DESALINATION PROCESS OF SINGLE SLOPE SOLAR STILL COUPLED IN CPC WITH CRESCENT ABSORBER

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ABSTRACT

The use of solar energy in thermal desalination processes is one of the most promising applications of the renewable energies. The thermal conversion of solar energy by means of solar concentrators makes it possible to reach high temperatures able to boil the salted water with pressures higher or equal to the atmospheric one. The desalination process is carried out by coupling a single slope solar still with compound parabolic concentrator (CPC). The experiments are carried out at January and February 2010. The newly designed crescent shaped absorber is at the focus of the CPC and its inlet and outlet are connected to the single slope solar still. The performance of the study is analyzed by two different modes. The single slope solar still is coupled with crescent absorber under top cover closed condition to avoid solar radiation which enters into the still alone and the still with open condition for the entry of solar radiation. The area of the still is about 0.25 m². The system temperature such as water (T_w), air (T_air), inner cover (T_in) and outer cover (T_out) are measured by type-K thermocouples and digital thermometers. The humidity and wind velocity are also recorded during the study. The hourly output and instantaneous efficiency are also calculated. The primary focus is on these technologies suitable for use in remote areas, especially those which could be integrated into other solar thermal energy systems.

Key Words: Desalination, Compound Parabolic Concentrator, Crescent absorber, Renewable energy, Solar radiation

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INTRODUCTION
The increase of population is the task of providing adequate supplies of fresh water may indeed become the most serious problem facing the world on the onset of this century. Source of fresh water must be found and the most likely sources are the great oceans and that can be desalinated by various methods. Among which the solar still create a new path to obtain fresh water using solar energy. P.T. Tsilingiris developed a simple dynamic computer model to investigate the performance and operational behavior of a large solar seawater desalination system based on a multi-effect distillation plant and a solar pond. The effects of various design and operational parameters on system behavior were investigated. A.A. Al-Karaghouli and W.E. Alnaser investigated single basin and double decker solar stills with the still sides insulated and without insulation. M.M. El-Kassaby designed and investigated solar still using a line concentrator of parabolic reflector type and a comparison of results are made with the theoretical ones. M.A. Porta, et al., have studied the dynamic effects in shallow solar stills. Result shows that the thermal inertia of these systems reside in the glazing, tray materials, insulation and brine. Experimental investigations have been carried out by Eduardo Rubio-Cerda, et al., in an attic-shaped solar still subject to natural conditions of Grashof numbers. Performance of the still was carried out by condensing covers under two still orientations. The optimum angle of a flat plate reflector and the optimum orientation of vertical multiple-effect diffusion solar still coupled with a flat plate reflector throughout the year were numerically determined by Hiroshi Tanaka and Yasuhi Nakatake. Results concluded that the daily productivity of the proposed still was predicted to be more than 30 kg/m²/day at any latitude throughout the year except for the winter season (from November to January) at 40°N latitude. Theoretical analysis of a basin type solar still with an internal reflector (two sides and back walls) and an inclined flat plate external reflector on a winter solstice day at 30° N latitude were investigated by Hiroshi Tanaka and Yasuhi Nakatake. B.Selvakumar, et al., studied the thermal performance and distillate yield analysis of a single sloped green house solar still for growing plants in cold climates through better utilization of the available sunlight. The internal heat transfer and external heat transfer modes along with the thermo physical properties were studied. Experimental Investigation to study the effect of coupling a flat plate solar collector on the productivity of solar stills was carried out by O.O. Badran and H.A. Al-Tahaineh. Other different parameters to enhance the productivity were also studied. Ali A. Badran, et al., have also been studied combined effect of a single-stage basin-type solar still and a conventional flat-plate collector to study the effect of augmentation on the still.

Design parameter of compound parabolic conical concentrator
A compound parabolic concentrator is simple assembly for reflection of normally incident radiation onto a receiver. It is made up of
sections that are joined together end to end to form trough type or dish type concentrators and the concentrators are relatively simple to manufacture. The compound conical concentrator sections are derived from a “Generating Parabola” described by the equation

\[ x^2 = 4ay \]  

(1)

Where ‘a’ is the semi-latus rectum, defining an effective focal length of the concentrator, x and y are the coordinates. The solar radiation falls in the form of parallel rays along the negative y axis. A circular cross section receiver of diameter ‘d’ is employed at the focus of the parabola.

\[ X_n = nd \]
\[ Y_n = \frac{nd}{4a} \]  

(2)

Which are the mid points of the nth section and these are the points of contact with the parabola. The inclination and length of the nth section are given by

\[ \tan(\theta_n) = \frac{n(d)}{2a} \]
\[ S_n = d \left( \frac{1 + n^2}{(2a/d)^2} \right)^{1/2} \]  

(3)

These equations are called the fundamental equations of the system. The characteristics parameter (2a/d) is the running integer of that section, making 45 with the x axis. The geometrical concentration factor is simply

\[ C_N = 2N + 1 \]

(4)

Using of shorter sections will not improve the concentration for the same diameter receiver whereas the longer sections will result in part of the concentrated radiation missing the receiver altogether. So the lengths ‘Sn’ should be the optimum lengths. The nth cone has a base of radius γn, an apex angle αn and the slant qn, and its shown in Fig. 1.

\[ \gamma_n = \frac{d}{n} \left( \frac{1}{2} \right) \]
\[ \alpha_n = \left( 90 - \theta_n \right) \]
\[ q_n = \frac{d}{n} \left( \frac{1}{2} \right) \tan \theta_n \]  

(5)

θn is the angle between the reflector segment and the horizontal axis(x axis)

The angle of the ‘dissected cone’ is a parameter needed for the construction. It is obtained when a cone is cut along a slant height qn. This angle is equal to the circumference of the cone base divided by the slant height.

\[ \Phi_n (\text{deg}) = 360 \cos \theta_n \]  

(6)

The concentration ratio factor for this system is defined as the ratio of the area of the receiver to the surface area of the absorber.

\[ CN = \frac{\text{Base of the nth cone}}{\text{Surface area of the absorber}} \]  

(7)
MATERIAL AND METHODS

Fabrication of single slope solar still

The water storage basin of the still is designed of area 0.50 m x 0.50 m using stainless steel. Bottom and sides of the still are coated with black paint for good absorption of solar radiation. An inlet pipe of ½ inch is used for pouring water into the still. The outer box for the still is made up of wood of thickness 4 mm with the length of 0.70 m and breadth of 0.70 m respectively. The bottom of outer box is filled with the sawdust insulation up to the height of the 0.11 m. The side wall is insulated with glass wool. This insulation reduces the conduction heat loss through the base and sides of the solar still. The top cover of the still is made by the glass of thickness 4 mm. The top cover is placed over the grooves which are provided at all sides for uniform resting. A 15° slope is maintained for top glass cover. Water Collection segment is placed at the desired position for collecting the evaporated water and it is of dimension 0.66 m x 0.038 m x 0.15 m. The pictorial view of the system shown in Fig. 2 (a).

Heat transfer coefficients

Internal heat transfer mode

Heat is transported inside the still by free convection of air. It releases its enthalpy upon air which is coming in contact with the glass cover. The heat transfer per unit area per unit time due to the convection is

\[ Q_{ci} = h_{ci} (T_w - T_g) \text{W/m}^2 \]  
(8)

Heat transfer mode inside the still due to evaporation is given by

\[ Q_{ei} = h_{ei} (T_w - T_g) \text{W/m}^2 \]  
(9)

Heat transfer mode inside the still due to radiative loss can be expressed as

\[ Q_{ri} = h_{ri} (T_w - T_g) \text{W/m}^2 \]  
(10)
Fig. 2: Arrangement of the still and concentration with absorber

Fig. 2 (a): Arrangement of the still and concentration with absorber
Heat transfer rate outside the still

Heat transfer per unit area per unit time outside the still is calculated using

\[ Q_{ac} = h_{ca} (T_g - T_p) + \varepsilon_g \sigma [(T_g + 273)^4 - (T_{sky} + 273)^4] \text{ W/m}^2 \]  

(11)

Here \( h_{ca} \) is a function of wind velocity and is given by

\[ h_{ca} = 5.7 + 3.8V \]  

(12)

\( T_{sky} = (T_a - 12) \) is the apparent sky temperature for long wave radiation.

The values of conduction heat loss through the base is given by,

\[ Q_{be} = h_b (T_W - T_a) \]  

(13)

Thermophysical properties

The density of water vapor can be obtained by the relation

\[ \rho_w = 0.0022P_w/T \]  

(14)

Where \( P_w \) is the partial pressure of water vapor (Pa, N/m\(^2\))

The latent heat vaporization can be evaluated by the following relation.

\[ L_{water}(T) = -0.0000061434T^3 + 0.005892T^2 - 2.36418T + 250079 \]  

(15)

The experimental study is performed and tested in Solar Energy Laboratory, Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore, India. The readings are taken in all the clear sunny days. The experimental procedures are started 9:00 hours to 16:00 hours. The saline water is poured inside the still in the morning. The absorber is made up of copper due to high thermal conductivity and low specific capacity. The crescent absorber gets heated with the help of concentrator. The water circulates from the still and the absorber through the pipe under thermo Siphon effect. The absorber was coated with black. The performance of the concentrator depends its optical efficiency which is in term depends on the reflector surface accuracy. The concentrator is tilted towards the sun and the experiment was done at different times in all days. The water in the absorber attained the maximum temperature in short intervals of time. So the water gets heated up and hence the moisture content of the air trapped between the water surface and the glass cover. The water vapor condenses on the interior surface, to tickle into a collector. The potable water output of the still is frequently measured by a measuring jar at regular intervals. The measuring jar is placed at the outlet of the still. The temperature of water, air, inner cover and outer cover temperature are noted at intervals of every fifteen minutes. Precision Pyrohelio meter was used for measuring the beam radiation and Pyranometer is used to record the total radiation in all days. This radiation is also recorded at regular intervals of time.

RESULTS AND DISCUSSION

Testing was performed with two modes of operation: (1) Single slope solar still top surface open condition operating with crescent absorber, (2) Single slope solar still top surface closed condition which is operating with crescent absorber for a period of 9:00 hours to 16:00 hours. Fig. 3 shows the variation of ambient temperature and solar radiation with respect to time. The average ambient air temperature is recorded
as 35.1°C and the average solar radiation recorded during the study is 810 W/m². These two known valid parameters are plays the vital role to enhance the productivity of the solar still as well as the efficiency of this particular system. **Fig.4** and **Fig.5** shows the variation of water temperature, air temperature, inner glass cover temperature and outer cover temperature which is recorded in the mode of single slop solar still coupled with crescent absorber under top cover open condition and single slope solar still top cover closed condition. The hourly productivity of the both the performance is shown in **Fig. 6**. In the first modes of the operation the productivity the still 2.1 litres per day and 1.03 litres/day for second mode of the operation. In the first mode of the operation the radiation enters in to the single slope solar still by two ways, radiation pass through the glass and through the concentrator with crescent absorber. The heat accumulates inside the still is very short intervals of time which shows the advantage of this work. So it is enhanced the system productivity. The second mode of the operation reveals that a perfect thermo Siphon process improves the system productivity even single slope solar still top cover closed condition. This heat energy circulation is mainly by the influence of crescent absorber and the concentrator. The comparison of efficiency with respect to time is shown in the **Fig. 7**. The efficiency of the first mode of study is calculated as 23.19% and 13.01% is the second mode of the still performance. **Fig. 8** and **Fig. 9** elucidate the variation of latent heat vaporization with respect to water temperature. Also it shows the linear fit curve for the latent heat with respect to temperature. An empirical fit to these data values is also made, and the equation obtained is shown in the diagram. The value of R² is equal to 0.99 in both the figures which represents the best fit curves of the data. These figures indicated that the latent heat decreases with the increases of temperature. **Fig 10** and **Fig. 11** show the variation of saturation pressure and vapor density with respect to temperature for both the studies. It reveals that, the saturation pressure and vapor density increases with the increases of water temperature.

![Variation of solar radiation and ambient temperature with respect to time](image_url)
Fig. 4: Variation of still temperature with respect to time for second mode of the operation

Fig. 5: Variation of still temperature with respect to time for first mode of the operation

Fig. 6: Hourly output with respect to time for both the performance
Fig. 7: Variation of instantaneously efficiency with respect to time

![Graph showing variation of instantaneous efficiency with time](image)

Fig. 8: Variation of latent heat with respect to time for still top surface closed condition

![Graph showing variation of latent heat with temperature](image)

Fig. 9: Variation of latent heat with respect to time for still top surface open condition

![Graph showing variation of latent heat with temperature](image)
CONCLUSION
The single slope solar still coupled with crescent absorber is studied and its efficiency is calculated. The influence of the absorber also tested by solar still top surface closed condition. The improvement in distillate yield is proved experimentally by system. In future this kind of work becomes a great application in environment friendly systems. It could also be paved a path for converting the saline water to pure drinking water in rural areas of India.
REFERENCES

SAVE THE ENVIRONMENT

- **Good environment is good health.**
- **Air pollution causes health hazards.**