Design of a Solar Distillation Plant

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Abstract— Parabolic collectors are used to collect the energy from the sun. And water purification is one of the fore most issue now a day a human is facing in rural areas, urban areas and also chemical industries. In the present work a case study has been carried out at SUES campus pharmacy laboratory to supply the distilled water and to carry out the experiments. The design for the Solar distillation plant works under the principle of concentrating the Sun's energy on a thermally conducting water tube to heat up the flowing water to vapour, there after it gets condensed and is later collected it in a pure form of water used for laboratories. The distillation is the requirements for this specific design are a target for distilling 80 litres of water per day regularly with low maintenance.

Keywords— Water Distillation, Solar collector, Concentrator, Design tube.

I. INTRODUCTION

Renewable energy is a form of energy which is not depleted till the world is alive. There are many energy sources out of which commonly use is solar energy and wind energy. Parabolic collector is one of the solar collectors used to trap energy from the sun. The principle behind this collector is evaporation and condensation process. Solar distillation technique is of the most useful method of extraction of distilled water from the source of sun.

This water is used to produce potable drinking water and also to produce water for lead acid batteries or in chemical laboratories. The level of dissolved solids in solar distilled water is approximately close to 3 ppm and bacteria free. The distillation is the requirements for this specific design are a target for distilling 80 litres of water per day regularly with low maintenance.

The process starts from the Sun that acts as the prime source of energy. An array of metal sheets act as a reflecting surfaces that reflects the energy carrying sunrays to their focus. These sheets are shaped parabolic and hence called parabolic concentrators. On the focal point of each of the concentrator is a metal tube that is designed to carry the feed water to be heated. The tube gets its required heat from the reflected solar energy and heats up the water to its vapour form. The heated vapour develops a pressure that is driven out from a vapour exit knob. As the process has a complete entry and exit scheme, it runs as a complete cycle until the source water is completely distilled and collected by a condenser mechanism.

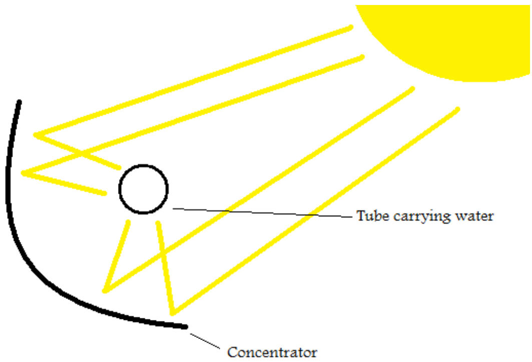

Fig. 1: Concentrator focusing the suns energy on the tube system.

II. BLOCK DAIGRAM

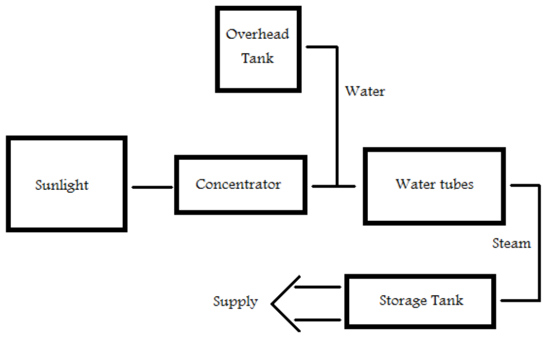

Fig. 2: shows the block diagram of the system

The design comprises of the following parts:

1. The Overhead tank
2. The parabolic concentrator
3. The central tubes
4. The water feed tubes
5. The vapour collector tubes
6. The condenser

The Overhead Tank: a tank is provided to send in water continually and systematically. Water is stored here before hand before the distillation system begins operation. Also the advantage is that water gets preheated due to direct incidence of sunlight on the tank before operation. The overhead tank is constructed of Aluminium. Two such tanks each of 40 ltr are provided to cater to the operation of 2 panels each.

Parabolic Concentrator: The concentrator being parabolic has the tendency to focus the rays on its eccentricity therefore the tube is heated in a short period of time. The parabolic concentrator must possess the quality of high thermally radiating nature with high radiating coefficients of 0.6- 0.9. There are several available materials that provide these qualities within economic costs due to the ease in availability. However, a coating of Aluminium plate on a good radiating metallic material ensures the best radiance of about 0.8.

The concentrators here are taken to be 75mm in diameter and 2m long, This feature is taken keeping in mind that heat has to be concentrated on to as less an area as possible for better utilization of the incoming resources.

Central Tubes: The design of the tube is special as it has to equally distribute the heat in all directions by maintaining equal thermal stresses on all portions of the tube.

The important points to be considered in designing the tube must be:

1. High thermal conductive capacity of the tube metal.

2. Lower thermal expansion of the material.

3. Equal distribution of thermal stresses in order to prevent thermal shocks and eventual cracking of the material.

4. Low corrosive nature and better life.

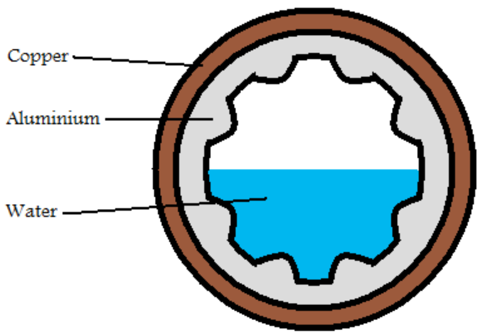

Fig. 3: shows the cross-section of the tube system with different materials coloured accordingly

The material that best suits the above features is copper. Copper tubes are vastly applicable in heating of materials in commercials designs. It possesses all the qualities of an ideal material for heating purposes. The table below compares the properties of the different materials that are closely competent with Copper. The materials have been given with regard to their linear expansion per degree Celsius of temperature, the thermal conductivity and the heat dissipating capacity expressed as specific heat of the material.

Table 1: Shows the different materials applicable for the design and their properties.

Material	Linear Expansion	Conductivity (W/m/°K)	Specific heat (J/gm°K)
Glass	3.3- 8.5	1.2- 1.4	0.84
Stainless Steel	17.3	16.3- 24	0.5
Copper	17	385	0.386
Aluminium	23	204	0.9

Thus, the design constitutes Cu to enable better conduction as well as non corrosive properties. The heated steam is pure and leaves out all the dissolved salts behind while boiling. These salts remain in the tube and the tube being non-corrosive, remain in an un-dissolved form.

These have to be released from time to time as they cause loss in the heat transfer. A provision has been provided by placing a Salt removal outlet. This outlet is activated and meant only for salt removal. For removing salt, this outlet is opened and a high pressure of water is flown from the Pressure monitor. This is the most robust and effective way for salt removal. The tubes are arranged in parallel to each other and at the focus of each concentrator. The diameter of each tube is 6mm. Diameter is indirectly proportional to the heat utilization of the tube. Hence, smaller the diameter more is its efficiency. These tubes are 28 in each panel and have individual entry and exit passages that are united at the common entry/exit points.

Advantages:

1. Simple and robust

2. Better heat management therefore better output.

3. Easy handling and lower management.

4. Occupies less space.

5. Absence of glass and other corrosive, heat absorptive materials.

6. Direct heating

Disadvantages:

1. Entry and exit tubes have to be specifically designed to cater to even distribution of water.

Water Feed tubes: Here, water has to be distributed equally and continuously. For this purpose, a specific tube is employed that has a decreasing diameter as the level of water is decreased (for distributing water to higher and lower level tubes equally). The inlet closer to the tank (higher level tube) has a diameter which continuously decreases as the water reached the bottom tube. According to the principle of Venturimeter, the pressure is increased and the level velocity is maintained. There is also a pressure knob to control the flow of water depending on the requirement.

Fig. 4 shows the exterior of the tube system

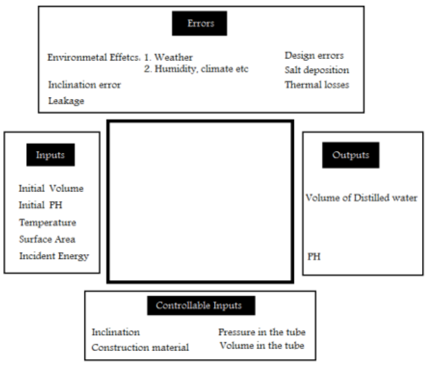

Fig. 5: shows the P-diagram of the system that considers the various input, output, error and controllable parameters.

Fig. 6 shows the solar angle calculator for various months.

The solar distillation plant consists of metal sheet (concentrator) which acts as a reflecting surface that reflects the energy carrying sunrays to their focus whose diameter is 75mm and is made of metal coated with aluminium. On the focal point is a metal tube which is made of Copper that is designed to carry the feed water to be heated which is 6mm in diameter. The whole setup has 50 such metal sheets with metal tubes at its focal point and each having a length of 2m which are arranged in parallel in such a way that it is inclined towards the sun, taking most of the sun rays into account. According to the data 20 long tubes are in 4 panels, 55m / panel. Assuming 2m long tubes, we need 28 tubes / panel. So, width of the panel is 2.1m (only for tubes) which is 4.2m panels (shown later in the calculations). This setup covers an area of 51m^2 approximately according to the mathematical calculations & solar radiation available for Hyderabad is 300 W / m^2 (changes from winter to summer, mainly summer).

The water which has to be distilled is taken from the over head tank; the water is evenly distributed among all the metal tubes at the rate of 6cc/sec or 0.006kg/sec & here the average velocity of water is 2mm / s which can be achieved by gravity. So heat required to raise the temperature up to 100^{0}C is 1.75KW (shown later in calculations). Finally the steam is collected and cooled. By minimizing values the flow has to be carefully controlled. The steam from the parallel panels to be collected together and cooled, using tap water to get the required 80litre distilled water.

III. SOLAR CALCULATION TO DETERMINE THE AMOUNT OF RADIATION

To calculate average density global and diffuse radiation on a horizontal surface at Hyderabad 17°27' north ,78°28' east during the month of may.

Average sunshine hours 12hrs

a=0.27 , b=0.5

$\overline{H}_g = \overline{H}_o[a+b(\overline{S}/\overline{S}_{max})]$ [2]

$\overline{H}_o$ = average density extra terrestrial radiation

For May, $\overline{H}_o = H_o$ on May15

Solar declination;

Where m=135

Δ=18.79°

Sunshine hour angle $W_s=\cos^{-1}[-\tan\Phi.\tan\delta]$

$=\cos[-\tan 17°27'.\tan 18.79]$

$=\cos[-0.10723]$

=96.156°

Day length $S_{max} = (2/15)W_s=(2/15)96.156=12.8$hour

$H_o=(24/\pi)1.353*3600[1+0.33\cos((360*135)/365)][(\pi/180)96.156*\sin17.5*\sin18.79+\cos17.5*\cos18.79 \quad *\sin 96.15]$

$H_o=35859.8$ KJ/m^2 day =415.04 w/m^2

$H_g=\overline{H}_o[a+b(\overline{S}/\overline{S}_{max})]$

=35859.8[0.27+0.5(12/12.8)]

Global radiation=26491 KJ/m^2 day=306 w/m^2

$\overline{H}_d/\overline{H}_g=1.411-1.696(\overline{H}_g/\overline{H}_o)$

Diffuse radiation H_d=26491[1.411-1.696*(26491/35859.8)]

=4188 KJ/m^2 =98.5 w/m^2

IV. SAMPLE PROBLEM TO CALCULATE THE EFFECT OF INDUCTION

Calculate the total insulation for a flat plate collector in Lucknow, where Φ, latitude 26°50'N date on 30th June, Tuesday 2PM (solar time). Collector surface is tilted by 20° to horizontal. Total radiation on a horizontal plane is 2.5 MJ/m^2 /hr. Diffuse no duration is 0.4. Ground reflectivity ρ=0.2?

Solution:-Given Φ=26.5°,β=20°,m=181 days

W=2*15=30°,I=2.5MJ/m^2/hr
(w= hour angle, 15°/hr)

ω=0 at noon

Solar declination δ=23.45[sin{(360/365)(284+m}]

δ=23.18° where m=181

R_b= (Beam radiation on tilted surface/beam radiation on horizontal surface)

R_b=(cos(Φ-β) cosδ.cosω+ sin(Φ-β)sinδ)/(cosΦcosδcosω+ sinΦsinδ) = 0.9436

I_c=I[R_b(1-I_d/I)+ I_d/I(1+cosβ/2)+ρ(1-cosβ)/2]

I_d=0.4(given)

ρ =0.2

I_c=2.4 mJ/m^2 hr =666 w/m^2

R=I_c/I=0.96

Total Insulation=2.4mJ/m ^{2} /hr

(I=2.5 mJ/m^2 /hr)

V. DESIGN CALCULATIONS:-

Water requirement 80lt. /day=20 lt. /hr

(assume for 4hrs working)

= (20*1000)/3600=5.55 cc/s =6 cc/s

=0.006 kg/s

Initial transfer 30°c,

Heat required to raise the temperature up to 100°c

= m Cp Δt

={0.006*4180*(100-30)}/1000 KW

=1.75 KW

Latent heat of steam (atm. Pressure) = 2256.7KJ/kg

Heat required=0.006*2256.7=13.54 KW

Total power requirement= 1.75+13.54=15.29KW=15.3KW

Solar radiation available for Hyderabad=300 w/m2

(Note: changes from winter to summer. This value for summer)

Area required for solar energy collection= (15.3*1000)/200

=25.5 m^2

An arrangement as in the design is suggested for the collector and water.

Inner diameter= 60mm

Outer diameter=75mm

All 75mm tubes are half tubes

Area available per meter=π (0.0751)

= 0.2355 m2/ m length

Length required =51/0.2355=216.56 m

≅ 220 m length

According to the data 220m length tubes in 4 panel, 55m /panel. Assuming 2m length tubes, we need 28 tubes /panel.

Width of the panel= 28* 75=2100mm

≅ 2.1 m (only for tubes)

2m*2.1m panels, 4 numbers accommodate this area.

Consider 6mm diameter tubes for water flow. We have 28*6mm diameter copper tubes for each panel.

Average velocity of water= (0.006 m3 /s)/ [(π/4)*0.006 *28*4 m2]

= 1.895 * 10-3 m /s = 2m/s

It can be achieved by gravity. By using value, the flow has to be carefully controlled .The steam from the parallel panels to be collected together and cooled using tap water to get the required distilled water.

VI. CONCLUSIONS

The following results were obtained after designing the solar collector the velocity to maintain for achieving the 81 liters of water in a day is 2m/s. The inner diameter of tube is 60mm, outer diameter 75mm. Total insulation required is 2.5 MJ/m^2/hr. Total radiation at declination 18.79°, hour angle 96.156°, day lenght 12.8hrs is 306 W/m^2. These data has been taken in to account in considerations for effective heat management for systems that are placed in mixed, temperate environmental conditions.

REFERENCES

[1]. Dr. Syed Nawazish Mehdi, Non Conventional Energy Sources.

[2]. Kothari D.P, Singal. K.C, Ranjan. Rakesh. Renewable Energy Sources and Emerging Technologies, PHI Publication

[3]. R.K Rajput, Non-conventional Energy Sources and Utilization (Energy Engineering), SChand Publications

[4]. S. Irfan Sadaq, S. Nawazish Mehdi, Ishrath M.M, Afroz Mehar, NBV. Lakshmi Kumari, "Performance Analysis of Solar Flat Plate

Collector", International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, Volume- 3, Issue-5, May-2015, PP: 69-74

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