SOLAR THERMAL DISH COLLECTOR

CAPSTONE DESIGN

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SOLAR THERMAL DISH COLLECTOR

Capstone Report

Student Statement:

I, Hamza Werzgan, sincerely state that I have applied ethics to the design process and in the selection of the final proposed design. And that, I held the safety of the public to be paramount and addressed this in the presented design wherever may be applicable.

_____________________________________________________
Hamza Werzgan

Approved by the Supervisor

_____________________________________________________
Dr. Hassane Darhmaoui
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# TABLE OF CONTENTS

ACKNOWLEDGEMENTS .................................................................................................................. ii
LIST OF FIGURES .......................................................................................................................... v
LIST OF TABLES ............................................................................................................................. vi

ABSTRACT ..................................................................................................................................... vii

1 INTRODUCTION .......................................................................................................................... 1
  1.1 Morocco’s environmental background and commitments ......................................................... 1
  1.2 Context ...................................................................................................................................... 1
  1.4 CSP Alternatives ....................................................................................................................... 2
  1.5 Concentrating Solar Power Dish .............................................................................................. 2

2 STEEPLE ANALYSIS .................................................................................................................... 3
  2.1 Societal Implications .................................................................................................................. 3
  2.2 Technological Implications ......................................................................................................... 3
  2.3 Economical Implications ............................................................................................................ 4
  2.4 Environmental Implications ....................................................................................................... 4
  2.5 Political Implications .................................................................................................................. 4
  2.6 Legal Implications ..................................................................................................................... 4
  2.7 Ethical Implications .................................................................................................................... 5

3 Concentration Solar Power Technologies .................................................................................. 7
  3.1 Parabolic Dish ............................................................................................................................ 7
  3.2 CSP Power Tower ...................................................................................................................... 8
  3.3 Parabolic Trough ......................................................................................................................... 9
  3.4 Linear Fresnel Reflector ........................................................................................................... 10
  3.5 Discussion ................................................................................................................................ 10

4 Geometry and Optical Performance of a Dish Stirling ............................................................... 13
  4.1 Geometry of the Dish Collector ................................................................................................. 13
  4.2 Sizing of the Collector/Receiver ............................................................................................... 15
  4.3 Geometrical Errors .................................................................................................................... 16

5 Modelling of the Dish Stirling Thermal Collector ....................................................................... 17
  5.1 Sun Tracking Model ................................................................................................................... 17
  5.2 Reflector Material Selection ...................................................................................................... 19
  5.3 Receiver Model .......................................................................................................................... 21
  5.4 Alpha Stirling Engine ............................................................................................................... 22
  5.5 Efficiency of the Collector/Receiver system .......................................................................... 23
LIST OF FIGURES

Figure 1. Parabolic Dish Stirling ........................................................................ 8
Figure 2. Noor III Power Plant in Ouarzazate .................................................. 9
Figure 3. Parabolic Trough Plant ....................................................................... 9
Figure 4. Linear Fresnel System ....................................................................... 10
Figure 5. A 3D illustration and a Graph of a Paraboloid of Revolution [4] .......... 13
Figure 6. Variation of the focal length with respect to the rim angle [6] .......... 14
Figure 7. Flux Density Distribution at the Receiver [5] ........................................ 16
Figure 8. Illustration of the Geometrical Errors .................................................. 17
Figure 9. The Sun's Position with Respect to Earth's Surface [7] ......................... 18
Figure 10. Illustration of Y and α ..................................................................... 19
Figure 11. Illustration of a Cavity Receiver (left) and a Modeled Geometry of the Cavity (right)................................................................................... 21
Figure 12. Working Cycle of an Alpha Stirling Engine [11] ............................... 22
Figure 13. PV and TS Diagram of a Stirling Engine [12] ..................................... 23
Figure 14. Heat Transfer at the Cavity Receiver [4] ............................................ 25
Figure 15. Variation of Conduction Losses Over Time ....................................... 33
Figure 16. Variation of Conduction Losses Over Time on a Summer Day .......... 33
Figure 17. Variation of Radiation Losses Over Time During Summer .................. 34
Figure 18. Variation of the Receiver's Thermal Efficiency on a Summer Day ........ 34
Figure 19. Electrical Power Output at the Different Times of a Summer Day ....... 35
Figure 20. Electrical Power Output at Different Times of a Fall Day .................. 36
Figure 21. Variation of Conduction Losses Over Time on a Fall Day .................. 36
Figure 22. Variation of Convection Losses Over Time on a Fall Day .................. 37
Figure 23. Variation of Radiation Losses Over Time on a Fall Day .................... 37
Figure 24. Variation of the Receiver's Thermal Efficiency Over Time on a Fall Day ........ 38
LIST OF TABLES

Table 1. Table of Potential Reflector Materials [9] ................................................................. 20
Table 2. Meteorological Data for Summer Day Simulation ................................................. 30
Table 3. Geometrical Parameters ....................................................................................... 31
Table 4. Sizing and Characteristics of the Receiver .............................................................. 32
Table 5. Thermal Losses at the Receiver from 10:00am to 4:00pm on a Summer Day ........ 32
ABSTRACT

Solar energy is the most popular renewable energy and it has been heavily utilized over the past decades mainly for electricity generation and water heating. The current technologies such as photovoltaic panels do not permit a high efficiency level as they are limited to an average efficiency of 15 to 18%. Concentrating solar power systems (CSP) are still undergoing research and testing, it is believed that they can achieve higher efficiencies between 20 and 25%. A CSP dish is a device that collects solar radiations and concentrates them at a focal point thanks to its reflecting parabolic shape. Besides optical properties, a Stirling dish comprehends of a thermodynamic aspect that consists of a Stirling engine converting thermal energy to mechanical energy which, in turn, is converted to electricity by an electric generator. In order to achieve high efficiencies, the design of such a system may be very complex as many aspects have to be optimized and many factors have to be taken into consideration.

The methodology of this work is a design attempt of a CSP Stirling dish featuring a solar tracking system to maximize the solar irradiance throughout the day. The design will comprehend many engineering stages starting by understanding all the parameters and aspects affecting the energy conversion process in general, then study each concept specifically (such as the optical efficiency of the system and the thermodynamic efficiency of the Stirling engine) by analyzing the related equations. In a dusty environment, it is important to mention the role an anti-soiling coating for the solar collector. In addition, this work will include a 3D model of the receiver created using the software SolidWorks and on which the testing will be undertaken. The thermal analysis will be conducted using fundamental equations. Finally, the results are to be simulated using Excel where the different parameters as well as weather data will be incorporated. Finally, the empirical results are summarized and interpreted.

Keywords: CSP, Concentrated Solar Power, SolidWorks, Stirling, Stirling Dish
INTRODUCTION

1.1 Morocco’s environmental background and commitments

As far as environment and sustainability are concerned, Morocco has been one of the main countries who rode the wave. Over the past decade, Morocco has given environmental reform and sustainable development a great priority. The kingdom has been ranked among the ten most conscious countries regarding climate change and the first country, in the world, which took measures to reduce CO2 emissions and developing the renewable energy sector. The COP22, held in Marrakech, was one among the many other summits during which Morocco expressed its deepest concern about preserving the planet. Energy has been a main thematic discussed during the COP22. Indeed, Morocco has committed to generate 42% of its energy needs from renewable sources by the end of 2020 and 52% by the end of 2030. Along with its commitments, the country has emphasized on its position by the implementation of new laws and regulations related to the matter (LOI-CADRE N° 99-12). Also, environmental awareness within the Moroccan society must be on the same wavelength with all these measures and reforms. However, the average Moroccan is, unfortunately, unaware environment-wise. Consequently, many initiatives were taken by Morocco as an answer to this issue. The “Mohammed VI Foundation for Environmental Protection” is one of these initiatives, actively working, to root these values within the Moroccan society.

1.2 Context

In an era where energy became the most important need for people to accomplish their daily tasks, energy sources became crucial for the development and flourishment of economies worldwide. It is important to note that 80% of worldwide electricity production is achieved through fossil fuels such as oil, gas and coal sources. The process of energy production not only pollute the environment heavily but also consumes the finite sources available on Earth. In order to satisfy the worldwide growing energy needs, renewable energies have been the main solution to this problematic. They consist of producing energy from sustainable and infinite sources such as the sun, the wind, geothermal sources and others. Solar energy is the renewable energy that has been the topic of most research conducted in the field.
As stated above, Morocco is one of the first countries to take measures as far as sustainability is concerned. Thanks to its geographical location, Morocco benefits from a relatively high solar exposure throughout the year and has the ability to implement most of solar energy technologies to produce electricity and also to limit the effects of greenhouse gases by reducing its fossil fuels’ consumption and thus its CO2 emissions.

1.4 CSP Alternatives

Renewable energy technologies are being adopted by several sectors in order to reduce their grid energy needs as more and more people are becoming environmentally aware. Besides the conventional technologies such as photovoltaic panels, wind turbines, etc., other techniques have been used to benefit the most from these clean and inexhaustible energy sources. While solar panels benefit from photons of sunlight to generate an electric potential, concentrating solar power systems benefit from the energy carried by the photons over a surface area and concentrates them at one point to increase its temperature. CSP systems comprehend parabolic trough collectors which are mainly used to heat water, tower plants which use directed mirrors to concentrate solar energy and there are also parabolic dish collectors which, thanks to their concave geometry, concentrate solar radiations at a focal point. CSP technologies generally achieve higher efficiency levels than other conventional solar energy technologies.

1.5 Concentrating Solar Power Dish

This project is about designing a CSP Stirling dish capable of delivering power to a small-scale house or to cover a part of a house’s energy needs, heating’s electricity needs for instance; however, it will depend on the results we will obtain from our testing and simulation. The device will be designed by taking into consideration the solar irradiance (taken from weather data) over a period of time (daily, weekly, monthly). The study will analyze the energy output of the device if it is to be implemented in the southern region of Morocco where solar radiation is significant, then we will compare it to the results obtained for the northern region where the yearly solar radiation is less important. CSP dishes usually feature mirrors to reflect the sunlight but other alternatives are possible such as coating the collector with a reflecting material, for example stainless steel or polished aluminum. The coating material is critical in the design process as coating materials have different reflection coefficients, therefore, the operating temperature of
the device will depend on it. The focal point of the parabolic dish is a cavity receiver containing a working gas that will be heated to start the Stirling engine. As its name indicates, the CSP Stirling dish uses an engine functioning with a Stirling thermodynamic cycle and operating at a temperature between 600 °C and 750 °C [1]. The engine converts the thermal energy to a linear mechanical motion which will be turned to a rotary motion using a crank slider mechanism and then transferred to an electric generator converting the mechanical energy to electric power. The Stirling engine and the electric generator constitute one unit known as the Power Conversion Unit (PCU).

This work will tackle the issue by exploring all the parameters influencing the efficiency of the system and deeply analyzing the energy conversion process and the related equations. Indeed, we will analyze how the geometry affects the concentration ratio, then moving to the optical properties to finish with the functioning of our Stirling engine and the electricity generation. The design will be achieved using SolidWorks and the thermal analysis will be conducted using the same software or a similar one; as for the Stirling engine we will simulate it with an Open Source software. The results will be summarized and interpreted accordingly.

2 STEEPLE ANALYSIS

2.1 Societal Implications

Energy demand has been increasing over the past decade especially in the housing sector and the industry. Conducting research on new solar technologies will help satisfy this increasing demand in energy and procure comfort to the user as one will contribute in preserving the environment. From another perspective, concentrating solar power systems can be deployed in Morocco’s rural areas as they are independent from the grid and can be employed in agriculture, for example, which is relatively demanding energy-wise.

2.2 Technological Implications

CSP technology is a branch of solar powered technologies which are mostly deployed in power plants but are not common for domestic uses as it is still undergoing research. This study will consider the possibility of powering smaller scale buildings (or building premises) and
benefitting from nowadays technologies to maximize the power delivered. This work is a part of the will of advancing renewable energy technologies. As for the techniques employed to achieve this work, SolidWorks™ by Dassault-Systèmes® will be the design support of this project and Microsoft Excel, on which the calculations are to be undertaken, will be the platform for our simulation.

2.3 Economical Implications

Investing in renewable energy technologies permits Morocco to limit its dependence vis-à-vis Europe as far as energy is concerned. Encouraging the use of such technologies in houses and smaller scale buildings will enable the users not only to be environmentally responsible but also reduce their electricity bills, reduce the global Moroccan energy demand and thus positively contribute to the flourishing to the country’s economy. For instance, implementing CSP technologies in agriculture would lower the cost of the agri-food products.

2.4 Environmental Implications

Morocco is one of the first countries to adopt environmental measures and set long term objectives to increase its green energy production. Electricity production nowadays still relies on fossil fuels combustion which is dangerous and harmful for the environment. With higher efficiencies, CSP technologies would encourage the adoption of renewable solutions over conventional grid electricity and thus help preserve the environment.

2.5 Political Implications

World’s economies depend on energy, therefore producing energy defines the level of a country’s independence. Investing on solar technologies works towards lowering Morocco’s dependence on European countries and confirm its leader position within the African continent.

2.6 Legal Implications
The Moroccan Law allows the resort to renewable energy technologies whichever the sector that might be concerned. The Moroccan Law also protects author rights and intellectual property; thus, every external information is properly cited, and authors are given credits.

2.7 Ethical Implications

This project and all its related deliverables will be achieved according to the university’s code of ethics. That said, all related works will be referenced and mentioned. This work will also reflect real data and will not, by any mean, hide unsatisfactory results.
CHAPTER 1
# 3 Concentration Solar Power Technologies

Concentrated Solar Power, commonly called CSP, systems are devices that generate solar power which is electricity obtained through converting sunlight. These systems often use mirrors, lenses or other reflecting materials to concentrate the sunlight, collected over the area of the collector, onto a much smaller area. The conversion process begins then when the concentrated sunlight is transformed to thermal energy (heat) which drives a heat engine (Stirling engine, steam turbine, etc.). Similarly, the heat engine generates mechanical energy (rotation) which is transferred to an electric power generator in order to produce electricity. However, despite the similar working principle, CSP systems can be divided to two categories which are line focus technologies and point focusing technologies. The diagram below shows some of the systems belonging to each category.

![Diagram of Concentration Solar Power Technologies](image)

## 3.1 Parabolic Dish

Parabolic dish concentrators concentrate light in a point which is called the receiver. They benefit from their geometry to achieve one of the highest efficiencies among all solar energy technologies. These systems collect the beams coming from the sun, and parallel to the axis of the parabola, and reflect them to the focal point where the thermal receiver is located. The collector must be optimally oriented towards sun and that is why most of parabolic dish collectors use a two-axis tracking system to constantly track the position of the sun in the sky. The surface of the collector is covered with reflecting mirrors or other coating materials with high reflection coefficients. This type of concentrators achieves the highest efficiencies since they do not experience much optical loss compared to other CSP technologies. The present
work will shed light on a special parabolic technology which is the Dish Stirling. They can be used either in power plants or for small-scale applications such as for off-grid electricity production for houses. The picture below is a photography of this type of parabolic dish collectors.

![Figure 1. Parabolic Dish Stirling](image_url)

3.2 CSP Power Tower

CSP Tower Powers are used exclusively in sustainable power plants as the system used in the Moroccan power plant Noor III in Ouarzazate. This concentrated solar power technology use sun-tracking mirrors called heliostats. They reflect and concentrate solar beams to a receiver at the top of the tower which is located in the center. The heat transferring fluid at the receiver can be heated up to 600 °C which produces steam that is used to a steam turbine which is similarly connected to a generator to produce electricity [1]. Research is still being conducted on one hand, regarding potential efficient heat transfer materials which will permit the achievement of greater temperatures; on the other hand, scientific research is focusing interest on energy storage materials in order to lower the losses [1]. The figure below is a picture of Noor III power plant in Ouarzazate.
3.3 Parabolic Trough

Parabolic trough systems have a parabolic collector coated with reflecting materials usually mirror-like materials. Similarly to all concentrated solar power systems, the parabolic trough reflects the incident solar beams which fall parallel to its vertex axis as shown in the figure below. Unlike point focus CSP technologies, systems relying on parabolic troughs are line focus technologies which is in this case a tube usually filled with oil or molten salt located at the focal plane of the system. The heated fluid is then carried to a steam engine to generate power. The operating temperatures for such systems can reach approximately 400 °C with an efficiency falling between 60 and 80%. The largest application of such technology is the power plant in Southern California [2].
3.4 Linear Fresnel Reflector

Linear Fresnel Reflectors are systems similar to parabolic trough systems. The reflectors are disposed an array of planar mirror-like panels. The reflectors laying on the axis of symmetry of the array are laid flat; however, the further we go from the center the more inclined are the reflectors. These panels reflect solar radiation onto a linear tube (the absorber) laying on the axis of symmetry and raised the temperature of the heat transferring fluid. A parabolic reflector is located on top of the absorber (as shown in the figure below) in order to reflect the disoriented solar beams onto the tube and thus achieve higher temperatures which vary between 200 and 500 °C at most. The heat transferring fluid is then carried to a turbine-generator system to produce electricity in power plants. Like the other CSP systems, Fresnel systems can feature heat storage or generate steam for instant grid electricity production [1].

![Figure 4. Linear Fresnel System](image)

3.5 Discussion

CSP technologies all work under a common principle which is collecting sunrays over a large area and concentrate them at a smaller area which corresponds to a circular surface for point focus CSP or over the outer surface of a cylinder for line focus CSP. The area used to welcome sunrays is called the solar collector and corresponds to a reflecting surface. The concentration point/line is called the focal point or focal line and it is where the receiver is located. The receiver features an absorber which is the medium used to carry the heat. For parabolic dish systems, the receiver comprehends, additionally to the absorber, a power conversion unit.
(PCU). Concerning the following work, it will analyze deeply a specific parabolic dish system which is the Dish Stirling and, as its name indicates, it uses a Stirling engine to convert heat to motion. The PCU of the Dish Stirling is made of a Stirling engine as well as an electric generator. The potential performance of a Dish Stirling, under Moroccan weather conditions will be discussed throughout the present work.
CHAPTER 2
4 Geometry and Optical Performance of a Dish Stirling

4.1 Geometry of the Dish Collector

Dish Stirling is a specific type of parabolic dish collectors. In order to reflect the solar radiation it uses reflecting coating materials or mirrors distributed over its aperture’s surface but most importantly it takes advantage of its parabolic shape to concentrate sunlight onto the receiver. The parabolic solar collector of this device is a paraboloid of revolution which is the shape obtained from revolving a parabola around its axis of symmetry [3]. The paraboloid of revolution, and thus the solar collector we are interested in, has a first important parameter which is the focal length. The focal length $f$ defines the distance at which the focal point will be located with respect to the vertex $V$ of the parabola. This vertex shows the deepest point of the paraboloid. In spatial geometry, the paraboloid of revolution is parameterized as follows,

$$ x^2 + y^2 = 4fz $$

Figure 5. A 3D illustration and a Graph of a Paraboloid of Revolution [4]

The depth and the outer diameter of the paraboloid are other geometric parameters that should be taken into consideration. The depth $h$ refers to the distance from the center of its aperture to the vertex $V$. On the other hand, the diameter $D$ is the diameter of the paraboloid’s aperture which is the circular surface of its upper base. These parameters are critical to defining the shape of the solar collector and thus to determining the position of its focal point $F$. If we take the two-dimensional plane $yz$, the equation of the parabola will simply be $y^2 = 4fz$. As $D$ is
directed along the $y$ axis and the plane of interest is the $yz$ plane, the $y$ parameter is simply the radius of the aperture $R$. Therefore, as $h$ is directed along the $z$ axis, the equation becomes as follows, $R^2 = 4fh$ which is equivalent to $\frac{D^2}{4} = 4fh$. Then, $f$ can be expressed as a function of parameters $h$ and $D$ as shown in equation (2).

$$f = \frac{D^2}{16h}$$

When designing a parabolic solar collector, the rim angle $\psi$ is the most important parameters as it gathers all the dimensions of the collector and thus defines its focal length. The rim angle refers to the angle made by the line, drawn from the edge of the rim to the focal point $F$, and the $z$ axis. $\psi$ is defined by equation (3).

$$\tan \psi = \frac{1}{\left(\frac{D}{8h}\right) - \left(\frac{2h}{D}\right)}$$

![Figure 6. Variation of the focal length with respect to the rim angle [6]](image)

The rim angle is the metric that defines how curved or flat is the parabolic dish collector. Consequently, a collector with a relatively great rim angle is relatively curved and one with a relatively small one is relatively flat [3].

Since, the upper base of the paraboloid is a circular surface, the aperture’s area is defined by the area of a circle. The area can also be expressed as a function of the rim angle and it is given by the following equation.
\[ A_a = 4\pi f^2 \frac{\sin^2 \psi}{(1 + \cos \psi)^2} \]

4.2 Sizing of the Collector/Receiver

The most common utilized types of receivers are cavity receivers and they are placed at the focal point; thus the concentration of sunrays will occur at its basis. The optical performance of the system is tightly related to the size of the receiver. The concentration ratio is another critical design parameter which refers to the ratio of the aperture’s area of the dish to the absorber/receiver’s area. For Dish Stirling systems, the concentration ratio can reach great values since the application of such systems require a great collector’s area. The geometric concentration ratio \( C_g \) is given by the equation below where \( A_{dish} \) and \( A_{rec} \) are respectively the area of the concentrator’s aperture and the area of the receiver’s basis.

\[ C_g = \frac{A_{dish}}{A_{rec}} \]

The geometric concentration ratio is only an approximation of the projected area of the collector on the aperture area of the receiver. In fact, the geometric concentration ratio does not take into consideration the deflected sunrays due to slope errors or the reflector material’s or mirror’s imperfections. This metric infers one main assumption which is that all the sunrays are uniformly distributed over the receiver’s aperture. From an optical perspective, we assume that the receiver’s aperture is exactly the same size as the sun’s image produced by the collector’s reflection. It is important to introduce the optical concentration ratio which is the exact measurement of the concentration ratio and it corresponds to the ratio of the radiant flux density at the receiver \( I_r \) (intensity at the receiver) to the direct normal irradiance \( DNI \). The optical concentration ratio is given by the following formula. The dimensions are given in Watts per meter square \( (W. m^{-2}) \) while \( C \) is dimensionless.

\[ C = \frac{I_r}{DNI} \]
The receiver aperture lays on the focal plane of the parabolic collector; however, the intensity is not uniformly distributed over it as seen in Figure 6. The graph shows the results obtained from experiments conducted on an experimental parabolic solar collector at $800 \text{W}.\text{m}^{-2}$ which is the average $DNI$ on a summer day. The graph shows the distribution of the flux density of the receiver’s aperture which is obviously not uniform but it becomes greater as we come close to the inner part of the aperture to reach its peak at the center [5].

### 4.3 Geometrical Errors

The optical efficiency is closely related to the whole system’s efficiency and it determines the energy input at the level of the receiver. The geometry described above defines the ideal shape of a parabolic solar collector; however, in reality, many factors have to be taken into consideration in the design process.

1. The slope error is angular deviation of the mirrors/reflecting material with respect to the ideal shape of the paraboloid which is caused during the production of the mirrors due to tolerances in the industry. This error can also be caused by the small deformations because of the mirrors’ weight or caused by the stress generated by the bearing structure. The slope error can be measured at the level of any point on the collector using methods such as deflectometry [5]. Thus, an average slope error can be calculated to evaluate the geometrical quality of the mirror.
2. Many of Dish Stirling applications feature a multi-facet reflecting surface using multiple mirror facets. In this case, the inexact mounting of the mirrors may cause geometrical errors as the light reflected can miss partially or completely the receiver’s aperture [5].

3. In order to consider the incoming sunrays as a direct normal irradiance (\(DNI\)), the device must include a two-axis tracking system which permits to keep the sun on its optical axis. As no tracking system is perfect, this may imply positioning and tracking disorientations and lead to geometrical errors. This type of errors occurs when the optical axis, along which the focal point is located, is not aligned with the sun [5].

![Figure 8. Illustration of the Geometrical Errors](image)

5 Modelling of the Dish Stirling Thermal Collector

5.1 Sun Tracking Model

As stated earlier, a parabolic dish collector or any point focus collector must feature a dual axis tracking system so that the aperture is constantly oriented towards the sun in order to keep the direct normal radiation, in other words sunrays, parallel to the optical axis of the collector where the focal point lays. The sun moves in the sky following a defined path characterized by two main angles which are the zenith angle (or the altitude angle) and the azimuth angle. The parameters of the sun’s path are illustrated below.
Altitude-Azimuth tracking is a two-axis tracking system as it follows the sun’s position with respect to a horizontal axis (azimuth) and with respect to a vertical axis (Altitude/Zenith). In order to define the governing equations of the sun-tracking system, some important parameters shall be introduced. The hour angle $\omega$ is the expression of time in angular measurements. It is expressed as the angle with respect to solar noon (12:00 AM) where the sun is at the highest altitude. It assumes that the sun moves 15° per hour ($360^\circ$/24h). The hour angle is 0.00° at 12:00 AM. Therefore, the angle sign is negative before noon and positive after noon. For example, at 9:30 AM, the hour angle will be equal to $-37.5^\circ$ (2.5 hours before noon times 15° per hour).

Then $\omega$ can be expressed by the following equation where $\Delta t$ refers to the local time minus 12.

$$\omega(t) = 15^\circ(t - 12) = 15^\circ \Delta t$$

The declination angle $\delta$ is the second parameter to be introduced and it refers to the sun’s angular position with respect to the equatorial plane and it is calculated by the following equation where $DoY$ indicates the day of the year as on the 1st of January, $DoY = 1$, and on the 31st of December, $DoY = 365$ [5].

$$\delta(DoY) = 23.45^\circ \sin \left(360^\circ \frac{284 + DoY}{365}\right)$$

The outputs of this tracking model would be the altitude angle $\alpha$ which is the angular position with respect to a vertical axis and the azimuth angle and it is equal to 0° when the sun is at the extreme west and 180° when it is at the extreme east. $\gamma$ is the azimuth angle which is the angular position with respect to a horizontal axis and it is equal to 0° at the extreme south and 180° at the extreme north. These parameters correspond exactly to the solar altitude angle and the solar
azimuth angle respectively. These coordinates are given by the following relation where $\Phi$ is the local latitude of the site where the device is to be implemented [5].

\[
\alpha(t) = \sin^{-1}\left(\sin \Phi \cdot \sin \delta(DoY) + \cos \Phi \cdot \cos \delta(DoY) \cdot \cos \omega(t)\right)
\]

\[
Y(t) = +/- \cos^{-1}\left(\frac{\sin \alpha(t) \cdot \sin \Phi - \sin \delta(DoY)}{\cos \alpha(t) \cdot \cos \Phi}\right)
\]

The sign of $Y$ is positive when $\omega(t) > 0$ and it is negative when $\omega(t) < 0$. The altitude angle and the azimuth angle are shown in the illustration below.

5.2 Reflector Material Selection

The selection of the material to be used to reflect the incoming solar radiation is a critical design criterion. It affects heavily the amount of solar radiation transmitted to the receiver. The surface of the collector must be highly reflective in order to minimize the energy absorbed by the reflector material and reflect most of the incident solar radiation to the focal plane. The usually used mirror materials have a great reflection property. In fact, the typical values of the reflectivity for such materials range from 0.7 to 0.95. Besides mirror materials, the surface may
be in the form of a polished metal such as aluminum or stainless steel. The most used material is silver coated glass. The material must also resist climatic conditions to ensure its long-lasting operating life. If the device is to be implemented in the south of Morocco, sandstorms may be a stress factor as dust will be left on the surface and will require a costly maintenance and the use of high volumes of water [8]. One of the promising and not expensive anti-soiling coating materials for CSP mirrors is titanium dioxide for its hydrophobic properties as it would not leave water droplets in the surface when the surface is being cleaned. It also contributes to the decomposition of dust particles thanks to its oxygen reactive radical anion [8]. Some of the reflector materials are proposed in the table below along with their reflectivity and emissivity.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Reflective (%)</th>
<th>Emissive (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymeric film, non metal</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>Aluminum, acrylic</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>Silver, aluminum acrylic</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>Silver, acrylic</td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>Aluminum</td>
<td>86</td>
<td>14</td>
</tr>
<tr>
<td>Aluminum, polyethylene</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>Plexiglas with mirror</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>Thermoplastic, silver, gold, brass, etc.</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Aluminum mylar</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>Polymer, copper, silvered, alumina</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>Polished stainless</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Ceramic metallic coating layer</td>
<td>95</td>
<td>5</td>
</tr>
<tr>
<td>Glass/silver 4 mm</td>
<td>93.8</td>
<td>6.2</td>
</tr>
<tr>
<td>Glass/silver 2 mm</td>
<td>94</td>
<td>6</td>
</tr>
<tr>
<td>Glass/silver 1 mm</td>
<td>94.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Miro 2–95</td>
<td>88.6</td>
<td>11.4</td>
</tr>
<tr>
<td>Miro 3–95</td>
<td>91.1</td>
<td>8.9</td>
</tr>
<tr>
<td>Anod aluminum</td>
<td>86.8</td>
<td>13.2</td>
</tr>
<tr>
<td>1000,90</td>
<td>89.8</td>
<td>10.2</td>
</tr>
<tr>
<td>ECP305+/aluminum</td>
<td>95.6</td>
<td>4.4</td>
</tr>
<tr>
<td>ECP305+/glass</td>
<td>96.1</td>
<td>3.9</td>
</tr>
<tr>
<td>Sunflex (polymer/aluminum)</td>
<td>86.9</td>
<td>10.1</td>
</tr>
<tr>
<td>SA 85/glass</td>
<td>88.1</td>
<td>11.9</td>
</tr>
<tr>
<td>SA 85/steel</td>
<td>88.2</td>
<td>11.8</td>
</tr>
<tr>
<td>Sol-gel coated silver</td>
<td>95.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Sol-gel coated aluminum</td>
<td>91</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1. Table of Potential Reflector Materials [9]

For this application, the preferred reflector material is the glass silver coated material Glass/Silver 2mm with a reflectivity of $\rho = 0.94$ (94%) as shown in the table. The anti-soiling coating for the reflector is titanium dioxide for its attracting properties.
5.3 Receiver Model

The receiver of Dish Stirling system is the connecting part between the parabolic solar concentrator and the heat engine used to produce mechanical work. This interface serves to absorb a large amount of the energy reflected by the collector. It also permits the heat transfer to the working fluid in the heat engine which is in this case a Stirling engine. The selection of the receiver comprehends different criteria which are most importantly good absorption rates of energy but also high heat transfer properties. In the design of solar dish systems, two main types of receivers’ geometry are considered and they are external receivers and cavity receivers. The advantage of cavities is that it reduces thermal losses and thus maximize the heat transferred to the working fluid. Indeed, a major part of the emitted radiation by the cavity remains inside it to be absorbed again by the heat engine. Also, convective heat losses are also limited in a cavity receiver compared to an external receiver which would be exposed to the outer environment. It is also important to note that, as stated earlier, the aperture of the receiver is located on the focal plane of the concentrator while the absorber is located behind it. Moreover, as seen in the figure below, the absorber size may be larger than the aperture’s size of the receiver; thus, the incoming radiation spreads inside the cavity before meeting the absorber which prevents the materials used to be thermally overstressed. The thermal losses experienced by the receiver will be discussed in the next section where a thermal model is proposed for our simulation.

![Figure 11. Illustration of a Cavity Receiver (left) and a Modeled Geometry of the Cavity (right)](image-url)
Thanks to these satisfying properties, cavity receivers are used for high-temperatures applications realized Dish Stirling systems, up to now, have been relying only on this kind of cavity geometry. Consequently, in the present work, we will be considering a cavity receiver which has a conical shape as seen on the SolidWorks modeled receiver in Figure 11.

5.4 Alpha Stirling Engine

The Stirling engine is a type of heat engines which takes advantage from the ability of gases to expand when heated and contract when they are cooled. In the engine, the gas is enclosed in fixed volume cylinders; therefore, its pressure will increase when it is heated and cooled down to decrease its temperature. The pistons of the cylinders are moved out when the pressure of the gas is high and they are moved in when the pressure is low. The movement of the cylinders causes a crank-shaft to rotate and produce mechanical work. The most used engine for solar energy applications is the Alpha Stirling Engine. It consists of a two-cylinder engine with a hot and a cold cylinder. The working principle is obviously similar to any other Stirling engine. The working fluid, which is in this case hydrogen for its high performance according to literature [10], is heated and expand in the cylinder which forces the hot piston to move downward and cause the fluid to move to the cold cylinder where it continues to expand extracting then more energy from it. The momentum of the crankshaft forces the hot piston to the top and extracting the fluid from the cold cylinder where its pressure drops because of the cooling [11]. The regenerator is not used in all Stirling engines but serves to improve the efficiency of the engine. It is located at the level of the air passage between the two cylinders. Its main purpose is to extract the heat from the hot cylinder when the working gas is flowing towards the cold one; therefore, the heat is being used again in the heating process. The cycle is shown in the figure below.

![Working Cycle of an Alpha Stirling Engine](image)

*Figure 12. Working Cycle of an Alpha Stirling Engine [11]*
For the application of the present Dish Stirling system, we will use an Alpha Stirling Engine with Hydrogen as a working gas. The capacity of our Stirling engine is designed to be 10-kW. It is important to mention that the capacity of our engine is subject to change depending on the results of our simulation and the maximum power output under different weather condition. The thermal efficiency of Alpha Stirling engine used for solar energy applications range from 65 to 75%. Therefore, we assume a nominal operating efficiency of $\eta_{st} = 0.70$ for our simulation which corresponds to the mean value of the given range.

5.5 Efficiency of the Collector/Receiver system

5.5.1 Optical Efficiency of the Concentrator

The optical efficiency of the concentrator is denoted as $\eta_O$, it evaluates how much radiation the collector is able to reflect towards the receiver. This parameter depends highly on the reflector’s materials, the geometry proposed for the design but it also depends on the industry tolerances when producing the reflecting surface which may cause imperfections. The optical efficiency is obtained through analyzing the combination of the different losses at the level of the collector [4].

The system is subject to shading loss which occurs due to the receiver and the Stirling Engine which block the sun from radiating on a little area over the concentrator. It is computed as the percentage of the receiver’s aperture over the dish’s aperture. The efficiency due to shading loss is therefore calculated as $\Upsilon = 1 - \frac{A_r}{A_a}$.
Reflectivity loss is another loss experienced by the concentrator, it refers to the radiation lost due to the emissivity of the concentrator. It depends on the reflectivity of the reflector material. The efficiency in this case is simply the reflectivity of our material which is \( \rho = 0.94 \).

At the level of the dish concentrator, a transmission/absorption loss may occur. A portion of the energy reflected by the dish’s surface is reflected in the air when it is reflected by the receiver’s surface. This loss is evaluated to be between 2-4\% [4]. In this study, we are not considering a transparent interface at the receiver’s opening so the receiver can be considered as a black body with null transmittance; thus, we are not including the transmittance loss in this analysis of optical losses but we will discuss it while developing the thermal model of the receiver. The efficiency of the system with regard to the transmission/absorption loss is \( \varepsilon = 1 - (2 - 4\%) \), we will take the average loss value 3\% and set \( \varepsilon = 0.97 \) (97\%).

The spillage loss shall be considered as well and it corresponds to the reflected radiation that miss the receiver’s entrance. It is estimated to be 1-3\% [4], therefore we take the efficiency considering this loss to be 2\% and we set \( \varepsilon = 0.98 \) (98\%).

Finally, the optical efficiency \( \eta_O \) is the product of all the previously stated efficiencies and it is given by

\[
\eta_O = \gamma \rho \varepsilon
\]

(11)

5.5.2 Receiver’s Thermal Efficiency

The thermal efficiency of the solar collector \( \eta_c \) is known as the ratio of the energy delivered to the receiver to the energy incident on the aperture of the dish collector where \( Q_u \) is the rate at which the energy is transmitted to the receiver and \( Q_s \) is the rate at which the collector receives solar radiation which corresponds to the DNI multiplied by the area collecting solar radiation \( Q_s = DNI \cdot A_a \). The rate at which the receiver receives energy (before heat loss inside the receiver) is the energy received by the collector minus the optical losses, therefore we can write it as \( Q_R = \eta_O Q_s = \eta_O \cdot DNI \cdot A_a \) [6]. The efficiency of the receiver describes its ability to transfer heat from the cavity to the absorber of the Stirling engine and it is given by

\[
\eta_R = \frac{Q_u}{Q_R} = \frac{Q_u}{\eta_O \cdot Q_s} = \frac{Q_u}{\eta_O \cdot DNI \cdot A_a}
\]

(12)
The direct normal irradiance depends on the geographical location of the site, the orientation of the collector as well as the weather data and time of the day since there is more solar exposure at noon compared to the early morning or the afternoon. Assuming steady states conditions, the energy absorbed by the heat transfer fluid is given by subtracting the heat loss $Q_L$ (from the receiver to the surroundings) from the energy reflected on the receiver by the collector $Q_R$ [6].

\[
\dot{Q}_u = \dot{Q}_R - \dot{Q}_L
\]

5.5.3 Thermal Model of the Cavity Receiver

Heat loss is the heat transferred to the surroundings. Heat can be transferred in three main ways: conduction, convection and radiation. As our cavity receiver is not a perfectly adiabatic cavity since it has an opening (aperture) and its insulation does not insulate the cavity walls completely from the surroundings; consequently, the cavity receiver of our system will experience thermal losses and they are analyzed thanks the following model.

5.5.3.1 Conduction Losses

The conduction losses are given as follows [13]
\[
\dot{Q}_{\text{cond}} = \frac{T_{\text{cav}} - T_{\text{amb}}}{\ln \left[ \frac{(d_{\text{cav}}/2)^{+} + \delta_{\text{ins}}}{d_{\text{cav}}/2} \right]/(2\pi k_{\text{ins}} L_{\text{cav}})}
\]  

\(T_{\text{cav}}\) is the cavity’s temperature and it is given by \(T_{\text{cav}} = \frac{\sqrt{QR}}{A_{\text{cav}} \epsilon \sigma}\) \[14\] where \(\sigma\) is a constant called the Stefan-Boltzmann constant and it is equal to \(\sigma = 5.67 \times 10^{-8} \, \text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}\). Whereas \(T_{\text{amb}}\) is the ambient temperature which is the temperature at a given time of the day expressed in Kelvins.

5.5.3.2 \textit{Convection Losses}

The convection losses are calculated using the convective heat transfer coefficient, which comprehends the natural heat transfer coefficient, approximated by the Nusselt number, and the forced heat transfer coefficient \[13\].

\[
h = h_{\text{natural}} + h_{\text{forced}}
\]  

\[
h_{\text{natural}} = \frac{Nu \, \lambda}{d_{\text{cav}}}
\]

Where \(\lambda\) is the thermal conductivity of air which depends on its temperature and its pressure. Since we will be dealing with the surroundings the conductivity of air can be approximated as the conductivity at ambient temperature and at atmospheric pressure.

\[
\dot{Q}_{\text{convection}} = h \cdot A_{\text{cav}} \cdot (T_{\text{cav}} - T_{\text{amb}})
\]

The Nusselt number is a number used in fluid dynamics to predict the ratio of convective heat transfer. In this present model, it is given by the following equation \[13\].

\[
Nu_{\text{natural}} = 0.088 \cdot Gr^{1/3} \cdot \left( \frac{T_{\text{cav}}}{T_{\text{amb}}} \right)^{0.18} \cdot (\cos \theta)^{2.47} \cdot \left( \frac{d_{\text{ap}}}{d_{\text{cav}}} \right)^{-0.982} \cdot \left( \frac{d_{\text{ap}}}{d_{\text{cav}}} \right)^{+1.12}
\]
θ is the incident angle and since we assume our system tracks the sun perfectly θ will be the altitude angle of the sun that is defined by equation (9). $G_r$ refers to Grashof number and it is defined by $G_r = \frac{g \beta_{air} (T_{cav} - T_{amb}) L_{cav}^3 \rho_{air}}{\mu^3}$ where $\mu$ is the viscosity of air, $\rho_{air}$ is the density of air, $g$ is the gravitational acceleration and $\beta_{air}$ is the coefficient of dilatation of air. We assume that air is an ideal gas, so $\beta_{air} = \frac{1}{T_{cav}}$.

The forced heat transfer coefficient is defined as below [13]

$$h_{forced} = 0.1967 V^{1.849}$$

### 5.5.3.3 Radiation Losses

An important part of the heat loss experienced by the receiver is due to radiation losses. Radiation heat transfers can be distinguished as two mechanisms, emission and reflection. The radiation loss is computed according to the relation below [4].

$$\dot{Q}_{\text{radiation}} = \varepsilon_{eff} A_{cav} \sigma (T_{cav}^4 - T_{amb}^4)$$

$\varepsilon_{eff}$ is the effective absorptance of the cavity receiver and can be calculated by the following equation

$$\varepsilon_{eff} = \frac{1}{1 + \left(\frac{1}{\varepsilon_c} - 1\right) \frac{A_{ap}}{A_{cav}}} [4].$$

Finally, the total heat loss from the receiver $Q_L$ is equivalent to

$$\dot{Q}_L = \dot{Q}_{\text{cond}} + \dot{Q}_{\text{convection}} + \dot{Q}_{\text{radiation}}$$

### 5.5.4 Efficiency of the system

The total efficiency of the system is the product of all the previous efficiencies multiplied by the efficiency of the power generator. Therefore the total efficiency will give us the amount of power generated in function of the direct normal irradiance. It would simply be the product of the total efficiency, the total area of the collector $A_a$ and the DNI.
Let us remind that \( \dot{Q}_S \) is not the amount of energy in Joules but the energy rate expressed in Joules/second or in Watts.
CHAPTER 3
6 Simulation and Results of the Model

6.1 Location and Hourly Weather Data of the Site on a Specific Day

The simulation shall be conducted under sunny conditions to test the reliability of the model. The site used for the Excel calculations is Agadir, Morocco with a latitude of 30°25’12”. The day simulated is a summer day, the 14th of June 2018. The direct normal irradiance, ambient temperatures as well as wind speeds have been extracted from historical weather data. The data has been analyzed on an hourly basis to evaluate the variation of the thermal efficiency of the receiver and the total electrical output of the system at different times of the day. Our model tests the Dish Stirling system performance from 10:00 AM to 4:00 PM. The collected weather data as summarized in the table below.

<table>
<thead>
<tr>
<th>Day Hour</th>
<th>DNI (W/m²)</th>
<th>Wind Speed (m/s)</th>
<th>Ambient Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>740</td>
<td>2.23</td>
<td>293.15</td>
</tr>
<tr>
<td>11</td>
<td>820</td>
<td>1.34</td>
<td>295.37</td>
</tr>
<tr>
<td>12</td>
<td>980</td>
<td>2.23</td>
<td>295.93</td>
</tr>
<tr>
<td>13</td>
<td>1020</td>
<td>2.68</td>
<td>298.15</td>
</tr>
<tr>
<td>14</td>
<td>990</td>
<td>1.34</td>
<td>298.7</td>
</tr>
<tr>
<td>15</td>
<td>860</td>
<td>3.12</td>
<td>300.93</td>
</tr>
<tr>
<td>16</td>
<td>640</td>
<td>2.68</td>
<td>302.04</td>
</tr>
</tbody>
</table>

*Table 2. Meteorological Data for Summer Day Simulation*

6.2 Calculation of Solar Position and Hourly Incident Angles

The input angles for trigonometric built-in functions on Microsoft Excel take angles in radians; that is why, the latitude of the site and the solar incident angles must be converted to radians.

$$\Phi = 30^\circ 25'12'' = 30.42^\circ = 0.53 \text{ rad}$$

The incident angles are exactly the altitude angles $\alpha(t)$ of the tracking system since we assume that the Dish Stirling is constantly oriented towards the sun. The incident angles are then calculated using equation (9). $\alpha(t)$ incorporates, as variables, the latitude of the site $\Phi$, the declination angle $\delta$ (which is a function of the day of the year) and the hour angle $\omega(t)$. 

30
6.3 Decision Parameters

6.3.1 Sizing of the Parabolic Dish and Receiver

The simulation conducted is done on a 5-m diameter parabolic dish Stirling system with a concentration ratio of 400. Therefore its receiver’s diameter is approximately 25 cm.

\[
C = \frac{A_a}{A_r} = \frac{D_a^2}{D_r^2} = 400, \text{ so } D_r = \sqrt[4]{\frac{D_a^2}{C}}
\]

Since the cavity is similar to a conical shape, let us estimate the diameter of the lower base of the cavity to \(d_{cav} = \frac{2}{5}D_r\). The diameter of the cavity is then equal to 15 cm.

6.3.3 Calculation of Geometric Metrics of the Collector

Relying on the equations stated in section 4.1, we calculate the geometric metrics of the receiver and the parabolic concentrator.

<table>
<thead>
<tr>
<th>Concentrator Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (m)</td>
<td>5.00</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>0.20</td>
</tr>
<tr>
<td>Reflectivity (-)</td>
<td>0.94</td>
</tr>
<tr>
<td>Focal Length (m)</td>
<td>7.81</td>
</tr>
<tr>
<td>Rim Angle (rad)</td>
<td>0.32</td>
</tr>
<tr>
<td>Aperture's Area (m²)</td>
<td>19.63</td>
</tr>
</tbody>
</table>

*Table 3. Geometrical Parameters*

6.3.4 Characteristics and Sizing of the Receiver

The results showing the characteristics of the receiver upon which the simulation is conducted are as in the following table.
In fact, to minimize heat losses through radiation, the cavity walls are insulated with an insulator of conductivity $k$.

### 6.4 Computation of Efficiencies

#### 6.5.1 Variation of the Thermal Efficiency of the Receiver

Throughout the day, the thermal losses vary due to many factors which are mainly the solar irradiance, wind speed which contributes to convection losses and ambient temperatures. After simulation, the results are summarized in the table below which shows the variation of heat losses throughout the day.

<table>
<thead>
<tr>
<th>$Q_{\text{cond}}$ (W)</th>
<th>$\text{Nu}$</th>
<th>$H_{\text{natural}}$ (W/m².K)</th>
<th>$H_{\text{forced}}$ (W/m².K)</th>
<th>$H_{\text{total}}$ (W/m².K)</th>
<th>$Q_{\text{conv}}$ (W)</th>
<th>$Q_{\text{rad}}$ (W)</th>
<th>$Q_{\text{loss}}$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.5839</td>
<td>6.3142</td>
<td>1.1046</td>
<td>0.8666</td>
<td>1.9712</td>
<td>57.1906</td>
<td>1749.0636</td>
<td>1866.8381</td>
</tr>
<tr>
<td>62.4244</td>
<td>1.5396</td>
<td>0.2693</td>
<td>0.3379</td>
<td>0.6073</td>
<td>18.1539</td>
<td>1938.3367</td>
<td>2018.9150</td>
</tr>
<tr>
<td>65.9034</td>
<td>0.2485</td>
<td>0.0435</td>
<td>0.8666</td>
<td>0.9101</td>
<td>28.7232</td>
<td>2317.0108</td>
<td>2411.6374</td>
</tr>
<tr>
<td>66.6030</td>
<td>1.5522</td>
<td>0.2715</td>
<td>1.2174</td>
<td>1.4889</td>
<td>47.4903</td>
<td>2411.6087</td>
<td>2525.7020</td>
</tr>
<tr>
<td>65.9717</td>
<td>6.3759</td>
<td>1.1154</td>
<td>0.3379</td>
<td>1.4533</td>
<td>45.9146</td>
<td>2340.5848</td>
<td>2452.4712</td>
</tr>
<tr>
<td>63.0727</td>
<td>14.5693</td>
<td>2.5487</td>
<td>1.6125</td>
<td>4.1611</td>
<td>125.6892</td>
<td>2032.8191</td>
<td>2221.5810</td>
</tr>
<tr>
<td>57.4734</td>
<td>24.2401</td>
<td>4.2404</td>
<td>1.2174</td>
<td>5.4578</td>
<td>150.2194</td>
<td>1512.0771</td>
<td>1719.7700</td>
</tr>
</tbody>
</table>

*Table 5. Thermal Losses at the Receiver from 10:00am to 4:00pm on a Summer Day*
The conduction losses inside the receiver varies over time and their variation is shown in the graph below.

![Variation of Conduction Losses Over Time](image1)

*Figure 15. Variation of Conduction Losses Over Time*

The convection losses refer to the heat transfer to the surroundings through the movement of air inside the receiver. The variation of these losses is shown below.

![Variation of Convection Losses Over Time](image2)

*Figure 16. Variation of Conduction Losses Over Time on a Summer Day*
The major part of the losses is through radiation as stated in section 5.5.3.3, the variation of radiation losses is as follows.

The thermal efficiency of the receiver depends on the total power collected by the receiver and the total thermal losses due to radiation, convection and radiation. The thermal efficiency of the receiver varies in function of time and reaches a maximum of 86% but does not change much until after 2pm. The results are shown in the following graph.
6.5.2 Comparison of the Power Output Variations

The system is expected to deliver different power values at the different times of the day. The results in the graph below shows the final power outputs of the Dish Stirling system. It takes into consideration the losses due to the optical losses of the concentrator as well as the thermal losses at the receiver. The thermal efficiency of the Stirling Engine is supposed to be 0.7 and the electrical power generator is supposed to convert 50% of the mechanical work to electricity. A maximum power of 5.5kW is reached between noon and 2:00pm as seen in the following graph.

![Power Output Graph](image)

*Figure 19. Electrical Power Output at the Different Times of a Summer Day*

6.5.3 Simulation Conducted on the 17th of October 2018

The second simulation has been conducted on a different day of the year in order to compare the metrics of losses as well as the final hourly power output. By changing the day of the year, the altitude angle changes too since it is a function of DoY and thus the angle of inclination of the receiver changes too. Obviously, direct normal irradiance values during the fall season will be less than during summer. However, the variation of windspeed and temperatures cannot be expected. Moreover, the heat losses depend a lot on windspeed and temperature values. The final power output during is less than during summer as expected and reaches a maximum of 3.6 kW which is still a very interesting result as the dish collector can also decently operate on
a different season. However, it will serve to cover only a part of the energy needs. Below, the results of the second simulation are presented.

*Figure 20. Electrical Power Output at Different Times of a Fall Day*

*Figure 21. Variation of Conduction Losses Over Time on a Fall Day*
Figure 22. Variation of Convection Losses Over Time on a Fall Day

Figure 23. Variation of Radiation Losses Over Time on a Fall Day
As seen in the results above, in either summer or fall, the CSP dish operate at high efficiencies (around 25-26%) and is able to produce decent amount of electricity. The power produced can cover energy needs of many applications such as households’ heating/cooling systems or to generate power to run industrial refrigerators (that are known to consume large amounts of electricity for example. However, since our modelling included a 70% efficient Stirling engine as well as a 50% efficient power generator, the study may be taken further by optimizing the thermal efficiency of the other parts of the power conversion unit. Furthermore, it would be also crucial to conduct a financial analysis to realize such system and determine its amortization with respect to energy savings.
7 Conclusion

Producing energy from renewable sources is one of the main issues the world is facing. Electricity production relies heavily on the combustion of fossil fuels which contributes not only in the rise of global CO₂ emissions but also in the exhaustion of energy sources on Earth. Several solutions have been implemented in order to produce electricity from inexhaustible sources such as the sun, wind and other indirect energy sources. Solar energy is the main potential source that is being exploited; thus, research in the field of renewable energies has been focused on the ability to convert the irradiated energy to electricity or heat. The conventional solar technologies used nowadays are photovoltaic systems. However, in power plants, concentrated solar power systems is the preferred technology for large scale applications. The use of CSP systems for households is still undergoing research and might be the future of renewable technologies since CSP systems exhibit very attracting performance in terms of efficiencies. Dish Stirling systems are among the various applications of CSP. Throughout the present study, the parameters affecting the energy conversion process, such as the geometry of the dish, the characteristics of the receiver and the thermal losses, have been carefully studied and analyzed. Indeed, these parameters are critical when evaluating the overall efficiency of the system. Research show that cavity receivers are the kind applied for systems achieving high temperatures. This kind of receivers contribute in the limitation of the thermal losses experienced by the system. Other losses might occur at the different other levels of the system, such as optical losses and losses due to imperfections at the level of the parabolic concentrator. Stirling engines are the mechanical power producer for such applications and losses occur at them too according to the first law of thermodynamics. A cavity receiver for the present design have achieved on SolidWorks. Furthermore, the relations and equations obtained throughout this work have been implemented on Microsoft Excel and values for the different parameters have been computed. The simulation and calculations are made under specific weather conditions from the morning to the mid-afternoon. Moreover, the site chosen for the calculations is Agadir in the south of Morocco. Results of thermal losses have been summarized and final output powers delivered by the system, over this period of time, are presented.
8 Future Work

Deeper analyses may be conducted in the design of a Dish Stirling system. The optimization of the receiver’s geometry and characteristics in order to experience the minimum possible losses can be studied. The bearing structure of such systems might be an issue, especially if the concentrator is of an important size. Therefore, a stress analysis can be performed on the system which leads to an optimal choice of materials used in the structure. From another perspective, a preliminary analysis of the energy delivered by the system is to be conducted in order to choose the suitable capacity of the Stirling engine utilized. For household applications, the energy consumption by each energy sector of the house is to be analyzed (heating/cooling, lighting, etc.) in order to determine which sector of energy the Dish Stirling is going to cover. Finally, the future work would include one or several issues of the ones stated above.
References


Appendix A

Initial Specifications

WERZGAN Hamza
EMS
SOLAR THERMAL DISH COLLECTOR
DARHMAOUI H
SPRING 2019

The purpose of this capstone project is to transform a parabolic dish, that Al Akhawayn disposed of, into an efficient solar collector which is an alternative system to photovoltaic panels and will generate electricity out of solar energy.

As in any engineering project, this capstone will obviously feature an analysis phase. It will, first, consist of measuring the maximum power the device may be able to deliver by taking into accounts different metrics such as the total area of the dish, the reflectivity of the coating material, the efficiency of the Stirling engine utilized as well as the efficiency of the coupled electric generator and so on. Then, the second part of the analysis is the study of the automation system for tracking solar radiations. This part will focus mainly about the mounted mechanisms (whether it would be a single or dual-axis rotation) as well as a study of the mechanical specs of the moving support such as the torque needed to move the structure.

Following the initial phase of analysis comes the design of the structure which will be focused on the parts of the structure stated above since the parabolic dish is already available. The design phase will mostly rely on simulation to evaluate the performance of the solar collector and identify any possible enhancements using one of the many softwares available for simulating solar thermal systems.

The implementation will be conducted by my supervisor and I, as well as professionals if needed, and it will consist of bringing the different parts together and transform the dish into the desired device. Testing will follow the successful implementation to make sure the solar collector is capable of reaching the required temperature for the proper functioning of the Stirling engine as well as delivering the required AC current. Same applies to the tracking system and ensure the highest possible radiation collection.

The project will be conducted following ethical principles and every related research/work will be work cited. This device will not only generate energy savings but will also fit in AUI’s process of going green. With an efficiency higher than the one of photovoltaic panels, this project may constitute a new horizon for solar energy research and development at AUI.

Approved: H. Darhmaoui
Appendix B

Excel Sheet