Biochemical and thermal analysis of the Performance Efficiency of Two solar stills using salty water

J. I. Eze, and L. S. Nnadi
ikejon85@yahoo.com
National Centre For Energy Research and Development, University of Nigeria, Nsukka
***Department of Food Science and Technology, University of Nigeria, Nsukka; Tel: +2348063285864**

Abstract-Salty water was used to compare and evaluate the effectiveness of rectangular-shaped solar still and (R) and pyramid-shaped solar still (P) in providing portable water for both industries and home uses. Salty water was procured from Ngene River in Ebonyi state, Nigeria. It was introduced into the solar stills and exposed to solar radiation for 3 days. The salty water and Eva water (control) were analyzed chemically, physically, microbiology and organoleptically. The results showed that the temperature of the environment for the 3 days varied from 27±^{o}C to 29±^{o}C while solar radiation varied from 115w/m^{2} to 140w/m^{2}. Absorbance of the radiation by the base of the pyramid-shaped still led to higher ($p<0.05$) temperatures (33^{o}C, 31^{o}C and 30^{o}C respectively for days 1, 2 and 3) compared to the top of the still (29^{o}C, 25^{o}C and 28^{o}C, respectively for days 1, 2 and 3). Similar trend was observed for the rectangular-shaped still. However, the R- still maintained higher temperatures at the base (34^{O}C, 31.5^{O}C and 30.8^{O}C, respectively for day 1,2 and 3) compared to the base of the P- still (33^{O}C, 31^{O}C and 30^{O}C for day 1,2 and 3 respectively).This resulted to higher temperatures of the distilled water from the R still (45.3^{O}C, 47.4^{O}C and 43.2^{O}C respectively for days 1, 2 and 3) compared to P still (41.4^{O}C, 43.5^{O}C and 42.5^{O}C,respectively for days 1,2 and 3). Analysis of water showed that the pH values of water from P (6.19±0.03) and R (6.21±0.00) were significantly ($p<0.05$) lower than that of Eva water (6.42±0.03) and salty water(7.00±0.00).The chlorine content, alkalinity, total dissolved solids, conductivity, total viable and coliform counts from the P- still did not significantly differ from those of R-still and Eva water but were significantly ($p<0.05$) lower than those of the salty water. Sensorily, the Eva water (control) was the most acceptable (5.0±0.00) compared to the P still water (2.5±0.85) and R still water (2.0±0.67).

Key words: Rectangular solar still, Pyramid solar still, sea water, distillation, efficiency

1 INTRODUCTION

Water is a precious natural gift. The ground water is over exploited to meet the increasing demand of the people. Less than 1% of earth's water is available for human consumption and more than 1.2 billion people have no access to safe drinking water. Over 50% of the world's population is estimated to be residing in urban areas and almost 50% of the mega cities having population over 10 million are heavily dependent on ground water, especially, in developing countries like India (Seibert *et al.* **2004**) **[1].** Surface water such as the sea water is frequently polluted by human activities, urbanization and industrialization. As natural fresh water resources are limited, sea water plays an important part as a source of drinking water as well. In order to use this water, it has to be desalinated (Badran and Al-hayek, **2000**) **[2].** Desalination refers to any of the several processes that removes some amount of salt and other minerals from saline water to provide water fit for human consumption and agricultural purposes. To achieve this, solar stills have been developed to be used for such desalination. A solar stilling of water is a low-tech way of distilling water, powered by the heat of the sun. In a solar still, impure water is contained outside the solar collector, where it is evaporated by sunlight shining through clear plastic. The pure water vapour (and any other included volatile solvent) condenses inside plastic surface and drips down off the weighed low points, where it is collected and removed.

2 MATERIALS AND METHODS

Procurement of raw materials

The salty water was obtained from Ngene River in Ebonyi State, Nigeria using a 20 liter white plastic gallon.

2.1 Equipment

The Rectangular-Shaped Distiller and Pyramid Shaped water Distiller used were developed at National Center for Energy, Research and Development, University of Nigeria Nsukk, **Fig. 1** and **Fig. 2**. Other equipment used include the measuring cylinders, hydrometer, hygrometer, thermometer, white plastic gallon, hose, funnel, masking tape and weighing balance.

2.2 Operation of the solar stills

These solar water distillers have tops made of glass with an interior surface made of waterproof membrane. These interior surfaces use blackened material to improve absorption of the sun's rays. The salty water was poured into the stills to partially fill the basin. The glass cover allows the solar radiations (short-wave) to pass into the stills which were mostly absorbed by the blackened base (Piston and Michael, **1998**) **[3].** The water heats up and the moisture content of the air trapped between the water surface and the glass cover increases. The base also radiates energy in the infra-red region (long wave) which was reflected back into the still by the glass cover, trapping the solar energy inside the still (the "greenhouse" effect). The heated water vapor evaporates from the basin and condenses on the interior of the glass cover. In this process, the salts and microbes that were in the original water would be left

vn the inclined
n and to

Fig. 1: Rectangular-shaped solar still

Fig. 2: Pyramid- shaped solar still

3 Analysis

3.1 Ambient Temperature: Periodically, the temperatures of the seawater, the base of solar still, transparent cover and the ambient were measured using I-Bk thermocouples. At sunset of each day, the volume of water distilled in the container is measured

3.2 pH Determination

The pH was determined in accordance with the method described by Odo and Ishiwu (**1999**) **[3].** Materials used for pH determination include. The Jemway pH meter, model 3510 which was standardized with buffer solution 4, 7 and 10 at ambient temperature after which the electrode was washed with distilled water, wiped with cotton wool and immersed in the water to be tested. Until the instrument displays a steady reading then the reading was recorded.

3.3 Total Hardness of Water Determination

The water hardness was determined using the method described by Gaines (**1993**) **[4].** Twenty- five cubic meter of the water sample was collected and 1m of NaOH was added to obtain a pH of about 12.00 using a Jemway pH meter. The magnesium hydroxide was allowed to precipitate without any need for filtration. Then cm of NH_3 buffer was added and two drops of Erichrome black T indicator also was added and was then titrated to blue end point. The volume was used to calculate the calcium content of the water.

3.4 Conductivity Determination

The method described by Odo and Ishiwu (**1999**) **[4]** was adopted. Conductivity was determined using WTW conductivity meter, model LF 90. The conductivity meter was standardized with 0.01 molar KCl, the electrode was rinsed with deionized water, wiped and dipped into the sample to be tested and left for some time to obtain a stable reading which was recorded in micro Siemens per centimeter (µs/cm).

3.5 Chloride Content Determination

Chloride content determination was done by Morh's Agromentric method **(2004) [5].** 20.5ml of sample to be determined was added 1ml of 1M of sodium hydroxide to adjust the pH. Then 1ml of potassium chromate was added as indicator and the sample was titrated against standard $AgNo_3$ until the colour changed to pinkish yellow.

3.6 Total Alkalinity Determiantion

The method described by Welscher (**1963**) **[6]** was employed. Fifty millilitre of water sample was pipetted into a conical flask and 2 drops of methyl red was added and titrated with standard 0.01m Hcl to a red end point.

3.7 Dissovled Solids Determination

The total dissolved solid was determined using the method described by Welscher (1**963**) **[6].** About 20cm^3 of water sample was measured into a weighed dish, heated gently in a water bath to dryness and cooled in desiccators. Heating and cooling was repeated until constant weight was obtained. The increase in the weight of the dish represents total dissolved solids, operation was repeated twice and the average weight increase of the dish was taken.

3.8 Microbiological Analysis:

3.98.1 Coliform in Water Determination

Coliforms in water were determined using (Franson, **1976) [7].** Coliforms are the common indicator for a particular group of micro-organisms for water pollution. It is a feacal contaminant and its presence in water is harmful to human health. 37.1 grams of the medium was suspended in one liter of distilled water. 10ml of resolic acid was added at 1% in NaOH solution and heated to boiling. It was cooled at room temperature and about 2mls of broth was added to each sterile absorbent pad placed in a petri dish.

3.8.2 Viable Count Determination

This was determined by using the method described by Franson (**1976**) **[8].** This is the total number of living micro-organisms present in the water. Agar plates were divided into eight segments with an indelible marker. A drop of the suspension was inoculated on each segment. These plates were then incubated for 24 hours at 37°C. Developed colonies were counted.

3.9 Sensory Evaluation

Raw untreated salty water, rectangular-shaped solar still treated water and the pyramid-shaped solar still treated water were subjected to sensory evaluation by twenty untrained judges for taste, colour, odour and overall acceptability evaluation. A 5-point category scale was used. This involved assigning the highest point to the most desirable and lowest point to the least desirable. The samples were arbitrarily coded to avoid giving any hint of the samples identity to the judges. The treated water samples were allowed for 24 hours to assume room temperature before serving to the judges so as to give an equal basis of assessment to the water samples.

4 RESULTS AND DISCUSSION

4.1 Comparative evaluation of selected parameters of the waters

This is presented in **Table 1**. The pH of the salty water, R-water and P-water were 7.00, 6.21 and 6.19 respectively while the pH of Eva water which served as a control was 6.42. The pH of R-water and P-water significant ($P<0.05$) from the pH of salty water and Eva water. R-water and P-water have lower pH when compared to the pH of the salty water and the Eva water. This is because as the solar radiation heats up the water, dissolved carbon (iv) oxide in the waters reacts with the water to form carbonic acid thereby reducing the water pH. This is in line with the report by Tiwari (**2004**) **[9].** The pH of the R-water and P-water conform to the range of permitted level given by NIS (**2007**) **[10]).**

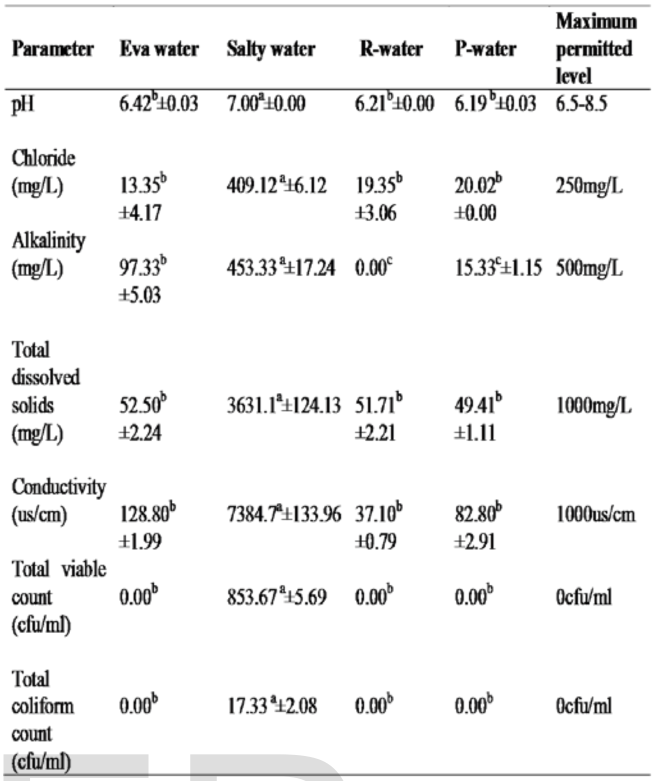
There were no significant differences ($p>0.05$) in the chloride content of Eva water, R-water and P-water but they significantly ($P<0.05$) differed from the chloride content of the salty water. This is due to the high chloride content of sea water.

The total dissolved solids of the Eva water, salty water, R-water and P-water were 52.5mg/l, 3631.1mg/l, 51.71mg/l and 49.41mg/l, respectively. There were no significant differences ($p>0.05$) in the total dissolved solids of the Eva water, R-water and P-water, but they significantly differed ($p<0.05$) from the total dissolved solids of the salty water. The high total solids content of the salty water is due to its high salt content. Total dissolved solids of R-water and P-water conform to the permitted level given by NIS **(2007) [10].**

There were no significant differences ($p>0.05$) in the conductivity of the Eva water, R and P but these were significantly different ($p<0.05$) from Salty water. The conductivity of the salt water was also higher than that of Eva water, R-water and P-water. This is because conductivity of water is determined by the level of chloride and total dissolved solids present in the water. This is in line with the report by Lomborg (**2001) [11].**

There were no total viable count and coliform in R-water and P-waters. This is as a result of evaporation which eventually condenses leaving behind the microorganisms. This agreed with report by Gadgil (**1998**) **[12].**

Table1: Comparative analysis of the distilled waters from different solar stills



Parameter	Eva water	Salty water	R-water	P-water	Maximum permitted level
pH	$6.42^{b}\pm0.03$	$7.00^{a}\pm0.00$	$6.21^{b}\pm0.00$	$6.19^{b}\pm0.03$	6.5-8.5
Chloride (mg/L)	13.35^{b} ±4.17	$409.12^{a}\pm6.12$	19.35^{b} ±3.06	20.02^{b} ±0.00	250mg/L
Alkalinity (mg/L)	97.33^{b} ±5.03	$453.33^{a}\pm17.24$	0.00^{c}	$15.33^{c}\pm1.15$	500mg/L
Total dissolved solids (mg/L)	52.50^{b} ±2.24	$3631.1^{a}\pm124.13$	51.71^{b} ±2.21	49.41^{b} ±1.11	1000mg/L
Conductivity (us/cm)	128.80^{b} ±1.99	$7384.7^{a}\pm133.96$	37.10^{b} ±0.79	82.80^{b} ±2.91	1000us/cm
Total viable count (cfu/ml)	0.00^{b}	$853.67^{a}\pm5.69$	0.00^{b}	0.00^{b}	0cfu/ml
Total coliform count (cfu/ml)	0.00^{b}	$17.33^{a}\pm2.08$	0.00^{b}	0.00^{b}	0cfu/ml

Values are mean of triplicated results ± Standard deviation

Means with same superscripts are not significantly different ($p>0.05$)

4.4 Sensory Evaluation of Eva water, Salty water, R-water and P-water

There were no significant differences ($p>0.05$) in all the sensory attributes tested for R-water and P-water **Table 2**, but they significantly differed ($p<0.05$) from Eva water, which had earlier been purified by a water processing company and also differed significantly ($p<0.05$) from salty water in some attributes. The preference of Eva water to that of other waters could be due to the efficient water purification process given to it

Table.2: Sensory evaluation of R-water and P-water

Samples	Colour	Odour	Taste	General Acceptability
Eva water	$4.89^{a}\pm3.33^{a}$	$4.89^{a}\pm3{,}33^{a}$	$5.00^{a}\pm0.00^{a}$	$5.00^{a}\pm0.00$
Salty water	$3.59^{b}\pm1.09$	$3.10^{b}\pm0.99$	$1.60^{c}\pm0.96^{c}$	$2.00^{b}\pm1.13$
R water	$3.30^{b}\pm8.23$	$2.90^{b}\pm0.74$	$2.90^{b}\pm1.10$	$2.00^{b}\pm6.67$
P water	$3.00^{b}\pm1.15$	$3.10^{b}\pm0.94$	$2.60^{b}\pm0.84$	$2.50^{b}\pm0.85$

Values are mean of 20-panelists
Score are structured on 5-point Hedonic scale
Means in the same column with the same superscript are not significantly different ($p>0.05$)

4.2 Ambient Temperature and solar radiation

During the three days of solar distillation, the solar radiation and the ambient temperature of the environment showed that the ambient temperature and solar radiation were low on day one while they highest on day two (**Fig.3**). On the 3rd day, it became low again. It was also observed that the ambient temperature varied in sympathy with the solar radiation.

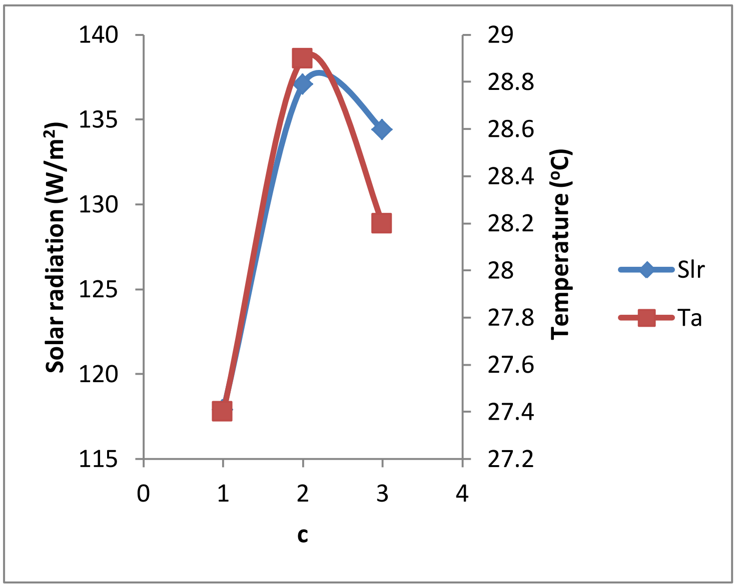


Fig 3: Ambient temperature and solar radiation

Keys: Ta= Ambient temperature day
Slr = Solar radiation

4.3 Temperature curve of the R-water and P-water with time

Figure 4 represents the rectangular shaped solar still water temperature (Rw) and the pyramid shaped solar still water temperature (Pw) during distillation against time. It was observed that in all cases, the R-water was higher than that of the P-water for the three days in which the analysis was carried out which resulted to the collection of higher quantities of water using the rectangular distiller at the end of each day. This was due to higher rate of evaporation in the rectangular shaped solar still (Tiwari *et al.* **2003**) **[13]**.

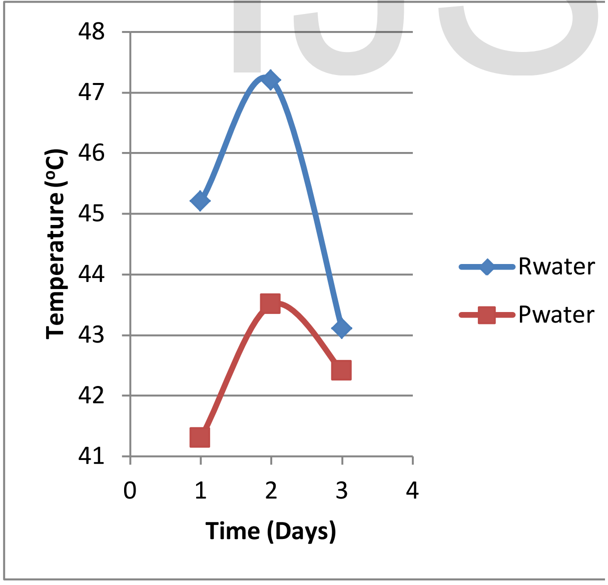


Fig.4: temperature of the R-water and P-water against time

Keys: R-water – water distilled using rectangular-shaped solar still
p-water- water distilled using pyramid-shaped solar still

Keys: R-water – water distilled using rectangular-shaped solar still
p-water- water distilled using pyramid-shaped solar still

4.5 Temperature curve of the R-water and P-water with time

Figure 4 represents the rectangular shaped solar still water temperature (Rw) and the pyramid shaped solar still water temperature (Pw) during distillation against time. It was observed that in all cases, the R-water was higher than that of the P-water for the three days in which the analysis was carried out which resulted to the collection of higher quantities of water using the rectangular distiller at the end of each day. This was due to higher rate of evaporation in the rectangular shaped solar still (Tiwari *et al.* **2003**) **[13].**

4.6 Temperature gradients of the glass top and the base of the pyramid-shaped solar still

This is presented in **Figure 5**. The temperatures of the interior components of the two solar stills were higher than the tops of the solar stills which is due to the transparent cover of the solar stills which allows radiant rays to pass through it down to the base of the solar stills where some of the rays are absorbed thereby increasing the temperature of the base (green house effect) (Singh and Tiwari, 2004). Also, in the 2nd day, the temperature of the top and the base of the pyramid-shaped solar still were also low. This could be as a result of leakages observed inside the solar still that eventually resulted to the loss of heat from the solar stills.

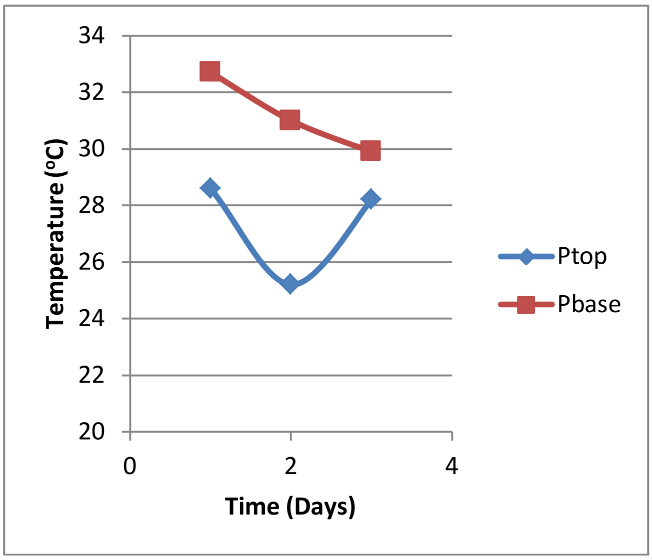


Fig.5: Temperatures of the glass top and the base of the pyramid-shaped solar still against time.

Keys: top – temperature of the glass top of the pyramid-shaped solar still

pbase- temperature of the base of the pyramid-shaped solar still

4.7 Temperatures gradients of the glass top of the rectangular-shaped solar still with time

This is presented in **Figure 6.** The average temperature of the glass top of the rectangular-shaped solar still was highest in day one, while the average temperature on the second day of the glass top was lowest in day two. The temperature of the base of the rectangular-shaped solar still was higher than the temperature of the glass top during the 3-day distillation time. This could be due to the transmission of radiant energy down to the base of the still thereby increasing the temperature of the base (Singh and Tiwari, (**2004**) **[9]].** Also, in the 2nd day, the temperature of the top and the base of the pyramid-shaped solar still were also low. This could be as a result of leakages observed inside the solar still that eventually resulted to the loss of heat from the solar stills.

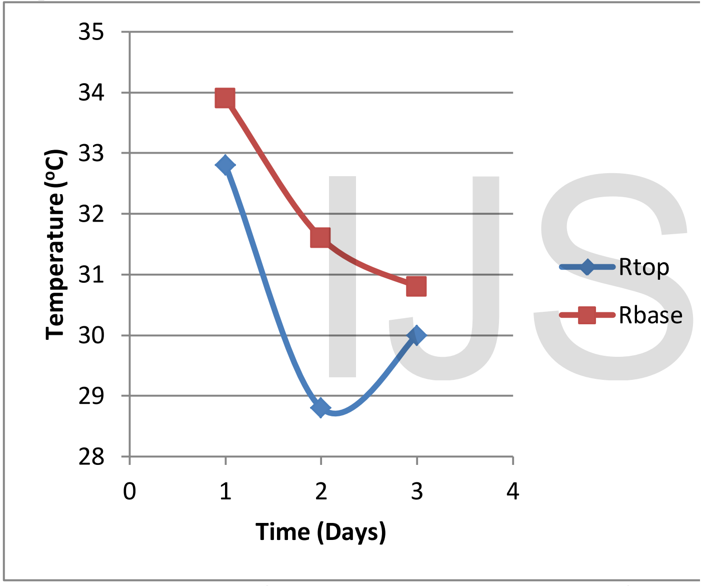


Fig.6: Temperatures of the glass top and the base of the rectangular-shaped solar still against time.

Keys: Rtop – temperature of the glass top of the rectangular-shaped solar still

Rbase- temperature of the base of the Rectangular-shaped solar still

5 CONCLUSION

Ebonyi salty water is a promising source of portable water for both home and industrial use only if it undergoes proper water treatment process, especially to reduce its high level of minerals. Solar still water treatment has shown to be an effective means of achieving this. The solar stills were able to produce water with acceptable pH, Chloride content, alkalinity, total dissolved solids, conductivity, coliforms and total viable contents. However, the rectangular-shaped solar still appeared to be more effective compared to the pyramid-shaped solar stills. The improved rectangular-shaped still would likely improve the sensory attributes of the treated waters.

6 REFERENCES

[2] Badran, O. O and Al- Hayek, I. (2004). The effect of using different designs of solar stills on water distillation. Brad Brown press, Mexico. Pp 485-497.

[7] Franson, M. (1976). Standard methods for the examination of water and wastewater.

[11] Gadgil, A. (1998). Drinking water in developing countries. Sashae press, Mexico city

[10] Lomborg, B. (2001) "Water science". The Skeptical Environmentalist. Cambridge university Press USA. Pp 27.

[5] Morh, G. (2004). Practical Manual on food technology,Nutrition and Dietetics for shorts and Industries. 2nd Edition.

[9] NIS (2007). Nigerian standard for Drinking water Quality. Standard organization of Nigeria, Abuja.

[4] Odo F.O. and Ishiwu C. M. (1999). Experimental Procedures for food and water analysis. Amazing grace printing and Publishing company. Enugu. Pp 96

[3] Pilson, U. and Michael, E. (1998) An introduction to the chemistry of the sea, Upper saddle River Solener publishers, cape Town pp 199-202.

[1] Seibert, U.G., Vogt, C., Brenning, R., Gebhard, O. and Hole, F. (2004). Autonomous desalination system concepts for seawater and brackish water in rural area, with renewable energies. Marrakech publishing company, morocco pp 525-528.

[13]Singh, H.N.and Tiwari G.N. (2004). Monthly performance of passive and active stills for different climatic conditions. Publishing inc. lowell pp 145-149

[8] Seibert, U.G., Vogt, C., Brenning, R., Gebhard, O. and Hole, F. (2004). Autonomous desalination system concepts for seawater and brackish water in rural area, with renewable energies. Marrakech publishing company, morocco pp 525-528.

[6] Welsher , F.J. (1963). Standard methods of chemical analysis, vol 2 part B. D. von No strand company in corporated.