Experimental Analysis of Double Slope Solar Still
Aniket Kavlekar

I. INTRODUCTION
Water is essential for all life forms on earth plants, animals and human etc. For fresh water requirements humanity is dependent on rivers, ponds, lakes and underground and water reservoirs, the available fresh water on the earth is fixed, but the demand of fresh water is increased, due to population growth and rapid industrialization. Industrial wastes and sewages discharge are mostly drained in the rivers, so the available fresh water is reduced. The ocean is the only available source for the large amount of water. But the ocean water contains salinity, so there is a need to desalinate the water. Desalination is one of humankind’s most primitive forms of water treatment and it is still a popular treatment solution throughout the world today. In natural solar desalination produces rain when solar radiation is absorbed by the sea and causes water to evaporate. The evaporated water rises above the earth surface and moved by the wind. Once this vapour cools down to its dew point temperature, condensation occurs and the fresh water comes down as a rain. The basic process is responsible for the hydrological cycle. This same principle is used in all the manmade distillation systems using alternate sources of heating and cooling [1]. Solar Still is a device which is used to perform the desalination purpose. Hence application of Solar Stills for distillation of sea or salty water for the production of fresh water is economical with respect to the energy requirements but the distillate rate is low. The Solar distillation involves all three modes of heat transfer. Heat flows from inside the solar Still to the environment through the transparent glass cover and the walls by conduction. Heat from the basin still, the vapors to the environment through radiations. Experimental results in Solar Still are being compared with the analytical result data of double slope solar still at climatic conditions of Vellore (latitude of 12.92020 N, longitude of 79.1330 E).

Key words: Solar Still, Evaporation, Condensation

II. LITERATURE REVIEW
Some researchers have focused on the experimental procedures to find a better design for solar stills. Tiwari et al. experimentally compared the three different types, and concluded that in winter a single slope solar still has better performance than a double slope one, whereas in summers the opposite results were observed [2]. Rai et al. have shown that solar still when coupled with the flat plate collector increases the distillate output by 24% compared to the single slope basin solar still [3]. Zeroual et al. reported that the performance is improved by using a partially cooled glass cover [4]. Tigris et al. found that coupling of flat plate collector with a solar still produces distillate output 5L compared with the output of 3L from the single slope basin solar still [5]. Badran et al. proved that, flat plate collector coupled with solar still increased the efficiency of 35% compared with single slope solar still basin Iranain climate conditions[6]. Kianifar and Mahian. Investigated the effect of using a low-powered fan and reported an improvement in productivity [7]. Al-Garni et al. showed that there is an optimum glass angle in which the output has a maximum value[8]. In addition of mathematical modeling, some investigations have been done based on computational fluid dynamic (CFD). CFD as a tool, has relatively low cost and high speed, while it can also simulate a real or an ideal condition. Moreover, CFD allows examining a large number of situations and gives a comprehensive set of parameters [9]. These advantages have encouraged the scientist to use the computational fluid dynamics for studying fluid phenomena in solar stills. Rheinlander used a finite difference algorithm to solve the governing equations in a single slope solar still. He showed a closed agreement between numerical and experimental mass transfer data. [10]

III. METHODOLOGY
A sectional view of a Simple Solar Still is shown in figure 2. It is an insulated metallic basin covered by a transparent glass. The basin is made up of GI sheet having a base area of 1.0 m x 1.0 m. The basin is double walled having 1” thermocoul sheet sand-witched between the walls to reduce heat losses from walls. The basin is painted with black epoxy paint from inside to increase its absorptivity and it is painted with silver enamel paint on the walls to create the adiabatic surface on the walls and reduce thermal losses. A transparent glass of 5 mm thickness covers the top of the still. For validation of the simulations results two experimental data were collected

A. Experimental Analysis of Solar Still:
The experiments were carried out from 1100 Hrs till 1300 Hrs. During each 20 minute time interval, an average temperature was set as boundary condition. It was assumed that in a time period of 20 min, the received solar radiation by the basin still as well as water and glass temperatures of
the basin reach to a steady state in fair weather condition. Boundary conditions for glass, bottom and collecting channel were considered as constant temperature boundary. Bottom plate is painted black to absorb maximum solar radiation. Solar intensity is based upon absorption factor and emissivity of glass, water and bottom. Based on the experimental results Radiative and Evaporative heat transfer coefficients are calculated. 

Formula used

1) \( h_1 = h_{ew} + h_{vw} \)

Where \( h_{ew} = \) Evaporative heat transfer coefficient

\[
0.016 h_{ew} \left[ \frac{P_w - P_g}{T_w - T_g} \right]
\]

\[
h_{ew} = 0.884 \left[ \left( T_n - T_g \right) + \frac{\left( P_w - P_g \right) (T_w + 273)}{268.9 \times 10^3 - P_g} \right]^{1/3}
\]

\( P_w = \) Partial pressure of water at Tw in N/m²

\( h_{vw} = \) Radiative heat transfer coefficient

\[
h_{vw} = 0.884 \left[ \left( T_n - T_g \right) + \frac{\left( P_w - P_g \right) (T_w + 273)}{268.9 \times 10^3 - P_g} \right]^{1/3}
\]

2) \( h_2 = h_{ra} + h_{ca} \)

where

\[
h_{ra} = C_g \left( T_g + 273.15 \right)^3 - (T_a + 261.15)^3 \]

\[
h_{ca} = \frac{C_w}{T_a - T_g}
\]

\[
h_{ca} = 0.9
\]

\( h_{cw} = 5.7 + (3.8 * V) \)

\( V = \) Velocity of wind in m/s

3) Hourly Yield Distillate:

4) \( m_e = \frac{h_{ew} \left( T_w - T_g \right)}{h_{fs}} \times 3600 \quad \text{kg/m}^2\text{hr} \)

\[
h_{fs} = 2257 \quad \text{kJ/kg}
\]

Table 1: Temperature Dependent Physical Properties

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific heat</td>
<td>( C_p )</td>
<td>999.234 + 1.104 * 10^{-4} T/°C</td>
</tr>
<tr>
<td>Density</td>
<td>( \rho )</td>
<td>2.715 \times 10^3 * 10^{-8} T/°C</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>( K_w )</td>
<td>0.0244 + 0.7659 * 10^{-4} T</td>
</tr>
<tr>
<td>Viscosity</td>
<td>( \mu )</td>
<td>1.7185 * 10^{-1} * 4.603 * 10^{-8} T</td>
</tr>
<tr>
<td>Latent heat of vaporization of water</td>
<td>( L )</td>
<td>3.615 * 10^6 * [1 - 7.56 * 10^{-4} T] * T</td>
</tr>
<tr>
<td>Partial saturated vapor pressure at condensing temperature</td>
<td>( P_0 )</td>
<td>2.2953 * 105 * 1.9749 * 10^{-4} * 10^{-1} * 1.332 * 10^{-4} * 10^{-1} * 10^{-1}</td>
</tr>
<tr>
<td>Partial saturated vapor pressure at water temperature</td>
<td>( P_w )</td>
<td>2.2953 * 105 * 1.9749 * 10^{-4} * 10^{-1} * 1.332 * 10^{-4} * 10^{-1} * 10^{-1}</td>
</tr>
</tbody>
</table>

Table 2: Symbols and Notations

1) Thermal Model:

The water vapour present above the water level is freely convected to the glass covering by the variation of density caused by the buoyant forces and variation in the temperature. This process occurs freely in natural mode. However, the transfer of heat from the external glass covering may take place in a free or forced mode, depending on the conditions outside. [2] This has been explained in detail in the Tiwari et al. General Convective heat transfer equation is given by;

\[
Q = h_{cw} \times A \left( T_c - T_{w} \right) = h_{cw} \times A \times \Delta T
\]

The relation for the non dimensional Nusselt number is determined by

\[
Nu = \frac{h_{cw}}{K_v} = C \left( Gr \times Pr \right)^n
\]

or

\[
h_{cw} = K_v \frac{L_v}{L_v} \times C \left( Gr \times Pr \right)^n
\]
Where Gr-Grashof number and Pr-Prandtl number.
The unknown C and n are determined by the regression analysis using the experimental data. Gr and Pr can be calculated by

\[
Gr = \frac{\beta g L^3 c \rho^2 \Delta T}{\mu^2}
\]

\[
Pr = \frac{\mu \times C_p}{K_v}
\]

\[
h_{tw} = 0.88 \left[ T_w - T_{ci} + \frac{(P_w - P_{ci})(T_w + 273)}{268.9 \times 10^3 - P_w} \right]^{\frac{1}{3}}
\]

The experimental results so developed are compared with the analytical results obtained by the Tiwari et al.

B. Calculation of Volume Fraction of Water:
The second part of the experimental studies includes the process of determining the volume fraction of water. This includes carrying out three set of tests.

1) PPM Test of Water:
Two samples of water are collected: First is the one which was put inside the solar still and the second which was collected out from the solar still. These two samples were tested for the following test to calculate the salts presents.

2) Hardness Test:
Hardness in water causes scale formation in boilers. It is also objectionable from view point of water use for laundry and domestic purposes, since it consumes a large quantity of soap. Generally, salts of Ca and Mg contribute hardness to natural waters, though other ions like strontium, ferrous and manganese also contribute hardness. Hardness may be classified either as (1) carbonate and non-carbonate hardness or (2) calcium and magnesium hardness or (3) temporary and permanent hardness. In alkaline condition EDTA reacts with Ca and Mg to form a soluble chelated complex. Ca and Mg ions develop wine red colour with eriochrome black ‘T’ under alkaline condition. When EDTA is added as a titrant the Ca and Mg divalent ions get complexed resulting in sharp change from wine red to blue which indicates end point of the titration. The pH for this titration has to be maintained at 10.0 ± 0.1.

3) Reagents:
1) Ammonia Buffer solution: Dissolve 16.9 g of NH4Cl in 143 ml concentrated NH4OH. Add 1.25 g of Magnesium salt of EDTA and dilute to 250 ml with distilled water.
2) Erichrome black T Indicator
3) Standard EDTA solution 0.01 M: Weigh 3.723 g of AR grade disodium ethylene –diame tetra acetate di-hydrate and dissolve in 1 litre of distilled water. Check the strength by standardizing with calcium solution
4) Standard calcium solution

4) Procedure of the Test:
Take 20 ml or suitable portion of sample diluted to 100ml in to a conical flask. Add 1-2 ml buffer solution. Add 1 or 2 drops of Erichrome black T and titrate with standard EDTA (0.01 M) till wine red colour changes to blue. Note down to vol. of EDTA required. (A) Run a reagent blank if buffer is not checked properly. Note the Vol. of EDTA required by blank (B). Calculate Vol. of EDTA required by sample, \( C = (A-B) \)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Volume of sample (ml)</th>
<th>Burette reading</th>
<th>Vol. of EDTA consumed (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>0</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Total Hardness as mg/l of CaCo3= \( (C \times D) \times 1000 \)/Volume of sample

Where C- volume of EDTA required by sample

D-1 ml of EDT = 1mg of CaCo3

- For Sample 1:
  Total hardness as mg/l as CaCo3= 17 x 1 x1000/20 = 850 mg/l
  This is 0.085% of the total volume of the water
- For Sample 2:
  Total hardness as mg/l of CaCo3= 1.4 x 1 x 1000/20 = 70 mg/l
  This is 0.007% of the total volume of the water

C. Chloride Test:
Chlorides occur in all natural waters in widely varying concentrations. Chlorides are usually present in water as compounds of Sodium, Calcium and Magnesium. Chlorides in reasonable concentrations are not harmful. At concentrations above 250 mg/l, it gives a salty taste to water. For this reason, chlorides are generally limited to 250 mg/l for potable water. Water usually high in chloride concentration indicates pollution from domestic sewage or industrial sewage.

The Mohr’s method or Argentometric method for the determination of chloride in water is based upon the fact that in solution containing chloride and chromate, silver reacts with all the chloride and precipitates before the reaction with chromate begins. The appearance of the brick-red color of the silver chromate precipitate is the end-point of the titration.

1) Reagents:
1) Potassium chromate indicator solution
2) Standard silver nitrate titrant, 0.030 N
3) Standard sodium chloride, 0.015 N

2) Procedure:
Take 100 mL of the sample or take appropriate amount and dilute it to100 mL. Fill burette with silver nitrate titrant. Add 2 to 3 drops of the potassium chromate indicator to the sample. Titrate the blank with standard AgNO3. The end point is the change of colour from yellow to brick-red (B) Titrate the sample in the same way to the same brick-red color (use blank titration as reference colour and be consistent in end-point recognition).(A). Calculate ppm Cl- and record with one decimal.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sample 1</th>
<th>Sample 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Volume (ml)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Initial Burette reading</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Final burette reading(ml)</td>
<td>29.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Total Chlorides as mg/l = (A x N AgNO₃ x 35450)/Volume of sample
Where A- ml AgNO₃ consumed
- For sample 1:
  Total chlorides = (29.5 X 0.0141 x 35450)/20
  = 734.772 mg/l
This is 0.0734772% of total volume of the water
- For sample 2:
  Total chlorides = (1.4 X 0.0141 x 35450)/20
  = 35 mg/l
This is 0.0035% of total volume of the water

D. Sulphate Test:
The sulphate ion is one of the major anions occurring in natural waters. It is of importance in public water supplies because of its cathartic effect on human when it is present in excessive amounts. For this reason, the recommended upper limit is 250 mg/l in water intended for human consumption. Sulphates are important in both public and industrial water supplies because of the tendency of water containing appreciable amounts to form hard scale in boilers and heat exchangers. Odour and sewer corrosion problems are resulted from the reduction of sulphate to hydrogen sulphide under anaerobic conditions.

Sulphate is precipitated in hydrochloric acid medium with BaCl₂ to form BaSO₄. The turbidity of BaSO₄ suspension is measured in Turbidity meter.

1) Reagents:
   1) Conditioning agent: Mix 50 ml glycerol with a solution containing 30 ml of concentrated HCl, 300 ml distilled water, 100 ml 95% ethyl or isopropyl alcohol and 15 g NaCl.
   2) Barium Chloride crystal: 20 to 30 mesh size
   3) Standard Sulphate solution: Dissolve 1.479 g of anhydrous Na₂SO₄ in 1 litre distilled water. This suspension contains 1 ml = 100 μg Sulphate.

2) Procedure:
Measure 100 ml water sample or suitable portion of sample made to 100 ml with distilled water. Add 5 ml conditioning agent and a spoon full of BaCl₂ crystals. Stir exactly for 1 minute. Pour the solution in to the glass cell of the turbidity meter and measure the turbidity. Prepare a calibration graph by using sulphate standard as described earlier. The standards can be made from 0 to 40 mg/l sulphate range by taking 0-40 ml standard solution and making up to 100 ml. Determine the concentration of given sample from the calibration chart plotted with known sulphate concentrations Vs turbidity.

a) Observation and Calculations:
   - For sample 1:
     Turbidity is found to be 490 NTU hence from graph sulphate concentration comes out to be 8.4 mg/l. That is 0.0084% of the total volume of the water.
   - For sample 2:
     Turbidity of the samples is found to be 150 NTU hence from graph sulphate concentration comes out to be 2.5 mg/l. That is 0.0025% of the total volume of the water. It is noted that as the process begins water in the basin is heated by supplying heat from the bottom. Water starts warming up gradually the still space saturates with the vapor
temperature difference $\Delta T$ between evaporative and condensing surfaces. It plays an important role in optimizing the yield and so ultimately convective mass transfer coefficient as well. The variation in the ambient temperature with time is negligible.

V. COMPARISON OF RESULTS

Comparison of the results obtained from the water sample collected before the filling into solar still and after passing through the solar still.

<table>
<thead>
<tr>
<th>Test</th>
<th>Before (mg/l)</th>
<th>After (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness Test</td>
<td>850</td>
<td>70</td>
</tr>
<tr>
<td>Chloride Test</td>
<td>734</td>
<td>35</td>
</tr>
<tr>
<td>Sulphate Test</td>
<td>8.54</td>
<td>2.5</td>
</tr>
</tbody>
</table>

By looking at the results we can conclude that solar still helps in reducing the hardness and salts of water which make it undesirable for domestic usage.

VI. CONCLUSION

In this paper the evaporation and condensation takes place in the experimental model. Due to solar radiation the water is vaporized and the model was able to show condensed water droplets on the glass. Droplets that slipped downward to the downcomer are also observed. Accumulated water produced where compared with the experimental results. They were in good agreement. Convective and evaporative heat transfer coefficients calculated by experimental and analytical where in good agreement according to the tiwari et al [2]. The experiments regarding the calculation of volume fraction of water showed that the device was able to decrease the amount of salt content considerably. The hardness, chloride and sulphate test indicate that the decrease in the amount of salt content makes the salt water fit for domestic purpose. This indicates the usability of the device and its importance for remote places where there is a scarcity of portable water. By having a detailed analysis of the device we will be able to predict the methods to improve the efficiency of the device. There by making the device feasible and usable to a wider population. This work could be extended by taking up the CFD analysis of the model.

REFERENCES