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Study of thermo physical properties and an improvement in production of distillate yield in pyramid solar still with boosting mirror

T. Arunkumar[1], R. Jayaprakash[2], A. Prakash[3], P.U Suneesh[4], M. Karthik[5] and SanjayKumar[6]

[1, 2]Solar Energy Laboratory, Dept. of Physics, Sri Ramakrishna Mission Vidyalaya, College of Arts and Science, Coimbatore-641020, TN, India.
[3]Dept. of Science and Humanities, RVS College of Engineering and Technology, Coimbatore, TN, India.
[4]Dept. of Physics, M.E.S College of Engineering, Kerala-679573, India,
[5]Dept. of Physics, Coimbatore Institute of Engineering and Information Technology, Coimbatore – 641109, TN, India.
[6]Centre for Appropriate Management, Chandragupt Institute of Management, Chajubagh, Patna- 800 001, Bihar, India.

jprakash_jpr@rediffmail.com; tarunmsc@yahoo.co.in; prof.ssinha@gmail.com; suneeshtvr@gmail.com

Abstract

We report the experimental analysis of a pyramid solar still with boosting mirror system for increasing the distillate yield rate under clear climatic conditions in Coimbatore (11° N latitude), India. The radiation received by the still is boosted up by reflecting the solar radiation. A tracking system keeps track of incident radiation into the still. The area of the still is 0.25 m^2. Water and ambient temperature are measured along with solar radiation and humidity at regular intervals of time. The inner and outer faces of the glass cover temperatures are also recorded. The average solar radiation received is 760.43 W/m^2. The daily average efficiency of the still was found to be 15%. A 2.9 $l/m^2/d$ distillate yield is obtained with the help of the boosting mirror; whereas, 1.52 l/m^2/day are collected without the boosting mirror. In this work an attempt has been made to study the effect of heat transfer within a pyramid solar still. The thermo physical properties of the still are analyzed for this study. Thermal conductivity dynamic viscosities of water are also studied for this system. The thermal conductivity is in the range of 26.77 x 10^{-2} Wm^{-2} C^{-1} to 29.64 Wm^{-2} C^{-1}. Dynamic viscosity ranges from 18.6 x 10^{-6} Nsm^{-2} to 20.2 x 10^{-6} Nsm^{-2}.

Keywords: Solar energy, booster mirror, desalination, potable water.

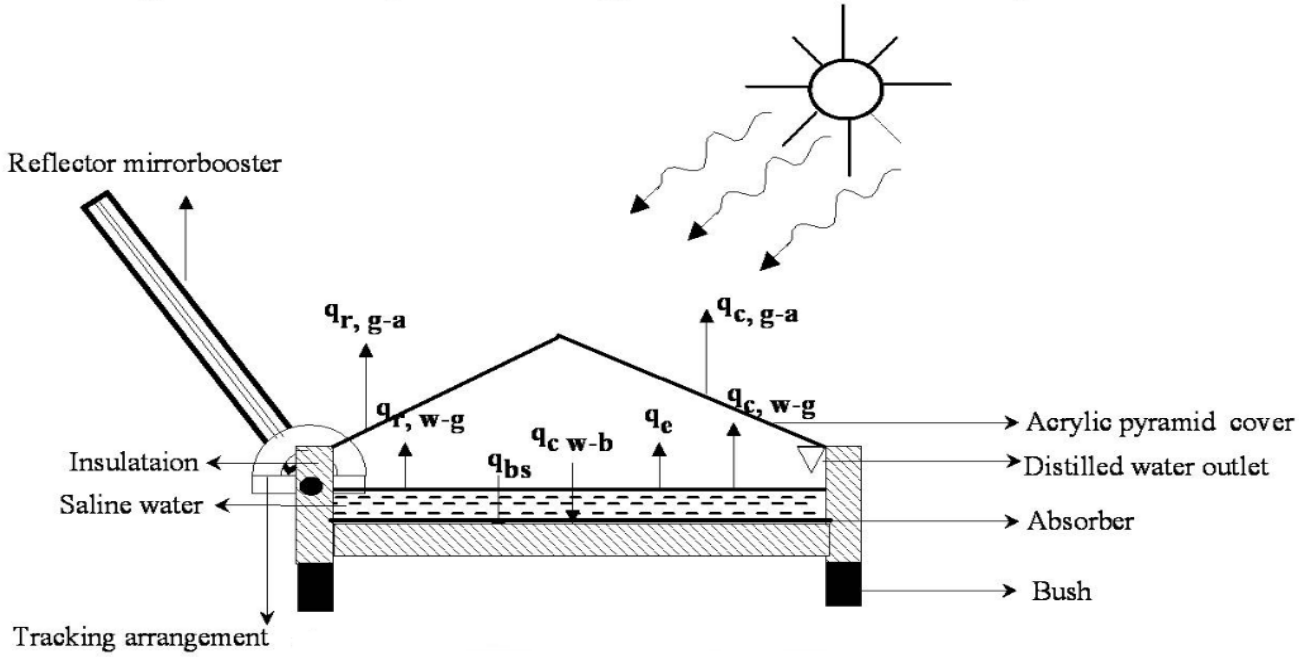
Introduction

Desalination of sea and brackish water offers the opportunity to significantly increase the world's supply of fresh water for drinking and other purposes. The proposed model presents a new approach to support the sustainable development of small communities in remote areas. Solar distillation is a relatively inexpensive, low-technology method to distillate water, especially useful where the need for small amount of yield exists. It is well known that solar distillation exhibits a considerable economic advantage over other salt water distillation processes, because of cost-free energy and reduced operating costs. Producing fresh water with solar stills would be one of the best solutions to supply water to small isolated communities with no technical facilities. The system is very simple but practical, for e.g., it is one of the most suitable technologies for desert plantation.

The basic principles of the solar water distillation are simple yet effective as distillation replicates the way nature purifies water. The sun's energy heats the water to the point of evaporation. As the water evaporates, water vapor rises, condensing on the glass surface for collection. This process removes impurities such as salts and heavy metals, as well as destroys microbiological organisms. The end results are water cleaner than the purest rain water. Solar energy is the best alternative heating source. It is inexhaustible clean and available in almost all parts of the world. The use of solar energy is however more economical than the use of fossil fuels in remote areas having low population densities, low rainfall and abundant available solar energy. Solar energy can easily provide enough water for family drinking and cooking needs.

1% of the world's fresh is accessible for direct human use. Underground water for drinking purpose is not always considered to be fresh drinking water. In some instances the salinity is probably too high for water to be considered as fresh drinking water instead it is called brackish water. The salinity of brackish water varies with location. In such cases, fresh water has to be either transported for long distances or connected with an expensive distribution water network at extremely high cost for usually a small population. Thus, solar distillation becomes very attractive and may be the solution for such a problem. According to Howe (1986) at an average water consumption of about 10 l person-per-day, a small community with a total population of 200 can benefit more from solar distillation than transporting water from a distances. In recent years, a number of models for solar

Fig. 1. Schematic representation of pyramid solar still with boosting mirror.



distillation have been presented in the literature by various investigators (Tiwari *et al*., 1985; Tiwari *et al.,* 1988; Yeh *et al*., 1988; Lessing *et al*., 1991; Tiwari & Lawrence, 1991; Sharma & Mullick, 1993; Tiwari *et al*., 1999; Hamdan *et al*., 1999) mainly, for single or double slope solar collectors. In either case, they operate on absorbing solar radiation through a transparent cover, usually made of glass, which is then transmitted to the water. The distilled water production rate can vary with the design of the solar still and location. The main concern is to enhance the amount of water produced. For example, attempts were made to increase the productivity of water by using different absorbing materials (Tamimi, 1987; Dutt *et al*., 1989; Akash *et al*., 1998). In other studies the still was operated at lower pressure (Yeh *et al*., 1985; Isaad, 1987). The productivity was found to increase by forcing air inside the still (Ali, 1991). Furthermore, some studies evaluated the performance of the solar still using an internal condenser (Ahmed, 1988).

This paper presents the performance evaluation of the acrylic pyramid solar still tested under climatic conditions of Coimbatore, India, in the summer seasons 2009. Hourly and daily measurements of still productivity, temperature of the water film, inner and outer glass cover temperature, ambient air and solar radiation were recorded. Outdoor tests have been carried out to determine the performance of the acrylic pyramid solar still. Being a big city (Coimbatore) and probably unknown to other people. It may worth to give some general-political and geographical information as follows:

Population: 42, 95,825; Location: 11°.00 N, 77°.00 E; Area: 105.5 Km^2; Ambient temperature: 34.7°C to 22.1°C (Summer), 32.2°C to 15.2°C (Winter); Humidity: 30%-89%; Wind: 10 Kts; Rain fall: 677.7 mm.

Experimental model

The water storage basin of the still is designed of area 0.5 m x 0.5 m. Solar still's bottom and the sides of the basin are painted black in order to enhance absorption of solar radiation. The 0.7 m x 0.7 m x 0.25 m outer box of the still is made up of 4 mm-thick wood and is filled with sawdust insulation up to the height of the 0.11 m. Glass wool is used as the insulation for the still side walls. The suitable provisions are made in the outer cover for the inlet pipes and distilled water collection pipe. The top pyramid cover is made up of transparent glass sheet of 4 mm thickness. A 15° slope is maintained on all sides of top cover. The boosting reflector consists of a 0.25 m^2 mirror glass with wooden frame. This reflector is attached to the semicircular metal plate for tracking purposes.

Experimental procedure

Experimental procedure is performed to evaluate the performance of the pyramid solar still with boosting mirror at the open terrace under Coimbatore (11°N latitude, India) climatic conditions. Before each test, the basin was filled with saline water as shown in Fig. 1. The experiment begins at 9:00 and readings are taken every half hour until 8 h have passed. The regular tracking is maintained for this whole study to boost the solar radiation into the still. The distillate output is collected by a measuring jar which is placed at the outlet of the still. The pre-calibrated thermocouples were placed inside the still and measured the water, air, inner and outer cover temperatures. The daily distillation yield rate is calculated by summing up the instantaneous yield. Fig. 2 shows the photographical view of pyramid solar still with booster mirror.

Fig. 2 . Pyramid solar still with boosting mirror.

The efficiency of the still is calculated using the formula:

$$h = \frac{(M \times L)}{(I \times A \times t)} \quad (1)$$

Where *M* is the mass of the distillate output, *L* is the latent heat of water, *I* is the solar radiation, *A* is the absorber area and *t* is the period of time.

Thermo physical properties

Thermo physical properties are estimated using the experimentally measured temperatures of evaporation and condensation surfaces and calculating the following relations.

The thermal conductivity is given by

$$K = 0.0244 + \left(0.7673 \times 10^{-4}\right)T_{av} \quad (2)$$

The dynamic viscosity of water can be found according to:

$$\mu = \left(1.718 \times 10^{-5}\right) + \left(4.620 \times 10^{-8}\right)T_{av} \quad (3)$$

Water density is obtained with:

$$\rho_w = \frac{0.0022\, p_w}{T} \quad (4)$$

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

The arithmetic mean (T_{av}) of the temperatures of evaporation and condensation surfaces can be expressed as follows:

$$T_{av} = \frac{\left(T_W + T_G\right)}{2} \quad (5)$$

The maximum saturation pressure of water vapor in moist air varies with the temperature of the air vapor mixture and can be expressed as:

$$P = 6893.03 \exp\,(54.63 - 12301/T' - 5.17 \ln T') \quad (6)$$

Where

$T' = (1.8T + 491.69)$

Latent heat of water is calculated as,

$$L_{water} = -0.00061432T^3 + 0.0058927T^2 - 2.36418T + 2500.79 \quad (7)$$

Results and discussion

The experiments were conducted in 2009 June to investigate the comparative performance between pyramid solar still with boosting mirror and without boosting mirror. The heat transfer coefficients, instantaneous efficiency and thermo physical properties were estimated from the collected data. Fig. 3 shows the variation of solar radiation with respect to time. The solar radiation increases in the morning and attained maximum in the noon and decreased to a lower value in the evening. Solar radiation during the study ranges from 400.23 W/m^2 to 1111.084 W/m^2. The average solar radiation received during the study 760.43 W/m^2. Fig. 4 shows the variation of humidity with time. It is shown that relative humidity varies from 55% to 21%.

Fig. 5 shows the variation of water and air temperature for the two experiments. Pyramid solar still with booster mirror produces the maximum water temperature (about 71°C) and without the reflector water temperature only reaches 52°C. The high temperature difference between the two methods reveals the influence of the boosting mirror. Evaporation mainly depends upon the water temperature. So an optimum high evaporation temperature is further maintained using the boosting mirror. Without the booster, the optimum evaporation time is limited. It reaches a maximum at noon and then it decreases. The distilled water yield is observed even at low radiation values. This is due to the thermal storage capacity of water in the still. Fig. 6 shows the variation of efficiency in time. Both efficiency and distillate yield increase as time passes. The efficiency observed during the study has a range of 1.77% to 32.73%. The maximum efficiency (14.66%) is obtained for pyramid solar still with external boosting mirror. The still efficiency is determined by average distillate output collection rate. Fig. 7 shows distillate yield varying in time. The total water collection for pyramid solar still is 1.5 l/m^2/day and with the help of the boosting mirror increases to 2.9 l/m^2/day.

Fig. 8 shows the variation of saturation pressure for pyramid solar still with and without boosting mirror. The saturation pressure increases with increasing temperature. From the figure it can be seen that the saturation pressure is in the range of 4974.80 Pa to

Fig. 3. Time-wise variation of solar radiation.

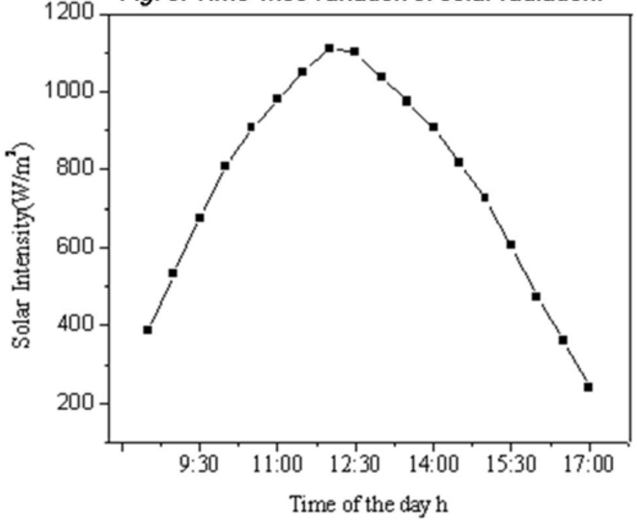


Fig. 4. Time-wise variation of humidity.

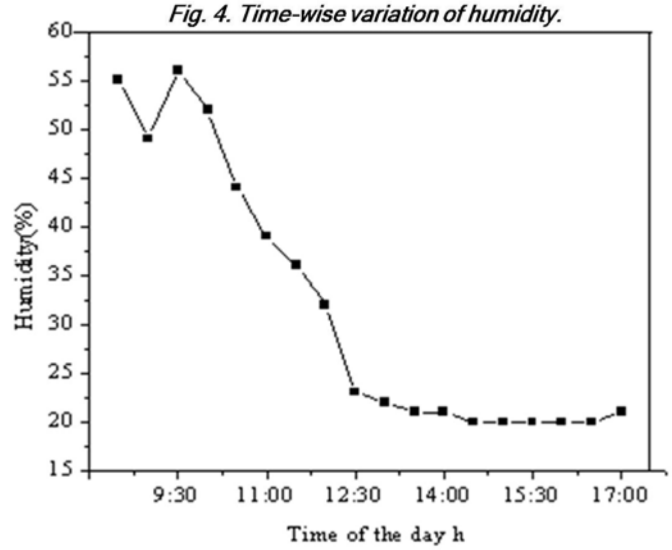


Fig. 5. Time-wise variation of temperature.

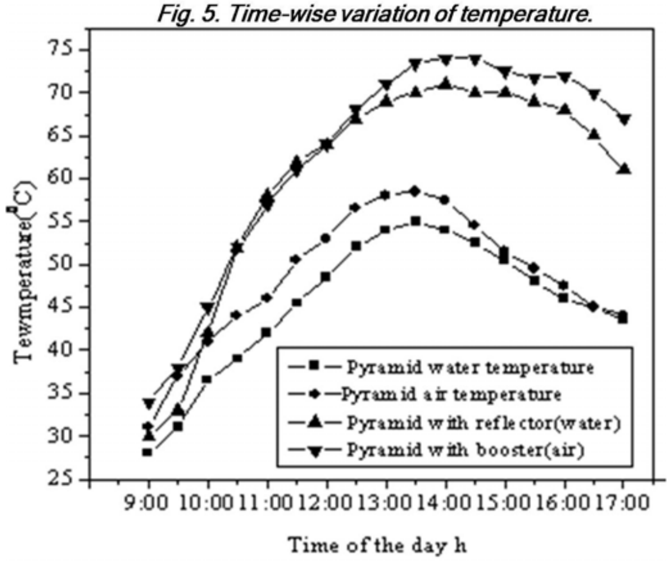


Fig. 6. Time-wise variation of solar still efficiency

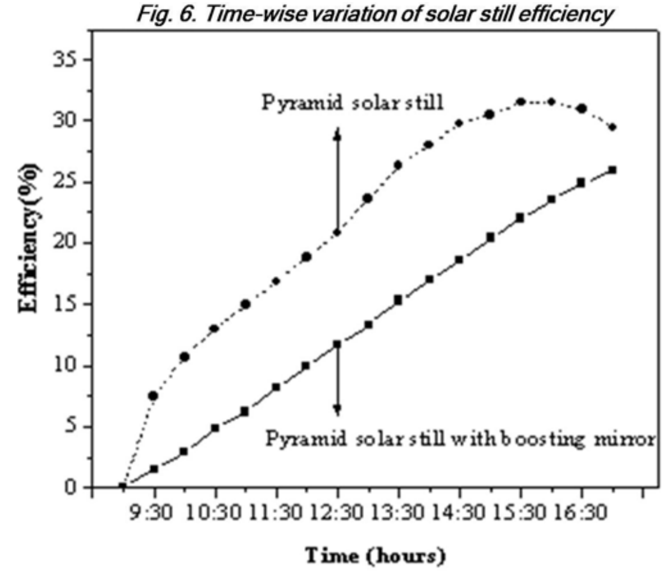


Fig. 7. Time-wise variation of collected water.

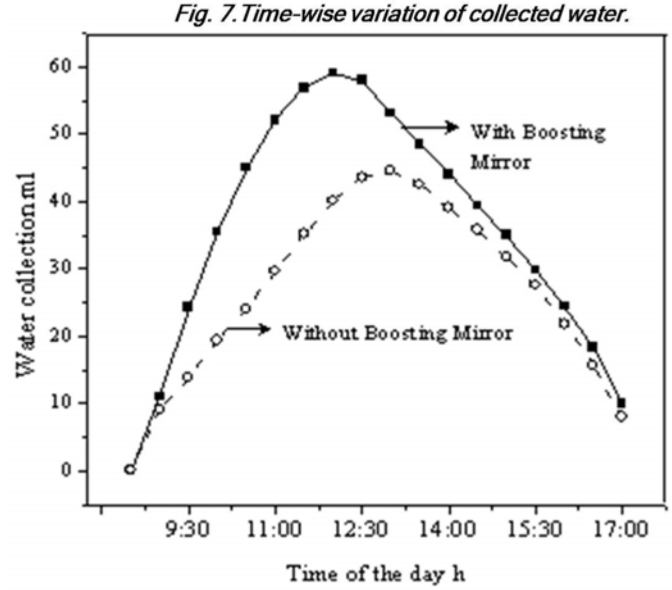
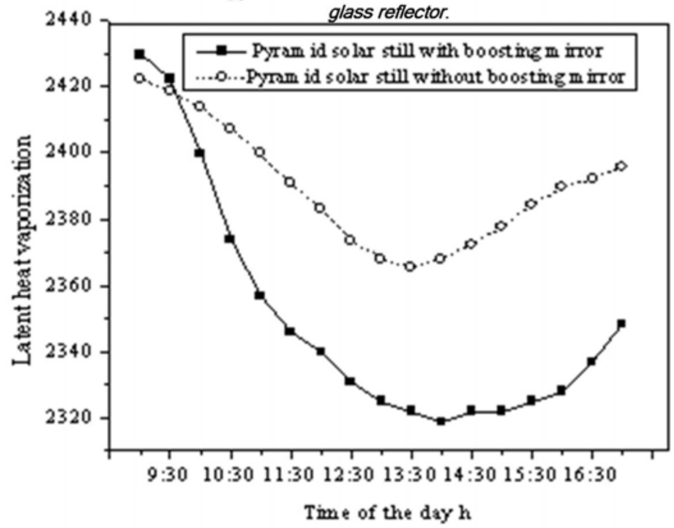


Fig. 8. Time-wise variation of latent heat of evaporation for pyramid solar still with & without external glass reflector.



Indian Journal of Science and Technology Vol. 3 No. 8 (Aug 2010) ISSN: 0974- 6846

Fig. 9. Time-wise variation of vapor density for pyramid solar still with & without external glass reflector.

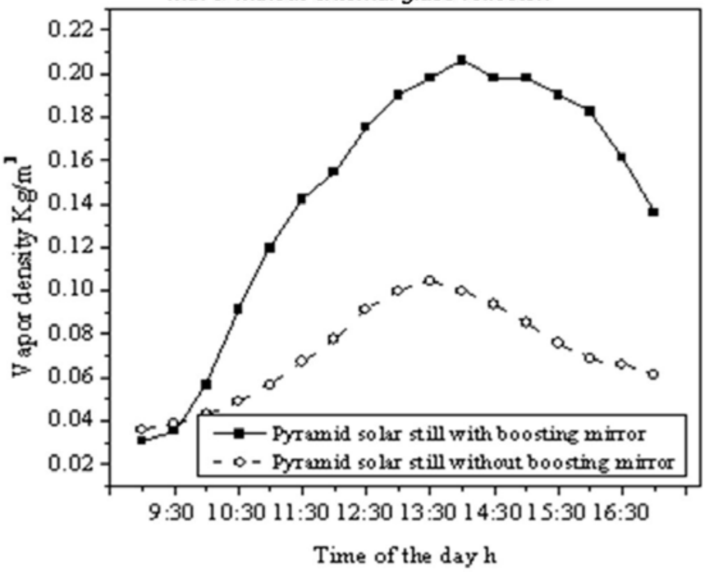


Fig. 10. Time-wise variation of saturation pressure for pyramid solar still with & without external glass reflector

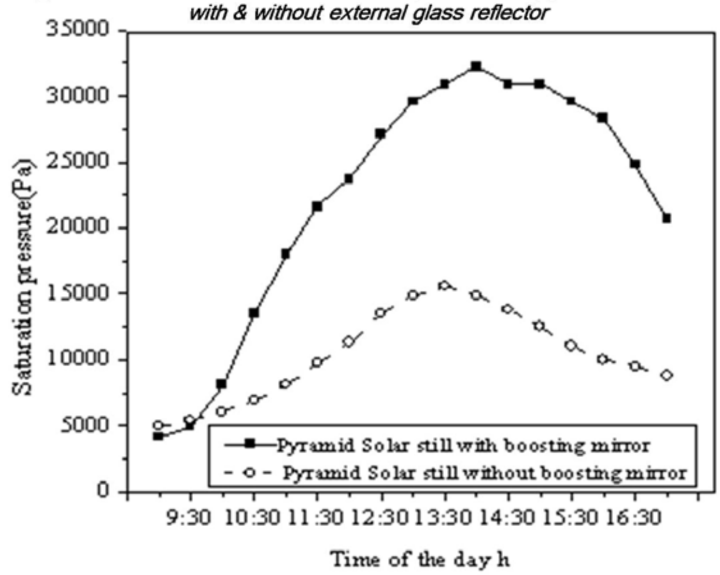


Fig. 11. Time-wise variation of dynamic viscosity for pyramid solar still with & without external glass reflector.

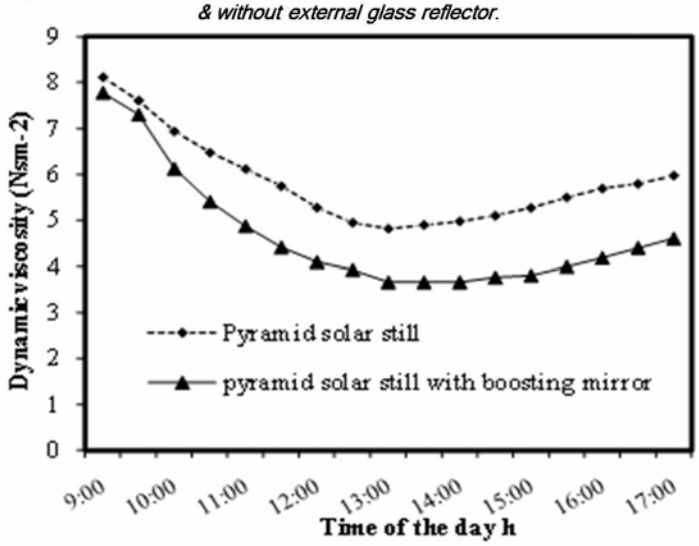
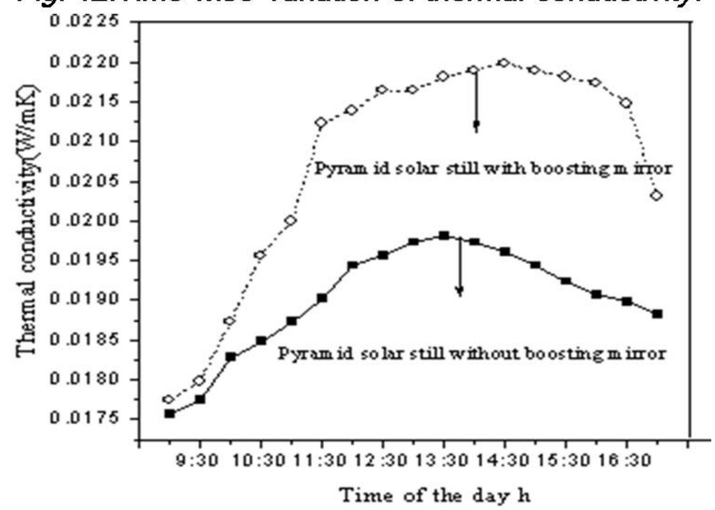


Fig. 12. Time-wise variation of thermal conductivity.



8774.45 Pa without boosting mirror and 4194.80 Pa to 20656.12 Pa with boosting mirror. Fig. 9 shows the vapor density with respect to pyramid solar still and still with boosting mirror. The average density of water vapor is 0.07133 Kg/m^3 without boosting mirror and 0.14501 with boosting mirror. These values are in good agreement with the constant values in the data book.

Fig. 10 shows the decrease in latent heat of vaporization as time varies for the two designs. The latent heat of vaporization calculated is in the range of 2422.29 to 2368.08 for pyramid solar still and 2429.63 to 2318.95 for a still with boosting mirror. Fig. 11 shows the variation of dynamic viscosity with respect to time for both the studies. The average dynamic viscosity of water obtained without boosting mirror is 5.84 Nsm^{-2} whereas with boosting mirror is 4.68 Nsm^{-2}. Fig. 12 shows the variation of thermal conductivity with respect to time. The thermal conductivity is 0.02075 W/m K with booster mirror and without booster mirror is 0.019014 W/m K. The thermo-physical properties such as saturation pressure, vapor density, latent heat and thermal conductivity are strongly influenced by the boosting mirror performance.

Conclusion

The pyramid solar still with external glass reflector was constructed and experimentally tested by two modes: pyramid solar still and the still with reflector arrangement have been presented. A heat transfer and thermo physical properties model is developed to study the thermal performance of these configurations. The outdoors experimental results during sunny clear days reveal the following points: the daily average efficiency of the still is 15%. A daily distillate yield of 2.9 l/m^2/day is obtained with the help of the boosting mirror. On the other hand, a 1.52 l/m^2/day distillate yield is collected without boosting mirror.

Solar energy is the best alternative heating energy source. It is inexhaustible clean and available in almost all parts of the world. Solar stills are inherently simple, environmental friendly and able to supply fresh water to remote areas where no fresh water is available. The health of most Indian population relies on the water quality. Solar distillation may enable the rural population access to clean drinking water. The awareness and wide use of solar water distillation probably help in improving health standards in India.

References

1. Ahmed ST (1988) Study of single-effect solar still with an internal condenser. *Solar Wind Technol*. 5(6), 637-643.
2. Akash BA, Mohsen MS, Osta O and Elayan Y (1998) Experimental evaluation of a single-basin solar still using different absorbing materials. *Ren. Energy*. 14, 307-310.
3. Ali H (1991) Experimental study on air motion effect inside the solar still on still performance. *Energy Conversion Management*. 32, 67-70.
4. Dutt D, Kumar A, Anand J and Tiwari G (1989) Performance of a double-basin solar still in presence of dye. *Appl. Energy*. 32, 207-223.
5. Hamdan MA, Musa AM and Jubran BA (1999) Performance of solar still under Jordanian climate. *Energy Conversion Management.* 40, 495-503.
6. Howe ED (1986) Measurements and control in solar distillation plants. *Desalination.* 40, 307-320.
7. Lessing HA (1991) Small modular, high-efficiency solar still. *Int. J. Solar Energy.* 9, 35-46.
8. Isaad MA (1987) A sub-atmospheric solar distillation unit. *Int. J. Solar Energy*. 5, 129-141.
9. Sharma V and Mullick S (1993) Calculation of hourly output of a solar still. *ASME J. Solar Energy Engg.* 115, 231-236.
10. Tamimi A (1987) Performance of a solar still with reflectors and black dye. *Int. J. Solar Energy*. 5, 229-235.
11. Tiwari G and Lawrence S (1991) Experimental evaluation of solar distiller units with FRP lining under PNG climate conditions. *Int. J. Solar Energy.* 9, 241-248.
12. Tiwari G, Gupta S and Kumar A (1988) Analytical model of inverted multi wick solar still. *Int. J. Solar Energy*. 6,139-150.
13. Tiwari G, Minocha A, Sharma P and Khan M (1999) Simulation of convective mass transfer in solar distillation process. *Energy Conversion Management.* 38, 761-770.
14. Tiwari G, Mukherjee K, Ashok K and Yadav Y (1985) Comparison of various designs of solar stills. *Desalination.* 60,191-202.
15. Yeh H, Ten L and Chen L (1985) Basin-type solar distillers with reduced pressure for improved performance, *Energy*. 10,683-688.
16. Yeh H, Tsai S and Ma N (1988) Energy balances in double-effect wick-type solar distiller. *Energy*. 13(2), 115-120.