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Experimental Verification and Analysis of Solar Parabolic Collector for Water Distillation

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Abstract—

The paper is concerned with an experimental study of parabolic trough collector with its sun tracking system designed and manufactured to facilitate rapid diffusion and widespread use of solar energy. The paper focuses on use of alternative source of energy (through suns radiation) which is easy to install, operate and maintain. Also, to improve the performance of solar concentrator, different geometries were evaluated with respect to their optical and energy conversion efficiency. To assure good performance and long technical lifetime of a concentrating system, the solar reflectance of the reflectors must be high and long term stable. During the research carried out, focus had been shifted from evaluation of the performance of concentrating solar collector to analysis of the optical properties of reflector and absorbing materials. The shift of focus was motivated by the need to assess long term system performance and possibilities of optimizing the optical efficiency or reducing costs by using new types of reflector materials and absorbing materials. The Solar Parabolic Trough Collector (SPTC) was fabricated in local workshops and the sun tracking system was assembled using electric and electronic components in the market, while the mechanical components making up the driving system were procured from the local market. The objective of the research is to obtain distilled water by heating it to a higher temperature by solar parabolic trough collector. Solar distillation is used to produce potable water or to produce water for lead acid batteries or in chemical laboratories as in this case. The level of dissolved solids in solar distilled water is less than 3 ppm and bacteria free. The requirements for this specific design are a target for distilling water regularly with low maintenance.

Keywords—

Solar parabolic collector, reflectors, distillation, maximum temperature, efficiency.

I. INTRODUCTION

The current industrial growth and environmental impacts show that solar energy for solar thermal power plants is the most promising of the unconventional energy sources. The most common commercially available solar power plants use parabolic trough concentrators.Solar energy is an exhaustible source of energy potentially capable of meeting a significant portion of all nations Future energy needs with a minimum of adverse environmental consequences. The current industrial growth and environmental impacts shows that solar energy for solar thermal plant is the most promising of unconventional energy source. The solar energy option has been identified as one of the promising alternative source for future. Solar thermal utilization is of great importance for environmental protection and conventional energy saving. In the next few years it is expected that millions of households in the world will be using solar energy as the trends in USA and Japan show. In India too, the Indian Renewable Energy Development Agency and the Ministry of Non-Conventional Energy Sources are formulating a programme to have solar energy in more than a million households in the next few years. However, the people's initiative is essential if the programme is to be successful. Form of Energy: Thermal energy. This energy is used for: Cooking/Heating, Drying/Timber seasoning, Distillation, Electricity/Powergeneration,Cooling,Refrigeration.Some of the gadgets and other devices:Solar cooker, Flat plate solar cookers, Concentrating collectors, Solar hot water systems (Domestic and Industrial), Solar pond, Solar hot air systems, Solar Dryers, Solar timber kilns, solar stills, Solar photovoltaic systems, Solar pond, Concentrating collectors, Power Tower, Air conditioning, Solar collectors, coupled to absorption, Refrigeration systems.

II. DISTILLATION OF WATER

Distilled water is water that has many of its impurities removed through distillation. Distillation involves boiling the water and then condensing the steam into a clean container. There are multiple types of distillation, but all of them depend on separating components of a mixture based on their different boiling points. In a nutshell, water is heated to its boiling point. Chemicals that boil off at a lower temperature are collected and discarded; substances that remain in a container after the water evaporates also are discarded. The water that is collected thus has a higher purity than the initial liquid. Municipal water supplies almost always contain trace components at levels, which are regulated to be safe for consumption. Some other components such as trace levels of aluminium may result from the treatment process (see water purification). Fluoride and other ions are not removed through conventional water filter treatments. However, distillation eliminates most impurities. Distilled water is also used for drinking water in arid seaside areas lacking sufficient freshwater, via desalination of seawater.

2.1 Solar Distillation

Solar distillation is the process in which the sun evaporates the water from lakes, rivers, oceans and other surface waters leaving salts and other minerals behind. This evaporated

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water eventually reaches the upper atmosphere where it re-condenses as clouds and precipitates back to the land. This is the basic principle behind the use of solar energy for distillation.

Figure 1: Model of Solar parabolic collector

As mentioned in the introduction, one of the limiting sources in desalination is the energy. What better energy source can be utilized than solar radiation? It is an intermittent, low-intensity, and very abundant energy source. Nearly 65 Btu are received by one square mile of land on a sunny, summer day. This amount is roughly equivalent to 15,000 barrels of petroleum. Heat or energy can be generated from solar energy to be used to operate a desalination process. It can also be used directly to distil water in equipment which both absorbs solar energy and serves as a distillation process.

The solar distillation method is fairly simple and is pretty much self-operating. Saline water is supplied either continuously or intermittently to a pool ranging in depths of approximately 1 inch to 1 foot. The bottom of the pool has a black surface which absorbs solar energy. The discards salts exit through a drain. A transparent cover composed of glass sheets or plastic film is supported above. These are arranged so that the surfaces slope downward into small troughs at their lower edges. These troughs are connected to channels or piping which transport the condensate to storage.

A majority of the solar energy is absorbed in the basin bottom with a small amount being absorbed by the salt water itself. Heat is absorbed by the salt water from the basin bottom, raising the temperature and vapor pressure of the water. Partial vaporization occurs and these vapors are transported upward to the transparent cover by convection covers. The cover is generally 10 to 30^{o} F cooler than the vapors and therefore condensation occurs. The condensation flows down the slope and collects in the troughs. The heat of condensation is transported through the cover and into the atmosphere. Only about half of the original feed is evaporated to prevent salt deposition onthe bottom of the tank. The rest goes to waste.

2.2 Basic Theory of Solar Parabolic Trough

The principle of the parabolic trough collector in solar radiation coming from the particular direction is collected over the area of the reflecting surface and in concentrated at the focus of the parabola, if the reflector is in the form of a trough of a parabolic cross-section, the solar radiation is focused along a line. Cylindrical parabolic concentrators are used in which absorber is placed along focus axis. In Parabolic trough collector, the surface area which absorbs solar radiations is very small compared to the area exposed to the Sun's rays. The cover may be flat glass or Fresnel lens. The sidewalls may be straight or curved as shown. The tubular receiver carries the fluid to be heated.The use of parabolic collectors gives optimum results with a parabolic collector; it must be steered so as to be pointed at the sun. Such steering involves substantial expense. A parabolic collector includes the receiver tube, the concentrator, power transmition, collector structure. The receiver is the element of the system where solar radiation is absorbed and converted to thermal energy. It includes an absorber tube, its associated glass cover, and insulations at its end.

2.3 Materials used

1. Highly Polished Aluminium Sheet as a reflector
2. Copper Tube as an absorber
3. Flexible ply as a backbone of the reflector
4. Plywood for Parabolic Support and Parabolic End.
5. Stainless steel pipe and copper couplings

Accessories:
1) Temperature Gauge
2) Pressure Gauge
3) Needle Valve
4) pH meter

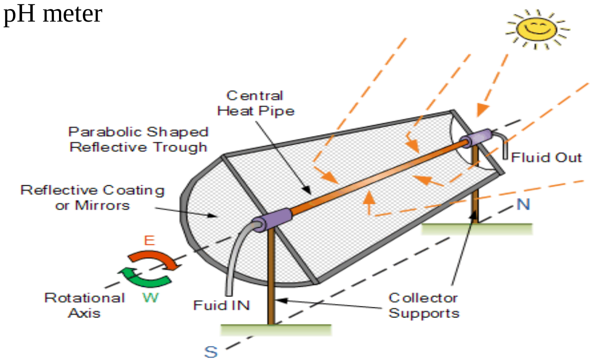


Figure-2: Principle of Parabolic Trough

III. Design of Parabolic Ends

From 8ft. x 4ft. plywood of 12mm thickness, two rectangular blocks of 48" x 36" were cut. Precise calculations for the base of the parabolic ends were done and the resultant points were marked on the plywood to cut one parabolic end into the desired shape using a manual wood cutter. Other parabolic end was given the same shape as the first one by placing it above the rectangular block. The focus was offset by 0.52mm to consider the thickness of highly polished Aluminium Sheet. A hole was made of diameter 19.1 mm at the focal distance from the vertex of the parabola for the pipe to pass through it.

3.1 Calculations for the parabolic End

Rim angle (ψ) = 95^{o}
Width (s) = 4ft

=1219.2mm

Aperture (W) = 2*s*tan (ψ/2) / [{sec (ψ/2)*tan (ψ/2)}+ln{sec(ψ/2)+tan(ψ/2)}]
= 2*1219.2*tan (47.5) / [{sec (47.5)*tan(47.5)}+ln{sec(47.5)+tan(47.5)}]
= 2661.046/[1.615+ln(1.480+1.09)]
= 2661.046/[1.615+0.943]
= 1040.28mm

Focal length (a) = W/[4*tan(ψ/2)]
= 1040.28/[4*tan(47.5)]
= 238.31mm

Equation of Parabola: $X^2 = 4*a*Y$
$X^2 = 4*238.31*Y$
$X^2 = 953.34*Y$

Figure-3: Solid work model and experimental design of Parabolic Ends.

3.2 Design of Parabolic Support

From 8ft. x 4ft. plywood sheet of 12mm thickness, two rectangular blocks of 42” x 36” were cut. These two blocks were further used to cut into the shape of pillars of required dimensions. From the same sheet two more rectangular blocks of 12’’ x 48’’ were cut which were used as the base for these pillars. A hole of 50mm was drilled into the parabolic support for bearing housing at the required height.

3.3 Assembly of Parabolic Trough Collector

` Parabolic trough was dissembled and improper parabolic ends were replaced by the properly designed parabolic ends. Also, flexi ply and highly polished aluminium sheet were unglued and fixed using a net and bolt assembly. This ensured a much better parabola for the reflecting surface. Absorber tube was inserted in the already drilled hole of both the new parabolic ends by keeping a distance of 4ft. 4in. between two ends. Then the flexible ply to which highly polished aluminium sheet was already bolted was attached to the base of the parabolic end with the help of nails to held it firmly and hence give the shape of the base of the parabolic end to the flexible ply. The entire assembly was mounted on the parabolic supports by inserting the pipe in the bearing one after the other. Temperature gauge and pressure gauge were attached to absorber pipe using the T-joints. At outlet of the absorber pipe tab was fitted.

Figure 4: Solid work model and Experimental setup of Solar Parabolic Collector.

IV. Testing & Results

Case – I : Testing

Inlet was taken from a tank at a height of 2m from the base of the parabolic trough. A transparent plastic pipe was use to connect the tank and inlet of the parabolic trough. Tab at the outlet was open by small amount. At the outlet a one litre beaker was placed initially to measure the mass flow rate of the water. Mass flow rate was found to be 4lt/hr. After checking the mass flow rate of water, the one litre beaker was replaced by a big beaker.

Conditions were good for testing. Weather was hot and there was no cloud cover blocking the direct (beam) radiations of the sun. Initial temperature of water in the tank was tested. It was 30^{o}c. Pressure gauge attached to flow pipe was showing a gauge pressure of 0.1bar. Testing was started at a local time of 9A.M. Temperature of water was measured after every one hour intervals. To ensure that the income beam radiations should always remain normal to the reflecting surface, parabolic trough was manually rotated after 15 minutes along with the sun about the focal line of the parabola and it was held in that position for 15 minutes by using strings. .

Initial pH of water was tested and it was found to be 6.10. Some water was collected in a small beaker around 1 pm considering that maximum temperature attained by the fluid will be at that time. This water was cooled to normal room temperature and tested for its pH.

Results :

Date: 27/03/2014.
Weather condition: Dry weather.
Minimum temp during observation: 30°C around 9am.

Maximum temp during observation: 104ºC around 1pm.
Initial pH of water: 6.10
Final pH of water: 6.85
Gauge Pressure: 0.1bar

Table 1:- Time vs Temperature

S.No.	Time	Temperature (^oC)
1	10 A.M.	50
2	11 A.M.	80
3	12 P.M.	100
4	01 P.M.	104
5	2 P.M.	102
6	03 P.M.	95
7	04 P.M.	90
8	05 P.M.	85

Calculation of Efficiency :

$\eta = Q / [A_c * H_b * R_b] * 100$
Where,

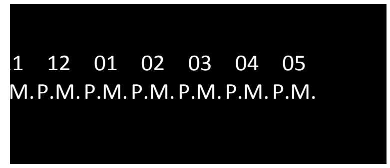
Q = Net useful heat gained by fluid (W)
$Q= mC_p(T_f-T_i)$
m = Mass flow rate of the fluid (Kg/sec)
C_p = Specific heat of fluid (J/KgK) = 4180 J/KgK for water
T_f = Maximum temperature attained by fluid (^oC)
Ti = Initial temperature of fluid (^oC)
A_c = Area of collector (m^2) = 1.49 m^2
H_b = Intensity of beam radiation (W/m^2) = 431.67 W/m^2 for Hyderabad
R_b = Tilt factor for beam radiation = 1 (Assuming collector is always normal to incoming beam radiations)

Mass flow rate (m) = 4ltr/hr
= 4kg/hr
= 0.00111kg/sec

Initial Temperature (T_i) = 30 ^oC
Maximum temperature (T_f) = 104 ^oC

Net useful heat gained by fluid (Q) = $mC_p(T_f-T_i)$
= 0.00111*4180*(104-30)= 343.688 W

Efficiency (η) = Q / [$A_c * H_b * R_b$] * 100
= 343.688/[1.49*431.67*1] *100
= 0.534*100 = 53.4%



Graph 1: Time vs Temperature on 27/03/2014

Case – II : Testing

It was open to carry out the testing for the entire day without sun’s radiations being blocked by the buildings or trees. Inlet was taken from a tab on the ground floor. Since water in this tab is coming from the tank above net height of the water was very high, approximately 32m from the base of the parabolic trough. Due to this height, pressure in the absorber pipe increased, increasing the boiling point of water. A transparent plastic pipe was use to connect the tab and inlet of the parabolic trough. Tab at the outlet was open by small amount. At the outlet a one litre beaker was placed initially to measure the mass flow rate of the water. Mass flow rate was found to be 4lt/hr. After checking the mass flow rate of water, the one litre beaker was replaced by a big beaker. Conditions were good for testing. Weather was very hot and there was no cloud cover blocking the direct (beam) radiations of the sun. Initial temperature of water in the tank was tested. It was 30^oc. Pressure gauge attached to flow pipe was showing a gauge pressure of 1bar. Testing was started at a local time of 9 A.M. Temperature of water was measured after every one hour intervals. To ensure that the income beam radiations should always remain normal to the reflecting surface, parabolic trough was manually rotated after 15 minutes along with the sun about the focal line of the parabola and it was held in that position for 15 minutes by using strings.

Initial pH of water was tested and it was found to be 6.10. Some water was collected in a small beaker around 1 pm considering that maximum temperature attained by the fluid will be at that time. This water was cooled to normal room temperature and tested for its pH.

Results :

Date: 30/03/2014.
Weather condition: Dry weather.
Minimum temp during observation: 30°C around 9am.
Maximum temp during observation: 106ºC around 1pm.
Initial pH of water: 6.10
Final pH of water: 6.90
Gauge Pressure: 1bar

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S.No.	Time	Temperature (^oC)
1	10 A.M.	50
2	11 A.M.	80
3	12 P.M.	102
4	01 P.M.	106
5	2 P.M.	101
6	03 P.M.	100
7	04 P.M.	98
8	05 P.M.	95

Calculation of Efficiency :

$\eta = Q / [A_c * H_b * R_b] * 100$
Where,

Q = Net useful heat gained by fluid (W)
$Q= mC_p(T_f-T_i)$
m = Mass flow rate of the fluid (Kg/sec)
C_p = Specific heat of fluid (J/KgK) = 4180 J/KgK for water
T_f = Maximum temperature attained by fluid (^oC)
Ti = Initial temperature of fluid (^oC)
A_c = Area of collector (m^2) = 1.49 m^2
H_b = Intensity of beam radiation (W/m^2) = 431.67 W/m^2 for Hyderabad
R_b = Tilt factor for beam radiation = 1 (Assuming collector is always normal to incoming beam radiations)

Mass flow rate (m) = 0.25ltr/hr
= 0.25kg/hr
= $6.94*10^{-5}$ kg/sec

Initial Temperature (T_i) = 30 ^oC
Maximum temperature (T_f) = 106 ^oC

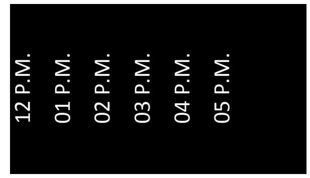
Net useful heat gained by fluid (Q) = $mC_p(T_f-T_i)$
= $6.94*10^{-5}*4180*(106-30)$ = 25.386 W

Latent heat of steam = 2256.7 KJ/Kg

Heat required to convert to steam = $6.94*10^{-5}*2256.7$ = 0.1566 KW = 156.61 W

Total Heat = 25.386 + 156.61 = 181.996 W

Efficiency (η) = $Q / [A_c * H_b * R_b] * 100$
= 181.996/[1.49*431.67*1] *100
= 0.2829*100
= 28.29%



Graph 2: Time vs Temperature on 30/03/2014

V. CONCLUSIONS

The results obtained in Case – I were great. Highest temperature obtained was 104^{o}C and efficiency of the parabolic trough was 53.4%. It was noted that heat was not sufficient enough for water to convert into steam but temperature of the water could go further more if water in the absorber pipe is at higher pressure. So, it was decided to test it a location where there is sufficient sunlight and pressure of the water is very high. Hence, the results obtained in Case – II were good. Highest temperature obtained was 106^{o}C and efficiency of the parabolic trough was 28.29%. Efficiency of the system was decreased but water was successfully converted into steam. The desired purpose of the research work was accomplished successfully which was to perform water distillation by heating the water to a higher temperature with the use of solar parabolic trough collector.

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