Performance Comparison of Cuboidal Box Type Solar Still with Different Feed System

Sumit Saini[1] Amol Tripathi[2]
[1,2]Rewa Institute of Technology, Rewa

Abstract— The need for pure drinking water in dry and remote areas is very acute particularly in Rajasthan, Kuchchh etc. The dry areas however have no shortage of solar energy which is available in plenty. Solar desalination is a technique to curb this problem in dry areas. The work presented in this paper relates to a cuboidal type solar still. The solar still is designed and a sheet of porous material (jute sack) is deployed on plane basin profile and saline water is fed by two different means. First still was fed by a reservoir kept at higher elevation and second one was fed by capillary action from reservoir kept at elevation lower than still. On this vary design, experimentation has been performed to compare the performance of cuboidal box type solar still with different feed systems and different parameters are measured in this process. The results are obtained at an inclination angle of 24˚ which is best suited for Rewa Madhya Pradesh (coordinates 24.53˚N, 81.3˚E). In this performance comparison the measurement of productivity and temperatures at different points on solar still.

Key words: Cuboidal Box Type Solar Still, Capillary Feed System, Elevated Reservoir Feed

I. INTRODUCTION

Desalination using solar energy is a technique of separating dissolved impurities and salts from water. It is a thermal distillation method using solar energy. In this method of distillation solar energy is used to produce fresh water from saline or brackish water. In the areas where sunlight is in abundance this method of desalination is quite feasible. A solar still is a vessel covered with glass which slopes down to a trough for collection of pure water. Simple solar still with a basin and glass cover was the first proposed design for solar water desalination. After this simple solar still designs, many other designs and modifications were proposed by different researchers with enhanced productivity.

Many researchers have done numerous advancements in this domain. Janardanan [1] established an analytical expression for the thermal efficiency of evaporative heat loss and heat transfer for open and closed cycle system of floating and tilted wick solar still. Dwivedi and Tiwari [2] worked out internal heat transfer coefficient for solar still using different thermal models. Arjunan [3] reviewed the advancement of solar distillation in India. Hansen[4] exercised an analysis on performance of inclined solar still with different new wick materials and wire mesh. Tiwari and Tiwari [5] analyzed the variation of heat and mass transfer in a passive solar still with water depth in summers. Alaian [6] investigated the performance of solar still augmented with pin-finned wick by experimental validation. Ayoub [7] studied solar desalination with enhanced production by the introduction of slow rotating drum in the basin and water sticks to its surface in the form of film and then gets rapidly evaporated. Srivastava[8] presented an experimental validation of effect of absorber material in single slope basin type still. Olalekam [9] used a solar still mounted on a sun tracking mechanism to improve the productivity.

Many researchers worked on inclined solar stills and solar stills with absorber materials. But no work has been done till date to check which feed system is most beneficial for this cuboidal box type solar still with porous basin. With the use of porous basin two types of feed system s can be installed. One is continuous flow feed system that works under the influence of gravity and another one is capillary feed system that works on the principle of capillary rise of fluid through a narrow passage. In this paper an experiment has been done to investigate the performance of cuboidal box type solar still with different feed systems. In this research work, an experimental analysis of performance comparison of cuboidal box type solar still with different feed systems deployed with porous material was exercised in the month of May in Rewa Madhya Pradesh (24.53˚N, 81.3˚E) and elevation of 304 m from sea level. Two stills with plane profile are kept in the experimental setup and one was fed with a reservoir under the influence of gravity and another was fed by a reservoir kept outside the still by capillary action.

II. MODELLING

The formation of vapors within the still is dependent on the heat transfer coefficient for evaporation. Heat transfer coefficient for evaporation is dependent on the convective heat transfer coefficient between glass cover and wet porous sheet of jute sack. The convective heat transfer coefficient depends upon the difference between the temperature of wet porous sheet and glass cover. It also depends on difference between partial pressures of vapor between wet porous sheet and the glass cover.

To find out the productivity theoretically, relations between convective heat transfer and evaporative heat transfer coefficient specified in [4,8] can be used.

The convective heat transfer between the wet porous material and glass cover is related as,

$$q_{cwg}=h_{cwg}(T_{wp}-T_g) \quad (2.1)$$

$$h_{cwg}=0.884\{[T_{wp}-T_g]+[(p_{wp}-p_g)(T_{wp})/(268900-p_{wp})]\}^{1/3} \quad (2.2)$$

Now, evaporative heat transfer coefficient between wet porous surface and glass cover depends upon convective heat transfer coefficient and can be obtained as,

$$h_{ewg}=0.01623\times h_{cwg}\times(p_{wp}-p_g)/(T_{wp}-T_g) \quad (2.3)$$

Now, heat transfer due to evaporation is given as,

$$q_{ewg} = h_{ewg}(T_{wp}-T_g) \quad (2.4)$$

Hence the quantity of distilled water per hour per square meter of basin area can be calculated from relation,

$$M_d=q_{ewg}/h_{fg} \quad (2.5)$$

III. DESIGN

This paper took into cognizance the fact that the still structure to be used should possess a number of features intended to guarantee an efficient and effective evaluation of results.

A. Box Type Still

Two cuboids shaped boxes are prepared from the waterproof plywood 9 mm thick. Dimensions of the boxes prepared were 0.8 m× 0. 6 m × 0.25m. Edges of boxes were sealed using leak proof sealant (epoxy glue). Walls of the still are painted with a thick coat of oil paint. Now, whole still is insulated using 15 mm thick Styrofoam (thermal conductivity = 0.33W/mK). The layer of insulation is painted black for maximum absorptivity. Waterproof sealant is also applied on the outer edges. As the glass cover and basin are parallel in the still, so it was needed to rest the still on an inclined stand (inclined at 24˚). The purpose of designing a still with parallel glass cover and basin was to reduce the distance between evaporative surface and condensing surface. As we know, the steam produced at low temperatures has very low enthalpy, this low enthalpy is lost when vapors spent their energy in reaching to the glass cover due to which some amount of vapor condenses prior to reaching the glass cover. In conventional glass slope type solar still these losses are very much dominant.

Fig. 1: Box type still

B. Glass Cover

A transparent glass cover of thickness 3.75mm and transmissivity 0.876 is placed on the top of the basin in order to slopes down it's surface into a small trough at it's lower edge.

Fig. 2: Still with glass cover

C. Distillate Channel

Distillate channel is the passage on which the cover glass slopes down and condensate gets collected in it. This distillate channel has a downward slope to make the condensate flow into the beaker. Generally distillate channel is made up of aluminium sheet but aluminium sheet posses a property of getting heated up due to which the condensate evaporates from channel and productivity decreases. To overcome this drawback 10th grade winding plastic is used to make the distillate channel. This plastic channel is also smooth which allows all of the condensate to flow down into the beaker.

D. Profiles

In two stills, different profile set-up was inserted for the purpose of comparison. Sheet of jute sack which was used in following profiles was blackened using No. 10 black die (generally used for clothes) so as to increase the amount of radiation to be absorbed by the material. The property that made me use jute sack to prepare still basin was it's thermal inertia. Thermal inertia of Jute is very less as compared to water. Thermal inertia is the property of material by virtue of which it resists any change in temperature. Thermal inertia also indicates the ability of material to store heat. The lower the value of thermal inertia there will be a higher and rapid rise in temperature as a result of which more amount of steam will get evaporated from surface and productivity of still will increase.

Fig. 3: Blackened porous sheet of jute

Plane profile was simply a porous sheet of jute sack rested on plane G.I. sheet (thermal conductivity 18W/m K). The G.I. sheet beneath the sheet of jute sack was blackened with oil paint mixed with some ash to increase the absorptivity. For testing the feed systems under identical conditions profiles for both the stills are provided with plane profile.

E. Feed System

As in this experiment focus was on the performance of stills using different feed systems. In order to compare two of the most common and simple feed systems two of our stills are checked under identical conditions.

1) Gravity Feed System

In gravity feed system, still is continuously feed by a reservoir kept at higher elevation and connected to still through a feed pipe. A horizontal pipe is fixed into the still with holes along its length for uniform distribution of water.

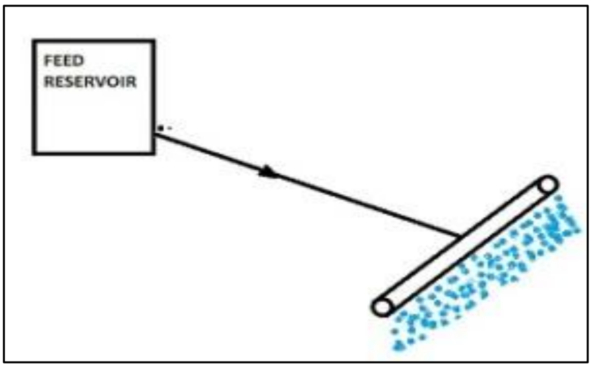

Fig. 4: Gravity feed system

2) Capillary Feed System

In this feed system, the extended length of jute sack is dipped into the water reservoir kept outside the still and water rises through capillary action and makes the jute wet. A combined capillary and gravitational action takes place, up to maximum point of elevation of still capillary action takes place as soon as the water reaches the point of maximum elevation water flows down wetting the jute sack rested on a G.I. sheet under the action of gravity.

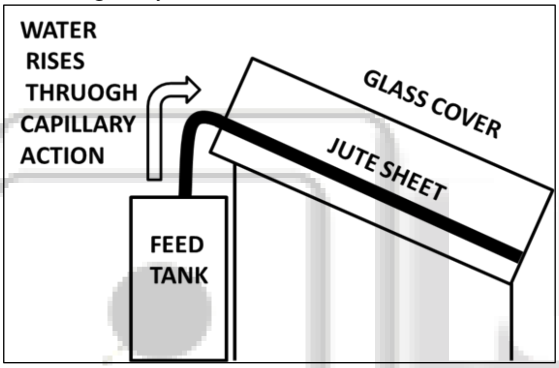

Fig. 5: Capillary feed system

IV. Experimental Setup

The experimentation was done in the month of May in year 2016. Readings of different parameters like glass cover temperature, basin temperature and productivity (ml/m^2) were recorded hourly from 6a.m. to 6p.m. for 10 days from 11th May to 20th May. In experimental setup, two solar stills of same size i.e. 0.8mX0.6mX0.25m were rested on stands. These stands have 24˚ angle of inclination with the horizontal. Then one of the stills was connected to a gravity feed reservoir and another was fed by capillary action.

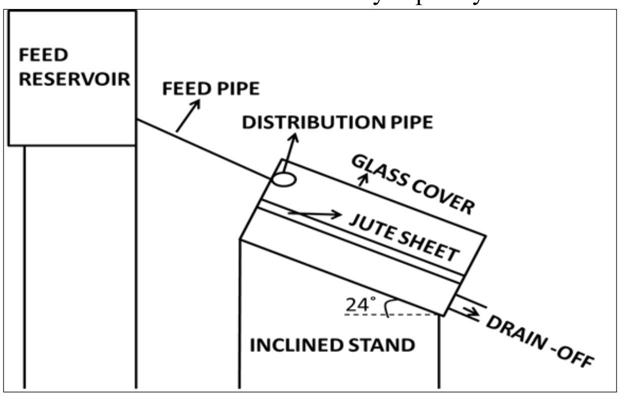

Fig. 6: Set-up for solar still

A drain off pipe was installed at the lower corner of stills for draining excess water from stills. This excess drain of water can be collected in another vessel o can be re-circulated to feed reservoir using a pump. In this case, drain off was collected in a vessel. Then stills were oriented with respect to the position of the sun at 6 a.m. using a hand held compass, such that maximum radiation fall on the stills. Beakers were placed underneath the outlet of the distillate channel for measuring the output or productivity.

Fig. 1: Experimental setup

A. *Instruments Used*

1) J-Type Thermocouple

A J-type thermocouple, with iron constantan bead was used to measure glass cover temperature and basin temperature. The operating range for the thermocouple was from -20˚C to 200˚C with the accuracy of ±1.1˚C. Alcohol type thermometers were also used with it.

Fig. 8: J-type thermocouple

2) Solar Power Meter

A hand held solar power meter TM-206 was used to record the solar radiation data. Specifications are as follows:-

Fig. 9: Solar power meter

- 3.5 digital LCD display with maximum reading of 2000 W/m^2.
- Display units W/m^2 and Btu.
- Data hold/max/min/function
- Ambient temperature measurement

V. RESULTS AND DISCUSSIONS

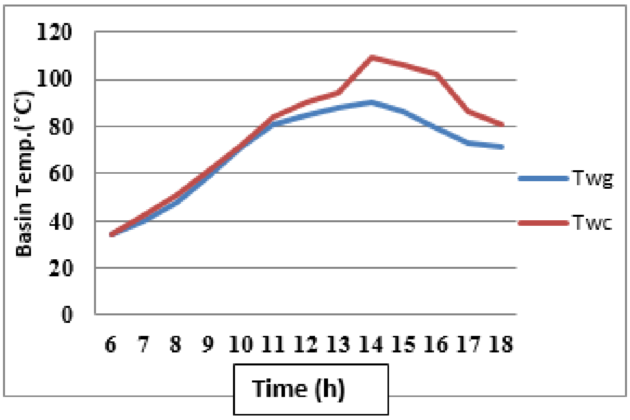

Fig. 10: Variation of basin temperature with time

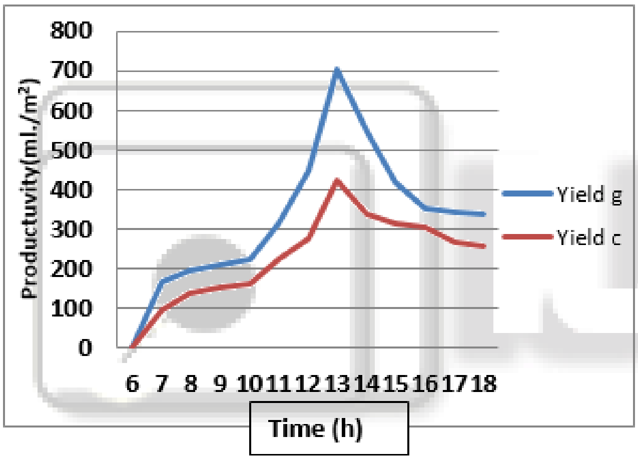

Fig. 11: Variation of productivity with time

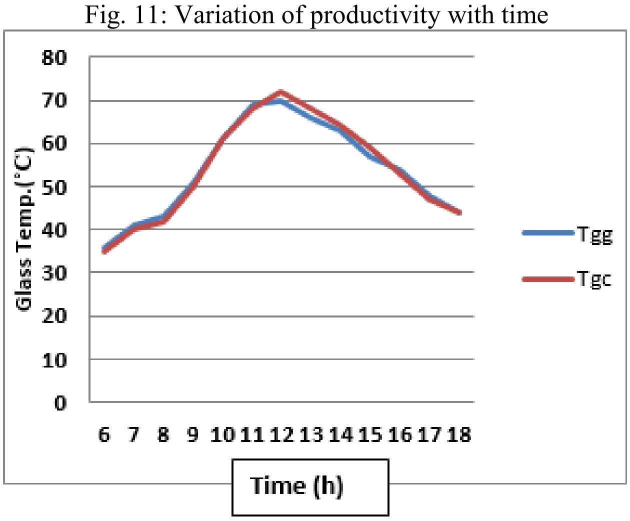

Fig. 12: Variation of glass temperature with time

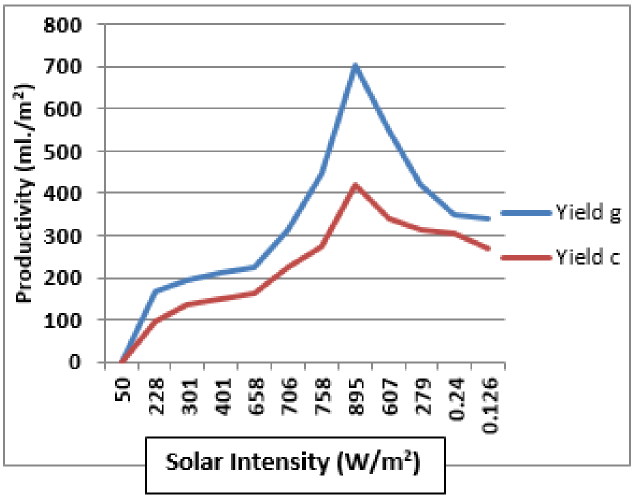

Fig. 13: Variation of productivity with solar intensity

T_{wg}= Temperature of basin with gravity feed system
T_{wc}= Temperature of basin with capillary feed system
T_{gg}= Temperature of glass cover of still with gravity feed
T_{gc}= Temperature of glass cover of still with capillary feed
$Yield_g$= Productivity of still with gravity feed system
$Yield_c$= Productivity of still with capillary feed system

The abrupt rise in basin temperature for solar still with capillary feed system was due to the formation of dry spots on the porous jute sheet because the water pumping capacity of capillary feed system was quite poor as compared to gravity feed system.

VI. CONCLUSIONS

From above experimental results following conclusion are drawn:-

- The day around productivity of the still with gravity feed system was found to be 33.3% more as compared to still with capillary feed system.
- Though the temperature of basin feed capillary feed system was very high as compared to still with gravity feed system but productivity was recorded on the lower side because of dry spots formation. As no water is available at dry spot so the effective area for evaporation decreases, hence the productivity decreases.

NOMENCLATURE

- h_{cwg} convective heat transfer coefficient (W/m^2°C)
- q_{cwg} convective heat transfer rate (W/m^2)
- h_{ewg} evaporative heat transfer coefficient (W/m^2°C)
- q_{ewg} evaporative heat transfer rate (W/m^2)
- T_{wp} temperature of basin (°C)
- T_g temperature of glass cover (°C)
- m_d quantity of water obtained (kg/hr)
- h_{fg} latent heat at basin temperature (kJ/kg)
- p_{wp} saturation pressure at basin temperature(mm of Hg)
- p_g saturation pressure at glass temperature (mm of Hg)
- SUBSCRIPTS
- wp basin
- g glass cover

REFERENCES

[1] Janardanan. Evaporative heat loss and heat transfer for open and closed system of a floating tilted wick solar still. Desalination 180 (2005) 291-305. DOI:10.1016/j.desal.2005.01.010
[2] V. K. Dwivedi & Tiwari. Comparison of internal heat transfer coefficients in passive solar still by different thermal models: An experiment validation. Desalination 246(2009)304-318. DOI:10.1016/j.desal.2008.06.024
[3] Arjunan. Status of solar desalination in India. Renewable and sustainable energy reviews 13(2009)2408-2418. DOI:10.1016/j.rser.2009.03.006
[4] R. Samuel Hansen. Performance analysis of inclined solar still with different new wick materials and wire mesh. Desalination 358(2015)1-8. DOI:10.1016/j.desal.2014.12.006
[5] Tiwari & Tiwari. Effect of water depth on heat and mass transfer in a passive solar still:in summer climate conditions. Desalination 195(2006)78-94.(November 2005).DOI:10.1016/j.desal.2005.11.014
[6] W. M Alain et-al. Experiment investigaton on the performance of solar still arrangement with pin finned wick. Desalination 329(2016)10-15. DOI:10.1016/j.desal.2015.10.010
[7] G. M Ayoub A solar desalination system with enhanced productivity.
[8] Pankaj K Srivastava. Effect of absorber materialon the performance of basin type solar still with multiple floating porous absorber. March 2013. DOI:ChemTechRes.2013.5C2
[9] Taiwo, Olalekam. Improving the performance of solar stills using sun tracking. 2010[THESIS] University of Strathclyde Engineering
[10] O. O. Badran. Experimental study of the enhancement parameters on a single slope solar still productivity. Desalination209(2007)136-143DOI:10.1016/j.desal.2007.04.022
[11] A. Safwat Nafey Enhancement of solar still productivity using floating perforated black plate. April 2001. Energy conversion and management 43(2002)937-946. DOI:SOI96-8904(01)00079-6
[12] S. A. El-Agouz. Performance evaluation of a continuous flow inclined solar still desalination system. Energy conversion and management 101(2015)606-615.DOI:10.1016/j.enconman.2015.05.069
[13] A Alaudeen. Study on stepped type basin in a solar still May 2013. DOOI:10.1016/j.ksues.2013.05.002

