DESIGN OF A PORTABLE SOLAR WATER PURIFIER AND DESALINATOR FOR APPLICATIONS IN REMOTE AREAS

CAPSTONE DESIGN
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DESIGN OF A PORTABLE SOLAR WATER PURIFIER AND DESALINATOR FOR APPLICATIONS IN REMOTE AREAS

Capstone Report

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List of Acronyms

\( f \): Focal point

\( \tau \): Glass transmissivity

\( \alpha \): Absorption of the receiver

\( L \): Length of the parabola

\( w \): Width of the parabola

\( h \): height of the parabola

OD: Outside diameter of the receiver tube

ID: Inside diameter of the receiver tube

\( \rho \): density of fluid

\( c_p \): specific heat

\( \dot{q} \): Heat flux

DNI: Direct normal irradiance

\( C_{goe} \): Geometric concentration ratio of the parabolic trough

\( h \): Heat transfer coefficient (convection)

\( k \): The thermal conductivity of the fluid

\( Re \): Reynolds Number

\( v \): Speed of the flow

\( \dot{m} \): Mass flow rate

\( \dot{v} \): Volume flow rate

\( \mu \): Kinematic viscosity of the fluid

\( \varepsilon \): Thermal emissivity

R: thermal resistance
\( \eta \): Efficiency of the parabola

Arc: Arch length of the parabola

x: Characteristic dimension of the parabola

\( R_{\text{cond}} \): Heat transfer due to conduction

\( R_{\text{conv}} \): Heat transfer due to convection

\( R_{\text{rad}} \): Heat transfer due to radiation

\( T_s \): Temperature of the surface

\( T_{\text{surr}} \): Temperature of the surrounding

\( T_{\infty} \): Temperature of the ambient

\( \dot{Q}_{\text{net}} \): Net of heat

\( \dot{Q}_{\text{abs}} \): total absorbed heat

\( \dot{Q}_{\text{loss}} \): total heat loss

\( R_{\text{total}} \): Total resistance of the pipe

\( h_L \): Head loss of the receiver

\( \Delta p \): Pressure difference between inlet and outlet of the pipe

\( \dot{W} \): power of the pump
List of Abbreviation

CPTC: Concentrated Parabolic Trough Collector

PTC: Parabolic Trough Collector

HCE: Heat Collector Element

HTF: Heat Transfer Fluid

ASRM: Advanced Solar Reflective Mirrors
1. Abstract

The purpose of this project is to design a portable solar water desalination and purification system for use in rural areas where drinkable water is very rare. The system shall produce a minimum of 5 liters of drinkable water per hour enough to sustain the need of a small rural family.

The system design will be based on parabolic trough concentrator technology in which sunlight energy is focused on a tube along the focal line. The fluid in the tube is heated to high temperatures by the energy of the sunlight which will cause the evaporation (thus phase-change) of pure water to have a high temperature vapor. This vapor will be taken into a coiled heat exchanger in order to evaporate 5 liters of brackish water (thus desalination) of water as well as its decontamination. Then, vapor will pass through a condenser then to a tank leaving the dirt and salt in the cleanable heat exchanger.

In our design we will consider the use of cost effective materials as well as a small PV system to sustain the needed pumping power.
2. Introduction

Food and drinkable water considered to be very precious in the rural areas around the world. Many charity initiatives were able to reduce the shortage of food while need of water has not witnessed the same initiatives. This shortage of drinkable water causes several serious diseases and causes death of young children. According to water.org organization, 332 million people are still without excess to the potable water. The universal problem still needs more collaboration in order to minimize the number of people in need for drinkable water. Our project targets this problem in order to help such people to enjoy desalinating and purifying their own water through the use of renewable energies. The system we are designing will mainly target the transformation of brackish water into drinkable water using PTC (parabolic trough collector) technology. This technology works by concentrating the sunlight into the pipes and causes change of the phase of water. The system is movable, and not expensive in order to respond to our target effectively. Applying this type of projects will defiantly reduce the greenhouse emission in which decreases global warming while providing poor people with a health-improving mean.
3. STEEPLE Analysis

1. Societal

   Public approval is the key for all energy management projects by encouraging people to invest in this type of projects. These life-style changing projects would help by providing potable water to the people in the rural areas. It would also decrease the infection of communicable diseases like Diarrhea, Cholera, and typhoid.

2. Technical

   Parabolic trough collector PTC is considered as one of the interesting designs for implementation in rural areas since it doesn’t require high costs or complex geometries. Also, making it movable would be an advantage for product selection in the market.

3. Environmental

   Any kind of projects has its impact on the environment. The impact of this project is investing the sunlight to desalinate water instead of using fossil or electrical boilers that increase the pollution of the environment. The implementation of this kinds of projects would definitely reduce pollution.

4. Ethical

   Social responsibility is the key of any project for and the implementation of this product would increase the awareness of the importance of providing people in remote areas with drinkable water. Also it would increase the awareness of saving water since people take it for granted while other people suffer to get it.
5. **Political**

Constructing this kind of projects will be as a free source of energy that will be used to cause phase change of the water inside the pipe. Indeed, saving energy is a save of money, and implementing energy management projects help to prevent energy poverty and allow the government to look for alternative sources of energy.

6. **Legal**

In order to operate in the environment we need to follow the law and avoid breaking the rules even if it could decrease the cost. We need to follow safety rules and avoid any violation of laws. For our project, no legal aspects were detected.

7. **Economic**

In fact, Investing in constructing such kinds of projects is investment with long payback period. Although it requires maintenance from time to time, it is better than buying bottled water or using electrical or fossil boilers which cost a lot of money.
4. Literature Review

Concentrated solar power (CSP) works on the principle of concentrating solar energy over a specific area to heat the surface up or to boil water inside a tubular absorber. Also, it could be used for electricity generation. Actually, there are four different types of CSP which are PTC, solar tower, LFC, and Stirling dish. Globally, PTC is considered to be 94% of all the CSPs [1]. In fact, parabolic trough collectors is not a new technology and it has it has been introduced into so many different countries in the world and for different purposes. In 1880, the first known parabolic trough collector was built by John Ericsson. In 1907 the first patent of parabolic trough collectors by the Germans Remshardt and Wilhelm for generation of steam. Also, in 1913 a pumping plant was constructed in Meadi, Egypt for irrigation purposes. [1] In fact, there are many applications for the concentrated parabolic collectors such as food and beverage, textile industry, chemical industry, and mostly in steam generation plants up to 400 °C. These industries need a temperature that do not exceed 250°C. [5]

4.1 Types of Concentrated Solar Power

4.1.1 Parabolic Trough Collector (PTC)

This type of solar collectors work based on concentrating the solar power over an evacuated tubular receiver (absorber) in order to boil water inside the tube (desalination facility) or for the generation of seam that will be used for steam turbines (electricity generation). There are many other applications like Air conditioning and milk pasteurization. [2]
4.1.2 Solar Towers

The structure has a field of mirrors that are called heliostat and can track the movement of the sun by moving in two axes. Then, it will concentrate the sunlight into a point on the tower that is carrying an evacuated pipeline that carries fluid inside like water and will be boiled using this energy and the steam can be used for the generation of electricity. Also, the pipe can carry molten salt as heat transfer fluid and the pipe will be as a thermal energy storage facility. [6]

4.1.3 Linear Fresnel Collectors

It works similar to PTC but instead of the parabolic reflector, they used plane mirrors in order to concentrate the sunlight on a metal tube which is carrying fluid. This method evaporate the fluid on the same way and could also be used for the generation of
electricity. The advantage of this method is that it doesn’t require a complex supporting structure to hold the mirrors. [3]

Figure 3 Linear Fresnel Collectors [1].

4.1.4 Stirling Dish

A parabolic-shaped dish is designed to concentrate the sun light on a focal point which is holding a receiver. This focus on one point could increase the temperature of the receiver into very high degrees. Usually, this receiver is employed for off-grid applications. [4]

Figure 4 Stirling Dish
5. Region of Implementation

In fact, this project was designed for a specific region in Morocco which is Ouarzazate. Ouarzazate is one of the southern cities in Morocco that enjoys the abundance of sunlight. The estimated number of hours between sunrise and sunset in winter is about 7 hours and about 11 hours in summer. The climate of Ouarzazate is desert with a latitude of 30.9335436 and longitude of -6.937015999999971. The annual air temperature was found using RETScreenExpert Software, which is 18.9 °C and the atmospheric pressure is about 89 kPa. The graph below shows the relation between temperature and each month using meteoblue as the following:

Since our project is dependent on solar energy, we are also interested to know the relation between the each month and the number of sunny days as the following:
Figure 6 Cloudy, Sunny, and Precipitations days in Ouarzazate, Morocco [2].

This graph shows the number of sunny days per month, and it is noticeable that Ouarzazate is sunny most of the days, which makes it an appropriate region for our project.
6. Design

Open non-evacuated parabolic trough with evacuated receiver (pipe) is the main design for our project with the following parts:

![Figure 7 Sample of parabolic Reflectors [3].](image)

6.1 Main parts of the design

1. Receivers (inner pipe of stainless steel and outer evacuated pipe of borosilicate)
2. Two metallic parts to hold the pipes
3. Reflecting Parabolic trough
4. Wooden support structure
5. Two ends for the sides
6. Highly sensitive tracking system

6.1.1 Receivers

In order to improve the CPCs ‘performance, we will be using low reflectivity evacuated tube as our heat collector element. In fact, the evacuated tube is composed of inner metallic pipe, and the outer pipe is evacuated and made of glass envelope. The two pipes are sealed tightly to keep the vacuum in the annulus between tubes and also to
accommodate difference in thermal expansion between the two materials [7]. Pipes are placed on the focal line of the reflecting parabolic trough for the maximum absorbance of energy [4]. The information below summarize the characteristics of the two pipes:

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Pipe 1</th>
<th>Pipe 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>Inner</td>
<td>Outer</td>
</tr>
<tr>
<td>OD</td>
<td>60.33 mm</td>
<td>75 mm</td>
</tr>
<tr>
<td>ID</td>
<td>58.68 mm</td>
<td>74 mm</td>
</tr>
<tr>
<td>Length L</td>
<td>2 m</td>
<td>2 m</td>
</tr>
<tr>
<td>Thickness t</td>
<td>1.65 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Material</td>
<td>Stainless Steel</td>
<td>Borosilicate</td>
</tr>
<tr>
<td>Thermal Conductivity k</td>
<td>14.9 W/m.k</td>
<td>1.2 W/m.k</td>
</tr>
<tr>
<td>Emissivity ε</td>
<td>0.35</td>
<td>0.9</td>
</tr>
<tr>
<td>Lateral Area</td>
<td>0.379 m²</td>
<td>0.471 m²</td>
</tr>
<tr>
<td>Cross Sectional Area</td>
<td>0.0027</td>
<td>0.004 m²</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>$9.6 \times 10^{-6}$ °C⁻¹</td>
<td>$3.3 \times 10^{-6}$ °C⁻¹</td>
</tr>
<tr>
<td>Transmittance τ</td>
<td>0.86</td>
<td>0.14</td>
</tr>
</tbody>
</table>

| Reflectivity (1-α)              |                             |                             |

Table 1 Characteristics of the two pipes

6.1.1.1 Volume of pipe

In order to generate 5.4 liters per hour that will be used for heating purpose to provide 5 liters of drinkable water for people in rural areas we will be using a pipe of Diameter of 5.868 cm and length of 2 m.

$$V = \pi R^2 \cdot L$$

$$V = \pi (2.934)^2 (200)$$

$$V = 5408.78 \text{ cm}^3$$

$$V = 5.4 \text{ liters}$$

6.1.1.2 Heat Transfer Fluid

The other important component of the system is the heat transfer fluid HTF, and it should be selected carefully during designing the system since it will be carrying heat to heat exchanger. The selection of this fluid depends actually on two main points;
geographical location, and operation temperature of the system. The geographical location is where the system is located, and thermal oils with low freezing point are mainly used as HTF in regions where temperature does not reach 0 °C [7]. The operation temperature also effects the system since it will affect the pressure resulted from the increase in temperature inside the pipe [8]. Therefore, the piping system should be made from very strong materials and maintenance should be regular which may increase the cost of the system. For our design, we selected pure water as the heat transfer fluid and mix it with refrigerant and anti-freezing chemicals to avoid freezing at night or with low temperature conditions. Although the system doesn’t operate at night, we need the antifreeze chemicals to ease heating HTF in the morning and it will take less time than heating it from the freezing point. The properties of water is the following:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density ( \rho )</td>
<td>( 1000 , kg/m^3 )</td>
</tr>
<tr>
<td>( C_p )</td>
<td>( 4.011 , J/g \cdot ^\circ C )</td>
</tr>
<tr>
<td>Viscosity ( \mu ) at 18.9 °C</td>
<td>( 1.002 \times 10^{-3} , kg/m.s )</td>
</tr>
</tbody>
</table>

| Table 2 Properties of Water at 18.9 °C. |

The energy required to heat up the water of about 5.4 kg from 18.9 °C to 120 °C as the following:

\[ Q = m c_p \Delta T \]
\[ Q = 5.4(4.011)(120 - 18.9) = 2190 \, KJ \]
The graph below shows the relation between the required heat and the temperature of fluid. We are considering the temperature of fluid to change from 0 °C to 120 °C and the ambient temperature is 18.9 °C. In this graph, we are trying to see the relation between the required heat and the temperature of heat transfer fluid. The negative sign means the temperature of the absorber is less than the temperature of the ambient and the direction of heat is from the surrounding to the absorber. On the other hand, the positive sign means the temperature of the absorber is greater than the temperature of the ambient, and the direction of heat is from the absorber to the surrounding. As shown, there is a linear increase between the temperature of the receiver and the required energy. Assuming no thermal losses from the pipe, if we want to increase the temperature of the fluid till 100 °C, the required energy is 0.5 kWh, and if we want to increase it till 120 °C, the required energy is 0.6 kWh.

\[
kwh = \frac{1}{3600} (KJ)
\]

\[
Q = \frac{1}{3600} (2190)
\]

\[
Q = 0.608 \text{ kWh}
\]
The graph below shows the relation between the required energy to heat the fluid until 120 °C while the temperature of the ambient is changing from 0 °C to 50 °C. As shown below, as much as the temperature of the ambient increases, the required energy to heat up water to 120 °C decreases. For example, if the temperature of the ambient is 0 °C, we will need 0.7 kWh to heat water to 120 °C, while if the temperature of the ambient is 50 °C, we will need only 0.42 kWh.

![Required Heat vs Temperature of Ambient](image)

*Figure 9 Relation between Required Heat and Temperature of the Ambient*

### 6.1.1.4 Power

Power is the rate of energy transferred to or from the system (absorbers). Supposing that we need to heat up pure water from 18.9 °C to 120 °C during one hour, power will be:

\[
\dot{Q} = \frac{Q}{\Delta t}
\]

\[
\dot{Q} = \frac{0.608}{1}
\]

\[
\dot{Q} = 0.608 \, KW
\]

\[
\dot{Q} = 608 \, W
\]
6.1.15 Mass Flow rate

The mass flowing in the system through a period of time which is one hour in our case. It is calculated as below:

\[ \dot{Q} = \dot{m}c_p \Delta T \]

\[ \dot{m} = \frac{\dot{Q}}{c_p \Delta T} \]

\[ \dot{m} = \frac{608}{4.011(120 - 18.9)} \]

\[ \dot{m} = 1.36438 \text{ g/s} \]

\[ \dot{m} = 1.36 \times 10^{-3} \text{ kg/s} \]

6.1.1.6 Velocity

It depends on mass flow rate of fluid, density of fluid and cross sectional area of the inner pipe. As the following

\[ \dot{m} = \rho VA \]

\[ V = \frac{\dot{m}}{\rho A} \]

\[ V = \frac{1.36 \times 10^{-3}}{1000(0.0027)} \]

\[ V = 5.03 \times 10^{-4} \text{ m/s} \]

6.1.1.7 Time per cycle

Time the system will take to raise the temperature of 5.4 liters of water from 18.9 °C to 120 °C.

\[ t = \frac{L}{V} \]
\[ t = \frac{2}{5.03 \times 10^{-4}} = 3970 \text{ s} \]
\[ t = 66 \text{ min per cycle} \]

6.1.1.8 Direct Normal Irradiance

Direct Normal Irradiance DNI: is the measure of the intensity of solar radiation per unit area in which is always held perpendicular or normal to the sunrays. For the maximum irradiance and the better performance of CPCs, it’s preferable to locate collectors normal to the incoming radiation [10]. For our case, the DNI of Ouarzazate is 2635 $\text{kwh/m}^2$/year which is about 300.917 $\text{w/m}^2$.

6.1.2 Reflecting Parabolic Trough

As we mentioned earlier, the reflecting parabolic trough is the main part of our design. It was designed depending on the energy needed to raise the temperature of water in the pipe from 18.9 °C to 120 °C and also depending on the direct normal irradiance DNI.

Since DNI is the heat flux \( \dot{q} = \frac{\dot{Q}}{A} \)

6.1.2.1 Area of the Parabola

Area of the parabola is calculated by using heat flux or DNI of Ouarzazate and the gained power from the parabolic trough to the receivers.

\[ A = \frac{\dot{Q}}{\dot{q}} \]
\[ A = \frac{608}{300.917} \]
\[ A = 2 \text{ m}^2 \]
The result we found above is for the assumption that there is no thermal losses from the system. However, in section 8, we made heat transfer analysis and also calculated the losses from the system to be 72.2 W. Therefore, it should be taken into consideration and make sure our trough is big enough to handle boiling the water and also the thermal losses. Then

\[ \dot{Q} = 608 \, W + 72.2 \, W \]
\[ \dot{Q} = 680.2 \, W \]

Recalculating the area with taken the thermal losses into consideration

\[ A = \frac{\dot{Q}}{\dot{q}} \]

\[ A = \frac{680.2}{300.917} \]
\[ A = 2.3 \, m^2 \]

6.1.2.2 Width of parabola

Since we know the area of the parabolic trough, which is equal to the area of the plate that is used to make the reflecting surface. As long as we know the area and length of the parabola, then width can be calculated:

\[ w = \frac{A}{L} \]
\[ w = \frac{2.3 \, m^2}{2 \, m} \]
\[ w = 1.15 \, m \]
6.1.2.3 Dimensions of the parabolic trough

<table>
<thead>
<tr>
<th>Dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>$2.3\ m^2$</td>
</tr>
<tr>
<td>Length L</td>
<td>2 m</td>
</tr>
<tr>
<td>Width w</td>
<td>1.15 m</td>
</tr>
<tr>
<td>Height h</td>
<td>1 m</td>
</tr>
</tbody>
</table>

*Table 3 Dimensions of the Parabolic Trough*

Dimensions of the parabolic trough are a sensitive factor since we have a constraint of the system to be portable that needs to be considered while designing the system. In fact, we fixed the height of the parabola as 1 m in order to make it easier to clean the parabola since it needs regular cleaning to maintain its efficiency. The other reason is to make our design portable and ease its movement. Also, the small height would make it easier in case it needs to be stored. Theoretically speaking:

$$Width < Length < 2\ Width$$

Therefore, our dimensions respect the constraint above.

6.1.2.4 The parabolic Geometry

Parabola has a very unique geometry enables it to concentrate the radiation over one point called focal point. Focal point is very small comparing to the parabola, therefore, energy is well concentrated at that point allowing the significant increase in temperature [11]. Moreover, Industry has been using this feature in many applications like steam generation and desalination systems and much more applications that require intensive solar radiation [12]. The following figure describes the geometry of parabola:
Focal point

Solar radiation can be concentrated and collected at this point, which means there is increase in temperature that is useful for many applications. The focal the equation of our parabola depends actually on two parameters which are the width and the height.

Equation of the parabola:

\[ x^2 = 4fy \]

Where:

\[ x = \frac{1}{2}(w) \]

Point will be:

\[ f = \frac{x^2}{4y} \]

\[ f = \frac{0.575^2}{4(1)} \]

\[ f = 0.0827 \text{ m} \]

\[ f = 8.27 \text{ cm} \]

The focus is: \( f = (0, 8.27) \)
Arc Length

In fact, arc length is the length of the curvature of the parabolic trough that depends mainly on the width and the height of the parabola, and in our case it is calculated as the following:

\[
\text{Arc} = 0.5\sqrt{16(h)^2 + (w)^2} + \left[\frac{w^2}{8h}\right][\ln(4h) + \sqrt{16(h)^2 + (w)^2} - \ln(w)]
\]

\[
\text{Arc} = 0.5\sqrt{16(1)^2 + (1.15)^2} + \left[\frac{(1.15)^2}{8(1)}\right][\ln(4(1)) + \sqrt{16(1)^2 + (1.15)^2} - \ln(1.15)]
\]

\[
\text{Arc} = 2.405 \, m
\]

Geometric Concentration ratio of a parabola

Geometric concentration ratio is basically a physical meaning of light concentration process. It describes the ratio between the reflecting surface and the receiver to describe the intensity of solar radiation received by the pipes (receivers). Yet, this ratio is accurate only when the radiation flux uniformly distributed over the aperture area. [19]

\[
C_{geo} = \frac{\text{Area of a parabola}}{\text{Area of the Receiver}}
\]

\[
C_{geo} = \frac{2.3 \, m^2}{0.379 \, m^2}
\]

\[
C_{geo} = 6.07
\]

Efficiency of a Parabola

Efficiency usually describes how certain resources are successfully used to get a certain results. It’s usually measureable mathematically or scientifically to avoid waste through the process of doing things. Efficiency of the parabolic trough is one of the main
parameters that can be calculated by calculating the gain and the area of the parabolic trough besides knowing the direct normal irradiance DNI [19].

\[ \eta = \frac{\dot{Q}}{DNI \times A} \]

\[ \eta = \frac{608}{300.917(2.3)} = 0.88 \]

\[ \eta = 88\% \]

This result shows that our system is efficient enough to be used as a desalination system.

6.1.3 Two metallic parts

After specifying the trough area and pipes we will need two parts to hold the receivers (pipes). These pipes will be placed at each end of the parabola with the height of 8.27 cm in order to keep the pipes on the focal line. Keeping the pipes on the focal line means the maximum absorbance of the sunlight since most of the sunrays directed on the parabola will be reflected by the surface of the parabola on the focal line [13].

6.1.4 Wooden Support Structure

Supporting structure is essential in any design for better performance and longer lifetime. For our design, a wooden structure will surround the parabolic trough from both sides in order to support it from any shattering [9]. The structure will be made of wood since its very light material that is appropriate for our portable design. Wood is very strong material that can hold the weight of the parabolic reflector. Also, it has a low thermal expansion in about $3 \times 10^{-6}$ which is preferable in such kinds of designs. Also, wood is very durable material which will be appropriate in a region like Ouarzazate.
However, it’s preferable to dye it with waterproof dye in order to protect it from rain, and increase its lifetime.

6.1.5 Two ends for the sides

Two ends are extremely important for this design since it reduces the energy lost from the system by convection and improve efficiency of the system. Also, they can be used as protection parts to protect the surface from dust and dirt in which it will reduce the maintenance cost. The dimensions of the ends will be the same as the ones of the parabolic trough. Meaning, the width of the ends will be 1.15 m with a height of 1 m.

6.1.6 Tracking system

Usually, parabolic trough are designed with high sensitivity tracking system in order to follow the sunrays during daylight. In fact, there are two types of tracking systems varying from to complex that can be categorized into two groups which are mechanical and electronic. In fact, electronic is preferred in general due to its high accuracy comparing the mechanical type. Also, electronic systems can be subdivided according to their mechanism: [21]

- Motors controlled by sensors in order to detect the magnitude of solar illumination.[21]
- Motors controlled by computers with a feedback unit and sensors in order to measure the solar flux on the receivers.[21]

In our project, the mechanical type is preferred since the design is made for people in rural areas, and reducing complexity matters. The other reason is because our design is open and electronic tracking system could damage under rainy days condition.
7. Materials of the system

7.1 Reflecting Surface for Concentrated Parabolic Trough Collectors

Efficiency of CPC is one of our priorities and choosing advanced reflective material is one of the most important steps that effect the performance of the PTC. For this purpose, a high reflectivity surface, a long lifetime, and with a reasonable cost are the criteria for choosing the material. Currently, there are many different types of reflecting materials such as silvered glass mirrors, aluminized reflectors, and also front-surface mirrors [14]. The following description shows the difference between those reflective materials:

- Glass mirror: it is considered the most widely used reflective surface in the market for many qualities. The advantage of glass mirrors is their reflective layer have excellent durability, it’s a heavy material and also fragile. In addition, making the curved shape requires sometime slumped glass which is expensive. In fact, there two ways to improve the quality of these reflectors; making a cooper free reflective mirror or using lead-free paints. In industry, we have multiple types of glass mirrors such as silvered glass mirrors, and copper-free mirrors. Slivered glass mirrors have thickness of 4mm, slumped glass with reflectivity of 93.5%. It’s designed to have multilayer paint system in order to resist the outdoor environment. The other type of glass is copper-free mirror, which has a thickness of 3mm and 4mm in the market and reflectivity of 93%. In fact, copper-free mirrors are cheaper than silvered glass mirrors but also it has less durability and reflectance. Therefore, for our project, we used silvered glass mirror not only for its properties but also for the fact that slivered glass mirror gain starts at
wavelength of 470 nm and continuous to infrared while Aluminized mirrors’ gain starts at the wavelength of 800 nm. [14]

- Aluminized Mirrors: polished aluminum substrate is used in this type of reflectors with a reflectivity of 90%. It’s cheaper than glass mirrors but it has very low durability.[14]

- Silvered polymer reflectors: It’s considered one of the cheapest reflecting materials with reflectivity of 94%. The disadvantage of this material is the fact that it shows slight changes in terms of reflectance during its lifetime earlier than expected.[14]

- Advanced Solar Reflective Mirror ASRM: It has a reflectivity of 95% which makes it the most reflective material among reflectors. It is made from silvered substrate with coating of alumina layer. [14]

7.2 Materials of Pipes

We specified earlier the dimensions and the design of the pipe to be composed of 2 pipes sealed together to keep evacuated. Now we are about to specify the materials of the pipes:

*Figure 11 Evacuated Receiver [5].*
• Inner pipe: this part is made of stainless steel that is made mainly from iron with other additives like 18% of Chromium, 8% nickel, and 0.08% of carbon. Stainless steel has an excellent absorbance and low emissivity to reduce radiation from the pipe. Stainless steel is used instead of Aluminum because higher thermal expansion between $21 \times 10^{-6}$ and $24 \times 10^{-6}$. Higher thermal expansion may cause changes that cause damages in the system or it could increase the maintenance cost. Also, Aluminum has a low absorptivity in about 0.9 which is not preferable in our system while the absorptivity of stainless steel is 0.915. In fact, Absorptivity is a very important property that needs to be taken into consideration while choosing materials for the system since it indicates the ability of the body to absorb the incident radiation. Also, stainless steel has small emissivity in which it reduces the thermal loses from the system. The thickness of this pipe is 1.65 mm since it’s the best size in the market that matches our expectations. Actually, stainless steel 304 is available in SunnyXinrui products with these specifications. [15]

To improve the performance and maximize the absorbance of the system we can paint the inner pipe in black, but we should be careful because radiation increases as well causing more thermal losses from the system. Therefore, if we choose to paint the metallic pipe in black, we should choose a selective coating to minimize the losses caused by radiation. [9]
• Outer pipe: this part is made of borosilicate glass and it is evacuated to reduce convection from the inner pipe to the surroundings. Borosilicate was chosen because it has a low coefficient of thermal expansion in about $3.3 \times 10^{-6}$ which makes it resistant to thermal shocks. In addition, borosilicate has a high deformation temperature (by which the glass starts deformation) in about 1650 °C. Also, borosilicate glass has a good transmittance of 0.86 which allows most of the incident light to pass through the glass to the inner pipe. The reflectivity of borosilicate is 0.14 which means it reflects only a small fraction of the incident light that is reflected from the parabola or directly from the sun. Also, borosilicate has a small coefficient of conductivity, which reduces the thermal loses from the system through conduction. The pipe that matches our needs is with OD of 75 mm and thickness of 1 mm. commercially, the market has a lot of options for borosilicate with different ODs and thickness specially the ones made in China and supplying the South European and North African markets. Also these companies are flexible in making the design the customer wants with a lead time of 1 week and reasonable prices. [15]

• Hydrogen getter: is the part is metallic and installed in the vacuum space in the tube which is responsible for evaluating vacuum settings inside the tube. [6]

• Opening: this opening is used for evacuating the tube annulus. Research has showed that low pressure is required inside the evacuated tube and as the pressure increases, the performance of the HCF decreases causing more heat loss from the metallic pipe to the surrounding. [6]
8. Heat Transfer Analysis

As a matter of fact 75% of direct solar radiation of the sun coming to earth can passes through the atmosphere and the other 25% is ether diffused by water-vapor molecules and atmospheric dust or scattered due to their short wavelengths [16]. Usually, parabolic trough collectors are supplied with accurate tracking systems in order to keep the parabolic trough perpendicular to the sunrays and diffuse the random rays that cannot be reflected on the focal point of the parabola. Actually, the absorbed rays by the receivers are either reflected by the parabolic trough on the focal line, or absorbed directly with no reflection. In general, the system benefits from both radiations in its performance and analyzing the performance of the CPTC requires deep analysis of both gain and losses of the system. In fact, four major factors effecting the energy generated by the system which are: the collector’s thermal properties, settings of the heat collectors elements, optical properties of the system, and ambient conditions for the chosen region. Therefore, heat gain by receivers, and thermal losses are very important to understand the energy balance of the system.

\[ \dot{Q}_{net} = \dot{Q}_{gain} - \dot{Q}_{lost} \]

To calculate \( \dot{Q}_{net} \) we need to find the gain by measuring the incident solar radiation, and Pyranometer is a device that measures direct and diffused solar radiation. For our case, we calculated the energy gained by the receiver to boil pure water inside the pipe. Also, we will use heat transfer analysis to calculate the heat lost from the system.
8.1 Energy Lost from the System

To investigate the performance of the system we need know the energy lost from the pipes while designing the system. Energy get lost in several ways, either inappropriate materials or heat transfer flows. In case of heat transfer, it’s either by conduction which is “the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interaction between particles” [17]. Also, heat transfer can be due convection which is “the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion” [17]. On the other words, to have convection we must have fluid, and if we have vacuum, convection is negligible most of the time because it is small comparing to the other flows. Last but not least, we have radiation which is “the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or the molecules” [17]. Meaning, radiation doesn’t need a medium to exist, and it happens in space and vacuum. The description below contains the information of the resistances resulted from the heat transfer due to HTF.

![Figure 12 Resistances due to HTF](image-url)
8.1.1 Convection from HTF to pipe

\( R_{\text{conv1}} \): heat transfer from fluid (Boiling water at 120 °C) to inner diameter of stainless steel pipe where heat transfer coefficient of convection at boiling temperature is \( h=3000 \text{ w/m.k} \)

\[
R_{\text{conv1}} = \frac{1}{hA}
\]

\[
R_{\text{conv1}} = \frac{1}{(\pi D_{\text{in.st}}+L)h}
\]

\[
R_{\text{conv1}} = \frac{1}{\pi(58.68+10^{-3})2+3000}
\]

\[
R_{\text{conv1}} = 9.042 \times 10^{-4} \text{ k/w}
\]

8.1.2 Conduction through Inner pipe

\( R_{\text{cond1}} \): heat transfer from inner to outer diameter of stainless steel pipe with coefficient of conductivity of 14.9 W/m.k and OD of 60.33 mm and ID of 58.68 mm.

\[
R_{\text{cond1}} = \ln\left(\frac{r_2}{r_1}\right)\frac{1}{2\pi L K}
\]

\[
R_{\text{cond1}} = \ln\left(\frac{0.030165}{0.02934}\right) = 0.000148
\]

\[
R_{\text{cond1}} = 1.48 \times 10^{-4} \text{ k/w}
\]

8.1.3 Radiation from inner pipe

\( R_{\text{rad1}} \): heat transfer from outer surface of stainless steel pipe to sky through the transparent glass where the emissivity of stainless steel is 0.35 and air temperature of 18.9 °C.

\[
R_{\text{rad1}} = \text{heat transfer from outer surface of stainless steel pipe to sky through the transparent glass where the emissivity of stainless steel is 0.35 and air temperature of 18.9 °C.}
\]
\begin{align*}
R_{\text{rad}1} &= \frac{1}{h_{\text{rad}1} A} \\
h_{\text{rad}1} &= \varepsilon\sigma\left( T_s^2 + T_{\text{surr}}^2 \right)(T_s + T_{\text{surr}}) \\
T_s &= 120 \, ^\circ\text{C} = 393 \, \text{K} \\
T_{\text{surr}} &= 18.9 \, ^\circ\text{C} = 291.9 \, \text{K} \\
h_{\text{rad}1} &= (0.35)(5.67 \times 10^{-8})(393^2 + 291.9^2)(393 + 291.9) \\
h_{\text{rad}1} &= 2.1 \frac{w}{m^2} \cdot k \\
\text{Then:} \\
R_{\text{rad}1} &= \frac{1}{(2.1)(\pi \times 60.33 \times 10^{-3})(2)} \\
R_{\text{rad}1} &= 1.256 \frac{k}{w} \\
8.1.4 \text{ Conduction through outer pipe} \\
R_{\text{cond}2}: \text{is the heat transfer from the inner diameter to the outer diameter of the glass pipe with coefficient of thermal conductivity of 1.2 W/m.k and OD of 75 mm and inner diameter of 74 mm.} \\
R_{\text{cond}2} &= \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi L K} \\
R_{\text{cond}2} &= \frac{\ln\left(\frac{0.0375}{0.037}\right)}{2\pi (2)(1.2)} \\
R_{\text{cond}2} &= 8.9 \times 10^{-4} \frac{k}{w} \\
8.1.5 \text{ Convection from inner pipe} \\
\text{Also there is a convection from stainless steel outer surface to the surrounding, but since we have evacuated tube, this convection will be neglected.}
8.1.6 Radiation from outer pipe

$R_{rad2}$: heat transfer from the outer surface of glass to the surrounding where the emissivity of glass is 0.90 and the ambient temperature is 18.9 °C and temperature of the surface will be:

\[
T_s = \frac{T_{\infty1} - T_{\infty2}}{2}
\]

\[
T_s = \frac{120 - 18.9}{2}
\]

\[
T_s = 50.5
\]

\[
R_{rad2} = \frac{1}{h_{rad2} A}
\]

Where:

\[
h_{rad2} = \varepsilon\sigma(T_s^2 + T_{surr}^2)(T_s + T_{surr})
\]

\[
T_s = 50.5 \degree C = 323.5 \text{ K}
\]

\[
T_{surr} = 18.9 \degree C = 291.9 \text{ K}
\]

\[
h_{rad2} = (0.9)(5.67 \times 10^{-8})(323.5^2 + 291.9^2)(323.5 + 291.9)
\]

\[
h_{rad2} = 5.96 \frac{w}{m^2.k}
\]

Then:

\[
R_{rad2} = \frac{1}{5.96 \pi (75 + 10^{-3})(2)}
\]

\[
R_{rad2} = 0.356 \frac{k}{w}
\]
8.1.7 Convection from outer pipe

\( R_{\text{conv2}} \): heat transfer from the outer surface of glass pipe to the surrounding where the heat transfer coefficient of air would be 10 W/m\(^2\).k and OD of 75 mm.

\[
R_{\text{conv2}} = \frac{1}{h_A}
\]

\[
R_{\text{conv2}} = \frac{1}{10\pi(75 \times 10^{-3})(2)}
\]

\[
R_{\text{conv2}} = 0.2122 \frac{k}{w}
\]

8.2 Total Resistance

Total resistance: is the sum of all the resistance in series and in parallel of the receivers.

\[
R_{\text{total}} = R_{\text{conv1}} + R_{\text{cond1}} + R_{\text{rad2}} + R_{\text{cond2}} + \left[ \frac{1}{R_{\text{rad2}}} + \frac{1}{R_{\text{conv2}}} \right]^{-1}
\]

\[
R_{\text{total}} = 9.042 \times 10^{-4} + 1.48 \times 10^{-4} + 1.256 + 8.9 \times 10^{-4} + \left[ \frac{1}{0.356} + \frac{1}{0.2112} \right]^{-1}
\]

\[
R_{\text{total}} = 1.4 \frac{w}{k}
\]

8.3 Total losses

Total energy lost from the both inner pipe (metallic one) and the outer pipe (glass) to the surrounding through conduction, convection and radiation where:

\[
T_{\infty1} = 120 \degree C = 393 K
\]

And \( T_{\infty2} = 18.9 \degree C = 291.9 K \)

\[
\dot{Q} = \frac{T_{\infty1} - T_{\infty2}}{R_{\text{total}}}
\]

\[
\dot{Q} = \frac{393 - 291.9}{1.4}
\]

\[
\dot{Q} = 72.2 W
\]
9. Fluid Mechanics Analysis

Reynolds number is a very important dimensionless quantity to indicate the nature of flow whether it is laminar, transitional, or turbulent flow. At large Reynolds number (Re>10000), the inertial forces are proportional to fluid density and square of fluid velocity while being relatively large to the viscous forces [18]. Therefore, the viscous forces cannot prevent these rapid fluctuations and causing a turbulent flow. In case of small Reynolds number (Re<2300), it means viscous forces can prevent this kind of fluctuations, and keep fluid in line to result a laminar flow. In the case of transitional flow or laminar-turbulent (2300<Re<10000), it means it’s the transition of laminar flow to be turbulent [18]. For our case, we will be investigating the nature of flow of water through stainless steel pipe.

<table>
<thead>
<tr>
<th>Viscosity of water $\mu$</th>
<th>$1.002 \times 10^{-3}$ kg/m.s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>3600 s</td>
</tr>
</tbody>
</table>

9.1 Volume Flow rate

Volume flow rate is actually the change of volume over time. And our volume is 5.4 liters and the time is one hour, the volume flow rate will be:

$$\dot{V} = \frac{V}{\Delta t}$$

$$\dot{V} = \frac{5.4 \times 10^{-3}}{3600}$$

$$\dot{V} = 1.5 \times 10^{-6} m^3/s$$
9.2 Mass Flow rate

Mass flow rate is the change of mass over time, and it could be also calculated using the density of HTF and the volume flow rate as the following:

\[ \dot{m} = \rho \dot{v} \]

\[ \dot{m} = (1005) (1.5 \times 10^{-6}) \]

\[ \dot{m} = 1.51 \times 10^{-3} \text{kg/s} \]

9.3 Average velocity

Average velocity: is the velocity by which the HTF moves through the pipe and it is calculated as the following:

\[ V_{avg} = \frac{\dot{v}}{A} \]

\[ V_{avg} = \frac{1.5 \times 10^{-6}}{0.003} \]

\[ V_{avg} = 5 \times 10^{-4} \text{ m/s} \]

9.3 Time per cycle

Is the needed period for a cycle to pass through the metallic pipe and it is calculated as the following:

\[ t = \frac{L}{V_{avg}} \]

\[ t = \frac{2}{5 \times 10^{-4}} = 4000 \text{ s} \]

\[ t = 66 \text{ min} \]
In fact, this result confirms what we calculated earlier that the time needed for 5.4 liter of pure water to increase its temperature from 18.9 °C to 120 °C and pass through the metallic pipe is 66 minutes.

9.4 Reynolds Number

A very important dimensionless quantity that describes the nature of flow of fluid and it is dependent on density of fluid, average velocity, viscosity of fluid, and the inner diameter of the pipe. It’s also a description of the proportionality between inertial forces and viscous forces through a pipe and independently from the roughness of the surface [18]. Reynolds number can be calculated as the following:

\[
Re = \frac{\rho \cdot V_{avg} \cdot D}{\mu}
\]

\[
Re = \frac{(1005)(5 \cdot 10^{-4})(58.68 \cdot 10^{-3})}{1.002 \cdot 10^{-3}}
\]

\[
Re = 29.43
\]

In fact, our Reynolds number is small, therefore, the flow is laminar.

9.5 Friction

“Friction is a function of Reynolds number only and independent of the roughness of the surface”. [18]

\[
f_{pipe} = \frac{64}{Re}
\]

\[
f = \frac{64}{29.43}
\]

\[
f = 2.175
\]
9.6 Head loss

“Represent the additional height that the fluid needs to be raised by a pump in order to overcome the frictional losses in the pipe” [18]. One other words, a certain energy that is needed in order to move a given volume of liquid through a pipe. Pressure difference or energy can actually cause the fluid to move but some of this energy is lost due to resistance to flow. This resistance is actually known as head loss and characterized by the friction between fluid and the surface of the pipe. It’s a function that depends of the friction, Length and diameter of the pipe, and the average velocity. Head loss is calculated as the following:

\[ hL = f \times \frac{L \times v^2}{2 \times D \times g} \]

\[ hL = (2.175) \times \frac{2 \times (5 \times 10^{-4})^2}{(58.68 \times 10^{-3})(2)(9.81)} \]

\[ hL = 9.4 \times 10^{-7} m \]

9.7 Pressure Difference

Pressure difference that required pumping power for a horizontal pipe that causes the HTF to move from the high pressure area to low pressure one [18]. By knowing this difference, we can see the type of pump appropriate for our system. To calculate the pressure difference between inlet and outlet, two assumptions need to be taken into consideration:

- Steady
- One-dimensional

\[ \Delta p = \rho g (z1 - z2 + hL) \]

\[ \Delta p = \rho g (hL) \]
\[
\Delta p = (1000)(9.81)(9.4 \times 10^{-7})
\]
\[
\Delta p = 9.2 \times 10^{-3} \text{ Psi}
\]

9.8 Power of Pump

The required power to operate a pump in order to push the pure water from inlet to outlet of the pipe. Also, it’s a quantity that is dependent on the volume flow rate and the pressure difference between inlet and outlet. It can be calculated as the following:

\[
\dot{W} = \dot{V} \times \Delta P
\]
\[
\dot{W} = (1.5 \times 10^{-6})(9.2 \times 10^{-3})
\]
\[
\dot{W} = 1.4 \times 10^{-8} \text{ W}
\]

This results shows that the need to pump pure water through the pipe is almost neglected. Therefore, we will be using a tank on a higher elevation so the pressure in the inlet will increase casing the heat transfer fluid to flow through the pipe.
10. The design of the system

This system is made of several parts that work in series in order to achieve the purpose of this project, which is water transformation of 5 liters of brackish water in order to make it drinkable.

![Diagram of the system](image)

*Figure 13 The Cycle of flows of the system*

10.1 Parabolic trough design

As explained earlier, the parabolic trough will use the sun radiation to heat 5.4 liters of water in around one hour to reach 120 °C. The user will get the benefit from the high temperature by passing it through insulated tubes to a heat exchanger. The parabolic trough has a cart of four wheels to make it portable, in case the user wants to move it to somewhere else, or to a sunnier spot.
10.2 Insulated tubes

Those tubes are exothermally important in circulating steam and pure water from the parabolic trough and the heat exchanger and vise versa in order to minimize the thermal losses from the system. In fact, not using these tubes will reduce the overall efficiency of the system.

10.3 Heat exchanger

A coiled design heat exchanger is used to heat brackish water from 18.9 °C to the boiling temperature, and the coiled design will allow maximum interaction between the coil and brackish water. Brackish water is briny water that has more salinity than fresh water but less than the salinity of seawater. Technically, brackish water contains salt with the range between 0.5 and 30 grams. In this heat exchanger, brackish water exchanges heat with the boiled water gradually, which means, the parabolic trough will keep heating water and pushing it to the insulated heat exchanger. The pure water will be
pumped again to the parabolic trough to reheat it again while the brackish water will be evaporated and taken to the condenser leaving salt, dirt, and other particles in the heat exchanger. Also heat exchanger is preferable to be made from insulated material from the outside to avoid thermal losses to the surrounding. The coils of the heat exchanger should be made from a very conductive material to boil brackish water during a short period of time. In our design, the heat exchanger has cylindrical shape that coils inside, very tight cover to avoid pouring brackish water from the heat exchanger. Also, this removable cover will allow the user to clean the heat exchanger from particles of salt and dirt resulted from evaporating brackish water. Also, it have 1 inlet and 2 outlets. The inlet will receive the boiled water coming from the parabolic trough through an insulated tube. The first outlet, will be the water in the coil that will be pumped back to the parabolic trough to heat it again also through an insulated tube. The other outlet will take vapor to the condenser through a natural flow from high pressure region to low pressure one.

![Figure 15 Design of the Heat Exchanger](image1.png)

10.4 Condenser

It’s a container of cold water that the vapor will pass through in order to condense it, and also has a spiral design. It doesn’t matter which type of water we will be using in order to condense the vapor since there is no contact between the two except the exchange of temperature. In our project, condenser does the opposite of the heat
exchanger; heat exchanger heats the water till it evaporates while the condenser will condense the vapor to make it drinkable water. For our design, the condenser will have similar design of the heat exchanger, but with the doubled size and the opposite purpose. It has a cylindrical shape with a removable cover and a coil inside that is connected to one inlet and one outlet. The inlet will receive vapor from the heat exchanger to pass through the coil. Since, the condenser has cold water, the water will get condensed in the coil. Then, the outlet will be connected to a tube that will take the desalinated water to the storage tank.

![Figure 16 Design of the Condenser](image)

10.5 Storage Tank

It’s where the drinkable water will be collected and stored, and it should be made either from plastic, or from a rustproofing transparent material. Rustproofing, to avoid any chemical reaction between the desalinated water and the material of the tank and also to prevent corrosion for longer life-time. Transparent material allows sunlight penetration through the tank that improves the desalination of water. Glass is a good choice but unfortunately, it’s breakable and wouldn’t be appropriate for the usage in rural areas. Transparent plastic is preferred in terms of cost and for its characteristics since our target
is poor people. Technically, the tank should be placed in elevation lower than the elevation of the condenser, so the water flow naturally to the tank due to difference in elevation.

![Figure 17 Design of the Storage Tank](image)

10.6 Normal pipes

We will need some normal pipes that are not necessarily insulated in order to take the vapor from heat exchanger to the condenser and then to the storage tank.

10.7 Pump

A pump will be responsible of circulating the pure water from the heat exchanger back to the parabolic trough and so on. This cycle is responsible for heating process gradually inside the heat exchanger. Steam will flow naturally from high pressure region to low pressure one to enter the heat exchanger. The heat exchanger contains brackish water to heat it while getting condensed again in the pipe then the pump will push it back to the parabolic trough to heat it again and so on. Since we need a small pressure difference to push water from the heat exchanger back to the parabolic trough, a pump of 1 liter/min would be appropriate since it consumes only 12 VDC.
In order to supply the pump, we need a source of generating electricity which is PV panel. Of course, we can use direct electricity source but since our project mainly depends on solar energy, we prefer using a small PV panel to generate our electricity. Since pump won’t be used for the whole day but for short periods of time, then, the need to electricity also reduced. Therefore, we need a PV panel that is able to produce about 10 W and 12 V to supply the small pump. Also it’s preferable to have TiO2 coating because
it works as self-cleaning mechanism that improves the PV panel performance and efficiency. The other advantage is reducing the need to clean the panel by hand that may scratches its surface and reducing its efficiency. [20]

Figure 20 PV Panel [6].
11. Cost Analysis

Cost-effective is an important feature in any project, and finding market acceptance depends mainly on the need for a certain project or service. Cost is a very sensitive factor in our project since our target is poor people in rural areas. Therefore, components should have reasonable prices and low maintenance cost to attract people to install such systems, otherwise, people will lose their interest and project will lose its market acceptance. In general, we have an idea about the prices in the market for all components except condenser since almost all the similar design use electricity to condense vapor. Therefore, we don’t have an exact idea of price of a condenser like ours. The table below contains the cost for each component:

<table>
<thead>
<tr>
<th>Material</th>
<th>Price in $</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silvered Glass Mirror</td>
<td>33/m²</td>
<td>2.3 m²</td>
</tr>
<tr>
<td>Wooden Structure and Wheels</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td>Stainless Steel Pipe</td>
<td>17/m</td>
<td>2 m</td>
</tr>
<tr>
<td>Evacuated Pipe</td>
<td>50/m</td>
<td>2 m</td>
</tr>
<tr>
<td>Low Consumption Pump</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>PV Panel</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Insulated Pipes</td>
<td>5/m</td>
<td>2 m</td>
</tr>
<tr>
<td>Normal Pipes</td>
<td>5/m</td>
<td>2 m</td>
</tr>
<tr>
<td>Storage Tank</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>Condenser</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td>441.9</td>
</tr>
</tbody>
</table>

Table 4 Cost Analysis of the System

Without the condenser, the total cost of our system is about $442, and we are assuming that the condenser won’t be very expensive since it doesn’t work on electricity. Overall, we are not expecting the total cost of the system to exceed $500 or it could exceed our expectations by a few dollars.
12. **Maintenance**

For a longer life time and better performance, maintenance is important for this kind of projects since it’s exposed to the harsh conditions of the environment. Starting by the parabolic trough, it needs to be cleaned regularly to remove dirt and dust and also for better reflectivity. Concerning the heat exchanger, it’s actually where salt and dirt will be accumulated and regular cleaning is required to for better conduction between the coils and brackish water. Fortunately, we won’t need to clean any pipe in the system because it’s designed to prevent any calcinations in tubes.
13. Conclusion

Since engineering is a problem solving practice, our problem was the lack of drinkable water in a rural area like Ouarzazate, and our suggestion was a parabolic trough collector solar collector. At first, we chose the region, and based on it, we made our calculations according to the climate conditions in Ouarzazate. Second, we calculated the needed energy to heat up water from 18.9 °C, which is the annual air temperature to 120 °C, and based on the required energy and the region of implementation, we calculated the area of the parabolic trough. After that, we found all the calculations regarding the dimensions of the parabolic trough, focal point and arc length. Moreover, we calculated the thermal losses from the system using heat transfer analysis. Then, we used Reynolds number to study the nature of flow. Also, we were able to calculate the geometric concentration ratio and the efficiency of the trough to be 88%. We also explained the purpose behind using our materials and what are the advantages and disadvantages for each one of them. After, we explained the whole cycle and part by part with their Solidworks designs. At the end, we designed a desalination system with respect to our constraints, which are portable, applicable, and cheap.
14. References


14.1 Reference of Pictures