Optimization the Performance of Single Basin Solar Still with Corrugated Wick Surface at High Places

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Abstract - ***In this work two single slope solar stills have been designed and constructed from Materials available in the local market. One is conventional and the other with a wick surface. This paper deals with the effect of corrugated work by wick surface on the performance of the still. The two stills were tested for three days, where the effects of solar radiation intensity and ambient temperature have been investigated. Saline water temperature in the still with jute cloth is raised to about 82 °C which appreciably reduces the heat losses from the still compared with the conventional still water temperature of about 76 °C. Still daily yield with the jute cloth is 4.20 kg/m2 per day while the conventional solar still is 3.30 Kg/m2 per day. Maximum efficiency of the still with the wick surface is found as 42% while the efficiency of the conventional solar still is 33%.***

KEY WORDS: *Conventional solar still, Single slope still, Still productivity, Still performance, Wick surface.*

1. INTRODUCTION

Saudi Arabia is one of the driest regions in the world, with no perennial rivers. Water is obtained from four distinct sources: non-renewable groundwater from the deep fossil aquifers, desalinated water, surface water, and renewable groundwater from shallow alluvial aquifers. Since the usable volume of the aquifers is not known, it is not clear how long groundwater mining can be sustained [1]. Solar distillers can be used to effectively remove many impurities ranging from salts to microorganisms and are even used to make drinking water from seawater. Solar stills have been well received by many users, both rural and urban, from around the globe. Many researchers have studied the performance of different designs of solar still and succeeded.

Many designs and modifications of the solar still have been proposed for improving its efficiency and productivity. Al-Hinai *et al*. [2] have developed a mathematical model for the productivity of a simple solar still for different climatic, design and operational parameters. The effect of water depth on heat and mass transfer of a passive type solar still has studied by Tiwari [3], who observed that the basin water depth varies inversely with the productivity of the solar still. The effect of a vertical flat plate reflector on the distillate productivity of a basin type solar still and a tilted-wick solar still has been evaluated by Tanaka and Nakatake [4-6]. They found that the distillate productivity of both stills can be remarkably increased during the spring and autumn seasons by using the vertical flat plate reflector, whereas the effect of the external reflector during the summer and winter seasons would be less than during spring and autumn.
Velmurugan *et al* [7] increased the productivity of a solar still by integrating fins at the basin plate of the solar still. A basin type still with internal and external reflectors has been investigated and tested by Khalifa and Ibrahim [8] over the 7 months from June to December. The external reflector was inclined forward during the experimental period. They reported that the increase in distillate productivity can be achieved by internal and external reflectors in outdoor experiments.
Kalidasa Murugavel *et al* [9] designed and fabricated a single basin double slope solar still. This still has been tested under laboratory conditions by using light cotton cloth, light jute cloth, sponge sheet of 2mm thickness and porous materials like washed natural rock. A characteristic equation of a double slope passive solar still by using experimental observations for climatic condition of New Delhi, India has been proposed by Dev *et al* [10]. They found that the non-linear characteristic curves are more accurate to analyze the performance and normal testing of the proposed still. Tanaka [11] theoretically analyzed the solar radiation absorbed on an evaporating wick of a tilted-wick solar still with a flat plate reflector extending from the back wall of the still and inclined backward, and predicted the distillate productivity of the still on a summer solstice day at 30oN latitude. In this work he found that the benefit of a vertical flat plate reflector is negligible, while a backwardly inclined reflector can increase the distillate productivity of the still on a summer solstice day. In the work of Sengar *et al* [12] Different solar stills were developed and evaluated for comparison with other solar stills. Wick type, W shape and

L shape of solar stills were designed on the basis of solar declination angle, slope of collector and available insolation. The newly developed solar stills were evaluated for load test and compared with the output of single and double slope solar still available in market.

2. MATHEMATICAL MODELLING

Governing equations for the solar still can be summarized by the following equations:

- Heat transfer by natural convection from the water surface to the inside surface of the glass cover:

$$q_c = 0.8831\left[(T_w - T_g) + \left(\frac{P_w - P_{wg}}{0.265 - P_w}\right)(T_w + 273)\right]^{1/3}(T_w - T_g) \tag{1}$$

- Heat transfer by evaporation and condensation from the water surface at the base of still to the inside surface of the glass cover:

$$q_e = 0.0061\left[(T_w - T_g) + \left(\frac{P_w - P_{wg}}{0.265 - P_w}\right)(T_w + 273)\right]^{1/3}(P_w - P_{wg})L_w \tag{2}$$

Where:

T_g, T_w mean temperature for inside glass cover and water surface respectively (^{o}C)

P_g, P_w pressure of water vapor at T_g, T_w respectively (MPa)

The values of P_g, P_w calculate by the equations (2) and (3):

$$\log P_w = -3.2154 + 3.13619\times10^{-2}T_w - 1.22512\times10^{-4}T_w^2 + 3.6384\times10^{-7}T_w^3 - 5.67607\times10^{-10}T_w^4 \tag{3}$$

$$\log P_{wg} = -3.2154 + 3.13619\times10^{-2}T_g - 1.22512\times10^{-4}T_g^2 + 3.6384\times10^{-7}T_g^3 - 5.67607\times10^{-10}T_g^4 \tag{4}$$

L_w latent heat of water evaporation at T_w, (J/kg)

It calculates by the following equation:

$$L_W = 2501.67\times10^3 - 2389\times T_W \tag{5}$$

- Heat transfer by radiation from the water surface to the inside surface of the glass cover:

$$q_r = f_{wg}\sigma[(T_w + 273)^4 - (T_g + 273)^4] \tag{6}$$

Where:

f_{wg} form factor of diffuse radiation between the water surface and inner lower surface of glass cover, this factor is done by the following relation:

$$f_{wg} = \frac{1}{\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1} \tag{7}$$

ε_W and ε_g the emissivity of the water surface and inner lower surface of glass cover respectively.

σ Stefan Boltzmann constant

The instantaneous thermal efficiency of the solar still is done by the ratio between the useful heat for evaporation q_e and the solar radiation intensity on the glass cover:

$$\eta = \frac{q_e}{G_t} \tag{8}$$

The inner efficiency of the still is defined as the ratio between the useful heat for evaporation q_e and the absorbed heat by water:

$$\eta_i = \frac{q_e}{\alpha_w \tau_g G_t} \tag{9}$$

α_W and τ_g are the absorptivity and transmissivity of the glass cover of the still respectively.

3. EPERIMENTAL SET-UP

A schematic diagram and photographic view of a single slope solar still with wick surface and conventional still are shown in the Figures (1, and 2). Schematic view of the still and arrangement of wick surface is shown in Fig -1. The wick surface is supported in corrugated frame. Fig -2 shows a photographic view both units. In the modified unit the lower part of the wick surface is immersed in the saline water to allow water to diffuse through the wick for the propose of increasing the evaporate surfaces. The wick layer has thickness of about 3mm and it's black to absorb solar radiation. While most of the incident solar energy is absorbed in the conventional still by the blackened surface of the basin through. The inside wall (3mm thickness) is black coated as well as the base of the still. An insulation layer of 20 mm thickness used to decrease the heat loss from the still to surrounding. An aluminum frame is installed to support the different still parts. The outside surface of the still is covered with plywood layer.

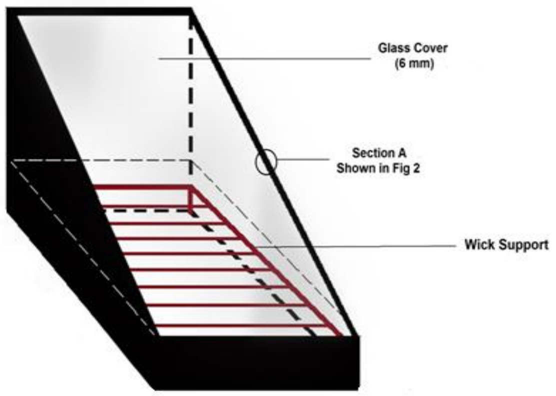

Fig -1: Schematic diagram of the solar still with wick support

The still has an effective basin area of 1.25 m × 0.8 m. The still cover is made of 0.006 m thick, ordinary transparent glass and kept on the frame at inclined position at an angle of 25° with the horizontal. An inclined passage is designed and mounted at the lower end of the still to collect the condensed water (yield) which flows down through the bottom of the glass cover and condensate is being taken outside and collected in a measurement jar. Hole is made at the side of the still frame for feeding the saline water.

The thermocouples wires are inserted through the holes provided at the side of the still and fixed at different points to measure the temperatures of basin, water, air–vapor mixture, inner and outer surfaces of the glass cover and ambient temperature. To keep the whole system in vapor tight, silicon rubber is used as sealant.

Fig -2: Conventional and modified solar still.

The solar radiation intensity is measured using A Kipp Zonen Pyranometer (CMP 6 model). The still is oriented along the east–west direction and inclined glass cover surface faces south to intercept maximum solar radiation.

Fig -3: Multi-channel temperature recorder

The experiments were conducted under the same climatic conditions for the two units. Experiments were conducted continuously for about three days. During experiments, water temperature (T_w), condensing surface (glass cover) temperature (T_{gl}), air–vapour temperature (T_{a-v}), ambient temperature (T_a), hourly still productivity (yield) and solar intensity were recorded for a period of 24 hours (8 am - 8 am). Experiments were conducted in the conventional still for quantities of saline water ranging (14-15 l/m^2).

4. RESULT AND DISCUSSION

In the conventional solar still, experiments were conducted for different days at same quantities of saline water in the basin to get the optimum quantity of fresh water. From the experiment, it was found that the conventional still with 10 kg of saline water gave maximum daily still yield. To evaluate the performance of the corrugated work still with wick surface experiments have been conducted in the same solar still under the different climatic conditions for different days at same quantities of saline water with same wick surface arrangement. Experiments were conducted and various parameters were observed such as temperature of the glass cover, temperature of the wick surface, temperature of the air–vapor mixture and hourly yield. Experimental observations for the corrugated work still with wick surface and with 10 kg of saline water are given in. Chart -1 shows the cumulative still yield in the corrugated work still with wick surface and conventional still for Monday with a maximum value of solar radiation intensity is about 1000 Wm^{-2} at same quantities of saline water. With 10 kg of saline water, the cumulative still yield in the corrugated work still with wick surface is 4120 ml while the conventional still yield is 3030 ml.

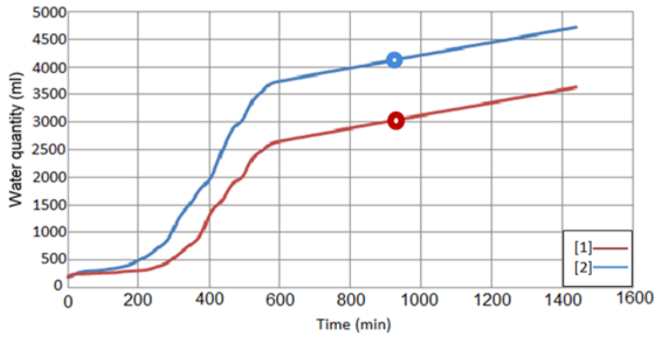

Chart -1: Variation of water quantity with time (Monday, February 13, 2012):
[1] - ***Conventional still*** and **[2] -** ***Modified still***

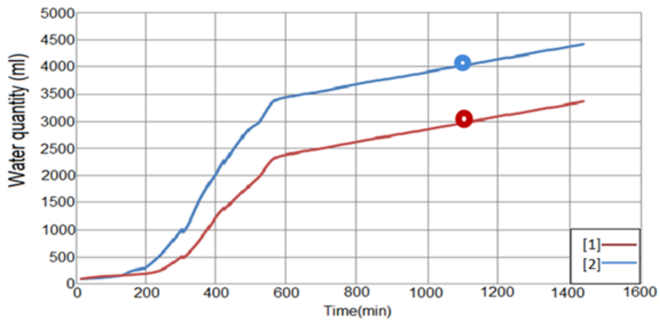

Chart -2: Variation of water quantity with time (Tuesday, February 14, 2012):
[1] - ***Conventional still*** and **[2] -** ***Modified still***

The cumulative still yield in the corrugated work still with wick surface and conventional still for Tuesday at same quantities of saline water was shown in Chart -2. The cumulative still yield in the corrugated work still with wick surface is 4020 ml while the conventional still yield is 3040 ml, where the solar radiation intensity can reach a maximum value of about 920 Wm^{-2}.

Chart -3 shows the cumulative still yield in the corrugated work still with wick surface and conventional still for Wednesday during 24 hours at same quantities of saline water. The cumulative still yield in the corrugated work still with wick surface is 3955 ml while the conventional still yield is 2860 ml, where the maximum value of solar radiation intensity is 900 Wm^{-2}.

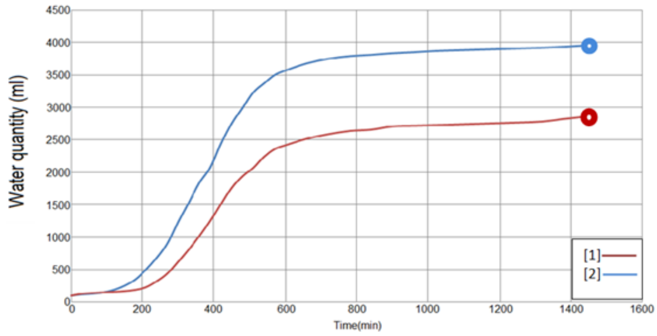

Chart -3: Variation of water quantity with time (Wednesday, February 15, 2012):
[1] - ***Conventional still*** and **[2] -** ***Modified still***

Charts (1,2, and 3) show that there are some differences in the cumulative still yield for different days due to the different climatic and solar radiation incident on the solar stills.
The Transient variation of temperature for day operation on February 13, 2012 is given in Chart -4. This Chart shows that the temperature of the glass for modified still is higher than the temperature of glass for conventional solar still as well as the temperatures inside the still and outside it.

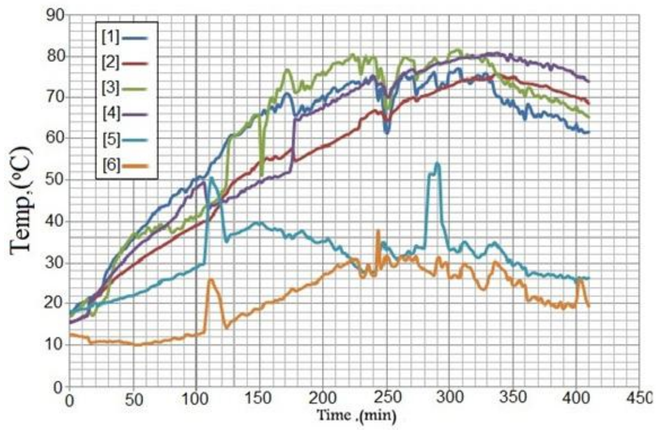

Chart -4: Transient Variation of Temperatures on (Monday, February 13, 2012):
[1]- ***Glass Temperature of conventional solar still.*** **[2]-** ***Vapor Temp. Inside conventional solar still.*** **[3]-** ***Glass Temp. of modified solar still***. **[4]-** ***Vapor Temp. inside modified solar still.*** **[5]-** ***Outside surface Temp. of conventional solar still.*** **[6]-** ***Outside surface Temp. of modified solar still .***

In Chart -5, The Transient variation of temperature for day and night operation on February 15, 2012 is given.

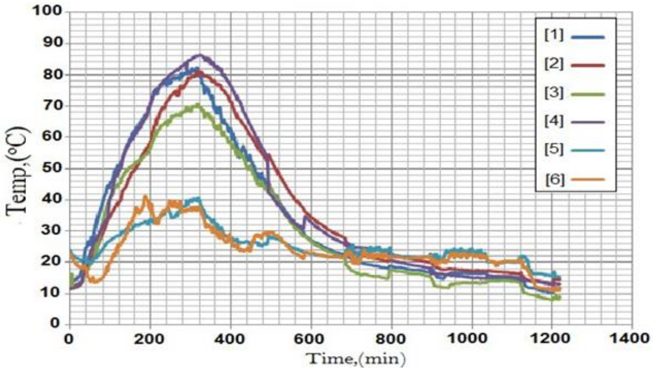

Chart -5: Transient Variation of Temperatures on (Wednesday, February 15, 2012):
[1]- ***Glass Temperature of conventional solar still.*** **[2]-** ***Vapor Temp. Inside conventional solar still.*** **[3]-** ***Glass Temp. of modified solar still.*** **[4]-** ***Vapor Temp. inside modified solar still.*** **[5]-** ***Outside surface Temp. of conventional solar still.*** **[6]-** ***Outside surface Temp. of modified solar still.***

From Chart -5 it is understood the temperature of the glass for modified still is higher than
the temperature of glass for conventional solar still as well as the temperatures inside the project and outside it. The reasons of deferent temperatures between the modified still and conventional one and the temperatures entire each still are the accumulation of latent heat of condensation released from the bottom of the glass cover and due to radiation loss from the water surface.

5. CONCLUSIONS

In this project, wick surface is an easily available material with low cost and attached in a simple way with. This study mainly deals with the effect of corrugated work by wick surface on the performance of the still and to optimize the performance. From the analyses of data collected over the span of three days, the following conclusions can be drawn:

- The system has the advantages of using a low cost, cheap material wick surface to enhance the still yield and its efficiency.
- Still daily yield with the jute cloth is 4.20 kgm^{-2} per day while the conventional solar still is 3.30 Kg m^{-2} per day.
- Maximum efficiency of the still with the wick surface is found as 42% and the internal efficiency for this still is 0.589 for α_w = 0.8 and τ_g = 0.89 while the efficiency of the conventional solar still is 33% and its internal efficiency is 0.46.

AKNOLWDGMENT

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BIOGRAPHY

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