PERFORMANCE EVALUATION OF SOLAR FLAT PLATE COLLECTOR

NIK MOHD QAMARUL SHAFIQ BIN NIK AHMAD KAMIL

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JUDUL: **PERFORMANCE EVALUATION OF SOLAR FLAT PLATE COLLECTOR**

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Saya **NIK MOHD QAMARUL SHAFIQ BIN NIK AHMAD KAMIL (861223-46-5353)**

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Alamat Tetap:

PT-1842-P, KG. GONG TOK NASEK
21100 KUALA TERENGGANU

PROF.DR.KORADA VISWANATHA SHARMA
(Nama Penyelia)

Tarikh: **6/12/2010** Tarikh : **6/12/2010**

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature :

Name of Supervisor : PROF. DR. KORADA VISWANATHA SHARMA

Position : LECTURER

Date : 6 DECEMBER 2010

STUDENT'S DECLARATION

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Name : NIK MOHD QAMARUL SHAFIQ BIN NIK AHMAD KAMIL

ID Number : MA08146

Date : 6 DECEMBER 2010

To my beloved father and mother

Mr Nik Ahmad Kamil Bin Nik Abdul Kadir
Mrs Zawiah Bte Kassim

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ABSTRACT

Flat Plate Collectors (FPC) is widely used for domestic hot-water, space heating/drying and for applications requiring fluid temperature less than 100^{o}C. The absorber plate of the FPC transfers solar energy to liquid flowing in the tubes. The flow can takes place due to thermosyphon effect or by forced convection. However, certain energy absorbed by the plate is lost to atmosphere due to higher temperature of the plate. The collector efficiency is dependent on the temperature of the plate which in turn is dependent on the nature of flow of fluid inside the tube, solar insolation, ambient temperature, top loss coefficient, the emissivity of the plate and glass cover, slope, etc. The objective of the present work is to determine the influence of the emissivity of the absorber surface, ambient temperature, spacing between the glass cover and the absorber surface on efficiency of flat plate collector. The influence of operating parameters on flat plate collector is numerical studied. Methods to reduce the losses and compare with the performance of evacuated tube collector (ETC) are proposed by using FORTRAN software. Related equations from previous researcher have been included in the FORTRAN coding the get the data. The influence of the emissivity of the absorber surface, ambient temperature spacing between absorber plate and the glass cover on convection heat transfer coefficient, the overall top loss coefficient are theoretically estimated. The overall top loss coefficient on the flat plate collector is also theoretically determined. It can be observed that the top loss coefficient for the flat plate collector where is between 2.59 $Wm^{-2}K^{-1}$ until 3.87 $Wm^{-2}K^{-1}$ while for the evacuated tube collector is 0.7 $Wm^{-2}K^{-1}$ until 1.04 $Wm^{-2}K^{-1}$, when the plate temperature is 300K until 350K.

ABSTRAK

Pengumpul plat mendatar (FPC) digunakan secara meluas untuk pemanasan air domestik, pemanasan ruang / pengeringan dan untuk aplikasi yang memerlukan suhu bendalir kurang dari 100^{o}C. Plat penyerap dari FPC memindahkan tenaga matahari kepada cecair yang mengalir dalam tiub. Aliran boleh berlaku kerana kesan thermosyphon atau dengan konveksi paksa. Namun, tenaga tertentu diserap oleh plat hilang ke atmosfera kerana suhu yang lebih tinggi dari plat. Kecekapan pengumpul bergantung pada suhu plat yang dalam bentuk bergantung pada sifat dari aliran bendalir di dalam tiub, sinaran matahari, suhu persekitaran, kerugian atas pekali, yang nisbah daripada tenaga radiasi (panas) meninggalkan (yang dipancarkan oleh) permukaan untuk yang dari hitam permukaan penyerap penutup kaca dan plat, kecerunan, dan lain-lain Tujuan dari penelitian ini adalah untuk mengetahui pengaruh nisbah daripada tenaga radiasi (panas) meninggalkan (yang dipancarkan oleh) permukaan untuk yang dari hitam permukaan penyerap permukaan penyerap, suhu persekitaran, jarak antara penutup kaca dan permukaan penyerap pada kecekapan dari pengumpul plat datar. Pengaruh parameter operasi pada pengumpul plat datar adalah berangka dipelajari. Kaedah untuk mengurangkan kerugian dan membandingkan dengan prestasi pengumpul tabung dievakuasi (ETC) yang dicadangkan dengan menggunakan perisian FORTRAN. Persamaan berkaitan dari kajian sebelum ini telah dimasukkan ke dalam kod FORTRAN bagi mendapatkan data. Pengaruh nisbah daripada tenaga radiasi (panas) meninggalkan (yang dipancarkan oleh) permukaan untuk yang dari hitam permukaan penyerap, suhu persekitaran, jarak antara plat penyerap dan kaca penutup pada pekali perpindahan haba mencapah, kerugian atas keseluruhan pekali secara teori dijangka. Kerugian atas pekali keseluruhan pada pengumpul plat mendatar juga secara teori telah ditetapkan. Hal ini dapat diamati bahawa kerugian atas pekali untuk pengumpul plat mendatar di mana adalah antara 2.59 $Wm^{-2}K^{-1}$ hingga 3.87 $Wm^{-2}K^{-1}$ sedangkan untuk pengumpul tabung dievakuasi adalah 0.7 $Wm^{-2}K^{-1}$ hingga 1.04 $Wm^{-2}K^{-1}$, ketika suhu plat 300K sampai 350K.

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Nu	-	Nusselt number (hd/k)
Ra	-	Rayleigh number, Gr.Pr
Gr	-	Grashof number
Pr	-	Prandtl number
H	-	Convective heat transfer coefficient, $Wm^{-2}K^{-1}$
h_W	-	Wind loss coefficient, $Wm^{-2}K^{-1}$
N	-	Number of glass covers
L	-	Spacing between the absorber plate and glass cover
T	-	Temperature, ^{0}C
K	-	Kelvin
T_{pm}	-	Absorber Plate means Temperature, ^{0}C
T_{∞}	-	Ambient Temperature, ^{0}C
ΔT	-	Temperature difference between enclosed surfaces
U_t	-	Overall Top Loss Coefficient, $Wm^{-2}K^{-1}$
ε	-	Emissivity
σ	-	Stefan–Boltzman constant, $Wm^{-2}K^{-4}$
μ	-	Viscosity of air
υ	-	Kinematic viscosity of air
α	-	Thermal diffusivity of air
δ_P	-	Plate thickness [m]
β	-	Collector tilt angle
a	-	Ambient
P	-	Absorber plate
G	-	Glass cover

LIST OF ABBREVIATIONS

FPC	-	Flat plate collector
ETC	-	Evacuated tube collector
FORTRAN	-	Formula Translation
SPC	-	Spacing between absorber plate and glass cover

Chapter 1

INTRODUCTION

1.1 Introduction

The current population of Malaysia is expected to rise from 25.6 million to approximately 28 million by the year 2010, with an annual growth rate of 2.4%. With this population growth rate the energy demand is also expected to increase, since energy consumption is an integral part and is proportional to the economic development and total population of a country.. In order to cope with the increasing demand for energy, it is universally accepted that renewable energy would be a sensible option in the future.

As Malaysia is located in the tropics, and receives a fair amount of sunshine, coupled with large forest and agricultural activities, the interest in renewable energy sources like solar energy use, biomass and hydro-electricity is high. Most renewable energy conversion can be done with no environmental consequences, and in the case of biomass, renewable energy generation provides a cleaner environment, from reduced waste or agricultural residues.

The solar energy option has been identified as one of the promising alternative energy sources for the future. In any collection device, the principle usually followed is to expose a dark surface to solar radiation so that the radiation is absorbed. A part of the optical concentration is done; the device in which the collection is achieved is called a flat plate collector (FPC). The flat plate collector is the most important type of solar collector because it is simple design, has no moving parts and required little maintenance. It can be used for a variety of applications such as reheating water (hot water), space heating/ drying in which temperatures ranging from 40^oC to about 100^oC are required.

People have harnessed solar energy for centuries. As early as the 7^{th} century B.C., people used simple magnifying glasses to concentrate the light of the sun into beams so they would cause wood to catch fire. More than 100 years ago in France, a scientist used heat from a solar collector to make steam to drive a steam engine. In the beginning of this century, scientists and engineers began researching ways to use solar energy in earnest. One important development was remarkably efficient solar boiler invented by Charles Greeley Abbott, an American astrophysicist, in 1936. The solar water gained popularity at this time in Florida, California and the Southwest. The industry started in the early 1920s and was in full swing just before World War II. This growth lasted until the mid 1950s when the low cost natural gas became the primary fuel for heating American homes. The public and world governments remained largely indifferent to the possibilities of the solar energy until the oil shortages of the 1970s. Today, people use solar energy to heat building water and to generate electricity.

Application of solar energy for domestic and industrial heating purposes has been become very popular. However the effectiveness of presently used flat plate collectors is low due to the moving nature of the energy source. Thus, a program will be run and the data from the program will be record. Discussion about the graft from the data will be made to make comparison about the performance of flat plate collector with the evacuated tube collector. Before that, the same program will be used to record some data about the performance of a flat plate collector with double glasses cover and make a comparison with single glass cover.

1.2 Project Background

In the solar-energy industry great emphasis has been placed on the development of "passive" solar energy systems, which involve the integration of several subsystems: Flat Plate collectors, heat-storage containers, fluid transport and distribution systems, and control systems. The major component unique to passive systems is the Flat plate collector. This device absorbs the incoming solar radiation, converting it into heat at the absorbing surface, and transfers this heat to a fluid (water) flowing through the Flat plate collector. The warmed fluid carries the heat either directly to the hot water or to a storage subsystem from which can be drawn for use at night and on cloudy days.

Since 1900, a large number of solar collector designs have been shown to be functional; these have fallen into two general classes:

i) Flat plate collectors: in which the absorbing surface is approximately as large as the overall collector area that intercepts the sun's rays.
ii) Concentrating collectors: in which large areas of mirrors or lenses focus the Sunlight onto a smaller absorber.

Since of energy crisis, there has been effort to develop new energy sources as a way to solve energy problem and at of there, solar energy has received special attention. The resource why solar energy has not been utilized as energy source for generating large power is considered as follows. The energy generated depends too much on time and seams to supply a stable power needed for a secondary energy source. It will require and enormous cost of equipment to effectively take energy at of such a moving energy source as the sun, and the energy cost obtained from the sun is comparatively high at present.

However, as a result of increase of prices of fossil and nuclear fuels, a feasibility of solar energy as a new energy source can be increased, when a very high energy conversion efficiency and a reduction of cost of equipment is obtained, due above reasons, solar energy is one of the best possible and easily available energy. For the betterment of mankind, now a day for various applications with solar energy is in use still. Lot of research work is going on to use the available solar energy to maximum extent.

1.3 Problem Statement

Nowadays, the renewable energy sources become important to reduce assumption and pollution to make energy. One of the sources is solar energy. Two most common solar collectors are flat plate collector (FPC) and evacuated tube collector (ETC). Many researchers have made their research to find which one of that solar equipment have high efficiency so the solar collector process can be operate efficiently. After years, there was many research discussed about this matter. Their situation was how to make a solar collector be more efficient by adding some of other gadget or parameter in it. This project will discuss and make a comparison between FPC and ETC to find which one of them has a high performance.

1.4 Objective

i) Determine the influence of the emissivity of the absorber surface, ambient temperature, spacing between the glass cover and the absorber surface on efficiency of flat plate collector.
ii) The simulation operate for evacuate tube collector (ETC) was also been made.
iii) The efficiency and the top loss coefficient of the FPC will be comparing to the ETC.

1.5 Scope

i) The focus is the influence of operating parameters on flat plate collector is numerical studied.
ii) Methods to reduce the losses and compare with the performance of evacuated tube collector (ETC) are proposed.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses about the previous researches that have been done about the related issues with this project. Definition of each term will also be included. Renewable energy, solar energy, solar collector are among the interested terms in this chapter. The sources of the review are extracted from journal, article, books and webs. Literature review is done to provide information about previous research and the relevant that can help to smoothly run this project.

2.2 SOLAR ENERGY

Solar radiation we receive on the Earth's surface comes directly or indirectly, and the sum of both components is measured as the global radiation. Solar radiation is received on the Earth's surface after being subjected to attenuation, reflection and scattering in the Earth's atmosphere. The radiation received without change in direction is called direct radiation*;* while that received after its direction has been changed by scattering is called diffuse radiation. The sum of both components is called the global radiation. Most radiation data are measured for horizontal surfaces.

In this context, “solar energy” refers to energy that is collected from sunlight. Solar energy can be applied in many ways, including to:

a) Generate electricity using photovoltaic solar cells.
b) Generate electricity using concentrating solar power.

c) Generate electricity by heating trapped air which rotates turbines in a solar updraft tower.
d) Generate hydrogen using photo electrochemical cells.
e) Heat water or air for domestic hot water and space heating needs using solar-thermal panels.
f) Heat buildings, directly, through passive solar building design.
g) Heat foodstuffs, through solar ovens.
h) Solar air conditioning

2.2.1 History of Solar Energy

People have harnessed solar energy for centuries. As early as the 7th century B.C., people used simple magnifying glasses to concentrate the light of the sun into beams so they would cause wood to catch fire. More than 100 years ago in France, a scientist used heat from a solar collector to make steam to drive a steam engine. In the beginning of this century, scientists and engineers began researching ways to use solar energy in earnest. One important development was remarkably efficient solar boiler invented by Charles Greeley Abbott, an American astrophysicist, in 1936. The solar water gained popularity at this time in Florida, California and the Southwest. The industry started in the early 1920s and was in full swing just before World War II. This growth lasted until the mid 1950s when the low cost natural gas became the primary fuel for heating American homes. The public and world governments remained largely indifferent to the possibilities of the solar energy until the oil shortages of the 1970s. Today, people use solar energy to heat building water and to generate electricity.

2.2.2 Solar Radiation in Malaysia

In Peninsular Malaysia, the monthly means of daily solar radiation vary from about 4.80 kWh m 2 in the states of Perlis, Kedah, Pulau Pinang and Northern Perak to about 3.00 kWh m -2 in the east coast with areas in Langkawi receiving the highest, and Kuantan, the lowest. Data for Sabah and Sarawak are only recently available, with the coastal region receiving higher solar radiation, but the highlands much lower levels. This variation is similar to that obtained between the east coast and the west coast of the peninsular. Measured data from more than 10 years of direct and diffuse solar radiation are available only for Penang and Kuala Lumpur. Data available for Penang show that the amount of direct radiation is normally less than 60% of the global solar radiation. This may give some reduction in performance of the collector system using a concentrator. Information on the availability and seasonal variability of global solar radiation for most regions of the country is sufficient for successful operation of solar powered devices that do not require focusing by concentrator. Statistical analysis shows that days with low daily solar radiation occur rarely in the west coast of the peninsula, while the east coast experiences a larger variability of daily global radiation.

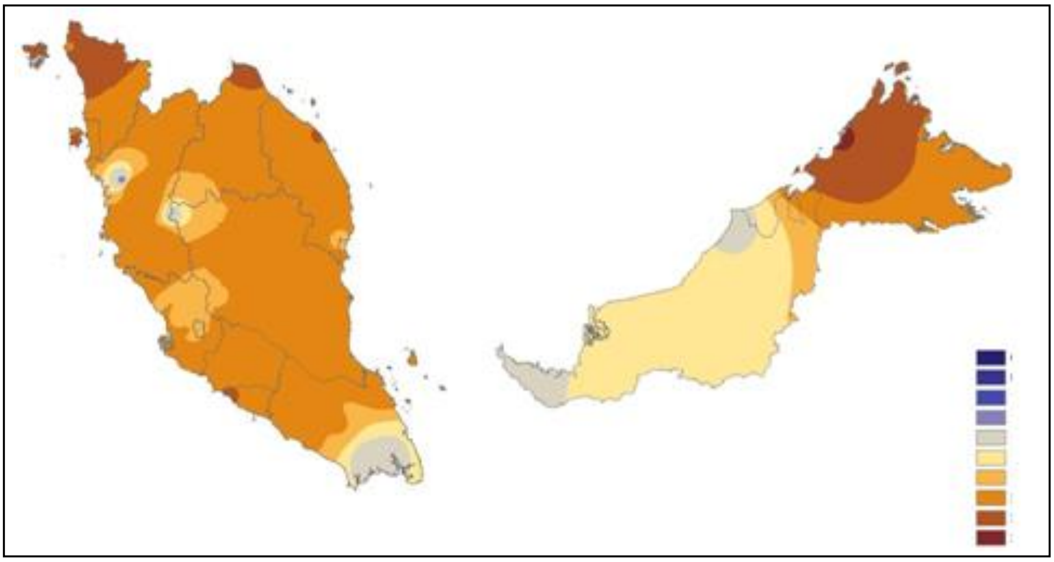

Figure 2.1: Average solar radiation (MJ/m^2/day)

(Source: Dalimin, M.N.2005)

The issue of rainfall has been raised in several forums, mainly related to the high amount of rainfall experienced by the country, especially along the east coast of Peninsular Malaysia and on the highlands of Sabah and Sarawak. One may have to look at the total solar radiation of these areas, which obviously has some effect. However, the duration of rainfall is short and the effect is less than what was earlier thought, as the downpour is normally very heavy and only for short periods. The issue of days with no sunshine has also been raised. The concern is mainly related to the amount of storage needed to cater for energy needs during the sunless days. From statistical data obtained, it has been found that the occurrence of total days without Sun is basically not happening in Malaysia. However, in most solar energy systems, in which storage is required, three days of storage capacity are normally designed. (Dalimin, M.N.2005)

Different types of solar collectors are used to meet different energy needs. Passive solar building designs capture the sun's heat to provide space heating and light. Photovoltaic cells convert sunlight directly to electricity. Concentrating solar power systems focus sunlight with mirrors to create a high-intensity heat source, which then produces steam or mechanical power to run a generator that creates electricity. Flat-plate collectors absorb the sun's heat directly into water or other fluids to provide hot water or space heating. And solar process heating and cooling systems use specialized solar collectors and chemical processes to meet large-scale hot water and heating and cooling needs.

Solar technologies produce few negative environmental impacts during collector operation. However, there are environmental concerns associated with the production of collectors and storage devices. In addition, cost is a great drawback to solar power. Although sunlight is free, solar cells and the equipment needed to convert their direct-current output to alternating current for use in a house is expensive. Electricity generated by solar cells is still more than twice as expensive as electricity from fossil fuels. Part of the problem with cost is that solar cells can the parabolic troughs that make up this concentrating solar power system generate power from the sun on a large scale operate during daylight hours. In contrast, a coal or natural gas plant can run around the clock, which means the cost for building the plant can be spread over many more hours of use.

2.2.3 Advantages and Limitations of Solar Energy

There are the advantages of solar energy:

a) Saves you money

i) After the initial investment has been recovered, the energy from the sun is practically free.
ii) The recovery/ payback period for this investment can be very short depending on how much electricity your household uses.
iii) It will save you money on your electricity bill if you have one at all.
iv) Solar energy does not require any fuel.
v) It's not affected by the supply and demand of fuel and is therefore not subjected to the ever-increasing price of gasoline.
vi) The savings are immediate and for many years to come.
vii) The use of solar energy indirectly reduces health costs.

b) Environmentally friendly

i) Solar Energy is clean, renewable (unlike gas, oil and coal) and sustainable, helping to protect our environment.
ii) It does not pollute our air by releasing carbon dioxide, nitrogen oxide, sculpture dioxide or mercury into the atmosphere like many traditional forms of electrical generations does.
iii) Therefore Solar Energy does not contribute to global warming, acid rain or smog.
iv) It actively contributes to the decrease of harmful green house gas emissions.
v) It's generated where it is needed.
vi) By not using any fuel, Solar Energy does not contribute to the cost and problems of the recovery and transportation of fuel or the storage of radioactive waste.

c) Independent/ semi-independent

i) Solar Energy can be utilized to offset utility-supplied energy consumption. It does not only reduce your electricity bill, but will also continue to supply your home/ business with electricity in the event of a power outage.
ii) A Solar Energy system can operate entirely independent, not requiring a connection to a power or gas grid at all. Systems can therefore be installed in remote locations (like holiday log cabins), making it more practical and cost-effective than the supply of utility electricity to a new site.
iii) The use of Solar Energy reduces our dependence on foreign and/or centralized sources of energy, influenced by natural disasters or international events and so contributes to a sustainable future.
iv) Solar Energy supports local job and wealth creation, fuelling local economies.

d) Low/ no maintenance

i) Solar Energy systems are virtually maintenance free and will last for decades.
ii) Once installed, there are no recurring costs.
iii) They operate silently, have no moving parts, do not release offensive smells and do not require you to add any fuel.
iv) More solar panels can easily be added in the future when your family's needs grow.

Above are the limitations of solar energy:

a) The initial cost is the main disadvantage of installing a solar energy system, largely because of the high cost of the semi-conducting materials used in building one.
b) The cost of solar energy is also high compared to non-renewable utility-supplied electricity. As energy shortages are becoming more common, solar energy is becoming more price-competitive.

c) Solar panels require quite a large area for installation to achieve a good level of efficiency.
d) The efficiency of the system also relies on the location of the sun, although this problem can be overcome with the installation of certain components.
e) The production of solar energy is influenced by the presence of clouds or pollution in the air.
f) Similarly, no solar energy will be produced during nighttime although a battery backup system.
g) As far as solar powered cars go - their slower speed might not appeal to everyone caught up in today's rat race.

2.3 SOLAR COLLECTOR

At the heart of a solar thermal system is the solar collector. A device used to collect, absorb, and transfer solar energy to a working fluid, such as water or air. The solar heat can be used for heating water, to back up heating systems, or for heating swimming pools. There are a number of different design concepts for collectors: besides simple absorbers used for swimming pool heating, more sophisticated systems have also been developed for higher temperatures, such as integral storage collector systems, flat-plate collectors, evacuated flat-plate collectors and evacuated-tube collectors. 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. In flat plate absorbers, two sheets are sandwiched together allowing the medium to flow between the two sheets.

2.3.1 Material for Solar Energy Collector

This section describes briefly some of the principal requirements for and the Properties of materials employed in solar collectors used for the transformation of solar energy into thermal energy.

2.3.1.1 Diathermanous Materials (Glazing)

The term "diathermanous" is applied to materials capable of transmitting radiant energy, including solar energy. From the standpoint of the utilization of solar energy, the important characteristics are reflection (ρ), absorption (α), and transmission (τ). The first two should be as low as possible and the latter as high as possible for maximum efficiency. According to the law of conservation of energy, the relationship between the absorbed, reflected and transmitted energy is:

$$\boldsymbol{\alpha + \rho + \tau = 1} \qquad (2.3.1.1.1)$$

Where,

α is the solar absorptance, i.e. the fraction of the incident solar radiation absorbed by a substance.

ρ is the solar reflectance, i.e. the fraction of the incident solar radiation reflected by a surface.

τ is the solar transmittance, i.e. the fraction of the incident solar radiation transmitted through a non-opaque substance.

The relative magnitudes of α, ρ and τ not only vary with the temperature, the surface characteristics, body geometry, and the material but also vary with wavelength. Solids and liquids are usually opaque in most engineering applications, and transmittance τ for this type of matter is zero. Gases, on the other hand, reflect very little, and ρ can therefore be neglected in a majority of problems. The purpose of the glazing is to admit as much solar radiation as possible and to reduce the upward loss of heat to the lowest attainable value. Glass has been the principal material used to glaze solar collectors because it has the highly desirable property of transmitting as much as 90% of the incoming short-wave radiation (solar), while virtually none of the long wave radiation emitted by the flat plate can escape outward by transmission. Glass of low iron content has a relatively high transmittance (0.85 - 0.90 at normal incidence) for the solar spectrum from 0.30 to 3.0μ, but its transmittance is essentially surfaces (3.0 - 50μ).

Plastic films and sheets also posses high short wave transmittance, but, because most of the usable varieties possess transmission bands in the middle of the thermal radiation spectrum, they may have long wave transmittances as high as spectrum, they may have long wave transmittances as high as 0.40. Plastics are also generally limited in the temperatures, which they can sustain without undergoing dimensional changes. Only a few of the varieties now available can withstand the sun's ultra-violet radiation for long periods of time. The glass that is generally used in solar collectors may be either single-strength (2.0 to 2.5 mm thick) or double-strength (3.0 - 3.5 mm). The commercially available grades of window or greenhouse will have normal incidence transmittances of about 0.87 and 0.85 respectively. For clear glass such as that used for solar collectors the 4% reflectance from each glass-air interface is the most important factor in reducing transmission, although a gain of about 3% in transmittance can be obtained by the use of water-white glass. Antireflection coatings of the kind used for camera and telescope lenses also can make significant improvement in transmission, but the cost of the process presently available is prohibitively high. The effect of dirt and dust on collector glazing is surprisingly small, and the cleansing effect of occasional rain seems to be adequate to maintain the transmittance within 2 - 4% of its maximum value. In addition to servicing as a heat trap by admitting short-wave solar radiation and retaining long wave thermal radiation, the glazing also reduces heat loss by convection. The insulating effect of the glazing is enhanced by the use of several sheets of glass or glass plus plastic.

Table 2.1: Transmittances for various glazing materials when the direct solar beam

Material	Transmittance (τ)
i) Crystal glass	0.91
ii) Window glass	0.85
iii) Polymethyl methacrylate (acrylic) (Acrylate, Lucite, Plexiglass)	0.89
iv) Polycarbonate (Lexan, Merlon)	0.84
v) Polyvinyl fluoride (Tedlar)	0.93
vi) Polyamide (Kapton)	0.80
vii) Polyethylene terephthalate (polyester) Mylar	0.84
viii) Fluorinated ethylene propylene (FEP Teflon)	0.96

(Source: Prasad, P.R., Byregowda, H.V. and Gangavati, P.B. 2010)

2.3.1.2 Absorber Plates

The primary function of the absorber plate is to absorb as much as possible of the radiation reaching through the glazing, to lose as little heat as possible upward to the atmosphere and downward through the back of the container, and to transfer the retained heat to the circulating fluid. In general, absorption of solar energy impinging on an absorber plate should be as high as possible, but re-emission (loss) outward from the collector should be minimized. In hydronic collectors the absorber is usually made of copper, aluminum or steel. Factors that determine the choice of absorber material are its thermal conductivity, its durability and ease of handling, its availability and cost, and the energy required to produce it. Absorber plates are usually given a surface coating (which may be a black paint) that increases the fraction of available solar radiation absorbed by the plate (its absorptance α). Black paints, for which $\alpha = 0.92$ to 0.98, are usually applied by spraying and are then heat-treated to evaporate solvents and improve adherence. These surfaces must be able to withstand repeated and prolonged exposure to high temperatures without appreciable deterioration or out gassing. It is well known that a black body is a perfect absorber of radiant energy and is a perfect radiator; that is, it has an absorptance α and an emittance ε, each equal to unity (emittance is the ratio of the amount of radiation emitted by the surface to the amount of "blackbody" or perfect radiator would emit at the same temperature). Actual surfaces do not behave like perfect absorbers or perfect radiators and have absorptance and emittance less than unity. Parenthetically, it may be pointed out that a black body is not necessarily non-luminous but may be as bright as the sun (which is not quite a black body). The term merely indicates a surface that is a perfect radiator and a perfect absorber. According to Kirchoff's law, at thermal equilibrium the absorptance and emittance of a body are the same.

The emittance of a surface varies with its temperature and its roughness. If it is a metal, it depends also on its degree of oxidation. Highly polished metals have low emittance, provided oxidation and surface imperfections are kept to a minimum. The absorptance of a surface depends on the same factors as the emittance and, strictly speaking, on the distribution of wavelengths in the spectrum of incident radiation. If the character of the absorbing surface is such that its absorptance is independent of the distribution of incident wavelengths, it is called grey, and its absorptance and emittance are the same even though thermal equilibrium does not exist - that is, even though the temperatures of the radiator and the receiver are not the same. Evidently, if the difference in temperature between an emitting and an absorbing surface is small, grey body conditions can be assumed with little error. For example, room temperatures and the temperatures attained by solar collectors or by ordinary radiators are nearly enough alike to permit each to be considered "grey".

Table 2.2 gives values of absorptance and infrared (IR) emittance for various Materials; it also gives values of reflectance. It is noteworthy that many common building materials have excellent emitting surfaces for long wave radiation.

Table 2.2: Solar absorptance, Infrared emittance and Reflectance for various surfaces.

Material	**α**	**ρ**	**ε**	**α/ε**
White plaster	0.07	0.93	0.91	0.08
Fresh snow	0.13	0.87	0.82	0.16
White paint	0.20	0.80	0.91	0.22
White enamel	0.35	0.65	0.90	0.39
Green paint	0.50	0.50	0.90	0.56
Red brick	0.55	0.45	0.90	0.60
Concrete	0.60	0.40	0.92	0.68
Grey paint	0.75	0.25	0.88	0.79
Black tar paper	0.93	0.07	0.93	1.00
Flat black paint	0.96	0.04	0.88	1.09
3M Velvet black paint	0.98	0.02	0.90	1.09
Granite	0.55	0.45	0.44	1.25
Graphite	0.78	0.22	0.41	1.90
Aluminum foil	0.15	0.85	0.05	3.00
Galvanized steel	0.65	0.35	0.13	5.00

(Source: Prasad, P.R., Byregowda, H.V. and Gangavati, P.B. 2010)

2.3.1.3 Selective Absorber

A surface that has a high absorptance and is a good absorber of solar radiation usually has a high infrared emittance as well and is a good radiator of heat. A flat-black paint that absorbs 96% of the incoming solar energy will also reradiate much of the energy as heat, the exact amount depending on the temperature of the absorber plate and the glazing. Ideally, one would like a surface to be selective, absorbing all the solar wavelengths and emitting none of the heat wavelengths, so that more heat could be transferred to the working fluid; for such a surface, $\alpha = 1$ and $\varepsilon = 0$. Selective absorbers can be manufactured that approach this ideal, and several are available commercially (Table 2.3). Selective absorbers often consist of a very thin black metallic oxide on a bright metal base. The oxide coating is thick enough to act as a good absorber, with $\alpha = 0.95$, but it is essentially transparent to longer wavelength heat radiation, neither absorbing nor emitting much of the 3 to 30 micron radiation. As a result, the efficiency of the collector is greater when this type of surface is used. To date, the most successful and stable selective absorber is made by electroplating a layer of nickel onto the absorber plate and then electrodepositing an extremely thin layer of chromium oxide onto the nickel. This combination is more resistant to water damage than the commonly used nickeloxide coating. The manufacturing processes by which selective coatings are applied tend to make selective absorbers expensive.

Table 2.3: Selective absorbers can be manufactured that approach this ideal, and several are available commercially

Selective Coatings	**α**	**ε**	**α/ε**
Black Chrome Black	0.93	0.10	9.3
Nickel on polished nickel	0.92	0.11	8.4
Black Nickel on galvanized iron	0.89	0.12	7.4
CuO on nickel	0.81	0.17	4.7
Co3O4 on silver	0.90	0.27	3.3
CuO on aluminum	0.93	0.11	8.5
CuO on anodized aluminum	0.85	0.11	7.7

(Source: Prasad, P.R., Byregowda, H.V. and Gangavati, P.B. 2010)

2.3.1.4 Thermal Insulation

Flat-plate collectors must be insulated to reduce conduction and convection losses through the back and sides of the collector box. The insulation material should be dimensionally and chemically stable at high temperatures, and resistant to weathering and dampness from condensation. Usually, glass-wool insulation 10 cm thick is recommended. it would be between if the insulation also could contribute to the structural rigidity of the collector, but more rigid insulating materials are often less stable than glass-wool. Temperatures in flat-plate solar collectors can be high enough to melt some foam insulations, such as Styrofoam. And some foam give off corrosive frames at high temperatures, which could damage the absorber plate.

2.3.2 Solar Collector Choice

The solar thermal collectors are devices capable of capturing solar radiation and sending a fluid, for later use the solar collectors are divided into two main groups:

a) Solar Collectors without concentration: They do not exceed the 70 ° C, so they are used in applications of low temperature. An example of an application would be producing hot water.
b) The Solar Collectors with concentration: Are the ones that using the methods of concentrating optics are capable of raising the fluid´s temperature over 70 ° C. These are applied in the solar thermal medium and high temperature.

2.3.3 Types of Solar Collectors

a) Solar Collectors without concentration

These collectors are characterized by not having methodic concentration of solar energy, so that the relationship between the collector and the surface is almost the absorption unit.

i) Flat plate solar collector:

Generally flat plate collector acts as a receptor that gathers energy from the sun and warm up a plate. The energy stored in the plate is transferred to the fluid. Usually, these collectors have a transparent cover glass or plastic taking advantage of the greenhouse effect, consisting of a series of copper tubes, which exposed to the sun absorb solar radiation and it is transmitted to the fluid passing through its interior. Its application is the production of hot water, air conditioning and heating of swimming pools.

ii) Air Collectors:

Its main feature is to have the air as a heat carrier fluid. They have a maximum temperature limit (convection processes have a minor influence on the air) and work better for a normal road, but in contrast with a low heat capacity and the process of heat transfer between plate and the fluid is bad. Its main application is the heating.

iii) Vacuum Collectors:

Those have a double deck envelope, sealed, insulated inside and outside. Its aim is to reduce losses due to convection. They are more expensive, in addition to losing the effect of vacuum with the passage of time. Its main application is the production of sanitary water, heating pools and air conditioning.

iv) Conical or spherical Collectors:

Its main feature is that the unit simultaneously captures and storages. Its receiving area is conical or spherical with a cover glass in the same geometry. With these geometries it ensures that the surface gets illuminated throughout the day, in the absence of shade, is constant. The installation is very simple, but there are problems with the stratification of water and the receiving surface is small. Its main application is the production of hot water through solar energy.

b) Solar Collectors with concentration:

These use special systems in order to increase the intensity of radiation on the absorbing surface and thus achieve high temperatures in the heat carrier fluid. The main complication is the need for a monitoring system to ensure that the collector is permanently oriented towards the Sun.

2.4 FLAT PLATE SOLAR COLLECTOR

Flat-plate collectors are the most common solar collectors for use in solar water heating systems in homes and in solar space heating. A flat-plate collector consists basically of an insulated metal box with a glass or plastic cover (the glazing) and a dark-colored absorber plate. Solar radiation is absorbed by the absorber plate and transferred to a fluid that circulates through the collector in tubes. In a liquid-based collector it is usually water.

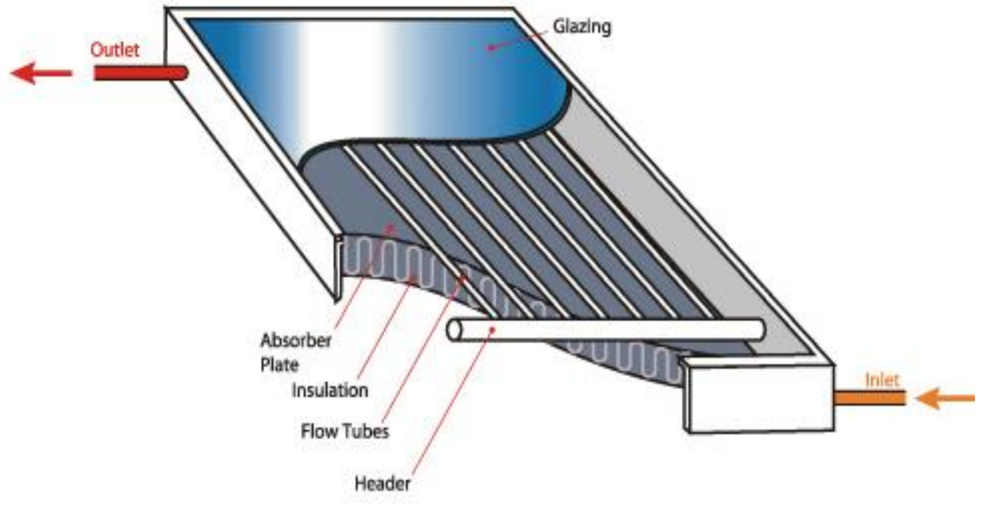

Figure 2.2: Details about solar flat plate collector

(Source: http://www.drenergyservices.com/Solar_Thermal.html)

Flat-plate collectors heat the circulating fluid to a temperature considerably less than that of the boiling point of water and are best suited to applications where the demand temperature is 30-70°C (86-158°F) and/or for applications that require heat during the winter months.

2.4.1 Components of Flat Plate Solar Collector

A flat-plate collector consists of an absorber, a transparent cover, a frame, and insulation. Usually an iron-poor solar safety glass is used as a transparent cover, as it transmits a great amount of the short-wave light spectrum.

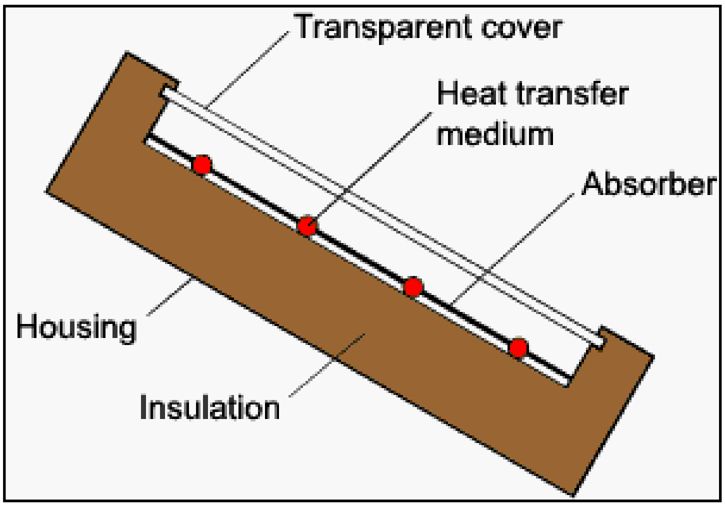

Figure 2.3: Sketch of a flat-plate collector

(Source: http//www.volker-quaschning.dearticlesfundamentals)

Simultaneously, only very little of the heat emitted by the absorber escapes the cover (greenhouse effect).

In addition, the transparent cover prevents wind and breezes from carrying the collected heat away (convection). Together with the frame, the cover protects the absorber from adverse weather conditions. Typical frame materials include aluminum and galvanized steel; sometimes fiberglass-reinforced plastic is used.

The insulation on the back of the absorber and on the side walls lessens the heat loss through conduction. Insulation is usually of polyurethane foam or mineral wool, though sometimes mineral fiber insulating materials like glass wool, rock wool, glass fiber or fiberglass are used.

Flat collectors demonstrate a good price-performance ratio, as well as a broad range of mounting possibilities (on the roof, in the roof itself, or unattached).

2.4.1.1 Absorber

The dark-colored component of a solar collector that absorbs solar radiation and converts it to heat, or, in a solar photovoltaic device, the material that readily absorbs photons to generate charge carriers (free electrons or holes). Absorbers are usually black because dark surfaces demonstrate a particularly high degree of light absorption.

The level of absorption indicates the amount of short-wave solar radiation being absorbed (i.e., not reflected). As the absorber warms up to a temperature higher than the ambient temperature, it gives off most of the accumulated solar energy in the 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 most 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.

The usual coatings provide a degree of absorption of over 90%. Solar paints, which can be mechanically applied to the absorbers (with either brushes or sprays), are less or not at all selective, as they have a high level of emission. Galvanically applied selective coatings include black chrome, black nickel, and aluminum oxide with nickel. Relatively new is a titanium-nitride-oxide layer, which is applied via steam in a vacuum process. This type of coating stands out not only because of its quite low emission rates, but also because its production is emission-free and energy efficient.

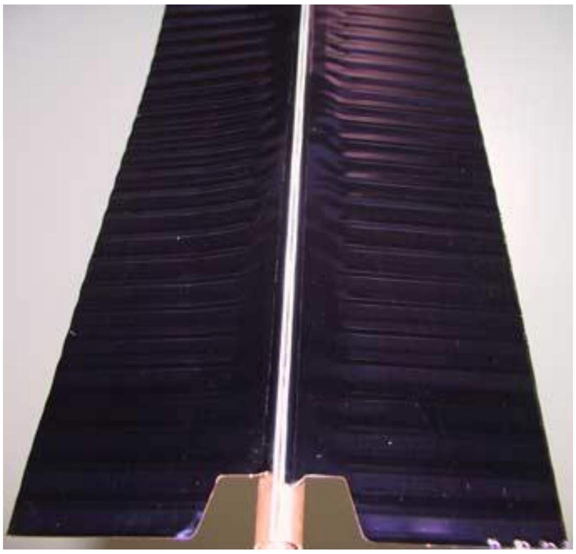

Figure 2.4: Absorber

(Source: http://www.daviddarling.info/images/solar_absorber.jpg)

2.4.2 Principal of Flat Plate Solar Collector

A flat plate solar collector is an energy conversion device that absorbs solar radiation and transfers the energy to a working fluid passing through the collector. A flat plate collector does not concentrate incident energy before absorption; hence, it is able to collect both direct and diffuse components of radiation. Flat plate collectors are used primarily for air and water heating. The principal features of flat plate collectors are:

a) A high transmission cover
b) An absorber plate coated with a high absorptance (solar) and low emittance (infrared) layer,
c) A high conductivity absorber plate with fin and tube construction or low conductivity plate with short heat conduction paths through the absorber,
d) Heat removal fluid passageways in good thermal contact with the absorber plate, and
e) Weather proof casing with insulation behind the absorber plate.

2.4.3 Operation of Flat Plate Solar Collector

Flat plate collectors capture solar energy by employing the green house effect. The glass covering permits up to 90% of the visible sunlight to enter the collector. Heat losses from solar water heating system take the three modes of heat transfer which is conduction, convection and radiation. The conduction heat losses occur from sides and the back of the collector plate. The convection heat losses take place from the absorber plate to the glazing cover. The radiation losses occur from the absorber plate due to the plate temperature. The heat losses from the transparent cover to the ambient air are due to irradiative and convective exchanges which are affected by the wind velocity, ground, and surrounding condition and by long wave radiation from the sky. When the light passes through the glass its frequency is changed slightly to a lower energy level. When the light strikes the absorbing surface of the flat plate inside, the light is absorbed as heat. The combination of the glass frequency change and the solar absorbing surface of the plate capture the maximum amount of energy. As the absorber plate heats up it begins to radiate energy as infrared (IR) or heat radiation. Glass is essentially opaque to IR wavelengths so the heat is trapped increasing the temperature.

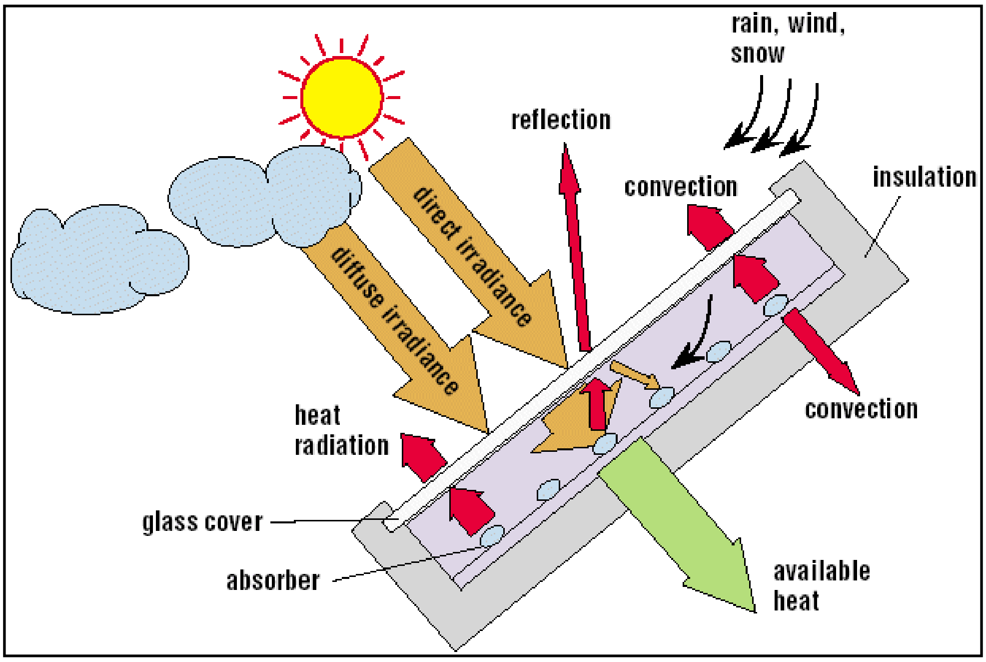

Figure 2.5: Operation of flat plate solar collector

(Source: Agbo, S.N. and Okoroigwe, E.C. 2007)

2.5 EVACUATED-TUBE COLLECTOR

A type of solar collector that can achieve high temperatures, in the range 170°F (77°C) to 350°F (177°C) and can, under the right set of circumstances, work very efficiently. Evacuated-tube collectors are, however, quite expensive, with unit area costs typically about twice that of flat-plate collectors. They are well-suited to commercial and industrial heating applications and also for cooling applications (by regenerating refrigeration cycles). They can also be an effective alternative to flat-plate collectors for domestic space heating, especially in regions where it is often cloudy. For domestic hot water heating, flat-plate collectors tend to offer a cheaper and more reliable option.

The collectors are usually made of parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. The fin is covered with a coating that absorbs solar energy well, but which inhibits radiative heat loss. Air is removed, or evacuated, from the space between the two glass tubes to form a vacuum, which eliminates conductive and convective heat loss.

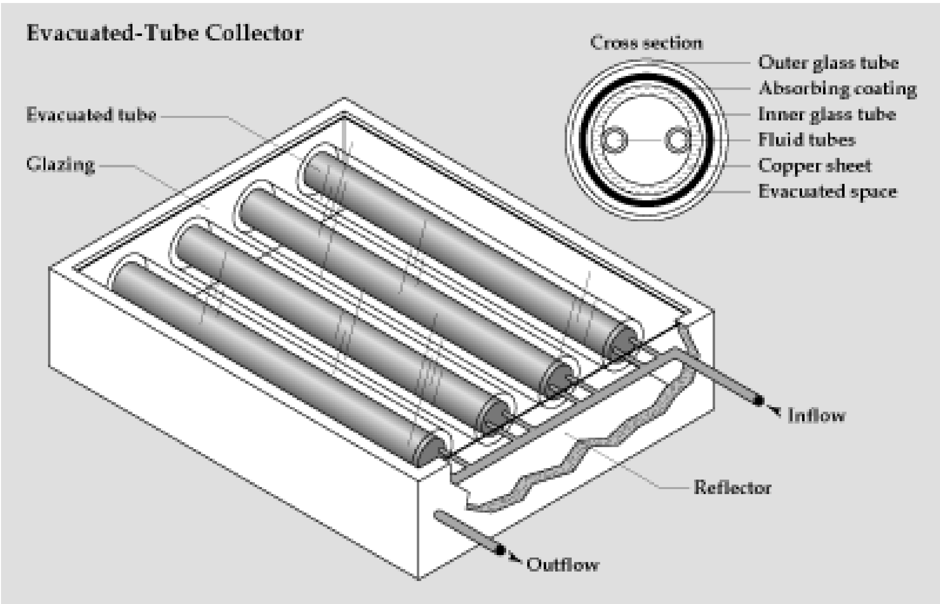

Figure 2.6: Detail about evacuated tube collector

(Source: http://www.iklimnet.com/save/solartubecollectors.html)

A new evacuated-tube design is available from the Chinese manufacturers, such as: Beijing Sunda Solar Energy Technology Co. Ltd. The "dewar" design features a vacuum contained between two concentric glass tubes, with the absorber selective coating on the inside tube. Water is typically allowed to thermosyphon down and back out the inner cavity to transfer the heat to the storage tank. There are no glass-to-metal seals. This type of evacuated tube has the potential to become cost-competitive with flat plates.

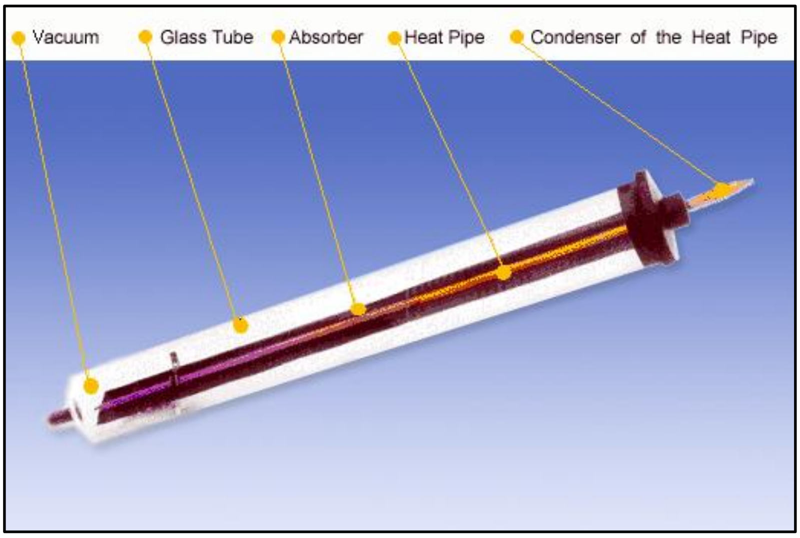

Figure 2.7: The example of evacuated tube collector

(Source: http://www.iklimnet.com/save/solartubecollectors.html)

2.5.1 Operation of 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. The heated liquid circulates through heat exchanger and gives off its heat to water that is stored in a solar storage tank.

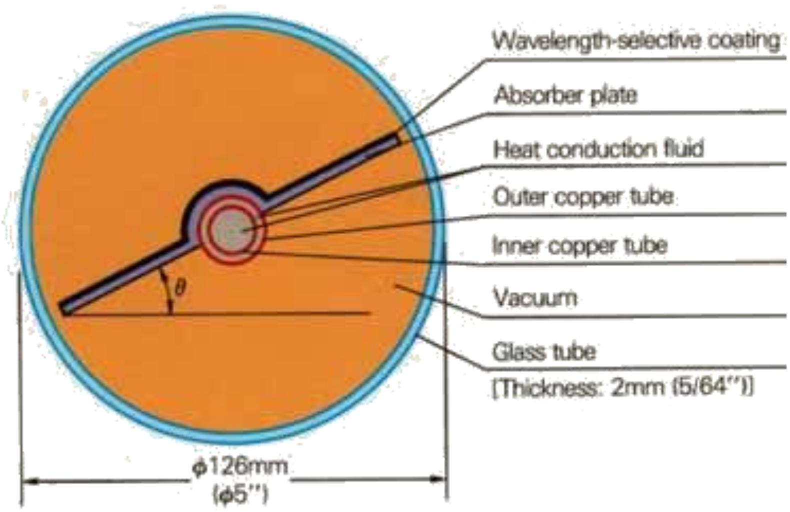

Figure 2.8: Cross section area of a evacuated tube collector

(Source: http://inforse.org/europe/dieret/Solar/solar.html)

Evacuated tube collectors are modular tubes which 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 importance compared with the amount of heat transferred to the liquid in the absorber tube. The vacuum in the glass tube, being the best possible insulation for a solar collector, suppresses heat losses and also protects the absorber plate and the "heat-pipe" from external adverse conditions. This results in exceptional performance far superior to any other type of solar collector.

2.6 FORTRAN

FORTRAN is a general purpose programming language, mainly intended for mathematical computations in e.g. engineering. FORTRAN is an acronym for FORmula TRANslation, and was originally capitalized as FORTRAN. However, following the current trend to only capitalize the first letter in acronyms, we will call it FORTRAN. FORTRAN was the first ever high-level programming languages, other high language programs include Ada, Algol, BASIC, COBOL, C, C++, LISP, Pascal, and Prolog.. The work on FORTRAN started in the 1950's at IBM and there have been many versions since. By convention, a FORTRAN version is denoted by the last two digits of the year the standard was proposed.

2.6.1 Why Learn FORTRAN?

FORTRAN is the dominant programming language used in engineering applications. It is therefore important for engineering graduates to be able to read and modify FORTRAN code. From time to time, so-called experts predict that FORTRAN will rapidly fade in popularity and soon become extinct. These predictions have always failed. FORTRAN is the most enduring computer programming language in history. One of the main reasons FORTRAN has survived and will survive is software inertia. Once a company has spent many man-years and perhaps millions of dollars on a software product, it is unlikely to try to translate the software to a different language.

A major advantage FORTRAN has is that it is standardized by ANSI and ISO. Consequently, if your program is written in ANSI FORTRAN 77 then it will run on any computer that has a Fortran 77 compiler. Thus, FORTRAN programs are portable across machine platform.

2.6.2 Fortran 77 Basics

A FORTRAN program is just a sequence of lines of text. The text has to follow certain syntax to be a valid FORTRAN program. We start by looking at a simple example:

```
program circle
real r, area
c This program reads a real number r and prints
c the area of a circle with radius r.
write (*,*) 'Give radius r:'
read (*,*) r
area = 3.14159*r*r
```

```
write (*,*) 'Area = ', area
stop
end
```

The lines that begin with a "c" are comments and has no purpose other than to make the program more readable for humans. Originally, all FORTRAN programs had to be written in all upper-case letters. Most people now write lower-case since this is more legible, and so will we.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is one of the important things to be considered in order to complete any research. The main reason is because this methodology wills make sure that our job following a right track until the project is complete. By doing the methodology, it will ensure that the project is following the objectives that have been stated earlier which mean it will follow the guideline based on the objectives. This chapter will discuss the method use to solve the problem of this project. Figure 3.1 shows the flow chart for the methodology of the study.

3.2 METHODOLOGY FLOW CHART

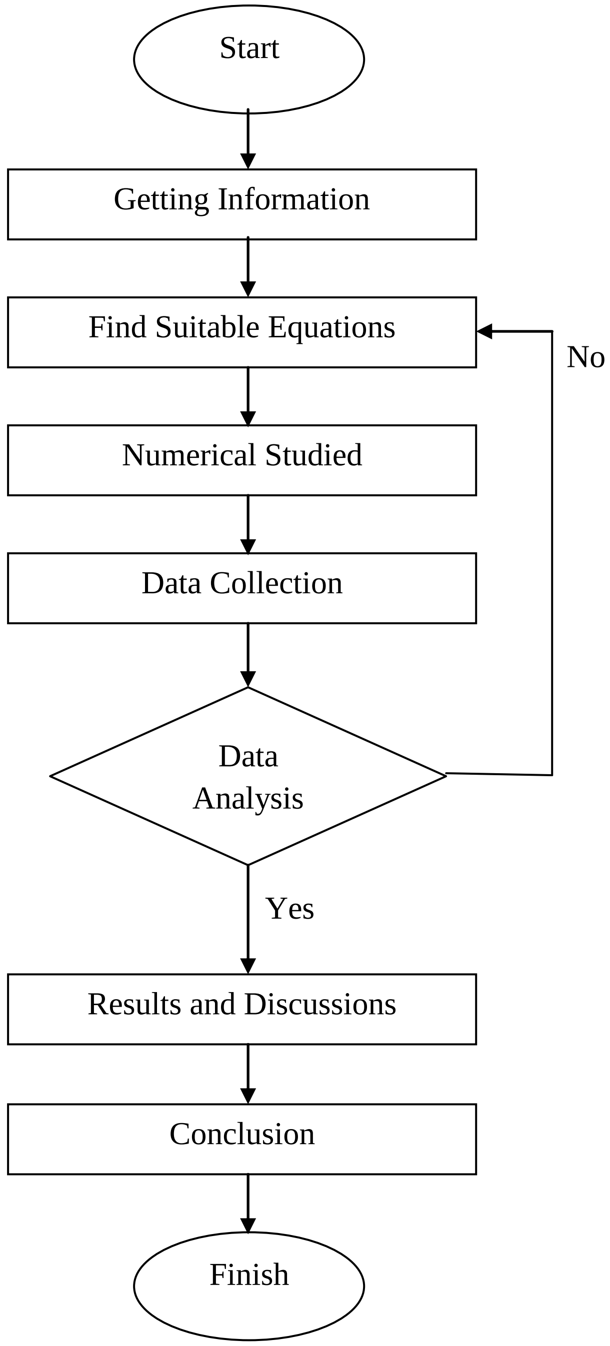

Figure 3.1: Flow chart of simulation

3.3 GATHER THE INFORMATION

The information about this project was about the performance evaluation of solar plate collector in the difference condition. The information was collected from certain source such as internet (related journal), UMP thesis, and related person to this field.

3.3.1 Information from Internet

The information from the internet was most important to assure non-stop information about this topic.

3.3.2 Information from Reference Book

One of main references to refer in order to get the information that related to the influence of emissivity of the absorber surface, ambient temperature and the spacing between the glass cover and the absorber surface on efficiency of flat plate collector by using a numerical studied. Some sort of the equations must be founded in order to perform the numerical studied that can interpret the data from the flat plate collector thus can be comparing with evacuated tube collector in the term of top loss coefficient. Although sometime the thesis and the journal content was not related to this project title and objective but the method is almost same and can be verified. So, it's sometime useful to this project. Reference book also is a main source to search information related to the project. Those include a book from library. After several inspections there were many international books that were related to this project. Below is a related book that can be a reference to this project:

i) S P Sukhatme and J K Nayak, 2009, Solar Energy, Principles of Thermal Collection and Storage, Third Edition, Tata McGraw-Hill Publishing Company Limited.
ii) Jeffrey Gordon, 2005, Solar Energy, the State Of The Art, ISES Position Papers, James & James (Science Publishers) Ltd.

iii) John A.Duffie and William A.Beckman, 2006, Solar Engineering of Thermal Processes, Third Edition, John Wiley & Sons, Inc.

3.3.2 Information from Related Person

The related person that was related to this project is the supervisor that guide on how to elaborate the concept of the solar flat plate collector and numerical studied method. Also related person was the other students that doing project that was related to the solar flat plate collector although the major title is different. Those persons give an advice and proper method to perform the analysis. Some discussion has been held to get a best result.

3.4 FIND SUITABLE EQUATION AND CODING

3.4.1 Overall Loss Coefficient and Heat Transfer Correlations

It is convenient from the point of view of analysis to express the heat lost from the collector in terms of an overall loss coefficient defined by the equation

$$q_1 = U_1 A_P (T_{pm} - T_a) \qquad (3.4.1.1)$$

where

U_1 = overall loss coefficient,

A_p = area of the absorber plate,

T_{pm} = average temperature of the absorber plate, and

T_a = temperature of the surrounding air (assumed to be the same on all sides of the collector)

The heat lost from the collector is the sum of the heat lost from the top, the bottom and the sides. Thus,

$$q_1 = q_t + q_b + q_s \quad (3.4.1.2)$$

where

q_t = rate at which heat is lost from the top,

q_b = rate at which heat is lost from the bottom, and

q_s = rate at which heat is lost from the sides.

Each of these loses is also expressed in terms of coefficients called the top loss coefficient, the bottom loss coefficient and the side loss coefficient and defined by the equations

$$q_t = U_t A_P (T_{pm} - T_a) \quad (3.4.1.2)$$

$$q_b = U_b A_p (T_{pm} - T_a) \quad (3.4.1.3)$$

$$q_s = U_s A_P (T_{pm} - T_a) \quad (3.4.1.4)$$

It will be noted that the definition of each of the coefficients is based on the area A_p and the temperature difference (T_{pm} - T_a). This is done for convenience and helps in giving the simple additive equation

$$U_1 = U_t + U_b + U_s \quad (3.4.1.5)$$

The losses can also be pictured in terms of thermal resistances as shown in the Figure 3.2. The overall loss coefficient is an important parameter since it is a measure of all the losses. Typical values range from 2 to 10 W/m^2-K

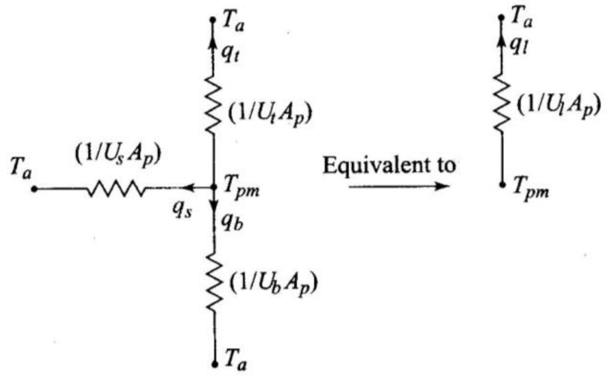

Figure 3.2: Thermal resistance network showing collector losses.

(Source: Sukhatme, S.P. and Nayak, J.K. 2009)

3.4.2 Top Loss Coefficient

The top loss coefficient U_t is evaluated by considering convection and re-radiation losses from the absorber plate in the upward direction. For purposes of calculation, it is assumed that the transparent covers and the absorber plate constitute a system of infinite parallel surfaces and that flow of the heat is one-dimensional and steady (Hottel, H.C., and Woertz, B.B. 1942). It is further assumed that the temperature drop across the thickness of the covers is negligible and that the interaction between the incoming solar radiation absorbed by the covers and the outgoing loss may be neglected. The outgoing re-radiation is of large wavelengths. For these wavelengths, the transparent cover will be assumed to be opaque. This is a very good assumption if the material is glass.

A schematic diagram for a two covers system is shown in Figure 3.3 in a steady state, the heat transferred by convection and radiation between (i) the absorber plate and the first cover, (ii) the first cover and the second cover, and (iii) the second cover and the surroundings must be equal.

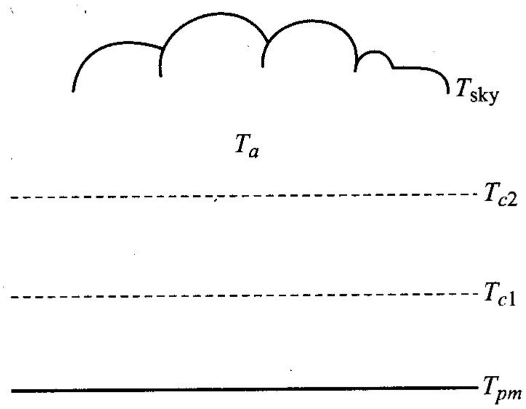

Figure 3.3: Calculation of the top loss coefficient

Source: Kumar, S., Chourasia, B.K. and Mullick, S.C. 2005

Hence,

$$\frac{q_t}{A_p} = h_p - c1 + \frac{\sigma\left(T_{pm}^4 - T_{c1}^4\right)}{\left(\frac{1}{\varepsilon_P} + \frac{1}{\varepsilon_C} - 1\right)} \tag{3.4.1.6}$$

$$= h_{c1-c2} + \frac{\sigma\left(T_{c1}^4 - T_{c2}^4\right)}{\left(\frac{1}{\varepsilon_c} + \frac{1}{\varepsilon_C} - 1\right)} \tag{3.4.1.7}$$

$$= h_w + \sigma\varepsilon_c\left(T_{c2}^4 - T_{sky}^4\right) \tag{3.4.1.8}$$

Where

$h_p - c1$ = convective heat transfer coefficient between the absorber plate and the first cover,

h_{c1-c2} = convective heat transfer coefficient between the first and second covers,

h_w = convective heat transfer coefficient between the topmost cover (in this case the second) and the surrounding air,

T_{c1}, T_{c2} = temperature attained by the two covers,

T_{sky} = effective temperature of the sky with which the radiation exchange takes place,

ε_p = emissivity of the absorber plate for long wavelength radiation, and

ε_c = emissivity of the covers for long wavelength radiation.

Equations (3.4.1.6), (3.4.1.7) and 3.4.1.8) constitute a set of three non-linear equations which have to be solved for the unknowns' q_t, T_{c1} and T_{c2}. However, before this can be done it will be necessary to have some correlations for calculating the convective heat transfer coefficients h_{p-c1}, h_{c1-c2} and h_w, and the sky temperature $T_{sky.}$

3.4.3 Heat Transfer Coefficient between Indicated Parallel Surfaces

The natural convection heat transfer coefficient for the enclosed space between the absorber plate and the first cover or between two covers is calculated by using one of the following correlations suggested by Buchberg (Buchberg, H., Catton, I. and Edwqrds, D.K. 1976). The correlations are based on an examination of available experimental data and all previous correlations.

$$Nu_L = 1;\ Ra_L \cos\beta < 1708$$

$$Nu_L = 1 + 1.446\left(1 - \frac{1708}{Ra_L \cos\beta}\right);\ 1708 < Ra_L \cos\beta < 5900$$

$$Nu_L = 0.229\,(Ra_L \cos\beta)^{0.252};\ \ 5900 < Ra_L \cos\beta < 9.23 \times 10^4$$

$$Nu_L = 0.157\,(Ra_L \cos\beta)^{0.285};$$

$$9.23 \times 10^4 < Ra_L \cos\beta < 10^6 \qquad (3.4.3.1)$$

Nu_L and Ra_L are the Nusselt and Raleigh numbers, respectively. The characteristic dimension L is the spacing between the surfaces, while properties are evaluated at the arithmetic mean of the surface temperatures.

3.4.4 Heat Transfer Coefficient at the Top Cover

The convective heat transfer coefficient (h_w) at the top cover is often referred to as the wind heat transfer coefficient. It has generally been calculated from the following empirical correlation suggested by McAdams (McAdams, W.A. 1954),

$$h_w = 5.7 + 3.8\ V_\infty \tag{3.4.4.1}$$

in which h_w is in W/m^2-K and V_∞ is the wind speed in m/s. this correlation is based on the experiments performed by Jurges in 1924 for flow of air at room temperature parallel to a heated vertical plate 0.5 m square. Since the direction of the wind is, in general, not parallel to the top glass cover, it is obvious that Eq. (3.4.4.1) suffers from certain limitations. Sparrow and Tien have suggested the following dimensionless correlation

$$j = 0.86\ (Re_L^*)^{-1/2} \tag{3.4.4.2}$$

where

- j = j-factor given by $\left(h_w/\rho C_p V_\infty\right)Pr^{2/3}$
- Re_L^* = Reynold number ($V_\infty L^*/\nu$) based on the characteristic dimension
- L^* = $4A_C / C_c$
- A_c = collector gross area, and
- C_c = circumference associated with the collector gross area.

Equation (3.4.4.2) was recommended on the basic of extensive experiments performed in a low turbulence wind tunnel on square and rectangular plates inclined at various angles of attack and yaw (Sparrow, E.M. and Tien, K.K. 1977).

Test (Sparrow, E.M., Ramsey, J.W. and Mass, E.A. 1979) presented results of an experimental investigation to determine the value of h_w from the upper surface of a rectangular plate of size 1.220 m×0.813 m inclined at an angle 40°. The experiments were conducted in the natural environment at mean wind speeds ranging from 1.5 to 5.6 m/s. Based on their data, they suggested the following equation:

$$h_w = 8.55 + 2.56\, V_\infty \tag{3.4.4.3}$$

where

h_w is in W/m^2-K and V_∞ is in m/s

The value predicted by Eq. (3.4.4.3) is typically about twice the values obtained from Eq. (3.4.4.2). Test state that there is a consideration amount of turbulence in the wind in a natural environment. As a result, tests conducted in a low turbulence intensity wind tunnel (as was done by Sparrow and his co-workers) significantly underestimate the value of h_w. Results of other investigators, Kumar (Kumar, S., Chourasia, B.K. and Mullick, S.C. 2005) substantiate the arguments of Test. It is therefore recommended that Eq. (3.4.4.3) be used for calculating the value of the wind heat transfer coefficient.

Sky temperature – the effective temperature of the sky is usually calculated from the following simple empirical relation in which temperatures are expressed in Kelvin.

$$T_{sky} = T_a - 6 \tag{3.4.4.4}$$

3.4.5 Bottom Loss Coefficient

The bottom loss coefficient U_b is evaluated by considering conduction and convection losses from the absorber plate in the downward direction through the bottom of the collector. It will be assumed that the flow of the heat is one-dimensional and steady in Figure 4.3. It most cases, the thickness of insulation provided is such that the thermal resistance associated with conduction dominates. Thus, neglecting the convective resistances, we have

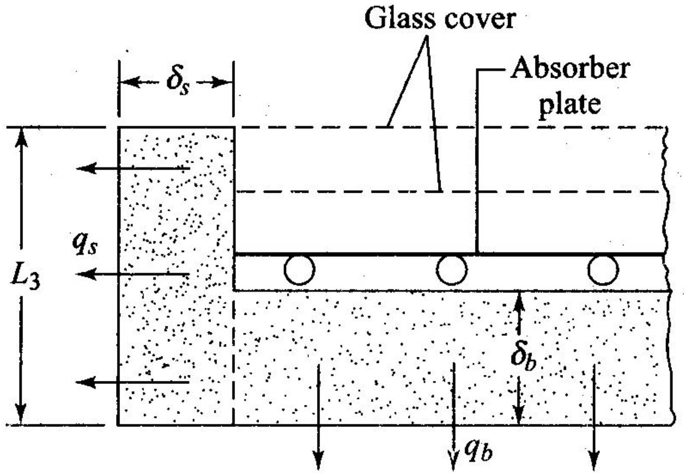

Figure 3.4: Bottom and side losses from a flat plate collector

Source: Sukhatme, S.P. and Nayak, J.K. 2009

$$U_b = \frac{k_i}{\delta_b} \tag{3.3.5.1}$$

Where

k_i = thermal conductivity of the insulation,

δ_b = thickness of the insulation.

3.4.6 Side Loss Coefficient

As in the case of the bottom loss coefficient, it will be assumed that the conduction resistance dominates and that the flow of the heat is one-dimensional and steady. The one-dimensional approximation can be justified on the grounds that the side loss coefficient is always much smaller than the top loss coefficient.

If the dimensions of the absorber plate are $L_1 \times L_2$ and the height of the collector casing is L_3, then the area across which heat flows sideways is 2($L_1 \times L_2$) L_3. The temperature drop across which the heat flows occurs varies from (T_{pm} - T_a) at the absorber plate level to zero both at the top and bottom. Assuming therefore, that the average temperature drop across the side insulation is (T_{pm} - T_a) /2 and that the thickness of this insulation is δ_s , we have

$$q_s = 2L_3(L_1 + L_2)k_i \frac{(T_{pm} - T_a)}{2\delta_s} \tag{3.3.6.1}$$

Thus, from Eq. (3.4.1.4),

$$U_s = \frac{(L_1 + L_2)L_3 k_i}{L_1 L_2 \delta_S} \tag{3.3.6.2}$$

3.4.2 Modified Equation from Previous Researchers

The equation above that was state is a basic equation that was used in the numerical method in this analysis. But, to get the best result in term of the heat losses and the torque heat lost coefficient, the basic coefficient must be modified. Below is the list of the modified equation that has been modified by the previous researcher that has done this research:

i) Hottel & Woeltz equation **(**Hottel, H.C., and Woertz, B.B. 1942**)** for top loss coefficient,

$$U_L = \left[\frac{N}{\left(\frac{c}{T_p}\right)\left(\frac{T_p - T_a}{N + f}\right)} + \frac{1}{h_W}\right]^{-1} + \frac{\sigma(T_P^2 + T_a^2)(T_p + T_a)}{\left(\frac{1}{E_p + 0.00591\, N\, h_W}\right) + \left(\frac{2N + f - 1 + 0.133E_P}{E_g}\right) - N} \tag{3.4.2.1}$$

with:

$-f = (1 + 0.089h_w - 0.1166h_w E_P)(1 + 0.07866\, N)$

$-c = 520(1 - 0.000051\phi^2)$

$-e = 0.43(1 - 100/T_P)$

Note: These relationships are valid for an angle of inclination ranging from 0 <φ <70°. For 70 ° <φ <90 °,must use φ = 70 °.

ii) Maholtra's equation **(**Malhotra et al. 1981**)** for top loss coefficient,

$$U_L = \left[\frac{N}{\left(\frac{204.43}{T_p}\right) \frac{\left({(T_p - T_a) L^3 cos\phi} \Big/ {(N+f)} \right)^{0.252}}{L}} + \frac{1}{h_w} \right]^{-1}$$

$$+ \frac{\sigma (T_p^2 + T_a^2)(T_p + T_a)}{\left(\frac{1}{E_p + 0.0425\, N(1 - E_p)} \right) \left(\frac{2N + f - 1}{E_g} \right) - N} \qquad (3.4.2.2)$$

with:

$$f = (9/h_w - 30/h_w^2)(1 + 0.091\, N)(T_a/316.9)$$
$$c = 204.429$$

Note: These relationships are valid for an angle of inclination ranging from 0 <φ <70°. For 70 ° <φ <90 °,must use φ = 70 °.

iii) Holland's equation **(**Hollands,et al. 1976**)** for top loss coefficient,

$$Nu = 1 + 1.44 \left[1 - \frac{1708}{Cos\beta . Ra} \right] \left[1 - \frac{Sin(1.8\beta)^{1.6} . 1708}{Cos\beta . Ra} \right] + \left[\left(\frac{Cos\beta . Ra}{5830} \right)^{1/3} - 1 \right] \qquad (3.4.2.3)$$

where:

$$Ra = \frac{g\beta (\Delta T) d^3}{\upsilon^2} \times Pr$$

3.5 NUMERICAL STUDIED

From the previous content these are the equation that was used in this project. Then, the next step is to perform the numerical method by using those equations. To perform this numerical method, FOTRAN software was used. Firstly, the coding must be developed using loop and loop. Secondly, the parameter of the flat plate collector was entered into the coding to make it combine with the equation that will be entered in the next step. In this parameter there are different types. There is the manipulated parameter that must been choose proper and the react parameter. The manipulated parameter that has been choose are ambient temperature, T_a (293K, 303K, 313K), emissivity of absorber plate, ε_p (0.05, 0.1, 0.95), wind loss coefficient, H_w (5 $Wm^{-2}K^{-1}$, 10 $Wm^{-2}K^{-1}$, 30 $Wm^{-2}K^{-1}$) and collector tilt from horizontal, β (20°, 45°).thirdly, the equation that was related was entered. Lastly, the software was running to get the data. The program will be fail to perform thus to the error in the coding so the correction must be done to make it succeed. The result will show in term of data list that has all the parameter that was entered before and has been calculated by using FOTRAN software. Then, the data was interpreted by using Microsoft Excel.

3.6 DATA COLLECTION

Data that was shown in FOTRAN was in the list of data that was interpreted in the Microsoft Excel to produce the graph. The graph was in the line graft type. For the graft variation of top loss coefficient with absorber plate and glass cover temperatures for the different plate, the result was getting by changes the emissivity of the absorber plate. For the graph effect of emissivity of absorber plate on efficiency, the result was getting by changing the value of emissivity of absorber plate. For the graft variation of top loss coefficient with absorber plate temperature, the result was comparing to the previous experimental data. For the graft effect of absorber plate temperature on efficiency for different value of wind loss coefficient, $h_{w.,}$ the result come by various the value of h_w. For the graft effect of efficiency on heat flux for different ambient temperatures, $T_{a.}$ The result was getting by changing the value of ambient temperature, T_a. For the graft effect of top loss coefficient on absorber plate temperature for different emissivity of absorber plate, the result was getting by changing the emissivity of the absorber plate and the collector tilt from horizontal.

3.7 DATA ANALYSIS

After the data was collect and interpret into graph, the comparisons will be seen in the flat plate collector and the evacuated tube to see which one is more effective in term of heat loss and top loss coefficient. If the result value was so far from the theory, the equations and the coding must be modified again.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter it will discuss about the graph that has been evaluate from the data that have been running from the FORTRAN software to make it easy to analysis. The bunch of graph can be analyzed to get the result that will make a statement about the efficiency of flat plate collector. This graph will prove the performance of the flat plate collector. This chapter have divide into 2 parts. First part, there will be a discussion about the performance about the flat plate collector based on the efficiency and the top lost coefficient. Second part is discussion about the performance of the evacuated tube collector based on the top lost coefficient.

4.2 DATA ANALYSIS

The temperature of the glass cover is estimated by numerical analysis. The present analysis is applicable for a wide range of parameters given in Table 4.1.

Table 4.1: Range of Parameters

Variable	Units	Range
Absorber Plate Temperature	K	310 – 390
Ambient Temperature	K	293-313
Absorber plate emittance		0.05-0.95
Glass cover emittance		0.88
Angle of Inclination of Collector	^{0}	20 – 45
Number of glass covers		2
Wind loss coefficient	W/m^2K	5 – 30
Reynolds number of flow		200-2000
Enclosure spacing	mm	20-25
Heat flux	W/m^2	300-1200

4.2.1 Data Analysis for Flat Plate Collector

The figure 4.1 has shown that the variation of top loss coefficient with absorber plate and glass cover temperature for different plate. Since the glass is transparent so it usually just make a sun beam go trough it but just absorb little amout of heat. Theoritically we want the top loss coefficient of the glass higher than the absorber because the one that collect the energy was the absorber so it can be used to heat the tube that located between the glass and absorber. If the top loss coefficient of the glass was low. The sun beam and the energy that was collector just struck in the glass and not been remove to the absorber and the tube.From the graph proved the theory because the glass only can hold the energy in a short period perpendicular to the value of temperature that increase. That mean the glass absorb the energy but at one point when temperature was higher enough,the energy will remove and transfer to the absorber. Thus, we need the absorber to have a low top loss coeeficient because we want it hold the energy for long period and decrease the heat loss that was absorb by the absorber. The absorber in this case can hold the energy in long period perpendiculat to the value of temperature that increase. That mean,even the temperature continuos increase but the value of energy still maintain.

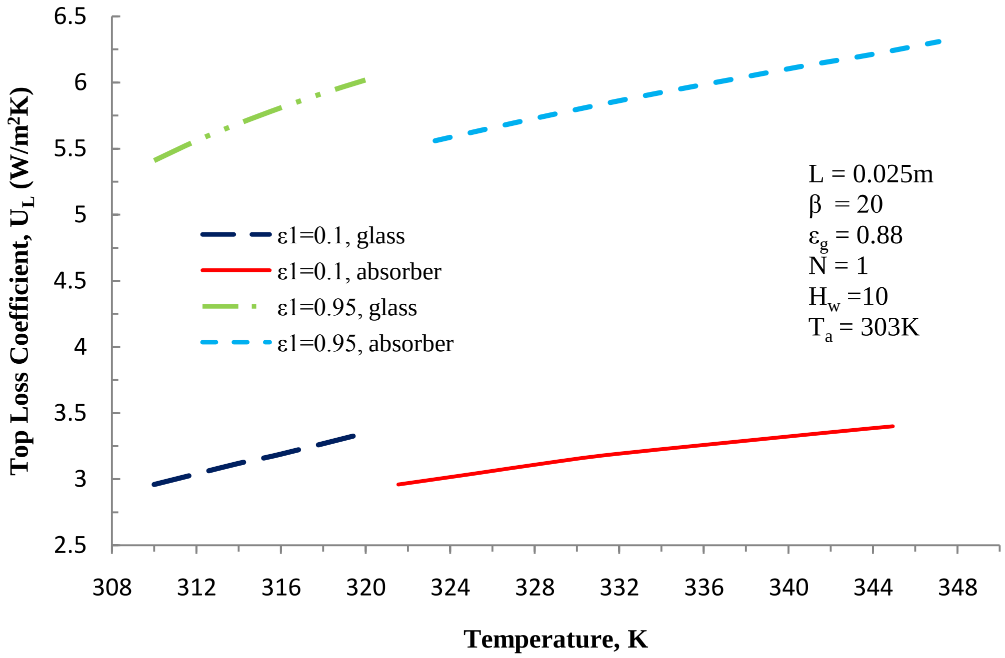

Figure 4.1: Variation of top loss coefficient with absorber plate and glass cover temperature for different plate

From the figure 4.2 that shown effect of emissivity of absorber plate (ε_p) on efficiency. In this experiment the value of emissivity for the absorber was 0.1, 0.05 and 0.95. From the graph we known that the absorber that has emissivity of 0.05 has a higher efficiency compare to the other. Also, the range of the decreasing the efficiency due to the increase of the temperature of the plate also lower than other. It can be observed, increase in the emissivity of absorber plate (ε_p) is to dissipate more heat to atmosphere and consequent reduction in efficiency of system. That mean the absorber can maintain the efficiency of it function even the temperature rapidly increase.

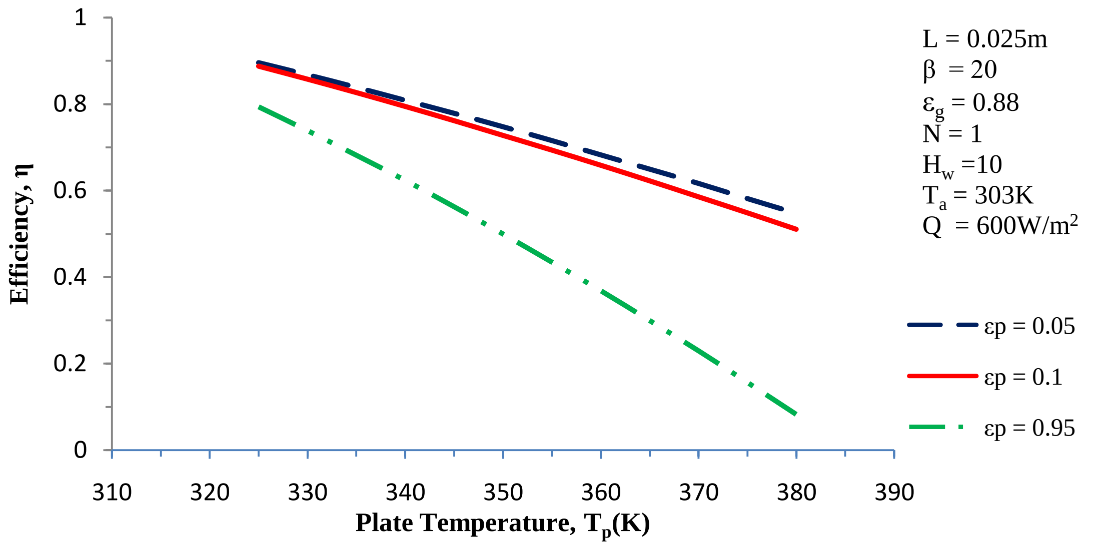

Figure 4.2: Effect of emissivity of absorber plate (ε_p) on efficiency

From figure 4.3 that shown the graph of variation of top loss coefficient (U_L) with absorber plate temperature. The emissivity of the absorber that was used was 0.05, 0.1 and 0.95.Note that, the top loss coefficient of the absorber should be low. So, in the graph has shown that the absorber of 0.05 in emissivity has a lower top loss coefficient compare to the other 2 value of emissivity.

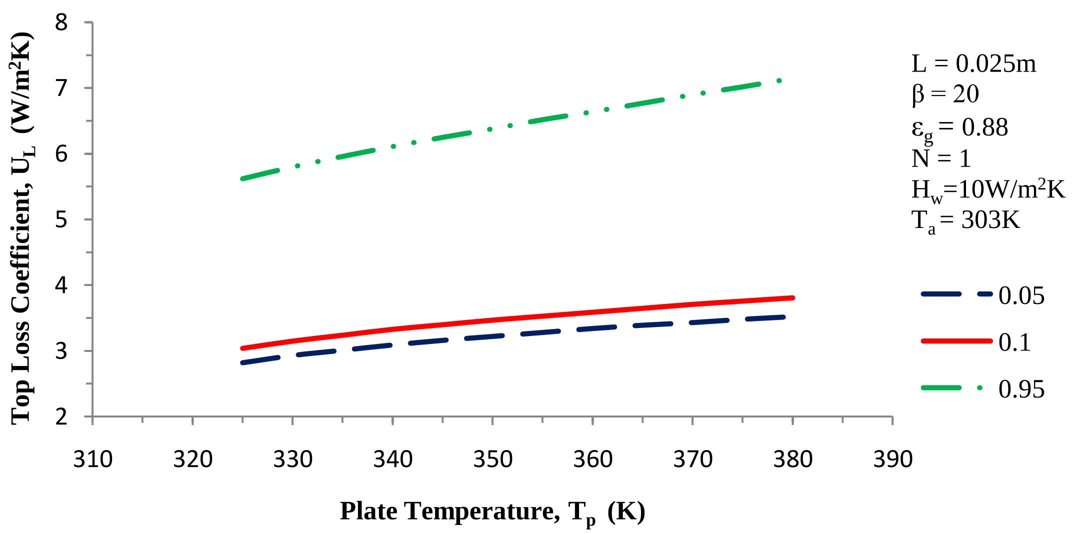

Figure 4.3: Variation of top loss coefficient (U_L) with absorber plate temperature

Wind loss coefficient (h_W) also one of the important parameter in this experiment to analyze the top loss coefficient and the heat loss coefficient of the absorber plate. figure 4.4 shown the effect of absorber plate temperature on efficiency for different values of (h_W).the value of wind coefficient that has been used was 5 $Wm^{-2}K^{-1}$, 10 $Wm^{-2}K^{-1}$ and 30 $Wm^{-2}K^{-1}$ .From the graph, the absorber that have the value of 5 in wind loss coefficient has a higher efficiency compare to other. As the wind loss coefficient, h_w increases, more amount of heat is dissipated to atmosphere and consequently lower efficiency can be expected.

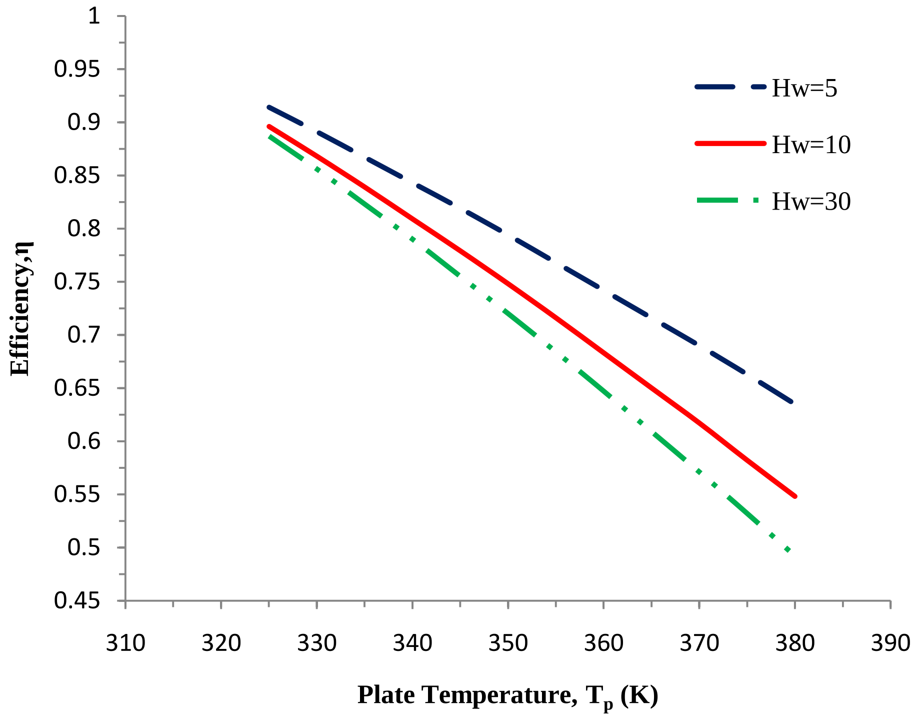

Figure 4.4: Effect of absorber plate temperature on efficiency for different values of (h_W)

In this experiment we need to get high efficiency in order to make the system was in the high performance process. Several parameter has been tested by changed the value so the suitable efficiency can be obtain. In this case, the ambient temperature value has been changed to several values that are 293K, 303K and 313K. In this experiment the absorber that has ambient temperature 313K has a higher efficiency and endurance the heat flux in a suitable range. It get decrease slowly perpendicular with the decreasing of the heat flux but the value of it efficiency was not rapidly decrease.

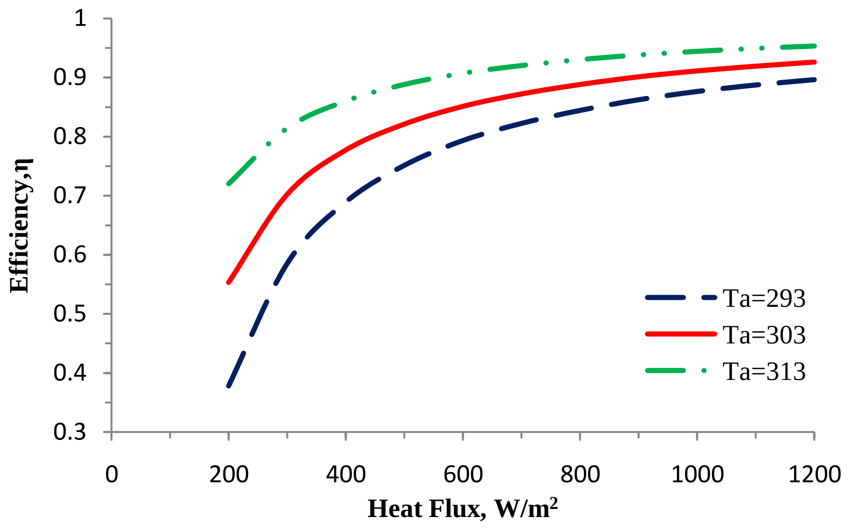

Figure 4.5: Effect of efficiency on heat flux for different ambient temperatures

Refer to figure 4.6, value for overall loss coefficient for single cover collector for different tilt angles for increasing absorber plate temperature. The emissivity of absorber plate 0.95 produced high loss coefficient compare to absorber plate that has emissivity that has 0.1.but between the absorber plate that have a emissivity of 0.95,the tilt 20 in value has a higher top loss coefficient.

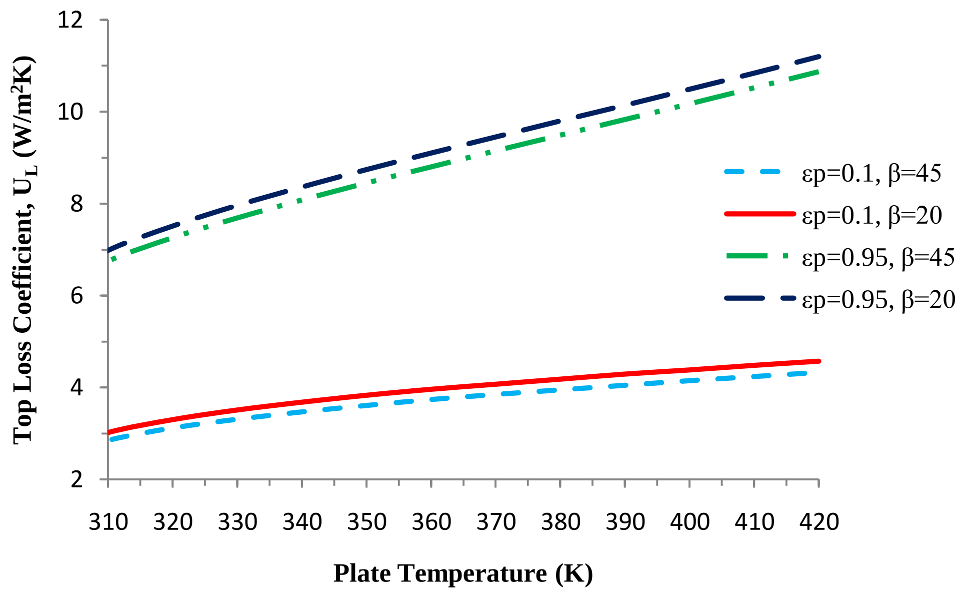

Figure 4.6: Effect of top loss coefficient on absorber plate temperature for different emissivity of absorber plate.

The convective heat transfer between absorber plate and glass cover, hc_{12} was high when the SPC was 0.05m.compare to SPC 0.025m that produced lower. The SPC 0.05m that has wind loss coefficient 30 $Wm^{-2}K^{-1}$ produced high convective heat transfer between absorber plate and glass cover compare to wind loss coefficient 10 $Wm^{-2}K^{-1}$. The values of hc_{12} are relatively high at the high absorber plate temperature and wind loss coefficients as the heat carried away by the wind is more. The values of hc_{12} at the low absorber plate temperatures and wind loss coefficients are low as the temperature potential existing between the plate and glass cover is less.

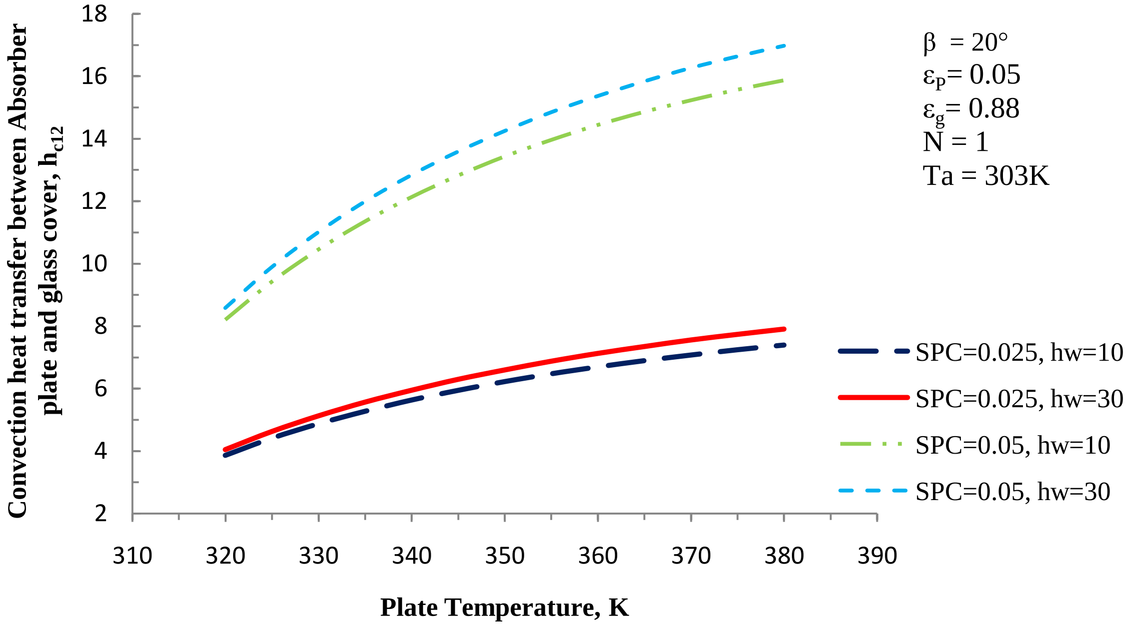

Figure 4.7: Variation of convective heat transfer coefficient between the absorber plate and glass cover, h_{c12} and plate temperature.

In the figure 4.8, the graft is top loss coefficient versus plate temperature. It show that the comparison result between theoretical and experimental data. As state before, the theoretical data is produce by a simulation using related formula as discuss in previous chapter. The experiment data is get from other researcher. The experiment data seem to be randomly plot but still follow the pattern. Theoretical data have a smooth pattern based on the point that plotted. That proved that, the theoretical data can be accepted to be the relevant result to simulate and be a reference source.

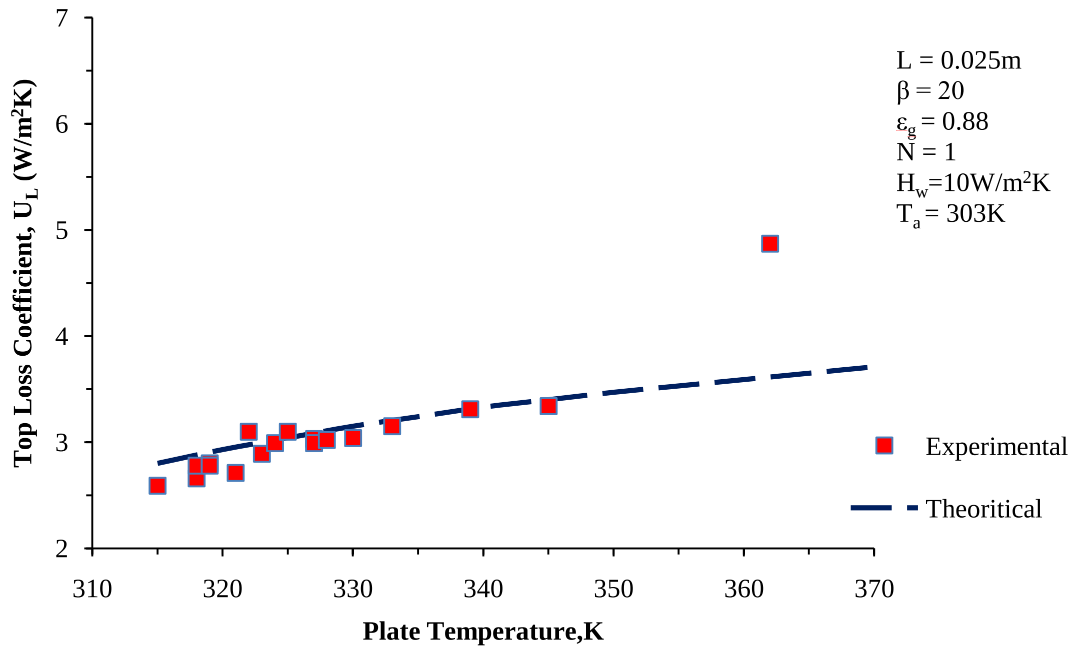

Figure 4.8: Variation of top loss coefficient (U_L) with theoretical and experimental data for FPC

4.2.2 Comparison between flat plate collector (FPC) with evacuated tube collector (ETC)

Refer to figure 5.1, the evacuated tube collector have low top loss coefficient compare to the flat plate collector. The gap quit big in value. This phenomenon happens because the radiation factor in both equipment. As we know from the previous chapter that evacuated tube collector does not experience the radiation process as the flat plate collector because of the vacuum condition in the tube. Note that the condition to experience the radiation in certain medium must have a plenty of atom or molecule to transfer the energy that was collected. In vacuum condition this wasn't happen that mean there wasn't atom or molecule that transfer the energy out once the energy absorb. This will decrease the top loss coefficient that means the efficiency also increase perpendicular to the absorber plate temperature. In these cases the evacuated tube collector has a lot advantages in energy saving compare to the flat plate collector but maybe the cost will play a role to decide the most beneficial equipment both of it.

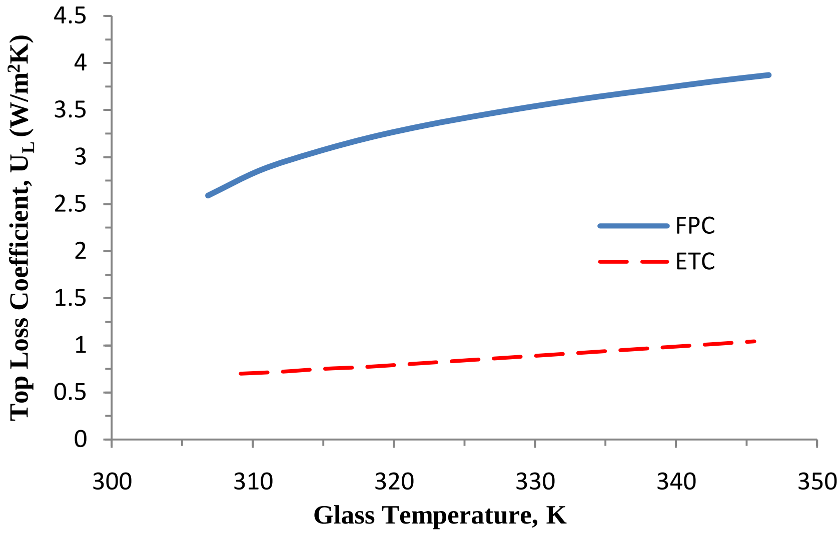

Figure 5.1: Variation of top loss coefficient with absorber plate temperature for different collector

In this experiment we need to get high efficiency in order to make the system was in the high performance process. Several parameter has been tested by changed the value so the suitable efficiency can be obtain. In this case, all the parameter that has been tested was all same and synchronizes for both FPC and ETC. In this experiment the absorber in the FPC has same ambient temperature as ETC. But ETC has low top loss coefficient compare to FPC. The ETC result seems to have advantages compare to FPC. It get decrease slowly perpendicular with the decreasing of the heat flux but the value of it efficiency was not rapidly decrease.

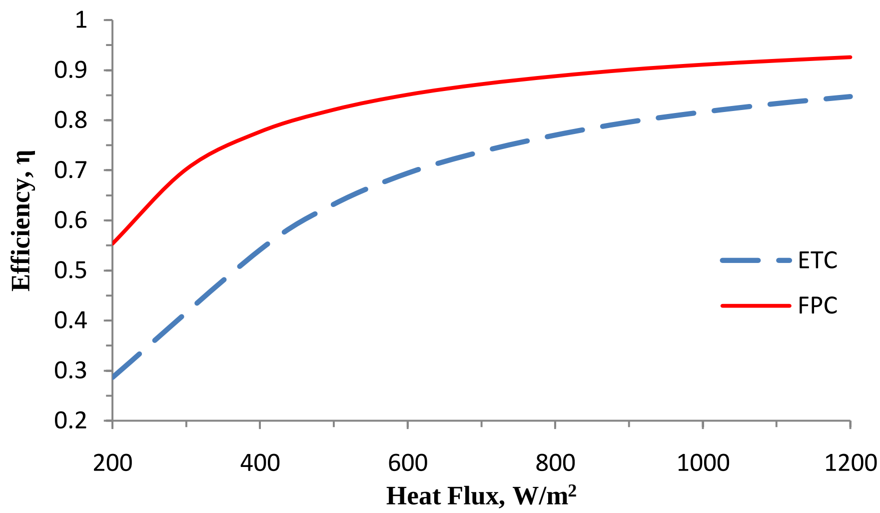

Figure 5.2: Effect of efficiency on heat flux for different collector

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter provides conclusion of finding for this project. For future reference, some recommendations are enlisted as a topic in this chapter for enhancement of knowledge in continuing this research of studying the performance of flat plate collector.

5.2 CONCLUSION

Theoretical analysis is performed on a flat plate collector with a single glass cover and it was compare to the experimental analysis. It can be concluded that the emissivity of the absorber plate has a significant impact on the top loss coefficient and consequently on the efficiency of the flat plate collector. The efficiency of the FPC is found to increase with the increasing the ambient temperature and decreasing the spacing between the glass cover and the absorber surface and decrease the emissivity of the absorber plate. There is no significant impact of tilt angle on the top loss coefficient.

The top loss coefficient of flat plate collector can be decrease by increase the emissivity of the absorber plate. When the top loss coefficient was decrease the efficiency of the flat plate collector will increase and be a rival to the evacuated tube collector .Although we know that the evacuated tube collector has a high efficiency compare to the flat plate collector and it almost impossible to flat plate collector to compete with the evacuated tube collector but at less we can increase the efficiency of the flat plate collector by method mention before because compare the cost material between the both of it. The flat plate collector was absolute have a low cost compare to the evacuate tube collector.

The ambient temperature also gives a big effect to the flat plat collector. Note that the evacuated tube collector can be operation efficiency in a low ambient temperature with decrease a little bit of the efficiency. But, in cases of the flat plate collector, the increase the ambient temperature will increase the efficiency. There is no significant impact of tilt angle on the top loss coefficient.

5.3 RECOMMENDATIONS

From the previous experiment, there are several suggestions that could be implanted as to improve results and obtained more accurate finding. The recommendations are as enlisted below:

i) To improve the performance of flat plate collector, conduct an experiment that used concentrator or solar tracking.
ii) Add more values to the parameter in the simulation process to increase the probability to achieve the most suitable value to increase the efficiency of the FPC.

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APPENDIX C

Gantt chart for FYP 1

PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Discuss with supervisor	■	■													
Verify the project title, objective and scope	■	■	■												
Research about title	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Collecting data	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Selecting the suitable formula									■	■	■	■	■		
Starting writing report											■	■	■		
Submit draft & report														■	
Presentation FYP1															■

Figure 6.1 Project planning for FYP 1

APPENDIX D

GANTT CHART FOR FYP 2

PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Discuss project flow															
Learn software and understand the coding															
Write equation into coding															
Software run															
Analysis data															
Prepare for full report															
Submit the report															
Presentation preparation															

Figure 6.2 Project planning for FYP 2