Investigation and performance analysis of solar still with different absorber plates

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Abstract— Among the active and passive solar still, when portable water requirement if less than 5 litters then passive solar still is used otherwise active solar still is used. Only the price of active solar still is more compared with passive solar still. Hence, it is a prime requisite of every researcher is to increase distillate output in passive solar still. Research states that, when distance between water and ice cover reduces, automatically distillate output and efficiency is increased due to decrease of losses. Hence, if a plate is set beneath the water level, at that time distance between the absorber plate and glass cover decrease and speed of travelling of vapor also decrease along with the saturation pressure of water increase. Here, chequered plates are going to employ, which increased convective and evaporative heat transfer coefficient by a diamond shape pattern on its surface.

Keywords- solar stills deep basin & shallow basin, chequered plate (Al), logger, thermocouples, discharge output.

I. INTRODUCTION

To provide pure water and adequate sanitation services to all people is perhaps the greatest developmental failure of the 20th Century. The most egregious consequence of this failure is the high rate of mortality among young children from preventable water-related disease. According to the report by the Pacific Institute of Oakland, California, over 76 million people will perish from water-related disease by 2020 unless urgent measures are taken. The report finds that water-related could remain more lives than the AIDS pandemic. The problem of non-availability of pure water is the most serious public health crisis and deserves far more attention and resources than it has had thus far. Two of the most significant issues from the international environmental point of view are water and energy. On one hand distribution of water depends on the available low cost energy, on the other hand large volume of water is a pre-requisite of the production of energy. Due to population increases, the irrational waste and especially severe contamination of the existing resources, so the availability and quality of fresh water resources is decreasing dramatically. In many parts of the world the pollution of rivers, lakes and ground water has significantly reduced the availability of fresh water. In facts as human needs for water and irrigation increases the reduction of water sources like wells increases. The scarcity of fresh water, especially in arid and semi-arid regions is high in and middle east regions, where abundant solar energy and salty water are available. In this neighborhood, many big cities and even small villages suffer from want of clean water. Some places not only re in lack of water, but also electric power grid connection as well and it is not possible to use electricity to provide fresh water. A. A. Sebaii, S. Enein, 1999 [1] In this paper a single slope, single basin solar still with movable absorber was designed and tested. The heat transfer from the upper to lower columns and vice versa occurs through the vents and the suspended absorber itself. A.A.Sebaii, S. Enein, 1998 [2] It is found an inverse proportionality between productivity and the thermal inertia of solar stills. They defined the thermal inertia as the time lag between the maximum instantaneous solar radiation and maximum evaporation rate. The overall thermal inertia of the sill involves a complex chain of separate heat storage and heat conduction links such as water – ground, water-air space, air-space roof and roof-ambient. Here they tried to decrease the thermal inertia and consequently increase the productivity as well as the still efficiency through rearrangement of the heat absorber in the stool. N. H. A. Rahim, 2002 [3] The existing conventional small solar desalination basin stills suffer from some drawbacks, which make them inefficient to be used as domestic solar desalination units. This is the cheap, simple and efficient method to store excess heat energy in horizontal solar desalination still, without bringing down the temperature of the urine in the evaporating zone during the day too much, and hence the daytime

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productivity rate. This scheme does not need any form of outside power. Rada Zarasvand Asadi, Fatihah Suja, (2013) [4] The experiment was done by running three types of effluent into a solar still. The pilot-scale solar still consisted of a stepped type solar still with an effective area of 0.8 m2. For diluted industrial wastewater and that the maximum turbidity was between 150 and 820 NTU (Nephelometric Turbidity Units) for both types of wastewater. The method was also successful in removing bacteria. Heterotrophic bacteria counts were enumerated to determine the inactivation percentage of HPC (Heterotrophic plate counts).

N. Rahbar,J.A. Esfahani, (2013) [5] The results also show that there is an optimum length in which the productivity is maximized. On the other hand, in a fixed length of a solar still, the specific height has an opposite effect on productivity. Moreover, the movement of water productivity is always similar to the movement of convective heat transfer coefficient. A. Ahsan, 2013 [6] This work aims at acquiring a low cost technique to be utilized in rural and coastal areas for converting saline water into potable water using solar energy. A triangular solar still (TrSS) was, therefore, designed and developed with cheap, lightweight, local and available materials. A number of field experiments were carried out to evaluate the effects of solar radiation intensity ambient air temperature and the initial water depth on the daily water production of the trees. A time lag of about and hour between the hourly peaks of solar radiation and water production is observed. Dr. S. Shanmugan, 2013 [7] A single slope, single basin solar still has been provided with a dripping arrangement to pour saline water drop by drop in the basin. The scheme has been examined with the dripping of saline water and different energy absorbing materials like pebbles, black granite stones, and concrete stones. It has been found that the concrete rocks in the watershed with the dripping of saline water to maintain least water depth have validated with the observational outcomes. Experiments were conducted in climate conditions of Chennai [latitude 13º 04'N, long 80º 17'E] in Tamilnadu from February to October 2013 with least water depth in basin use of energy absorbing materials. The experimental result which use of absorbing materials, high production rate in concrete stones with compared other energy absorbing materials. Hitesh N. Panchal and P. K. Shah [8] Solar distillation is one of the important methods of getting clean water from brackish and sea water using the free energy supply from the sun. Here, the experiment is made with three identical solar stills. First two solar stills consist of plates like Aluminum and Galvanized Iron. Third solar still is taken as conventional solar still. Performance of solar stills having aluminum plate and Galvanized iron plate is tested and compared with conventional solar still under same climate conditions of Gujarat. It is found from the experiment that, solar still having Aluminum plate increases distillate output of 45 % and Galvanized iron sheet increases up to 15 % compared with conventional solar still. Manoj Kumar Sain, Mahendra Singh Rajpoot, 2013 [9] The performance of an inverted absorber and single slope solar still have been observed at various water depths with total dissolved solid (TDS) for the climatic condition of Jaipur, Rajasthan. By the various plots between solar radiation and yield production at varying depth has been studied. A comparison between the reflections of an inverted absorber solar still (IASS) and single slope, solar still (SS) was likewise established. Further the efficiency of the IASS was improved by the use of reflectors.Hiroshi Tanaka*, Yasuhito Nakatake,2006[10] This paper presents a numerical analysis to investigate the effect of the vertical flat plate external reflector on the distillate productivity of the tilted wick solar still. We propose a geometrical method to estimate the solar radiation reflected by the external reflector and absorbed on the evaporating wick, and also performed numerical analysis of heat and mass transfer in the still to predict the distillate productivity on four days (spring and fall equinox and summer and winter solstice days) at 30EN latitude. We found that the external reflector can increase the distillate productivity in all but the summer seasons, and the increase in the daily amount of distillate averaged over the four days is predicted to be around 9%.

II. Experimental Set-up

Based on literature review, the present investigation sought to make a contribution toward the global efforts in addressing the shortage of clean water supply domestic / commercial utilities. In this context, the purpose of the present investigation was to prepare an advanced solar still that would assist in increasing the accessibility of fresh water in remote and isolated regions. After literature review an passive solar still is selected for further growth which causes a single slope system. The selected still is in a position to generate an ample amount of distill water for a normal four person family water requirement. To develop the aforesaid unit, first we plan the system by drawing still schematic diagrams and component design. The next phase in a modular prototype solar still will be developed and tested based on evacuated glass tube basin heating elements. Testing of an engineering product is vital to establish its performance under the real condition. It is necessary to know how the solar system collects and dissipates energy. This includes transmission absorbs solar radiation and transfer of heat from system to environment. The test methods needed to measure the operation of solar systems to receive the exact resolution and provide a reliable common basis for comparing system performance.

Material Selection

A. Glazing: Should have high transmittance for solar radiation, opaque to thermal radiation, resistance to abrasion, long-life, low cost, high wet ability for water, lightweight, easy to handle and apply, and universal availability. Materials used are: glass or treated plastic.

B. Basin Tray: Should have long life, high immunity to corrosion and low price. Materials used are: wood, galvanized iron, steel, aluminum, mild steel, asbestos cement, masonry bricks, concrete, etc.

C. Sealant: Should remain resilient at very low temperatures, low cost, durable and easily applicable. Materials used are: putty, tars, tapes silicon, armor and sealant.

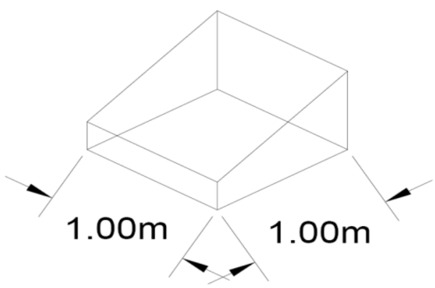

Figure 1 Cross sectional view of schematic arrangement of still experiment

III. PROCEDURES

Development of an engineering process or product involves designing and testing stages. A new process or product is often designed, tested, re-designed and re-tested until a satisfactory outcome. Thus, some kind of experimentation is required to assess the effect of a change in an independent variable (factor) on a dependent variable (outcome). A factor may be qualitative or quantitative, with the former type having no numerical difference between its levels. In contrast, a quantitative factor is measured on a suitable scale. The possible qualities or values taken by a factor are known as levels. The purpose of an experimental design and procedures for data acquisition and processing are described. A randomized block design was found suitable for this investigation, and it was used to take measurements for analysis and interpretation.

Figure 2 Schematic Diagram of Experimental Set up with

The experimental set-up consists of.

a. Fabricated passive solar still
b. Distilled water collection beaker
c. Insulation (FRP): absorptivity is high. so, it is used to reduce losses.
d. Stand
e. K-type thermocouple wire: - it is the device used extensively for the measurement of the body temperature.
f. Temperature indicator

To achieve the above goal, the following specific objectives of the research were therefore set out:

Design and drawing the solar still schematic diagrams.

a. Development of light weight, cost effective, efficient and economical solar still.
b. The system optimizations i.e. design parameters viz. Solar still parameters: basin, frame, evacuated glass tube heat receivers and basin tray etc.
c. The economical insulation and its material selection to reduce the solar still walls, heat losses from the basin and precise instrumentation etc. for experimentation.
d. Investigations on techno-economic viability of designing solar still.
F Testing of a single slope basin passive solar still coupled with aluminium chequered plates.

IV. Mathematical modeling.

Thermal modeling of solar distillation system is founded on energy balance equation for each component of distillation unit, namely, glass cover, watermarks and basin liner. These energy balances mainly depend on the design and climatic parameters of distiller unit

The design parameters are as follows:

- The thickness of glass cover and insulating materials.
- Absorptivity of glass cover and basin liner.
- Heat capacity of a glass cover, absorbing surface and water mass.
- Reflectivity of glass cover, water surface and basin liner surface.
- Quality of water to be distilled etc.

The climatic parameters mainly depend on the following positions:

- Solar radiation.
- Ambient air temperature.
- Wind velocity.
- Sunshine (day length) hours.

By thermal modelling, we can design a solar distillation unit for a given capacity. Thermal modelling can be used to make a decision regarding the shape of the distiller unit for maximum yield as per requirement. Using the measured values of solar intensity, wind speed and ambient temperature as input data, the daily output of the solar still is calculated. The mathematical model is developed according to the relations of heat transfer coefficients. The energy balance equations of the solar still could be written and presented as following assumptions

- The temperature gradient across the thickness of the glass cover is insignificant.
- Heat transfer coefficient is considered to be constant in the selected time interval.
- The heat capacity of the basin liner and the insulation are neglected.
- The saline water in the basin is treated as fresh water.
- The floating aluminium chequered plate with absorptivity of 0.8.
- The radiative, convective and evaporative heat losses are linear with the temperature.
- The physical properties of water, aluminium chequered plate, glass are constant in the operating temperature range of the proposed system.
- As absorptivity of water is very low it is assumed that solar rays are striking directly on gravel.

Theoretical analyses (i.e. Modeling) of different solar desalination systems are an effective tool for predicting their productivities. Time dependant energy and mass balance equations are used for modeling, in EXCEL.

Energy Balance for Solar Still:

The energy balance of different components of a solar still is as follows: The thermal process of the glass cover. Solar radiation coming from the sun, heats the glass cover, but the temperature of the glass due to high transmissivity does not rise too much, also the glass cover is heated by the latent heat of condensation. Moreover, the radiative and convective heat losses are occurring from the glass cover of ambient air.

The formula for finding out the temperature of the inner surface of condensing glass cover to ambient air.

Glass cover:

$$\alpha_g I(t) + [q_{rw} + q_{cw} + q_{ew}] = [q_{rg} + q_{cg}] \quad (1)$$

Basin liner:

$$\alpha_b I(t) + q_b \left[q_{bg} + q_s \frac{A_s}{A_{ss}} \right] \quad (2)$$

Water mass

$$\alpha_w I(t) + q_b = (MC)_w \frac{dT_w}{dt} + [q_{rw} + q_{cw} + q_{ew}] \quad (3)$$

Top Loss Coefficient:

Due to small thickness of glass cover, the temperature in the glass may be assumed to be uniform. The external heat transfer, radiation and convection losses from the glass cover to the outer atmosphere can be expressed as:

$$q_g = q_{rg} + q_{cg} \quad (4)$$

$$q_{rg} = h_{rg}(T_g - T_a) \quad (5)$$

$$q_{cg} = h_{cg}(T_g - T_a) \quad (6)$$

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$$h_{rg} = \frac{\varepsilon_g \sigma \left(T_g^{\ 4} - T_{sky}^{\ 4}\right)}{T_g - T_a} \tag{7}$$

Where,

$$T_{sky} = T_a - 6 \tag{8}$$

By submitting value of qcg and qrg in equation (3.4) then,

$$q_g = h_{1g}\left(T_g - T_a\right) \tag{9}$$

Where, h1g is the convective and radiative heat transfer coefficient from glass to ambient:

$$h_{1g} = h_{rg} + h_{cg} \tag{10}$$

$$h_{1g} = 5.7 + 3.8V \tag{11}$$

Bottom and Side Loss Coefficient

Heat is also convected from the water in the basin to the ambient through the insulation and subsequently by convection and radiation from the bottom or side surface of the basin. The bottom loss coefficient Ub can be written as:

$$\mathrm{U_b} = \left[\frac{1}{\mathrm{h_3}} + \frac{1}{\mathrm{k_i}/\mathrm{l_i}} + \frac{1}{\mathrm{h_{cb}} + \mathrm{h_{rb}}}\right]^{-1} \tag{12}$$

$$\mathrm{h_b} = \left[\frac{1}{\mathrm{k_i}/\mathrm{l_i}} + \frac{1}{\mathrm{h_{cb}} + \mathrm{h_{rb}}}\right]^{-1} \tag{13}$$

Values of (hcb+hrb) can be found from equation (3.10)

Similarly, the side heat loss coefficient (Ue) can be approximated as:

$$\mathrm{U_e} = \left(\frac{\mathrm{A_{ss}}}{\mathrm{A_s}}\right) \cdot \mathrm{U_b} \tag{14}$$

In the former equation the radiative heat transfer from water surface to the glass cover is calculated as follows.

$hrw = σ[(Tw+273)^2+(Tgi+273)^2]$

If the side area of still (Ass) is very small comparing with basin liner still area (As), then the overall side heat losses coefficient (Ue) can be neglected.

Internal Heat Transfer Coefficient:

Internal heat transfer is occurs between water surface and the glass cover. There are three methods of heat transfer from water surface to the glass cover, radiation, convection and evaporation.

Radiative Heat Transfer Coefficient:

Between any two bodies there are differences in temperature, and then there are a radiation heat transfer will occur between them. Here, water surface and glass cover are considered as infinite parallel planes [ ]. Radiation between the water and glass is given by:

$$\dot{\mathrm{q}}_{\mathrm{rw}} = \varepsilon_{\mathrm{eff}} \cdot \mathrm{F_{12}} \cdot \sigma[(\mathrm{T_w} + 273)^4 (\mathrm{T_{ci}} + 273)^4] \tag{15}$$

Where, hrw may be obtained from equation:

$$\mathbf{h_{rw}} = \boldsymbol{\varepsilon_{eff}} \cdot \boldsymbol{\sigma}\left[(\mathbf{T_w})^2 + (\mathbf{T_{ci}})^2\right] \cdot [\mathbf{T_w} + \mathbf{T_{ci}} + \mathbf{546}] \tag{16}$$

The effective emittance between the water surface and the glass cover will be:

$$\frac{1}{\varepsilon_{\mathrm{eff}}} = \frac{1}{\varepsilon_{\mathrm{w}}} + \frac{1}{\varepsilon_{\mathrm{g}}} - 1 \tag{17}$$

The value of hrw is almost independent of temperature for normal operating temperature range (80°C) and varies

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between 7 and 10 W/m^2 (^{0}c).

Convective Heat Transfer Coefficient:

Convection occurs across the humid air in the enclosure by free convection, due to the temperature difference of humid air between the water surface and the glass cover. It may be obtained by:

$$q_{cw} = h_{cw}(T_w - T_g) \tag{18}$$

Where, heat loss coefficient by convection from water h_{cw} may be obtained from expression of:

$$h_{cw} = 0.884\left[T_w - T_{ci} + \frac{(P_w - P_{ci})(T_w + 273)}{(268.9 \times 10^3 - P_w)}\right]^{1/3} \tag{19}$$

Evaporative Heat Transfer Coefficient:

Due to condensation of the rising vapor on the glass cover, there are heat loss by the evaporation between the water surface and glass cover, this can be expressed by:

$$q_{ew} = h_{ew}(T_w - T_g) \tag{20}$$

Where,

$$h_{ew} = 0.016273 \times h_{cw} \times \left(\frac{P_w - P_{ci}}{T_w - T_{ci}}\right) \tag{21}$$

Then, the total internal heat transfer coefficient between water surface and glass cove can be expressed as:

Pw=exp{ 25.317- 5144/Tw+273.15 }

Pgi=exp{ 25.317- 5144/Tgi+273.15 }

$$h_{1w} = h_{rw} + h_{cw} + h_{ew} \tag{22}$$

Substituting equations from (3.4 to 3.22) in equations (3.1), (3.2) and (3.3) then the energy balance equations become

$$\alpha_g I(t) + h_{1w}(T_w - T_g) = h_{1g}(T_g - T_a) \tag{23}$$

$$\alpha_w I(t) + h_{1w}(T_b - T_w) = (MC)_w \frac{dT_w}{dt} + h_{1w}(T_g - T_a) \tag{24}$$

$$\alpha_g I(t) = h_{1w}(T_b - T_w) + h_b(T_b - T_a) \tag{25}$$

Substituting the values of Tg and Tb from equation (3.22) and (3.24) in equation of (3.23) and simplifying, then the result is:

$$\frac{dT_w}{dt} + aT_w = f(t) \tag{26}$$

Where,

$$a = \frac{U_L}{(MC)_w} \tag{27}$$

$$f(t) = \frac{(\alpha\tau)_{eff} I(t) + U_L T_a}{(MC)_w} \tag{28}$$

$$(\alpha\tau)_{eff} = \alpha_b \frac{h_w}{h_w + h_b} + \alpha_w + \alpha_g \frac{h_{1w}}{h_{1w} + h_{1g}} \tag{29}$$

Where, $U_L = U_b + U_t;$ (30)

$$U_b = \frac{h_w h_b}{h_w + h_b} \text{ and } U_t = \frac{h_{1w} h_{1g}}{h_{1w} + h_{1g}} \tag{31}$$

Tw = f (t)/ a [1- e^-(at)+ Two* e^-(at)] (32)

Solar Still Specification

The technical specifications of the solar still used are shown in table 1.

Specification	Dimension
Basin area , m^2	1
Glass area , m^2	1.22
Glass thickness , mm	4
Number of glass	1
Slope of the glass	23^0

V. Results

From figure 3 seen that the comparison between actual & theoretical value of water temperature. So, figure 3 shown that theoretical reading is higher as compared to actual reading. The 10% error is occurred.

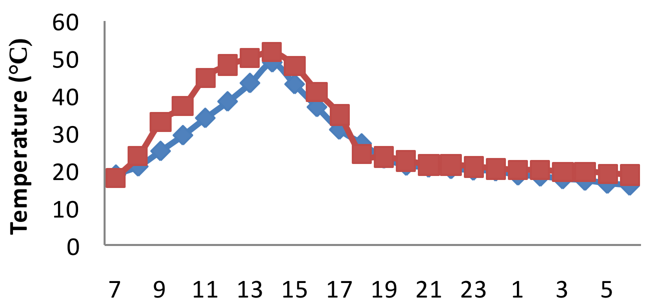

Figure 3 Comparision of Water Temperature for Actual &Theoretical (chequered plate)

From figure 4 seen that the comparison between actual & theoretical value of glass temperature. So, figure 4 shown that theoretical reading is higher as compared to actual reading. The 19% error is occurred.

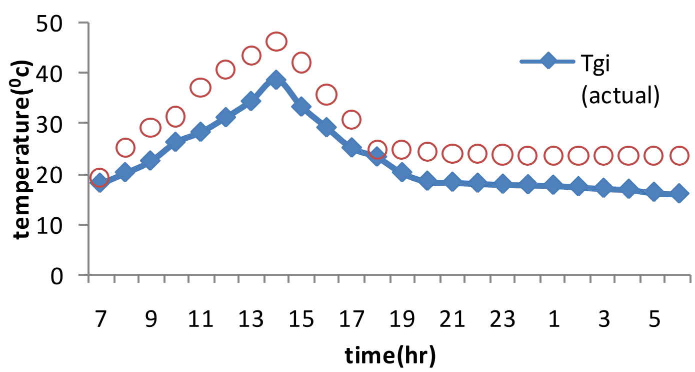

Figure 4 Comparision Of Glass Temperature For Actual& Theoretical (chequered plate)

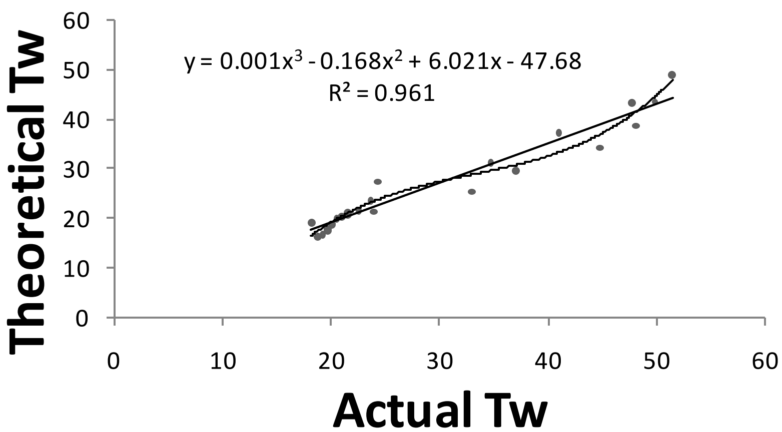

Figure 5 co-relation between actual & theoretical value for water

From the figure 5 seen that the comparison between actual & theoretical value of water temperature. So, figure 5 shown that theoretical reading is higher as compared to actual reading. The 14% error is occurred.

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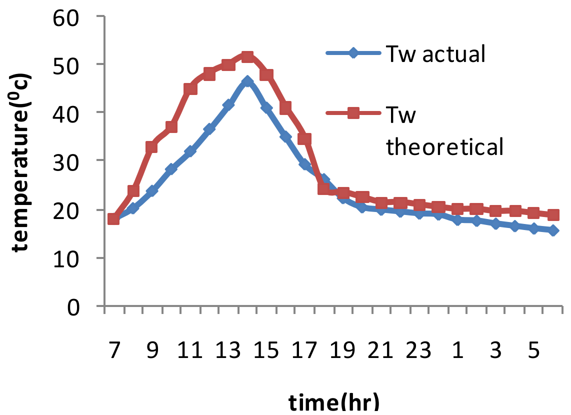

Figure 6 Comparision of Water Temperature For Actual & Theoretical (Plain

From figure 6 seen that the comparison between actual & theoretical value of glass temperature. So, figure 6 shown that theoretical reading is higher as compared to actual reading. The 18% error is occurred.

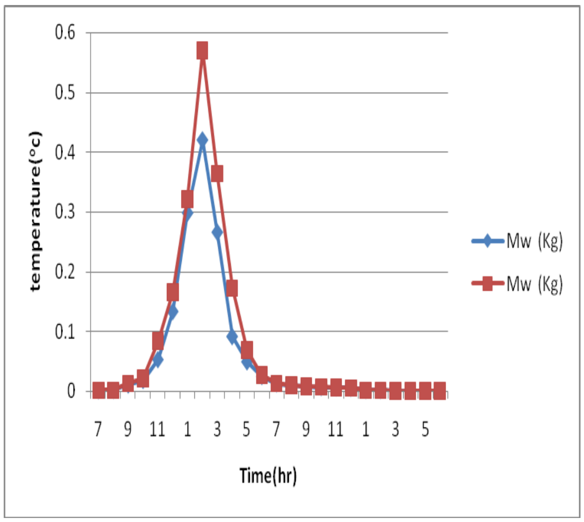

Figure 7 Comparision Between Aluminium Plain &Chequered Plate

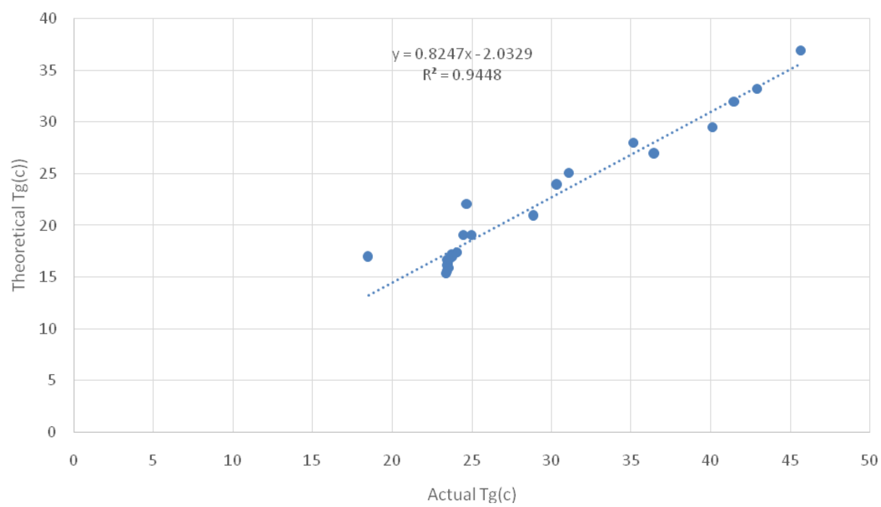

Figure 8 co-relation between actual & theoretical reading for glass.

VI. Conclusion

Theoretical work is constructed to predict the performance in productivity of passive single basin single slope, solar still using different operational parameters the ambient conditions solar intensity are considered to have an effect on overall solar still productivity it has been established that overall system efficiency in terms of daily output will increase by increasing the basin water and the use of latent heat of condensation for further distillation. Further increasing temperature difference between the evaporating and condensing surface can increase the daily output hear we conclude that daily output will increase **31.27%** compared to Al plane plate by using chequered plate.

Symbols:

A_s basin liner still area, (m^2)
Ass side still area (m^2)
h_{cb} basin liner convection heat transfer coefficient (W/ m^2)
h_b basin liner overall heat transfer coefficient (W/m^2 K)

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hcg glass cover convection heat transfer coefficient (W/ m^2C)
h_{cw} heat loss coefficient by convection from water surface (W/ m^2 C)
h_{ew} heat loss coefficient by evaporation from water surface (W/ m^2C)
h_{rb} basin liner radiative heat transfer coefficient (W/ m^2 C)
h_{rg} glass cover radiative heat transfer coefficient (W/ m^2 C)
h_{rw} basin water radiative heat transfer coefficient (W/ m^2 C)
h_{tg} total glass heat transfer loss coefficient (W/ m^2 C)
h_w convective heat transfer coefficient from basin to water (W/ m^2 C)
h_{tw} total water surface heat transfer loss coefficient (W/ m^2 C)
$I_{(g)}$ solar intensity (W/ m^2)
M total mass productivity/day (kg/day)
P_g glass saturated partial pressure (N/ m^2)
P_w water saturated partial pressure (N/ m^2)
q_g rate of total energy from the glass cover (W/ m^2)
q_b rate of total energy from basin liner (W/m^2)
q_{bg} rate of energy lost from basin liner to the ground (W/ m^2)
q_{cg} rate of energy lost from the glass cover by convective (W/ m^2)
q_{ew} rate of energy lost from water surface by evaporation (W/ m^2)
q_{cw} rate of energy lost from water surface by convection (W/ m^2)
q_{rg} rate of energy lost from the glass cover by radiation (W/ m^2)
q_{rw} rate of energy lost from water surface by radiation (W/ m^2)
q_s rate of energy lost from the basin liner through the side of the still (W/ m^2)
T_{g0} temperature of basin water (C)
T_{gin} temperature of inside glass (C)
T_a ambient temperature (C)
T_b basin liner temperature (C)
T_{sky} sky temperature (C)
T_w still water temperature (C)
t time (s)
U_b overall bottom heat lost coefficient (W/ m^2 C)
U_t overall top heat loss coefficient (W/ m^2 C)
U_e overall side heat loss coefficient (W/ m^2 C)

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