad (4.30)$$

where, '+' indicates that only positive values have to be taken. If the value within the bracket is negative, take it as zero.

β is the tilt angle

(iii) Combined free and forced convection from the glass cover to the atmosphere

Convective heat losses due to wind action from the collector surface to the ambient could be studied under two conditions:

(a) For roof mounted collectors, the heat loss coefficient is given by

$$\text{hwind} = 8.6\, V^{0.6}/L^{0.4} \quad (4.1.31.a)$$

where, L is the cube root of the house volume and

V is the velocity of wind

(b) For collectors placed on ground, the following equation can be used

$$h_{wind} = 2.8 + 3\,V \quad (4.1.31.b)$$

or

$$Nu = 0.86.R_e^{0.5}.P_r^{0.33} \qquad (4.1.31.c)$$

for wind blowing over the glass cover of solar collector.

Another set of correlations that could be used to estimate the free convection from a heated plate (glass) to atmospheric air at normal pressure is given by

$$h = 1.42\left(\frac{\Delta T.Sin\beta}{L}\right)^{0.25} \qquad (4.1.31.d)$$

for laminar flow when Gr < 10^9. However, if the flow is turbulent, the following relation could be used.

$$h = 0.95(\Delta T.Sin\beta)^{1/3} \qquad (4.1.31.e)$$

Grashof number (Gr) is given by

$$Gr = Ra/Pr = g(\Delta T)\beta' L^3/v^2 \qquad (4.1.31.f)$$

where,

β' is the coefficient of expansion of fluid. For ideal gases, it is given by 1/T
g is the acceleration due to gravity
ΔT is the temperature difference
L is the plate spacing (or air gap)
v is the kinematic viscosity

Heat loss due to radiation

Heat may also be transferred into regions where a perfect vacuum exists (in contrast to the mechanisms of conduction and convection where energy transfer through a material is required). The mechanism is electromagnetic radiation.

a) Thermal Radiation: is defined as the energy transferred by electromagnetic waves that originate from a system because of the temperature of the system.

b) Total emissive power: is the total thermal radiation energy emitted by a surface element into the entire volume above the surface per unit time per unit area [emissive power, radiant flux density].

c) Black Body: In the study of real surfaces it is convenient to define an ideal surface. The ideal surface is called a black surface or a black body, where all energy incidents upon the body are absorbed, regardless of direction, wavelength or any often identifiable energy characteristic. Since, all energy is absorbed $\alpha = 1$, $\rho = 0$, $\tau = 0$.

A perfect absorber is also a perfect emitter. So, the emissive power of a black body is only a function of temperature.

d) Emissivity (ε): The total emissive power of a real surface is determined in terms of an idealized black surface. Any real surface emitting thermal radiation at temperature T has a total emissive power less than that of a black surface at T, and this ratio is called emissivity.

$$\varepsilon(T, system) = \frac{E(T, system)}{E_b(T)} \tag{4.1.32}$$

Thermal radiation is in the wavelength extending from 0.1 to 100 μm (visible is from 0.35 to 0.75 μm). This propagation takes place in the form of discrete quanta, each having an energy given by

$$E = h\nu \tag{4.1.33}$$

h - Planck's Constant (J/s) 6.625×10^{-34}

ν - frequency (1/s)

The important laws of radiation are as follows:

Planck's law: This gives the monochromatic emission of a black body, defined as the energy emitted by a perfect radiator per unit wavelength at the specified wavelength per unit area per unit time at temperature T as

$$E_{b,\lambda} = \frac{2\pi hc^{2}\lambda^{-5}}{e^{hc/k\lambda T} - 1} \qquad (4.1.34)$$

c - speed of radiation

k - Boltzman's constant (J/K) = 1.3805×10^{-23}

When the radiation is propagated through a medium whose refractive index is 1 [strictly in vacuum but also could be considered for air], then the above form is reduced to

$$E_{b,\lambda} = \frac{C_1\lambda^{-5}}{\exp(c_2 / \lambda T) - 1} \qquad (4.1.35)$$

C_1 $= 3.741 \times 10^{-16}$ W.m^2

C_2 $= 0.014388$ mK

It is of interest to estimate the emissive power for all wavelengths at a given temperature. This is given by Stefan Boltzman law.

Stefan Boltzman Law : This law states that the total radiation from a perfect black body (from $\lambda = 0$ to $\lambda = \infty$) is proportional to the fourth power of the absolute temperature of body.

$$\text{(ie)} \quad E_b \, \alpha \, T^4 \qquad\qquad \text{(ie)} \quad E_b = \sigma T^4 \qquad (4.1.36)$$

σ - Stefan Boltzman Constant = 5.6697×10^{-8} W/m^2 K^4

Wein's Displacement law: This states that the product of the wavelength of the maximum value of the monochromatic intensity of emission and the absolute temperature is constant. Mathematically,

$$\lambda_{max}T = 2897.8\ \mu m\ K. \qquad (4.1.37)$$

Wein's 2^{nd} Law: This is expressed under the form

$$E_{b,\lambda,max} = BT^5 \qquad (4.1.38)$$

where T - K,

$B = 1.287 \times 10^{-11}\ W/m^2.\mu m\ K^5$ when λ is in μm

or $1.287 \times 10^{-5}\ W/m^3\ K^5$ when λ is in m

$E_{b,\lambda,max}$ is in $W/m^2\ \mu m$ or W/m^3

The parameter to be estimated for radiative heat transfer is the emissivity, which depends on the wavelength and the temperature of the body. To simplify the analysis, it is assumed that the monochromatic properties are constant over all wavelengths and a surface having this characteristic is known as a gray body. For calculations, we can assume that the real surface can be considered as a gray body with a particular emissivity.

The monochromatic emissivity is equal to the monochromatic absorptivity for any surface when in thermal equilibrium (ie) the equality between ε_λ and α_λ applies only

when the temperature of the source of the incident radiation (sun) is equal to the temperature of the body (absorber plate for example). Thus, it should be underlined that the emissivity of the absorber plate (or any earthly body) is never equal to the absorptivity of the incident solar radiation.

Heat transfer in the radiation mode from the solar collector is due to the two following aspects:

(i) Heat transfer between the absorber plate and the glass cover and when there are two glass covers, heat transfer between the two glass covers and

(ii) Heat transfer to the sky called sky radiation

All the sample calculation 4.1.1 above can be seen in Appendix A1.

4.2 THERMAL ANALYSIS OF FLAT SOLAR COLLECTOR

Knowing the mechanisms of heat transfer involved in the flat plate solar collector, we can now estimate the losses occurring in the collector system. This will help in identifying areas where particular losses (for example, radiation) are high and thus change/modify configurations to reduce them. In this context, it is important to note that the losses occur from the region of high temperature to the region of low temperature (i.e.) from the absorber plate to the ambient).

In the following sections, the heat losses from the various components of the solar collector will be first studied so as to obtain the overall heat loss coefficient factor, which can depict the losses for the entire collector.

4.2.1 Energy Balance Equation

For any thermal system, we can write the overall energy balance equation per unit collector area at steady state as

$$Q_u = Q_i - Q_l \tag{4.2.1}$$

where Q_u - useful energy

Q_i - input energy and

Q_l - losses

Thus, for a flat plate solar thermal collector, the useful energy delivered is the difference between the absorbed incident radiation and the total heat losses from the collector. In order to design an efficient system, it is important to know:

(a) The heat absorbed [H_a] by the flat plate collector (absorber), which depends on the cover system optics and the absorptance of the absorber plate.

(b) The total heat losses from the system. As the heat loss will be from the absorber plate (which is at the highest temperature in the system) to the ambient (the lowest temperature), it is convenient to write the heat loss as

$$Q_l = U_L (T_p - T_a) \tag{4.2.2}$$

where U_L is the total or overall heat loss coefficient

T_p is the mean plate temperature and

T_a is the ambient temperature

Estimation of overall heat loss coefficient (U_L)

For the analysis, let us consider a single glass cover system. The energy balance study will estimate the heat loss through the top, bottom and sides of the collector individually and give in terms of the overall heat loss coefficient for the collector.

To simplify the analysis, the following assumptions are made:

- Performance is in steady state
- Heat flow through the cover and back insulation is one dimensional only
- Absorber plate and cover are at uniform temperature
- Properties are independent of temperature
- Dirt and dust on collector are neglected are there is no shading on collector surface.

Heat loss through the top:

The energy loss from the absorber plate to the ambient through the top covers is due to both convection and radiation.

At steady state conditions, the heat transfer between the absorber and cover 1 = the heat transfer between cover 1 and the ambient.

Therefore, the heat loss through the top ($q_{l,t}$) per unit collector area is sum of the heat loss due to radiation and to convection. Considering the heat transfer between the absorber plate and the glass cover 1 and noting that

T_p - absorber plate temperature

T_{c1} - temperature of cover 1

ϵ_p - emissivity of absorber

ϵ_{c1} - emissivity of cover 1

$h_{c,p-c1}$ -convective heat transfer coefficient between the plate and the cover

the heat loss through the top (or front) of the collector ($q_{l,t}$) is given by

$$
\begin{aligned}
q_{l,t} &= h_{c,p-c1} \cdot (T_p - T_{c1}) + \frac{\sigma(T_p^4 - T_{c1}^4)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_{c1}} - 1} \\
&= h_{c,p-c1} \cdot (T_p - T_{c1}) + h_{r,p-c1}(T_p - T_{c1}) \\
&= (T_p - T_{c1})(h_{c,p-c1} + h_{r,p-c1})
\end{aligned}
$$

where, $h_{r,p-c1} = \dfrac{\sigma(T_p + T_{c1})(T_p^2 + T_{c1}^2)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_{c1}} - 1}$

is the radiation heat transfer coefficient between the absorber and cover 1.

Writing $(h_{c,p-c1} + h_{r,p-c1}) = \dfrac{1}{R_1}$,

where R_1 is the resistance to heat transfer between the absorber plate and cover 1, we have

$$q_{l,t} = \frac{T_p - T_{c1}}{R_1}$$

By a similar analysis, the heat loss from cover 1 to the ambient is given by,

$$q_{l,t} = h_w(T_{c1} - T_a) + \sigma.\varepsilon_{c1}(T_{c1}^4 - T_s^4)$$

where h_w is the convective heat transfer coefficient due to wind

T_a is the ambient temperature and

T_s is the sky temperature

Simplifying,

$$q_{l,t} = h_w(T_{c1} - T_a) + \frac{\sigma\varepsilon_{c1}(T_{c1} + T_s)(T_{c1} - T_s)(T_{c1}^2 + T_s^2)(T_{c1} - T_a)}{(T_{c1} - T_a)}$$

we have $$q_{l,t} = \frac{(T_{c1} - T_a)}{R_2}$$

where, $$R_2 = \frac{1}{h_w + h_{r,c1-a}}$$

is the resistance between cover 1 and the ambient

we arrive, for this two cover system, the heat loss through the top cover as,

$$q_{l,t} = \frac{T_p - T_a}{R_{top}}$$

where, R_{top} is the sum of the two resistances

$$R_{top} = R_1 + R_2$$
$$= \frac{1}{U_{top}} \qquad (4.2.3.a)$$

$$\therefore q_{l,t} = U_{top}\left(T_p - T_a\right) \qquad (4.2.3.b)$$

which gives the heat loss through the top (or front) of the collector.

Heat loss through the bottom:

The heat loss from the absorber plate to the ambient through the bottom is due to conduction through the insulation and then by a combination of convection and radiation from the insulator to the ambient. At steady state, the heat loss from plate to insulator is equal to the heat loss from insulator to ambient ($q_{l,b}$).

Considering the heat transfer through the insulation (due to conduction), the rate of heat transfer ($q_{l,b}$) is given by

$$\therefore q_{l,b} = \frac{k}{l}(T_p - T_b)$$

$$q_{l,b} = \frac{(T_p - T_b)}{R_4},$$

where , k is the thermal conductivity of the insulator

l is the thickness of the insulator

T_b is the temperature at the back of the insulator and

$$R_4 = \frac{l}{k}$$

No.	Materials	k	Heat Flux (q")	Heat Loss
1	Paper	0.180	18.0	27.00
2	Leather	0.159	15.9	23.85
3	Teflon	0.350	35.0	52.50
4	Rubber (soft)	0.130	13.0	19.50
5	Rubber (hard)	0.160	16.0	24.00
6	Fiber Glass	0.036	3.6	5.40
7	Asbestos	0.580	58.0	87.00
8	Plywood	0.120	12.0	18.00
9	Plaster Board	0.170	17.0	25.50
10	Cement Plaster	0.720	72.0	108.00
11	Sand	0.270	27.0	40.50
12	soil	0.520	52.0	78.00
13	Granite	2.790	279.0	418.50
14	Fir Wood	0.110	11.0	16.50
15	Yellow Pine Wood	0.150	15.0	22.50
16	Clay	1.300	130.0	195.00
17	Asphalt	0.062	6.2	9.30
18	Chrome Brick	2.300	230.0	345.00
19	Bakelite	1.400	140.0	210.00
20	Cotton	0.060	6.0	9.00

Table 4.2.1: Different Types of Materials with Different Types of Heat Loss and Heat Flux

Delta T (K) = 80

Thickness, t = 0.8 m

Area = 1.5 m^2

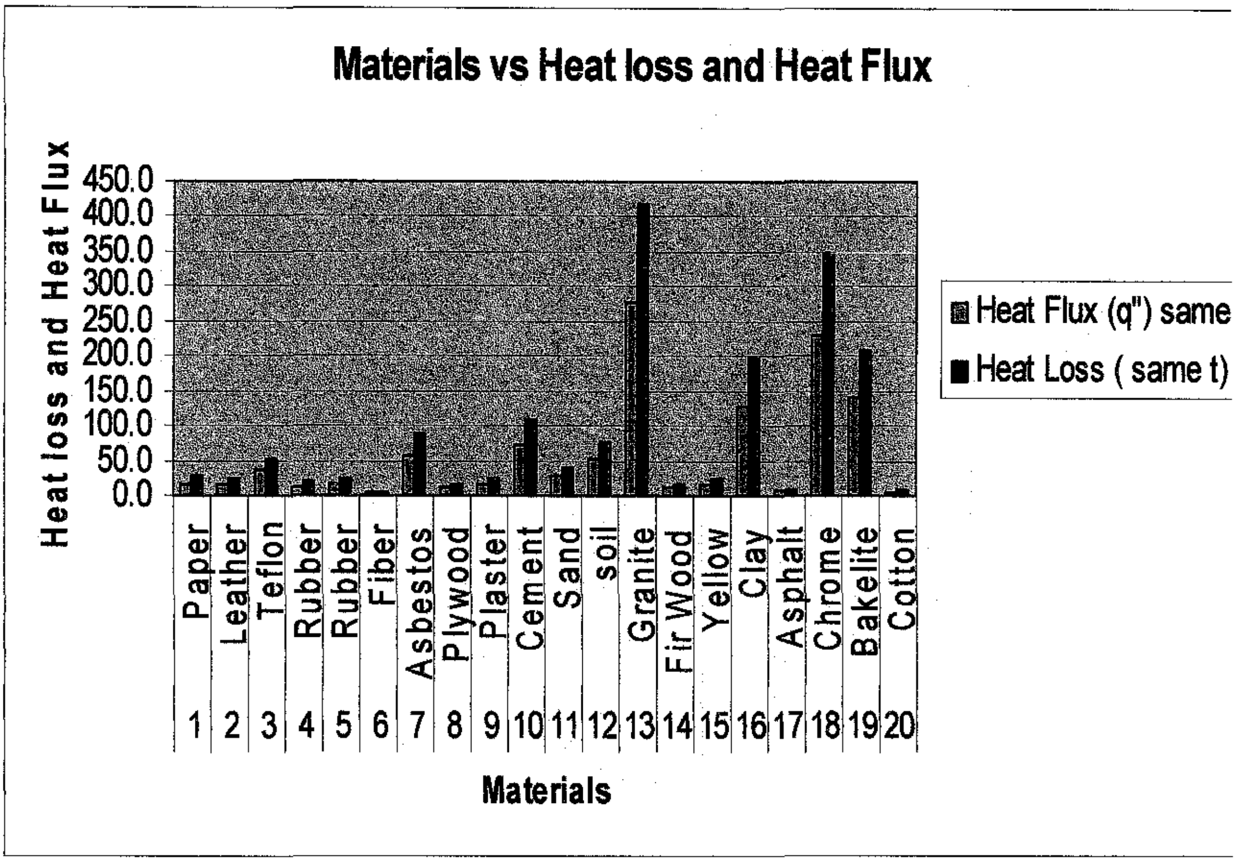


Figure 4.2.1: Graph of Materials vs Heat Loss and Heat Flux

As it can been seen above in the graph, the author can conclude that fiber has the lowest heat loss and heat flux. While for granite, it would produce the highest heat loss and heat flux. So in the design process, the author has conclude that to take fiber glass as insulator for the bottom part and side of the solar collector since it gave the least heat loss through conduction.

No	Materials	Dif. t (m)	Heat Flux (q") Diff. t	Heat Loss (Diff. t)
1	Fiber Glass	0.50	5.760	8.640
2	Fiber Glass	0.55	5.236	7.855
3	Fiber Glass	0.60	4.800	7.200
4	Fiber Glass	0.65	4.431	6.646
5	Fiber Glass	0.70	4.114	6.171
6	Fiber Glass	0.75	3.840	5.760
7	Fiber Glass	0.80	3.600	5.400
8	Fiber Glass	0.85	3.388	5.082
9	Fiber Glass	0.90	3.200	4.800
10	Fiber Glass	0.95	3.032	4.547
11	Fiber Glass	1.00	2.880	4.320
12	Fiber Glass	1.05	2.743	4.114
13	Fiber Glass	1.10	2.618	3.927
14	Fiber Glass	1.15	2.504	3.757
15	Fiber Glass	1.20	2.400	3.600
16	Fiber Glass	1.25	2.304	3.456
17	Fiber Glass	1.30	2.215	3.323
18	Fiber Glass	1.35	2.133	3.200
19	Fiber Glass	1.40	2.057	3.086
20	Fiber Glass	1.45	1.986	2.979
21	Fiber Glass	1.50	1.920	2.880
22	Fiber Glass	1.55	1.858	2.787
23	Fiber Glass	1.60	1.800	2.700
24	Fiber Glass	1.65	1.745	2.618
25	Fiber Glass	1.70	1.694	2.541
26	Fiber Glass	1.75	1.646	2.469
27	Fiber Glass	1.80	1.600	2.400
28	Fiber Glass	1.85	1.557	2.335
29	Fiber Glass	1.90	1.516	2.274
30	Fiber Glass	1.95	1.477	2.215
31	Fiber Glass	2.00	1.440	2.160
32	Fiber Glass	2.05	1.405	2.107
33	Fiber Glass	2.10	1.371	2.057
34	Fiber Glass	2.15	1.340	2.009
35	Fiber Glass	2.20	1.309	1.964
36	Fiber Glass	2.25	1.280	1.920
37	Fiber Glass	2.30	1.252	1.878
38	Fiber Glass	2.35	1.226	1.838
39	Fiber Glass	2.40	1.200	1.800
40	Fiber Glass	2.45	1.176	1.763

Table 4.2.2: Analysis Heat Loss with Different Thickness

k = 0.036

m = 1.5 m

Delta T = 80 K

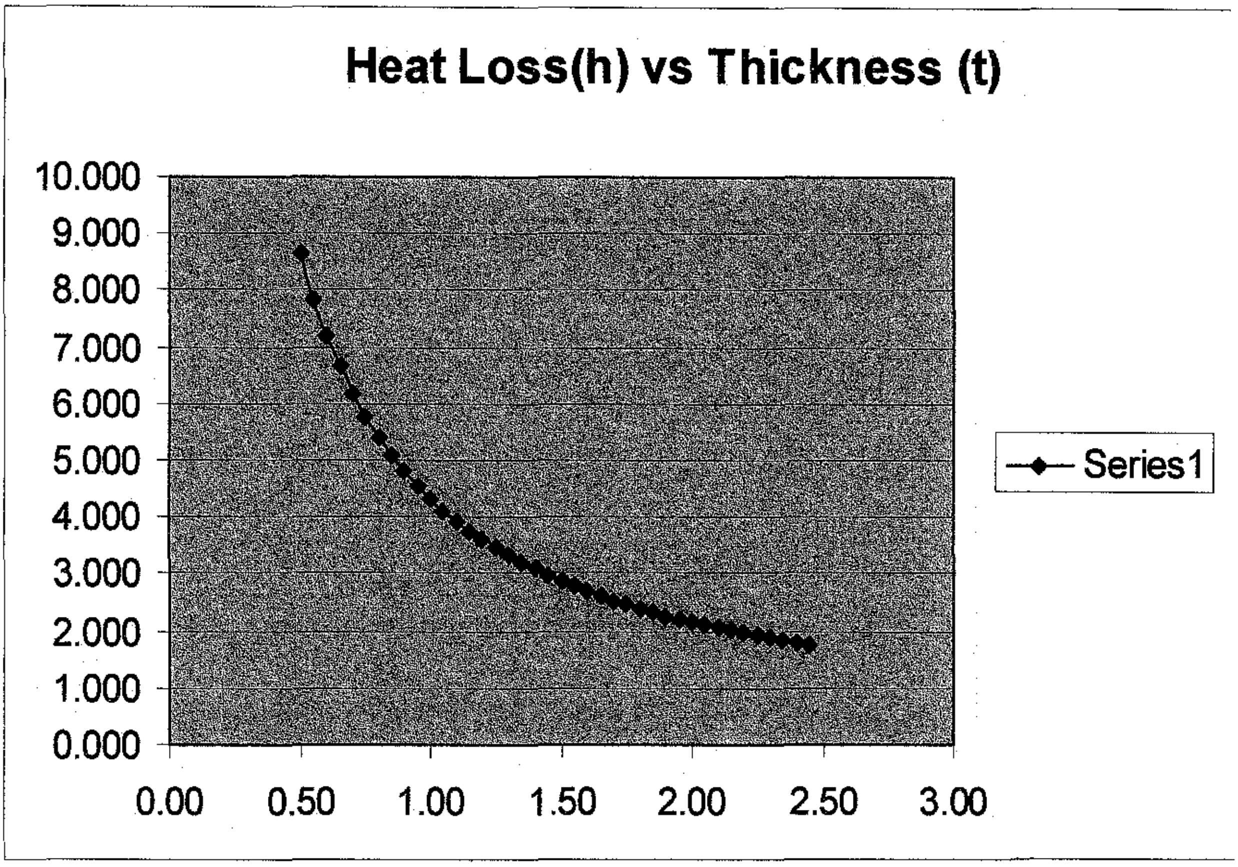


Figure 4.2.2: Graph Heat Loss vs Thickness

The heat transfer from the bottom (or back) of the insulator to the ambient is due to both convection and radiation and is given in terms of the convective and radiative heat transfer coefficients $h_{c,b\text{-}a}$ and $h_{r,b\text{-}a}$ respectively as

$$\therefore q_{l,b} = h_{c,b-a}(T_b - T_a) + h_{r,b-a}(T_b - T_a)$$

But, since the temperature at the bottom of the casing will be low, the radiation loss could be neglected. Therefore, the above equation reduces to

$$\therefore q_{l,b} = h_{c,b-a}(T_{b-}T_a) = \frac{(T_b - T_a)}{R_5}$$

where, $R_5 = \dfrac{1}{h_{c,b-a}}$ is sometimes neglected in comparison with R_4.

Therefore, the loss through the bottom is given by,

$$q_{l,b} = \frac{(T_p - T_a)}{R_{bot}},$$

where, R_{bot} is the sum of the two resistances

$$R_{bot} = R_4 + R_5$$

$$\therefore q_{l,b} = U_{bot}\,(T_p - T_a)$$

$$\text{where, } U_{bot} = \frac{1}{R_{bot}} \tag{4.2.4}$$

Heat loss through the Edge:

In a well designed system, the edge losses are negligible. As the top and bottom losses are referenced per unit collector area, the edge losses also need to be referenced per collector area and can be estimated as

$$Q_{l,e} = \frac{T_p - T_a}{R_{edge}}$$

where ,

$$R_{edge} = \frac{1}{U_{edge}} and$$

$$U_{edge} = \frac{U_{edge}{}^{1} . A_p}{A_c}$$

where, k_e is thermal conductivity of edge insulation

l_e is the insulation thickness.

A_p is the outside perimeter area of collector

= 2 (1+b) t

where, 1, b and t are the length, breadth and thickness of the collector respectively

A_c is the collector area

$U_{edge}{}^{1}$ is given by $\frac{k_e}{l_e}$

Therefore,

$$\therefore Q_{l,e} = U_{edge} \cdot (T_p - T_a) \tag{4.2.5}$$

Total heat loss coefficient

Combining equations 4.2.3, 4.2.4 and 4.2.5, we get the total heat loss occurring between the mean plate temperatures (T_p) and the ambient (T_a). These three heat losses can be combined and given in terms of a single parameter called the overall heat loss coefficient (U_L) as shown below:

$$\begin{aligned} q_{TOT} &= q_{l,t} + q_{l,b} + q_{l,e} \\ &= U_{top}(T_p - T_a) + U_{bot}(T_p - T_a) + U_{edge}(T_p - T_a) \\ &= (U_{top} + U_{bot} + U_{edge})(T_p - T_a) \\ &= U_L(T_p - T_a) \end{aligned} \tag{4.2.6}$$

where, U_L is the total heat loss coefficient of the collector

The thermal losses are due to conduction, convection and radiation to the surroundings and are represented by the product of the overall heat loss coefficient (U_L) and the difference between the mean plate temperature (T_p) and the ambient temperature (T_a). Therefore, the useful energy gain (Q_u) can be written for a collector of aperture area A_c as,

$$Q_u = A_c\,[H_a - U_L\,(T_p - T_a)] \tag{4.2.7}$$

(i) The main difficulty is in estimating the mean plate temperature (T_p), which is not measured. Normally, the only known temperature will be the temperature of the fluid entering the collector.

(ii) The calculation of heat transfer through the various interfaces needs knowledge of the interface temperatures, which are generally unknown and for which an iterative procedure has to be adopted, especially to estimate the top loss heat coefficient (U_{top} or U_t). The steps are (for a single glass cover system):

(a) Assume the glass cover temperatures so that $T_p > T_{g1} > T_a$. (Note: The subscripts g1, used here are the same as c1, used earlier. They refer to glass or cover).

(b) From the heat transfer correlations for convection (equation 4.1.30. for heat transfer between parallel plates (Nu) and puttting h=Nu.l/k) and equation 4.1.31.b for heat transfer due to wind) and radiation (for heat transfer between parallel plates using equation 4.1.39.a and for radiative heat transfer between cover and sky equation 4.1.40.a), estimate the individual heat transfer coefficients.

(c) Calculate the resistances R and therefore, the top loss coefficient (equation
4.2.3.a).

(d) Estimate the new values of the glass cover temperatures using

$$q_{top} = U_t(T_{plate}-T_{ambient})$$

$$= (T_{plate} - T_{g1})(h_{c,p-g1} + h_{r,p-g1})$$

$$= (T_{g1} - T_{g2})(h_{c,g1-g2} + h_{r,g1-g2})$$

to get

$$T_{g1,\,new} = T_{plate} - [\,(U_t\,(T_{plate} - T_{ambient}))/(h_{c,p-g1} + h_{r,p-g1})]$$

$$T_{g2,\,new} = T_{g1} - [(U_t\,(T_{plate} - T_{ambient}))/(h_{c,g1-g2} + h_{r,g1-g2})]$$

(e) Compare the new glass cover temperatures with the assumed value (a). If they are close to each other (say, within 0.5°C), the assumed values are reasonable and the top loss coefficient is got from (c). Otherwise, with the new values of glass cover temperature, recalculate b, c and d until the assumed glass cover temperatures are reasonably close to the newly calculated values.

However, the top loss heat coefficient and be estimated directly by the following equation by Klein (1975).

$$U_t = \left\{ \frac{N}{\dfrac{C}{T_{pm}}\left[\dfrac{T_{pm}-T_a}{(N+f)}\right]^e} + \frac{1}{h_w} \right\}^{-1} + \frac{\sigma(T_{pm}+T_a)(T^2{}_{pm}+T^2{}_a)}{(\varepsilon_p 0.00591 N h_w)^{-1} + \dfrac{2N+f-1+0.133\varepsilon_p}{\varepsilon_g} - N}$$

(4.2.8)

where, N = no of glass covers

f = (1+0.089 h_W - 0.1166 h_W ε_p) (1+0.07866 N)

C = 520 (1-0.000051 β^2) for 0° < β < 70°.

for β > 70°, use β = 70°

$e = 0.43\left(1-\frac{100}{T_{pm}}\right)$

β = collector tilt (degrees)

ε_g = emittance of glass (0.88)

ε_p = emittance of plate

T_a = ambient temperature (K)

T_{pm} = mean plate temperature (K)

h_W = wind heat transfer coefficient ($W/m^{2\,0}c$)

4.3 TEST RUN MODEL OF FLAT-PLATE COLLECTOR

After completing the task of making the model of flat-plate collector with honeycomb, the author test run the model to see the effect of honeycomb. The data is taken from early in the morning until late in the evening. The author used halogen lamp for constant direct because this type of lamp can give such energy as a sun, and it give a constant light to the collector.

This test run was carried out without using a circulation of water so the water inlet for every half an hour is quite constant and not keep increasing. The data was taken in two days time after completing making the model. There are two types of condition data was taken out that are flat-plate collector without honeycomb and flat-plate collector with honeycomb.

The author took the data manually using thermometer to get an accuracy of reading. There are no leaks whether in the risers or collector pipe during the test run is carried out. Both data can be seen in a table and graph as been stated in the next page.

Time	Inlet Temperature (^0C)	Outlet Temperature (^0C)
8:00	23.0	24.0
8:30	22.5	25.0
9:00	23.0	26.0
9:30	23.0	26.5
10:00	22.5	27.0
10:30	23.0	28.0
11:00	23.0	29.0
11:30	22.5	30.5
12:00	23.0	31.0
12:30	22.5	32.0
13:00	22.5	33.0
13:30	23.0	34.0
14:00	23.0	35.5
14:30	23.0	36.0
15:00	22.5	37.0
15:30	22.5	37.5
16:00	23.0	38.0
16:30	23.0	39.0
17:00	23.0	40.0

Table 4.3.1: Data for Model without Honeycomb

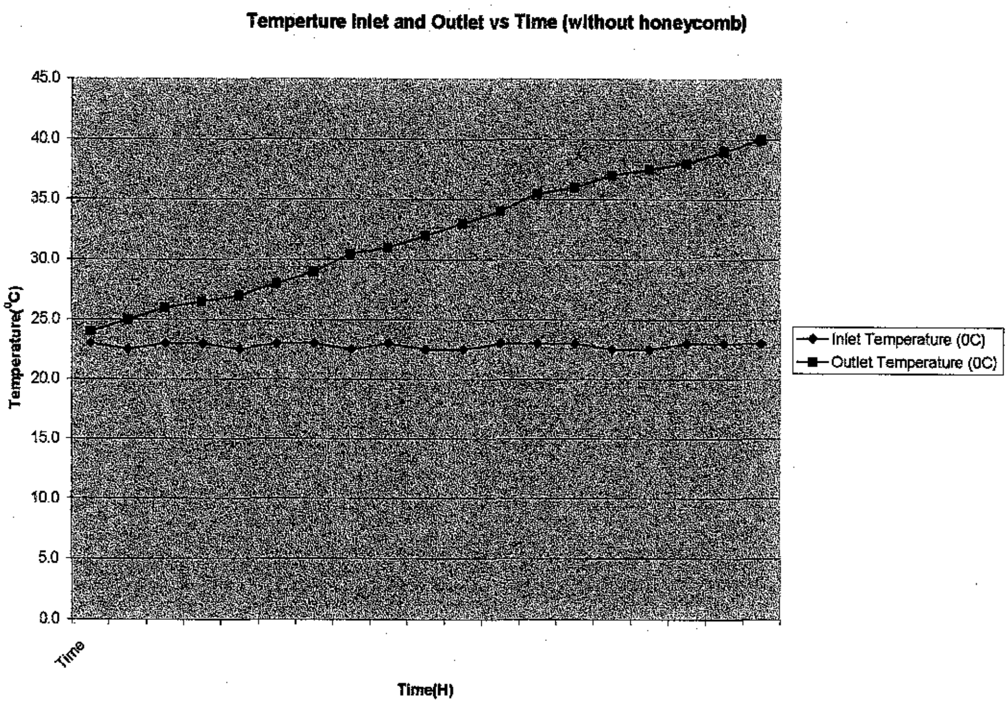


Figure 4.3.1: Graph of Water Inlet and Outlet of Flat-plate Collector without Honeycomb

Time	Inlet Temperature (^{0}C)	Outlet Temperature (^{0}C)
8:00	23.0	23.0
8:30	23.0	23.0
9:00	22.5	23.5
9:30	22.5	24.0
10:00	23.0	25.0
10:30	22.5	25.5
11:00	22.5	26.0
11:30	23.0	26.5
12:00	23.0	27.0
12:30	23.0	28.0
13:00	22.5	28.5
13:30	22.5	29.0
14:00	22.5	29.5
14:30	23.0	30.0
15:00	23.0	31.0
15:30	22.5	31.5
16:00	23.0	32.0
16:30	23.0	33.0
17:00	22.5	34.0

Table 4.3.2: Data For Model with Honeycomb

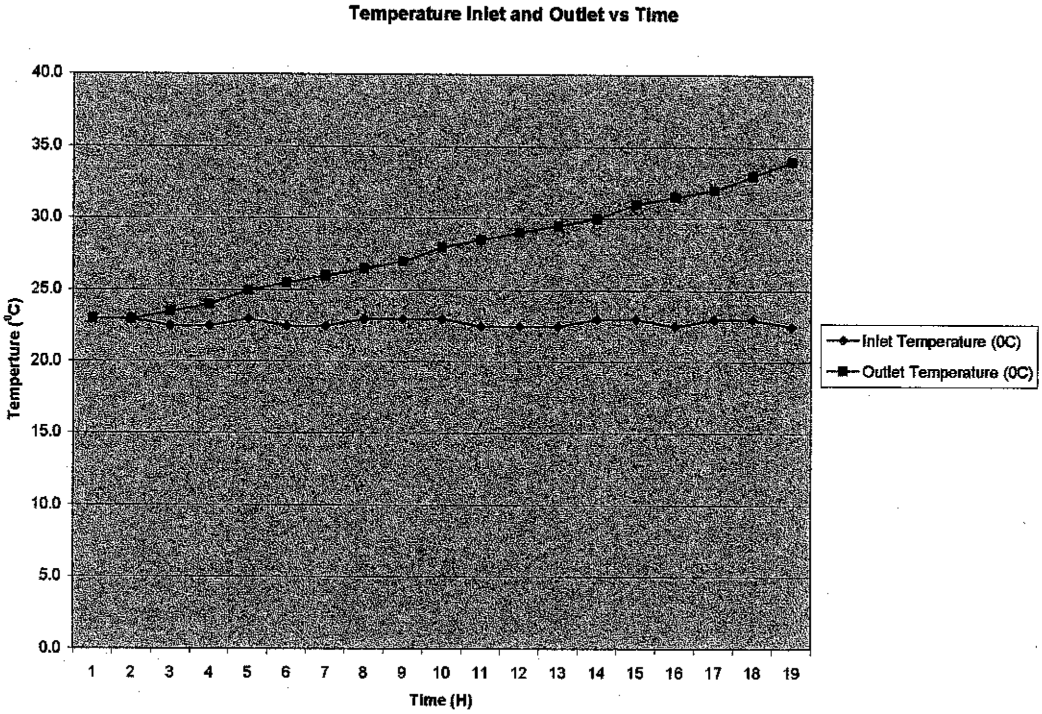


Figure 4.3.2: Graph of Water Inlet and Outlet of Flat-plate Collector with Honeycomb

From the above result of two conditions, the author can finalized that the temperature cannot be increased with honeycomb inside the flat-plate collector. There a some reason why the practically model can't get the same result as been predicted theoretically. The reason why because;

- The above plate and risers of solar collector is not fully covered with honeycomb since the amount of straws that the author bought to be honeycomb is not enough. Then there is air gap, so there are still heat losses through convection. The function of honeycomb been put inside the collector is to reduce heat loss through convection
- The type of honeycomb been used is not cleared enough as glass tube, so the sun light can't get through it smoothly. If we can get honeycomb as cleared as glass tube and as thick as straws, it will improve a lot to model.
- There is a crack at the middle of the flat-plate collector and some pieces of the glass are broken already. Because of this the flat-plate collector is not improve at all.

- The outlet water of collector is not been circulating to the inlet of the collector. If the inlet water of collector is using the outlet water, the temperature of the water will increase rapidly and continuously.

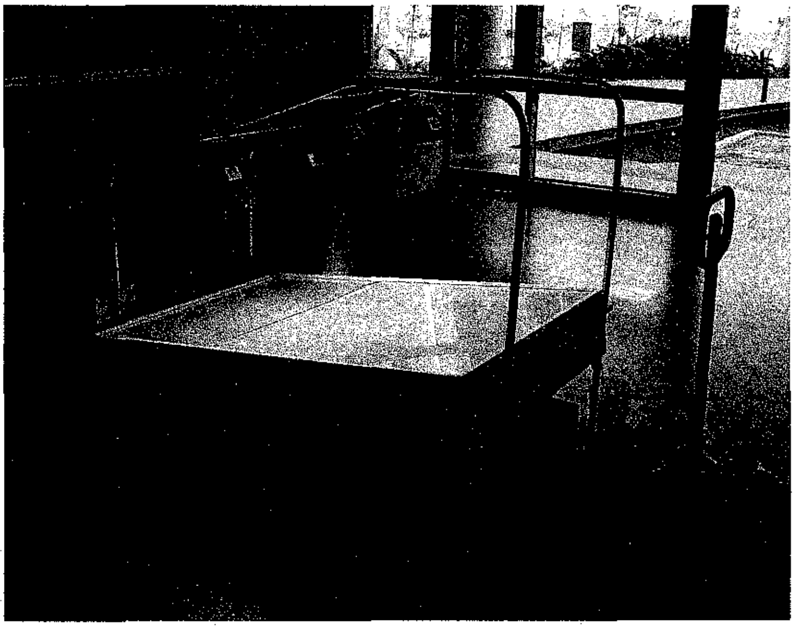


Figure 4.3.3: The Author Test Run the Model of Flat-plate Collector

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Solar energy is a recourse that is there for the taking. All that is needed is to produce the necessary hardware. From this final Year Project, the author gained a lot of things and accomplished a few objectives as stated in the beginning but the main objective is not accomplished. Some of the objective have been accomplished, is that the author knows the basic principle working of the solar flat collector, the equation of calculation involved, the heat transfer principles and calculation.

Beside that the author has been made two types of model of solar collector. The two models are flat-plate collector with different size. One is small model, with the area just as big as A4 paper and the other one is a big model that is 1m x 1.5 m. The small model is used in during the presentation while the big one can be tested and used as real solar flat-plate collector.

During this study, the author had introduced to new things to improve the flat-plate collector through technically, which transparent insulation is also known as honeycomb. It is an exciting innovation, able to create a heat flow form outside, ambient to the inside of the collector. Transparent insulation has a high potential for increasing the efficiency of solar thermal system. But as practically the author have not approved yet the efficiency of solar collector can be improved by this technology. There is some reason why this objective is not accomplished that has been stated in the chapter 4.

5.2 RECOMMENDATION

Recommendation in continuing this project for the next student is that, the student can test run the model that have been made by the author and do some modification on the model to improve it more. Some how, in continuing this project, the student can find alternatives to replace the straws with something as cleared as glass tube but the thickness is as thin as the straws being used for the transparent insulation.

References

1. Frank P. Incropera and David P. Dewitt, *Introduction to Heat Transfer, 3rd Edition*, John Wiley & Sons Inc. 2001.
2. Robert A. Ristinen, Jack J. Kraushaar, *Energy & The Environment*, John Wiley & Sons Inc. 1999.
3. David Kut and Gerard Hare, *Applied Solar Energy*, John Wiley & Sons, 1979.
4. Ralph C. Bohn, Angus J. MacDonald, *Energy Tech: Power & Transportation*, Glance McGraw-Hill. 2000.
5. Edited by Godfrey Boyle, *Renewable Energy – Power for a Sustainable Future*, Oxford University Press, in association with The Open University, Milton Keynes. 2002.
6. B. Anderson and M. Rioden, *The New Solar Home Book*, Brick House, Amherst, NH. 2000.
7. Tom Bitzer, *Honeycomb Technology*, Chapman & Hall. 2001.
8. G.N. Tiwari, *Solar Energy – Fundamentals, Design, Modeling and Applications*, Alpha Science International Ltd. 2002.
9. John Twidell and Tony Weir, *Renewable Energy Sources*, E & FN SPON, 1998.
10. www.azom.com.
11. www.sunwindsolar.com
12. www.ashrae.org
13. www.ases.org
14. www.ntis.org
15. www.canren.gc.ca/tech_appl
16. www.eere.energy.gov
17. www.solarexpert.com/Heat-theory.html
18. www.fsec.ucf.edu
19. www.asme.org/education/precollege/ideas
20. www.solarserver.de/wissen/sonnenkollektoren-e.html
21. www.canren.gc.ca/tech_appl
22. europa.eu.int/comm/energy_transport/atlas/htmlu/envfutpot.html

APPENDIX A

Example: A given glass 0.3 cm thick has a refractive index 1.526 and the extension coefficient 0.1 cm^{-1}. Calculate the radiation transmitted by the glass when the angle of incidence of the incident radiation is 60°. Also estimate its absorptance.

$n_2 = 1.526$; $K = 0.1$ cm^{-1}; $d = 0.3$ cm; $\theta_1 = 60°$; $n_1 = 1$

$$\theta_2 = Sin^{-1}\left(Sin\theta_1 . \frac{n1}{n_2}\right) = 34.6°$$

for 1 glass plate

$$\rho = 1 - \frac{1}{2}\left[\left(\frac{1-\pi_p}{1+\pi_p}\right) + \frac{(1-\pi_n)}{(1+\pi_n)}\right]$$

$$\pi_p = \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)}$$

$$= 1.46x10^{-3}$$

$$\pi_n = \frac{Sin^2(\theta_2 - \theta_1)}{Sin^2(\theta_2 + \theta_1)}$$

$$= 0.185$$

$\therefore \rho = 0.157 \quad \therefore \tau_r = 1 - \rho = 0.843$

and optical length $L = \dfrac{d}{Cos\theta_2} = 0.364\ cm$

$\alpha = 1 - e^{-KL} = 0.030$

$\therefore \tau = 1 - \alpha - \rho = 0.813$

Example: A flat plate solar collector has a glass cover of thickness 15 mm. Determine the rate of conduction heat transfer through the glass if the bottom side is at 45C° while the top is at temperature of 40°C.

$$Q/_A = -R\frac{dT}{dx} = -0.75\frac{5}{15x10^{-3}} = 250\ W$$

Example : **A glass cover of a flat plate collector of area 1x1 m is inclined at 30^0 to the horizontal. If the glass is at a temperature of 45^{0}C and the ambient is at 25^{0}C, how much heat is lost by convection.**

By calculating the Grashof number from equation 4.1.31.f, $Gr = 1.3x10^9$
Therefore, the flow is turbulent.
From equation 4.1.31.e, $h = 2.1$ W/m$^{2 0}$C for $\Delta T = 20^0$C, $\beta = 30$
Therefore, the heat loss due to convection (Q) is

$$Q = h.\,A\,.\Delta T$$
$$= 42\ W$$

Example: A surface has a spectral emissivity of 0.85 at wavelength less than 1.5 μm, 0.6 between 1.5 to 2.5 μm and 0.35 for wavelength longer than 2.5 μm. The surface is at a temperature of 1000 K. What is the average emissivity over the entire wavelength and the total emissive power of the surface.

$\lambda_1\ T = 1.5\,(1000) = 1500\ \mu m\ K$

$\lambda_2\ T = 2.5\,(1000) = 2500\ \mu m\ K$

from table 2.1.3,

$$\frac{E_{b,o-\lambda,t}}{\sigma T^4} = 0.0131 \quad \& \quad \frac{E_{b,0-\lambda_2 T}}{\sigma T^4} = 0.1614$$

$$\therefore \frac{E_{b,\lambda_1 T-\lambda_2 T}}{\sigma T^4} = 0.1614 - 0.0131 = 0.1483$$

$$\text{and } \frac{E_{b,\lambda_2 T-\infty}}{\sigma \tau^4} = 1 - 0.1614 = 0.8386$$

∴ The average emissivity

over the entive wavelength $= (0.85)\,(0.0131) + (0.6)\,(0.1483) + 0.35\,(0.8386)$

$= 0.3936$

& the total emissive power

of the surface $= \varepsilon \sigma T^4$

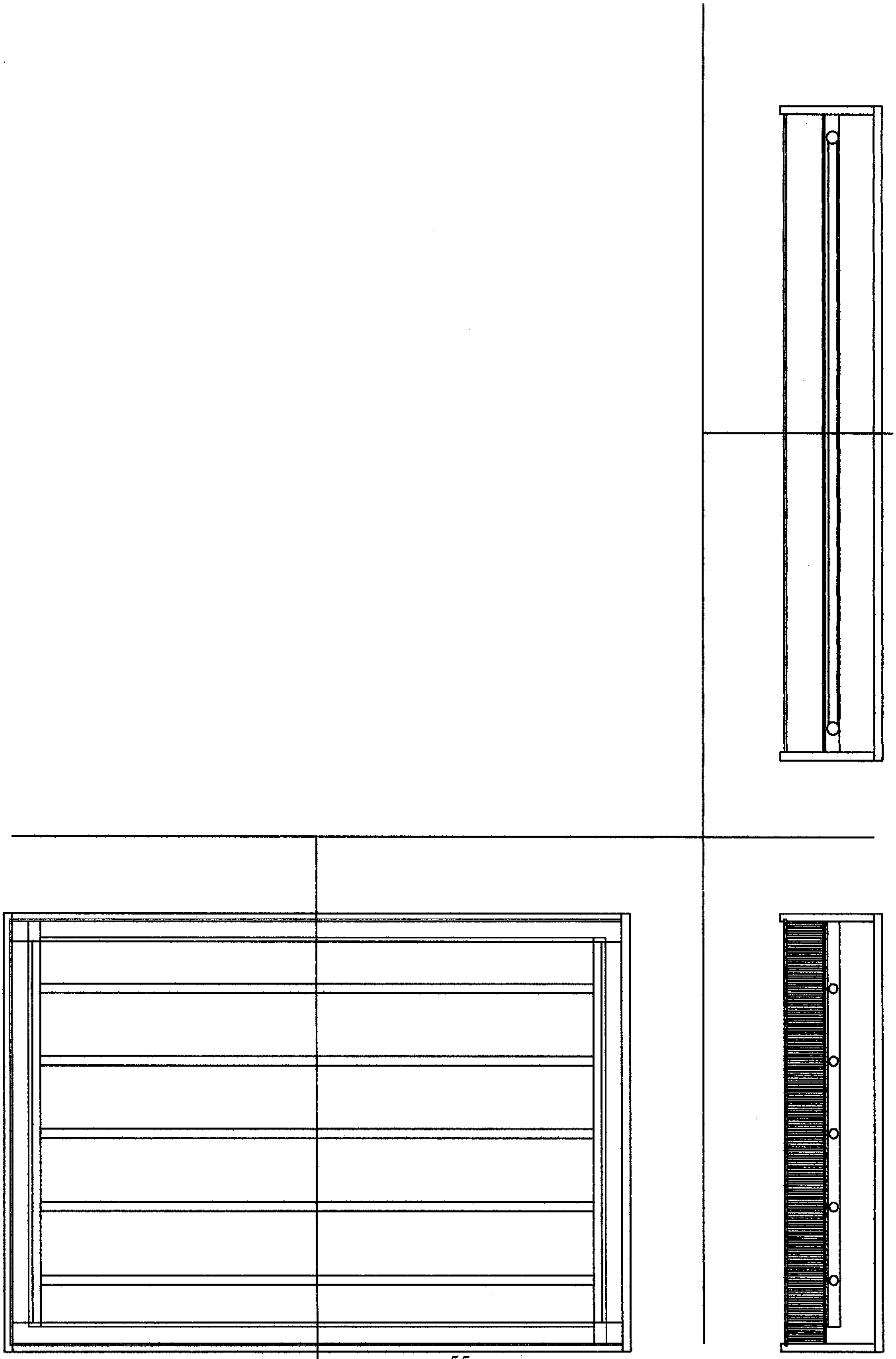
$= (0.3936)\,(5.669740^{-8})\,(1000^4)$

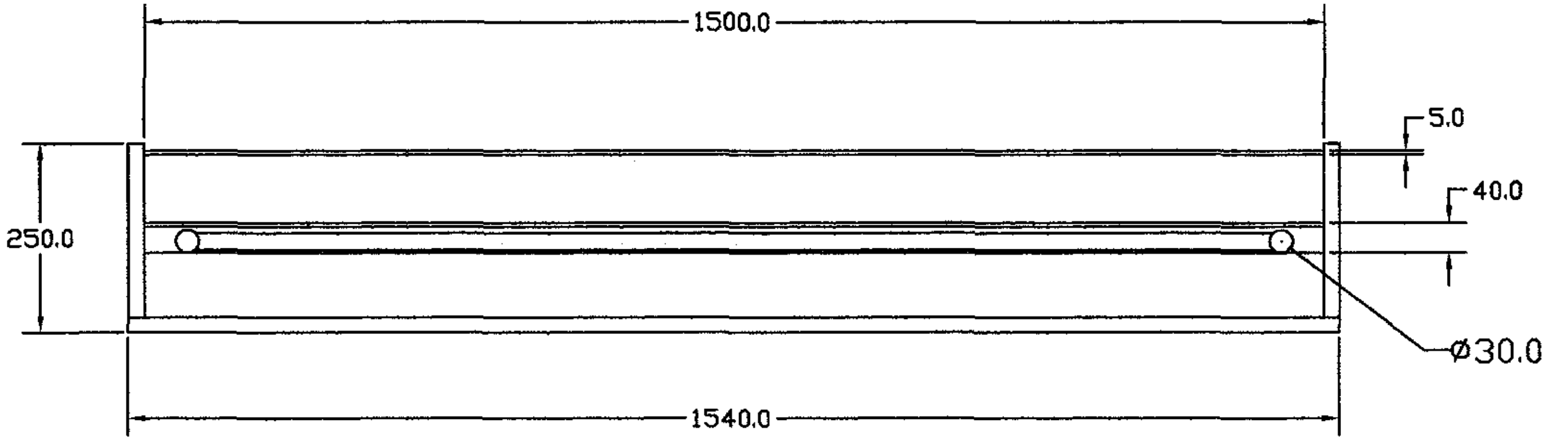
$= \underline{22320}\ W/m^2$

APPENDIX B

	ACTIVITY	WEEK														
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
1	Research & Development		■													
2	Brain storming; Decision making; Problem Defining; Identify objectives.		■	■												
3	Project Proposal				■											
4	Research & Development (Stage 1)				■	■	■									
5	Evaluation of progress made.					■	■									
6	**1ST PROGRESS REPORT**							■								
7	Research & Development (Stage 2)							■	■							
8	Evaluation of progress made.								■	■						
9	**2ND PROGRESS REPORT**										■					
10	Finalize design and concepts.										■	■				
11	Preparation for Poster Exhibition											■	■			
12	Poster Exhibition													■		
13	Preparation for Final Report											■	■	■		
14	Final Report														■	
15	Preparation for Presentation														■	
16	Presentation															■

APPENDIX C

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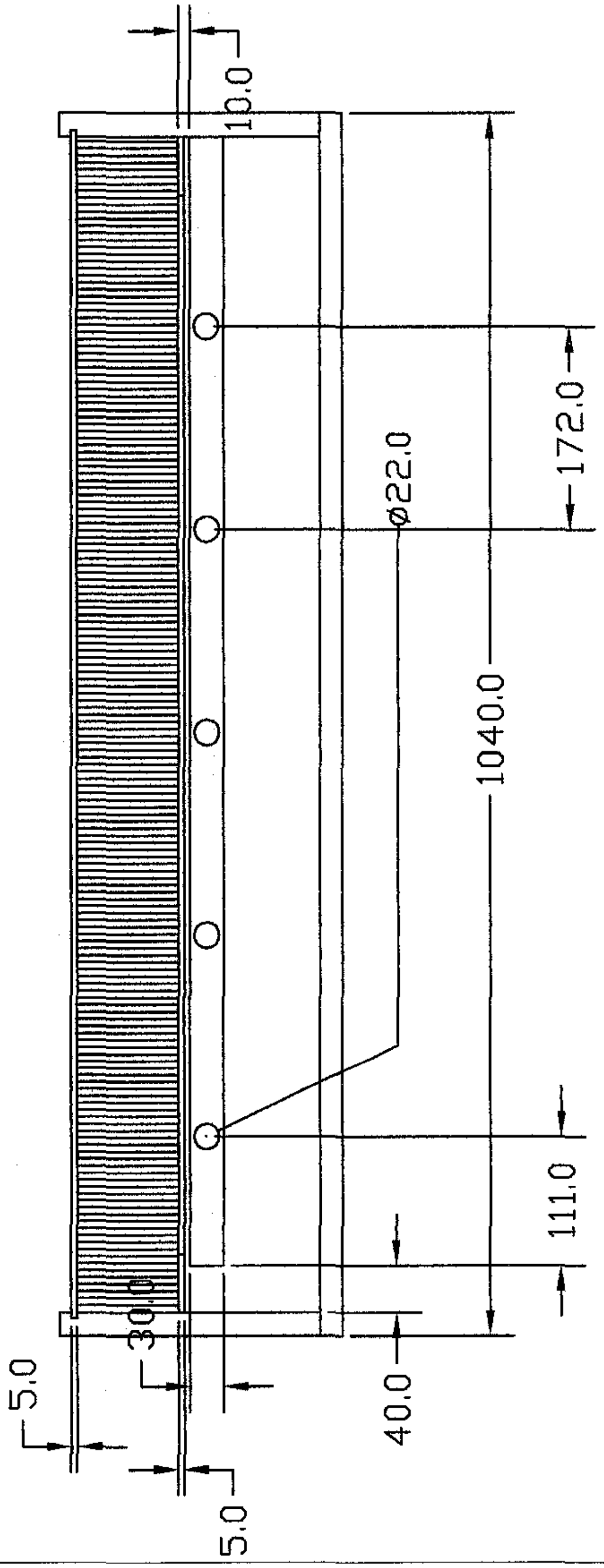
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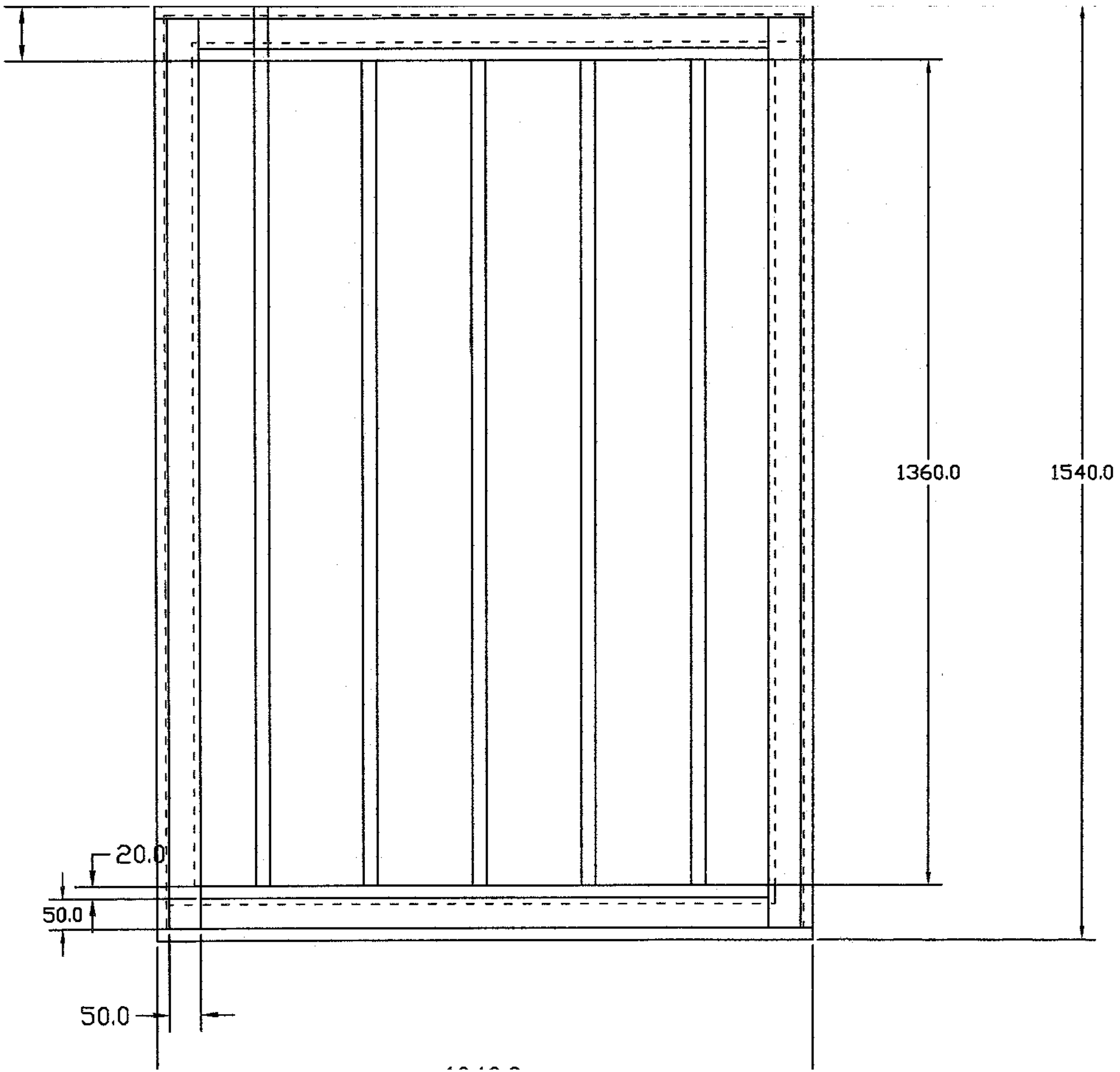
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