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Entitled

Theoretical study on thermal performance of solar air collector with fins and baffles

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Dedication

I dedicate my work to :

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NOMENCLATURE

$T1$	Glass temperature. (K)
$T2$	Absorber plate temperature. (K)
Tf	Air flow temperature. (K)
Ta	Ambient air temperature. (K)
Ts	Sky temperature. (K)
I	Incident solar radiations. (W/m2 K)
$h1$	Convective heat transfer coefficients between glass cover and air stream. (W/m2K)
$h2$	Convective heat transfer coefficient between the absorber plate and air flow. (W/m2K)
$hr21$	Radiation heat transfer coefficient. (W/m2K)
hrs	Radiation heat transfer coefficient. (W/m2K)
hw	Wind convection heat transfer coefficient. (W/m2K)
Cp	Heatcapacity of air. (J/Kg K)
Kf	Thermal conductivity of air stream. (W/m K)
kbi	Thermal conductivity of insulation. (W/m K)
UL	Top heat loss coefficient. (W/m2K)
Ub	Bottom heat loss coefficient. (W/m2 K)
$\dot{m}$	Mass flow rate. (Kg/s)
V	Wind velocity. (m/s)
Nu	Nusselt number
Re	Reynolds number

W	Width collector. (m)
L	Length of collector. (m)
Xbi	Insulation thickness. (m)
d	Spacing between absorber plate and glass cover. (m)
Dh	Equivalent hydraulicdiameter. (m)
A	Cross section of flow area. (m 2)
P	Wetted perimeter. (m)
Q	The useful heat transferred to air
$Hfin$	Height of fins. (m)
$tfin$	Thickness of fins. (m)

Greeks symbols

ε1	Emissivity of glass cover
ε2	Emissivity of absorber surface
α1	Absorptivity of absorber plate
α2	Absorptivity of cover glass
τ	Transmissivity
ρ	Density of air stream (Kg/m2)
σ	Stefan –Boltzmann constant
μ	Dynamic viscosity of air stream (Kgm-1S-1)

Résumé

Dans cette étude, nous avons examiné l’impact des ailettes et des chicanes sur les performances thermiques d’un système de collecteur solaire à air à simple passage fonctionnant en convection forcée. Un modèle théorique a été développé, impliquant la division du collecteur en plusieurs éléments différentiels le long de la plaque. Ce modèle repose sur la résolution numérique des équations d’énergie pour chaque composant du collecteur, suivie de l’application des équations d'équilibre thermique à ces éléments. Les résultats obtenus à partir de notre code numérique FORTRAN concordent étroitement avec les conclusions de recherches précédentes.

Mots-clés : Chicanes, Efficacité, Ailettes, Collecteur d'air solaire.

Abstract

In this study, we investigated the impact of fins and baffles on the thermal performance of a single-pass solar air collector system operating under forced convection. A theoretical model was developed, which involves dividing the collector into multiple differential elements along the plate. This model relies on numerically solving the energy equations for each component of the collector and subsequently applying thermal equilibrium equations to these elements. The results obtained from our FORTRAN numerical code closely align with previous research findings.

Keywords: Baffles, Efficiency, Fins, Solar Air Collector, SAH .

ملخص

في هذه الدراسة، قمنا بدراسة تأثير الزعانف والحواجز على أداء الحرارة لنظام جامع الهواء الشمسي بمرور واحد يعمل بالتسخين القسري. تم تطوير نموذج نظري يتضمن تقسيم المجمع إلى عدة عناصر تفاضلية على طول اللوحة. يعتمد هذا النموذج على حلاً عددياً لمعادلات الطاقة لكل جزء من المجمع ثم تطبيق معادلات التوازن الحراري على هذه العناصر. أظهرت النتائج التي تم الحصول عليها من خلال برنامجنا العددي FORTRANتوافقاً وثيقاً مع نتائج الأبحاث السابقة.

الكلمات المفتاحية: حواجز ، كفاءة ، زعانف ، جامع الهواء الشمسي.

General

Introduction

General Introduction

Background of the Study

Solar energy systems can be classified as ; solar thermal systems and solar PV system. In solar thermal systems, the function of a solar collector is the conversion of solar radiation on its surface into energy. Numerous types of solar energy collectors have been devised in recent years among which Solar Air Heater (SAH) is commonly used device.

Solar air heaters (SAH) form the foremost component of solar energy utilization system. These air heaters absorb the irradiance and convert it into thermal energy at the absorbing surface and then transfer this energy to a fluid flowing through the collector.

This Master work delves into optimization and enhancement of solar air heaters through the incorporation of fins and baffles aiming to amplify their thermal performance and overall energy efficiency.

Fins are extended surfaces attached to the absorber plate, increasing the surfaces area for heat transfer and promoting convective heat exchange between the absorber plate and the air.

Baffles, on the other hand, are strategically placed within the collector to guide and control the flow of air, promoting better heat distribution and reduced stagnation zones. The integration of fins and baffles in solar air collectors has been proposed as means to optimize heat transfer, improve thermal performance, and make these systems more efficient and adaptable to various applications.

Problem Statement

Despite the increasing emphasis on renewable energy sources, achieving efficient and cost-effective utilization of solar energy for space heating and industrial applications remains a significant challenge. Solar air collectors, which harness solar radiation to heat air for various purposes, hold promise as a sustainable solution. However, the performance of these collectors is influenced by numerous factors, including design configurations such as the incorporation of fins and baffles. While there exists a substantial body of research on solar air collectors, there remains a gap in understanding the comprehensive impact of fins and baffles on the thermal performance and overall efficiency of such systems. Therefore, this study aims to address this gap by investigating the thermal preferences of solar air collectors equipped with fins and baffles. By comprehensively examining the intricate interplay between heat transfer mechanisms, fluid dynamics, and design parameters, this research seeks to provide essential insights that contribute to the optimization and advancement of solar air collector technology.

Aim of Study

The primary aim of this thesis is to investigate and optimize the performance of solar air heaters equipped with fins and baffles, aiming to enhance their energy efficiency and applicability for various heating requirements.

Methodology of the Study

A standard research methodology is followed to achieve the objectives of this research. This methodology begins with an analysis bibliography which allowed us to identify the problems to be addressed in this thesis and to link them to previous work. This will make it possible to acquire a good basis in the chosen field of research.

Thesis Organization

The thesis consists of 4 chapters

First chapter is a presentation for a study of the solar deposit with some notions and astronomical definitions, commonly used in any field related to solar.

The second chapter proposal a critical review of the literature of the previous works events related to the subject.

The third chapter is devoted to the summary of laws and relationships mathematics describing the mechanisms of heat transfer in the indicated collector previously, the different equations of heat balances relating to the operation of the solar system, in the presence of baffles or not, and a numerical simulation of the phenomenon thermal.

The last chapter presents the result obtained by numerical calculation. These results are compared with those encountered in the literature.

The work is concluded with a general conclusion where the whole work is summarized

Chapter One :

Solar Energy Technology

1 .1 Introduction

In world where the demand for sustainable and renewable energy solution is ever-growing the utilisation of solar energy stands out as a beacon of promise. The sun, our planet's most abundant source of energy, radiates an immense amount of power that remains largely untapped. Solar energy holds the potential to address pressing environmental concerns, reduce carbon emissions, and provide a cleaner alternative to conventional fossil fuels.

1.2 Solar Management:

1.2.1 Radiation and Energy:

Radiation: The transfer of energy via electromagnetic waves that travel at the speed light, the velocity of light in vacuum is approximately 3 x 10^8 m/s. the time it takes light from the sun to reach the Earth is 8 minutes and 20 second. Heat transfer by electromagnetic radiation can travel though empty space. Any body above the temperature of absolute zero (-273.15o C) radiate energy to their surrounding environment.

The many different types of radiation is defined by its wavelength. The electromagnetic Radiation can vary widely. [1]

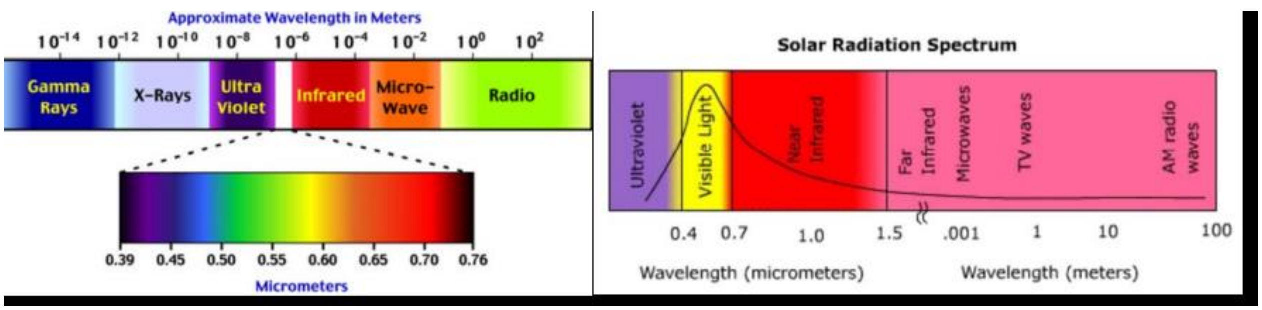

Figure 1-1: Approximate wavelength in metre [3]

Atmospheric effects: Solar radiations is absorbed, scattered and reflected by components of the atmosphere, the amount of radiation reaching the earth is less than what entered the top of the atmosphere, it classify to:

- Direct Radiation: radiation from the sun that reaches the earth without scattering
- Diffuse Radiation: radiation that scattered by the atmosphere and clouds

- Global Radiation: The global spectrum comprises the direct plus the diffused light[2]

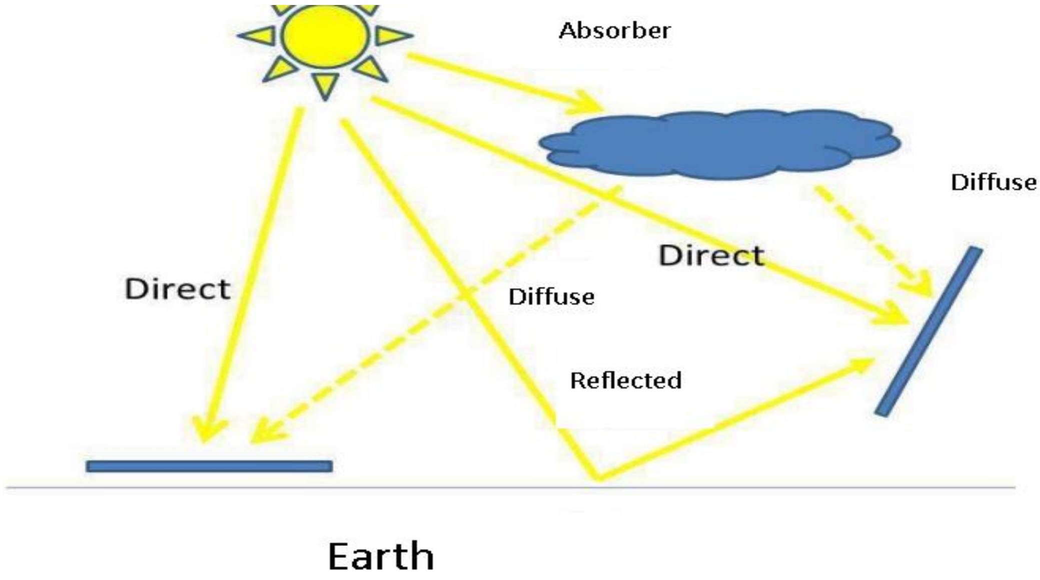

Figure 1-2 : Different types of solar radiation [2]

Air mass: represent how much atmosphere the solar radiation has to pass through before reaching the Earth's surface it equals 1.0 when the sun is directly overhead at sea level [2]

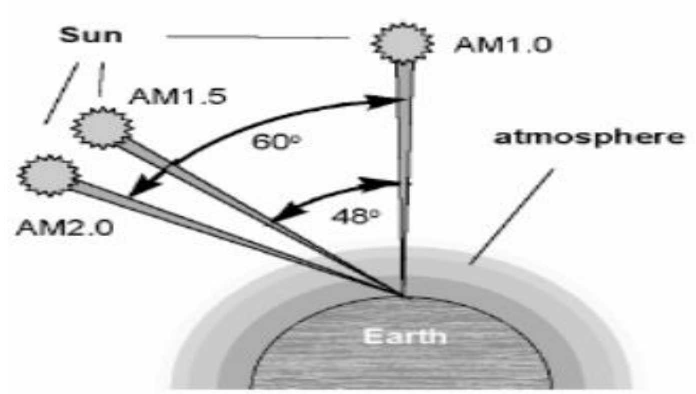

Figure 1-3 : Air mass explanation [2]

1.2.2 Sun_Earth Relationships:

The solar constant; G_{sc} is the energy from the sun ; per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation, at mean Earth_Sun distance, outside of the atmosphere. [3]

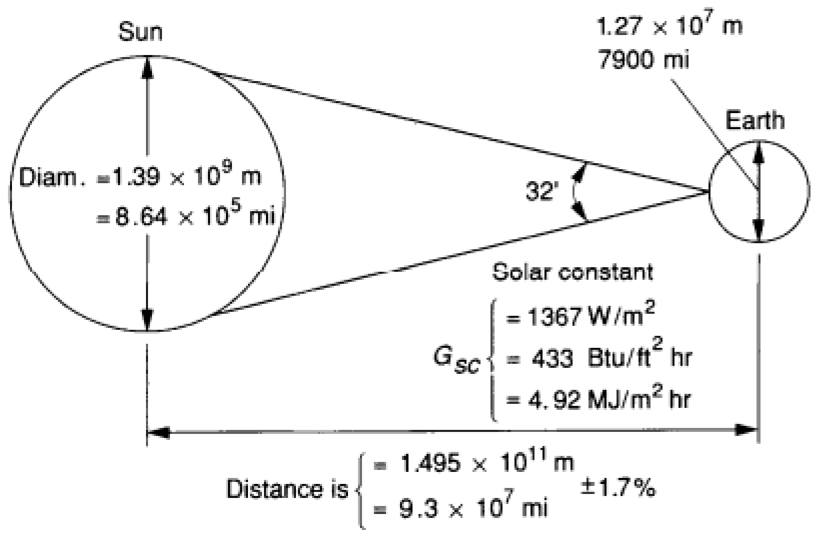

Figure 1-4: Sun_Earth distance[4]

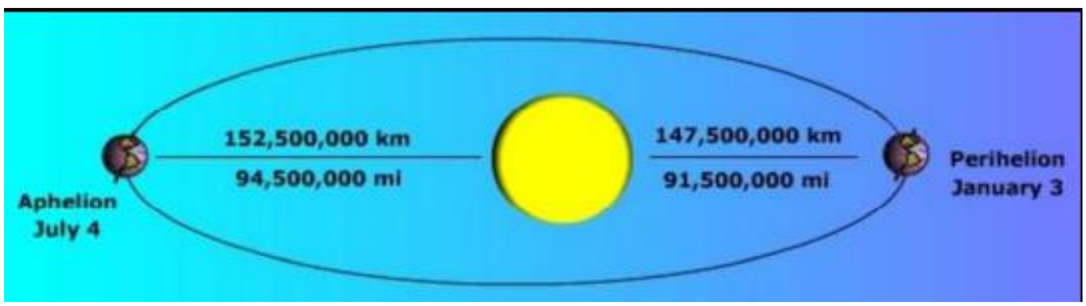

Figure 1-5: Earth's elliptic orbit [4]

The earth elliptical path causes only small variation in the amount of solar radiation reaching the earth. [4]

The Earth's axis is tilted 23.27 ° from being perpendicular to the plane of the ecliptic. The axis of rotation remains pointing in the same direction as it revolves around the Sun, pointing toward the start Polaris. The constant tilt and parallelism causes changes in the angle that a beam of light makes with respect to a point on Earth during the year, called the sun angle. [4]

The most intense incoming solar radiation occurs where the sun's rays strike the Earth at the highest angle. As the sun angle decreases, the beam of light is speared over a larger and decreases in intensity. During the summer months the Earth is inclined toward the Sun yielding high sun angles. During the winter, the Earth is oriented away from the Sun creating low sun angles. [4]

Figure 1-6: Sun's angles [4]

1.2.3 Calculation of the position of the Sun:

1.2.3.1 Position parameters:

- ✓ **Geographical coordinates:**

- Longitude (L)

It is the angle between the meridian of the place and the meridian origin of the longitudes (Greenwich in England), positive in the East and negative in the West.

There are 23 meridians separated by 15° giving rise to the 24 spindles Timetables. [5]

- Latitude (φ)

It makes it possible to locate the angular distance of any point from the equator, varying from 0° at the equator to 90° at the North Pole.

- Altitude (Z)

The altitude of a point corresponds to the vertical distance between that point and a surface of theoretical reference (mean sea level).

- ✓ **Hourly celestial coordinates:**
- Time angle (w)

The angle formed by the angular displacement of the Sun around the polar axis in the course from East to west relative to the local meridian.

The angular displacement of the Sun around the polar axis in the cycle from east to west relative to the local meridian. It is nil at solar noon, negative in the morning, and positive in the afternoon, given by [3]:

$$\omega = 15.\ (TSV-12) \tag{1}$$

ω: in degrees.

TSV: Right solar time by hours, The hourly angle of 15° is therefore the equivalent of one hour in TSV.

- Declension (δ)

The solar declination δ is the angle formed by the direction of the Sun and Earth's equatorial plane. This angle varies seasonally from -23.45° to +23.45°. It varies according to Cooper's equation [4]

$$\delta = 23.45 * \sin\ (360/365 * (J-81)) \tag{2}$$

Such as:

J: Number of the day of the year from the first of January

- ✓ Horizontal celestial coordinates:

The location of the Sun is determined by two angles which are:

- height (h)

The angular height or solar altitude refers to the angle created between the horizontal plane of the observer's location and the direction of the celestial body. This angle can be calculated using trigonometric principles.

[4]

$$\sin h = \sin \quad \sin \varphi + \cos h \cos \varphi \cos \qquad (3)$$

- Azimuth (α)

It is the angle between the meridian of the place and the vertical plane passing through the Sun counted positively towards the West [4].

It is given by the following relation:

$$\cos \alpha = (\sin h \sin \varphi - \sin \quad) / \cos h \cos \varphi \qquad (4)$$

1.2.3.2 Time parameters:

a) Universal Time (TU)

Universal Time (TU) is determined by Sun's passage time at the meridian

original or called GMT (Greenwich Meridian Time) [3].

TL = UT + offset

b) True solar time (TSV)

True solar time (TSV) is the hourly angle between the meridian plane passing through the center of the Sun and the meridian of the place considered.

Given by the expression:

$$TSV = 12 + w/15 \qquad (5)$$

$$TSV = TL + Et + 4(Lr - Ll) + D$$

With:

TL: Legal time.

D: Time lag.

Lr: Reference meridian longitude.

Ll: Longitude of the place counted positively to the west and negatively to the east And: Equation of time given by:

$$Et = 9.87 \sin 2\beta - 7.53\cos\beta - 1.5\sin\beta$$

With:

$$\beta = 360(n-81)/365 \tag{6}$$

Mean Solar Time (MST)

Mean solar time is the time that separates, on average, two successive passages of the Sun at the meridian of a place, the average solar day has a period of 1 day = 24h 00mn 00s [5].

$$TSM = TSV - ET$$

d) Sunrise and sunset

From the height h, we can deduce the sunrise and sunset times of the Sun, making h=0 [4].

Means:

$$\cos\omega s = -\tan\varphi \tan\delta \tag{7}$$

The length of the day, in hours, is given by:

$$Dj = (2/15)\operatorname{acos}(-\tan\varphi \tan\delta) \tag{8}$$

(e) Fraction of insolation

The duration of insolation is a variable that presents a non-stationary quantity, it finds its explanation in the variation of its average during the year, because of the seasonality of the process, indeed it varies from one day to another, the sunshine of a site expressed by the fraction of insolation ≪ σ" defined by the report. [6].

$$\sigma = Sh / Dj \quad (9)$$

With:

Sh: the number of sunny hours or sunstroke durations.

1.2.4 The solar field in Algeria:

Algeria boasts an extensive solar resource, ideal for a wide range of solar applications. The solar domain encompasses data that provides insights into the variation of available solar radiation over a specific timeframe. This data serves a crucial role in simulating the functionality of solar energy systems and ensuring precise sizing based on the required energy demand [6].

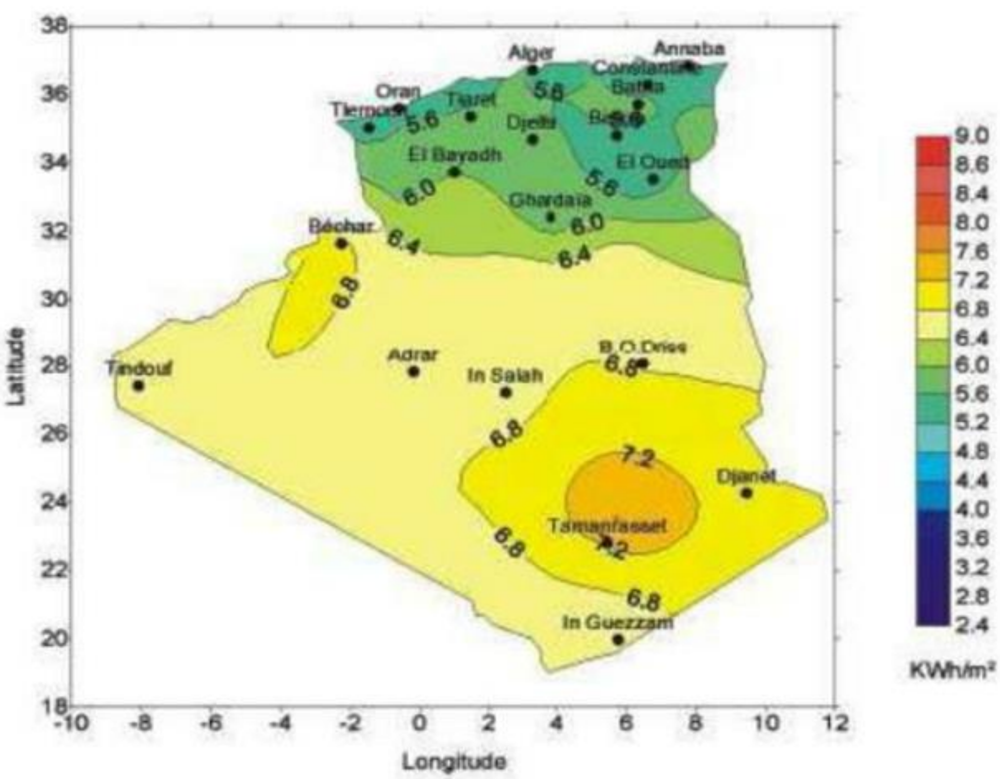

Figure 1-7: Annual average of global solar irradiation received [6].

1.3 Solar air collector:

1.3.1 History:

The utilization of metal mirrors to generate heat can be traced back to approximately 212 BC when Archimedes made this pioneering discovery. In 1615, Salomon de Gaus constructed a solar pump that relied on air heated through solar radiation.

The emergence of solar water heaters in California in 1910 marked a significant milestone in the history of renewable energy. Solar thermal technology experienced substantial growth between 1973 and 1985, largely in response to the oil crisis. However, this rapid expansion, coupled with deficiencies in technology and installation, resulted in various underperforming systems.

Towards the end of the 18^{th} century, Lavoisier developed a solar oven capable of reaching temperatures as high as 1800°C, achieved by concentrating the Sun's rays using a liquid medium.

Throughout the 19^{th} century, Augustin Mouchot contributed numerous inventions to the field, including solar pasteurization, solar distillation, solar cooking, solar pumping, and parabolic concentrators to power thermal machines.

In 1910, Franck Shuman took a monumental step by constructing a large-scale thermo-solar power plant.

As the 20^{th} century drew to a close, a range of power plants and concentrating solar furnaces were deployed following extensive prototyping efforts. [8]

1.3.2 Description of solar air collectors:

1.3.2.1 Operation principle:

The solar collector is an open thermodynamic system that converts the solar radiation it receives into thermal energy that can be used for many thermal applications. The schematic diagram of a flat solar collector is shown in Figure 1-8

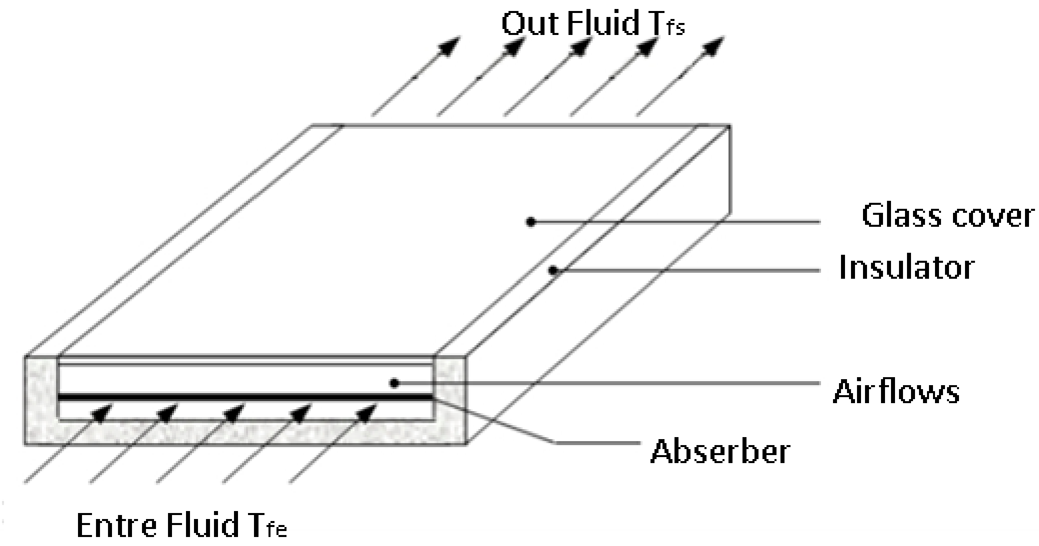

Figure 1-8: Schematic diagram of a Solar Air Collector [9]

The absorbent wall warms up because of the absorption of incoming solar radiation. The fluid flowing under this wall recovers by convection some of this absorbed energy and undergoes a temperature increase Tfs – Tfe through the collectors. [9]

1.3.2.2 Construction of Solar Air collector

Glazing

The inclusion of glazing, typically a transparent plate or cover plate, within a solar energy system is of paramount importance. Its primary function is twofold: firstly, to facilitate the entry of incident solar radiation into the device and secondly, to significantly curtail energy losses due to the re-radiation of infrared energy. To fulfill these objectives effectively, the glazing material should possess high transmissivity to the solar spectrum while concurrently exhibiting substantial opacity to long-wavelength (infrared) solar radiation. Typically, one or more sheets of transparent plate glass are employed to facilitate the efficient transfer of solar energy from the sun into the solar collector or absorber within the solar system [10].

The specific purposes of the cover plate are as follows:

1. To maximize the transmission of solar energy to the absorber plate.

2. To minimize losses from the absorber plate to the surrounding environment.

3. To provide shielding for the absorber plate, protecting it from direct exposure to weather conditions.

The selection of cover plate materials for solar applications encompasses several crucial considerations, notably strength, durability, resistance to degradation, and solar energy transmission [11]. Various glazing materials can be employed, including glass, plastic, acrylics, fiberglass, and other transparent substances, with glass being the most commonly utilized material within this context [10]. Amongst glass varieties, tempered glass stands out due to its enhanced durability and capacity to withstand thermal cycling. When choosing glass for cover plates, mechanical strength becomes a pivotal factor in safeguarding against breakage from extreme wind and snow loads. This mechanical strength is directly proportional to the square of the glass’s thickness. Therefore, cover plates for solar collectors typically need to be at least 0.33 cm thick [11].

Duct

In solar air heaters (SAHs), ducts assume a critical role in supplying fresh air and facilitating the exhaust of warm or hot air through natural and forced convection mechanisms. Importantly, the air velocity within these ducts significantly impacts the efficiency-related parameters of SAHs. Additionally, it has been observed that introducing artificial surface roughness to the ducts or absorber plates of SAHs positively influences heat transfer. This artificial geometry induces turbulence within the laminar sub-layer due to flow separation and reattachment between the repeated ribs. Consequently, heat transfer between the absorber plate and the flowing fluid in an SAH is enhanced. Furthermore, recirculation flow further augments convective heat transfer. Studies have indicated that incorporating perforations in ribs, blocks, or baffles can improve hydraulic performance [10].

Absorber Plate

The absorber plate within a solar system must possess high thermal conductivity, adequate tensile and compressive strength, and robust corrosion resistance. Copper is a preferred material due to its exceptionally high thermal conductivity and corrosion resistance. Collectors can also be constructed from materials such as aluminum, steel, galvanized iron sheets, various thermoplastics, and metal alloys. A standard fabrication procedure for an absorber plate involves utilizing a sheet of metal and insulation for the non-flow surface, contingent upon the type of SAH in question.

Solar radiation absorbed by this metal sheet would heat it and some of the heat is transferred to air. This hot air is used for practical applications. [11]

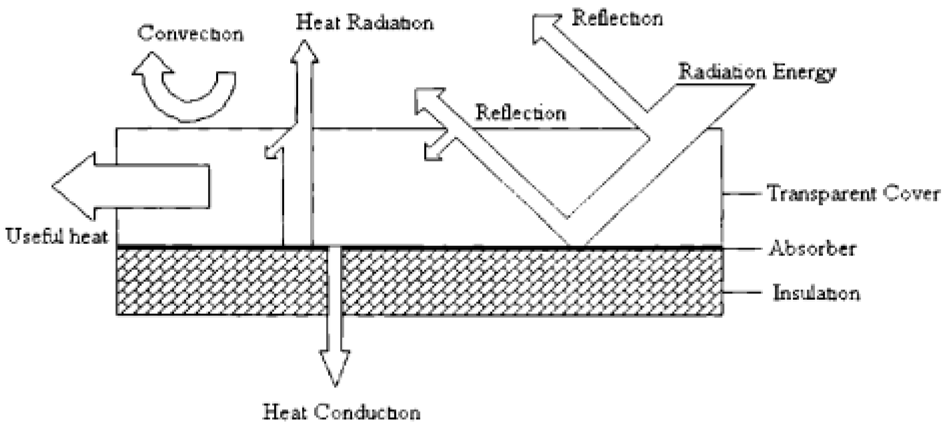

Figure 1-9Fundamentals of a flat plate solar air collector with flow over the absorber[11]

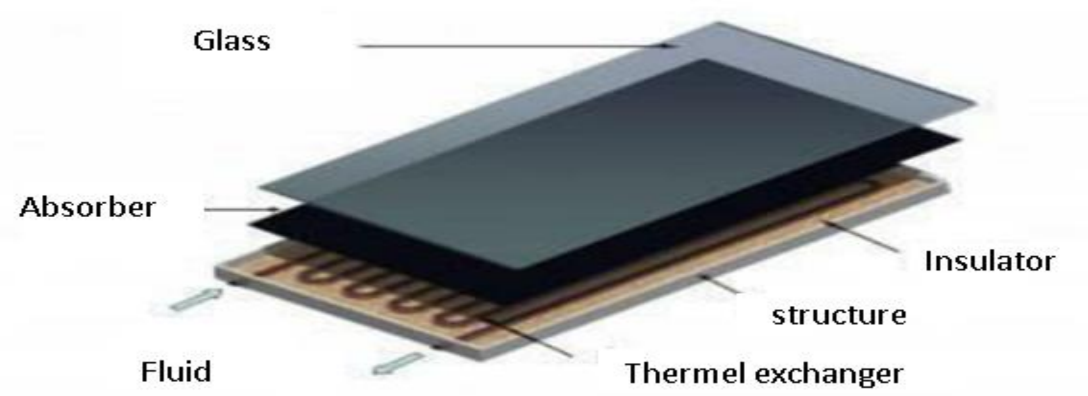

Figure 1-10: Solar collector components [11]

Insulation

Insulation serves the vital purpose of mitigating heat loss from the absorber plate, primarily stemming from conduction and convection. Typical insulating materials employed include rock wool or glass wool. The specific insulating arrangement, whether beneath or on the sides of the absorber plate, depends on the particular design employed. An essential criterion for effective insulation is its ability to withstand and resist heat transmission [10].

1.3.3 Different types of flat air solar collectors:

The types of solar collectors are very diverse even if their composition remains approximately the same

There are three main categories of flat air collectors:

1- Flat absorber collector.

2- Permeable absorber collector.

3- Variable geometry absorber collector

1.3.3.1. Planar absorber collector:

As the name suggests, the absorber is a flat sheet. The difference between these sensors lies in the number of glazings used and the type of airflow in these collectors. [12]

Several types of airflow are possible in this type of collector:

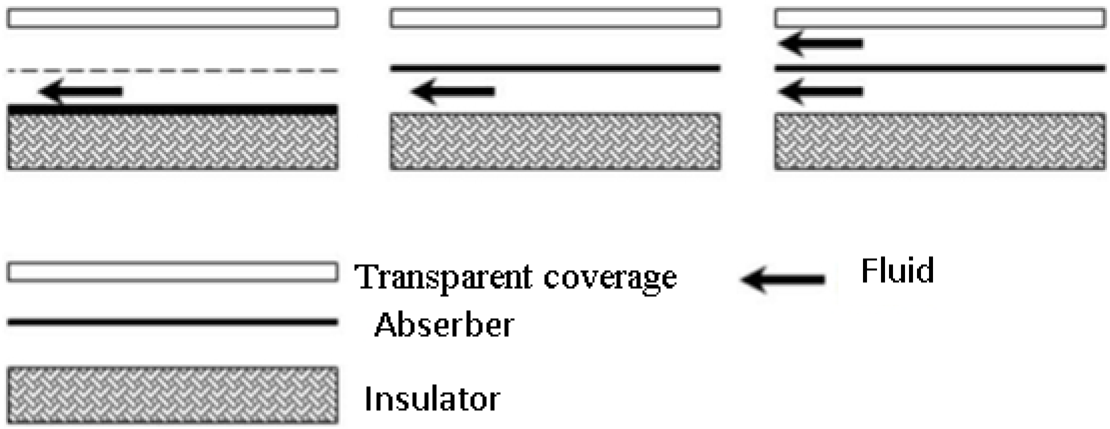

Figure 1-11: Air flows in solar collectors [12]

1.3.3.2. Permeable absorber collector:

In that type of collectors, the absorbers are a permeable matrix (see Figure 1-6). Thus the incident solar energy penetrates the mass of the absorber. The permeable absorber collector always consists of an insulated box, air enters the glass space, and absorber where it begins to heat up by convection under the glazing. Then the air continues to heat up by passing through the absorbing matrix. [12]

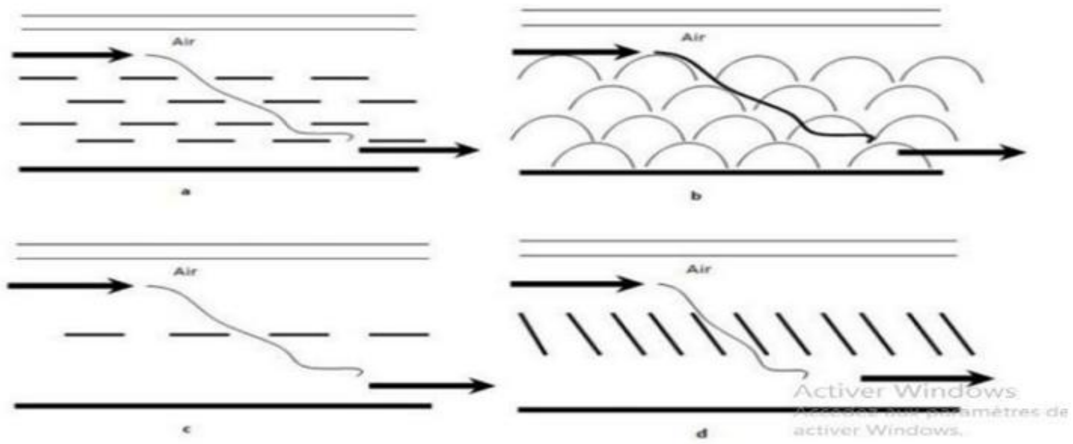

Figure 1-12: Permeable absorber Collector [12]

1.3.3.3. Variable geometry absorber collector:

These collectors come in many variants (see Figure 1-7), the idea behind these variants is to play on the geometry of the absorber, to increase the exchange surface. The most commonly used forms are:

Figure 1-13: Different types of variable geometry absorbers [12]

1.3.4 Performance exposure:

The performance of a collector is related to its solar exposure, it is its optimal orientation due south, and the absence of shade during the day. The inclination will also play according to the seasons, a collector with a low slope will be very exposed in summer when the sun will be high on the other hand will be able to adapt for winter operation [12]

1.3.5 Applications of Solar Air Heater:

It is technically feasible to use solar heated air for providing energy for almost any application that uses solar heated liquids. The important areas of application are the following.

1.3.5.1 Space Heating and Cooling of Buildings

Various types of air heaters have been conceptualized and utilized in both heating and cooling systems. Air heaters find application exclusively in buildings equipped with active heating and cooling systems. They are also integrated with desiccant beds to facilitate solar air conditioning. Furthermore, the heat generated by air heaters can be harnessed to warm the generator of an absorption air conditioner for cooling purposes [10].

1.3.5.2 Drying and Curing of Agricultural Products

Another promising domain for the utilization of solar air heaters is in the drying and curing of agricultural products. In developing countries, agriculture plays a pivotal role in the economy, making the significance of drying processes directly relevant to economic growth. A key advantage of this approach is the maintenance of hygienic conditions during the drying process, significantly reducing the risk of food contamination by dust or bacteria. The circulation of air within these systems can be achieved through the use of fans or by relying on natural convection, leading to the classification of these heaters as either active or passive dryers [10].

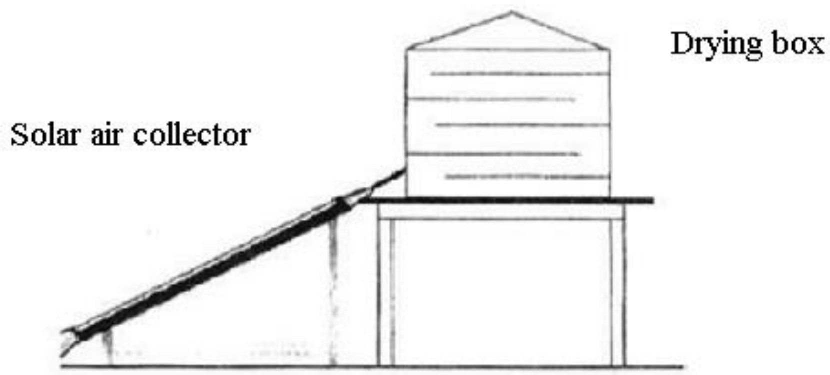

Figure 1-14: Solar drying. [10].

1.3.5.3 Industrial Applications

The adoption of solar air heaters for industrial purposes is currently experiencing a significant upswing. In the timber industry, solar air heaters are instrumental in providing the hot air required for seasoning timber. Similarly, within the plastic sector, these heaters find application in the curing of plastics. Additionally, solar air heaters are deployed for the regeneration of dehumidifying agents in various industrial settings. They are integrated into industrial processes, particularly within cogeneration systems, to fulfill diverse applications. Consequently, the use of solar air heaters within the industrial sector is rapidly gaining momentum [10].

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Chapter Two

Literature Review

2.1 Introduction

In the quest for efficient and sustainable energy solutions, solar air collectors have emerged as a focal point of research and innovation. This chapter delves into a comprehensive review of existing literature pertaining to solar air collectors, elucidating the key findings, advancements, and challenges that shape the landscape of this technology. By delving into the body of knowledge accumulated through bibliographical research, we lay the foundation for a deeper understanding of the evolution and potential of solar air collectors in harnessing the sun's energy for practical applications.

2.2 Review for previous works on solar air collectors with fins and baffles

Moummi et all [1] conducted an investigation on turbulent flow between the absorber and lower plate, aiming to reduce dead zones through the utilization of rectangle fins perpendicular to flow (Figure). Their primary objective was enhance the efficiency of air based solar collector. The experimental findings indicate that the implementation of such artificial roughness can result in a substantial increase in thermal efficiency, potentially reaching up to 80%.

Moreover, when comparing this type of collector with one lacking artificial roughness and equipped with two type of absorbers, selective and non_selective, they observed that the selectivity of the absorber did not exhibit a remarkable enhancement in thermal efficiency for solar collector equipped with rectangular baffles. However, a significant improvement was noted in the case of the smooth collector. It is worth noting that this improvement lacks practical significance since the thermal efficiency of the latter is limited to 55%, .Even high flow rates.

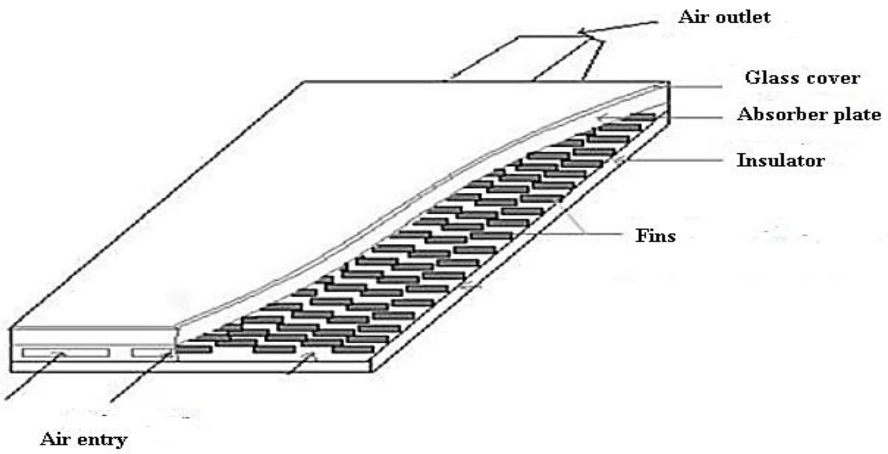

Figure 2-1 Fins rectangular plates oriented parallel [2]

Youcef_Ali et al [2] conducted an experimental study aimed at examining the enhancement of thermal efficiency in a flat solar collector equipped with rectangular fins arranged parallel to the airflow. These fins, affixed to the bottom of the absorber plate, were positioned in a staggered manner with the primary goal of generating vortices (Figure 2-2) . The authors achieved thermal efficiencies of 68 for double glazing and 78 for triple glazing at a mass flow rate of 50 kg/hm2.These efficiencies are higher when compared to flat collector without fins. Their findings indicated that the panel with triple glazing outperforms the one with double glazing due to the reduction in overall heat losses, despite a decrease in the amount of radiation transmitted to the absorber.

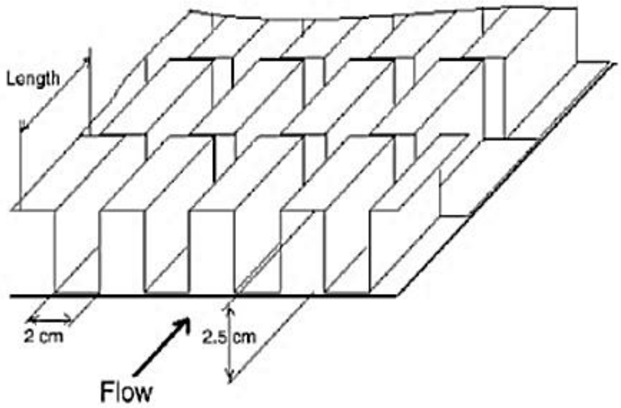

Figure 2-2 Fins rectangular plates oriented parallel to the flow and welded to the underside of the absorber[2]

A**. Ahmed-Zaïd et al** [3], present a comparison between the results obtained in the case of the solar collector with obstacles and the collector without obstacles (SC). The different forms studied, both simple and interesting, concern, as shown in Figure 2-4 and Figure 2-3 .

Figure 2-3: DCL Baffles Layout [3],

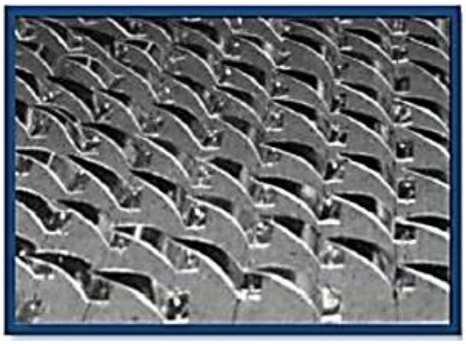

Figure 2-4 OCL Baffles Layout[3],

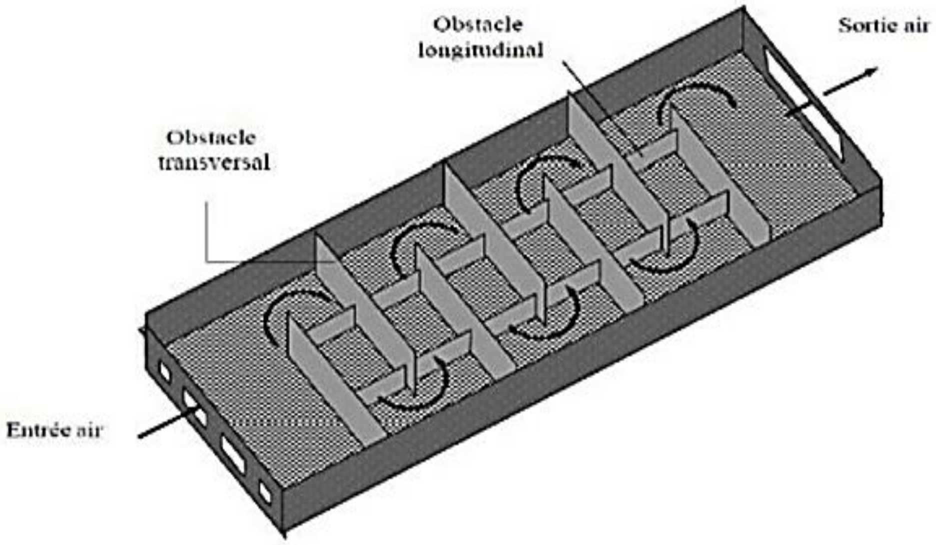

Figure 2-5: Collector with baffles TL [3],

In this study it appeared that using baffles in the dynamic vein of flat solar collector remains an effective way to improve its performances.

Labed et al. [4] conducted a theoretical and experimental study of a flat air-based solar collector equipped with a somewhat specific pattern of artificial roughness placed within the mobile air stream to induce increasingly turbulent flow between the absorber and the lower plate (Figure 2_ 6).

The fluid passes between these artificial roughness elements (baffles) in the form of channels, which are both parallelepiped and trapezoidal, facilitating good fluid distribution and reducing dead zones. They also presented results from the theoretical analysis of the collector with baffles and compared them to those obtained from a smooth-surfaced air-based solar collector without baffles. By adding trapezoidal-shaped baffles, the authors and their collaborators were able to achieve significant improvements in collector efficiency, up to 15%. This improvement is reflected in an increase in the outlet temperature and a decrease in the absorber temperature.

The study highlights the highly favorable role played by these baffles in enhancing thermal exchange due to their presence in the useful air stream. However, it should be noted that these baffles result in pressure losses compared to a smooth channel (a collector without baffles).

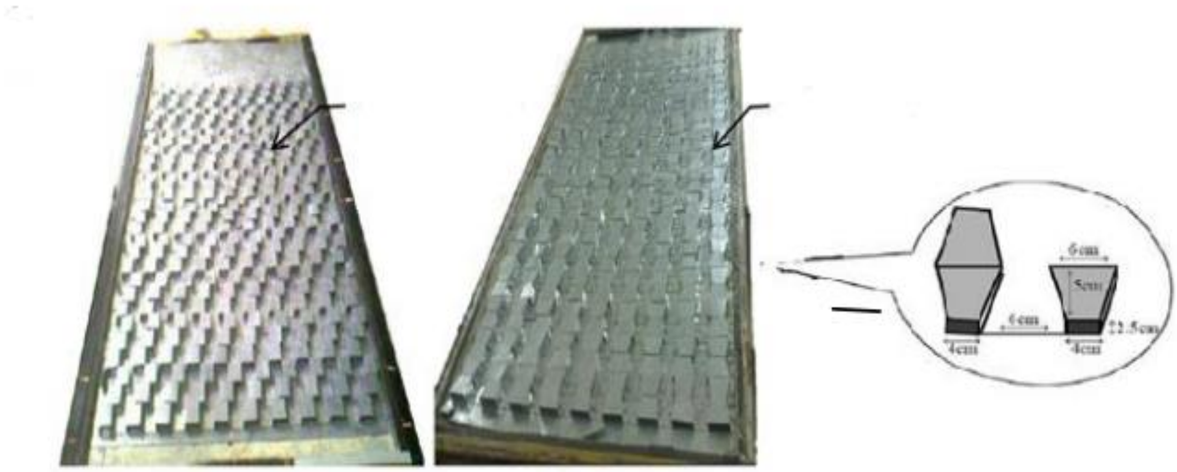

Figure 2-6: The baffles used by Labed et al[4]

Aoues et al . [5] conducted a series of experimental test on an air based solar collector with the aim of optimizing its thermal performance. The dynamic air channel of the collector, with a height of 25mm located between the absorber plate and galvanized steel plate placed on the insulation, was equipped with artificial roughness of various shapes (model 1 and model 2) and different arrangements (A and B) (Figure 2-7)

The introduction of obstacles into the path provided for the heat transfer fluid results in an increase in thermal exchange with the absorber. The authors concluded that the geometry of the passage in the cross sectional area perpendicular to the flow plays a significant role. Consequently, the comparison of the performance of the studied configurations led to the selection of configuration B1 as the one that would yield the best efficiency.

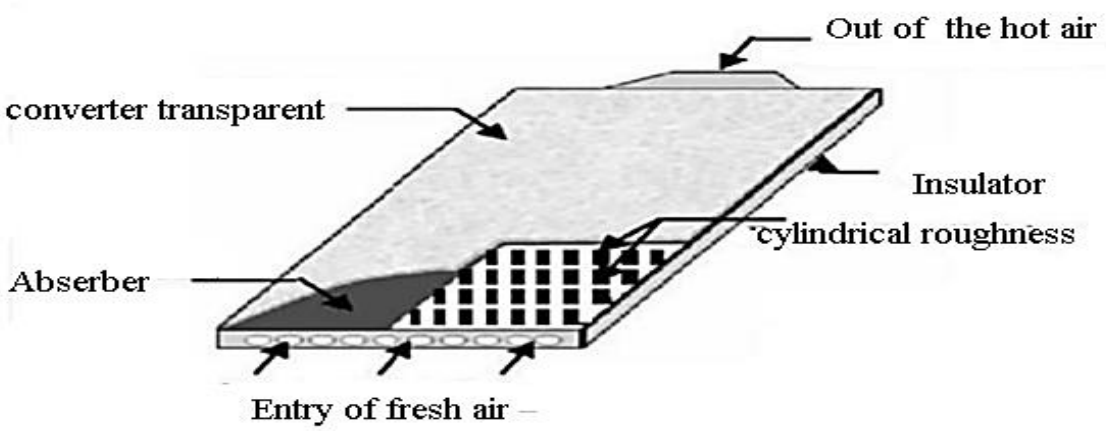

Figure 2-7: Flat air collector with cylindrical roughness[5]

Furthermore, **Aoues et al**. [5] conducted theoretical work aimed at improving the convective heat transfer coefficient between air and the absorber by placing cylindrical baffles perpendicular to the flow in the dynamic air channel between the absorber plate and the insulation (Figure 2-7). The authors studied three types of collectors: a flat air-based collector without baffles, a flat air-based collector with cylindrical baffles arranged in aligned rows, and a flat air-based solar collector with baffles arranged in a staggered pattern (Figure 2-8). The authors found that the highest efficiency was achieved with staggered arrangement of cylindrical baffles, while the lowest efficiency was observed for the smooth collector (collector without baffles

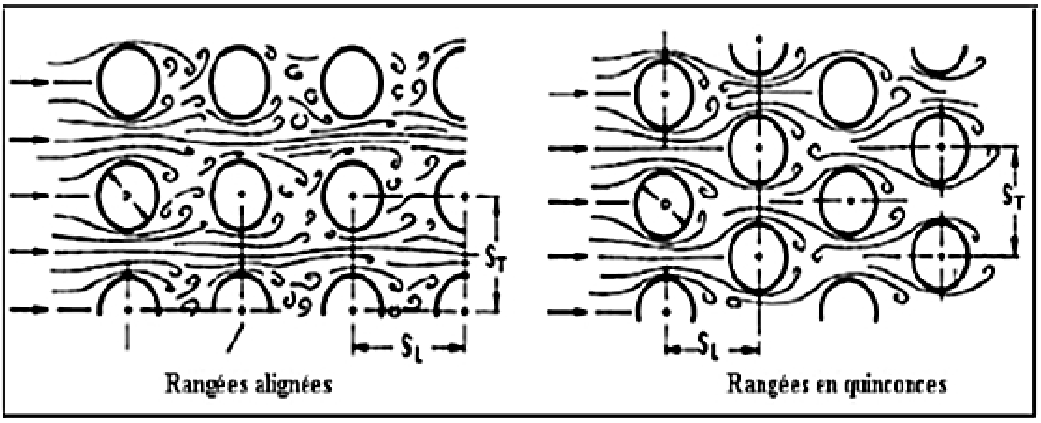

Figure 2-8: The different arrangements of cylindrical baffles. [5]

Aissaoui et al [6 This study presents a theoretical investigation into a single-pass solar air collector, examining its performance both with and without the presence of fins and baffles affixed to the absorber plate. The researchers have introduced a mathematical model that involves dividing the collector into numerous differential elements along its length. Thermal balance equations are subsequently applied to each of these elements in tandem. Utilizing a FORTRAN numerical code, the temperature profiles of various components, including the glass cover, air flow, and absorber plate, are computed.

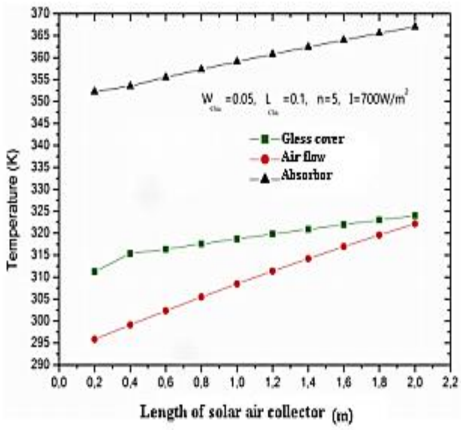

Figure3.4 Outlet temperature distribution along solar collector with fins and baffles attached

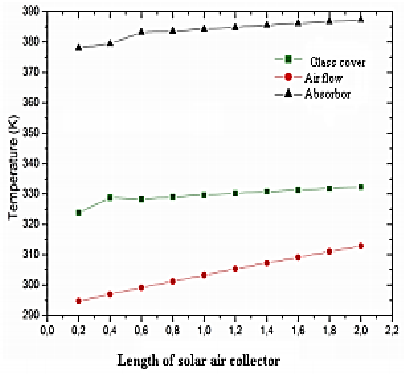

Figure3.3 Outlet temperature distribution along the solar air collector without fins attached

Figure 2-9 Outlet temperature distribution along the solar air collector with/ without fins attached [6]

Through a comprehensive energy analysis, the study reveals that the incorporation of fins and baffles, coupled with an increase in the number of fins and the density of baffles (achieved by widening baffles and reducing the spacing between them), leads to a consistent enhancement in energy efficiency, particularly as the mass flow rate is increased.

.

2.3 Conclusion:

On this chapter we present bibliographical research on solar air collectors, a clearer picture emerges of the strides taken in advancing this technology. Through a systematic exploration of past studies, it becomes evident that solar air collectors have undergone a dynamic evolution, propelled by an unyielding quest for improved energy efficiency and sustainable alternatives. While challenges persist, the collective knowledge accumulated from these studies acts as a guiding light, directing researchers and practitioners toward innovative solutions that can shape a greener and more energy-efficient future. As we move forward, armed with the insights gained from these bibliographical investigations, we are poised to carve new pathways in the realm of solar air collector technology

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Chapter Three

Mathematical model

and Numerical Simulation

3.1 Introduction

In this chapter, I will introduce the mathematical model for a solar air collector equipped with fixed fins and baffles affixed to the absorber plate. This model is constructed upon a numerical solution approach to the energy equations within each constituent component of the collector.

3.2. Insulator Modeling

The thermal balance of an insulator, related to the surface unit, is described by the following equation:

$$Ig = Q_u + Q_p + Q_s \tag{1}$$

In this equation, the terms are defined as follow : Q_u represents the total useful energy carried by the fluid coil, Q_p accounts for heat losses through various modes of heat transfer to the ambient environment, and Q_s represents the energy stored in different parts of the insulator.

In the case of steady-state collectors, the amount of energy stored Q_s In different parts of the insulator is negligible, leading to the simplified equation: **[1]**

$$I_g = Q_u + Q_p \tag{2}$$

The behavior of the sensor as modeled in a dynamic regime using nodal discretization. The modeling of the thermal behavior of the solar collector in a dynamic regime is accomplished through fictitious discretization into a specified number of time steps. The equations are derived by formulating energy balance for each node. **[1]**

3.3 The mathematical model of Solar air Heater with fins and baffles attached by the absorber plate

a. Energy balance at the Glazing level

$$S1 + hr21(T2 - T1) + h1(Tf - T1) = UL\,(T1 - Ta) \tag{3}$$

$$(h_{r21} + h_3 + U_L)\,T_1 - h_3T_f - h_{r21}T_2 = S_1 + U_LT_a \qquad \textbf{[4]}$$

b. **Energy balance at the fluid**

$mC_p dt_f = \varphi h_3 (T_2 - Tf)wdx - h_3(T_f - T_1)\ wdx$

$mCp\ (dt_f/wdx) = \varphi h_3\ (T_2 - T_3) - h_3(T_f - T_1)$ (5) **[4]**

$l_1(T_{f1} - Tf(i-1) = \varphi h_3\ (T_2 - T_3) - h_3(T_f - t_1)$

$h_3 t_1 - (\varphi h_3 + h_3 + l_1)Tfi + \varphi h_3\ T_2 = l1T_{fi-1}$

$mCp(dt_f/w\ dx) = l_1(T_{f1} -_{ft-1})$

c. **Energy balance through the absorber**

$\varphi h_3 (T_2 - T_f) + h_{r23}(T_2 - T_1) + U_h(T_2\ T_a) = S_2$

$-h_{r21}\ T_1\ (\varphi h_3 + h_{r21} + U_b)\ T_2\ \varphi h_3 T_f\ U_b T_a = S_2$ $S_2 = ra_2 I_g$ **[4]**

$-hr21\ T1 - \varphi h_3 T_f + (\varphi h_{3\,+}\ hr21 + U_b)\ T_2 = S_2 + U_b T_a$

where φ is the dimensionless coefficient defined as follows :

$\varphi = 1 + (Afin/Ap - Afin)\ \eta fin + Abaff/\ Ap - Afinb$ (6) **[4]**

$\eta ailet$:fin's efficiency is given by

$\eta fin = \tanh(mHfin)\ /mHfin$

where

$m = (\ (2h3(L + tfin)\ /Kfin^{Lt}fin\ ))^{1/2}$

$\eta baff$ is efficiency given by the blew empirical (7) **[4]**

$\eta baff = (W\ baff/\ Dh\ )^{\ 0.0518}\ (\ L\ /Lbaff)^{-0.2247}$

As note ,in no fins and baffles attached plate case the value of φ is 1.

The system of equations is expressed in matrix form for the variables

$$\begin{bmatrix} (h_{r21} + h_3 + U_L) & -h_3 & -h_{r21} \\ h_3 & -(\varphi h_3 + h_3 + \Gamma_1) & \varphi h_3 \\ -h_{r21} & -\varphi h_3 & (\varphi h_3 + h_{r21} + U_b) \end{bmatrix} \begin{bmatrix} T_1 \\ T_f \\ T_2 \end{bmatrix} = \begin{bmatrix} S_1 + U_L T_a \\ -\Gamma_1 T_{f,i-1} \\ S_2 + U_b T_a \end{bmatrix}$$

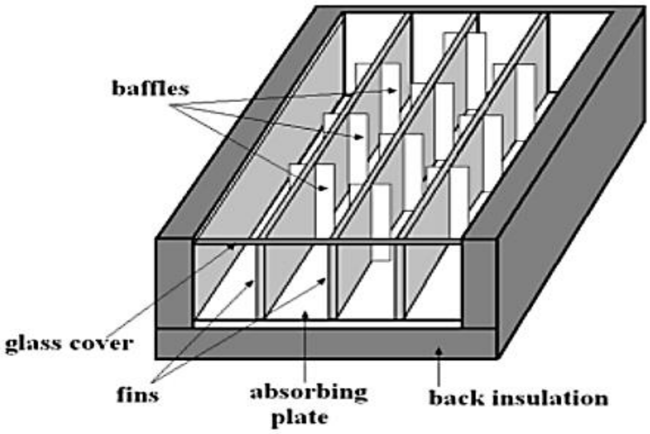

Figure 3.1 Schematic diagram of the studied model for solar air heater with fins and baffles attached cover absorber plate **[4]**

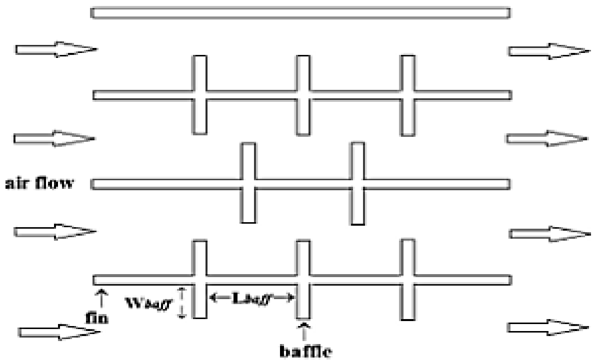

Figure 3.2 Top of view of a tasted solar air collector**[4]**

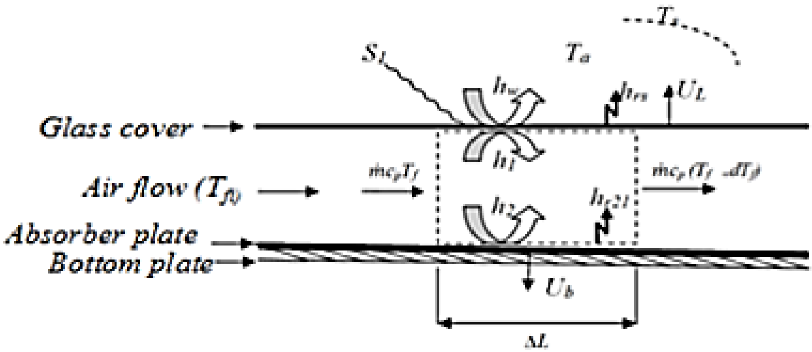

Figure 3.3 Schematic represent the heat transfer in different element of the collector **[4]**

3.4 Modeling of thermal exchange coefficients

In addition to the general assumptions mentioned for modeling collectors using the slice method, the following specific assumptions are made

- Thermal losses on the lateral walls are negligible.
- Steady_state and transmit regimes.
- Thermal conduction in the direction of flow is negligible.
- The direction of the external wind is always assumed to be parallel to the faces of the solar air collector.
- Transverse temperature gradients in the absorber are negligible.

To determine the various thermal exchange coefficients, the following relationship will be used, depending on whether it involves radiation or convection heat transfer. **[3]**

3.4.1 Radiative transfer

- Radiant heat transfer

the absorber solar radiation absorber is :

$S1 = \tau.\ \alpha 1.I$ (8) **[3]**

With :

τ= Transmissivity

I= Incident solar radiations (W/m^2 k)

$\alpha 1$= Absorptivity of the absorber plate

- Radiative transfer coefficient between the absorber plate and the sky .

  Its possible to specify the radiative transfer coefficient between the glass cover and the sky from the formula

$hrs = \sigma\varepsilon 1(T1 + Ts)(T1^2 + Ts^2)(T_1 – T_s) /(T_1 – T_a)$ (9) **[3]**

with :

hrs=Radiation heat transfer coefficient. (W/m2K)

σ =Stefan –Boltzmann constant

$\varepsilon 1$ =Emissivity of a glass cover

$T1$ = Glass temperature. (K)

Ts =Sky temperature. (K)

T_a = Ambient air temperature. (K)

The temperature of the sky is given by the formula **[2]** :

Ts = 0.0552 $Ta1{,}5$ (10)

- *Radiative transfer coefficient between the cover glass and the absorber plate*

The radiation heat transfer coefficient from the absorber plate to the glass cover is estimated as follows:

$hr_{21} = (T_{12} + T_1 + T_2) / (1/\varepsilon_2 + 1/\varepsilon_2 - 1)$ (11)

with

hr_{21} = Radiation heat transfer coefficient. (W/m^2K)

T_2 = Abserber plate teperature. (K)

ε_2 =Emissivity of absorber surface

3.4.2 Convective Transfer

- Wind's effect

To determine the external convection coefficient by using :

$hw = 5.7 + 3.8V$ (12)

hw = Wind convection heat transfer coefficient. (W/m^2K)

The coefficient of convective heat transfer between the absorber and airflow is a critical factor. To ascertain the internal convective heat transfer coefficient for rectangular channels in both laminar (Re≤2300) and turbulent (Re≥2300) flow regimes, we employ equations (13) and (14)

$Nu = h_3\, D\text{h} / k_f = 4.4 + 0.00398(0.7 R_e D_\text{h} / L)^{1.66} / 1 + 0.0114(0.7 R_e D_\text{h} / L)^{1.12}$ (13)

$Nu = hD_{h} / K_f = 0.0158\, Re^{0.8}$ (14)

$Dh = 4\, A/P = 2(W\, d - nH_{fin} t_{fi}) / (W + d) + n\, (Hfin + Hfin)$ (15)

With

Nu Nusselt number

D_h Diameter of equivalent hydraulic . (m)

k_f Air stream's thermal conductivity . (W/m K)

P Wetted perimeter. (m)

A Air flows's cross area section. (m 2)

d Spacing between absorber plate and glass cover. (m)

L Length of the collector. (m)

R_e Reynolds number

W Width collector. (m)

$Hfin$ Height of fins. (m)

Tfin Thickness of fins. (m)

3.5 Coefficient of thermal losses

3.5 .1 Toward the rear of the solar air collector

The coefficient of thermal losses over the rear of solar air collector determine as

$Ub = 1 / i = \sum^{n}{}_{1} \ X_{bi} / k_{bi} + 1/ h_w$ (16)

With

Ub Bottom heat loss coefficient. (W/m^2 K)

X_{bi} Insulation thickness (m)

k_{bi} Insulation's thermal conductivity. (W/m K)

h_w Wind convection heat transfer coefficient. (W/m^{2}K)

3.5.2 In front case :

In this case the thermal losses's coefficient determine as :

$UL = hw + hrs$ (17) **[4]**

With

UL Top heat loss coefficient. (W/m^2K)

hrs Radiation heat transfer coefficient. (W/m^2K)

h_w Wind convection heat transfer coefficient. (W/m^2K)

$dT_f\ x \approx (Tf,i - Tf,i-1\ ) /\ \Delta x$ (18) **[4]**

h1= h2.

The useful heat transferred to air can be written in terms of the mean fluid and inlet temperatures as follows :

$Q = \Gamma\ (Tf - Tf,-1)$ (19) **[4]**

$\Gamma = m\ Cp\ /(W\Delta x)$

3.6 Thermal Efficiency and useful Energy

Given that the inlet and outlet air temperatures are known, the following equation can be employed to represent the useful energy **[2]**

$Q_u = mCp\ (T_{fs}, - T_{fi})$ (20) **[4]**

Therefore; the thermal efficiency of the collector can be calculated as :

$n = Q_u /\ I_gA_p = mcp\ (T_{fs}, - T_{fi}\ ) /\ I_gA_p$ **[2]** (21) **[4]**

3.7 Calculation Program

A code in FORTRAN language allows as to determine the temperatures of the various components of the system within a spatial and temporal loop.

This facilitates obtaining the temperatures of the glazing, absorber, and insulation for single pass collectors system, with and without baffles. **[4]**

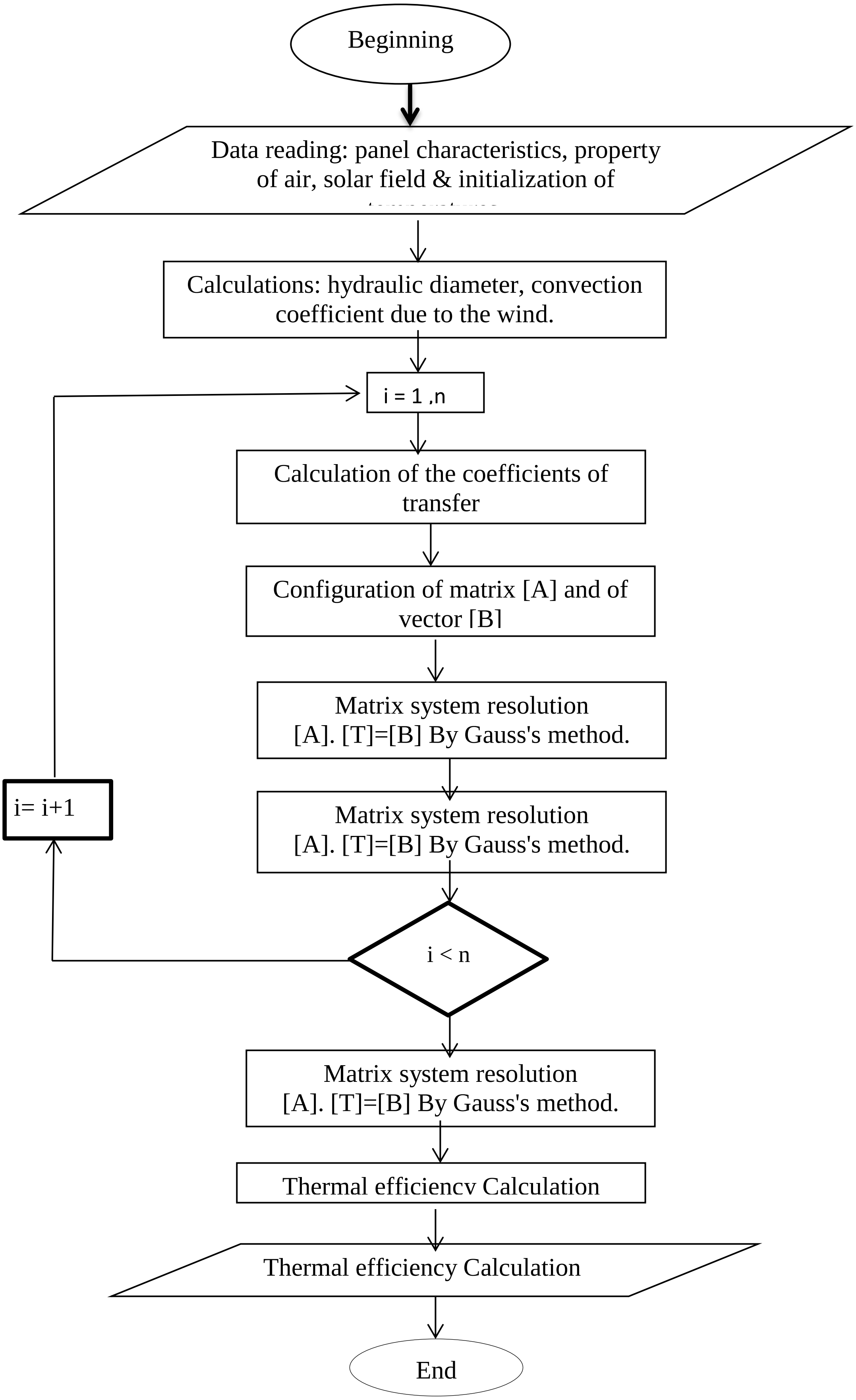

Figure 3.4 Simplified Flowchart of the main program for single pass solar collector **[4]**

3.8 Conclusion

This chapter present a thermal modeling on solar air collector, presenting a general description and equations of the heat balance, furthermore introduce a mathematical and numerical models adopted to characterize the flows and heated transfer all about solar air collector.

3.9 Bibliographic References

[1] **K. Aoues, N. Moummi, M. Zellouf, A. Labed, E. Achouri**, « Etude de l'influence desrugosités artificielles sur les performances thermiques des capteurs solaires plans à air », Revue des Energies Renouvelables, vol 11, N°2, p 219 227,(2008).

[2] **F. Mokhtari , D. Semmar, A. Hamid** « L'Influence de la Configuration de l'Absorbeur sur les Performances Thermiques d'un Capteur Solaire à Air » Centre de Développement des Energies Renouvelables, B.P. 62, Route de l'Observatoire, Bouzaréah, Alger, Algérie Rev. Energ. Ren. : Journées de Thermique (2001).

[3] **F. Mokhtari , D. Semmar, A. Hamid** « L'Influence de la Configuration de l'Absorbeur sur les Performances Thermiques d'un Capteur Solaire à Air » Centre de Développement des Energies Renouvelables, B.P. 62, Route de l'Observatoire, Bouzaréah, Alger, Algérie Rev. Energ. Ren. : Journées de Thermique (2001).

[4] **Faris AISSAOUI** « Contribution à l'étude du transfert de chaleur d'un capteur solaire placé dans un climat aride : cas de la région de Biskra. Thèse de Doctorat (2017).

Chapter Four

Data Analysis and Discussion

4.1 Introduction

In this chapter, we will present and validate the results of the models mathematics developed from the analysis of the energy balances of the different single and double pass air solar panels, without and with steady state baffles and transient with those of experimentation and literature. Additionally, we conduct a parametric study whose aim is to optimize the sizing of the solar panel air plane. At the end of this chapter, we represent the main graphical results obtained, in the form of curves and tables.

4.2 Results Validation

4.2.1 Solar air collector with fins and baffles

In this section, a comparison was made with the work conducted by Aissaoui et al . On flat-plate solar air collector equipped with fins and baffles attached to the absorber plate. Figure 4.1 illustrates the variation of efficiency as a function of mass flow rate for a fixed solar irradiance value (I=900). A high degree of agreement was observed between the results of the current study and those of Aissaoui et al. [1]

A second validation was performed using the outcomes of Aissaoui et al research for solar air collector without artificial roughness (without baffles and fins); where air flows between the absorber plate and the glass cover (Figure 4.2)

An acceptable lavel of agreement was found between the results of this study and those of Aissaoui et al[1]

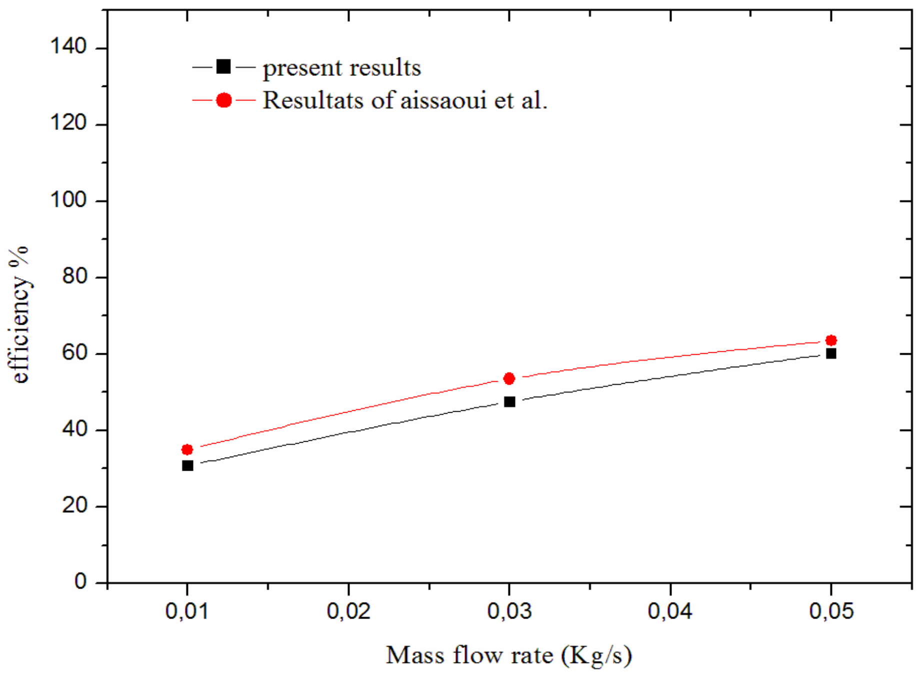

Figure 4.1 Outlet temperature as a function of function of distance along the solar air heater without fins

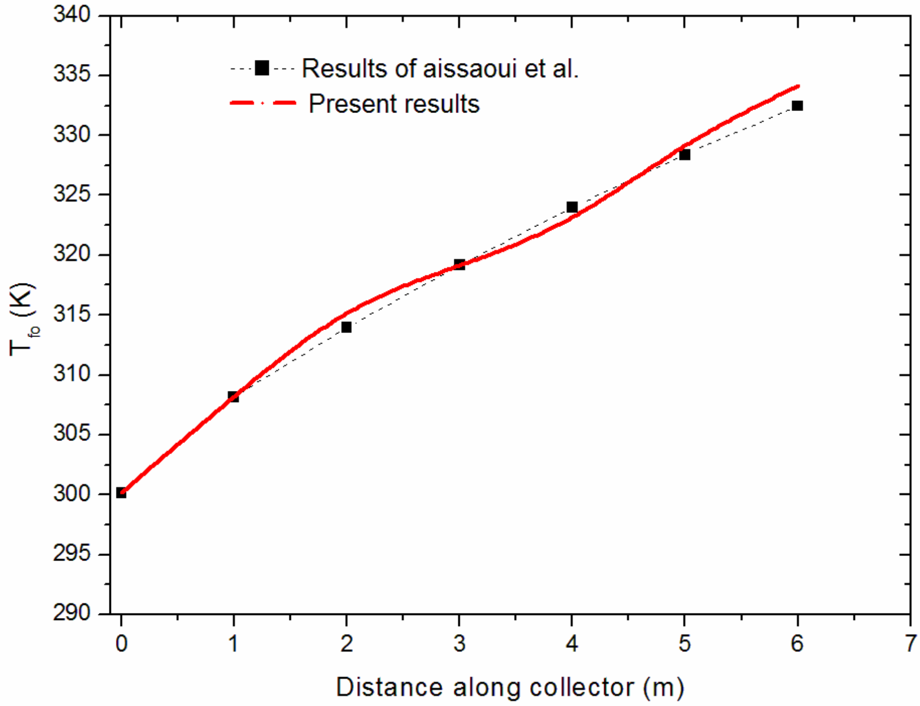

Figure 4.2 Evolution of Outlet Air Temperature and Solar Radiation Intensity over time

.Figures 4.3; 4.4 and 4.5 illustrate the variation in fluid outlet temperature concerning mass flow rate for a constant solar irradiance value (I_g=1100 w/m^2) and different parameters: baffles width (W_{baffle}), the number of fins (N_{fin}), and the pitch between baffles (L_{baffle}), respectively.

It is evident that, across all mass flow rates, the fluid's outlet temperature increases with an escalation in these parameters (W_{baffle}, N_{fin}).

Unlike Figure3.5 which demonstrate the pitch variation between baffles in comparison with result from a smooth collector. This discrepancy arises due to an enhanced heat transfer rate between the absorber plate and the heat transfer fluid. In turbulent flow conditions, geometric parameters exhibit a lesser impact on the outlet temperature.

As per Figures 4.3; 4.4 and 4.5, a subtle alteration in the profile evolution becomes noticeable within the region where the flow undergoes a transient regime (mass flow rate ranging from 0.02 kg/s to 0.03 kg/s). We attribute this shift to the utilization of dissimilar heat transfer coefficient correlations for laminar and turbulent regimes.

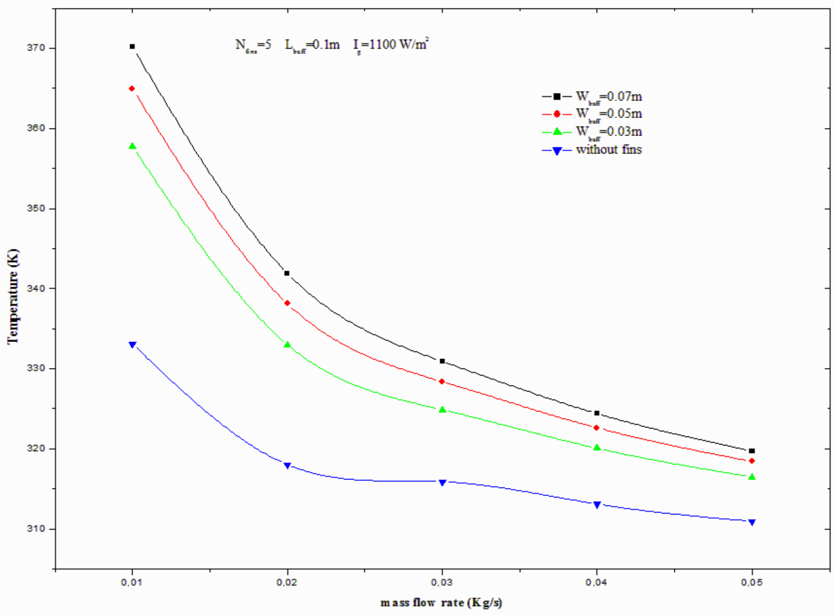

Figure 4.3 Variation of outlet air temperature as a function of mass flow rate for various widths of baffles

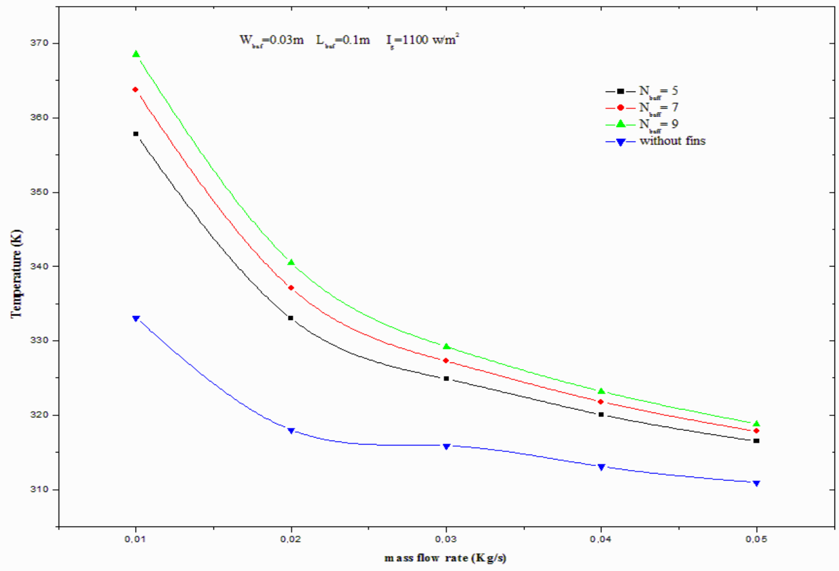

Figure 4.4 Variation of outlet air temperature as a function of mass flow rate for various numbers of fins and baffles

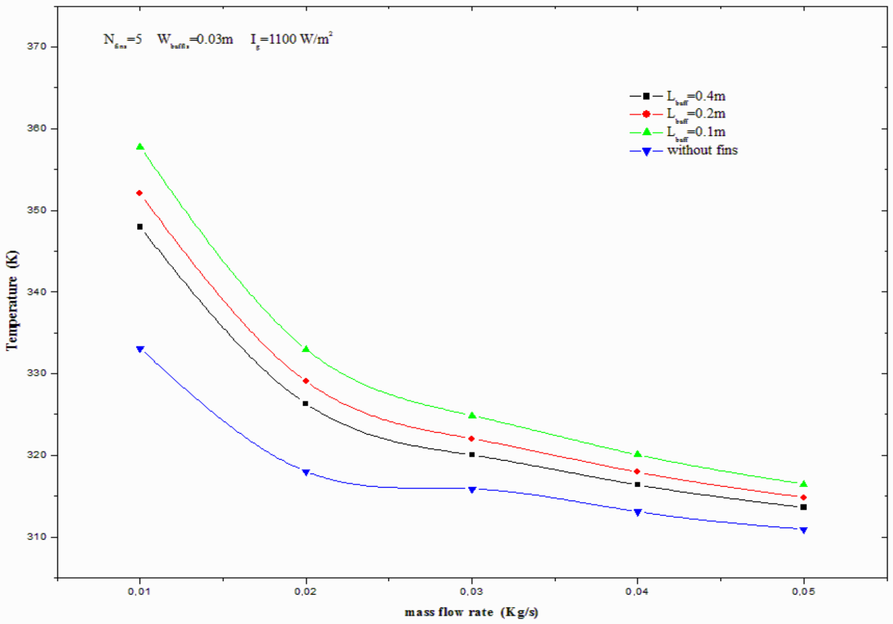

Figure 4.5 Variations of outlet air temperatures as a function of mass flow rate for various widths of baffles

To gain a clear insight into the spatial temperature variation of each component of the solar air collector, both with and without artificial roughness, Figure illustrate that the highest temperature is observed in the absorber.

This elevation in temperature is a consequence of the substantial power it absorber. In descending order; the temperature of the glass cover follows, attributed to the absorption of incident radiation on one hand and the heat dissipated by the absorber in the form of radiation and convection on the other hand. The lowest temperature is associated with the heat transfer fluid.

Furthermore, a marginal difference between the glass cover and fluid temperatures at the outlet of the solar collector with artificial roughness, on the order of 2K, is noted.

This is likely due to the convective coefficient between these element, which exhibits significant value.

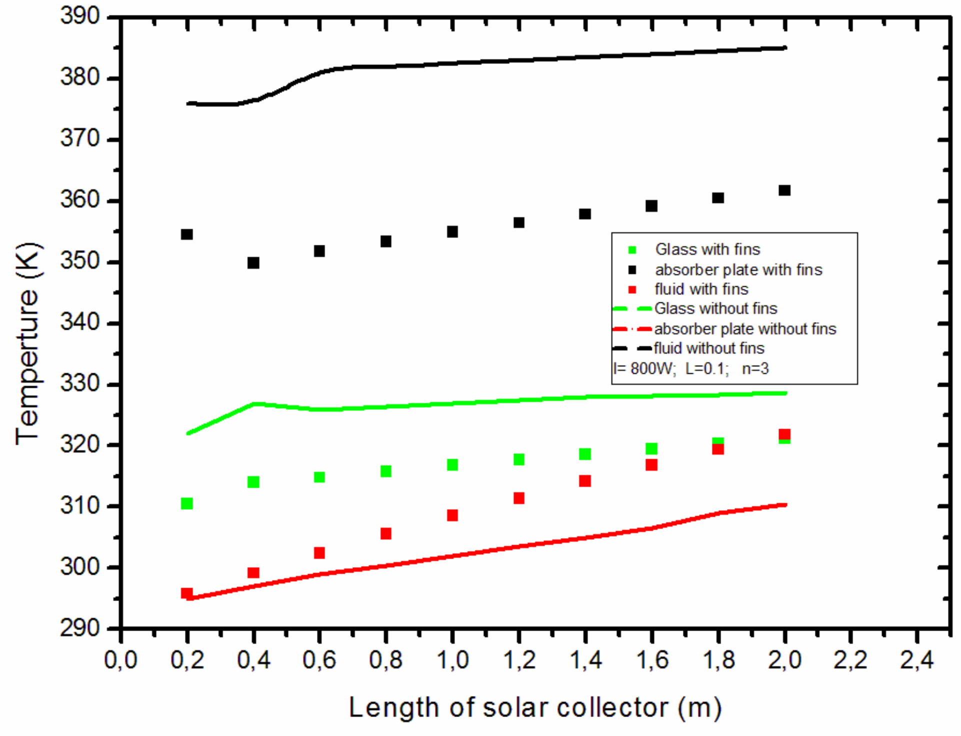

Figure 4.6 Outlet temperature distribution along the solar air collector with / without fins attached

4.3 Conclusion

This chapter present and validated the result of the mathematical models developed to analyse the energy balance of single pass solar air heater with fins and baffles. The comparison of the obtained result with experimental data and existing literature confirmed the validity and accuracy of the proposed models.

Furthermore, the parametric study conducted allowed for the optimization of the design of the solar air collector by identifying key parameters that influence its energy performance. The primary graphical results were presented in the form of curves and tables, providing a clear and concise overview of the conclusions drawn. These findings offer essential insights for the design and enhancement of solar air heaters with fins and baffles, thus contributing to the development of sustainable solar energy.

4.4. References

[1] F. AISSAOUI . H. Abdelmoumene, Abdelhafid Brima, Youcef Belloufi , Moussa Belkhir , Numerical study on thermal performance of a solar air collector with fins and baffles attached over the absorber plate, laboratories de Gene mecanique ,university of Beskra , Algeria , 2017

General Conclusion

In conclusion, this thesis has endeavored to contribute to the field of solar air collectors with a focus on systems incorporating fins and baffles. Through a comprehensive exploration of thermal preferences, heat transfer mechanisms, and mathematical modeling, several noteworthy findings and contributions have emerged.

The study commenced by establishing the theoretical framework necessary for the analysis of solar air collectors, including the formulation of key assumptions to simplify complex systems. These assumptions provided a foundation for the development of mathematical models that have been instrumental in simulating and understanding the thermal behavior of such collectors. Notably, these models consider factors such as conduction, radiation, and convection, shedding light on the intricate interplay of heat transfer mechanisms within the collector.

A critical aspect of this research involved the exploration of parameters influencing collector performance. From dimensions like collector length and duct height to environmental factors such as wind direction and fluid flow rates, each parameter was systematically investigated. This exploration culminated in valuable insights, including the revelation that longer collectors and lower duct heights can enhance thermal performance.

The development of a numerical calculation code, based on the finite difference method, represents a significant contribution of this thesis. This code facilitates the dynamic simulation of single-pass solar collectors while accommodating the specific thermophysical characteristics of their components. Rigorous validation through experimental trials further solidifies the credibility of this computational tool.

Moreover, the study's results bring to light the intricate relationship between internal and external parameters and their immediate impact on collector operation. In particular, the influence of the absorber's high absorption coefficient on its temperature relative to other components underscores the importance of this parameter in design considerations.

In essence, this thesis advances our understanding of solar air collectors with fins and baffles, providing valuable insights into their thermal preferences and performance. The mathematical models and computational tools developed here offer practical utility for engineers and researchers in the field of renewable energy. As we continue to explore sustainable energy solutions, the knowledge generated by this research contributes significantly to the broader goal of harnessing the power of the sun for a cleaner and more sustainable future.