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Investigation of salt contamination effects on the performance characteristics of the evacuated tubes solar water heater

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Abstract:

The influence of salt layer contamination of thickness below (2 mm) on solar evacuated tubes water heater performance parameters was investigated experimentally in several operating weather conditions on October and November 2011 at Baghdad location taking into consideration the effect of ambient conditions and collector inclination angle. It was concluded that the salt thickness have a minor effect on the collector efficiency, water circulation in the tubes and the heat loss coefficient from the storage tank. While on the other hand, the collector angle and the ambient have a greater effect on the above-mentioned parameters.

Keywords: Salt, Solar, evacuated tube, contamination, performance.

الخلاصة:

تم دراسة تأثير تكون ترسبات ملحية ذات سمك لا يتجاوز الملمترين على خصائص اداء السخان الشمسي ذو الانابيب المفرغة من العواء في شهري تشرين الاول والثاني ولظروف مناخية متغيرة لمدينة بغداد، تم الاخذ بنظر الاعتبار تغير درجة حرارة الهواء الخارجي و زاوية ميلان المجمع الشمسي على كل من كفاءة التسخين، معدل تدفق الماء المدور في الأنابيب وكذلك مقدار فقدان الحرارة من خزان السخان. وجد بان الترسبات الملحية ذات تأثير قليل نسبيا اذا ما قورن بتأثير العوامل الاخرى كزاوية ميلان الانابيب و الظروف الجوية المحيطة.

Nomenclature:

Symbol	Definition
ETSH	Evacuated Tube Solar Heater
A_t, A_c	Tank section and collector surface areas (m^2)
Cp	Water specific heat (kJ/kg $^{\circ}$C)
G	Accumulated solar radiation (W/m^2hr)
I	Solar radiation intensity (W/m^2)
M	Tank water mass (kg)
m	Tube water mass (kg)
$\dot{m}$	Water circulation flow rate (kg/sec)
n	No. of tubes in collector
Q	Water- in-tube discharge rate (L/min)
$Q_{collecter}$	Heat loss from tank (J)
T_{amb}	Ambient air temperature ($^{\circ}$C)
T_m	Tank mean thermocouples reading ($^{\circ}$C)
T_f, T_i	Final and initial water tank temperatures ($^{\circ}$C)
T_{out}, T_{in}	Tube mean hot & cold water temperatures ($^{\circ}$C)
U_L	Heat loss coefficient ($W/m^{2\circ}C$)
β	Collector inclination angle (degree)
ρ	Water density (kg/m^3)
ΔT_C	Water temperature difference without sunrise ($^{\circ}$C)
ΔT_H	Water temperature difference with sunrise ($^{\circ}$C)

Introduction:

One of the important factors that affect on the heating efficiency and durability is the salinity of the water [**Adnan, B.M., [1993]]** In Iraq, Tigris and Euphrates water quality have been declined greatly in the recent years because of random dams' constructions; this leaded to increase the salinity of water until reached to (600 mg/litre) as announced in 2002 for Euphrates River.

Adnan, B.M., [1996] investigated the salinity effect on the cylindrical reservoir heater performance characteristics such as, heater durability, convection heat transfer coefficient from the heater to the

water and minimum required time. He concluded that the increased salinity from 200 mg/litre (distilled water) to 500 mg/litre (normal water) decreased the heater durability operation by 30%, the convection heat transfer coefficient had also decreased by 21% and also the required time for heating the water 40°C increased about 7%.

The evacuated tube solar water heater has significantly improved heating efficiency than the other heaters types as illustrated by several researchers. **Budihardjo I. et al., [2003]** simulated the performance of the ETSH evaluation through TRNSYS program and compared the results with experimental work. They studied the collector efficiency, tank heat loss coefficient and the natural circulation flow rate variations when the heater is operated in Sydney. They concluded that this heater gives higher efficiency and a significant increase in circulation flow rate at increased ambient temperature.

Yu Z. et al., [2005] compared the performance of the ETSH and the cellular heat pump flat solar collector using two operating fluids, water and acetone experimentally. They concluded that the heat loss coefficient of the cellular heat pipe flat solar heater is 54% less than that of the ETSH and the daily average efficiency of solar absorbency is 15% higher; when the water temperature of heating is lower than 65°C.

Mangal D. et al., [2010] performed an experimental comparison between the ETSH and the flat plate collector; they studied the effect of the outlet air velocity for the both heaters. They found that the outer air velocity have less effect on the ETSH performance; also, the ETSH have less heat loss to the environment that leads to faster water heating as compared to the flat plate solar water collector.

Shahi M. et al., [2010] made a numerical simulation of steady natural convection flow and heat transfer in single-ended evacuated solar tube in the ETSH with non-uniform heat input, they assumed adiabatic seal end of the tube and also the tube opening to be subjected to copper-water nano fluid, they used fully implicit finite volume control method to solve the governing equations. The results showed that the tubes inclination angle is the most important affecting factor on the heater, where at 35 degree the maximum mean nusselt number is obtained, and the maximum output flow rate is increasing with inclination angle degree.

Yan S. et al., [2010] performed numerical and experimental modelling of circulation rate in the ETSH, the velocity and temperature field as well as the process of convective heat inside the evacuated tubes have been modelled, the results showed that this heater had only one disadvantage is the water flow in tube and tank connection becomes unstable and turbulent, this may lead to mixing between cold and hot flows.

The aim of this research is to investigate experimentally the effect of salt contamination in the evacuated tube on the performance characteristics of the solar heater such as collector efficiency, water circulation rate and the heat transfer loss coefficient variation for original and salted tubes.

Experimental layout:

1. System description:

In order to study the salt layer effect on the ETSH performance, two identical solar heaters were tested under the same weather conditions in two locations at Baghdad city as shown in figures (1a&b) which represent the salted and the non-salted tubes heaters respectively. Their main components are:

A. Evacuated glass tubes (20).

B. Storage tank (120 litres).

C. Mounting frame.

Each tube made from extremely strong borosilicate glass [GB/T, 1998] with high chemical and thermal shock resistance. The tube outer surface is transparent allowing light rays to pass through with minimum reflection. The inner side of each tube is coated with a selective coating **(aluminum-nitride)** that gives excellent solar radiation absorption with minimum reflection. **The coating is applied during tubes manufacturing using a magnetic sputtering technique, which is simply the removal of atomized material from a solid by energetic injection of its surface layers by ions or neutral particles**. Between the two tube layers, an annular space filled with air is evacuated via special machine that also inserts a barium getter at the tube bottom end to maintain vacuum between the tube layers to eliminate conductive and convective heat loss. Therefore, the tubes are able to absorb the energy from infrared rays that pass through clouds. The top end of these parallel tubes is connected to the storage tank.

The storage tank consists of upper (hot water) and lower (cold water) sections. The tank is insulated by high insulating material (Rock Wool) in order to reduce the heat losses. Storage tank is placed at the top of the collector frame.

2. Measurement instruments arrangement:

A. Storage tank:

Four thermocouples type (K) were placed at different levels in the tank to estimate the mean temperature rise of the hot water. The thermocouples reading bulb was insulated with a PFA

insulation to avoid water interfering on the readings. Another thermocouple is installed to read the ambient air temperature.

B. Evacuated tubes:

The collector consists of 20 evacuated tubes .Four thermocouples were placed at the three middle tubes open cross section, three were inserted at the upper surface of the tube opening to measure the mean hot water temperature and one thermocouple inserted at the bottom of the tube surface opening for the cold water temperature. In addition, a high precision ruler was used to measure the salt layer thickness in the salted heater. The frame has an offset inclination angle of 45°.

Performance analysis of the solar heater:

1. The heat loss coefficient of the tank:

According to the National GB/T 12915-91 [GB/T, 1991] standard relation to calculate the average heat loss coefficient (U_L) from the heater tank:

$$U_L = \frac{M * C_P * (\Delta Tc)}{Ac * (T_c - T_a) * dt} \quad (1)$$

2. The collector efficiency:

Collector efficiency as described by **Budihardjo et al. [2003]** is the fraction of the useful energy transferred from the collector divided by the integrated solar radiation multiplied by the tank area as expressed in the following relation:

$$\eta = \frac{Q_{collector}}{G * A_t} \quad (2)$$

Where,

$$G = \int_{t_1}^{t_2} I dt \quad (3)$$

The useful transferred energy is the summation of the increase in fluid internal energy and the heat loss from the system tank that is simplified by the relation [**Budihardjo et al. 2003**]:

$$Q_{collector} = m * C_P * (\Delta T_H) + U_L * A_t * (T_m - T_{amb}) \quad (4)$$

3. Water circulation rate:

From the collector tube water temperature readings. Water circulation rate could be calculated from the relation adopted by **Morrison G.L. et al. [2005]** as follows:

$$\dot{m} = \frac{Q_{collector}}{C_p * n * (T_{out} - T_{in})} \quad (5)$$

$$Q = \frac{\dot{m}}{\rho} \quad (6)$$

Testing procedure:

In order to evaluate the collector efficiency and heat transfer loss coefficient during the day light, thermocouples readings were taken from 9 o'clock till 16 o'clock in both sunny, clouded and raining days of October and November 2011.

The readings were taken for both salt-contaminated tubes with a thickness of less than (1mm) and non-salted tubes collector, the mean water tank temperature was evaluated from the average of thermocouples readings in the tank in each hour respectively.

An important factor have been studied is the collector inclination angle (β) that is varied from 35-45 degrees through lifting up the two assemblies in the front position.

The solar radiation intensity readings for Baghdad location cited by [وجدي, **2003**] are used to complete the heater performance parameters evaluation.

Table (1) shows a sample of the maximum heating temperature rise during the selected operation test days for both original and salted tubes.

Results & Discussion:

1. Collector efficiency:

Figure (2) shows the relationship of collector efficiency with the ambient temperature rise at inclination angle (35°) for both salted and new tubes. It is clear that salt have a minor effect especially at T_{amb}<35°C due to the low salt contaminations thickness.

When changing the inclination angle to 40 and 35 degree, the efficiency of the salted tubes has decreased by 5-7% and 6-9% respectively than the new tubes as shown in figures (3 and 4) for the same temperature rise limit mentioned above.

2. Water circulation rate:

Figures (5, 6 and 7) indicate that the circulation discharge rate depends greatly on the inclination angle rather than the salt layer contamination where (Q) has varied by maximum of 1% for salted tubes.

3. Heat loss coefficient:

The heat loss coefficient appeared to be greatly dependent on the collector inclination angle rather than the tubes salt layer as shown in figures (8, 9 and 10). It is clear that the loss coefficient is greater by 2-4% for T_{amb} >35˚C for the salted tubes and increases with collector angle variation by 7-11%.

Conclusions:

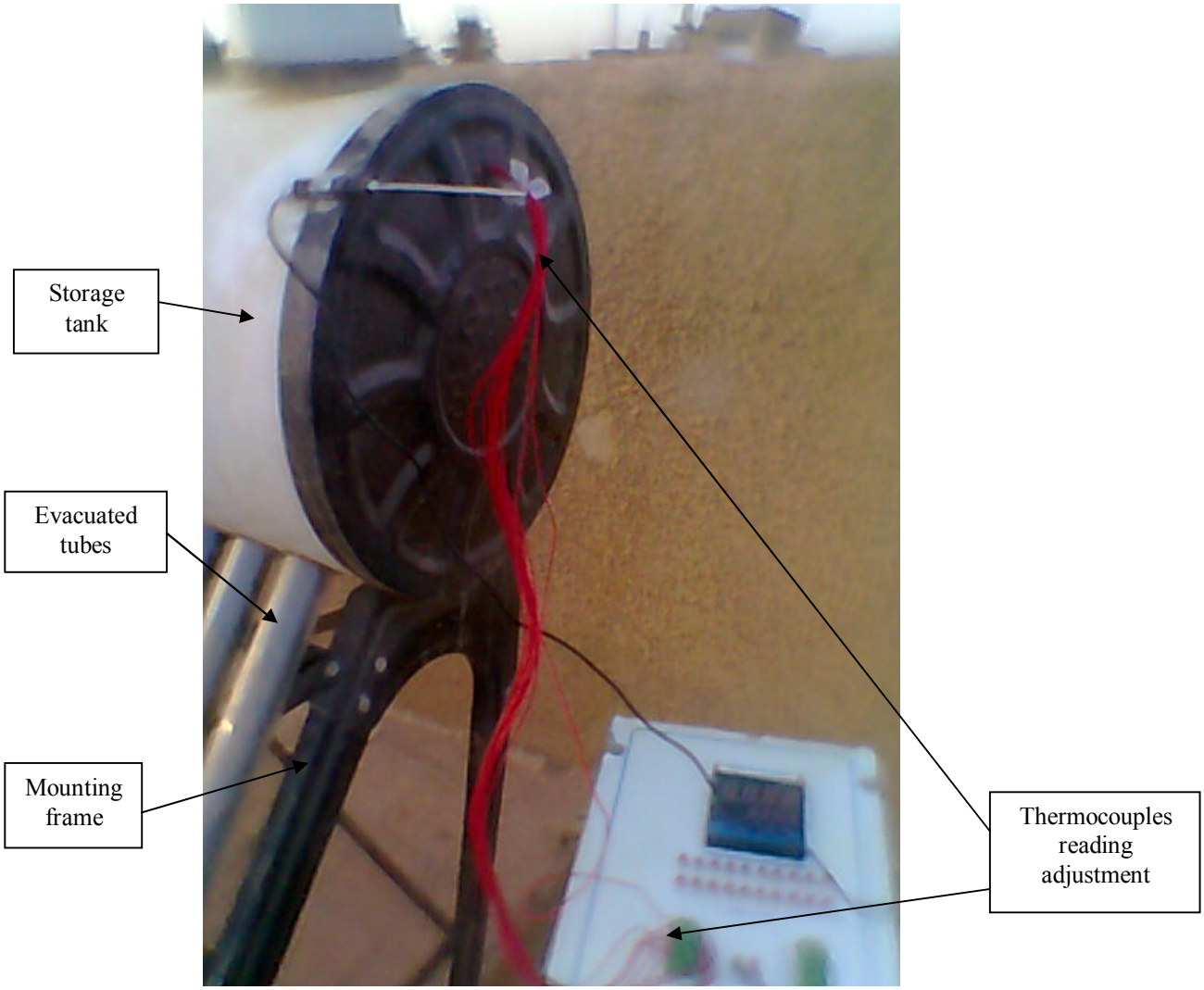
1- The salt layer thickness below (2) mm has a small effect on the performance of the heating in the evacuated tubes solar water heater, this due to the low decreased heat absorption from sun light. In addition, it could be concluded that increased salt layer thickness could cause lower heating performance.

2- From the above results, it is obvious that the salt effect could be avoided through increasing the collector inclination angle to a desired value depends on the ambient conditions and the salt layer growing thickness.

Table (1): Water temperature rise and ambient conditions in the selected operating days of collector operation (β=45◦)

Date	Weather forecast	Max T_{amb}	ΔT_{max}	
			Original	Salted
22/10/2011	Raining	23	30	26
24/10/2011	Partially clouded	32	40	38
26/10/2011	Sunny	36	55	53
28/10/2011	Clouded	28	32	30
31/10/2011	Sunny	35	50	49
2/11/2011	Partially clouded	29	45	44

(a)Salted tubes heater



(b)Original tubes heater

Figure (1): Experimental apparatus layout

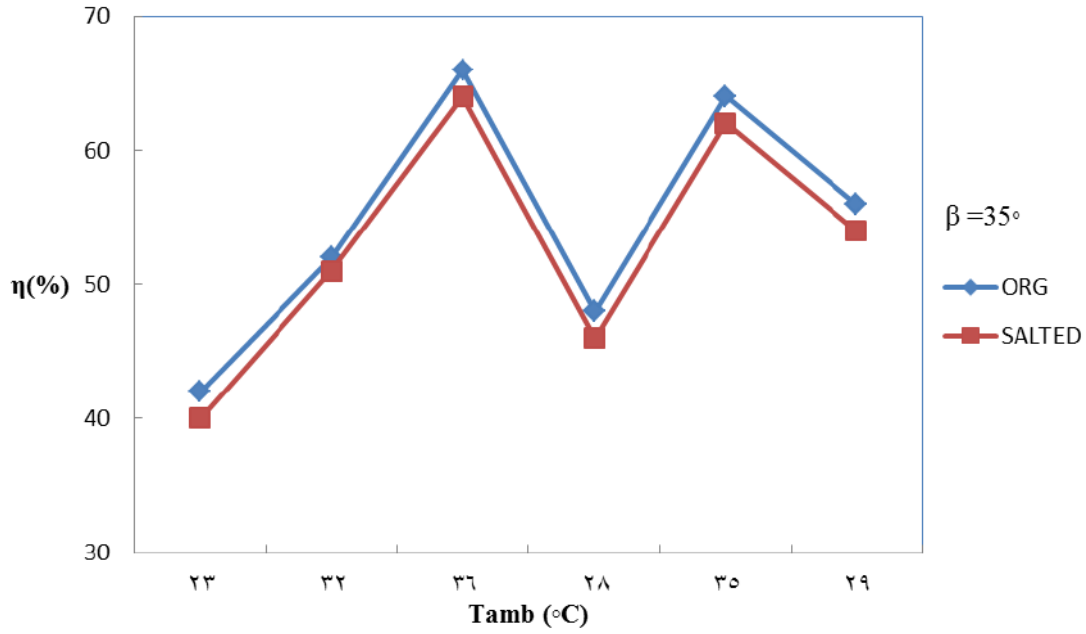


Figure (2): collector efficiency variation with the ambient temperature for original and salted tubes

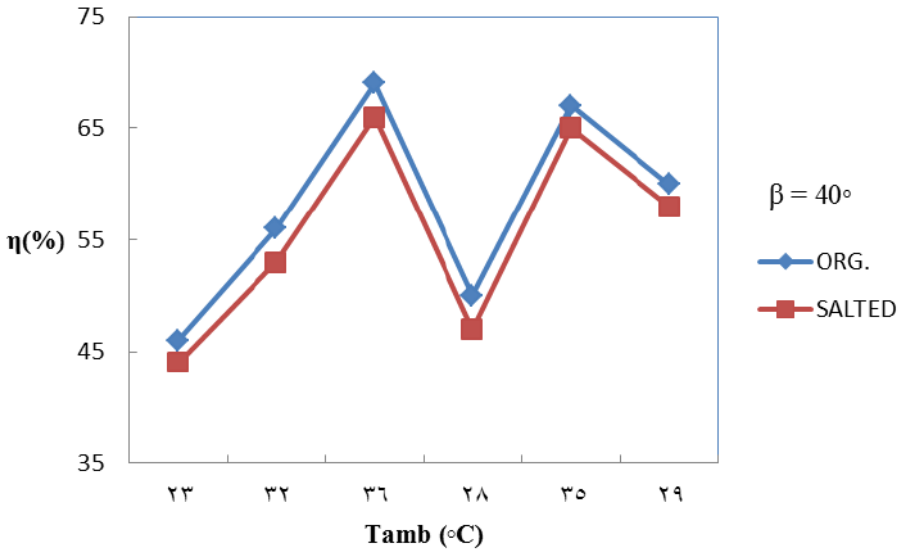


Figure (3): collector efficiency variation with the ambient temperature for original and salted tubes

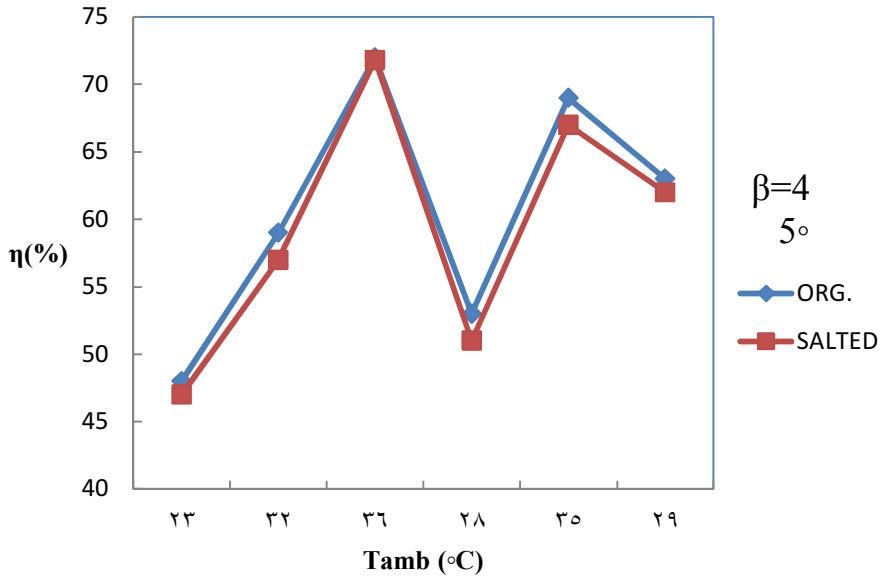


Figure (4): collector efficiency variation with the ambient temperature for original and salted tubes

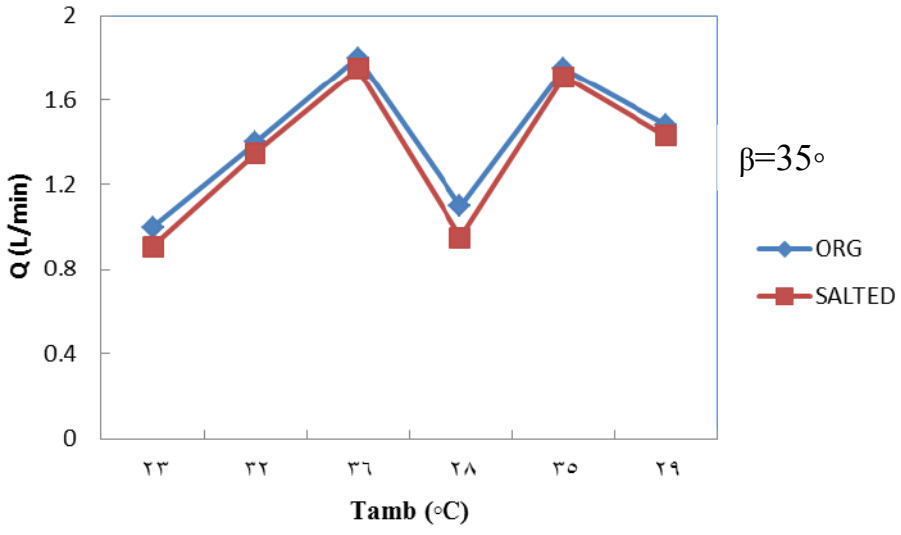


Figure (5): Water circulation rate variation for the original and salted tubes

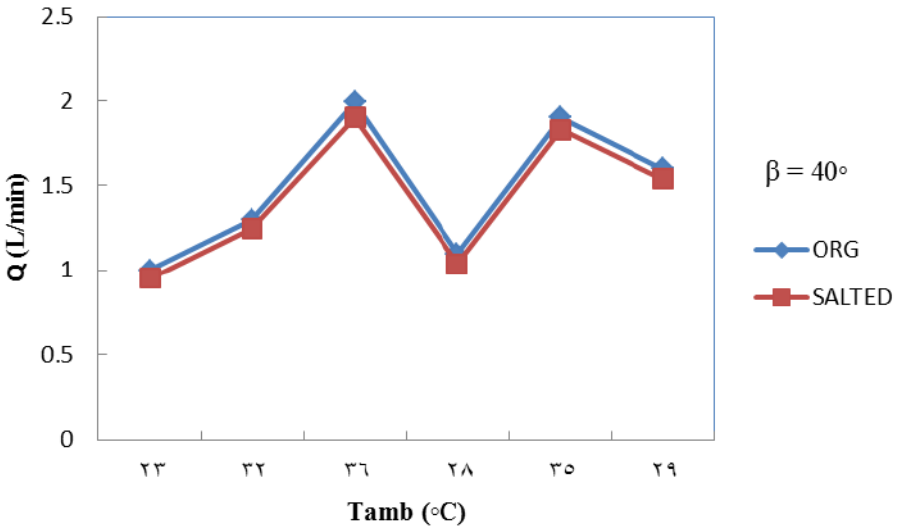


Figure (6): Water circulation rate variation for the original and salted tubes

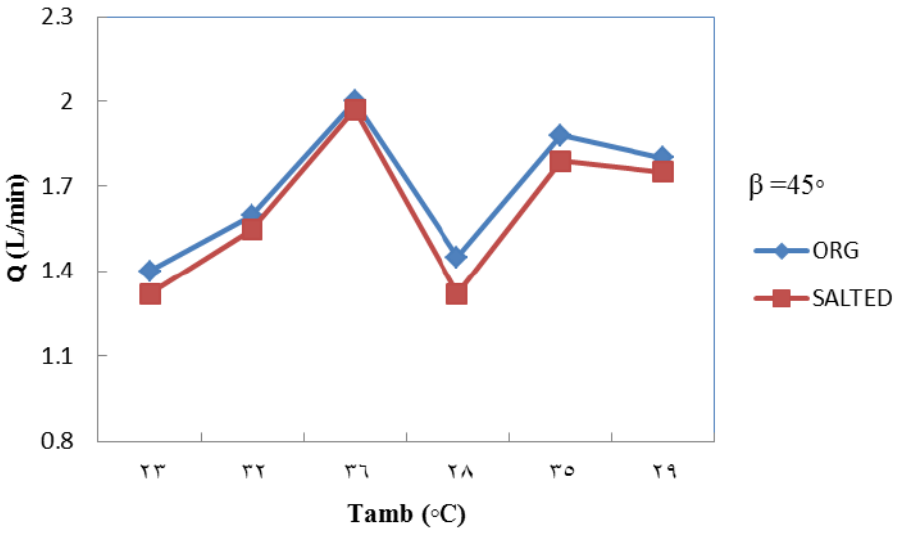


Figure (7): Water circulation rate variation for the original and salted tubes

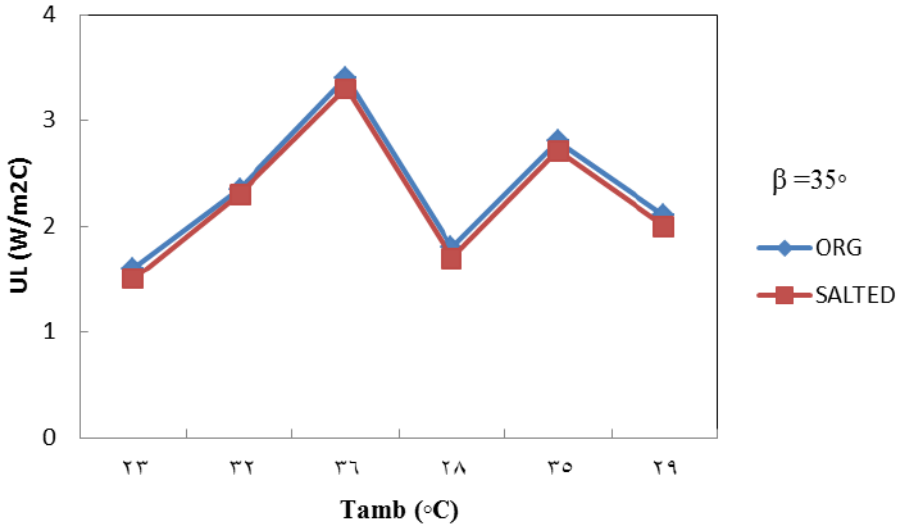


Figure (8) Heat loss coefficient variation with ambient temperature for original and salted tubes

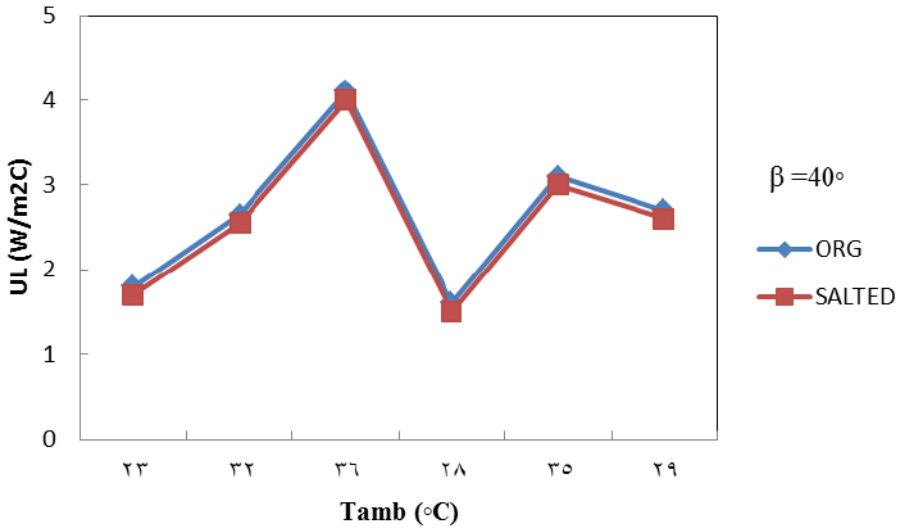


Figure (9) Heat loss coefficient variation with ambient temperature for original and salted tubes

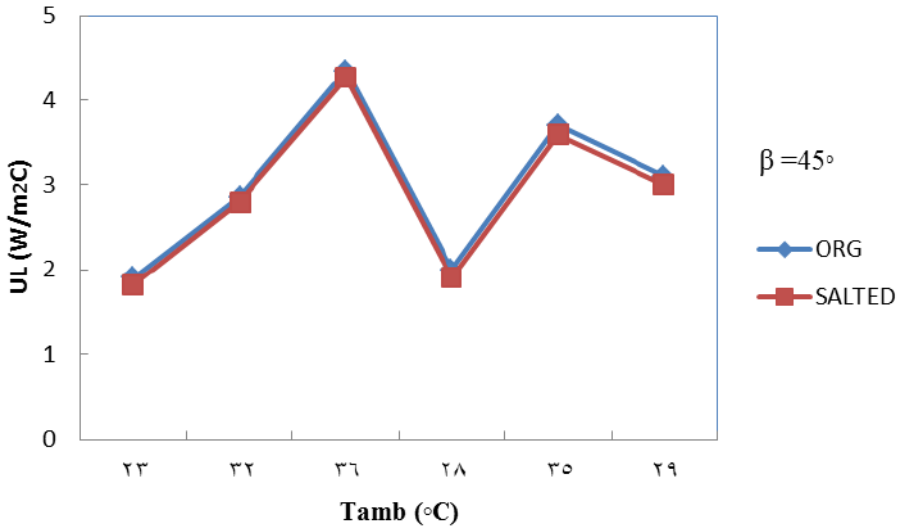


Figure (10): Heat loss coefficient variation with maximum temperature for original and salted tubes

References:

- Adnan M., **"Studying salinity effect on cylindrical heaters performance"**, Basrah Eng. J., Volume (.2), Issue(.6), 1996, pp.27-33.

- Budihardjo I., Morrison G.L,.and Behnia M., **"Development of TRNSYS Models for Predicting the Performance of Water-in-Glass Evacuated Tube Solar Water Heaters in Australia"**, Destination Renewable ANZSES J., 2003, pp. 1-10.

- GB/T technical report No. 12915**, "Experimental Method for the Thermal Performance of Home Solar Heater"**, cited by [Yu et al., 2005], 1991.

- GB/T technical Report No. 9505,**" Glass evacuated tube Technique specification"**, 1998.

- Mangal D., Lamba D.K, Gupta T. and Jhamba K., **"Acknowledgement of Evacuated Tube Solar Water Heater over Flat Plate Solar Water Heater"**, Int. J. of Eng., Volume (4): Issue (4), 2010, pp.280-284.

- Morrison G.L., Budihardjo I. and Behnia M. **"Measurement and simulation of flow rate in a water-in- glass evacuated tube solar water heater ",** Solar Energy J. , Volume (78), Issue (2), 2005, pp: 257-267.

- Shahi M., Mahmoudi A. H. and Talebi F.**, "Numerical simulation of steady natural convection heat transfer in a 3-dimensional single-ended tube subjected to a Nano fluid"**, Int. Communications in Heat and Mass Transfer, 2010, vol. 37, pp. 1535–1545.

- Yan S., Tian R., Yu W, and Li S., **"Flow Structure in a Water-in-Glass Evacuated Tube Solar Water Heater"**, National Natural Science Foundation Report No. 50766002, 2010.

- Yu Z. T., Hu Y. C, Hong R. H. and Cen K. F.**, "Investigation and analysis on a cellular heat pipe flat solar heater"**, J. Heat Mass Transfer, vol. 42, 2005, pp. 122–128**.**

- نجلاء محمد وجدي ، " **الكفاءة الحرارية للسقوف ذات الاقبية للتبريد الخامل صيفا" في الابنية الواطئة "**، مجلة جامعة الملك عبد العزيز للعلوم الهندسية، المجلد ١٤، العدد ١، ٢٠٠٣، ص : ٦١-٨٦

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