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System Design for Freon Driven Solar Thermal Pump

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Abstract: ***Unlike other Solar Pumps, here is a concept where we don't need to use Solar photo-voltaic cells to generate electricity to run the pump. Instead, we directly absorb solar heat from the solar radiation to heat up a working fluid, turn it into vapour and use the pressure developed by this volumetric expansion to create a reciprocating motion which can run a pump to pump out ground water. This pumped out water is further used for condensing the vaporised working fluid back to liquid state so that it can be returned back to the cycle. Solar collectors can achieve temperaturesupto 200ºC and much more. The trick is to use a low boiling point working fluid such as Freon R-11. It has a typical boiling point of around 22ºC. So, even if a temperature of 100ºC is applied, we can derive high pressure vapour and this can be utilised to run the pump. A Solar photo-voltaic cell has a maximum efficiency upto 29%, but this system is expected to have much more efficiency.***

Keywords: Solar Thermal, Pump, Renewable Energy

1. Introduction

The project, *Solar Thermal Pump*, deals with the utilization of solar thermal energy to run a pump. Conventional Solar Pumps use Solar Photovoltaic cells to generate electricity which later runs the pumps. There is a huge loss of energy in the process as the efficiency of the commercial solar photovoltaic cells range merely from 9-14 %. Therefore, the need of alternative method of solar power harvesting arises.

The concept of Solar Thermal Pumps is very simple. It absorbs the solar heat, and heats up the *working fluid,* which is a liquid of low boiling point, to generate vapor. During this process, the volume increases, and this increase in volume creates a pressure on the container walls. If this pressure is channeled, it can perform work.

In a Solar Thermal Pump, this pressure is channeled to generate a to and fro motion or reciprocating motion with the help of an External Combustion Engine also known as ECE. This motion is used to pump the water. The pumped water is further used to cool the vapors, thus, eliminating the need of a separate condenser.

2. Components to be Used

The Main components of the Solar Thermal Pump will be:
1) Compound Parabolic Solar Collector
2) Storage tank for working fluid
3) External Combustion Engine
4) Condenser
5) Freon pipes
6) Water pipes

3. Study and Redesign of the Compound Parabolic Solar Collector

First we need to study the existing Compound Parabolic Solar Collector available in the market and redesign it to achieve higher output from the apparatus.

3.1 Studying the Existing System

A Solar CPC was collected from the market, manufactured by Maharishi Solar situated at Noida. The ratings of the system are mentioned were noted down. Now, in order to study the optical properties, a hand-sketched diagram was drawn as mentioned next. The optical angles are mentioned here. The dimensions of length are mentioned in decimetres and the angles are mentioned in degrees.

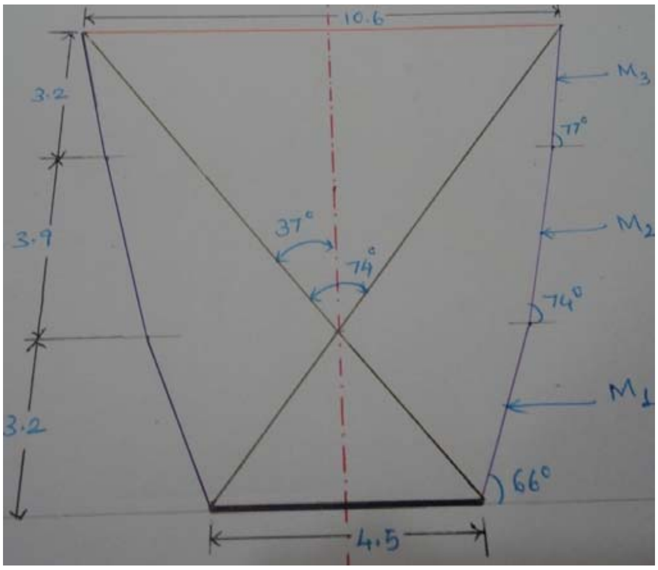

Figure 1: Dimensional details of the existing CPC
Geometric C = 2.36 and maximum C = 1.66

Only intermittent tracking is required. This depends on the value of concentration ratio and the allowed angular offset for the incident rays on the aperture plane. Hence it becomes important to know the amount of energy reaching the target w.r.t different solar incident angles. This analysis is done by edge-ray principle as explained in the following figure:

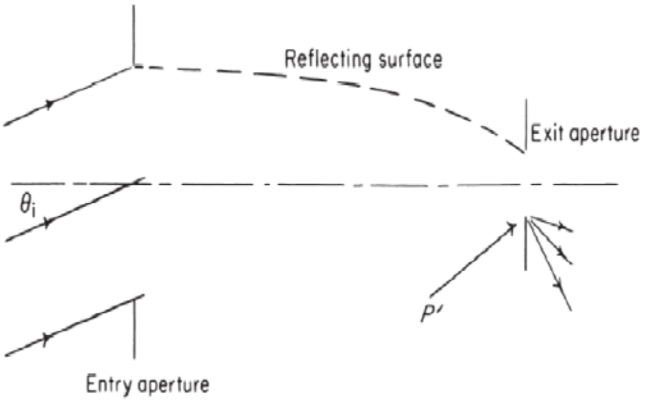

Figure 2: Edge Ray Principle

It is required that all the rays entering at the extreme collecting angle θ_i shall emerge through the rim point P of the exit aperture. For a concentrating collector the amount of diffused radiation that can be collected is given by 1/CR. The general Concentration Ratio for a CPC is around 3-10. Thus the advantage of a CPC is that it can collect diffuse radiation too. Thus its performance is satisfactory in cloudy atmosphere also. For an ideal two-dimensional CPC system concentration ratio relationship is

$$\mathbf{C = 1/\sin \theta_a} \qquad \text{..........(Eq. 1)}$$

Hence, the ray tracing analysis shows that an offset angle of 10^o and 15^o can be allowed. An offset of 10^o is considered here and accordingly the slope for different days is calculated by the empirical equations coming next. For a plane rotated about a horizontal east-west axis with a single daily adjustment so that the beam radiation is normal to the surface at noon each day.

$$\cos \theta = \sin^2 \delta + \cos^2 \delta \cos \omega \qquad \text{(Eq. 2)}$$

The slope of this surface will be fixed for each day and will be

$$\boldsymbol{\beta = |\phi - \delta|} \qquad \text{(Eq. 3)}$$

After studying these details, the hourly optical efficiency was noted down for the entire day, and the details were plotted in a graph as follows:

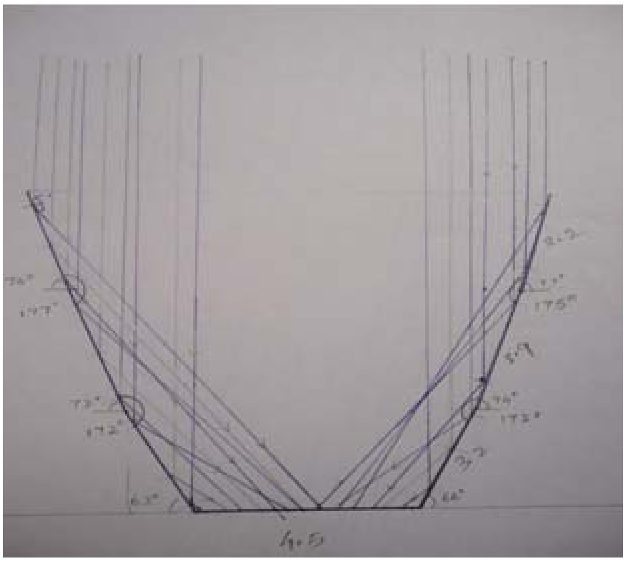

Figure 3: Ray tracing for 0º Incidence Angle

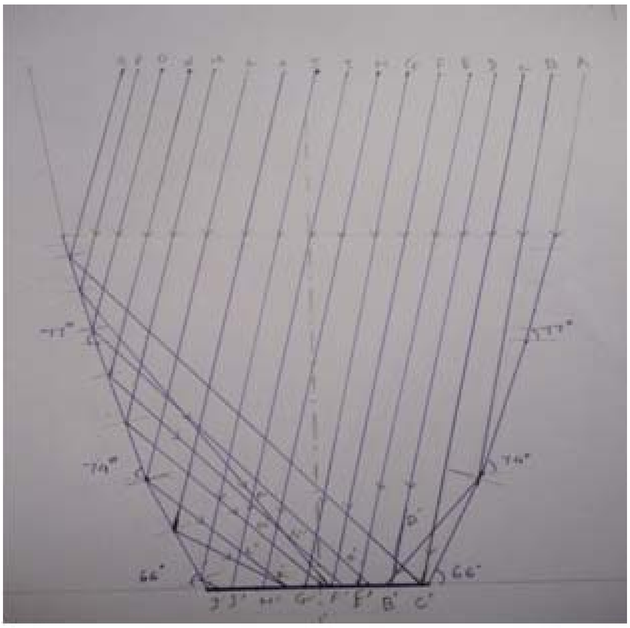

Figure 4: Ray tracing for 10º Incidence Angle

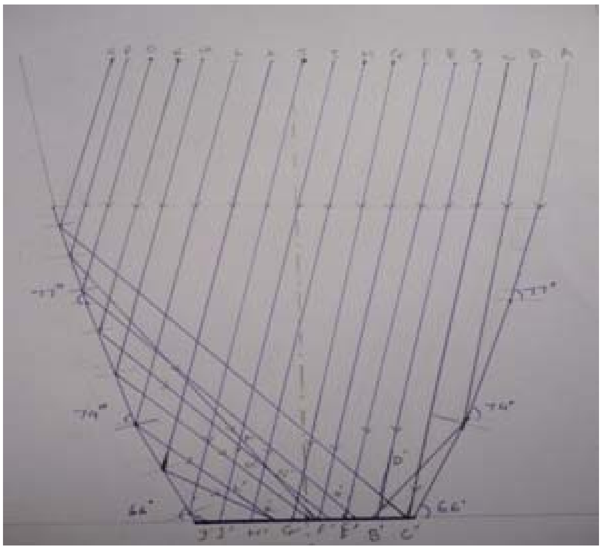

Figure 5: Ray tracing for 15º Incidence Angle

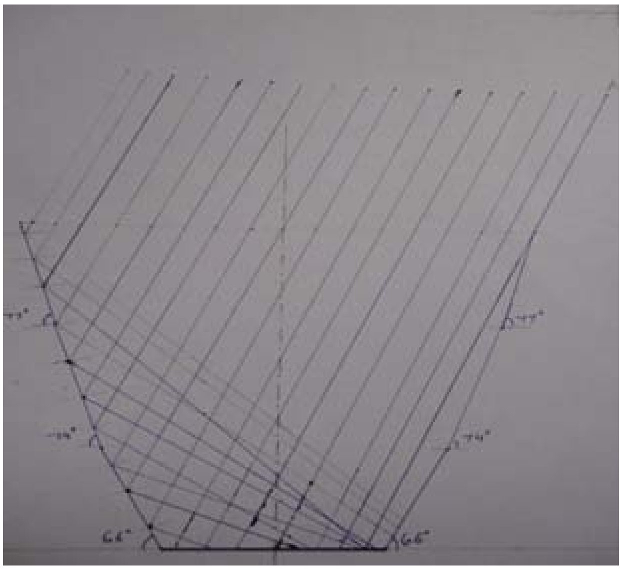

Figure 6: Ray tracing for 20º Incidence Angle

After studying these details, the hourly optical efficiency was noted down for the entire day, and the details were plotted in a graph as follows:

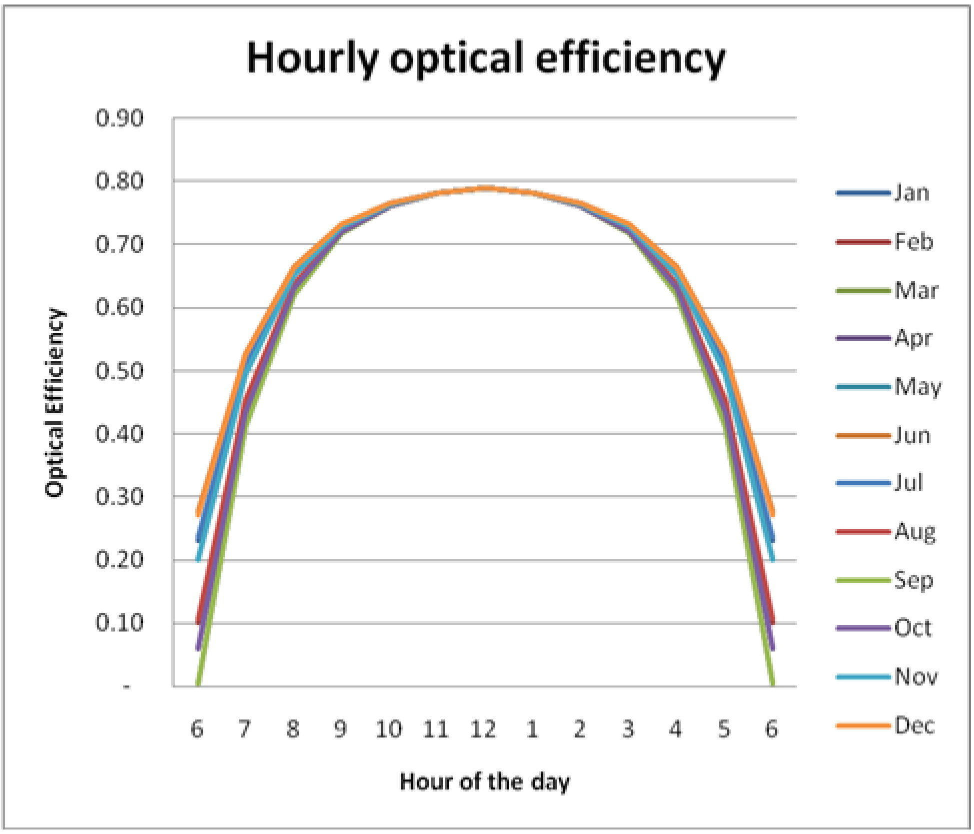

Figure 7: Optical efficiency Vs. time graph

Also, the heat intercepted by the collector was noted down for a whole year, and the graph obtained by plotting the values is shown below.

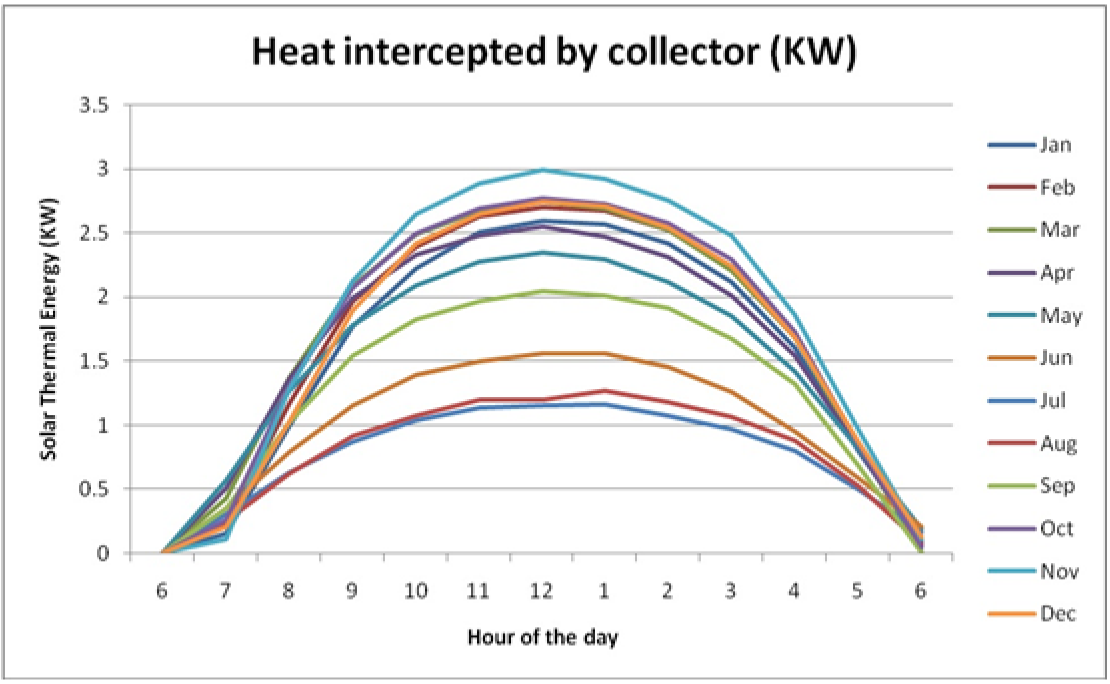

Figure 8: Heat intercepted by the collector Vs. the hours of the day around the year in graphical form.

3.2. New Model Design

In order to obtain higher outputs from the Compound parabolic collector, the system needs to be redesigned. We changed the dimensions of the existing system and achievedbetterresults. The details of these modifications are presented below:

With these modifications, the ray tracing was again done for 0º and 10º incidence angle. The hand sketch canned copies are shown on the next page. It has been confirmed by observation that the new design yields better output. The heat intercepted by the collector (in kW) was also noted down and the graph was plotted, which showed a good increase in the output power.

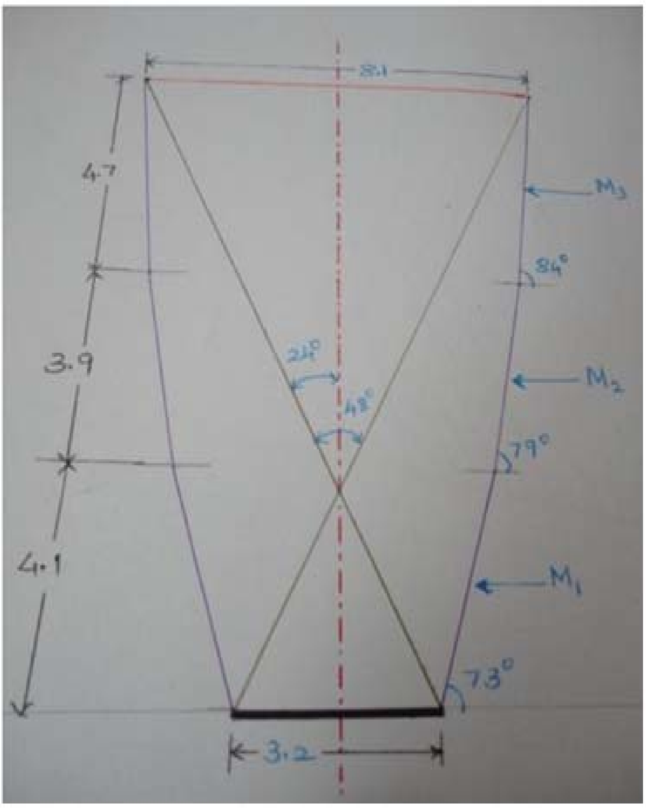

Figure 9: New design for the Compound Parabolic Collector

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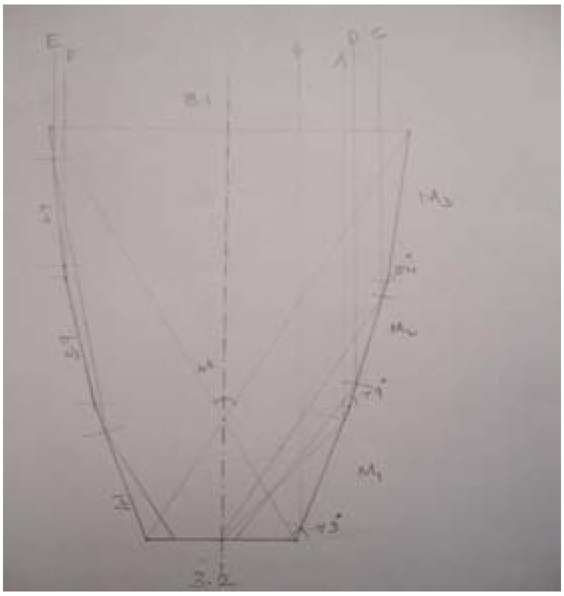

Figure 10: Ray tracing for 0º incidence angle

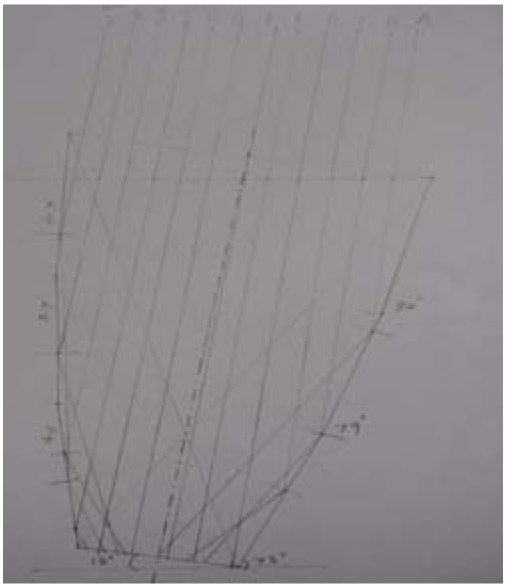

Figure 11: Ray tracing for 10º incidence angle

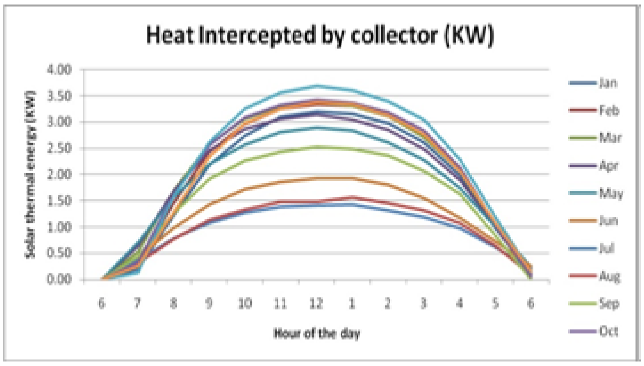

Figure 12: Graphical presentation of Heat intercepted by Collector Vs. Hours of the day

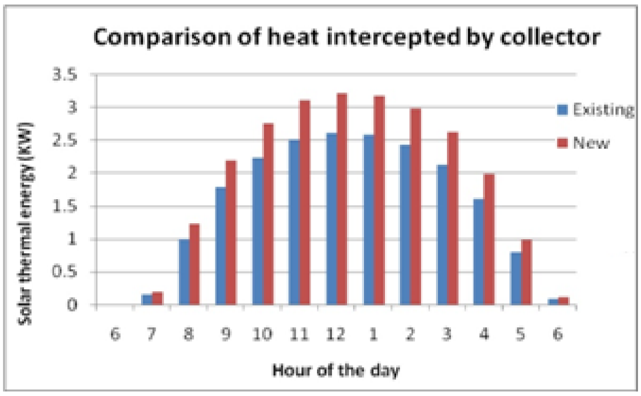

Figure 13: Comparison of the existing and newly designed system

Thus, we are achieving higher heat interception using the new design of the Compound Parabolic Solar Collector. This design is to be used in the Solar thermal Pump to achieve optimal efficiency.

4. Choosing the Working Fluid

After considering a number of fluids, Freon R-11 came out to be the most suitable fluid to start with. It has a boiling point of 23.6°C (74.5°F), vapour pressure of 12.8 psia at 68ºF, vapour density of 5.89 at 23.8ºC and 37.4 at 93.3ºC. Based on these properties, it is an ideal fluid to start with, as the working fluid.

5. Working Mechanism

The working mechanism of the pump is quite simple. The working mechanism can be divided into four parts. These four parts are briefly described below:

5.1 Heating up of Working fluid

The working fluid or the Freon R-11 will be heated up and converted into super-heated vapour using the Compound Parabolic Collector. The boiling point of Freon R-11 is about 23ºC and the temperature achieved by the Solar CPC is about 150-200ºC. Thus, we can easily achieve super-heated vapour using the collectors.

5.2 Running the Engine

The engine used here is quite similar to an external combustion engine. The super-heated vapour enters the cylinder and due to volumetric pressure, it pushes the piston back till it reaches the release valve. Once the piston moves past the release valve, the vapour is released and the restoring spring pushes the piston back to its rest position. There it is again ready for another cycle of reciprocating motion.

5.3 Pumping

This reciprocating motion is used to pump water. The mechanism can be quite simple and similar to a hand-pump as well.

5.4 Condensation of the Working Fluid

Using the water pumped out, the working fluid can be cooled and returned back to the storage tank where it can be proceeded again for another cycle of operations.

6. Historical Prospects

The Solar Thermal Pump design was first attempted by Bharat Heavy Electricals Limited in the 1980's. But later, the idea was dropped as Solar PV cell operated Solar Pumps gained more and more popularity. But, BHEL planned this pump with water as working fluid, and the key idea employed here is to use a low boiling point liquid (Freon R-11) as the working fluid. The reason being, by the temperature achieved by the Solar collector, this working fluid can be turned into high pressure steam, which can provide good efficiency to the pump.

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