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Design and Analysis of Solar Water Purification System

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Abstract - *Pure and clean drinkable water is an urgent need, Often water sources does contain harmful bacteria's therefore they cannot be used for drinking purpose. Pure and clean water is also required in some industries, hospitals, labs and schools. To decontaminate the water a distillation is one the process that can be used for purification of water. For that process heat energy is required and it can be obtained from solar radiation. In this process, water is heated and get evaporated, due to density difference water becomes vapour and foreign particle removes from it and then it is condensed in condensing chamber/solar still as a result we get highly pure water by using a solar still coupled with "parabolic trough solar collector". It was observed that the amount of purified or distilled water from the solar still coupled with "parabolic trough solar collector" as compare to a typical solar still.*

Key Words: **condensation, evaporation, distillation, solar radiation, parabolic trough solar collector etc…**

1. INTRODUCTION

It is best known that sun is the sole most reliable supply of energy where bright light and heat emitting from it, is being harnessed by humans since the past using a variety of ever evolving technologies and practices. Such practices might include the removal of undesirable chemicals, substance, materials and biological contaminants from water, which is known as the decontamination of water. Most of the water is impure for human application specially for drinking however water purification process may also be designed for a various purposes, such as medical, pharmaceutical, labs and industrial applications. There are various purification process for water treatment like filtration, chlorination, distillation, boiling etc. Distillation is one of the processes for water purification, and sun radiation is one amongst many forms of heat which can be used to power that method. Sun radiation has the advantage of zero fuel cost and it is free from emission. Water purification involves removing various waterborne pathogens (disease which carries organisms) the sun provides key elements that destroy the pathogens. Solar water purification system is one of the system which can used for purification of water. It works on the principle of evaporation and condensation this is also called as distillation with additional use of parabolic trough solar collector it is a combination of two water purification process, solar water disinfection system (SODIS) and the solar distillation process. This purification process involves purifying water for household and drinking purposes, by using solar energy for water purification now a days become more common as it is usually a low-cost technology solution that captures the heat energy from the sun to create water cleaner and safer for human use. This water treatment is particularly beneficent for those who lives in rural areas, as they don't have any other forms of infrastructure for water treatment and more important, electricity is also a major concern there. The best thing about the solar water purification system is that it does not require any fuel or electricity it also good for the environment.

2. Methodology

The design methodology of this project includes a design of a thermosyphonic based solar water purification system it consist of two major component one is condensing basin also called as solar still and other one is parabolic trough solar collector. The analysis is carried of condensing basin as well as parabolic trough solar collector. This water purification system is designed for the estimated output of about 4 to 5 liters per day which is sufficient for our requirement.

2.1 Design Calculation

a) Parabola Design

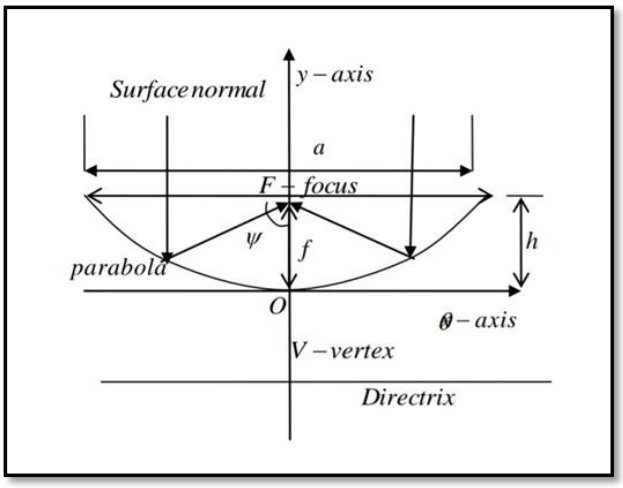

Fig -1: Nomenclature of Parabola [1]

Basically parabola is a conic section, created by the intersection of a right circular conical surface and a plane parallel to a generating straight line of that surface. Another

method to generate a parabola is to examine a focus point and a line on a plane. The locus of points in that plane that are equidistant from both the line and point is a parabola.

The line passing through the focus and perpendicular to the directrix (the line through which parabola split through the middle) is called as "axis of symmetry". Axis of symmetry has the point through which parabola is intersected is known as "vertex", and the curvature is greatest at that point. Parabolas can open right, left, up and down or in some other arbitrary direction.

a) Parabola Design Specification

Diameter (d) = 0.15 m
Depth (h) = 0.035 m

Focal point can be determined as $f = \frac{a^2}{16 \times h}$

Where, f = focal length (m)
a = Aperture (m)
h = Depth of parabolic collector

$f = \frac{0.150}{16 \times 0.035} \rightarrow$ 0.04 m or 40.17 mm

Verification of Results

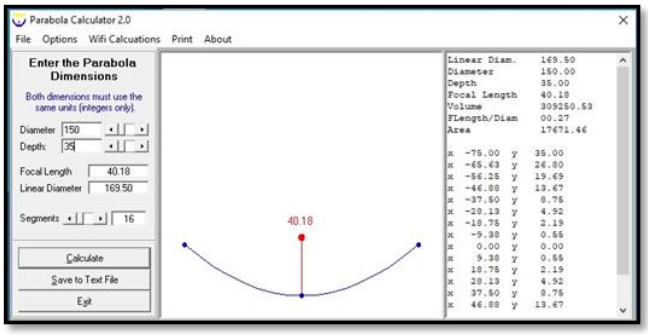

Fig -2: Parabola Calculation Result Verification

The above results are obtained it is verified by using the software called parabolic calculator 2.0 which is a very helpful tool in finding out the focal length and some other important parameters of a parabola. This is a freeware program which is written to help students to design the solar collector. This software calculates the focal length and (x, y) coordinates for a parabola of any given diameter and depth. It helps us to finalize what size and shape parabola to make it gives the result very quickly and the interface of this software is very simple to use.

b) Optical design of parabolic collector

* Concentration Ratio:-

The concentration ratio of a parabolic trough solar collector is define as the ratio of parabolic collector aperture area to the total area of the absorber tube / receiver tube.

$$\text{Concentration Ratio} = \frac{\text{Aperture Area}}{\text{Receiver Area}}$$

Where, Aperture Area (Aa) = width of collector × length of collector

$= 0.366\ m^2$

Receiver Area (Ar) = π × do × L

$= 0.115\ m^2$

Concentration ratio (CR) can be calculated as,

$CR = \frac{0.366}{0.115} = 3.2$

c) Thermal Analysis

Solar irradiation, I = 1367 W/m^2 (referred from research paper Solar Irradiation)
Radiation available on solar collector,

Q = I × Ac

Where, Ac = Area of parabolic collector

$\therefore$ Q = 1367 × 0.3721

Q = 508.66 Watt

* Temperature on solar parabolic collector (Tc)
According to Stefan Boltzman Law

Tc = 466.48°C

* Heat Available on concentrator after reflecting solar radiation from parabolic collector

$Q_{con} = Q \times \rho$

Where ρ = Reflectivity of material $\rho = 0.8 \rightarrow$ Aluminium foil

= 508.66 × 0.8

Q_{con} = 406.9 W

* Temp of concentrator (T_{con})

T_{con} = 77.14°C

* Mass flow rate through concentrator

$m = \rho AV$

Where, ρ = Density of fluid flowing

V = Velocity of fluid

$\therefore$ But initially the tank of dirty water is elevated from datum (ground) at a certain height by law of conservation of energy, fluid possess some potential energy, and this converted into kinetic energy

$\therefore$ Potential energy = Kinetic energy

$mgh = \frac{1}{2} mV^2$

$V = \sqrt{2gh}$

$$V = \sqrt{2 \times 9.81 \times 1.22}$$

$$V = 4.5 \text{ m/s}$$

$$m = 998 \times 1.327 \times 10^{-4} \times 4.5$$

$$m = 0.5 \text{ kg/s}$$

* Discharge/Volume flow rate

$$Q = A \times V$$

$$Q = 5.97 \times 10^{-4} \text{ m}^3/\text{s}$$

d) Water Purification rate

Now,
We just analyse that maximum sunshine hours is 5 hours throughout the day.
So total Heat available is

$$Q = 406 \times 5 \times 3600$$

$$Q = 7308 \text{ KJ}$$

∴ Energy balanced equation for unsteady state

$$m_1 \left(h_1 + \frac{v1^2}{2}\right) + Q = m_2 \left(h_2 + \frac{v2^2}{2}\right)$$

Where,
Initial Mass of dirty water = 5kg
Enthalpy of saturated water (h_1) at 30°C = 125.7 KJ/Kg
Enthalpy of water (h_2) at 100°C = 2257.9 KJ/Kg
m_2 = mass of purified water (Kg)

$$\therefore 5 \left[125.7 \times 10^3 + \frac{(4.5)^2}{2}\right] + 7308 \times 10^3 = m_2 \left[2257.9 \times 10^3 + \frac{(5.043)^2}{2}\right]$$

$$m_2 = 3.5 \text{ Kg}$$

Theoretically,

$$\% \text{ of purified water} = \frac{\text{Water Output}}{\text{Water Input}}$$

$$= \frac{3.5}{5} \times 100$$

% of purified water = 70%

d) Construction

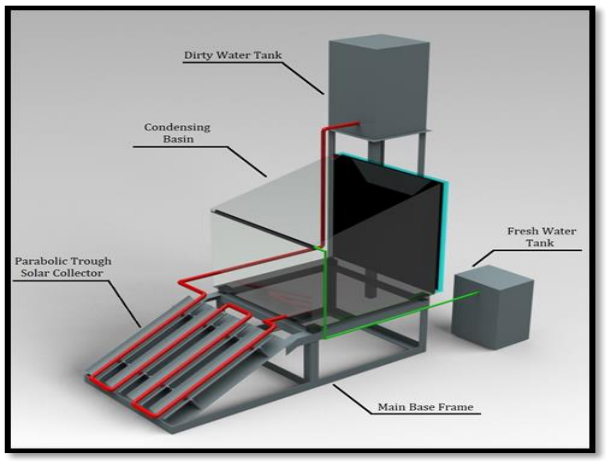

Fig -3: Assembly CAD model of solar water purifier

The system consist of four main following components as explained below.

1) Main Base frame:-

The main base frame also called as stand it is nothing but the structure made up of mild steel by using 1.5 inch L shape fabricating angle which is made up of mild steel all the component of the solar purifier will be mounted on it like condensing basin solar collector solar collector supporting plate as it a base of our purifier so that it should be enough strong to hold all the component so that it can withstand the load of all the component mounted on it.

2) Condensing Basin:-

Condensing basin is one of the most important part where the evaporations of water will takes place that evaporated water will stick to the top wall glass cover which is inclined water drops will slide through this glass and collected at the end through half tube which is connected to outlet water tube and fresh water will be collected in separate chamber.

The size of the condensing basin is 2x2 ft. and top glass cover is inclined. Selection of proper material of the basin is very important. Most feasible material for basin is Galvanized Iron sheet because of its good thermal and mechanical properties. First talking about its properties, Galvanized Iron is a corrosive resistance which is most important because inside the condensing basin hot evaporated water is condensed and convert it into a liquid phase. A wall of glass wool is attached to the galvanize iron sheet wall to avoid the heat loss glass wool is a good insulator its thermal conductivity is 0.0343 W/mk. It is fire proof till 300°C, It has excellent tensile strength, it is lightweight and easily available in the market. The inner walls of the condensing basin will be painted with black

colour so it act as a black body which helps to carry the maximum radiation incident on it.

3) Parabolic trough Solar Collector:-

Now solar collector and concentrator are second most important part of model. solar collector made up of polished aluminium it has a good thermal conductivity as well as good reflectivity of radiation. This polished surface helps to reflect all the sun radiation towards the concentrator to heat up the water as fast as possible. Second property of this material is super lightweight as compare to other reflective materials like anodized aluminium and other alloy of aluminium. Using a sheet of 2 to 3mm thick and parabolic shape of radius 75 mm to concentrate all the radiation at a single point or line of concentrator.

4) Four Pass copper Tube:-

Concentrator has a copper tube of 15 mm outer diameter and consist of "4" number of passes. Copper is selected because of its thermal conductivity which is around 385 W/mK. Likewise silver has a high thermal conductivity as compare to copper but it is expensive, selecting copper is most optimum between silver copper.

e) Working

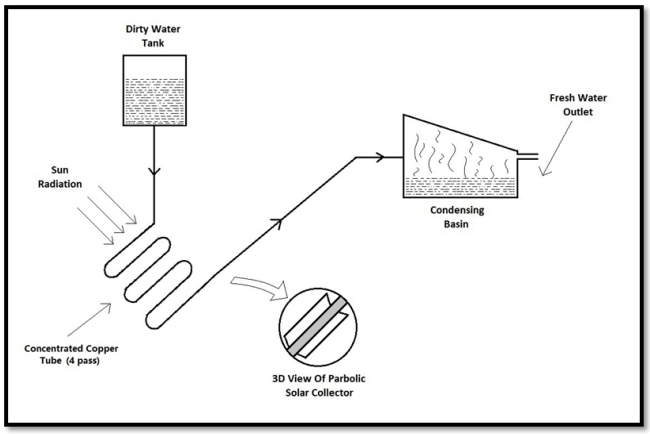

Fig -4: Schematic diagram of the system

First the water is coming from the dirty water tank whose temperature is not that much high it is around 26 to 27°C then it enters into the four pass copper tube which has four passes where waters gets heated due concentrated sun radiation its temperature increases the outlet of the copper tube is connected with condensing basin through which water enters into the condensing basin where it gets heated more as the condensing basin has a top glass cover which also allows some radiation to enter into the condensing basin the inner wall is painted in black color which acts as a black body to trap more heat. As time passes heated water try to evaporate and gets condensed on the top glass cover. The evaporated water stick to the top glass cover in the form of droplets and it gets collected through the outlet tube and it goes into separate fresh water storage tank.

Table -1: Dimensions and Material selection

Sr. No	Component	Dimensions	Material
1	Main Base Frame	2 Ft x 4 Ft 1.5 inch L Angle	Mild Steel
2	Parabolic trough Solar Collector	R75-600 mm	Aluminium
3	Copper Tube	R10 x 9 Ft	Copper
4	Condensing Basin	2 Ft x 2 Ft 1.8 Ft Height &30°	G.I sheet & Glass sheet
5	Dirty Water Tank	1.5 Ft x 0.5 Ft x 0.5 Ft	G.I Sheet
6	Dirty Water Tank Stand	0.5 Ft x 0.5 Ft x 4 Ft 1.5 in L Angle	Mild steel

CONCLUSION

This solar water purifier is designed and analyzed under the consideration solar radiation. This analysis permits to examine the influence of some internal and external parameter on the operating system. The analysis gave the result that dirty water heated from normal ambient temperature to 327K (54°C) water is partially vaporize, By taking the design parameter under the consideration of unsteady state and a time period of 5 sunshine hours. Hence, theoretical purification rate of water is around 3.5 to 4 Litres per day. So efficiency of solar water purifier is around 70%.

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