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Experimental validation and enhancement of some solar still performance correlations

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ABSTRACT

Performance correlations for a basin-type solar still were developed from research data reported in the literature. Among these were correlations that show the effect on productivity of brine depth, cover tilt angle and dye. The aim of this paper is to validate and enhance these correlations experimentally. The root mean square (R^2) value is used as the criterion to measure such enhancement. The R^2 value is increased from 0.832 to 0.865 for the brine depth correlation, from 0.734 to 0.793 for the tilt angle correlation and from 0.833 to 0.904 for the effect of dye correlation.

Keywords: Desalination; Correlations; Performance; Solar still

1. Introduction

In a previous paper [1], performance correlations for a basin-type solar still were developed from research data reported in the literature. These correlations show the effect of some important parameters on the productivity of solar still. Among these were brine depth, cover tilt angle and the effect of adding dye to the brine water. This paper is devoted to the validation and enhancement of the correlations of these three parameters using the experimental results from the present investigation. For this purpose, solar stills were constructed and tested with different brine depths, different cover tilt angles and using brine with and without dye. The root mean square (R^2) value of the correlations of these parameters is used as the criterion to measure the degree of enhancement to the correlations.

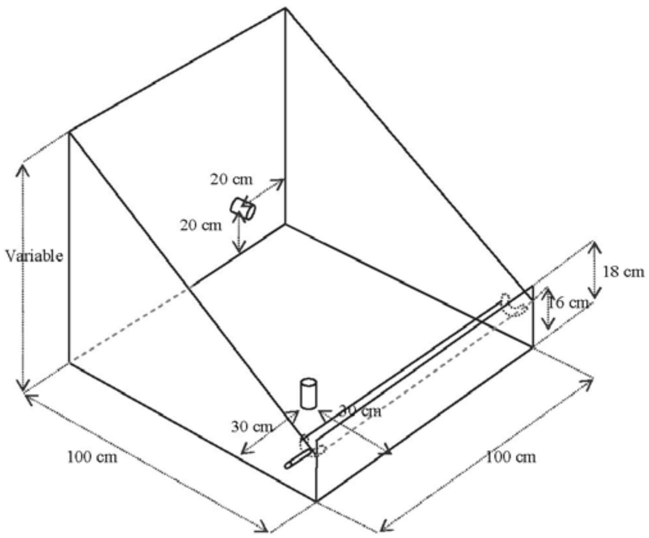

Fig. 1. Schematic diagram of the experimental still.

2. Experimental stills

Single-sloped basin-type solar stills (Fig. 1) were constructed from 0.8-mm-thick galvanized steel and 4-mm-thick glass cover. The basin of the still is painted black to maximize the absorption of solar radiation. The tests were carried out on clear days in Baghdad, Iraq (latitude angle 33.3°N) with each test repeated twice or

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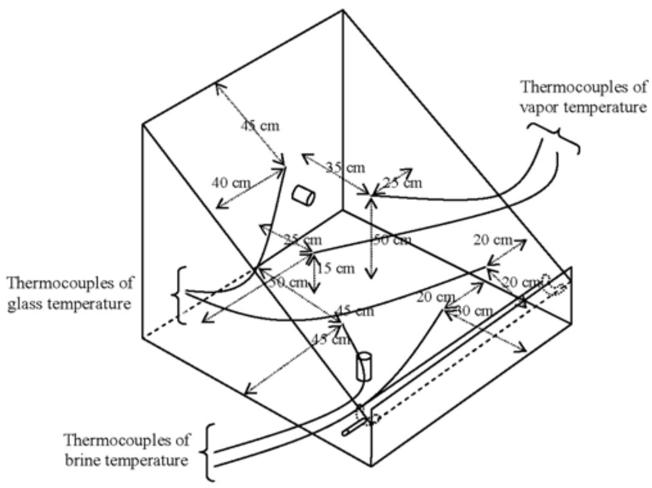

Fig. 2. Thermocouple locations in the still.

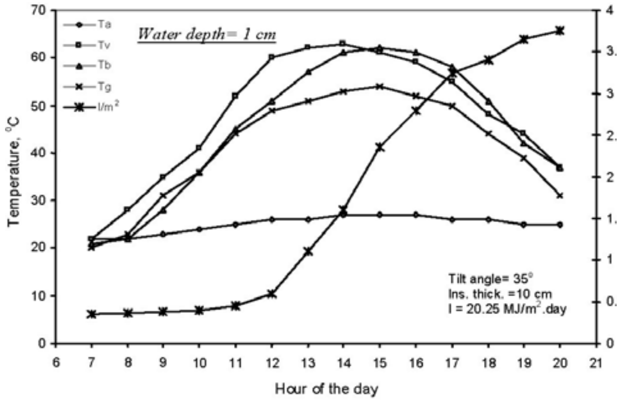

Fig. 3. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with brine depth of 1 cm.

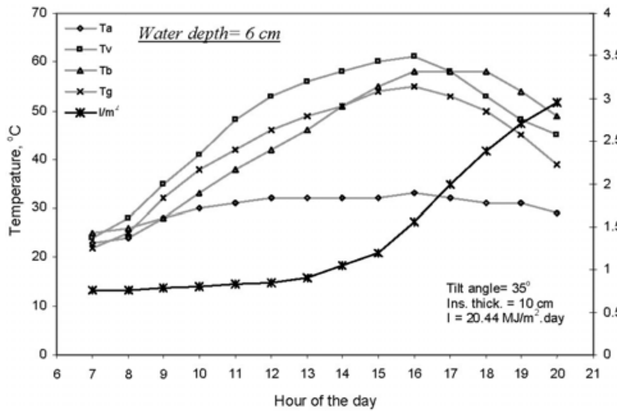

Fig. 4. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with brine depth of 6 cm.

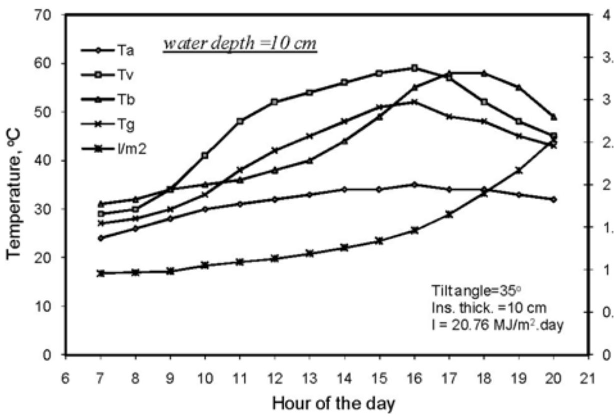

Fig. 5. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with brine depth of 10 cm

three times if needed to verify the results obtained. A batch feeding of water with salinity of 1100 to 1400 ppm is used in these tests. Hourly measurements of distilled water are conducted; the nocturnal production for each test is measured at 7:00 am of the following morning. Copper-Constantan thermocouples, covered with reflective shields where necessary, are used to measure the glass, brine and vapor temperatures at the locations shown in Fig. 2.

3. Results

3.1. Brine depth

The effect of brine depth on productivity is investigated in a still with a 35° cover tilt angle, 10 cm insulation thickness and without dye for water depths of 1, 4, 6, 8 and 10 cm. Figs. 3–5 show the results of three of these tests.

It can be seen that the still with the lower brine depth shows a higher day-time output and operates with larger water-glass temperature difference. The still with the higher brine depth, however, has a larger nocturnal production (the initial value of the production line in these figures) due to the continuous production during off-sunshine hours. Fig. 6 shows the exponential curve fitted to the data from all tests, and Table 1 gives the correlation. It is evident that the productivity decreases with the increase of water depth.

As given by the previous survey [1], Garg and Mann [2], Tiwari and Madhuri [3], Kamal [4], Akash et al. [5], Al-Hayek and Badran [6] studied the effect of brine depth on the productivity. Their data, the experimental results from the present study and the correlation obtained from both are shown in Fig. 7. Table 1 shows the correlations reported using their results [1], the one created from the present experimental results and the modified correlation from both.

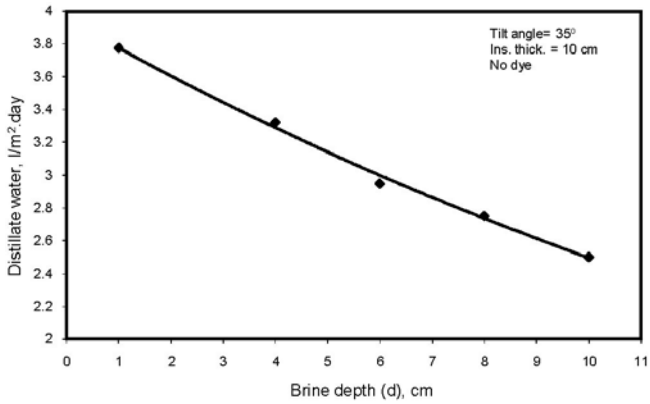

Fig. 6. Variation of still productivity with brine depth.

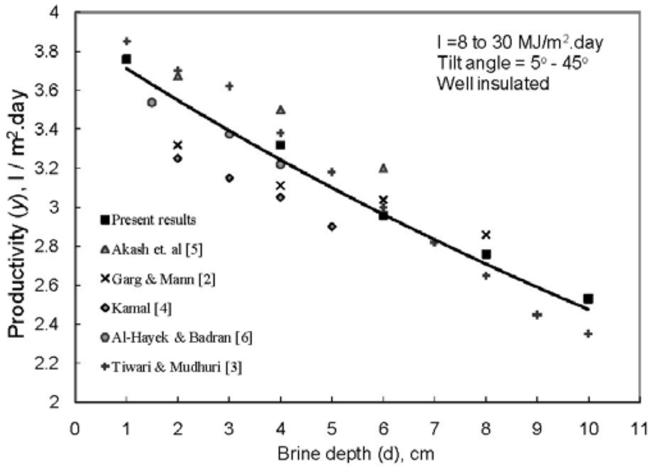

Fig. 7. Variation of still productivity with brine depth.

Table 1
Brine depth correlations

Source	Correlation	R^2
Literature [1]	$y = 3.884\ e^{-0.0458\,(d)}$	0.832
Present results	$y = 3.929\ e^{-0.0444\,(d)}$	0.996
Modified	$y = 3.881\ e^{-0.0450\,(d)}$	0.865

y is the productivity (l/m^{2}d) and (d) is the brine depth (cm).

3.2. Cover tilt angle

The effect of tilt angle on productivity is investigated in a still with 4 cm brine depth, 10 cm insulation thickness and without dye for tilt angles of 45°, 35°, 25°, 15° and 5°. Figs. 8–10 show the results of three of these tests.

Fig. 11 shows the second-order polynomial curve fitted to the data of these tests and Table 2 gives the correlation. It is evident that the productivity has a maximum value at some angle around 30°.

As previously reported [1], Baibutaev and Achilov [7,8], Al-Jobouri and Khalifa [9], Kamal [4] and Akash et al. [5] experimentally studied the effect of tilt angle on the productivity. Fig. 12 shows the second-order polynomial curve fitted to all data including those from the present investigation. Table 2 shows the correlation reported using their data [1], the one created from the present

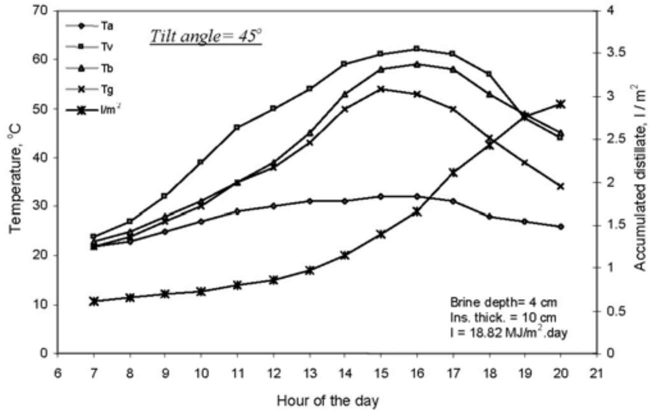

Fig. 8. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with 45° tilt angle.

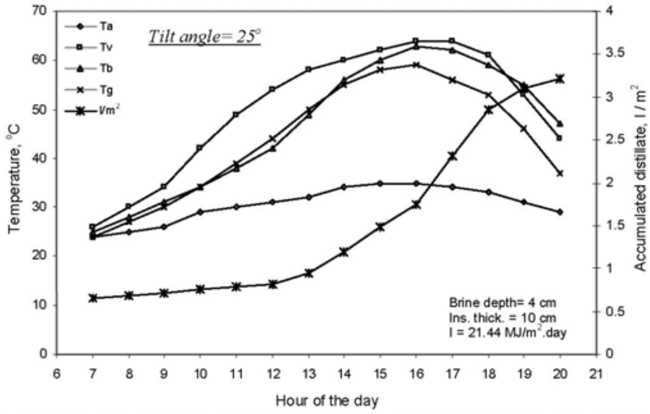

Fig. 9. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with 25° tilt angle.

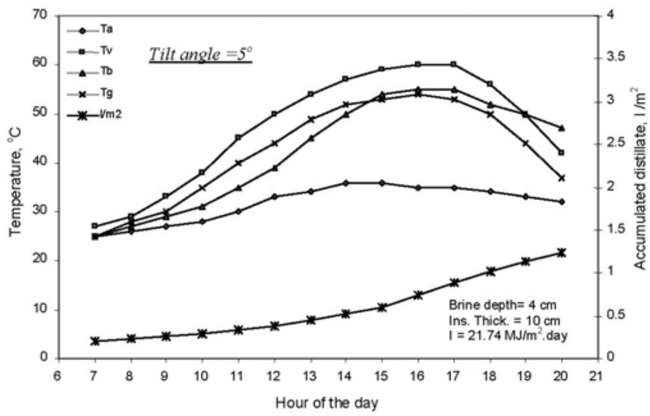

Fig. 10. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with 5° tilt angle.

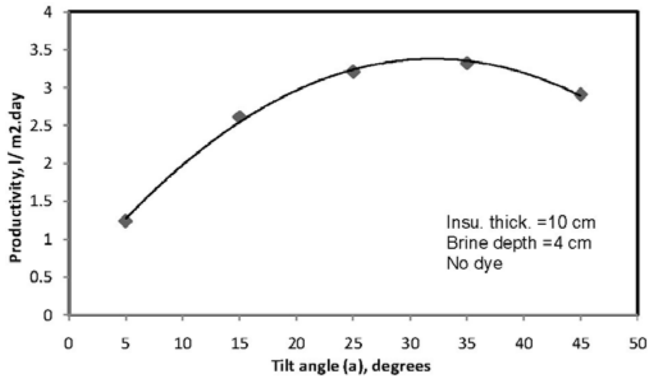

Fig. 11. Variation of still productivity with tilt angle.

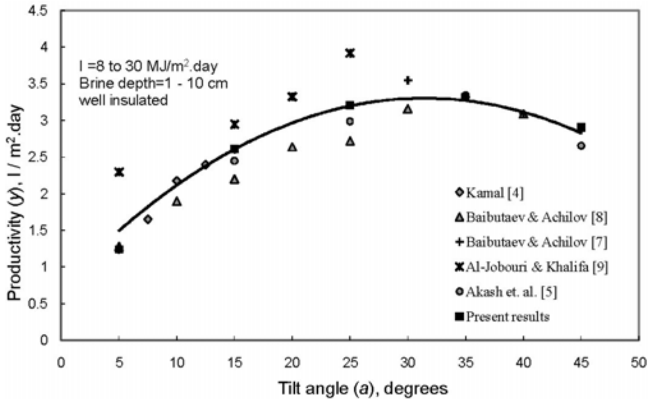

Fig. 12. Variation of still productivity with tilt angle.

Table 2
Tilt angle correlations

Source	Correlation	R^2
Literature [1]	$y = -0.0025\,(a)^2 + 0.1562(a) + 0.7007$	0.734
Present results	$y = -0.0029\,(a)^2 + 0.1851(a) + 0.4160$	0.997
Modified	$y = -0.0026\,(a)^2 + 0.1628(a) + 0.7481$	0.793

where y is the productivity (l/m^{2}d) and (a) is the tilt angle (°).

experimental results and the modified correlation from both.

3.3. Effect of adding dye

In a conventional solar still most of the solar energy is absorbed by the base of the still that becomes hotter than the water contained. Almost all the solar energy entering the still gets absorbed by the water itself when dye is added and the base does not get heated much and consequently less heat is lost from it. The effect of dye on productivity is examined by adding black water-soluble dye to the brine with a concentration of 50 ppm. Four tests were conducted: two with and without dye in a still with a 35° tilt angle and another two in a still with a tilt angle of 25°. It is found that the addition of dye causes an enhancement in the daily productivity by 25.7% for the still with the 35° tilt angle and by 24.6% for the still with the 25° tilt angle. It is clear from Figs. 13–16 that the productivity from the stills with dye is greater than those without dye.

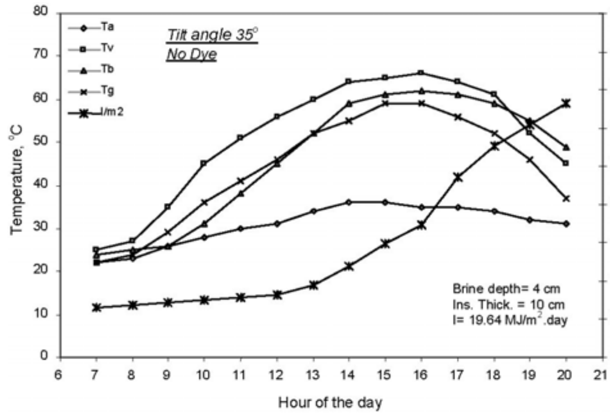

Fig. 13. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with tilt angle of 35° operating with no dye.

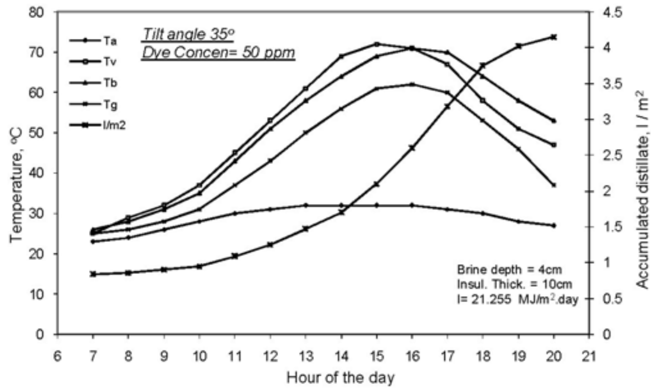

Fig. 14. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with tilt angle of 35° operating with dye.

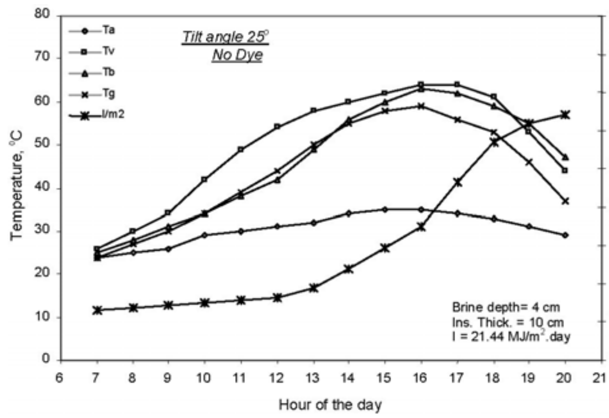

Fig. 15. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with tilt angle of 25° operating with no dye.

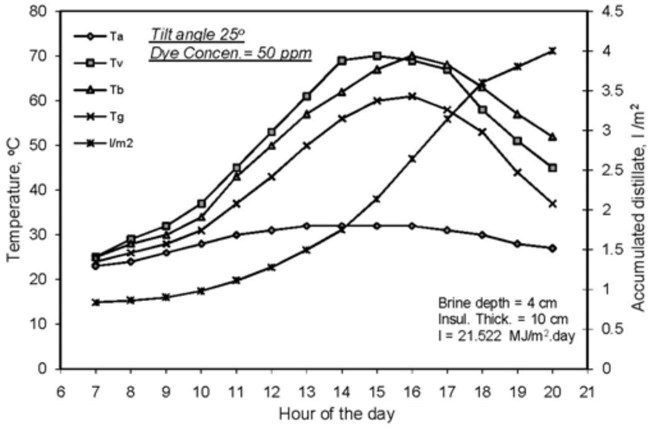

Fig. 16. Time variation of ambient (Ta), vapor (Tv), brine (Tb) and glass (Tg) temperatures and accumulated distillate for still with tilt angle of 25° operating with dye.

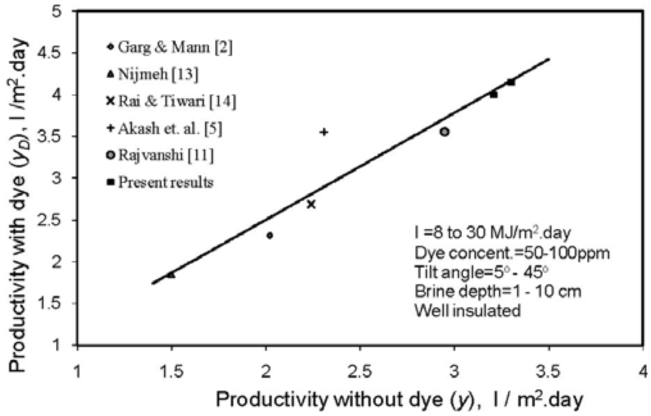

Fig. 17. Variation of still productivity with and without dye.

As reported previously [1], Garg and Mann [2], Rajvanshi [11], Akash et. al. [5], Al-Hayek and Badran [6], Nijmeh [13] and Rai and Tiwari [14] experimentally examined the effect of adding dyes on the productivity of the still. Fig. 17 shows the correlation obtained from their data and the data from the present investigation. Table 3 shows the correlation reported using their results [1], and the one that is modified by the present experimental results.

The correlations of Tables 1–3 are valid for the following conditions:

- Passive basin-type solar still under solar radiation between 18 and 26 MJ/m^2.d.
- Galvanized iron body.
- Insulation thickness between 5–10 cm of polystyrene or any other insulation with equivalent conductivity.
- Glass cover with tilt angle between 20° and 35°.
- Brine depth ranging from 2 to 5 cm.
- Latitude angles between 20° and 35° N.
- Dye concentration ranging from 50 to 100 ppm (Table 3).

Table 3
Dye effect correlations

Source	Correlation	R^2
Literature [1]	$y_D = 1.2122\,(y)^{1.0467}$	0.833
Modified	$y_D = 1.2343\,(y)^{1.0189}$	0.904

y_D and y are the productivity (l/m^{2}d) with and without dye, respectively.

4. Conclusions

An experimental investigation was carried out to validate and enhance the correlation of three parameters that show the effect of brine depth, cover tilt angle and dye on solar still productivity. The study confirmed the trend of these correlations and yielded new enhanced ones. The root mean square (R^2) value was used as the criterion to measure such enhancement. The R^2 value increased from 0.832 to 0.865 for the brine depth correlation, from 0.734 to 0.793 for the tilt angle correlation and from 0.833 to 0.904 for the effect of dye correlation.

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