International Journal of Latest Research in Engineering and Management" (IJLREM)
ISSN: 2456-0766
www.ijlrem.org Volume 2 Issue 3 ǁ March. 2018 ǁ PP 07-15

Design and Fabrication of a Single Slope Solar Still Using Brackish Water

[1,]Kotingo K.W, [2,]Jumbo E.E , [3,]Tuaweri T.J
Department of Mechanical/Marine Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

ABSTRACT: *The design and fabrication of a solar still as well as an experimental study were properly carried out. The solar still is made up of some component that consist of an exterior wooden box, which houses the entire still unit firmly griped to the base stands, the flat plate collector is made of aluminium sheet which is used for making the still unit, the isolating material used in lagging is to minimize the heat lose, it is made up of a foam and channel for water inlet and outlet passage made of a PVC pipe. Brackish water was used in carrying out the experiment; the sun was the source of power which radiates the required solar energy that is converted to heat energy for the effective function of the unit. Solar energy passes through the effective absorber glass and heat up the water in the still unit which causes the water to vapourize. The vapour rises and condenses on the underside of the absorber glass to form droplet and run through, were purified water is collected via water outlet channel to the storage can. Some result gotten from the Experiment and calculations are as follows; intensity of the sun in Amassoma is 88W/m^2, Saturated Pressure is 102.146N/m^2,Evaporated heat transfer 10.31W/m^2K, and 10.83W/m^2K and also mass of distilled water produce is 0.233Kg and 0.141Kg Respectively.*

KEYWORDS: *Solar radiation, Evaporation, Condensation, Distillation of Water and Intensity of the Sun*

I. INTRODUCTION

Solar water purification also known as solar evaporation method is proven to be highly effective in cleaning up water to provide safe portable drinking water for house hold purpose and, in the society, at large. Solar water treatment in particular is beneficial for rural communities without other form of water purification infrastructure and more importantly, the most positive feature about solar water purification is that there is no requirement of fuel, it precisely due to lack of fuel that makes solar applications relatively superior than conventional sources of energy as it doesn't cause pollution or health hazards.In the south-south region of Nigeria, Bayelsa, Amassoma, solar energy is available with large amount of sea water or underground water (Yamali and Solmus, 2008). Therefore, designing a system for the effective collection and utilization needs adequate knowledge of the nature of solar intensity which is the energy produced by the sun and collected on the earth, the sun creates its energy through thermo-Nuclear process that converts about 650,000 tons of hydrogen to helium every second. (Asimov 1969). Some other application of solar includes heating and cooling of building, cooking, drying and electricity generation etc. solar water purifier uses natural evaporation and condensation, which is the rain water process. These allow the natural pH buffering that produce executed taste as compared to steam distribution. Solar water purifier can easily provide enough water for our family and industrial needs. About 96.5% of the earth's mass lies in its oceans, while the remaining 3%, 2.53% is fresh water; and only a portion around ~0.36% is available to the people. The basic principle of solar distillation is simple but effective. The system harvests the heat from the sun directly in a simple piece of equipment to purify water. The equipment commonly called solar water purifier, consists basically of a flat plate collector coated with black and a transparent glass cover. The sun energy heats up the blackish water to a point of evaporation inside the solar still collector. This process separates impurities, heavy metals and micro biological organisms in the original water, after evaporation of the solution by solar radiation.

II. METHODS AND MATERIALS

The materials required for this paper were collected from the local market. The solar still basins were fabricated from the local fabricator workshops in Amassoma town. The PVC pipes and U Channels for trough were purchased from the local market. The M-seal was used as sealing material to make the basin water-tight to control the evaporated water drops. Selected physical parts of solar still like still basin, transparent top, condensing arrangement, trough, insulation etc. Were constructed and tested for solar distillation process. The rectangular plates were cut at the diagonals to prepare a tray shape and welded to form a water holding basin. The transparent glass sheet was selected for the top for providing passage of solar energy and side walls of solar still. The top rectangular rooftop of appropriate size was cut in transparent glass and fitted with M-seal. The trough of PVC plastic was cut in U shape and vertically placed to collect the condensate and facilitate the flow to the collection container or the measurement system.

Design Analysis : The performance of solar still is governed by different factors such as solar insulation, heat transfer mechanism as well as the environmental aspects. This section summarizes the different relations used for performance evaluation and economic analysis of solar stills.

Intensity of the sun

The intensity of the solar radiation after passing through the atmosphere is calculated below

Average distance of the sun from the earth =1.5x10^{8}km Considering a sphere of radius 1.5x10^{8}km with the sun at its center.

Let S_S= surface area of this imaginary sphere

A_E=cross sectional area of the earth

r_S= radius of the sphere

r_e= radius of the earth

Therefore,

$A_E = \pi r_e{}^2$ ---------------------------------- --- 3.1

$A_E \;\; = 3.142 \times (6.4 \times 10^6)^2$

A_E =1.287 x $10^{14} m^2$

S_S=$4\pi r_s{}^2$ --- 3.2

S_S= 4x3.142 $\times$ (1.5$\times$ 10^{11})^2

$S_S\, = 2.828\; \times 10^{23} m^2$

$\text{Percentage of sun's output} = \left[\left(\frac{A_E}{S_S}\right) \times 100\right]$ (3.2)

$\text{Percentage of sun's output} = \left[\left(\frac{1.287\times10^{15}}{(2.828\times10^{23})}\right) \times 100\right]$ --- 3.3

Percentage of sun's output = 0.0000000455%

This means that the earth receives 0.0000000455% of the sun's energy.

Hence Amassoma would receive radiation at the rate of:

Let R_C= Extraterrestrial radiation

A = Continental land area

I_{SC}= extraterrestrial solar constant

Therefore,

$R_C\, = I_{SC} A$ --- 3.4

= 1353×706×10^6 = 9.55×10^{11}W/m^2

Therefore, for a yearly average sunshine hour of 9 hours/day

R_C = 9.55×10^{11}×366×9

R_C = 3.146×10^{11}Wh/yr

Assuming a clearness index of 47%, since 47% of extra-terrestrial radiation reaches the earth surface (Folarami, 2013). Terrestrial radiation in Amassoma land area = $\left[\left(\frac{47}{100}\right) \times 3.146 \times 10^{11}\right]$

$\text{Terrestrial radiation in Amassoma land area} = 1.479 \times 10^{11}\text{Wh/yr}$

The part of solar radiation that reaches the surface of the earth without being scattered, absorbed or reflected is direct radiation and it is the most intense. The intensity of the direct radiation reaching the surface of the earth is a function of time of the day, latitude of location and declination angle (Awachie, 1982). To calculate the direct radiation reaching Amassoma a function of time of the day (t), for a location (γ) with the sun at declination angle (δ)

Let Z -Zenith Angle

γ -Latitude of location
δ -declination angle
t -hour angle of the sun
I_Z -Direct Normal Radiation
I_{SC}-Extraterrestrial solar radiation constant
S and C are climatographic ally determined constants which have values of 0.357 and 0.678 respectively (Folaranmi, 2009).
The Zenith angle is calculated thus:

$$\text{Cos Z} = \sin(\gamma)\sin(\delta) + \cos(\gamma)\cos(\delta)\cos(t) \text{ ----------(3.5)}$$

$$\text{Cos Z} = \sin(5°)\sin(0°) + \cos(5°)\cos(0°)\cos(0°)$$

$$Cos\ Z = 0.0872 \times 0 + 0.9961 \times 1 \times 1$$

$$Cos\ Z = 0.9961$$

$$Z = Cos^{-1}(0.9961)$$

$$Z = 5.06°$$

The intensity of the solar radiation after passing through the atmosphere is calculated

$$I_Z = I_{SC}e^{-c(\sec Z)s} \text{ ---------- 3.6}$$

$$I_Z = 1353e^{-0.357\left(\frac{1}{\tan(5.06)}\right)\times 0.678}$$

$$I_Z = 88W/m^2$$

This formula gives the value of the direct radiation on Amassoma and it is the maximum value possible. In practice, only systems using full tracking mechanisms can collect this radiation.

Estimation of Solar Radiation on Tilted Surfaces

The solar flux falling on the tilted glass cover is given by the relations in equation 3.1

$$\mathrm{I_t = I_bR_b + I_dR_d + (I_b + I_i)R_r} \text{ …….. 3.7}$$

$R_bR_dR_r$are tilt factor related to beam, diffuse and reflected radiations.
They are obtained using the following relations.

$$\mathrm{R_b} = \frac{\cos\theta}{\cos\theta_z} = \frac{(\sin\delta\sin(\emptyset - S) + \cos\ \delta\cos W\cos(\emptyset - S)}{(\sin\emptyset\sin\delta + \cos\emptyset\cos\delta\cos W)}$$

$$\mathrm{R_d} = \frac{(1 + \cos S)}{2}$$

$$\mathrm{R_r} = \frac{(1+\cos S)}{2} \text{ ---------- 3.8}$$

Energy Balance; If the evaporation processes inside the still unit is considered as isobaric atmospheric process at thermal equilibrium, then all the absorbed solar radiation is utilized for evaporation and thermal losses. An energy balance for steady state around the water basin is given in equation 3.7

Rate of energy in = Rate of energy out

$$\mathrm{(a_w + a_b)I_{(t)} = Q_{ew} + Q_{losses}} \text{ (Tamini, 1987) …….. 3.9}$$

a_w Is the solar flux absorbed by the water mass
a_b Is the solar flux absorbed by the basin liner

The Water and Glass Temperature

The water and condensing cover (glass) can be calculated from equation 3.12 and 3.8 (kumar and Tiwari, 1996)

$$\mathrm{T}_{w_2} = T_w e^{-A_1 t} + \frac{\mathrm{A_2}}{\mathrm{A_1(1-e^{-A_1t})}} \text{ …….. 3.10}$$

Where $A_1 = \frac{1}{m_w} \times 4186.0\left[\frac{h_3h_b}{h_3+h_b} + \frac{h_1h_2}{h_1+h_2}\right]$

$$\mathrm{A_2} = \frac{1}{\mathrm{m_w}} \times 4186.0\left[\frac{\alpha_1 + \mathrm{h_3}}{(\mathrm{h_3} + \mathrm{h_b})\alpha_2}\mathrm{It} + \mathrm{A_1T_a}\right]$$

$$\mathrm{T_g} = \left(\frac{\mathrm{h_1T_w + h_2T_a}}{\mathrm{h_1 + h_2}}\right) \text{ …….. 3.11}$$

The Saturation Pressure

$\mathrm{P_w}$ and $\mathrm{P_g}$ Represented saturation pressure of basin water and glass cover at initial temperature.
Saturation pressure is completed using equation 3.11

$$\mathrm{P_{(t)}} = \exp\left(25.317 - \frac{5144}{\mathrm{T+273}}\right) \text{ …….. 3.12}$$

$$P_g = \exp\left(25.317 - \frac{5144}{T_g + 273}\right)$$

Where $T_g = 37.05°C$ $T_w = 42°C$

$$P_g = \exp\left(25.317 - \frac{5144}{37.05 + 273}\right)$$
$$P_g = \exp\left(25.317 - \frac{5144}{310.05}\right)$$
$$P_g = \exp(25.317 - 16.59)$$
$$P_g = 23.7\ N/m^2$$
$$P_w = \exp\left(25.317 - \frac{5144}{T_w + 273}\right)$$
$$P_w = exp\left(25.317 - \frac{5144}{42 + 273}\right)$$
$$P_w = 24.43\ N/m^2$$

$at\ 1p.m$

Where $T_w = 48°C$, $T_g = 40.08\ °C$

$$P_w = \exp\left(25.317 - \frac{5144}{48 + 273}\right)$$
$$P_w = \exp\left(25.317 - \frac{5144}{321}\right)$$
$$P_w = \exp(25.317 - 16.025)$$
$$P_w = 25.26\ N/m^2$$
$$P_w = exp\left(25.317 - \frac{5144}{40.08 + 273}\right)$$
$$P_w = 24.156\ N/m^2$$

At 2p.m

$T_g = 43.54°C$, $T_w = 54°C$

$$P_g = exp\left(25.317 - \frac{5144}{43.54 + 273}\right)$$
$$P_g = 24.65\ N/m^2$$
$$P_w = exp\left(25.317 - \frac{5144}{54 + 273}\right)$$
$$P_w = 26.06\ N/m^2$$

At 3p.m

$T_g = 47.30°C$, $T_w = 62°C$

$$P_g = exp\left(25.317 - \frac{5144}{47.30 + 273}\right)$$
$$P_g = 25.26\ N/m^2$$
$$P_w = exp\left(25.317 - \frac{5144}{62 + 273}\right)$$
$$P_w = 27.08\ N/m^2$$

At 4p.m

$T_g = 38.78°C$, $T_w = 45°C$

$$P_g = exp\left(25.317 - \frac{5144}{38.78 + 273}\right)$$
$$P_g = 23.97\ N/m^2$$
$$P_w = exp\left(25.317 - \frac{5144}{45 + 273}\right)$$
$$P_w = 24.85\ N/m^2$$

The Evaporative Heat Transfer

The heat gained by the evaporating water can be estimated from equation 3.13

$$Q_{ew} = 16.273 \times 10^3 h_{ew} \left\{\frac{P_w - P_g}{T_w - T_g}\right\} \quad \text{……. 3.13}$$

The convective heat transfers co-efficient (h_{ew})

Dunkle's equation for evaluation of internal heat transfer coefficient is from the water surface to the glass and given by equation 3.9

$h_{ew} = 0.884\ \left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{(268.9\times10^3 - P_W)}\right]^{\frac{1}{3}}$ (Dunkle, 1961) ……... 3.14

The constants C and n are calculated by regression analysis for known hourly distillate output
The evaporative heat transfer coefficient is given by

$$h_{ew} = 0.884\ \left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273)}{(268.9\times10^3 - P_w)}\right]^{\frac{1}{3}}$$

At 12p.m – 5p.m the value of h_{ew} are as follows:

Day 1
$h_{ew} = 1.950W/m^2K$
$h_{ew} = 2.0935W/m^2K$
$h_{ew} = 2.193\ W/m^2K$
$h_{ew} = 2.123\ W/m^2K$
$h_{ew} = 1.950\ W/m^2K$

Day 2
$h_{ew} = 1.1601\ W/m^2K$
$h_{ew} = 1.898\ W/m^2K$
$h_{ew} = 2.000\ W/m^2K$
$h_{ew} = 2.000W/m^2K$
$h_{ew} = 1.950\ W/m^2K$
$h_{ew} = 1.8224\ W/m^2K$

The Mass of the Distillate Produced per hour

The quantity of distillate produced is determined from equation 3.15
$m_w = h_{ew}\left(\frac{T_w - T_g}{L}\right) \times 3600$ (Tiwari et al 1989) …………………. 3.15
The values of m_w from 12p.m – 5p.m for day 1 and 2 are:

Day1
$m_w = 0.033419\ Kg$
$m_w = 0.044364Kg$
$m_w = 0.05340\ Kg$
$m_w = 0.05340Kg$
$m_w = 0.04847\ Kg$
$m_w = 0.0041837\ Kg$

Day 2
$m_w = 0.02998\ Kg$
$m_w = 0.03699\ Kg$
$m_w = 0.03699\ Kg$
$m_w = 0.03342\ Kg$
$m_w = 0.02547\ Kg$

Finally the volume of distilled water produced can be calculated from equation 3.15
$\rho = \frac{m_w}{v}$ …………………………………………. 3.16
where density of distilled water is $(\rho) = 1000Kg/m^3$
Therefore volumes of distilled water produced in two days, from 12p.m to 5p.m are:
$v = \frac{m_w}{\rho}$

Day1
$v = 33.419ml$
$v = 44.36ml$
$v = 53.4ml$
$v = 53.4ml$
$v = 48.5ml$
$v = 33.4ml$

Day 2
$v = 41.2ml$
$v = 30ml$
$v = 37ml$
$v = 37ml$
$v = 33.4ml$
$v = 25.5ml$

Performance Test: The performance test of the single slope still was carried out for 8hours in two (2) consecutive days between 10:00 a.m. to 5:00p as shown in table 3. The brackish water was supplied to the absorber plate using a tap valve to a depth of 4cm, a Thermometer is hung between water and condensing cover to measure vapor temperature. The following parameters were measured every hour during the experiments: still temperature and weight of distilled yield was measured using measuring jar.

Results : Experiment analysis on single slope solar still, results obtained on daily basis for a week was carried out in varying weather condition. Weather conditions play an important role in determining the production of distilled water. Production on a bright and sunny day is higher compare to raining day, reason is not far-fetched and this is because on a day solar collector traps more heat energy from the sun. The intensity of solar energy falling on the still is the single most important parameter affecting production. The daily distilled water output is determined by the amount of energy utilized in vaporizing of water.

Table 1: Specification of solar still

S/N	Item Description	Quantity or Number required	Material Used	Reason
1	Wooden outer most box	1	Wood	Easily sourced,light and cheap
2	Absorber plate	1	Aluminum	Good heat absorber
3	Insulation material	3kg	Foam	Good heat insulator
4	PVC pipe	1 meter	Plastic	Light and easily absorbs heat
5	Cover sheet	1	Glass	Highly efficient
6	Storage Can	1	Plastic	For storage of distilled water

Table 2: Thermal Properties of Materials

Materials	Thermal conductivity	Specific heat capacity
Wooden box	5.23×10^{-4}W/m.K	1680J/kg.K
Absorber plate (steel)	43.0 W/m.K	470 J/Kg.K

Table 3: Operation Parameters

Day 1

Time (hr)	Temperature		Quantity yield (ml)
	Ambient T(°C)	Still T (°C)	
10a.m	33.5	38.5	—
11a.m	34	49.5	—
12p.m	35.5	52.5	33.4
1p.m	37	60.5	44.3
2p.m	34.5	61.5	53.4
3p.m	36	63	53.4
4p.m	35	59.5	48.5
5p.m	34.5	53.3	33.4
Total			266.4

Day 2

Time (hr)	Temperature		Quantity yield (ml)
	Ambient T(°C)	Still T (°C)	
10a.m	34	40.5	—
11a.m	42	50.5	—
12p.m	55.5	51.5	4.2
1p.m	40	57.5	30
2p.m	35	55.5	37
3p.m	37	57.5	37
4p.m	36.5	55.5	33.4
5p.m	34.5	50	25.5
Total			167.1

In table 3, it is evident that in the first day the quantity of distilled water produced was more, due to the sunny weather that was experience that day, but the second day the quantity of distilled water produced was less than that of the first day. This shows that the quantity of water produced depends on the amount of sun (that is it been determined by the weather) when it is sunny it produces more water but when it's rainy/cloudy it produces less or no water.

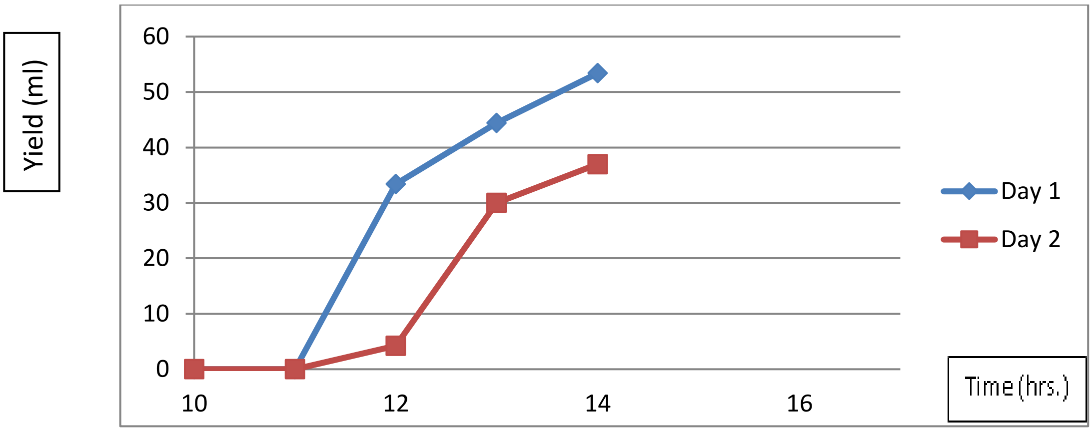
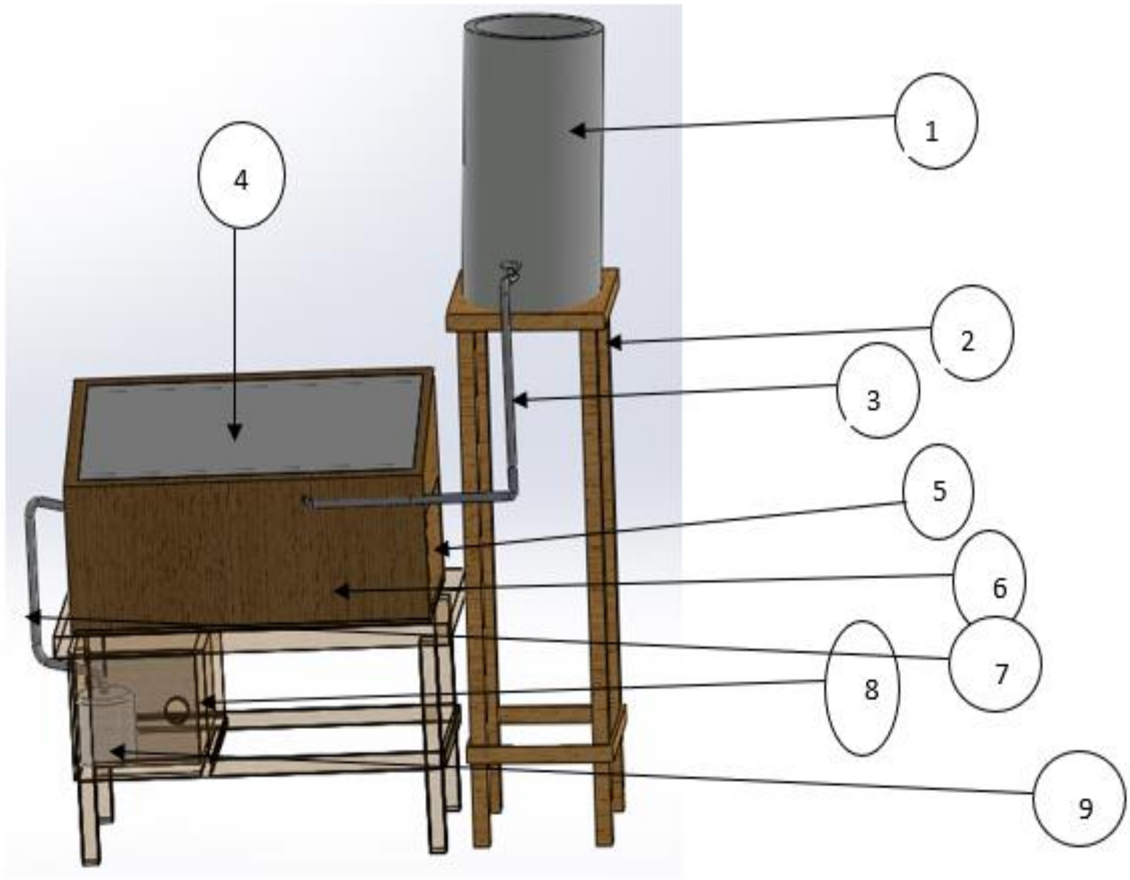


Figure 1: Chart showing yield against Time



S/N	COMPONENT	DRAW NO:
1	Feed water tank	1
2	Water tank stand	2
3	Supply pipe	3
4	Glass cover	4

Fig 2: 3D Isometric view

III. CONCLUSION

The distillate output varies with the temperature inside the still, with the maximum output occurring at the highest temperature. The solar still harness the energy of the sun to purify brackish water and so presents a promising alternative to time (hr.) fresh water from saline water in remote areas having low population densities, low rain fall and abundant available free solar energy, hence the use of solar energy is more economical than fossil fuel in terms of operational cost, the cost of construction and also no chemicals or filters are used. This cost-effective design is expected to provide the rural communities an efficient way to convert the brackish water into drinkable water. Solar still design and fabrication is easy and could be manufacture with the locally available materials and skill. Use of solar stills is going to play a significant role in reducing water borne diseases in the rural areas. Distilled water can be used for drinking purposes, applications in hospitals replenishing batteries, and so on.

REFERENCES

1. Abu-Hijleh, B.A and Rababa'h, H.M. (2003) "Experimental study of a solar still with sponge cubes in basin", Energy Conversion and Management, No. 44, pp. 1411-1418.
2. Al Hayek, I. and Bardan, O.O. (2004) "The effect of using different designs of solar stills on water distillation" Desalination, No. 150, pp.230-250.
3. Al-Karaghouli, A.A and Alnaser, W.E. (2004) "Experimental comparative study of the performance of single and double basin solar still", Applied Energy, No, pp 77, 317-325.
4. Asimor, I (1968) Understanding Physical.The electron, proton and neuton, scur borugh. Quebec, New American Library of Cumada Ltd
5. Ibrahim, S.M.A. (1996) The Forced Circulation Performance of a Sun Tracking Parabolic Concentrator Collector, Renew. Ener. 9 (1–4) pp 568–571
6. Kalogirou, S.A. (2005) "Seawater desalination using renewable energy sources," Progress Energy Combustable Science, Vol. 31. No. (3), pp 242-281.
7. Khalifa, A.J.N. (2010) "The effect of cover tilt angle of the simple solar still on its productivity in different seasons and latitudes" Energy Conversion and Management No. 52, pp. 431 -436.
8. Kumar, S and Tiwari, G.N.(2009) "Life cycle cost analysis of single slope hybrid (PV/T) active solar still, Applied Energy, No 86, pp. 1995-2004.
9. Malik, M.A. Tiwari, G.N. Kumar, A. and Sodha, M.S. (1982) "Solar distillation, a predict study of a wide range of solar and optimum design, construction and performance, Pergamon press, New York.
10. Müller, *C*., K. Schwarzer, E. Vieira da Silva, C. Mertes, Solar Thermal
a. Desalination Systems with Multi-layer Heat Recovery, Solar-Institut Jülich,
11. Universidade Federal do CearaNafey, A.S. Abdelkader, M. Abdelmotalip, A. andMabrouk, A.A. (2001) "Solar still productivity enhancement", Energy Conversion and Management, No. 42, pp. 1401-08.
12. Omar, O. B. and Mazen, M. A. (2007) "Evaluating thermal performance of a single slope solar still," Heat And Mass Transfer, No.43, pp. 985- 995.
13. Rajesh, T. and Tiwari, G.N. (2005) "Effect of water depths on Internal Heat and Mass Transfer for Active Solar Distillation" Solar energy, No. 173, pp. 183- 200.

14. Salah, A. Omar, B. andMazen, M. (2008) "Performance evaluation of a modified design of a single -basin solar still," Desalination, No.219, pp.222-230.
15. Tamini, A. (1987). "Performance of Solar Still with Reflectors and Black Dye", International J. Solar Wind Technology.No.4, Vol. 443.
16. Tiwari, G.N. Gupta, S.P. and Lawrence, S.A. (1989)."Transient Analysis of Solar Still in the presence of Dye", Energy Conversion.Management, No. 29, Vol. 59.
17. Velmurugan, V. and Srithar, K. (2011) "Performance analysis of solar stills on various factors affecting the productivity," Renewable Energy and Sustainable Energy, No. 15, pp. 1294– 1304.
18. World Bank Final Report (2004) A Review of Key Issues and Experience in Six Countries, Seawater and Brackish Water Desalination in the Middle East, North Africa and Central Asia.
19. Yamali C and Solmus I, (2007). Theoretical investment of a humidification dehumidification dissipating of system configure a double pass flat plate solar air heater