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Performance and comparative study of a passive solar still in a forest area between summer and winter conditions in south India

V. Ramesh Srenyvasan[1]

Assistant Professor,
Department of Mechanical Engineering
K L University, Vijayawada,
Andhra Pradesh, India

R.Ajay[2]**, V.Ganesh karthikeyan**[3] **, K.Praveen kumar**[4]

Student: M.E.CAD/CAM[2,4]
Kumaraguru College of Technology[2,4]*,*
Assistant Professor: Dept of Computer Science Engineering[3]
Adithya Institute of Technology[3]*, Coimbatore, Tamil Nadu, India*

Abstract

In this paper, an attempt has been made to unearth the performance of a passive solar still (Double slope) in winter conditions, and summer conditions and comparative study also done in sathyamangalam. This area is forest area and at the same time it is a mountain area also. The study started from the month of February2013 and went up to June 2013 subsequently it took place between August2012 and January 2013. In this experiment a double slope solar still was used. The area of the still is 0.5 m2. The objective of this paper is to observe the behavioural variation of the still in two different climatic conditions and providing these stills for irrigation. The performance of the still has to be find out for different climatic conditions and using this type of still for irrigation in this particular area. This type of irrigation will be benefited for this area.

Keywords: Solar Still, Distillate Output, Water Level.

INTRODUCTION

Solar desalination is getting more importance for obtaining potable (or) drinking water. The main benefit of this process is that, it does not utilize costly and usual conventional petroleum products, which creates problem. The solar energy is naturally and freely available. It s maintenance cost is very low. In many areas of the world, the desalination of sea water is a common method for producing drinking water, whose importance is currently increasing. Many desalination techniques have been developed during the past decades. Thermally driven distillation plants Such as Multi Stage Flash evaporation (MSF), Multi Effect Distillation (MFD) are playing an important role in desalination stills. The operating temperatures of these thermally operated and conventionally powered processes are in the range of about 70ºCto 120ºC. Single slope solar stills can be used, for water desalination and distillation. They are considered as one of the cheapest and basic solutions for fresh water production in aried areas. Excellent work on the use of renewable energy in various types of desalination systems and a detailed study of the various solar thermal collectors and applications were presented by kalogirou et al.[1-4] Many experiments and theoretical assignments has been conducted, in the single basin solar stills for testing the performance of different critical parameters. So many types of absorbing materials, have been used by akash et.al[5] and Nijmeh et al[6] to study the changes in a solar still, and thus ensured the productivity of water, using a single basin solar still with double slopes. Akash et.al[7] examined the effect of using a single slope solar still with various cover tilt angles for water at35 degrees, 45 degrees and 55 degrees and found the optimum tilt angle for water production is 35degree. Also, the authors have studied the effect of the salinity of water on solar distillation, and came to a conclusion that the distilled water production decreased with salinity. Nafety et al.[8, 9] investigated the important parameters affecting solar still performance using for still design, important parameters considered in the same weather conditions. A general equation is developed, to estimate the daily productivity of a single sloped solar still, Experiments on black rubber (or) black gravel materials within a single sloped solar still as a storage medium to improve the still productivity. Khalifa et al.[10] conducted an experimental study on new designs of basin type solar stills, and checked the effect of some modifications on the productivity and efficiency. These modifications included pre heating of feed water by means of a solar heater and utilizing external and internal condensers for vapour condensation as well as for feed water pre heating.

MATERIALS AND METHODS

Boukar and Harmim[11, 12] have approached the effect of desert climate conditions on the performance of a simple basin, single slope solar still and a similar one coupled with a flat plate solar collector. The performance and effectiveness of the simple still is compared with the existing coupled one. They have highlighted that the coupled still is more efficient and productive than the simple one. An experimental study has been conducted by Karaghouli [13]and Naser[14] between single basin and double decker having the same basin area. The authors have come to a conclusion. Those are i) adding 2.5 cm of insulation material, to the solar still sides causes noticeable, increase in yield, and ii) the daily average still production for the double basin still is around 40% higher than the production of the single basin still. Aboul- Enein et al.[15] have produced a simple transient mathematical model for different parts of the still. The authors also found the thermal and overall performance of the both experimentally and theoretically and the influence of cover slope on the daily productivity of the still. Single basin still useful for an analytical solution by applying energy balance equations for this transient mathematical model was used by Sebaii et al[16-

[18], for vertical solar stills to conduct parametric investigation. He found that the daily yield of the still increases directly with the still length, width and wind speed up to certain values. Furthermore, the effect of wind speed on the daily yield of different configurations of single slope solar stills with single, double and triple basin using computer simulation. He has found that daily yield increases with the increase of wind speed up to a critical velocity beyond which the increase in production becomes unimportant. Hamdan et al[19] conducted an experimental and theoretical work to find the effectiveness of single, double and triple basins solar still. Jubran et al.[20] have developed a mathematical model to find out the yield and thermal characteristics of a multi stage solar still basin with an expansion nozzle and heat recovery in each stage of the single basin still. Hinai et al.[21, 22] have attained the use of mathematical model to estimate the yield of a simple solar still under different climatic and weather conditions and design conditions, and operational parameters in Oman. In addition, two mathematical models developed to compare the yield of single effect and double effect solar stills under different climatic and weather conditions, design conditions, and operational parameters. Sebaii et al[23] is the giving importance to the thermal performance Mathioulakis et al.[24] submitted a simplified theoretical method for the evaluation of the performance of a typical solar still and the prediction (or) performance of long term water production work. In addition Voropoulis et al.[25] have conducted an evaluation for this simple method in three steps, the first being experimental find out of the coefficients and successive prediction of the output, the second being calculation of coefficient values through analytical relations and correlation From the above studies, it is possible to develop different types of solar stills to improve the irrigation in this particular area. Before going different types of stills my approach is to study the behavioural variation of double slope solar still in considering and without considering the heat capacities under different climatic conditions to provide irrigation throughout the year. The performance of simple double slope solar still for this particular location is using a way of conversion is very much useful for irrigation. The work is to develop a double slope solar still for winter and summer conditions and using so many stills like that for irrigation purpose for this area. Figure 1 shows the solar still taken for experiment in climatic conditions of sathyamangalam, Tamilnadu, India. The solar still consists of 0.5m^2 area Solar and condensing cover (or) glass cover with an inclination of 35 degrees, fabricated to accommodate water from 20 mm and 30 mm to facilitate the experiment. The bottom surface of the still was painted black paint to receive maximum solar radiation as well as increase absorptivity. It is understood that output of solar still becomes maximum for least water depth in basin. Bottom part of solar still must be insulated to prevent heat transfer losses. To arrest the leakage between top cover and solar still, a rubber gasket is provided. The output from the still is collected through a channel fixed at the length side of the basin and a plastic pipe is provided to drain distillate water to an external measuring jar.

Mathematical modelling for conventional still without considering heat capacities

Mathematical equations that describe the performance of each component of the system for the conventional still are presented in this section. The method of solving these sets of equations to predict the system performance is presented. The computer program has been developed. In the conventional still, main system components are basin surface, saline water, and glass cover. Mathematical model is developed by considering each component separately and energy balance equation is written for each component. Thermal circuit for one side of the double slope solar still is given. The primary requirement of a solar still is to utilize the heat from solar radiation to evaporate the saline water and dissipate the heat from the condensing vapour. Energy balance equations has to be considered for the various components of the conventional still is considered as,

F or glass cover:

{Rate of energy absorbed by glass cover out of solar radiation strikes on it} + {Rate of energy received from water surface by evaporation, convection and radiation} = Rate of energy lost to atm by convection and radiation

$$I(t)A_{gl} + U_{ow\,gl}\left(T_w - T_{gl}\right) = \left(h_{c\,gl\text{-}a} + h_{r\,gl\text{-}a}\right)\left(T_{gl} - T_a\right) \quad \text{Eq1}$$

{Rate of energy absorbed by the water out of solar radiation, convection strikes on water} + {Rate of heat energy absorbed by water from basin by Convection} = {Rate of energy stored in water due To its specific heat} + {Rate of heat loss from water to glass cover by radiation and evaporation}

$$I(t)A_w + h_{c\,b\text{-}w}\left(T_b - T_w\right) = M_w C_{P\,w}\frac{dT_w}{dt} + U_{o\,w\text{-}gl}\left(T_w - T_{gl}\right) \quad \text{Eq2}$$

{Rate of energy absorbed by basin out of solar radiation strikes on it} + {Rate of heat from basin to water by convection} = {Rate of heat lost from basin to atmosphere through bottom and sides of the still by conduction, convection.

$$I(t)A_b = h_{c\,b\text{-}w}\left(T_b - T_w\right) + U_{o\,b\text{-}a}\left(T_b - T_a\right) \;\ldots\ldots\ldots \text{Eqn 3}$$

$$T_{bi+1} = \frac{1}{h_{cb-w} + U_{ob-a}}\left[I(t)A_b + h_{cb-w}T_{wi} + U_{ob-a\,a}\right] \quad \text{Eqn 4}$$

The set of equations or mathematical model for the convectional still without considering the heat capacity of the basin liner and glass cover are considered. For the saline water, its thermal mass depends on the depth of the saline water. So the temperature of the saline water is the parameter which influences the still hourly yield. The input parameters include climatic data and operational parameters.

By using thermo physical parameters, equations, are simplified as given below

$$T_{gl\ i+1} = 1.041\times10^{-3} I(t) + 0.874 T_{wi} + 4.389 \quad \text{...... Eq. 5}$$

$$T_{w\ i+1} = 1.003\times10^{-4} I(t) + 0.745 T_{b\ i} + 0.084 T_{gl\ i} + 0.162 T_{w\ i} \quad \text{....... Eq.6}$$

$$T_{b\ i+1} = 2.143\times10^{-3} I(t) + 0.997 T_{w\ i} + 0.053 \quad \text{.........Eq.7}$$

A computer programme has been developed for the solution of the above said linear equations (5) and (6) and linear equation (7). A time step of 60 seconds is used in the simulation. Numerical calculations are initiated assuming that temperatures of different components of the still are to be equal to their initial temperature at t = 0 as Tw_I, $T_{gl\ I}$ and $T_{b\ i}$. Iterations are made for the time step of 60 seconds and for the input of solar intensity which is assumed to be constant for that one hour, temperatures of water, basin and glass cover after one hour for are found out. Then for the variation of input (solar intensity) for the next one hour, variations of temperatures of the different components are found out.

After knowing the hourly variations of T_b, T_w and Tg hourly yield per unit area can be evaluated as given below:

$$m = \frac{h_{eva\ w\text{-}gl}\left(T_w - T_{gl}\right)\times3600}{h_{fg}} \frac{kg}{m^2 hr} \quad \text{....Eq.8}$$

$H_{f\ g}$ is the latent heat of evaporation, (J/ Kg) can be taken from the steam table for the hourly average temperatures of water. The procedure is repeated with the new values of T_g, T_w and $T_{g\ 1}$ for additional time intervals. System productivity and efficiency of the system can be calculated using the relationship as given below:

$$\text{Efficiency} = \eta = \frac{h_{fg} P_d}{I_{ave}} \quad \text{..........Eq.9}$$

h_{fg} - Latent heat of evaporation of water = 2366 x 10^3 J/Kg for the average saline water temperature of 57ºC. It is energy required to evaporate 1 Kg of water; P_d – daily yield in kg / m^2 day and I_{ave} – average solar intensity = 560 W/m^2 day.

Mathematical modelling for the conventional still with considering heat capacitiess

All the materials have their own specific heat and according to their specific that materials hold some amount of heat energy within it. So the heat transfer between the system components of a solar still and thermal losses from those components will vary but depending on their thermal properties like heat capacity, absorptance and thermal conductivity. Due to this, the temperature variation of the different components of a solar still is not only the function of solar intensity but also the function of their thermal properties. So it is necessary to consider the heat capacity of all the components of a conventional still. In previous section, mathematical modelling was developed by assuming the heat capacities of the basin and glass cover that are negligible. In this section, mathematical model has been developed by considering the heat capacities of the basin and glass cover and performance of the still is compared. Figure 3 shows the thermal circuit diagram considering the heat capacity of basin and glass cover.

In the previous section, heat capacity of the water was considered in mathematical modelling. Hence using equation, variation in the water temperature according to solar intensity can be taken as equation.

$$T_{w\ i+1} = 1.703\times10^{-5} I(t) + 0.364 T_{b\ i} + 0.014 T_{gl\ i} + 0.621 T_{w\ i} \quad \text{..... Eq. 10}$$

The energy balance for the glass cover and basin with considering its heat capacity are:

For glass cover:

{Rate of energy absorbed by the glass cover out of solar radiation strikes on it} + {Rate of energy received from the water by convection, radiation and evaporation} = {Rate of energy stored in glass cover due to its heat capacity} + {Rate of heat lost from the glass cover to atmosphere.

$$I(t) A_{gl} + U_{ow\ gl}\left(T_w - T_{gl}\right) = M_{gl} C_{P\ gl} \frac{dT_{gl}}{dt} + \left(h_{c\ gl\text{-}a} + h_{r\ gl\text{-}a}\right)\left(T_{gl} - T_a\right) \quad \text{......... Eq. 11}$$

Hence, solution for the equation is,

$$T_{gl\ i+1} = \frac{C_2}{a_2}\left(1 - e^{-a_2 t}\right) + T_{gl\ i} e^{-a_2 t} \quad \text{...Eq12.}$$

For the basin liner:

{Rate of energy absorbed by the basin liner out of solar radiation strikes on it} + {Rate of energy stored in the basin due to its heat capacity} = {Rate of heat from basin by convection mode} + {Rate of heat from basin to atmosphere through bottom of the still}

For the differential equation solution is

$$T_{b\ i+1} = \frac{C_3}{a_3}\left(1 - e^{-a_3 t}\right) + T_{b\ i} e^{-a_3 t} \quad \text{.......Eq.13}$$

Using the thermo physical properties of glass cover and basin surface equations are simplified as

$$T_{g\ i+1} = 5.25\times10^{-4} I(t) + 0.43 T_{w\ i} + 0.496 T_{gl\ i} + 2.289 \quad \text{......... Eq14}$$

$$T_{b\ i+1} = 7.43\times10^{-4} I(t) + 0.997 T_{w\ i} + 4.7\times10^{-8} T_{bi} + 0.021 \quad \text{..........Eq 15}$$

$$T_{w\,i+1} = 1.703\times10^{-5} I(t) + 0.364 T_{b\,i} + 0.014 T_{gl\,i} + 0.621 T_{w\,i} \quad \text{..........Eq. 16}$$

Similar to previous section, C Program was developed for solving the above said non linear equations. With respect to hourly varying solar intensity, hourly variations of system components temperatures T_b, T_w, and T_{gl} are found out. From these temperatures, hourly yield per unit area and still efficiency can be calculated as per the equations. Theoretical hourly yield for different period from morning 9.am to evening 7.00p.m is calculated for both the cases which are considered with and without the heat capacity of the glass cover and basin of the conventional still. For validating the mathematical model and finding the effect of heat capacities of the glass cover and basin theoretical hourly yields are compared with experimental values. Hence, the effect of heat capacity of the basin and glass cover on the performance of the still can be found out.

RESULTS AND DISCUSSION

Parameters affecting the performance of a still both in winter and summer conditions depend on ambient conditions, operating conditions and design conditions. Ambient conditions are ambient temperature, solar intensity, and wind velocity. Operating conditions are depth of water, orientation of the still and inlet temperature of water.

Following parameters were selected for the selection of the material of the solar still and cover, slope of the cover, distance between the water and the cover and number of covers used. Very important point from the work is ambient conditions are not under control, so those optimum designs must satisfy the requirements of the operating conditions and design conditions. The main parameters are wind velocity, depth of saline water, ambient temperature, distance between the water and glass cover, number of glass covers, degree of salinity of water, solar intensity. However, the experiments were conducted during winter and summer conditions in consideration with the following parameters. They were temperature variation of saline water, glass covers temperature and air- vapour mixture with time for different quantity (depth) of saline water in a conventional still. From these consequences, the interpretation of temperature variations for different still components gives the effect of depth of saline water on the performance of the conventional still. Hence, the relationship between the quantity (depth) of saline water and hourly yield were investigated.

Tests revealed wide variation in temperature of water which could be the water quantity in the still and the ambient temperature. In morning times, if water level is least the yield is good. There is a good proportionality between thermal mass and solar intensity. At high temperature at around 12 noon thermal mass can be increased so that better yield can be achieved. After 6pm the specific heat of water is used to heat the water. At that time also the yield is considerable. So the final point is the 30mm water depth is highly suitable for better water yield for this geographical location. By using number of stills like this with so many modifications the irrigation for this particular area is possible. Generally the performance of the still is slightly affected in winter conditions because of low solar insolation. Apart from that in both summer and winter conditions in summer the yield is increasing and in winter condition the yield is decreasing due to less solar radiation in winter condition in all depths. Especially in winter condition due to less thermal mass at 20mm depth the yield is satisfactory. While considering 30mm depth, the yield is less due to high thermal mass in winter condition but during summer the yield is found to be stable.

When there is 40mm depth, the yield is high due to its thermal mass the time taken to produce. In winter condition the yield is very less.

So from the above the conclusion is 30mm depth of water is highly suitable for irrigation and the still dimension must be $0.5m^2$.

The above said result is applicable for both considering with and without considering the heat capacities.

Variation of still yield in different depths:

In general, the yield is in escalating trend. Due to summer the yield is increasing precipitously, up to 12pm and since this is a forest area it is getting stagnated for I hour, then after 2pm again it is increasing steeply upto 4pm. Up to 4pm it is the phenomenon due to high solar intensity. After 4 pm also the yield is maintained but progressively decreasing up to 6pm. especially after 4pm the yield is imminent because of latent heat of water. The main connotation of 20mm depth in summer is the thermal mass is very low. Consequently the yield is very fast.

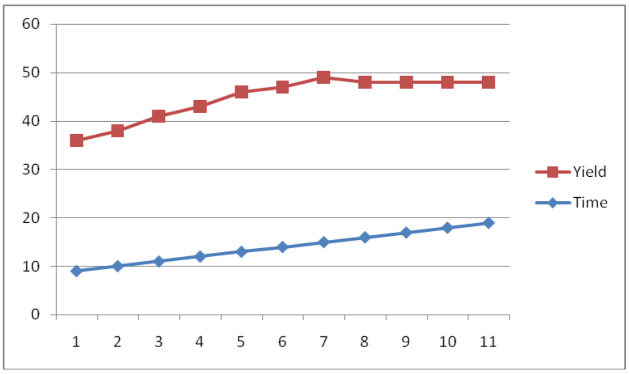

Figure 1. Hourly yield at 20mm water depth (summer)

In winter the climate temperature is stumpy. So, the thermal intensity is also squat. Due to this the yield is also little. Especially, after 5 pm the latent heat of water is not that much so the yield is nought.The main significance is in spite of low thermal mass the yield is poor due to low solar intensity.

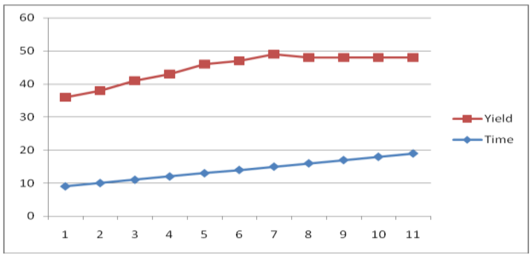

Figure 2. Hourly yield at 20mm depth: (winter)

In this case also the yield is good. Upto 10am the yield is very low. This is because of high thermal mass compare to 20mm depth. After 10 am the yield is rapidly increasing due to high solar intensity. Reminiscent of 20mm depth after 5pm the yield is there due to latent heat of water.

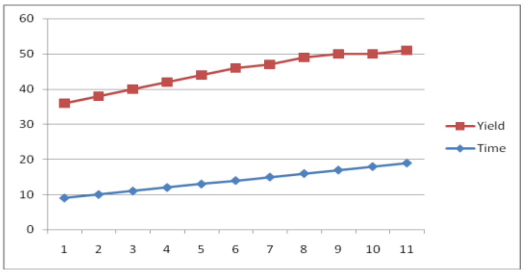

Figure 3. Hourly yield at 30mm (summer)

In winter due to low solar intensity the yield is getting spread out. That is due to fluctuation in the solar intensity. After 2pm, the yield is increasing because some thermal energy is available. Comparatively the yield is lower while comparing with summer conditions

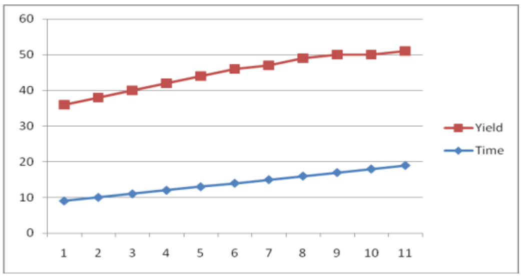

Figure 4. Hourly yield at 30mm (winter):

Like other cases of summer the yield is good. The time taken for the yield is more, due to high thermal mass.

Hourly yield at 40mm (winter): The time taken for yield is more, due to less solar intensity and high thermal mass. The yield is less. Especially due to low latent heat of water the yield becomes very minimum after 5pm.

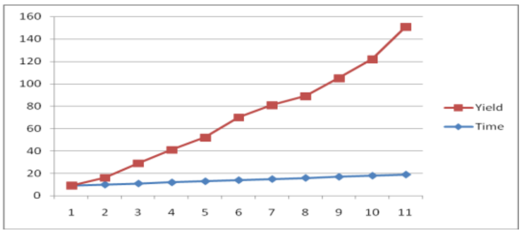

Figure 5. Hourly yield at 40mm (summer):

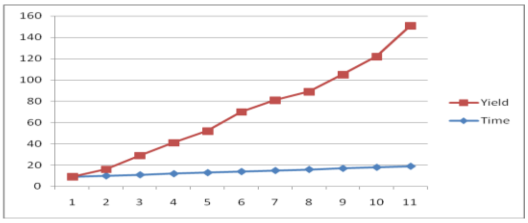

Figure 6. Hourly yield at 40mm (winter)

Water temperature variations:

The conclusion is water has high specific heat. It is taking much time to become hot. Even in summer it is gradually increasing from 8am to 12pm. After, it is increasing fastly and upto 6pm it is maintained at constant temperature level. The temperature increases gradually but not exceeding definite level.

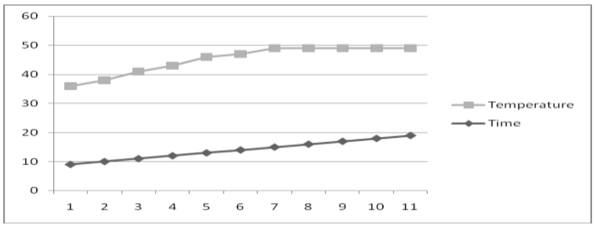

Figure 7. Water temperature variation at 20mm depth

In winter due to low solar intensity the yield is getting staggered. That is due to fluctuation in the solar intensity. After 2pm, the yield is increasing because some thermal energy is available. Comparatively the yield is lower while comparing with summer conditions. After 6pm the decrease in temperature is very fast.

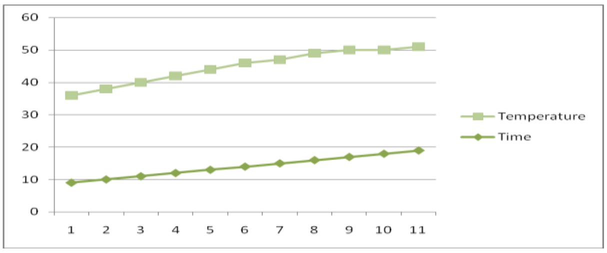

Figure 9. water temperature variation at 30mm depth

The water temperature increases gradually upto certain limit that is upto 2 pm and then it is maintained in the same level after 6pm also. The decrease in temperature is very slow. There is some yield in this case also.

The water temperature increases very slowly due to the solar intensity. The overall temperature also low while compare with summer conditions. After 5pm the temperature drop of water is very fast and attainining very minimum value.

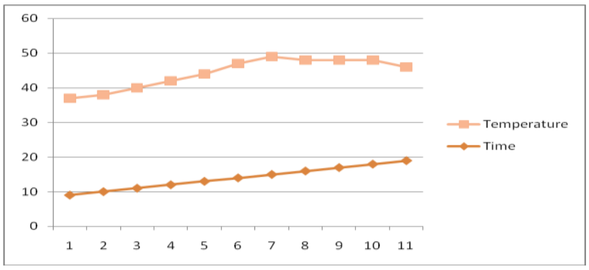

Figure 11. Water temperature variation at 40mm depth

Due to summer around 9am the temperature is around 28 c. It is steadily increasing to 58 C due to green house effect inside the still. After, 6pm the temperature drop is not too much due to heavy thermal loss. The temperature augment of water is very low. So, the yield is also very not as much of summer conditions.

CONCLUSION

The yield depends on mainly on solar intensity. Apart from that, the depth of water is also playing a imperative role. By using 40 mm depth is highly suitable in summer conditions. In this circumference solar intensity matches with the thermal mass. But in winter condition due to low solar intensity 20mm depth is most preferable. So, the final conclusion is using always 30mm depth of water is highly apposite in both winter and summer conditions. Setting these types of solar stills on land for irrigation can be done in this particular area. Depend on the crop variety the number of stills can be fixed. It is to be decided by still design also. It may be active or passive still. The modifications in still are also playing an important role. In future the different types of stills with modifications can be tried to accommodate different types of corps. In India in this region mostly potato, cabbage, etc are grown up. First the plan is apply this method in this sathyamangalam area and then apply this method to other parts of tamilnadu in India. The selection of still type is also (active or passive) based on the type of corp, then could do with of the corp. Making this method as practice and carry out as a habit for arid area farmers is also somewhat difficult task. But day by day this will be a practice in future**.**

REFERENCES

[1] E. 1A. A. Al-Karaghouli and W. E. Alnaser, Appl. Energy 77, 317 (2004).
2A. A. Al-Karaghouli and W. E. Alnaser, Appl. Energy 78, 347 (2004).

[2] 3S. A. Kalogirou, Prog Energy Combust. Sci. 30, 231 (2004).

[3] 4S. A. Kalogirou, Prog Energy Combust. Sci. 31, 242 (2004).

[4] 5B. A. Akash, M. S. Mohsen, O. Osta, Y. Elayan, Renew. Energy 14, 307 (1998).

[5] 6S. Nijmeh, S. Odeh, B. Akash, Int. comm. Heat mass transfer 32, 505 (2005).

[6] 7B. A Akash, M. S Mohsen, W Nayfeh, Energy convers. Manage. 41, 883890 (2000).

[7] 8A. S. Nafey, M. Abdel Kader, A. Abdelmotalip, A. A. Mabaruk, Energy Convers. Manage. 42, 1401 (2000).

[8] 9A. S. Nafey, M. Abdel Kader, A. Abdelmotalip, A. A. Mabaruk, Energy Convers. Manage. 42, 1401 (2001).

[9] 10A. J. Khalifa, A. S. AI- Jubouri, M. K. Abed, Energy Convers. Manage. 40, 1835 (1999).

[10] 11M. Baskar and A. Harmim Desalinarion 137, 15 (2001).

[11] 12M. Baskar and A. Harmim Desalinarion 168, 21 (2001).

[12] 13A. A. Al- Karaghouli and W. E. Alnaser, Appl. Energy 77, 317 (2004).

[13] 14A. A. Al- Karaghouli and W. E. Alnaser, Appl. Energy 78, 347 (2004).

[14] 15S. Abdul Encin, A. A. El- Sebail, E. El-Bialy Renew. Energy 14, 299 (1998).

[15] 16A. A. El- Sebaii, Energy convers Managa. 41, 523 (1998).

[16] 17A. A. El- Sebaii, Energy convers Managa. 41, 523 (2000).

[17] 18A. A. El- Sebaii, Energy convers Managa. 45, 1187 (2000).

[18] 19M. A. Hamdan, A. M. Musa, B. A. Jubran, Convers. Manage. 40, 495 (1999).

[19] 20B. A. Jubran, M. I. Ahmed, A. F. Ismail, Y. A. Abakar, Energy convers. Manage. 41,1107 (2000).

[20] 21H. Al- Hinai, M. S. Al- Nassri, B. A. Jubean Desalination 150, 75 (2002).

[21] 22H. Al- Hinai, M. S. Al- Nassri, B. A. Jubean Desalination 150, 75 (2002).

[22] 23A. A. El- Sebaii, Convers. Manage. 45, 1187 (2004).

[23] 24E. Mathioulakis, K. Voropoulos, V, Desalination 122, 85 (1999).

[24] 25K.Vorpoulos, E. Mathioulakis, V. Beleslotis, Desalination 153, 87 (2003).

[25] 25K.Vorpoulos, E. Mathioulakis, V. Beleslotis, Desalination 153, 87 (2003).