Augmentation of Single Basin and Pyramid Still Desalination Using Common Biomass Heat Source and Analytical Validation Using RSM.

A. Senthil Rajan, K. Raja, P. Mari Muthu

Department of Mechanical Engineering, Momanded sathak polytechnic, Kilakarai-623806, Tamil Nadu, India.
Department of Mechanical Engineering, University College of Engineering, Anna university Ramanathapuram-623501, Tamil Nadu, India.
Department of Mechanical Engineering, Syed annmal Engineering, Ramanathapuram-623501, Tamil Nadu, India.

ABSTRACT

Solar desalination is one of the methods to produce fresh water from saline water. The productivity of single basin still is very low compared to other desalination methods. **Objective:** From the previous researcher works it is found that the productivity of the still is depends on increase in temperature of the saline water, area of the basin and decrease in depth of water. The main objective of this work is to improve the performance of single basin solar still and pyramid solar still coupled with a common biomass heat source to enhance the productivity. In single basin, pyramid stills heat exchangers are placed at the bottom of the basin area. The heat exchanger is connected to a common biomass boiler heat source to receive heat energy. This arrangement increases the water temperature in the stills and also increases the productivity in the still. Biomass used in the heat source is eco friendly. Experiments are conducted in solar and biomass modes with various water depths, sensible, latent heat, evaporative materials placed in both the stills and the results are analyzed using RSM software. A conventional still is fabricated and run parallel with the experimental setup for comparison. **Results:** It was found that 2cm water depth produces maximum output. Use of seashell as solid sensible heat storage materials in the still improves productivity by 72% than conventional still. The use of sponge as evaporative surfaces increases the area of exposure and still productivity by 68% the use of wax as latent heat materials increases 54% productivity than conventional still. **Conclusion:** From the overall observation it is found that maintaining lower depth of water in the basin increases the productivity and maximum output is achieved when biomass heat source is used instead of solar mode. The introduction of sensible heat storage materials increases the overall productivity in the still.

INTRODUCTION

Country development depends on growth of industrial sector. The industry depends upon power and water. Rain s the main source of water in many parts of the country due to insufficient quantity of rain water people suffers from water scarcity and many more water borne diseases are caused due to impure water to solve the current issues water from desalination process may be used. The desalination is low cost and cheap even sea water can be treated and converted to drinking water. Many researches are done to increase the productivity of solar still. Badran (2007) fabricated a single slope solar still and studied the performances using different operational parameters. From the study they found that the depth of water affects the productivity. Aybar et al.,(2005) uses evaporative surfaces such as black cloth wick on the bare plate they compared the production rate of bare plate against wick. The results showed that the productivity of wick is 3 times that of bare plate. Moustafa and Brusewitz (1978) fabricated a stepped still and collector with wick the performances shows that by reducing ration losses the productivity can be improved. Velmurugan and Srithar (2007) uses mini solar pond as a heat source along with stepped still and single basin still connected in series many types of sensible, evaporative surfaces are used in their work. The productivity is increased when compared to conventional still. Hiroshi and Yashuhi (2003) fabricated a diffusion type solar still using heat pipes in the collector surface. The productivity is increased by 13% than basin type still. Hassan E.S. Fath and H.M. Hosny (2004) uses additional condenser inside the still and reduces the glass temperature. Bassam and Hamzeh (2002) analysis different sizes of sponge cubes inside the still to increase the evaporation in the still by capillary action. The results showed that there is 18% to 27% increase in productivity than conventional still. Velmanirajan et.al,(2012) analyses

**Objective:**

From the previous research works it was concluded that the increase in the productivity is due to increase in water temperature. In this present work a single basin still and a pyramid type stills are connected to a common biomass heat source. Biomasses such as wood, palm wastes are used in the biomass boiler. The fire tube boiler supplies heat energy to the saline water through the heat exchangers placed inside the bottom of both the basins. The heat exchanger exchanges the heat to the saline water inside the still. The evaporation and condensation occurs inside the still through glass covers. The still behaves as a condensing unit. The system does not depend on solar radiation. Experiments are done with different types of water depths, sensible, latent heat and evaporative materials both in solar and biomass modes.

**Experimental Setup and Procedure:**

The single basin solar still and pyramid type single basin still having same basin area 0.81x 0.82 x 0.75m.size are connected to the common biomass heat source. Both the basins are painted black to absorb maximum solar radiation. The side and bottom sides of the stills were insulated with 0.004m thick thermocol insulation layer (015w/m-k thermal conductivity) to reduce heat losses in the still. The condensing surface of the single basin still is made of plain glass with 4mm thickness is fixed at 30° inclination to the horizontal axis. Similarly a pyramid type still having glass area 1.2m² inclined 30° to the horizontal acts as condensing surface. Silicon rubber sealant is used to hold the glass intact with the still to prevent the vapor leakage from the still. Collection troughs were provided below the lower edges of the glass cover to collect the condensate. Distillate outlets were provided to drain the water through hoses and to store in jars. Provisions were made to supply raw water, drain the basin water and insert thermocouples. The biomass boiler having 133mm outer diameter and shell thickness12mm and height 550mm made of cast iron was used as a heat source. The boiler is fire tube type internally fired with locally available biomass materials. The lower portion of the boiler is called the furnace where biomass is fed in to the furnace through fuel input door. The burnt ashes are collected at the lower end and removed periodically. The lower end of fire tube is connected to the furnace and upper end is connected to chimney. Boiler drum has inlet and outlet to admit the feed water from the boiler. The feed water is supplied to the boiler drum by gravity from the input feed water supply tank which is placed above the height of the boiler. Safety valves and pressure gauges are fitted above the boiler drum for safety aspects. The exhaust gases after passing through the fire tubes are exhausted to the atmosphere through chimney provided at the top of the boiler. The boiler is supplied with biomass and fired manually. The inlet end of both the heat exchangers is connected to the boiler outlet pipe through common connector and outlet end was connected to the circulation pump to circulate water again to the boiler drum. Both the Solar stills are supplied with 2cm depth of water through the inlet pipe in the still. Biomass boiler was filled with feed water supplied from the inlet supply tank. Biomass having 1kg of mass is fed inside the furnace through the fuel supply door and ignited manually. Water in the drum gets heated the burnt gas passes through the inner side of the fire tube and exhausted to the atmosphere through the chimney. While passing, the burnt gas gives out the heat to the water in the outer drum. Thus the water gets boiled. The boiled water is circulated inside both the solar stills through the heat exchangers and the circulation pump. The water inside the solar still absorbs heat from the heat exchangers and evaporated in to vapors reaches the bottom surface of the glass cover. The top surface of the upper basin was Cooled externally the vapors condenses and collected in the condensate collection channel as Distilled water. A collection flask collects the distilled water. Water circulation and the burning process in the boiler were stopped when basin temperature reaches about 75°C for once flow mode. In the solar mode the still is exposed to solar radiation and the biomass boiler is cutoff from the still. Before starting the experiments the glass cover was cleaned by using cotton cloths.

**Response Surface Methodology:**

Response surface methodology is a mathematical modeling tool used to predict the output relationship with respect to the multi input parameters. The mathematical expression for the output responses can be arrived with respect to the input factors. The model predicts the value of the unknown output for any desirable input. The results can be compared with experimentalvalues obtained for the same. The degree of the closeness of predicted and experiment avaluwil show the excellent fit of the model for the particular experiments. The response surface methodology is a type of optimization that applies an approximation technique to the objective and other functions of an optimization problem. For approximation, it uses a function called a response surface. A response surface is approximate result. The Box-Behnken experimental design of RSM has been chosen to find the relationship between the response functions and variables using the statistical software package Design Expert Software 8.0.7.1. (Stat-Ease, Inc.. Minneapolis. USA). The Box-Behnken design can be considered as a highly fractionalized three-level factorial design where the treatment combinations are the midpoints of edges of factor levels and the centre point. These designs are rotatable (or nearly rotatable) and require three levels of each factor under study. Box-Behnken designs can fit full quadratic response surface models and offer advantages over other designs. The advantages of the Box-Behnken design over other response surface designs are: (a) it needs fewer experiments than central composite design and similar ones used for Doehlert desins; (b)
in contrast to central composite and Doehlert designs, it has only three levels; (c) it is easier to arrange and interpret that other designs; (d) it can be expanded, contracted or even translated; and (e) it avoids combined factor extremes since midpoints of edges of factors are always used. The level second order design demand comparatively lesser number of experimental data for precise prediction. Here, a total number of 29 experiments including three centre points are carried out for four parameters. The interaction between the variables and the analysis of variance (ANOVA) has been studied using RSM.

Fig. 1(a): Experimental setup internal view  (b) Experimental set up with glass cover.


Fig.1(c): Sea shell  Fig.1(d): Wax filled in billet  Fig.1(e): Heat exchanger with sponges
RESULTS AND DISCUSSION

Effect of water depths:
The effect of water depth in the still basin in the productivity is shown in fig.2. It is evident that as the water depth increased, the productivity will be decreased. This is due to be increase of the heat capacity of the water in the basin, results, in lower water temperature in the basin leading to lower evaporation rate. 2 cm depth produces 70% more output than conventional still. 3 cm, 4 cm produces 58% and 36% more than conventional still in solar mode.

Effect of sensible heat storage materials on productivity:
The fig.3 shows the productivity of sea shell as solid sensible heat storing materials placed inside still with 2 cm water depth and tested. The productivity of seashell are 72% more than conventional still when operated under biomass mode. The maximum productivity was 989 ml/m$^2$ at the starting and the productivity decreases to 612 ml/m$^2$ towards the end. This was clearly shown in the fig.2 in red and blue colors. The calcium content present in the seashell retains the heat and helps to increases the water temperature in the still.

Effect of evaporative surfaces on productivity:
Due to capillary action sponge absorb more water. Thus exposure area is increased. This leads to increase the evaporation rate in the still. As shown in fig.4 the total productivity is increased by about 68% than conventional still when operated under biomass mode. The maximum productivity is 811 ml/m$^2$ at the starting and lower production of 444 ml/m$^2$ at the end.

Effect of latent heat storage:
The fig.5 shows the productivity of latent heat storage material. The wax absorbs heat and melted during melting wax gives out the heat to the water in the basin thus the water temperature gets increased. After gives out heat again it solidifies and absorbs heat thus continuous charging and discharging of wax results in increasing the water temperature and productivity in the still. Waxes are introduced in the still in the form of small billets. An aluminum billet having 10 mm diameter and 30 mm long are packed with wax at half of the volume is kept inside the still to improve water temperature. The maximum productivity of 837 ml/m$^2$ is obtained in both the stills together at the starting.

Annova output:
The following table.1 shows the analysis of variance (ANNOVA) for the experimental values. The result indicated that the predictability of the model is 99% confidence and the predicated response fit well with those of experimentally obtained values. The p-value is less than 0.0001 for the entire model which indicates that the model is statistically significant. The tables .1 shows the model values for water depth tested with 2 cm water depth in both pyramid and single basin still.
Table 1: ANOVA output for 2 cm water depth in modified still.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>594061.8</td>
<td>5</td>
<td>118812.4</td>
<td>500.0719</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>A - Time</td>
<td>515109.1</td>
<td>1</td>
<td>515109.1</td>
<td>2168.054</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>B - Water depth</td>
<td>73594.11</td>
<td>1</td>
<td>73594.11</td>
<td>309.7518</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>AB</td>
<td>23 34217</td>
<td>1</td>
<td>23 34217</td>
<td>0.097924</td>
<td>0.7579</td>
</tr>
<tr>
<td>A^2</td>
<td>9812.983</td>
<td>1</td>
<td>9812.983</td>
<td>41.30208</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>B^2</td>
<td>5577.705</td>
<td>1</td>
<td>5577.705</td>
<td>23.47612</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Fig. 2: Effect of water depth in conventional still.

Fig. 3: Effect of sensible heat storage material in modified stills.

Fig. 4: Effect of Latent heat storage material in modified still.
Fig. 5: Effect of Evaporative materials in modified stills.

**Optimization:**

Graphical optimization displays the area of feasible response values in the factor space. Regions that do not fit the optimization criteria are shaded. Any "window" that is NOT shaded satisfies the multiple constraints on the responses. The area that satisfies the constraints will be yellow, while the area that does not meet the criteria is gray in color. The flags show predictions for all responses at that location in space. The fig.6 shows the overlay plot for different sensible heat storage, latent heat storage and evaporative surfaces with 2cm water depth for once flow mode. The main aim of optimization is to maximize the output between the limits 400 to 760ml/m² under various materials. In the fig.6 maximum outputs of 400 to 700ml/m² are covered in the region as indicated by yellow color from 10hrs to 15hrs after that the region marked dark color fails to satisfy our conditions. Hence productivity in those regions is below our required limit.

Fig. 6: Optimization in modified stills.

**Conclusion:**

An experimental work has been conducted to predict the productivity of a single slope solar still and pyramid solar still coupled with common biomass boiler using different solid, liquid sensible heat storage mediums and various evaporative materials and water depths.

Based on the experimental results the following conclusions are made:

- An increase in the water temperature is due to heat supplied in the biomass heat source. Changes in solar radiation do not affect production. Solar still behaves as condensing unit. Biomass is eco friendly.
- Cost of water production is low. Glass cover cooling increases the condensation rate in the still.
- Use of seashell as solid sensible heat storage materials in the still improves productivity by 72% than conventional still. The use of sponges as evaporative surfaces increases the area of exposure and still productivity by 68%. The use of wax as latent heat materials increases 60% productivity than conventional still.
- Lower water depth in the still increases 70% productivity in the still. Single basin and pyramid still coupled with common heat source produces more yield than conventional still. Productivity of pyramid still is more when compared to single basin type solar still.

**REFERENCES**


