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CONTRIBUTION TO THE THERMAL TRANSFER .

ع/ إمضاء رئيس القسم

مساعد رئيس قسم الآلية والكهروميكانيك
مكلف بما بعد التدرج والبحث العلمي
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جامعة غرداية
قسم الآلية والكهروميكانيك -2-
كلية العلوم و التكنولوجيا

وزارة التعليـــم العالـــي و الـبحــث العلــمـــــــي

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UNIVERSITY OF GHARDAÏA

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جامعـــة غرداية

كلية العلوم والتكنــولــوجيـــا

قسم الآلية و الكهروميكانيك

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Presented by:

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Theme

CONTRIBUTION TO THE THERMAL TRANSFER STUDY OF FLAT WATER SOLAR COLLECTOR.

Before the jury:

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Praise be to God Almighty first and last for His success, and thanks to Him for granting us patience and effort to make this humble work a success.

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Dedication

I am very pleased to dedicate this work to:

- My beloved mother, my dear father
- My brothers and sisters, especially my little brother Abde Rahman and my little sister Fatima Al-Zahra
- All my family, near and far
- My friends and those who love me, especially my friend Hamza
- I dedicate my graduation thesis to all my dear family and friends, each in his name.
- To those who helped me accomplish this humble work and for their encouragement
- And also to all my teachers

Mohamed elmahdi

Dedication

Praise be to God who enabled us to prepare this humble note

I dedicate the fruits of this success to the most beautiful gifts, the one who gives me life every time is my mother, the reason for existence

To all my loved ones, my brothers, my friends, you were my support and strength

To the creditors, my dear teachers, may God reward you with all the best

To all members of the batch without exception

To all co-workers

Thank you all.

Mustapha

SUMMARY

ABSTRACT

In this Master's thesis, we present a theoretical study of solar energy. We present one of the methods of exploiting solar energy, which is thermal conversion, by describing the flat water solar collector, its operating principle, its various parameters, and its characteristics.

The numerical resolution of a planar water solar collector model, in the steady state, was performed using a computational code written in MATLAB, taking into account the variation of some collector parameters and the convergence of the evolution of the fluid (water) temperature field. Through the approved digital model, the effect of some qualitative and quantitative factors involved in the formation and operation of the flat water solar collector on its thermal behavior was analyzed.

Keywords: solar energy, solar collector, MATLAB, heat transfer

الملخص

نقدم في هذه المذكرة دراسة نظرية للطاقة الشمسية، نقدم إحدى طرق استغلال الطاقة الشمسية وهي التحويل الحراري، وذلك من خلال وصف المجمع الشمسي المائي المسطح، ومبدأ تشغيله، ومعلماته المختلفة، وخصائصه .

تم إجراء الاستبانة العددية لنموذج مجمع شمسي مائي مسطح، في الحالة المستقرة، باستخدام برنامج حسابي مكتوب فيMATLAB ، مع الأخذ بعين الاعتبار اختلاف بعض معلمات المستشعر وتقارب تطور مجال درجة حرارة السائل (الماء). من خلال النموذج الرقمي المعتمد تم تحليل تأثير بعض العوامل النوعية والكمية الداخلة في تكوين وتشغيل المجمع الشمسي المائي المسطح على سلوكه الحراري.

الكلمات المفتاحية: الطاقة الشمسية، مجمع شمسي، MATLAB،نقل حراري.

Résumé

Dans cette mémoire, nous présentons une étude théorique de l'énergie solaire. Nous présentons une des méthodes d'exploitation de l'énergie solaire, qui est la conversion thermique, en décrivant le capteur solaire plat à eau, son principe de fonctionnement, ses différents paramètres et ses caractéristiques .

La résolution numérique d'un modèle de capteur solaire planaire à eau, en régime permanent, a été réalisée à l'aide d'un code de calcul écrit en MATLAB, prenant en compte la variation de certains paramètres du capteur et la convergence de l'évolution du champ de température du fluide (eau). Grâce au modèle numérique approuvé, l'effet de certains facteurs qualitatifs et quantitatifs impliqués dans la formation et le fonctionnement du capteur solaire plat à eau sur son comportement thermique a été analysé.

Mots clés : énergie solaire, capteur solaire, MATLAB, transfert de chaleur.

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NOMENCLATURE

a	Azimuth	-
alb	Soil Albedo	-
C_p	Massic heat	$Kj.kg^{-1}°C^{-1}$
d	Diameter	m
dj	Day length	-
e	thickness	m
G_r	Grashof number	-
h	Angular height	degree
h_c	Convection exchange coefficient	$w.m^{-2}.k^{-1}$
h_r	Radiation exchange coefficient	$w.m^{-2}.k^{-1}$
Nu	Nusselt number	-
Re	Reynolds number	-
S	Direct radiation	$w.m^{-2}$
T_a	Air blade temperature	°C
T_{ab}	Absorber temperature	°C
T_f	Average fluid temperature	°C
TL	Time equals	hour
T_p	Plate temperature	°C
TSM	Mean solar time	hour
TSV	True solar times	hour
TU	Universal time	hour
T_v	Window temperature (Température de la vitre)	°C
T_{fs}	Cold fluid outlet temperature	°C
T_{cs}	Hot fluid outlet temperature	°C
T_e	Temperature of the outer wall of the tube in contact with the fin	°C
T_{fe}	Cold fluid inlet temperature	°C
T_{ce}	Hot fluid inlet temperature	°C
T_m	Mean temperature	°C
G	Global Radiation	$w.m^{-2}$
Pr	Prandtl number	-
NUT	Number of transfer units	-
TLM	Logarithmic average of temperature differences	°C

L_p	Plate length	m
L	longitude	degree
2l	Fin width	m
k	Overall exchange coefficient	$w.m^{-2}.k^{-1}$
R_a	Rayleigh number	-
S	Plate surface	m^2
$\emptyset$	Heat flux	w
ρ	Volumic mass	$kg.m^{-3}$
λ	Thermal conductivity	$W.m^{-1}°c^{-1}$
μ	Dynamic viscosity	Pa.s
2α	Opening angle	degree
β	Collector tilt	dzgree
δ	Variation of solar	degree
w	Hour angle	degree
φ	latitude	degree
σ	Fraction d'insolation	-
ψ_0	Longitude Greenwich	-
ε_v	Glass emissivity	-
ε_{ab}	Emissivity of the absorbing plate	-
Δ	Time difference	hour
ε	Efficiency	-

General

introduction

The increase in global demand for energy and the use of non-renewable energy sources such as fossil fuels has reduced the availability of these sources and has led to a difficult economic situation for countries, unstable social living conditions for the population and serious impacts on the environment. In order to reduce the high cost of these energies and help reduce greenhouse gas emissions, it is necessary to turn to renewable energy sources such as solar energy. The latter is considered one of the cleanest and cheapest sources of energy that can be converted into thermal and electrical energy. Therefore, research has been conducted on solar energy conversion processes such as solar photovoltaic energy and solar thermal energy.

Over the past three decades, research has focused on improving low and medium solar heating systems used for domestic and industrial applications such as water and space heating. These systems generally use planar solar collectors. This main component, is a heat exchanger that absorbs incident solar radiation by converting it into heat, then transferring the heat to a fluid (usually water or air) passing through it. Although it produces not too high temperatures, it has the advantage of being the simplest in design and having lower maintenance costs and therefore the most used for solar heating systems in residential sectors and industrial.

In order to better support and succeed in the development of solar energy production, Algeria considered a strategy focusing on the development of inexhaustible energy resources such as solar energy, and began the green energy dynamism by launching an ambitious program. It aims to achieve energy savings by 2030 of approximately 63 million tons of oil equivalent, for all sectors (construction, public lighting, transportation, industry) through the introduction of effective lighting, thermal insulation, and solar water heaters.

Thus, the simulation of the performance of the flat solar collector is necessary to properly determine its behaviour in one of its applications which is heating in the solar system. To achieve this, it is necessary to study the effect of operating parameters on its performance.

Given the important and effective role that the solar collector plays in converting solar energy into thermal energy, searching for innovations in its design to improve its performance and reduce related losses in order to introduce solar thermal energy technology is necessary.

Our work is summarized in four chapters:

First, we provided a general introduction that includes the framework within which this work takes place.

The first chapter focuses on the latest developments through bibliographic research.

The second chapter provides a presentation of the solar field and general information about flat thermal collectors.

The third chapter presented the mathematical model of the problem based on thermal balances, describing the thermal behavior in the solar collector and the appropriate hypotheses.

In the fourth chapter, we presented the results obtained in the form of graphical curves and discussed them.

We conclude this thesis with a general conclusion that summarizes the experimental study.

Chapter I: Bibliographic synthesis

I. 1. Introduction:

Since ancient times, man has sought to produce energy, as it was one of his most important interests. One of the energies that humans have used for a long time is the energy of the sun, and it can be defined as the sum of light rays (light energy) and heat (thermal energy) emanating from it. Solar energy is one of the most promising renewable energies for a clean and unpolluted world. Photovoltaic energy is characterized by converting light energy into electrical energy and exploiting all light spectrums, while thermal energy depends on concentrating the sun’s heat to heat the heat carrier, which is mostly water. Thermal water heaters or solar thermal collectors are devices that allow the conversion of radiant energy into thermal energy, based on the phenomenon of global warming, and this is explained by the fact that glass is a material that is almost transparent to solar radiation while it is almost opaque to infrared rays, which is a solar flux that passes through the vitrage, The heating object is thus trapped behind this vitrage, since the radiation emitted by this object cannot pass through the vitrage.

Two types of solar collectors can be distinguished[1]

1- Flat solar collectors: Flat collectors absorb solar radiation through a black-coated panel equipped with fine tubes designated for heat transfer fluid. When it passes through the pipes, its temperature (liquid or air) rises due to the heat received by the absorption plate.

2- Concentrated solar collectors: Flat collectors generally cannot heat heat transfer fluids to very high temperatures. On the other hand, it is possible to use concentration collectors but they are more complex and more expensive. They are semicircular reflectors that reflect and focus solar energy onto a tube in which a heat transfer fluid circulates. This concentration increases the intensity and the temperatures obtained on the receiver (called the target) can reach several hundred or even several thousand degrees Celsius.

The solar water heater is characterized by its thermal performance and relies heavily on the transmission, absorption and conduction of solar energy and fluid process.

The performance of the collector is mainly reflected in its efficiency. In practical terms, this efficiency depends on useful energy, which we seek to constantly increase:

• By increasing the amount of solar energy received by the absorber,

• By reducing heat loss towards the back of the collector (non-receiving areas) and towards the front of the collector (between the absorber and the environment).

In this chapter, we will give a simple overview of the history of solar cells and the main work that was carried out on some models of solar water heaters.

I. 2. Historical review:

The idea of using solar-powered collectors has been recorded since prehistoric times. During the 18th century, solar furnaces were built capable of smelting iron, copper, and other metals.

The French scientist Antoine Lavoisier designed a furnace that reached a temperature of 1750 degrees Celsius.[2]

In 1767, the Swiss-French scientist Horace Benedict de Saussure designed and implemented the first solar thermal oven that could be used for cooking. Figure 1-1 shows the design of this device. It is made of two wooden boxes, a small box inside a large one, with an insulator (cork) between them. The inside of the small box is painted black, and the top is covered with three separate layers of glass, with air between the adjacent layers of glass. By placing the upper part of this box facing the sun, and moving it until the glass is perpendicular to the sunlight, in a few hours, the temperature inside will reach more than 100 degrees Celsius. Thus, it becomes a thermal box heated by the sun. To determine the source of the heat, de Saussure carried the thermal box to the summit of Mount Carmon. He found that although the air temperature there was about five to ten degrees lower than on flat land, the inside of the box could also reach the boiling point of water. This effect was attributed to the purity of the air at the top of the mountain, where solar radiation is strongest.[2]

Horace de Saussure's experiment is a demonstration of the "greenhouse effect", and led Joseph Fourier to explain the Earth's equilibrium temperature through the infrared absorption of the Earth's atmosphere. Fourier explained his theory of the greenhouse effect by analogy with De Saussure's thermal box, where layers of glass preserve heat inside it.

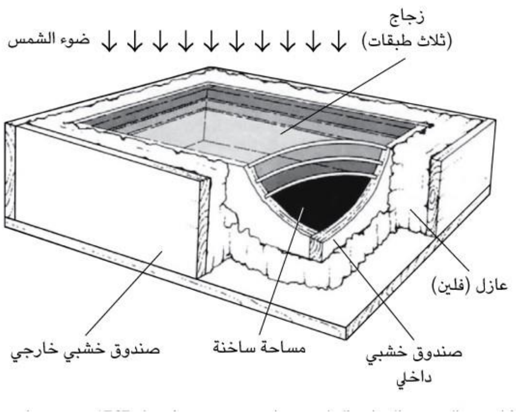


Figure I-1: Horace de Saussure’s thermal box: in 1767[2]

The collapse of the solar water heater business in California did not mean it was completely over; With its real estate boom in the 1920s and 1940s and no natural gas, Florida became the center of solar water heaters; Figure 1-2 It is estimated that 25 to 60 thousand solar water heaters were installed in Miami between 1920 and 1941.[2]

Figure I-2: Day & Night solar water heater in Florida.[2]

During the 19th century, attempts were made to convert solar energy into other forms that relied on the generation of low-pressure steam to power steam engines. In 1875 Mouchot made a major advance in the design of solar collectors by making a reflector shaped like a short cone. [2]

The increase in heat received by the absorber has been studied by many researchers. Studying the effect of using a selective coating (coating the absorber with a matte black dye) to increase the percentage of absorbed radiation. Moreover, the effect of absorber plate thermal conductivity on the performance of solar collectors was studied by transient simulation system and they confirmed that the characteristic factors such as collector efficiency factor and heat dissipation factor are highly dependent on the absorber thermal conductivity.[3]

Ben Khalifa presented a mathematical model that makes it possible to calculate the heat loss towards the front of a planar solar collector. A mathematical program was used to study the effect of some physical and engineering factors on the thermal loss coefficient towards the front of the collector. Thus, it was found that the front heat loss coefficient increases with the increase in the emissivity of the absorbent material, the temperature of the absorbent plate, and the coefficient of heat exchange with the surrounding air, and decreases with the increase in the distance between the two plates. Pipette and glass. [3]

The performance improvement of a solar collector with a crossed wavy absorber plate that enhances turbulence, in-channel heat transfer and fluid flow rate was analyzed and their results showed that solar collectors with crossed wavy absorber plates have better thermal efficiency compared to flat collectors.[3]

Abdi and Masoudin conducted an experimental and theoretical study of the performance of two types of flat collectors with different absorber plate shapes. They mainly studied the effect of the geometric shape of the fluid passage (convex shape and concave shape) on the effectiveness of the collectors in the case of direct contact with water-absorbing plates. By comparing the theoretical and experimental results, it was found that the collector equipped with a convex-shaped absorption plate gives better efficiency than a concave-shaped absorption plate.[3]

Rabil and Andersen [3] analyzed the geographical conditions, orientation, inclination angle, and nature of the collector material and explained the influence of these parameters on the thermal efficiency of the system. Their results demonstrated the impact of these aspects on the performance of the solar collector.

Hegazy and Soliman studied the effect of dust accumulation on the glass cover of the solar collector experimentally at different inclination angles. The results indicated that the partial reduction of the glass transmittance depends on dust deposition in conjunction with the panel inclination angle, exposure period, and climatic conditions of the site. Thus, for tilt angles from 0° to 90°, they showed that the 0° tilt angle is the most contaminated with a mixture of coarse and fine dust particles and that the 90° tilt angle represents a lower amount of dust accumulation.[3]

Zerrougui, Duffy and Beckman made several assumptions regarding the collector mass flow rate such as neglecting the head area, uniform distance between the riser tubes, laminar flow and uniform flow distribution in the tubes and these assumptions proved useful in designing the thermosiphon system.[3]

Chaurasia conducted experiments to design and develop a low-cost solar water heating system using concrete. The hot water temperature obtained in this study ranged from 36°C to 58°C. This type of collector is very useful for low temperature household applications. Architects can use this to design a building roof that can act as a low-cost solar collector to provide hot water at moderate temperatures in buildings to meet various purposes during the day.[3]

In 1990 scientists developed Dufresne, J.-L. Lahellec, A. Chounet, L.-M. Dynamic characterization of the solar component presented us with the general problem of specifying a multiparameter nonlinear model. This model has three goals: first, it should allow the designer to understand and improve its components; They can then be integrated into a global system model (building and control devices) to study real performance; Finally, it is a guide for monitoring to achieve the above two objectives (global coherence).[4]

In 1990 Knani, H heated four greenhouses using 4, 6, 8 and 10 passive sleeves under furrow irrigation system and compared them with control. The bioclimatic results showed a good effect on the minimum air and soil temperature, where an increase of 1.2 °C of minimum soil temperature and 1.3 °C of minimum air temperature was obtained depending on the number of sleeves and the tightness of the greenhouse. The agronomic results obtained show a significant increase in earliness and a low increase in total production, allowing sleeve recovery in less than two crops.[5]

In 1998 Njomo, D presented an analysis of unsteady heat exchanges in an air heater consisting of a transparent outer plastic cover, such as plexiglass, whose role is to protect the collector from accidentally thrown stones, and a transparent inner glass cover that produces the greenhouse effect necessary to heat the absorber. . It is shown that in the quasi-steady state, the energy balance equations of the heater components cascade into a single first-order differential equation, which is able to predict the thermal behavior of the collector. The solution to this differential equation is written as an explicit expression for the local temperature of the fluid flowing in the collector in terms of the time-dependent incident solar intensity.[6]

In 1999, Garg and Adhikari proposed a modeling program for a hybrid solar PV/T antenna collector that makes it possible to predict its thermal and electrical productivity. The efficiency of photovoltaic panels is calculated by a decreasing linear function. This solar collector consists of a transparent cover, a black painted absorber, and a well-insulated back support (Figure 1-4). The photovoltaic cells are glued to the absorber using an adhesive layer chosen due to its good thermal conductivity and dielectric properties.[7]

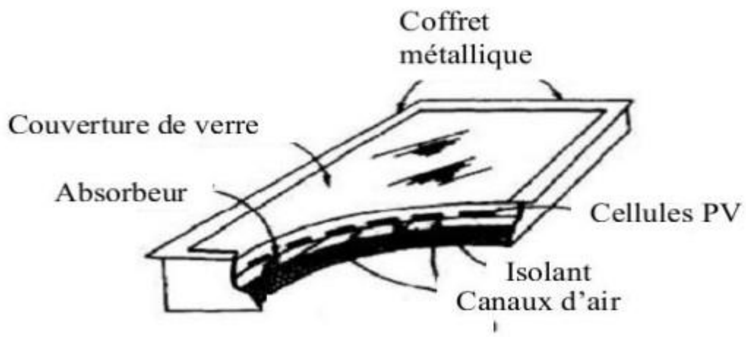


Figure I-3: Schematic drawing of Garg's PV/T hybrid solar collector[7]

In 2001 Serres, L, Trombe, A and Miriel, J used numerical tools to determine the solar flux absorbed by a surface in a glass room. The results then show that even for an individual not directly exposed to sunlight, absorbed fluxes can be comparable to other conditions of human heat balance. Then the effect of the solar absorption coefficients of the room walls and clothing on these fluxes was studied. Finally, the authors evaluated the impact of these fluxes on all heat exchanges between the inhabitant and its environment, by adapting the PMV formula to the presence of solar radiation. We then show that exchanges between humans and their environment are severely disrupted, and that heat load increases by large proportions.[8]

In 2009, Amraqui, S presented a numerical modeling of natural convection coupled with thermal radiation in a solar collector equipped with spacers attached to its glass. Three cases of solar collector placement were studied: (a) the collector was placed in a gravitational field whose direction was perpendicular to the temperature gradient, (b) the collector was placed perpendicular to the gravitational field, and (c) the solar collector was inclined at 45 degrees from the horizontal. . The heat transfer fluid considered is dry air (Pr = 0.71) and its physical properties, apart from its density, are assumed to be constant at the average temperature T0. In addition, the flow is considered incompressible, laminar, and two-dimensional, and the radiative surfaces are assumed to be grayscale and isotropic in emission/reflection.[9]

In 2009 Khalfallaoui, S presented the modeling of a solar thermal system. Taking into account the global approach to achieving the energy balance of each element of this system, the energy efficiency of the solar system and the instantaneous efficiency of solar collectors in a steady state were studied. As well as installing a solar tracking device. The study also focused on thermal energy gain using a solar tracker compared to a configuration where solar collectors are installed at different inclinations.[10]

In 2012 Motte, F conducted a bibliographic study to identify the obstacles to the development of the solar thermal sector and show the necessity of integrating it into the existing structure. The H2OSS solar cornice is part of this logic: it is a flat solar thermal collector with selective absorption, integrated within a gutter that then ensures a dual function (rainwater recovery and solar energy capture). This thesis aims to improve the performance of an innovative, highly integrated solar collector built with the aim of commercializing it.[11]

In 2012 Ferahta, F.Z presented an interpretation of the flow and transport mechanisms in internal natural convection, in 3D geometry in the wind blade of a solar collector in order to find the optimal design that allows adequate thermal control and energy performance.[12]

In 2006, K. TOUAFEK presented an experimental study of the thermo-photovoltaic hybrid collector. The goal is to implement a prototype of a hybrid collector to evaluate its electrical and thermal performance. The results obtained indicate that this type of collector constitutes a good alternative to separately installed conventional photoelectric modules and thermal collectors.[13]

K. TOUAFEK presented in 2008 a numerical simulation of the thermal behavior of a solar-thermal photovoltaic hybrid collector, followed in 2009 by a thermal study of a photovoltaic-thermal (PV/T) hybrid collector with jacketed air intended for home heating. The study concerns the determination of heat maps for a hybrid photoelectric-thermal collector covered by an additional window above the classical module. They determined the temperature distribution at each point of the hybrid air collector for different (air) flow rates. [6] The results give the temperature distribution in the hybrid collector with vented and unvented air, for the air inlet temperature of 30 °C they had an outlet of 60 °C and the temperature of the collector's protective glass equaled about 70 °C. For the same PVT collector with covered air, but with ventilation and an air inlet temperature of 20°C, they had an outlet of 40°C and a temperature of the collector's protective glass equal to approximately 60°C. Therefore, we notice that increasing air flow leads to a decrease in the temperature level at the outlet of the covered hybrid air collector.

In 2013, TOUAFEK K. et al presented a new hybrid collector design in which the collector contains two absorbent plates, one below the photovoltaic module and one above the dielectric layer in order to increase the overall performance of the hybrid collector. Collector (Figure 1-6). A numerical modeling and simulation study was conducted to evaluate the electrical and thermal performance of this type of collector. This study was supported by experimental tests to verify the validity of the developed numerical model. The mathematical model is based on a system of energy balance equations for each component of the hybrid collector. The results gave a thermal efficiency ranging between 22% and 68% from eight in the morning until noon, with a maximum thermal power of 290 watts and a maximum electrical power of 46 watts. Note that the air circulates at a mass flow rate of 0.022 kg/s and the air temperature at the outlet reaches 35°C. Therefore, the application of this new design gives good thermal and electrical efficiency compared to traditional hybrid thermal collectors.[13]

Figure I-4: Image of the hybrid collector studied by TOUAFEK [13]

I. 3. Conclusion:

Over the past 50 years, many buildings have been designed with solar collectors to heat the working fluid that feeds mechanical equipment, and solar water heaters have also begun to be manufactured. The industry has grown very rapidly in many countries around the world. Water shortages have always been a human problem, so one of the first attempts was to use solar energy to desalinate seawater. [3]

In the twentieth century, many experiments were conducted on the performance of solar water heaters, and many improvements were made to it and it became increasingly popular, allowing us to get an overview of techniques for improving the performance and efficiency of this system.

The performance of a solar collector depends largely on the absorption and heat transfer quality of the absorber plate; Therefore, several research projects have been launched to propose new absorber plate arrangements in order to increase the performance of solar collectors.

The performance of a solar collector is affected by several factors.[3] In particular, we find:

• External parameters such as solar radiation, ambient temperature, etc.

• Internal parameters (building parameters) such as absorption, coverage, working methods and insulation quality.

• Position parameters such as collector inclination angle.

Chapter II: Solar collector technology

II.1. Introduction:

The energy coming from the sun to the Earth is considered the primary source of most of the energy on Earth. The exploitation of solar energy depends on the means of collecting it and on the amount of radiation that reaches the surface of the Earth in the area in which solar energy is to be exploited. The value of the solar radiation that reaches the Earth depends on the amount of it that is reflected, dispersed, and absorbed during Its path through the atmosphere.

Solar energy is one of the most important sources of renewable energy that can be utilized and is available in all regions of the world. In this chapter we will talk about solar radiation and solar collector technologies.

II. 2. Solar energy:

Solar energy is a renewable resource. It is derived from the sun's rays. Solar energy is converted directly to electricity through solar photovoltaic panels. Solar rays, collected off reflective surfaces, heat an object in a process that creates solar thermal energy.

II.2.1. The Sun :[14]

The Sun is a giant star that consists of 74% hydrogen, 25% helium, and a fraction of heavier elements. It draws its energy from nuclear fusion reactions which transform, in its core, hydrogen into helium. In its current state, the core of the Sun transforms every second more than four million tons of matter into energy which is transmitted to the upper layers of the star and emitted into space in the form of electromagnetic radiation (light, solar radiation) and particle flows (solar wind).

Approximately 9229.3 protons (hydrogen nuclei) are converted to helium every second, releasing energy at a rate of 4.26 million tonnes of matter consumed per second, producing (392.192 kJ) per second.

II.2.2. Structure of the Sun:

The sun is not a homogeneous sphere we can distinguish:

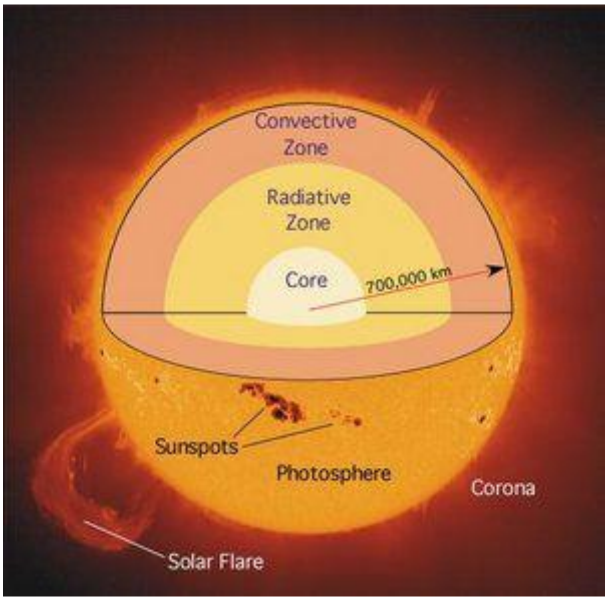


Figure II-1: Structure of the sun in section

a) The heart or nucleus:

The core is the only part of the Sun that produces a notable amount of heat through fusion, the rest of the star gets its heat solely from energy coming from the core. All of the energy produced in the core must pass through many successive layers to the photosphere, before escaping into space in the form of solar radiation or particle flows.

b) The radiation zone:

The radiation zone or radiative zone. The solar material is so hot and so dense that the transfer of heat from the core to the outermost layers is done by thermal radiation alone.

c) The convection zone:

In the convection zone, the matter is no longer dense enough or hot enough to evacuate heat by radiation: it is therefore by convection, according to a vertical movement, that the heat is conducted towards the photosphere. The temperature there goes from 2 million to 6000 kelvins

d) The photosphere:

The photosphere is the visible part of the Sun's surface. Below it, the sun becomes opaque to visible light. Beyond the photosphere, visible light is free to propagate through space, and its energy to escape entirely from the Sun. Solar light has approximately the electromagnetic spectrum of a black body (which allows its temperature to be estimated at 6000 kelvins, or 5727 degrees Celsius).

II. 3. Movement of the earth around the sun :

The path of the earth around the sun is an ellipse located in a plane called the ecliptic plane. The eccentricity e of this ellipse is very small (e 0.017), which means that the earth-sun distance only varies by ±1.7% compared to the average distance which is 149.6 million kilometers[14].

The earth also rotates around an axis called the pole axis. This axis passing through the center of the earth is called the terrestrial equator. The angle that the plane of the latter makes with the direction of the earth-sun is called the declination. It varies throughout the year symmetrically from -23.26’ to +23.26’, as shown in the following figure:

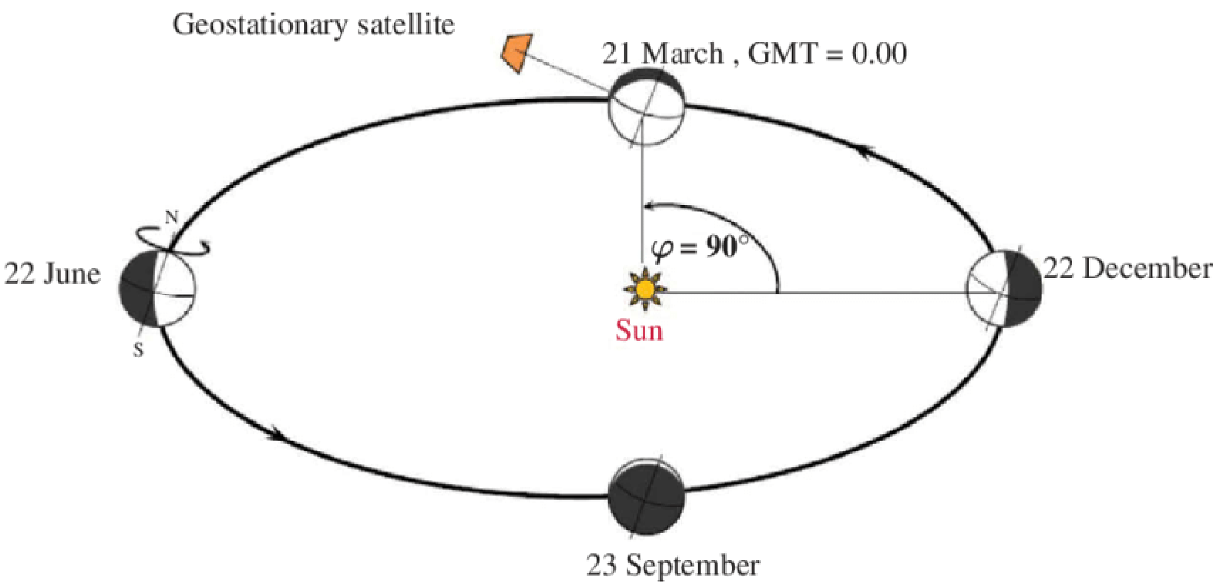


Figure II-2: Movement of the earth around the sun

II. 4. Calculating the position of the sun:

Calculating the position of the sun requires determinations of position and time parameters.

II. 4. 1. Position parameters:

Position parameters encompassing terrestrial, equatorial and horizontal coordinates.

II. 4. 1. 1. Errestrial coordinates:

Any point on the terrestrial sphere can be located by two coordinates called terrestrial coordinates, latitude φ and longitude L.

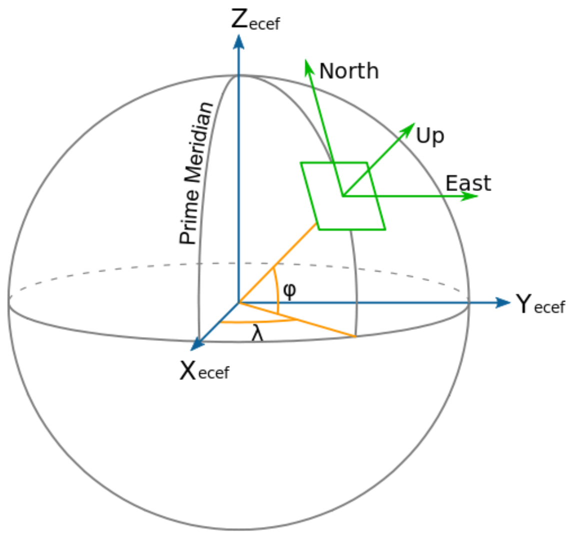


Figure II-3: The terrestrial coordinates of a given location

a- Latitude φ:

It is the angle formed by the vertical of a given location with the terrestrial equatorial plane. It is expressed in degrees and ranges from 0° for a place on the equator, to 90° for the poles, positive in the Northern hemisphere, negative in the Southern hemisphere.

b- Longitude:

This is the angle formed by the meridian of the site with the reference meridian (Greenwich meridian), positive in the West, negative in the East.

c- The inclination:

It is the angle between the plane itself and the horizontal

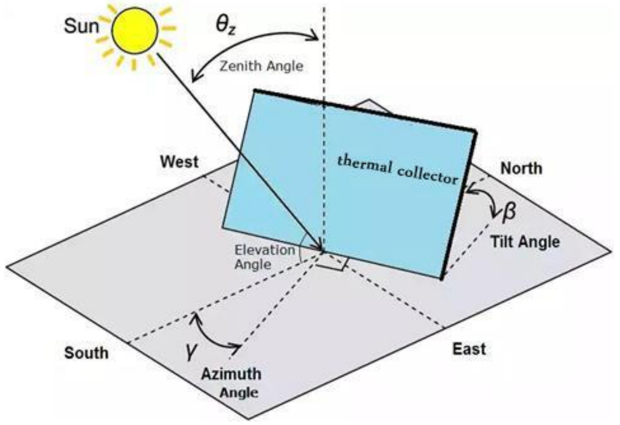


Figure II-4: diagram that shows the tilt angle in a thermal collector

ß= 0° for a horizontal plane facing upwards.

ß= 90° for a vertical plane.

ß = 180° for a horizontal plane facing downwards.

II. 4. 1. 2. Equatorial coordinates

The reference plane is the celestial equator, the coordinates used are the declination and the hour angle ω.

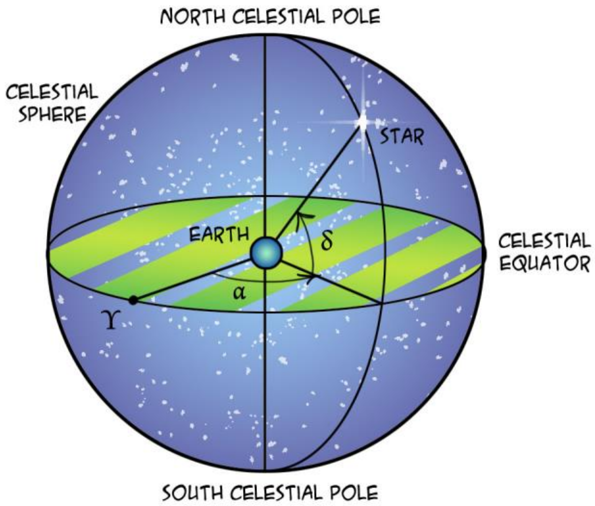


Figure II- 5: Equatorial coordinates.

a- the declination δ:

It is the angle formed by the direction of the earth/sun with the terrestrial equatorial plane, or even the angle formed by the ecliptic plane and the terrestrial equator. It varies from -23.27' to +23.27' during the year.

δ = +23°27' at the summer solstice (June 22);

δ = -23°27' at the winter solstice (December 22);

δ = 0 at the spring equinox (March 21) and the autumn equinox (September 23).

It is given by the following formula:

$$\delta = 23{,}45\sin[0{,}980(j + 284)] \quad \text{(II-1)}$$

With: j, the number of the day of the year which varies from 1 to 366

Or:

$$\delta = 23{,}45\sin\left[\frac{360}{365}(n - 81)\right] \quad \text{(II-2)}$$

n: it is the number of the day of the year for example n=1 corresponds to January 1st

b- hour angle ω :

It is the angle formed by the celestial meridian plane and the projection of the earth/sun direction on the plane of the celestial equator, or again, it is the angular displacement of the sun around the polar axis in its course from east to west relative to the local meridian. It is zero at solar noon, negative in the morning and positive in the afternoon.

It is given by:

$$\omega = 15(TSV - 12) \quad \text{(II-3)}$$

With:

ω: in degrees;

TSV: true solar time.

Or:

$$\omega = \frac{\pi}{12}(TSV - 12) \quad \text{(II-4)}$$

With:

ω: in degrees;

TSV: in hours.

II. 4. 1. 3. Horizontal coordinates: [1]

The position of a star in space can be identified by its horizontal coordinates defined on the celestial sphere. These coordinates depend on the location of observation and this is why they are also called local coordinates. The reference plane is the astronomical horizon. The height and azimuth constitute the horizontal coordinates.

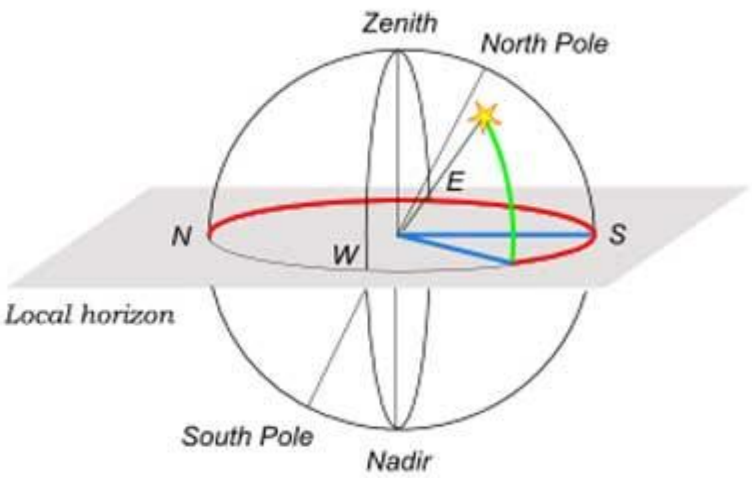


Figure II-6: The horizontal coordinates of a star.

a- Angular height h:

This is the angle that the direction of the star makes with the horizontal plane (i.e. the tangent to the ground). We count the heights of the sun positively towards the zenith from 0° to 90°.

It is given by the following formula:

$$\sin h = \cos\delta . \cos\omega . \ \cos\varphi + \sin\delta . sin\varphi \quad \text{(II-5)}$$

b- Azimuth a:

This is the angle that the plane of the local meridian makes with the vertical plane passing through the star. It is measured from 0° to 360° from West to East.
It is given by:

$$\sin a = \frac{\cos\delta.\sin\delta}{\cosh} \qquad \text{(II-6)}$$

II. 4. 2. Time parameter:

a- True Solar Time (TSV):

This is the time given by sundials. It is defined from the daily rotation of the earth on itself and its movement around the sun, but because of the irregularities of the earth's movement, it cannot be used as a time scale. It is given by the following relation:

$$TSV=TSM+ET \qquad \text{(II-7)}$$

TSM: mean solar time;
ET: equation of time.
Or:

$$TSV = 12 + \frac{\omega}{15} \qquad \text{(II-8)}$$

b- Mean solar time (MST):

This is the mean solar time assuming uniform movement of the earth around its axis, i.e. the mean solar day lasts 24 hours. It is given by the following formula:

$$TSM=TU-ET \qquad \text{(II-9)}$$

TU: universal time;
ET: equation of time.
Or:

$$TSM = TU \pm 4(\psi - \psi_0) \qquad \text{(II-10)}$$

ψ : Longitude of the place;
ψ_0: Greenwich Longitude =0.

c- Equation of time (ET):

It indicates the correction which allows you to go from true solar time to mean solar time. This correction varies from -14 to +16 minutes during the year, this means that the sun can pass the meridian 16 minutes ahead or 14 minutes behind the average time. It is expressed by the following formula:

$$ET=9.87\sin 2N'-7.53\cos N'-1.5\sin N' \qquad \text{(II-11)}$$

With:

$$N' = \frac{360}{365}(\mathrm{n} - 81) \qquad \text{(II-12)}$$

N': in degree;

n: the date of the year;

ET: in minutes.

d- Civil time (Tc):

This is the average time with the origin at midnight.

e- Universal Time (UT):

This is the civil time of the Greenwich meridian, given by:

$$\mathrm{TU} = \mathrm{TSM} \pm \frac{\psi}{15} \qquad \text{(II-13)}$$

f- Legal time (TL):

This is the time which takes into account the time zone in which most of the country is located, we find it shifted by a whole number of hours compared to the original time zone (Greenwich), given by:

$$\mathrm{TL} = \mathrm{TU} \pm \Delta \qquad \text{(II-14)}$$

With:

Δ : The offset in hours from the Greenwich meridian.

g- length of day:

In order to determine the length of the day, we must know two moments of the day, which are sunrise and sunset. These two instants take place when the solar rays coincide with the horizontal, that is to say sin h =0, in formula (2-5).

Solving this equation gives us:

$$\omega \mathrm{l} = -\omega \mathrm{c} = -\arccos(-\mathrm{tg}\varphi.\mathrm{tg}\delta) \qquad \text{(II-15)}$$

With:

l and c: respectively designate sunrise and sunset.

The length of the solar day is given by the following formula:

$$\mathrm{dj} = \frac{1}{15}(\omega \mathrm{c} - \omega \mathrm{l}) = 2\frac{\omega \mathrm{c}}{15} \qquad \text{(in hours)}$$

II. 5. Solar thermal collectors:

Solar thermal collectors are devices designed to intercept solar energy (photons) transmitted by the sun's rays thanks to the absorber (a black body, constituting the collector, characterized by very high absorption properties and very low emissivity) before transferring it to a heat transfer fluid in the form of heat. This thermal energy is transported by the heat transfer fluid circulating through each of the sensors to the installation or storage location.

II. 5. 1. Types of collectors:[2]

Solar thermal collectors differ depending on the nature of the heat transfer fluid that transports the heat: water or air. Solar water collectors are used to produce domestic hot water and for space heating. In air thermal sensors, air circulates and heats up on contact with the absorbers. It is then ventilated into homes for heating or drying food products. To transform the energy contained in solar radiation, we must first capture it. Depending on the structure of the sensor, the collection of this energy can be done in two ways: concentration or flat surface.

a. Unglazed flat collectors:

Their structure is quite simple, they are made up of a set of dark-colored opaque pipes which play the role of both an absorbent plate and piping in which the heat transfer fluid circulates directly. As they do not have insulation or transparent cover they are intended for low temperature applications, for example for outdoor swimming pools.

b. Glazed flat collectors:

In this type of collector, the heat transfer fluid, very often water mixed with antifreeze, passes through a parallel or serpentine circuit, fixed in a frame and placed between single or double glazing, and a rear insulating panel. The operating temperature is generally between 30°C and 80°C.

Figure II-7: Glazed plane collectors [2]

c. Vacuum tube collectors:

In this model, the heat transfer fluid circulates inside a double vacuum tube. The principle is the same as for flat glass collectors, insulation being simply ensured by the absence of air molecules (under vacuum). The operating temperature is generally between 80°C and 200°C.

Figure II-8: Evacuated tube collector [2]

d. Concentration collectors:

They can be distinguished above all by the way in which solar radiation is collected and concentrated. They are classified into two categories:

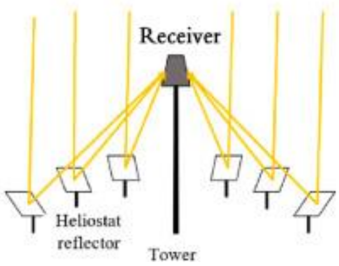
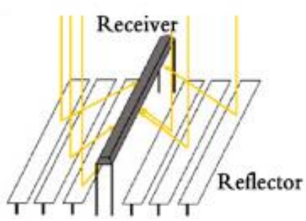
Linear concentration system:

- Cylindrical-parabolic collector

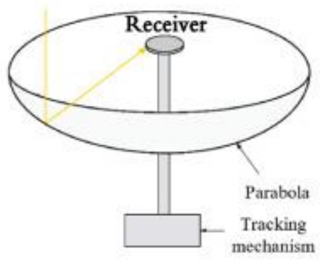
Its structure is made in such a way that all the solar rays, reflected by the parabolic cylindrical mirror, are concentrated on the horizontal receiving tube where the heat transfer fluid will be heated to very high temperatures.

- Fresnel mirror collector

It consists of slightly curved rectangular mirrors. These mirrors are assembled to form strips of movable and orientable mirrors around their own central axes. This axis, which is generally horizontal, is oriented most of the time in an East/West direction (or the North-South axis during the summer) to give them an adequate orientation to reflect the incident rays of the sun in the direction of a concentrator tube in which a heat transfer fluid circulates.

	Spot concentration	Linear concentration
fixed		

mobile



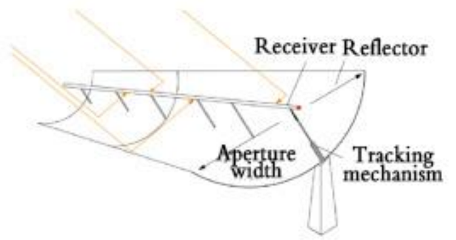


Figure II-9: Concentration collectors[15]

Point concentration system

- Tower power plant

It essentially consists of a field of reflectors with two tracking axes called heliostats. These concentrate direct solar radiation onto a receiver mounted on a tower. The heat transformed in this solar tower can be used for electricity production

- Parabolic mirror sensor

It is a point concentrator having a parabolic symmetry of revolution. The solar rays reflected by the dish converge towards the focus. It is orientable thanks to a mobile mount around two axes (azimuthal mount and equatorial mount). The need to mobilize the parabola along two axes to follow the path of the sun is the main limit of this type of system. Concentrated solar radiation heats the heat transfer fluid of an associated heat engine called the “sterling engine” which transforms thermal energy into mechanical energy then into electricity. The instantaneous solar-electricity conversion efficiency is greater than 22% but operating and maintenance costs remain high.

II. 5. 2. Constituents of the water plane solar collector (FPSC):[2]

A flat collector essentially consists of a transparent cover, an absorber, a heat transfer fluid, thermal insulation and a box.

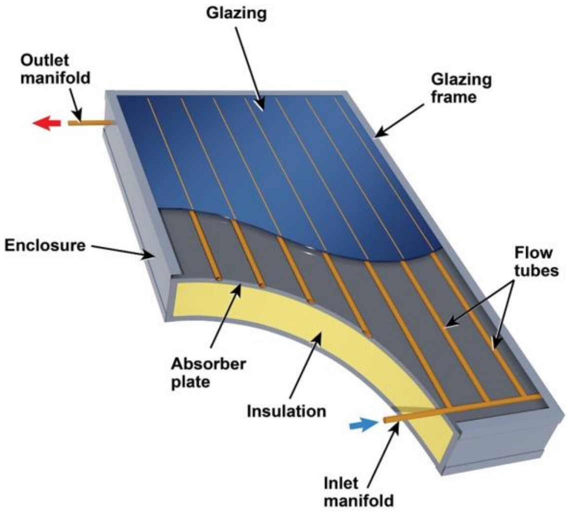


Figure II-10: The components of the solar collector

a. Glazing:

It is a surface made of a material transparent to visible radiation but opaque to infrared radiation, making it possible to create a greenhouse effect which reduces thermal losses towards the front of the absorber. Most glazing is based on acrylic glass with an anti-reflective coating. If effective glazing is desired, it must have the following properties:

- reflect the light radiation to a minimum whatever its inclination;
- absorb light radiation to a minimum;
- have good thermal insulation by keeping infrared radiation to a maximum;
- resist over time the effects of the environment (rain, hail, ...) and large temperature variations.

b. Absorbent plate:

The absorber is the essential element of the solar collector, it absorbs global solar radiation of short wavelengths and converts it into heat. It is made up of a plate into which tubes are integrated in which the heat carrier circulates. The material constituting the absorber is most often: copper, stainless steel or aluminium.

It is strongly necessary to ensure good contact between the absorber sheets and the heat transfer fluid tubes in order to reduce the thermal contact resistance as much as possible.

c. Coolant:

The working fluid is responsible for evacuating the heat stored by the absorber and transmitting it to where it must be consumed. It is chosen based on its thermo-physical properties and taking into consideration the following conditions:

- be chemically stable when it reaches a high temperature;
- have antifreeze properties depending on local weather conditions;

- possess high specific heat and thermal conductivity in order to transport heat efficiently;
- have anti-corrosive properties depending on the nature of the sensor material;
- have a low viscosity in order to facilitate the task of the circulation pump;
- be readily available and inexpensive.

d. Thermal insulation:

The absorber must transmit the captured energy to the heat transfer fluid while avoiding heat losses by conduction, convection and radiation, from the various peripheral parts to the outside. The suitable solutions are as follows:

Front part of the absorber: The air space located between the window and the absorber behaves like an insulator with respect to the transmission of heat by conduction. However, if the thickness of this blade is too great, natural convection occurs, resulting in a loss of energy. By placing two panes, we limit losses due to re-emission as well as losses by conduction and convection.

Rear and side parts: In order to limit thermal losses at the periphery of the sensor, one or more layers of insulation can be placed which must resist high temperatures, but for greater precaution a layer of insulation is added on the inside of the cover. Generally, the thickness of the insulation is around 5 to 10cm. Mineral wool and synthetic materials (glass wool, expanding polyurethane foam or polystyrene) are generally the insulating materials used.

e. Cover:

The trunk is generally made of aluminium or wood. It encloses the absorber and the thermal insulation of the sensor, thus protecting them against humidity and mechanical damage.

II. 5. 3. Parameters characterizing the operation of a flat collecor:

The parameters characterizing the operation of a planar sensor can be classified into two categories: external parameters and internal parameters.

a. External settings:[2]

The main external parameters that can directly influence the performance of a planar sensor are:

- Sunshine parameters: solar radiation, position of the sun, duration of sunshine.
- Ambient temperature
- Wind speed

b. Internal settings:

Geometric parameters:

- Position parameters: tilt angle, sensor orientation.
- The surface of the sensor
- The dimensions of different elements: thickness, length and width.

Operating parameters:

- The inlet temperature of the heat transfer fluid.
- The mass flow rate of the heat transfer fluid.
- The temperatures of the different elements of the collector.

These parameters influence the useful power, which is higher and the fluid outlet temperature will be high. In other words; better performance.

II. 6. The working principle of the solar heater: [15]

Solar collectors transform solar radiation into heat using an absorber (a black body characterized by very high absorption and very low emissivity properties). The absorber transfers the heat to a heat transfer fluid (generally brine) circulating through each of the collectors.

When the temperature difference between the sensor probe (T1) and the probe at the bottom of the tank (T2) exceeds a few degrees, the circulators switch on.

The heat transfer fluid, circulating in the primary circuit, then routes the solar energy from the collectors to the storage tank(s) through an exchanger.

The storage tank(s) accumulate(s) the heat produced.

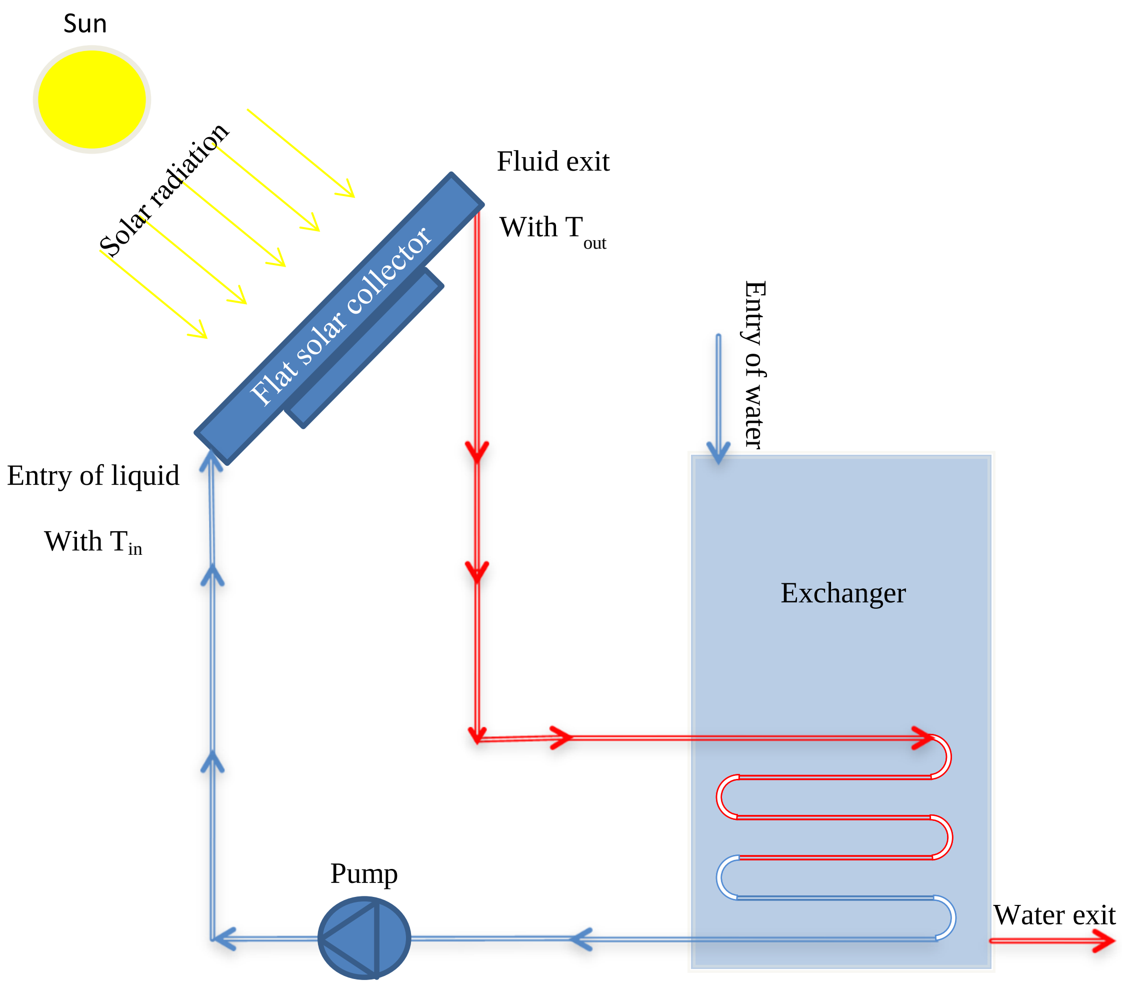


Figure II-11: The working principle of the solar heater

II. 7. Conclusion :

In the twentieth century, the solar water heater was invented, many improvements were made, and it became increasingly popular. We presented a historical overview of it in the first chapter. Concentrated solar thermal electricity, on the other hand, is a bright spot in solar power generation.

For all solar thermal applications, the first step is to convert solar radiation energy into heat. In terms of materials and mechanical construction, the basic requirement is to absorb as much sunlight as possible and lose as little thermal energy as possible.

Chapter III: Thermal balance for the collector solar

III.1. Introduction:

The absorber is the basic element of the thermal collector. Its role is to transfer the heat generated by solar radiation to the heat transfer fluid. The flow received by the fluid requires an exchange surface consisting of a mother surface (tube) and a fin surface (corrugated plate), figure (III-1). Modeling this heat exchanger requires establishing a thermal equilibrium. This will take into account the fluxes received by the panel and tubes by conduction, radiation and conduction.

Engineering data:

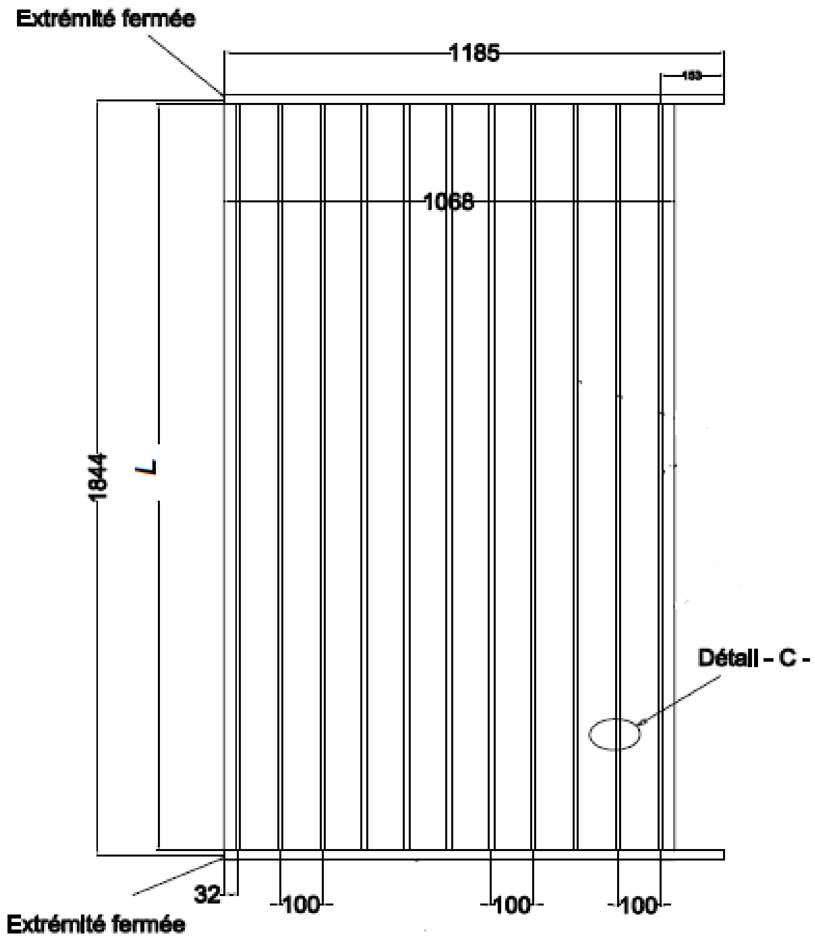


Figure III-1: Absorbent plate (mm)

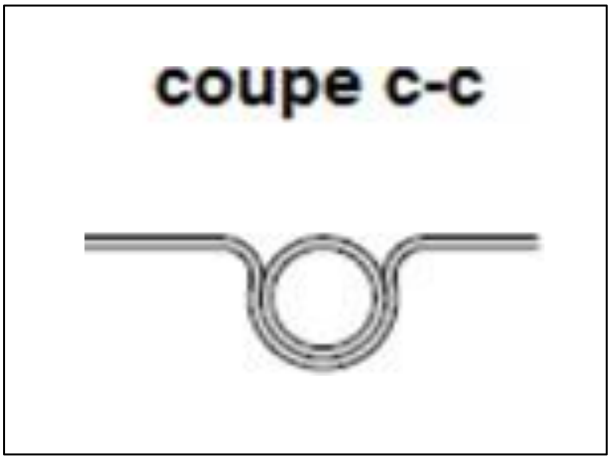


Figure III-2: A section of the painting

S = 2 L .N .[+ l]: the surface of the plate.

L: Length of the board.

N: number of tubes.

2l: large bottle size.

The filaments consist of a double tubular shape (III-3). The flow is collected through capillaries that travel in the form of an Au tube (III-4).

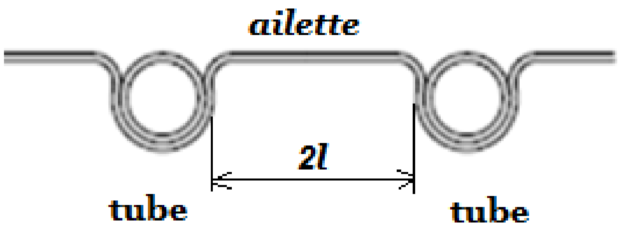


Figure III-3: Identifying the tube-fin assembly.

The characteristics of solar water heating are grouped in the following panel:

Flat collector dimensions (mm)	1208 x 2008 x 104
Corrugated board (absorption)	Aluminum plate 0.3 mm thick λ= 204 W/m°C
Pipes: Type Number Dimensions	 1mm thick copper 11 12X1822 mm

	λ= 386 W/m°C
Pure absorption surface	2.13 m^2
Selective surface The nature of the absorbent surface and its properties	Matte paint Absorption: = 95% Emissions: =5%
Rockwool insulation	Conductivity: = 0.035 W/m°C Bottom thickness = 30 mm Lateral thickness on both sides = 20mm
Glazing	Thickness = 4 mm Emissions: =7% Transmittance 80 90%
Collectors	Copper tube. Thickness 1 mm Diameter = 22 mm Length = 1185 mm

Table (III-1): Characteristics of the solar heater studied.

III.2. Thermal balance:

Hypotheses:

- The system is permanent
- Unidirectional delivery
- $\rho;\ \lambda; C_p$ assumed constants

Thermal equilibrium by the element dx allows us to write, Figure (III-4):

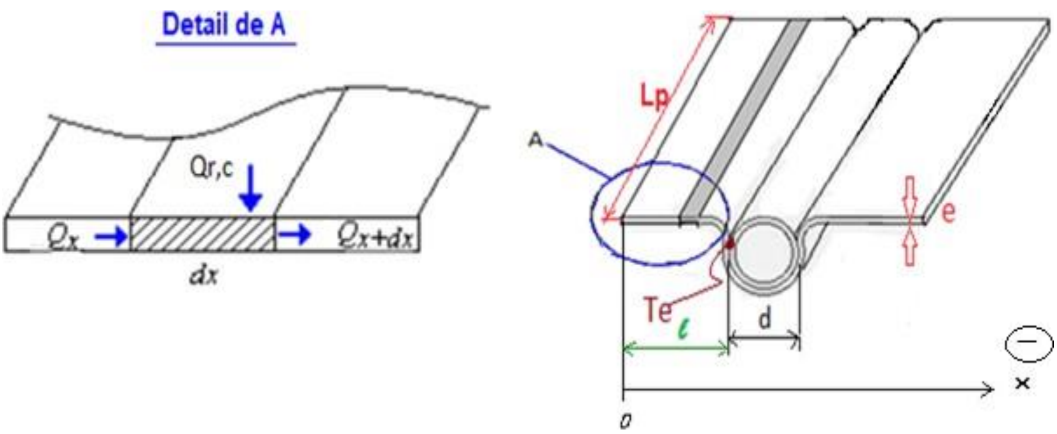


Figure III-4: Thermal balance on the fin element in a tube fin assembly.

Thermal balance on the fin element (dx); Write in the form:

$$\emptyset_{x+dx} - \emptyset_{x} - \emptyset_{r,c} = 0 \quad \text{(III-1)}$$

$\emptyset_{r,c}$ is the mutual flow of convection and radiation between the window and the absorber:

$$\emptyset_{r,c} = \emptyset_{r} + \emptyset_{c} = (h_r + h_c).\left(T_p(x) - T_v\right).S \quad \text{(III-2)}$$

With:

$$h_r = \frac{\sigma.(T_{ab}^2+T_v^2)(T_{ab}+T_v)}{\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_v}-1} \quad \text{(III-3)}$$

T_{ab} : Average temperature of the absorbent pad.

T_v : Average window temperature.

h_r : Radiation exchange coefficient between the window and the absorber.

h_c : Heat convection exchange coefficient between the window and the absorber.

ε_p : Emissivity of absorber

ε_v : Emissivity of glass

The convective heat transfer coefficient between the absorption plate and the glazing is estimated by the relationship proposed by Hollands et al. Based on experience, this relationship allows determining the Nusselt number for tilt angles ranging from 0 degrees to 60 degrees, so that:

$$Nu = \left[1 + 1.44\left[1 - \frac{1708}{R_a cos\beta}\right]^{+}\left[1 - \frac{1708(sin1.8\beta)^{1.6}}{R_a cos\beta}\right] + \left[\left[\frac{R_a cos\beta}{5830}\right]^{1/3} - 1\right]^{+}\right] \quad \text{(III-4)}$$

Or thermal baths in (+) are only in the case where it is positive.

The thermophysical properties of air as a function of temperature are calculated by:

$$\left.\begin{aligned} Cp_{air} &= 1005{,}48 - 0{,}01014T + 0{,}001138T^2 + 0{,}62 \times 10^{-3}T^3 + 0{,}1613 \times 10^{-7}T^4 \\ \rho_{air} &= 1{,}3043 - 0{,}00203T - 10^{-5}T^2 \\ \mu_{air} &= [1{,}7164 + 0{,}01327T + 0{,}00019T^2 + 0{,}1057 \times 10^{-5}T^3] \times 10^{-5} \\ \lambda_{air} &= 0{,}02415 - 0{,}00008T \end{aligned}\right\} \text{(III-5)}$$

Then the parameter h is given by:

$$h_c = Nu \times \frac{\lambda_{air}}{e_{pl-v}} \quad \text{(III-6)}$$

With:

β: collector inclination angle.

e_{pl-v} : The distance between the absorption plate and the glazing.

λ_{air} : thermal conductivity of air.

$R_a = G_r + P_r$: Rayleigh number

Or:

$$P_r = \frac{\mu Cp}{\lambda} \quad \text{(III-7)}$$

By developing the relationship (III-1) for the different flows, we find:

$$\emptyset_x = -\lambda_p \frac{\delta T_p(x)}{\delta_x}\bigg|_x L_p e \quad \text{(III-8)}$$

$$\emptyset_{x+dx} = -\lambda_p \frac{\delta T_p(x)}{\delta_x}\bigg|_{x+dx} L_p e \quad \text{(III-9)}$$

$$\emptyset_{r,c} = (h_r + h_c).\left(T_p(x) - T_v\right).dx.\ L_p \quad \text{(III-10)}$$

With:

λ_p: Conductivity of the plate

L_p *and* e: Thickness and length of the absorbent.

By replacing the different flows with their expressions and unit length, we obtain:

$$-e\lambda_p \left[\frac{\delta T_p(x)}{\delta_x}\bigg|_{x+dx} - \frac{\delta T_p(x)}{\delta_x}\bigg|_x\right] - \left[(h_r + h_c).\left(T_p(x) - T_v\right).dx\right] = 0 \quad \text{(III-11)}$$

By dividing equation (4-10) by dx, e *and* λ_p We get:

$$\frac{\left[\frac{\delta T_p(x)}{\delta_x}\Big|_{x+dx} - \frac{\delta T_p(x)}{\delta_x}\Big|_x\right]}{dx} = \frac{-\left[(h_r+h_c).\left(T_p(x)-T_v\right)\right]}{e\lambda_p} \quad \text{(III-12)}$$

When dx becomes 0 we get:

$$\frac{d^2T(x)}{dx^2} = \frac{-\left[(h_r+h_c).\left(T_p(x)-T_v\right)\right]}{e\lambda_p} \quad \text{(III-13)}$$

With the following classical boundary conditions:

Fin end: $\frac{dT}{dx}\Big|_{x=0} = 0$

Fin base: $T|_{x=} = |Te|$

Te: The temperature of the outer wall of the tube in contact with the fin.

Assuming that:

$$m = \sqrt{\frac{(h_r+h_c)}{e\lambda_p}} \quad \text{and} \quad \psi = -\left(T_p(x) - T_v\right) \quad \text{(III-14)}$$

Equation (III-12) is reduced to:

$$\frac{d^2\psi(x)}{d^2} - m^2\psi(x) = 0 \quad \text{(III-15)}$$

The boundary conditions become:

$$\left.\frac{dT}{dx}\right|_{x=0} = 0 \quad \text{(III-16)}$$

And: $\psi|_{x=l} = |Tv - Te|$

Equation (4-15) is a differential equation without a second member. The general solution is given by:

$$\psi = C_1 shmx + C_1 chmx \quad \text{(III-17)}$$

Applying the boundary conditions follows:

$(\frac{d\psi}{dx})_{x=0} = 0$ $C_1=0$

$\psi|_{x=l} = |Tv - Te|$ $C_2 = \frac{Te - Tv}{ch(ml)}$

$$\psi(\text{x}) = C_2 ch(mx)$$

So the expression for the temperature distribution in the plate is:

$$\text{T(x)} = [Tv - Te]\left[\frac{ch(mx)}{ch(ml)}\right] + Tv \quad \text{(III-18)}$$

In the case where the flow discharges immediately at the fin-to-tube contact points, as shown in Figure (III-5), the fluid is written through the thickness of the tube:

$$\emptyset_1 = -\lambda_p S_p \left.\frac{dT}{dx}\right|_{x=l} = 2m\,\lambda_p S_p.(Te - Tv).th(ml) = \frac{(Te-Tv)}{\frac{1}{2m\,\lambda_p S_p.th(ml)}} \quad \text{(III-19)}$$

This flow is transferred to the pipe by conduction through its thickness, which is written:

$$-\frac{\lambda_t}{e_t}S_p \ \ (Te - T_{p2}) = \frac{(Te-Tv)}{\frac{e_t}{\lambda_t S_p}} \quad \text{(III-20)}$$

This same flow is transmitted by convection from the inner wall of the tube towards the liquid, which means:

$$h_{cv,f}.S_p.(T_{p2} - T_f) = \frac{(T_{p2}-T_f)}{\frac{1}{h_{cv,f}S_p}} \quad \text{(III-21)}$$

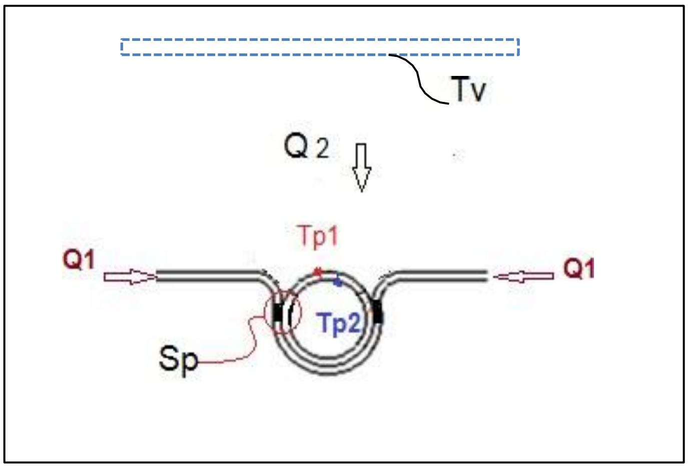


Figure III-5: Layout of the Sp element

With: $T_f = \frac{(T_{ec}-T_{cs})}{2}$

T_{es}: Fluid temperature at the collector inlet.

T_{cs}: Fluid temperature at the collector outlet.

T_f : Average temperature of the liquid.

The convective transfer coefficient between water and the inner wall of the pipe was estimated using empirical formulas via the Nusselt number depending on the flow regime.

In the laminar system (Re), we will use the relationship proposed by Sider and Tate, meaning:

$$N_u = 1{,}86\left(ReP_r\frac{d}{l}\right)^{1/3}\left(\frac{\mu_f}{\mu_p}\right)^{0.14} \quad \text{(III-22)}$$

Given the low variation in viscosity with temperature and the small differences we encounter, we will neglect the difference between the fluid's wall viscosityμ_p and its viscosityμ_f.

$$\text{Which gives us: } N_u = 1{,}86\left(ReP_r\frac{d}{l}\right)^{1/3} \quad \text{(III-23)}$$

In the turbulent regime (1000<Re), it is proposed by the same previous hypotheses:

$$N_u = 0{,}023Re^{0{,}8}(P_r)^{1/3}\left(\frac{\mu_f}{\mu_p}\right)^{0.14}$$

Considering: $\mu_f = \mu_p$ it is : $N_u = 0{,}023Re^{0{,}8}(P_r)^{1/3}$

The transmission coefficient $h_{cv,f}$ is given by:

$$h_{cv,f} = \frac{\lambda_{eau}N_u}{d} \quad \text{(III-24)}$$

The thermophysical properties of water as a function of temperature are calculated by:

$$\left.\begin{array}{l} Cp_{eau} = 4196{,}35 - 0{,}81714T + 0{,}00934T^2 + 10^{-5}T^3 \\ \rho_{eau} = 1000{,}26 - 3{,}906 \times 10^{-2}T - 4{,}05 \times 10^{-3}T^2 \\ \mu_{eau} = [1{,}632 + 13{,}63 \times e^{-0{,}025T}] \times 10^{-4} \end{array}\right\} \quad \text{(III-25)}$$

$$\lambda_{eau} = 0{,}55867 + 0{,}00203T - 10^{-5}T^2 \quad \text{(III-26)}$$

With:

d :the tube's diameter.

λ_t : Thermal conductivity of the tube.

e_t : Pipe thickness

λ_p : Thermal conductivity of the plate.

$T_a = \frac{T_v + T_{ab}}{2}$: Air blade temperature.

Finally, the flow transmitted by the fins to the fluid is written, taking into account: $T_v \approx T_a$

$$\emptyset_1 = \frac{T_a - T_f}{\frac{1}{2m\,\lambda_p S_p . th(ml)} + \frac{e_t}{\lambda_t S_p} + \frac{1}{h_{cv,f} . S_p}} \quad \text{(III-27)}$$

The flux transmitted by all the fins is written in the form:

$$\emptyset_1' = N\emptyset_1 = kS_a(T_a - T_f) \quad \text{(III-28)}$$

With: $S_a = N * 2l * L$

The flux received by radiation and convection at the surface of the tube$(S_2 = 2\alpha r_e L)$, Figure (III-6), is written:

$$\emptyset_2 = \emptyset_r + \emptyset_c = (h_r + h_c).(2\alpha r_e L)(T_a - T_{p1}) \quad \text{(III-29)}$$

$$\emptyset_2 = \frac{T_a - T_{p1}}{\frac{1}{(h_r + h_c).(2\alpha r_e L)}} \quad \text{(III-30)}$$

This flow is transmitted to the pipe by conduction through the thickness of the pipe, thus:

$$\emptyset_2 = \frac{T_{p1} - T_{p2}}{\frac{1}{2\pi.\,\lambda_t . L} ln\frac{d_e}{d_i}} \quad \text{(III-31)}$$

This same flow will be transferred by convection from the inner wall of the tube towards the fluid, so that:

$$\emptyset_2 = \frac{T_{p2} - T_f}{\frac{1}{h_{cv,f} . (2\alpha r_i L)}} \quad \text{(III-32)}$$

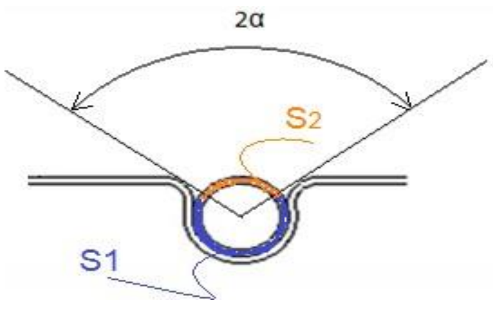


Figure III-6: A representative diagram of two sections

Finally, the radiated and convective flow at the surface S2 is written:

$$\emptyset_2 = \frac{T_a - T_f}{\frac{1}{(h_r + h_c).(2\alpha r_e L)} + \frac{1}{2\pi.\,\lambda_t . L} ln\frac{d_e}{d_i} + \frac{1}{h_{cv,f} . (2\alpha r_i L)}} \quad \text{(III-33)}$$

The flow received by all pipes is written:

$$\emptyset_2' = N\emptyset_2 = k' S_t(T_a - T_f) \quad \text{(III-34)}$$

With: $S_t = N * S2$

The total flow received by the absorber is written:

$$\emptyset_t = \emptyset_1^{'} + \emptyset_2^{'} = N(T_a - T_f)[kS_a + k'S_t] \qquad \text{(III-35)}$$

$$\emptyset_t = \frac{N[kS_a + k'S_t]}{S} \times S(T_a - T_f)$$

$$\emptyset_t = KS(T_a - T_f) \qquad \text{(III-36)}$$

With:

$$S = S_a + S_t \qquad \text{(III-37)}$$

$$K = \frac{N[kS_a + k'S_t]}{S} \qquad \text{(III-38)}$$

$$K = N\left[\frac{1}{\left(\frac{1}{2m\,\lambda_p.th(ml)} + \frac{e_t}{\lambda_t} + \frac{1}{h_{cv,f}.}\right)\frac{S_2}{S_p}} * \frac{S_a}{S} + \frac{1}{\frac{1}{(h_r + h_c).} + \frac{1}{2\pi.\,\lambda_t.L}.S_2 ln\frac{d_e}{d_i} + \frac{1}{h_{cv,f}.}} * \frac{S_t}{S}\right] \qquad \text{(III-39)}$$

K: total exchange coefficient of the absorber.

S: absorbent surface

The case in which the flow is evacuated by the fins to the liquid through the thickness of the tube assuming that the tube-fin connection is perfect, Figure (III-7), written:

$$\emptyset_1^{''} = -\lambda_p S_p \left.\frac{dT}{dx}\right|_{x=l} = \frac{T_v - T_e}{\frac{1}{-2m\,\lambda_p.th(ml)}} = -\frac{\lambda_a}{e_a} S_p.(T_e - T_0) = -\frac{(T_e - T_0)}{\frac{e_a}{\lambda_a S_p}} \qquad \text{(III-40)}$$

This flow is transmitted to the tube by conduction through the thickness of the tube at surface S1, and is written:

$$\emptyset_1^{''} = -\frac{(T_m - T_{p2})}{\frac{e_a}{\lambda_t.S_{1ext}}} \qquad \text{(III-41)}$$

This same flow is transmitted by convection from the inner wall of the tube towards the liquid, and is written:

$$\emptyset_1^{''} = -\frac{(T_{p2} - T_f)}{\frac{1}{h_{cv,f}.S_{1i}}} \qquad \text{(III-42)}$$

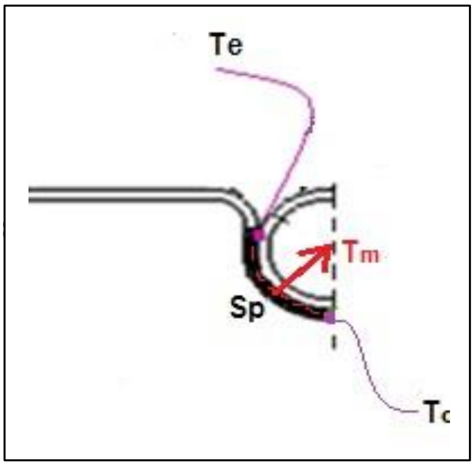


Figure III-7: Layout of the element Sp

In this case we have: $S_p = \frac{S_1}{2}$

With:

$S_{1i} = (\pi - \alpha)Lr_i$: The inner surface of the pipe

$S_{1ext} = (\pi - \alpha)Lr_e$: The outer surface of the pipe

e_a : Fin thickness

T_0 : Fin temperature at the middle of the tube, Figure (III-7)

Assuming that:$-T_v \approx T_a$

Also: $T_m = \frac{(T_0 - T_e)}{2} \approx T_0$

T_m : Average fin temperature when $x \in [l, l + (\pi - \alpha)r]$

So we get:

$$\emptyset_1'' = \frac{T_a - T_f}{\frac{1}{2m\,\lambda_p S_p . th(ml)} + \frac{e_\alpha}{\lambda_\alpha S_p} + \frac{e_t}{\lambda_{t.} S_{1ext}} + \frac{1}{h_{cv,f} . S_{1_i}}} \quad \text{(III-43)}$$

The flux transmitted by all the fins is written as :

$$\emptyset_1''' = N\emptyset_1 = kS_a(T_a - T_f) \quad \text{(III-44)}$$

The total absorption flux is written:

$$\emptyset_t = \emptyset_1''' + \emptyset_2' = N\left[kS_a\left(T_a - T_f\right) + k'S_t(T_a - T_f)\right] \quad \text{(III-45)}$$

$$\emptyset_t = \frac{N[kS_a + k'S_t]}{S} S\left(T_a - T_f\right)$$

$$\emptyset_t = KS\left(T_a - T_f\right) \quad \text{(III-45)}$$

With:

$$K = N\left[\frac{1}{(\frac{1}{2m\,\lambda_p.th(ml)}+\frac{e_t}{2\lambda_t}+\frac{1}{2h_{cv,f}}.)\frac{S_2}{S_p}} * \frac{S_a}{S} + \frac{1}{\frac{1}{(h_r+h_c)}.+\frac{1}{2\pi.\,\lambda_t.L}.S_2 ln\frac{d_e}{d_i}+\frac{1}{h_{cv,f}}} * \frac{S_t}{S}\right] \quad \text{(III-46)}$$

Efficiency Calculation:

$$\varepsilon = \frac{surface\ avec\ tube\ et\ plaque\ ondulée}{the\ equivalent\ surface\ area\ of\ the\ tube} = \frac{S_{tube}}{S_{real}} \quad \text{(III-47)}$$

The width of the fin is 88 mm, and the number of tubes required to be placed in the fin is 7, so the entire absorbent plate requires 88 tubes.

$$S_{real} = 2L(\alpha r + l) * 11 \quad \text{(III-48)}$$

$$S_{tube} = \pi.rL * N_{tube} \quad \text{(III-49)}$$

So it is:

$$\varepsilon = \frac{2{,}1822(\frac{\pi}{4} * 6 + 44)}{\pi * 6 * 1822 * 88} = 0{,}64$$

Discussion follows the value of K given respectively by (III-39) and (III-46):

$$K = N\left[\frac{1}{(\frac{1}{2m\,\lambda_p.th(ml)}+\frac{e_t}{\lambda_t}+\frac{1}{h_{cv,f}}.)\frac{S_2}{S_p}} * \frac{S_a}{S} + \frac{1}{\frac{1}{(h_r+h_c)}.+\frac{1}{2\pi.\,\lambda_t.L}.S_2 ln\frac{d_e}{d_i}+\frac{1}{h_{cv,f}.}} * \frac{S_t}{S}\right] \quad \text{(III-50)}$$

$$K = N\left[\frac{1}{(\frac{1}{2m\,\lambda_p.th(ml)}+\frac{e_t}{2\lambda_t}+\frac{1}{2h_{cv,f}}.)\frac{S_2}{S_p}} * \frac{S_a}{S} + \frac{1}{\frac{1}{(h_r+h_c)}.+\frac{1}{2\pi.\,\lambda_t.L}.S_2 ln\frac{d_e}{d_i}+\frac{1}{h_{cv,f}}} * \frac{S_t}{S}\right] \quad \text{(III-51)}$$

If: $\alpha=\pi/2$, the width of the fin increases, and therefore the overall coefficient increases.

If: $\alpha\to 0$ the fin width decreases, and therefore the overall modulus decreases.

If: $\alpha\to\pi$ the fin width increases, so the overall modulus decreases.

So, to improve the overall exchange coefficient K, we must respect the opening angle $\alpha=\pi/2$

III. 3. Thermal losses of the collector:

In equilibrium, the useful heat rate provided by the solar sensor is equal to the energy rate absorbed by the fluid transferring heat less directly or indirectly from the area to the environment. These thermal losses are due to the temperature difference between the different components of the solar sensor as well as with the surrounding environment.

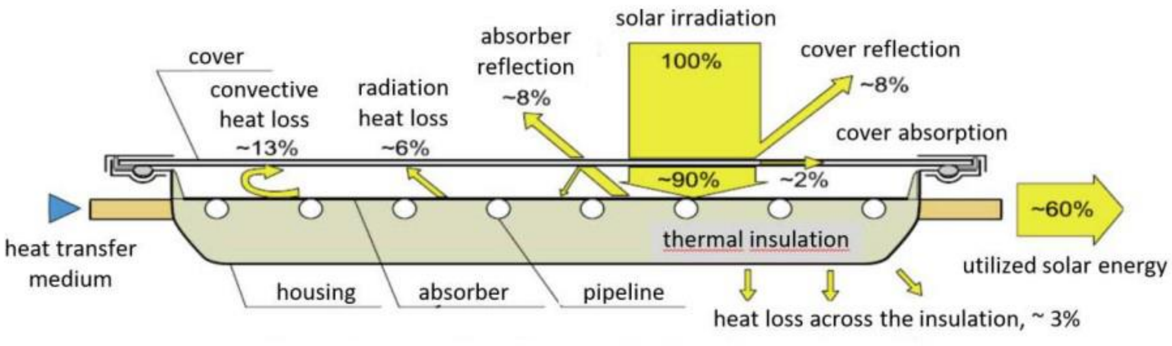


Figure III.8: Typical heat losses from a flat solar collector

They can occur by the interference of three heat transfer modes:

1- Heat load losses:

This transmission mode intervenes between the cover and the external environment, the absorber and the air blade, the air blade and the cover. The thermal loss coefficient increases with increase in absorber emissions, its temperature, and heat exchange coefficient with surrounding air while it decreases with increase in distance between absorber and vitrification.

2- Losses through delivery:

Conduction losses can occur between the absorber and the window when they are very close, as they are located at the back and sides of the sensor.

3- Radiation losses:

The material used of the cover allows incident solar radiation to pass through, but is opaque to the infrared radiation collected by absorption brought to a temperature between 35 to 100 degrees Celsius. The inner side of the lid absorbs this infrared radiation, then undergoes a temperature increase and half is radiated outward and half toward absorption (greenhouse effect). Thus, the loss by radiation has been halved and the addition of the cover reduces these losses.

These losses can be classified into three categories:

- Losses to the top
- Losses down
- Collateral losses.

Chapter IV: Results and Discussions

IV. 1. Introduction:

In this chapter we will discuss the overall results obtained through numerical simulations performed using Matlab based on the changes in outlet temperatures, efficiency and heat losses with respect to changes in solar radiation at different inclination angles.

Knowing that:

- Inlet temperature T_{in} = 25°C;
- Ambient temperature T_{amb} = 20°C;
- Panel efficiency 0.7.

The simulation allowed to obt§ain the following curves:

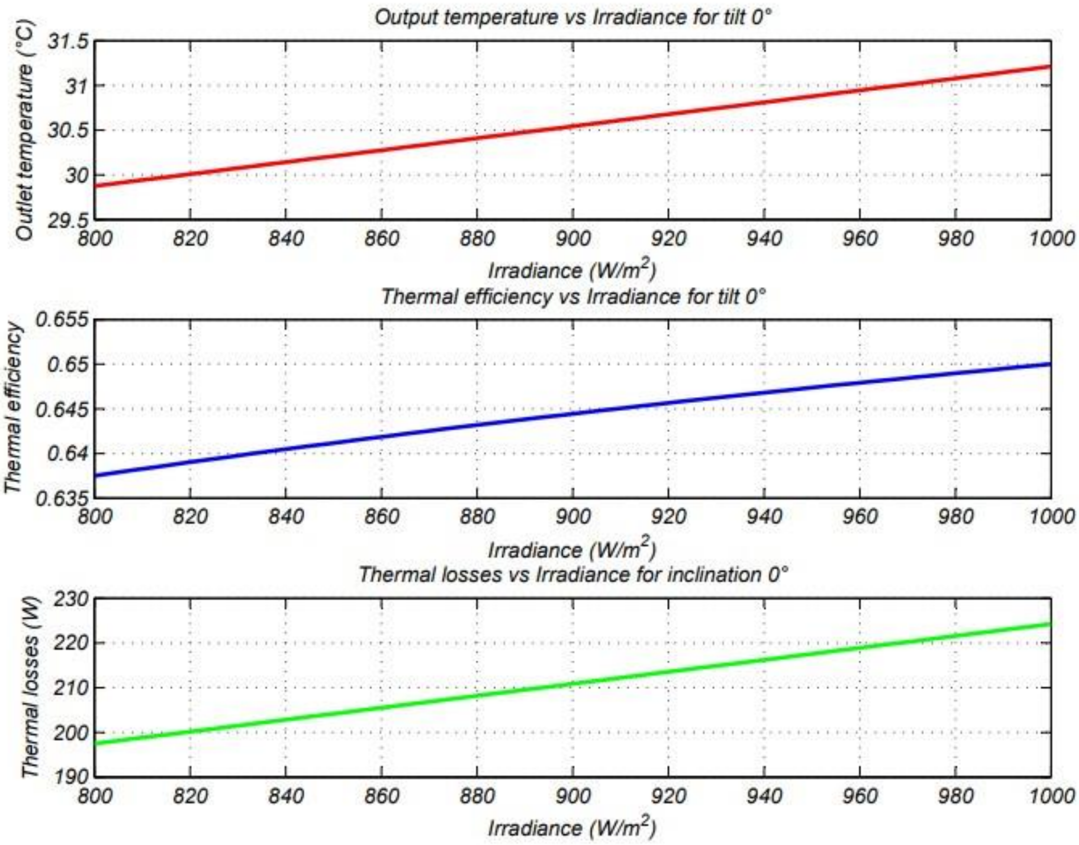


Figure IV.1: Graphic curves representing the evolution of outlet temperature, efficiency and losses as a function of radiation at an inclination of 0°

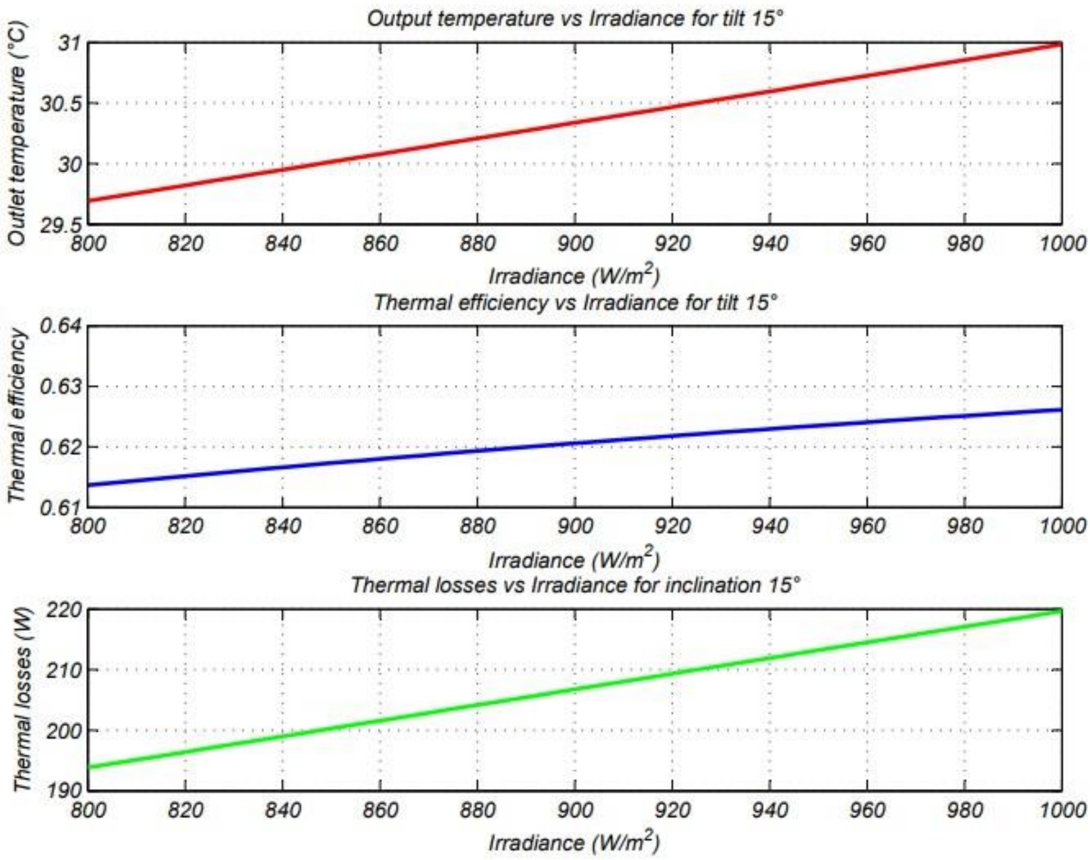


Figure IV.2: Graphic curves representing the evolution of outlet temperature, efficiency and losses as a function of radiation at an inclination of 15°

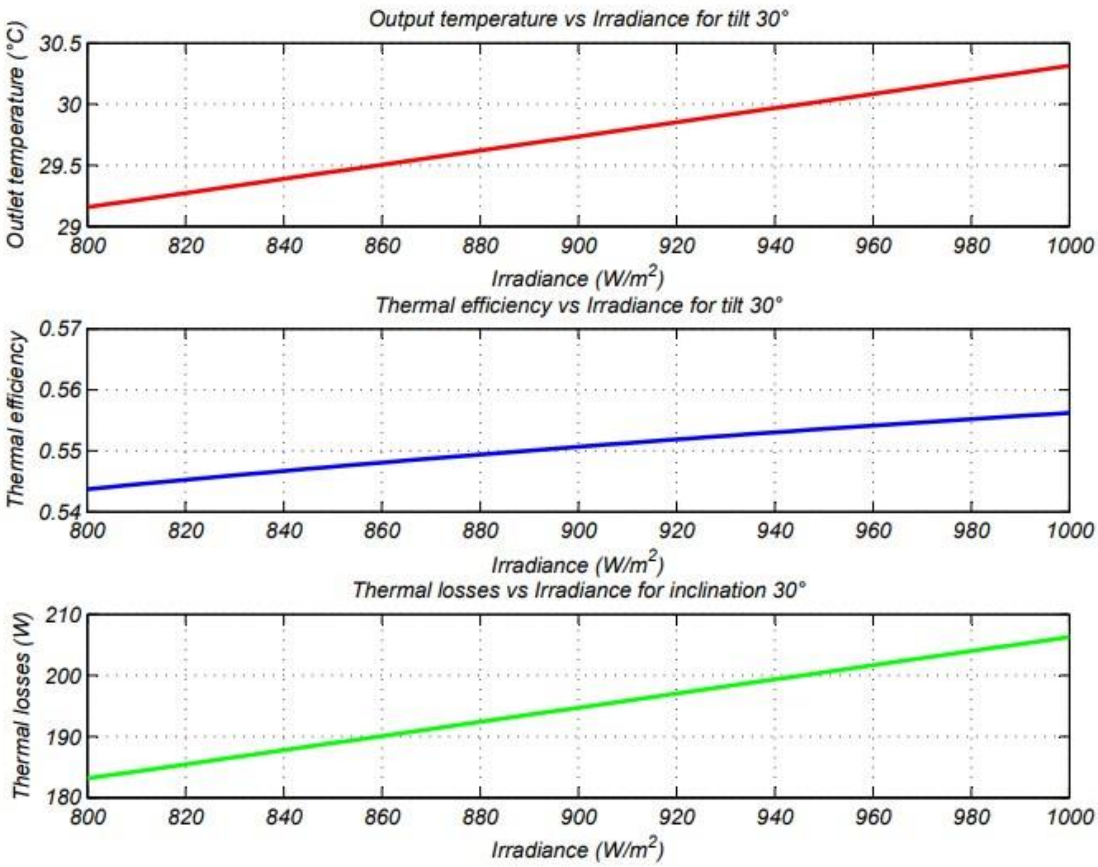


Figure IV.3: Graphic curves representing the evolution of outlet temperature, efficiency and losses as a function of radiation at an inclination of 30°

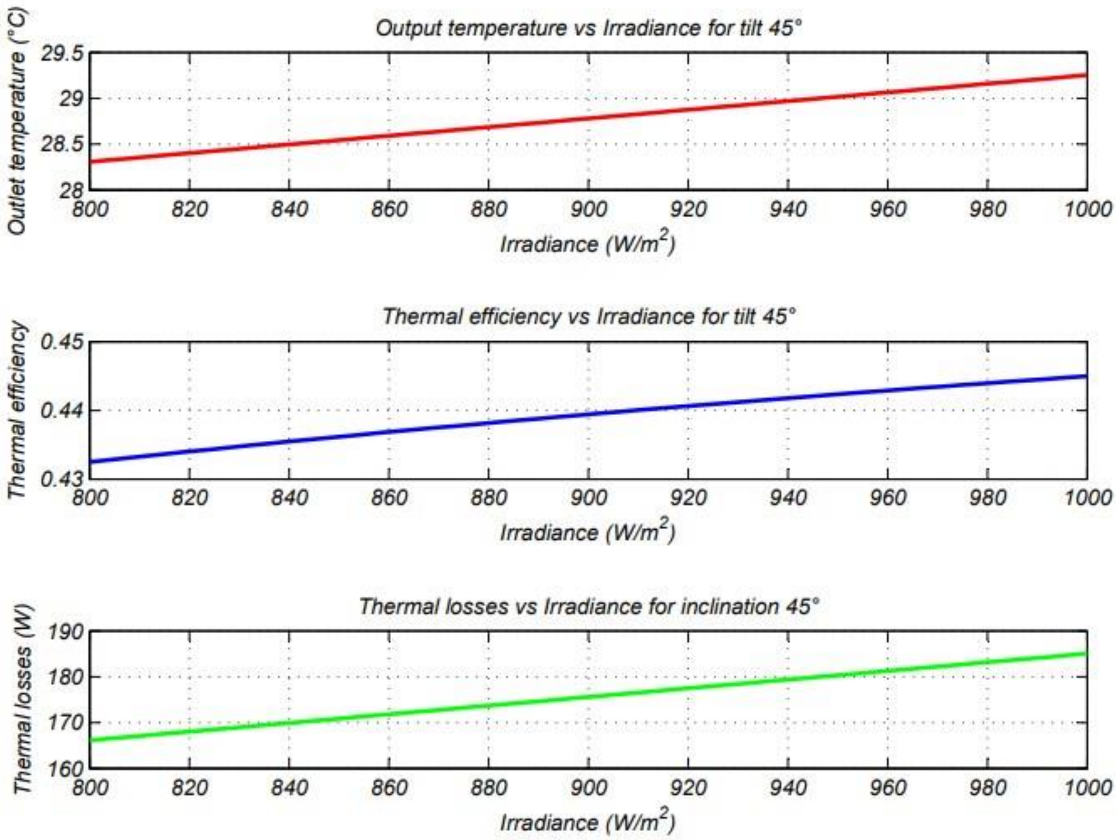


Figure IV.4: Graphic curves representing the evolution of outlet temperature, efficiency and losses as a function of radiation at an inclination of 45°

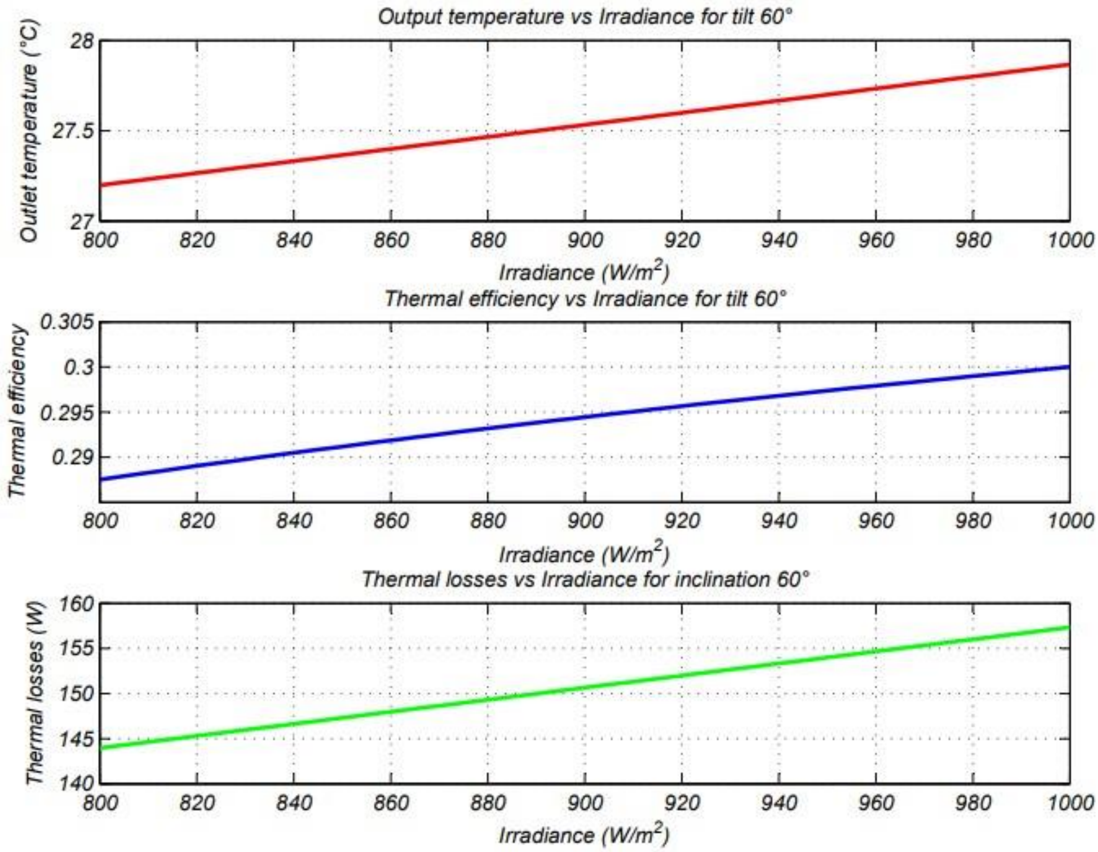


Figure IV.5: Graphic curves representing the evolution of outlet temperature, efficiency and losses as a function of radiation at an inclination of 60°

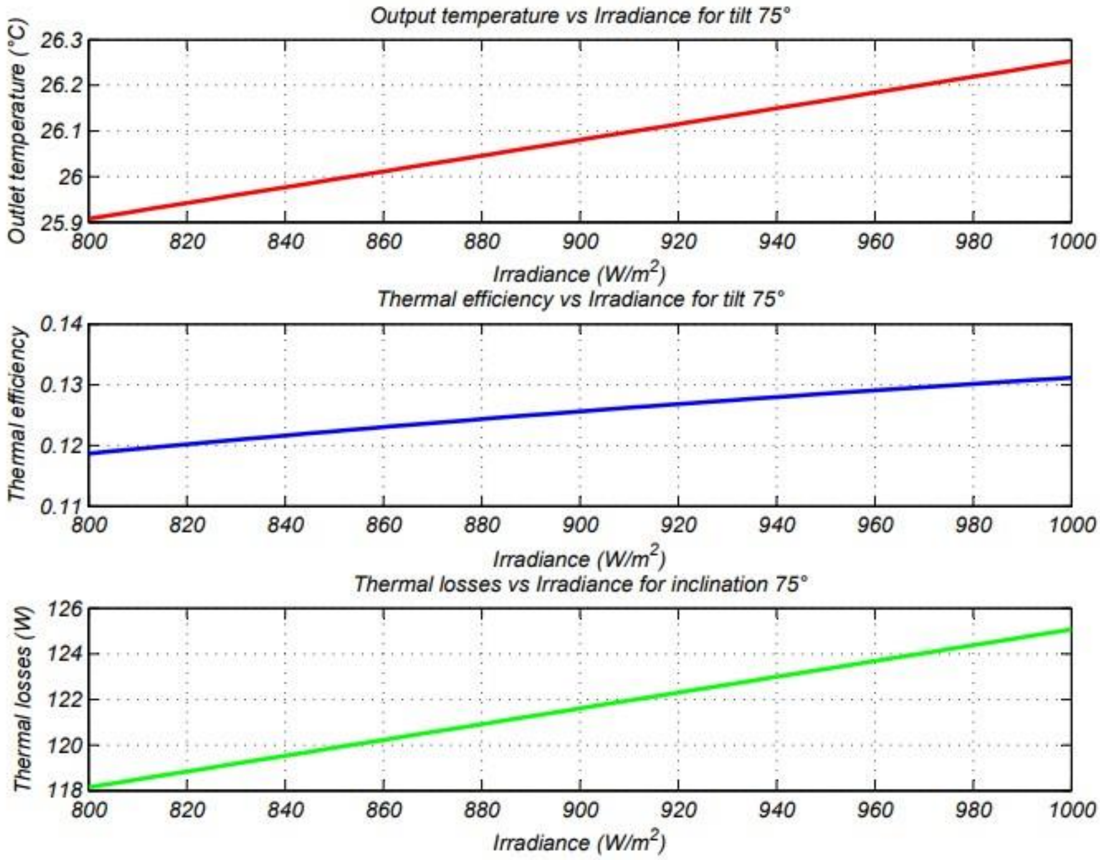


Figure IV.6: Graphic curves representing the evolution of outlet temperature, efficiency and losses as a function of radiation at an inclination of 75°

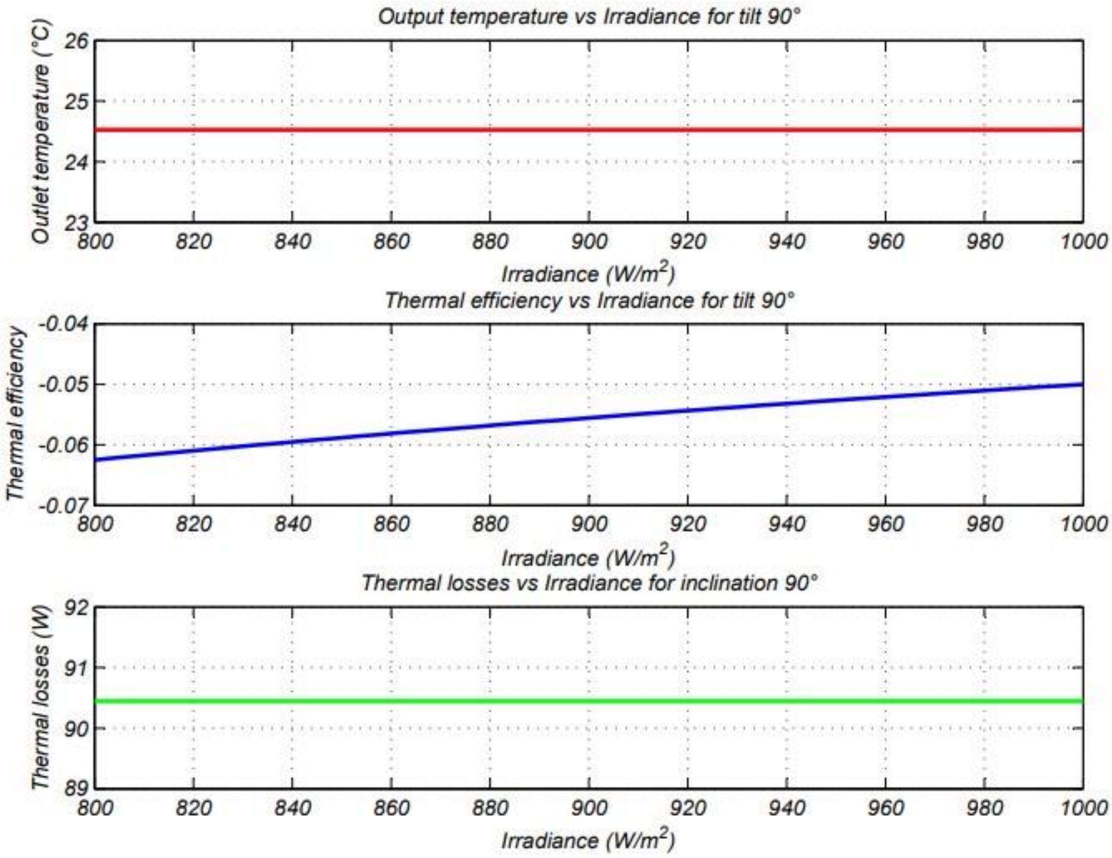


Figure IV.7: Graphic curves representing the evolution of outlet temperature, efficiency and losses as a function of radiation at an inclination of 90°

IV. 2. Analysis of the results:

We notice, almost in the last seven figures that there is a direct relationship between the intensity of solar radiation and each of the temperatures at the outlet, the thermal efficiency, and the thermal losses (following the same pattern).

The results for outlet temperatures, efficiency and thermal losses at 1000 W radiation intensity per inclination angle are summarized in the table below:

Angles of inclination	0°	15°	30°	45°	60°	75°	90°
Outlet temperature	31.25 ˚C	31 ˚C	30.25 ˚C	29.25 ˚C	27.9 ˚C	26.25 ˚C	24.5 ˚C
Efficiency	0.65	0.625	0.555	0.445	0.3	0.13	-0.05
Thermal losses	224 w	220 w	205 w	185 w	154 w	125 w	90.5 w

Table (IV-1): Summary of simulation results at a radiation of 1000 w per tilt angle.

It is clear to us from the results obtained the extent to which the inclination angle of the flat solar collector affects its thermal performance, as the difference was clear in the efficiency and quantity of thermal losses, especially the final temperature (T_{out}), between the different cases. The results showed that efficiency depends on the solar radiation capacity. As the radiation increases, the efficiency increases. As for the tilt angle, on the contrary, when $\beta \rightarrow \pi/2$, the efficiency of the solar collector decreases .The results showed that thermal losses depend on the ability of solar radiation. As radiation increases, losses increase. As for the tilt angle, on the contrary, when $\beta \rightarrow \pi/2$, the thermal losses of the solar collector decrease. At an inclination angle of 0° (the collector is horizontal), we obtain a comfortable temperature and high efficiency (0.65 and 31.25 °C), but with large thermal losses of more than 220 watts. At an inclination angle of 90 degrees (the collector is vertical), we get small heat losses, and an unsuitable temperature (24 ° C). The efficiency decreases rapidly at this angle and becomes negative -0.05, which means that the plate temperature decreases instead of rising. At an inclination angle of 30°, we obtain a relatively acceptable temperature, moderate efficiency, and lower thermal losses compared to an inclination angle of 0°. Therefore, the inclination angle of 30° can be chosen as the best angle for the thermal accumulator to achieve a good temperature due to the average efficiency and small losses. We can conserve these losses by developing solar coatings to increase absorption, and thermal losses can also be exploited in home heating.

General conclusion

In this thesis, we studied solar energy, which is a renewable, non-polluting energy source. To do this, we began by presenting a historical overview of solar collectors in the first chapter, then we presented one of the methods for exploiting solar energy, which is thermal conversion, by describing the flat water solar collector, its operating principle, various parameters, and characteristics.

On the other hand, we have presented the necessary concepts for mathematical modeling of the thermal behavior of a water-based rooftop solar collector by describing the basic stages of the energy balance in part.

The numerical resolution of the model, in the steady state, was performed using a computational code written in MATLAB, taking into account the variation of some collector parameters and the convergence of the evolution of the fluid (water) temperature field. Through the approved digital model, the effect of some qualitative and quantitative factors involved in the formation and operation of the flat water solar collector on its thermal behavior was analysed.

Then we presented the results obtained from the numerical study of the flat water solar collector, through a graphical depiction in the form of curves (Ts, hm, η,), which allowed us to determine the internal and external parameters that most influence the efficiency of the solar collector. We note that:

- The window must have a high transmission factor for visible radiation.
- Using an absorbent plate with a high absorption coefficient and thermal conductivity improves the efficiency of the collector.
- Higher ambient temperature improves the thermal efficiency of the solar collector.
- Fluid flow has an improving effect on thermal efficiency but has a moderate effect on the outside temperature.
- Operate with proper orientation and inclination.

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