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Evaluation of basin and insulating materials in solar still prototype for solar distillation plant at Kamusuchiwo community, High Guajira

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Abstract.

Solar distillation is a technology suitable for producing distilled water in remote areas of civilization. Within the project of drinking water plant using solar distillation in Kamusuchiwo community, underlying this research that wants to determine the best combination of absorbent materials and insulators. There were assessed two types of insulators and two types of basin materials, this in order to improve the efficiency of the distillation and applying to the plant to will be constructed.

The results were satisfactory, reveal that water production dependent of the basin and water temperatures until noon when the sun is at the zenith, then at the afternoon, water production depends of distiller's internal heat. The efficiency was considerable when you consider factors such as cloud cover and wind that decrease the production of water, these variables limit the optimal functioning of the distiller. The applied experimental design allowed us to determine that the best material to use in basin is aluminum and the best material insulating was sawdust, combination of these materials will be use in water solar plant.

Key words

Distillation, still, desalinization, insulating, drinking water, basin, aluminum, stainless steel, sawdust, Styrofoam

1. Introduction

The water is one of the most important resources, of total world water, only 1% is drinking water, 97% is seawater and 2% is ice. Colombia is the northeast country in South America that has a 35.800 mega cubic meter of water demand in 2011, is considerate as one of the more hydric water country in the world, the performance of hydric average is 63 l/s km2, that is, six times the world performance hydric average (10 l/s km^2) and three times Latin American performance (21 l/s km^2) [1]. However, 50% of population in Colombia don´t have drinking water, specially the afro and indigenous communities localized in depressed areas like the Wayuu, people indigenous, where this research born, emerged of seawater distillation project which is being supported by COLCIENCIAS, government institution for science and technology and is being development by SOLARIS S.A.S. The community live in Guajira Department (12º N latitude), located in desert of Guajira, they extracted water of Jaweys (Australian wells), these jaweys are dry eight months of year and are polluted especially by particular material that come from coal mine port, 2 Km of distance to community. By compensation of environmental impact of Cerrejon mine, each family receives only 800 lt/week, however these 25 lt/day per person, it is half of vital minimum and it doesn´t cover all the water community needs. These precarious conditions, arid environment and air pollution, request a sustainable water solution using local resources and renewables energies. The Guajira Department has the best solar radiation in Colombia, about 6- 6,5 Kwh/m^2d [2], where it is possible to use stills to desalinate sea water, that is 200 meters close to community. Distillation is perhaps, a unique sustainable way to produce drink water from seawater, but stills, have a lot of heat lost in their components and this problem gives a low performance in basin where water is evaporated and them is condensed in glazing cover. Whereby, water project needs a study to get a high yield than other stills, analyzing specially the materials of the basin and insulating. In view of this, a lot of research worked are undertaken to improve the productivity of the solar still and since the publications on this topic are very abundant in the literature, we content ourselves to quote here a few more recent anterior works. So, over the past years, a set of papers have been published by Tiwari and his different collaborators. Generally, these various studies both theoretical and experimental have practically included some influencing parameters on the solar distillation such as: Climatic conditions, condensing cover material and solar still slope [3].

2. Building prototype still

The first steep to evaluate still materials performance is making still. The construction of still requires analyzing variables at the zone where the project will be making, like: solar radiation, latitude, solar angle, and still variables as: solar angle, mirror angle and area basin. It was chosen a double slope still, because is the most still used and has a better cost-benefit ratio. Shape still was built with steel as can see in figure 1, the still dimensions are 89 cm long, 70 cm width, and 77 cm of high.

Fig. 1. Still structure

A. Still Materials

Once the structure still is ready, it has to select the materials to be proved. First, there was the criteria selection of basin materials, is these materials have a high absorption capacity, low reflectivity and little conductivity. For still basin, was selected two materials; stainless steel and aluminum, these materials have a high conductivity 25 (W/m-k) and 209 (W/m-k) respectively [4], also these are no so expensive, they have a good durability, they are local available and these have low toxicity [5]. The basin dimensions are 83 cm width and 60 cm long; therefore the area is 0.5 m^2.

Second, it was choice insulating materials, this is an important part of still because these materials should have low conductivity and should be easy to get in local area. For this experiment, was choice sawdust and Styrofoam; these materials have low conductivity 0,09 and 0.037 respectively [6], and there were local availability, especially sawdust. Insulating area is the same of basin area; however insulating thickness is 5 cm because a further increase in insulation thickness would result in rise the total yield. Increasing the thickness beyond 5cm has a little effect on the still production [7].

Other important still material is the glazing cover, it is located of top to still, where the steam is condensate and a little clean water drops are produced and then it is collected in troughs. There is much information about glazing cover and it´s common to use polyethylene, acrylic and tempered glass, however, these materials are expensive and they can´t get in local areas. For this research, was decide to choose a ordinary glass with 5 mm of thickness, because it is cheaper than other materials, it has 50 years of life expectancy, has 86% of solar transmittance and 2% of infrared light transmittance [8]. It may be that tempered glass has better transmittance than ordinary glass, but it is most expensive and it´s more delicate; if still is installed in desert, fastest winds can be rises stones that can break glazing cover.

Once, still was made and materials were selected, it is important to make mechanical and hydraulics tests, for example: look a possible holes in basin, hydraulic leaks in pipeline and wind infiltrations; still should be as hermetic as possible, any disturbance into still, cause that internal temperature down and also still yield.

Significant effects of the wind speed are reported, for a range of 0 m/s to 20 m/s output daily almost doubled during the period of insolation, water temperature is changed by over 15°C, where as the temperature difference between the water and the cover varies approximately 11 ° C [9].

3. Design Experiment

For this research was chosen factorial design experiment, thus used two independent variables and each of one has two levels; first, basin materials (A): stainless still (A_1) and aluminum (A_2). Second, insolating materials (B): Styrofoam (B_1) and sawdust (B_2), in next figure is possible understand better.

Table I. – Design Experiment

	A_1	**A_2**
B_1	A_1 B_1	A_2 B_1
B_2	A_1 B_2	A_2 B_2

Factorial design is extremely useful because allow to researcher evaluated effects of each independent variable into dependent separately and effects of independent variables jointly [10]. In this research our independent variables are the basin materials and insolating materials, were linked with dependent variables, which are the following: basin temperature, Water Tº, shape Tº, internal glass Tº, external glass Tº and volume of water produced. Also were measured ambient temperature, relative humidity and direct solar radiation, the instruments used in measurements as following:

Table II. - Type Sizes

Instrument	Parameter
Thermo hygrograph	Ambient Tº, RH
Voltmeter	Tº
Test tube	Water volume

The experiment was made in situ conditions, still was carry to Kamusuchiwo community where desalinization plant will be build. Still orientation was west to east because in this form still received more radiation than other orientation as looking in the following figure 2. The measurements were made for each test in one day; therefore, the whole experiment was development in 4 days, since 8 am to 6 pm, each ten minutes be measured variables.

Fig. 2. Prototype still

4. Results and discussion

In desert conditions, still operation was good; the seawater beginning to evaporate, and then, many drops are collected efficiently in two troughs which leading water to test tube, each ten minutes was measurement of water temperature (T_w), basin temperature (T_b), external basin temperature (T_{eb}), environmental temperature (T_e), water volume (V_w), relative Humidity (RH). We should extremely carefully to look tightness, because it observed that wind affected significantly the still yield; any wind infiltration could down still internal heat and consequently decrease distilled water volume.

A. *Analyzing Still Materials*

The distilled production was representative in three tests; maximum production was 410 ml in aluminum and sawdust test. Wind speed was very equal in all test, therefore wind conditions don´t affect the experiment.

Table III. – Water Produce

	A_1	A_2
B_1	305 ml	310 ml
B_2	310 ml	410 ml

The first test that realized was A_1B_1 and then; A_2B_1, A_1B_2, A_2B_2; each test lasted ten hours and only was observed in day. Of the results, is interesting to evaluate the relation between water produce and other dependent variables. Water temperature in basin has a negative correlation with water produce, when Tw rise, water volume decrease, chiefly at afternoon, after 1 Pm, in zenith, as we can see in next figure. This could remark in other researches; Ahsan for example, studied the parameters affecting the performance of solar still, in his research observed when solar radiation was the highest at about 1 Pm, at this time the value of water temperature was the highest of about 54º C [11]. Also it can be inferred that Tw decrease after 1 pm, like Arunkumar presents in his researcher on Coimbatore, India (11º N Latitude), almost the same latitude in La Guajira, water temperature decrease at the same time and keep its downward curve until night [12].

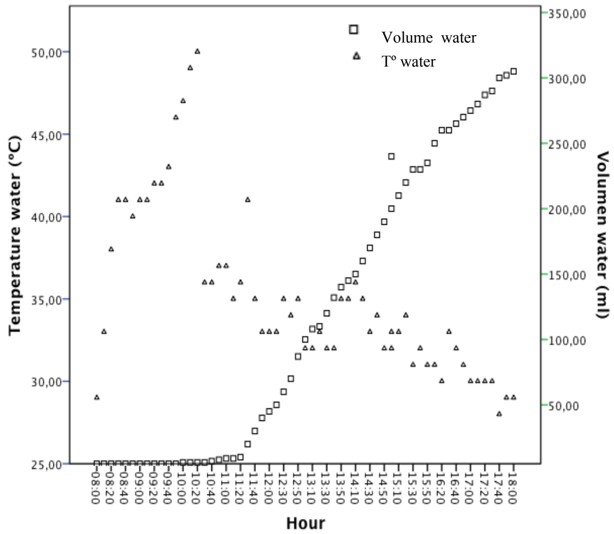

Fig. 3 Negative correlation between water Tº and water produce for first test.

The decrease of Tw to 1 Pm as we can see in the next figure, it means that later noon the water temperature is not important to evaporate water, in the afternoon, the responsible to produce water is the amount of heat stored into the still, particularly, evaporative heat transfer coefficient, which it´s an important parameter to analyzing the system performance [13].

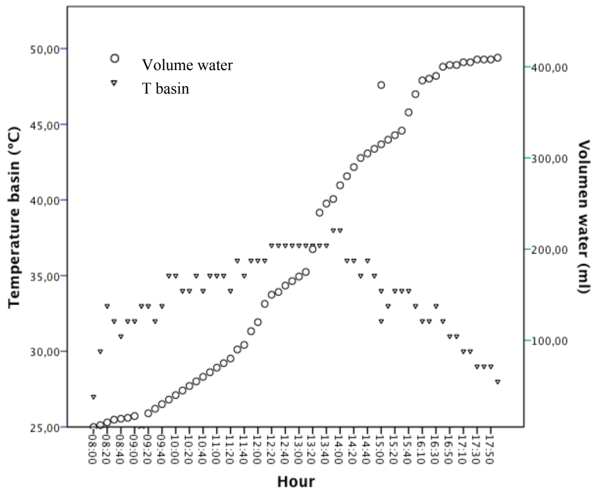

Fig. 4 Negative correlation between Tº basin and Water produce, fourth test.

Water temperature has a positive correlation to basin temperature, indicating that it´s directly proportional between basin materials to water; second and fourth test where was used aluminum, T_b was more high than T_w, until noon as we can see in the next figure, the basin has more energy to send water, and that helps to increase the distilled water produced in afternoon, when all temperatures comes down. Others two tests, were used stainless steel, most of the time water temperature was higher than basin temperature, in these cases, water warming had more speed than basin, whereby this material doesn´t give much energy to water evaporating.

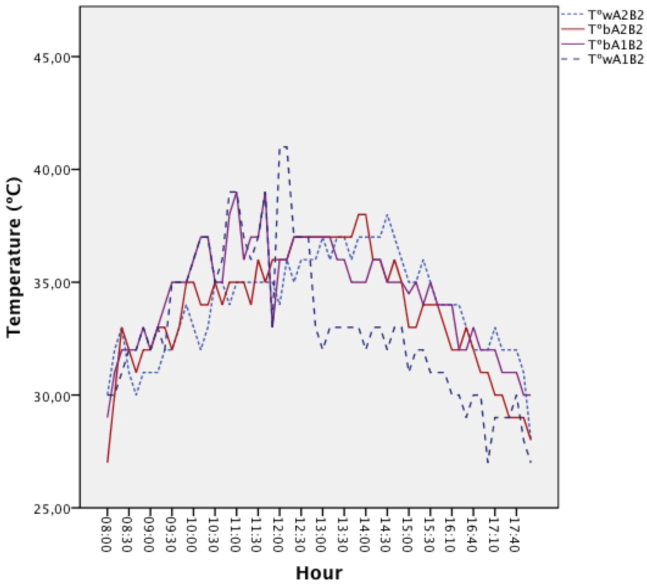

Fig. 5 Basin T° Vs water T° for second and four tests.

On the other hand, there is a positive correlation between external basin temperature and basin temperature, it´s very strong, for example, the fourth test (0,986 Pearson correlation) where was used sawdust. The work of insolating materials is avoid the lost heat in basin, and this only occurs moderately using sawdust, in third and fourth test; $T_{eb} > T_b$ until noon, in afternoon $T_{eb} < T_b$ as we can see in the next figure. Apparently sawdust can´t hold heat in the morning but it can hold heat after 1 Pm, this is suitable because in these hours T_b reduced significantly, and it's the moment when most needed isolate heat into the still.

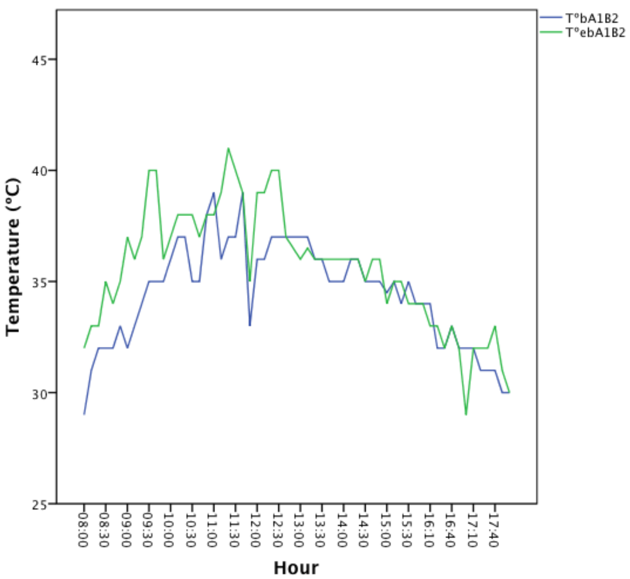

Fig.6 Basin T° Vs. External basin T° for third test.

Second test, was used Styrofoam that shows a different behavior between T_{eb} and Tb; in this case $T_{eb} < T_b$ in morning and $T_{eb} > T_b$ in afternoon. Styrofoam lost insolated capacity in the most important moment of day, when was produce more water in still.

B. *Analyzing environmental variables*

The environmental variables are very important to considerate is this research, for example, environmental temperature can be a indicator of how external conditions can influence heat into still and water production. There is a negative correlation between environmental temperature and water volume, the first experiment was a strong negative correlation, at that day the temperature rise until 44ºC at 10:00 Am, this atypical conditions, produce distilled water increase and environmental temperature decrease, this occurs in the afternoon. Other tests had similar conduct among these, at 1 Pm decrease environmental temperature, but still continuous producing water. Environmental temperature has a similar tendency than temperatures measured in tests, in following figure we can see the curve.

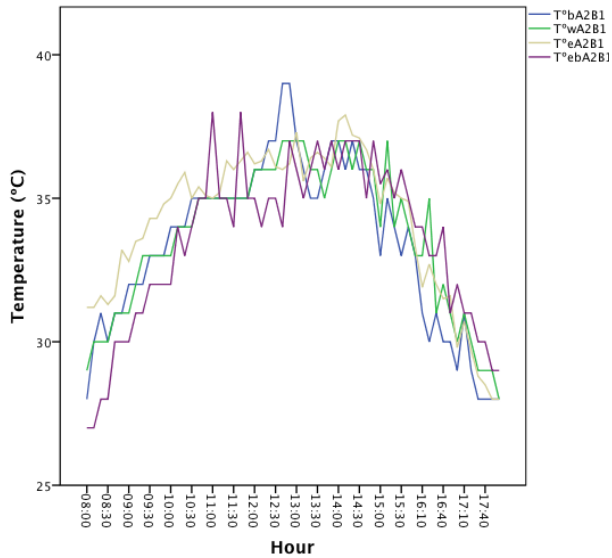

Fig.7 Temperatures in fourth test.

Also observed how Relative humidity had effect to produce water in still. In four tests realized, RH was between 40 % and 70%, with a maximum of 88%, is a high value of RH for desert conditions, however Kamusuchiwo Community lives near to sea, that gives more steam water at local atmospheric.

There is a positive correlation in first and third tests in relation with RH. Fourth test had a weak negative correlation (-0,136), in following figure we can see how in the morning, RH decreases, due to atmospheric warming, for a high radiation in this time of day. At 13:20 Pm, the RH had a minimum value, and in afternoon RH returned to highs values.

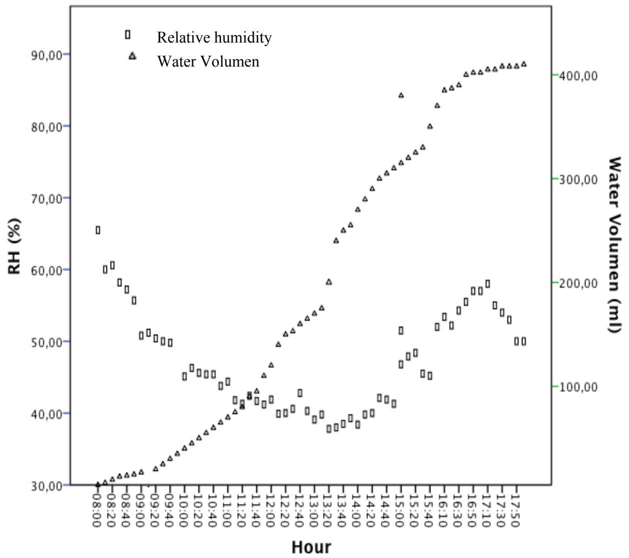

Fig. 8 Relative Humidity Vs. Water produce for fourth test

C. Statistics analysis

Generally in a factorial experimental design experimental tests are performed for all combinations of the levels of the factors. It will be used as analysis of variance of the main tools for analyzing statistical data. To statistics analysis was used SPSS software where was found following results:

The interaction is significant ($p = 0.009$). There are differences in the means of production of distilled water to different temperatures at each level of factor materials and vice versa. In Anova analyzing, the significance values are all less than 0.05, including the interaction is 0.009. This means that insulation temperature and absorption materials (basin materials) influence the volume of distilled water produced. The system also displays the R square value in this case, 0,521, indicating that 52 % of the production of distilled water from the distiller is explained by the model.

In the results also was include the following graphics. Residual Graph shown in Figure 9. From residual Graphic can conclude that the model is relatively good, as the chart predicted versus observed has a tendency to be on a straight growing.

Figure 10 is a graph of mean temperatures of the basin, water and the external basin of the still, with each combination of materials. Concluded this factorial experiment has an interaction, and there are intersections in second and fourth tests; the thermal balance between the three temperatures of the graph (T_w, T_b, T_{eb}) indicates that thermal equilibrium are in these tests (2,4).

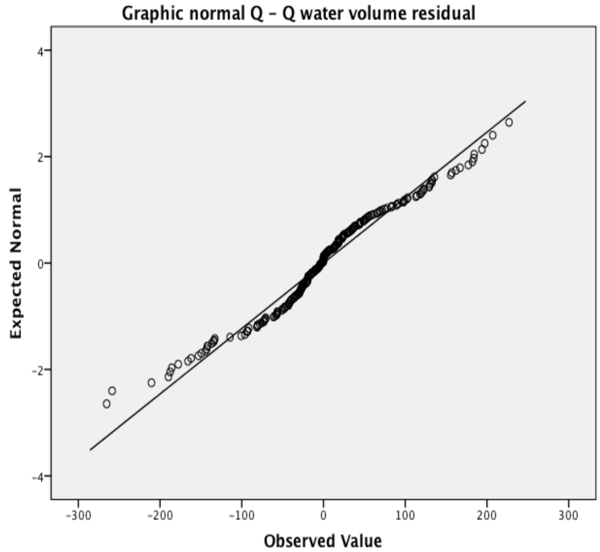

Fig. 9 Water volume residual

However of the insolating materials, sawdust had the better performance than stainless, also this material is easy to found in local stores, so the fourth test A_2B_2 (Aluminum-sawdust), was the best combination for the production of distilled water. Others researcher like Murugavel presented a positive results used aluminum, he proved different fin configurations in the basin, the aluminum rectangular fin covered arranged in length wise direction was more effective and gave slightly higher production than other materials [14]. Also El-Sebaii, designed and fabricate a single slope solar still with aluminum movable baffle suspended absorber plate and used thick layer (0.075m) of sawdust to minimized heat losses; the daily productivity of the modified solar still is increased from 4,736 to 5,737 kg/m^2/day compared to the conventional solar still [15].

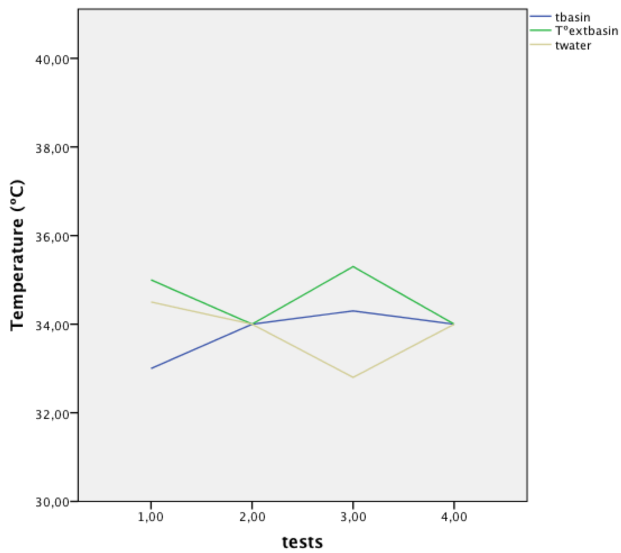

Fig. 10 Graphic of means temperatures versus the four tests.

D. Still Efficiency

Still average produce was 333 ml; maximum produce was 410 ml in fourth test and minimum was 305 ml. Still yield is related between the energy related effectively absorbed for water and incident solar energy. The efficiency of a still can be calculated by the following Equation:

$$n = \frac{m \times lv}{Is} \times 100\% \quad (1)$$

Where m is the daily output (kg/m^2), L_v is the latent heat of evaporation of water (kJ/kg) and I_s, is the daily total solar radiation (kJ/m^2). Solar radiation during the experiment was variable, second day was very cloudy in the morning and it was raining at noon, which reduces the production of water and still efficiency. In following table can see average solar irradiation for test days and still yield for each test:

Table IV. – Water Produce

Test	**Materials**	**Solar radiation (Wh/m^2)**	**Efficiency %**
A_1 B_1	Stainless steal-Styrofoam	5100	13%
A_2 B_1	Aluminum-Styrofoam	4500	14%
A_1 B_2	Stainless Steal-sawdust	5060	13%
A_2 B_2	Aluminum-sawdust	5200	17%

How we can observed in the table, more efficient test was the fourth, it was the experiment that produced more distilled water, since 9 am started to distill exponentially as see in figure 8.

5. Conclusions

The most effective test for the production of distilled water was the fourth (A_2B_2) is a mixture of sawdust and Aluminum. This test was the one that showed a greater efficiency in the distillation, producing 410 ml.

Found that there is a significant interaction between the measured temperature and water production. This reaffirms the importance of the materials of the distiller in the efficiency of this and that your choice is very important when it comes to build a large distiller.

It was determined that the heat in the water exists within the distiller is important for the start of the distillation, however, after the conditions change and means responsible for the production of water is the evaporation latent heat within the distiller.

To maintain optimum vaporization heat within the distiller is very important that it is fully sealed, as high winds can infiltrate the distiller and reduce the efficiency

It was observed that the two limiting variables in the solar distillation, in desert conditions on the sea were cloudiness and winds coming from the northern hemisphere.

Sawdust low effectiveness as an insulator in the morning, however, it appears that after half a day is when its function is important, because the heat insulation of the apparatus at times when the production of distilled water is exponential.

References

[1] IDEAM, "Estudio nacional del agua 2010", Instituto de Hidrología, Meteorología y Estudios Ambientales, República de Colombia 2010,pp. 69.

[2] IDEAM, "Atlas solar de Colombia, Instituto de Hidrología, Meteorología y Estudios Ambientales, República de Colombia 2010, pp. 5.

[3] Anil Kr. Tiwari, G.N. Tiwari, Effect of the condensing cover's slope on internal heat and mass transfer in distillation: an indoor simulation, Desalination, 180,pp. 73–88.

[4] William D. Callister Jr, "Introducción a la ciencia e ingeniería de los materiales", Department of materials science and engineering the university of Utah. Ed reverté S.A. 1998, Tomo II, pp. A-6.

[5] Joel Gordes, Horace Mc Cracken, "understanding solar still" volunteers in Technical Assistance (VITA), Vol1, pp.15.

[6] Joel A. Gutiérrez, Alejandro D. González, "Determinación experimental de conductividad térmica de materiales aislantes naturales y de reciclado", Avances en Energías Renovables y Medio Ambiente, in Asades 2012, Vol. 16, pp.47.

[7] Samy m. elsherbiny, Hassan e.s. Fath, "Performance of diffusion stills under Egyptian climatic conditions", International Journal of Solar Energy, vol 16, pp.285.

[8] Joel Gordes, Horace Mc Cracken, "understanding solar still" Volunteers in Technical Assistance (VITA), Vol1, pp.15.

[9] Francisco José P. Zimmermann. Estadística para investigadores. Escuela Colombiana de Ingeniería, Vol.1, pp.161-175.

[10] Eduardo Rubio Cerda, "Estudio experimental de un destilador solar orientable de gran tamaño", Centro de Investigaciones Biológicas del Noroeste, S.C. SSDA 11- 05, pp. 346-349.

[11] A. Ahsan, Parameters affecting the performance of a low cost solar still, Applied energy, Vol. 114, pp.924-930.

[12] T. Arunkumar, "Study of thermo physical properties and an improvement in production of distillate yield in pyramid solar still with boosting mirror", Indian Journal of Science and Technology, Vol. 3 No. 8, pp. 879-874.

[13] K. Kalidasa Murugavel, K. Srithar, "Performance study on basin type double slope solar still with different wick materials and minimum mass of water", Centre for Energy Studies, National Engineering College, K. R. Nagar, Renewable Energy Vol. 36, pp.616-620.

[14] Pınar İlker Ayav & Gürbüz Atagündüz, 2007, "Theoretical and experimental investigations on solar distillation of IZTECH campus área seawater, Desalination", Vol. 208, pp.169–180.

[15] El-Sebaii AA, Aboul-EneinS, El BialyE. Single basin solar still with baffle suspended absorber. Energy Conversion and Management, Vol. 41, pp.661–675.