Design and Experimentation of Double Slope Desalination Unit Coupled with Photovoltaic Thermal Collector

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Abstract. Solar cells being highly sensitive to temperature, I-V characteristics of the cell get adversely affected with temperature rise. Solar insolation heats up the panel which may lead to the decrease in efficiency. For longer life of cells, waste heat produced has to be discarded. Hybrid photovoltaic solar thermal system consists of photovoltaic modules and thermal collector. Placing thermal collector at back side of panel helps in waste heat extraction (water/air/any substance can be used as fluid medium). If the fluid medium is water, it can be given to desalination unit which in turn helps to improve the solar still performance. The main problem solar still facing is its lower productivity. Feeding the preheated water from PV/T system is a feasible solution. This in turn improves system efficiency. This paper discusses a simple design of desalination unit coupled with photovoltaic thermal system and ways and means to improve the performance of desalination unit.

1. Introduction
Renewable energy is the non-toxic, harmless, eco-friendly type of energy. Solar, wind, geothermal, biomass, hydroelectric energy etc. are different forms of this energy. Among this, solar energy being an economic and highly reliable option, its use for energy production is fast increasing throughout the years.

Solar panels convert the sun’s incident radiation into electricity. This process is devoid of pollution. Photovoltaic cells are semiconductor cells. Increase in temperature reduces the band gap which further affects the semiconductor properties. One of the parameters that is being adversely affected by temperature is open circuit voltage ($V_{oc}$). There is slight increase in current with increase in temperature (shown in the graph). But this does not reduce the effect due to the decrease in voltage ($V_{oc}$).

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Numerous approaches to enhance the efficiency of solar panels have started since decades. One such option is placing of collector for extracting undesired heat from the modules. Flat plate collector, concentrated collector, evacuated tube collectors etc. are some types of collectors available. The main parts of thermal collector consists of absorber and fluid medium for collection of heat. Detailed review on PV/T system is given by T.T. Chow in [2]. Also, major developments in the design and experimentation of different collectors are explained. Mainly concentrated on air type and liquid type collectors. Detailed description about its design, performance and installation are given. Additionally an endeavour to investigate the design of concentrated collectors is done. Similar work was done by Anil Kumar et al. [3] in which main focus was given to PV/T in Indian subcontinent. Most works on PV/T were done on foreign climatic conditions. The circulation of fluids can be of two modes: active and passive circulation. Study on natural circulation of fluid in PV/T system is explained in [5]. Key role in photovoltaic energy conversion process is for operating temperature. A brief discussion on operating temperature of silicon based cells and temperature effect on cell efficiency has been done in [6].

Obtaining fresh water for drinking is major crisis world is facing today. Even though 75% of our earth is roofed with water, 97% is not portable. Solar distillation can be a feasible solution for obtaining fresh water especially for rustic zones. It is simple device used for distillation purpose which uses sun’s radiation to heat water inside the still. Water gets heated and evaporates and condense on cover glass at the top. Collected water is in pure form. This can be used for drinking purposes. Wide research on the performance of solar still influenced by different variables has been done by Chirag Rabadia [7]. The parameters influencing the yield can be tilt angle of system, insulation level, irradiance, wind velocity in the region and many other factors. As a step to improve efficiency, Fresnel lens [3] or solar concentrators can be used [8]. For different collector angles, various designs and experimentation were carried out for single slope solar still in [9]. A different method was taken by Ali et al., [10] using photo-catalysts. Doing so, the still performance was considerably increased. Experiments were conducted with nano-fluids by Elango et al. [11]. Relation of yield with water depth has been experimented by Bilal A Akash et al in [12]. Similar works are done in [13]. The waste heat collected finds useful in applications like solar water heating, space heating, agricultural drying, processing of water for industrial heating and many other purposes [14]. Test standards for thermosyphon solar water heating for domestic purposes is given in [15].

This paper put forward a practical approach to evaluate the solar still integration with PV/T system. Here main focus is given for obtaining more fresh water meanwhile improving the efficiency of solar panels.

2. Design Calculations
The hybrid system consists of PV-T and solar still. The desalination unit is coupled with PV-T system such a way that water enter in natural circulation mode.
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2.1. PV-T system
PV-T system consists of solar modules and thermal collector.

2.1.1. Solar modules. The present work uses a polycrystalline solar module of size 0.85 m x 0.679 m. The electrical data of module is given below:

Table 1. Electrical data of module

| Specifications                   | Value |
|----------------------------------|-------|
| Maximum rated power, $P_{\text{max}}$(W) | 70    |
| Open circuit voltage, $V_{\text{oc}}$(V)    | 22.1  |
| Rated voltage, $V_{\text{mpp}}$(V)          | 18.1  |
| Short circuit current, $I_{\text{sc}}$(A)   | 3.99  |
| Rated current, $I_{\text{mpp}}$(A)         | 3.88  |

The main cause in decrease in efficiency is due to accumulation of heat at back side of panel. Below graph shows the variation of temperature at both sides (front and back sides) of polycrystalline panel based on experiment conducted in the month of May:
Figure 3. Temperature profile at front and back side of polycrystalline silicon panel

Above graph shows the rise in surface temperature of polycrystalline silicon panels. Since panels are normally tested at 25°C (STC) before installation, decrease in performance of the cells have been noted when exposed in sun for longer time [3]. The variation in decrease in efficiency is found to be from 10-25% depending on the location of installation.

Depending upon the incident radiation, the electrical efficiency is given by,

\[ \eta_{ele} = \frac{(V_{mpp}) \times (I_{mpp})}{G \times A} \]  

(1)

2.2. Thermal collector
Thermal collector is designed for same dimensions of that of solar module. Sheet and tube collector design is adopted. Aluminium sheet (dimensions taken same as solar module, 0.85m x 0.679m) of thickness 1mm is used as absorber plate and copper tubes of diameter 12mm is bend into serpentine structure having spacing 8cm in between is used for flow of water. For good thermal insulation, glass wool is placed and enclosed by waterproof plywood.

2.3. Solar still
Double slope desalination system is being coupled with PV-T system such a way that water enters in natural circulation mode. Side walls and basin walls of solar still are constructed using galvanized iron (GI) sheet. Provision for inlet and outlet for collection of pure water is made in the walls and basin respectively. Heat loss is minimized by providing good insulation. Leakage of water is prevented using sealants (M-seal).

2.4. Mathematical modelling
Taking still efficiency to be 30 percent [14], the useful solar radiation for distillation process is calculated for the month of May. Based on this, the yield is estimated. The total area required for the still is 0.671 m². For the side walls (front and back side), the dimensions are 1.15 m x 0.159 m while the edge walls dimensions are 0.579 x 0.05 m. The basin height is as selected as shallow basin produces more yield. The depth of water in the basin influences the convective heat transfer coefficient between water in the basin and inner surface of glass cover [14]. The total area of double
slope glass cover is 0.338 m$^2$. The tilt of glass cover depends on geographical location. Each glass cover dimensions being 0.585 m x 0.579 m is used.

3. Experimentation
The experimental setup is a hybrid system where waste heat from the PV-T system is being given as feed water to desalination unit. Readings of solar panel are taken from 9am to 5pm. The yield of desalination system is measured every 24 hours. Various methodologies are adopted to compare the yield of solar still at different conditions as given below:
- With thermocol insulation only
- Black coating with thermocol insulation
- Feeding preheated water
- Sprinkling water on glass cover (during noon hours)

4. Results and discussion
The following parameters were measured at the end of each hour:
- Solar irradiance
- Glass cover temperature
- Inlet and outlet water temperature of PV-T system
The total yield from the still is measured for 24 hours.

4.1. Volume of the water obtained from the still at various conditions

| Factors added to improve still efficiency | Water depth (cm) | Yield (ml) |
|-----------------------------------------|-----------------|-----------|
| Only thermocol insulation               | 1 cm            | 800       |
| Thermocol insulation and black coating  | 1 cm            | 1200      |
| Preheated water given                   | 1 cm            | 1500      |
| Sprinkling water on glass cover         | 1 cm            | 1580      |

The yield of solar still at different conditions were measured and compared i.e., with thermocol insulation alone, black coating with thermocol insulation, feeding preheated water and sprinkling water on glass cover (noon hours). Adding black coating has increased the yield by 66% from initial condition (solar still with thermocol insulation only). Back coating absorbs heat than letting it through. Total solar reflectance (TSR) property of black is less than 5%. In the hybrid system, the preheated water from the PV/T is fed into still. This process has two highlights. One is cooling of PV panel has been done and other involves increasing the temperature of water in the still basin. Later in turn helps in increasing evaporation as evaporation rate of heated water is more. Thus the yield also increases. Output of about 2 litres was expected from theoretical calculations. But from experimental results, a maximum of 1.58 litres is obtained.

4.2. Glass cover temperature variation
Higher temperature of glass cover indicates higher heat transfer rate of evaporation between the basin’s water surfaces to the glass cover [16]. The inner glass cover temperature is high during hours 11.30am to 3.30pm. This is the time of maximum yield.
Figure 5. Glass cover temperature & irradiance plotted over time

Normally the variation in temperature between inner and outer glass cover is not high. But a little difference is observed during day hours. If temperature difference between the basin water and glass cover is maintained high, the performance can be enhanced. Sprinkling water on glass cover (outer) has improved the frequency of condensation rate. The yield was found to be increased by 80 ml.

5. Conclusion
Water desalination unit coupled with PV-T system focuses on increasing the efficiency of solar panels by removing waste heat which gets accumulated at bottom of the panels. A flat plate thermal collector (FPC) is designed, fabricated and attached to the solar panel. Experiment is conducted on both panels, with and without the thermal collector to evaluate the performance at different conditions. This heated fluid from collector is fed to double slope desalination unit to improve the yield of fresh water. The modelling of still was done after detailed study. The experimental results indicates that the main parameters influencing efficiency of still are depth of water, preheated water, cover plate temperature, and insulation.

This work is well suited for remote areas as the construction and installation of the hardware unit is simple and economical. Rustic zones are constantly devoid of fundamental components. This work focuses mainly on increasing the performance of both photovoltaic panel and the coupled desalination unit. Added advantage of the project is obtaining fresh water and electricity as end products. The experimental results shows that by incorporating various parameters, the performance of the still can be enhanced. In situations where preheated water is not fed into solar still, it can be utilized for other household purposes.

Initially, when brackish water was given to the still, the efficiency was less. But when preheated water from PV/T system was given, efficiency improved by 50%. It is also inferred that higher the glass cover temperature better is the rate of evaporation. Maintaining the thermal difference between the glass cover surface and basin water results in better yield.

Solar irradiance being a major deciding factor, it is evident from the results that yield is maximum during higher irradiance levels. The yield can be further increased by concentrating sunlight using mirrors or reflectors into the still. Additional attempts to enhance productivity of solar still comprise the use of thermal absorbents like sponges, gravel or other thermal energy storage materials.
References

[1] Prajapati K C and Patel J 2015 *J. Alter. Source and Technol*. 6 14-34
[2] Chow T T 2010 *Appl Energy* 87 365-79
[3] Kumar A, Baredar P and Qureshi U 2015 *Renew. Sust. Energ. Rev*. 42 1428-36
[4] Rajesh V R, Harikrishnan K, Chaithanya K K and Subi Salim 2016 *Int. J. Renew. Energ. Res*. 6 250-253
[5] He W, Chow T T, Ji J, Lu J, Pei G and Chan L S 2006 *Appl Energy*. 83 199-210
[6] Dubey S, Sarvaia J N and Seshadri B 2013 *Energy Procedia*. 33 311-21
[7] Manokar A M, Murugavel K K and Esakkimuthu G 2014 *Renew. Sust. Energ*. 38 309-22
[8] Chaithanya K K, Rajesh VR and Suresh R 2016 *Mat. Sci. Eng*. 149 012182
[9] Obayemi J D, et.al. *Int. J. Sci. Eng. Res*. 5 1523-1534
[10] Ali M I, Ali S M and Siddhartha T R 2012 *Int. J. Adv. Res. Technol*. 5 2005
[11] Elango T and Murugavel K K 2015 *Elsevier*. 359 82-91
[12] Akash B A, Mohsen M S and Nayfeh W 2000 *Energy Convers Manag*. 41 883-90
[13] Tripathi R and Tiwari G N 2005 *Elsevier*. 2 187-200
[14] Chow T T, Ji J and He W 2007 *J. Sol. Energy. Eng*. 129 205-9
[15] Joshi S V, Bokil R S and Nayak J K 2005 *Sol. Energy*. 78 781-98
[16] Mahian O, Kianifar A, Heris S Z, Wen D, Sahin A Z and Wongwises S 2017 *Nano Energy*. 36 134-55