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EFFECT OF WATER COLUMN LENGTH PASSING THROUGH THE SOLAR PANEL ON ITS THERMAL PERFORMANCE

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ABSTRACT

Two identical solar water heaters (solar panels) have been built and installed at the Agricultural and Veterinary Research Station of King Faisal University in order to study the effect of water column length passing through the solar panel on its thermal performance. Each solar panel having a surface area of 2 m^2 (2 x 1 m) with different number of copper pipes (but they had the same total length of 20 m). Operating liquid (water) was continually cycled through the solar panels using natural and forced systems of circulation. After passing through solar panel, the heated water was stored in an insulated storage tank (300 litres). The daily average overall thermal efficiencies during this experimental work for the short and long pipes of solar panels were 71.73% and 61.13% respectively. Consequently, the solar panel with short pipes was found to be more efficient than the solar panel with long pipes by 17.29%.

INTRODUCTION

Solar energy has the potential for providing a significant portion of the support energy used in agricultural applications. Most solar energy systems are capital intensive, therefore care has to be taken with the system design to achieve the optimum configuration. General solar system design procedures have often resulted from experience gained in the construction and operation of several systems, but this has normally taken a number of years to develop an acceptable method. In a design sense, the essential operational elements can be listed as : 1) a solar absorbing plate treated (painted with dull-black paint) to have a good absorptivity in the solar spectral range from 0.3 μ to 3 μ and preferably a poor emissivity in the long wavelength or infrared radiation region above 3 μ (Charters and Window, 1978), 2) flow passages for containing the heat transfer fluid usually either water or air either integrally formed in the absorbed plate or thermally well bonded to it by mechanical connection of some type of thermal paste (Duffie and Beckman, 1980), 3) a well insulated box to minimize the rate of heat loss from the base and edges of the container (Fanney and Klein, 1988).

Solar energy can be used to produce heat in various temperature ranges as needed to serve the agricultural industry (George *et al.*, 1980). For temperature lower than 100 °C, flat plate type solar collectors are usually the most economical, while concentrating type solar collectors are necessary for temperatures exceeding 100 °C (Wustling *et al*., 1985). If a fluid which is usually water is circulated through suitable paths formed in the plate or allowed to run over the surface of the plate, some of the absorbed energy will be transferred to the fluid. The rest of the absorbed energy will be dissipated to the surroundings through radiation, convection, and conduction. These outward losses may be substantially reduced by incorporating the flat plate into an insulated box fitted with transparent or translucent covers, so that more of the absorbed energy is passed into the fluid rather than to the environment.

The thermal performance of solar domestic hot water systems is influenced by the rate which heat transfer fluids within the system are circulated (Fanney and Klein, 1988). The increase in solar collector thermal efficiency resulting from increased tank stratification often outweighs the efficiency decrease resulting from a lower heat removal factor (Jesch and Braun, 1984). As the water volume inside the solar collector per unit area of absorber black plate is increased, the heat transfer area is increased and rate of absorbed solar energy converted into useful heat gain to storage is thus increased (Abdellatif *et al*., 1990).

The main objective of the present experimental work is to investigate under clear sky conditions, the influenced of length of water column passing through the flat plate solar panel on its thermal performance.

DESCRIPTION OF SOLAR ENERGY SYSTEMS

One of the solar energy systems was designed, built and installed in the workshop of the Agricultural Engineering Department (King Faisal University, Saudi Arabia). It consisted of two major components; solar panel and insulated storage tank. Solar panel consisted of five components; a panel box, an absorber plate, a copper pipes, an insulation material, and a glass cover. The panel box is rectangular in shape and made of aluminium bars (4 mm thick) and sheets (2 mm thick). The gross dimensions of the panel box are 2.0 m long, 1.0 m wide, and 0.10 m deep with a net upper surface area of 2.0 m^2. The absorber plate is formed of an aluminium sheet 2.0 m long, 1.0 m wide, and 2.0 mm thick with a net surface area of 2.0 m^2. It was painted with matt black paint. A 12.7 mm diameter copper pipes were attached to the upper surface of the black absorber plate using wire ties each 10 cm long throughout the length of each pipe. The total length of copper pipes employed in the solar panel was 20 m. It was also painted with matt black paint. These pipes were run in a parallel direction as shown in Figure 1. In the bottom and sides of the panel envelop, 5 and 2.5 cm of fiberglass wool insulation sheets were placed to reduce the heat losses from the back and sides of the solar panel respectively. To minimize the reflection of radiation and reduce the heat losses by convection, a clear glass cover 5 mm thick was placed to cover the panel box. The air space between the black absorber plate and the clear glass cover was 5 cm as suggested by many researchers (Duffie and Beckman, 1980 and Rumsey, 1982). The insulated storage tank is cylindrical in shape, and made from two layers of steel sheets (3 mm thick). To minimize the energy losses from the stored energy in the storage tank, 2.5 cm thick of fiberglass wool insulation sheet was placed in the space between the two layers of steel sheets. Also, the outside perimeter of the storage tank was surrounded by 2.5 cm of insulation. The storage tank was connected to the solar panel by two junctions. One junction was between the bottom of the storage tank (cold water) and the bottom of the solar panel (water inlet). The other one was between the top of the storage tank and the top of the panel (water outlet). The water was pumped between the storage tank and the panel using 0.5 hp pump. After passing through the solar panel, it was stored in a 300 litres insulated storage tank.

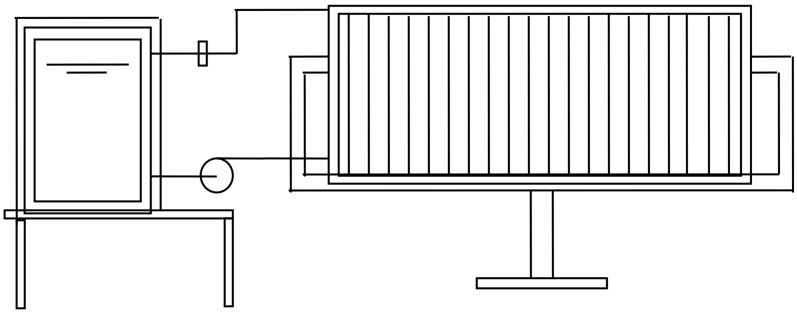

Fig. 1 : Schematic diagram of the solar energy systym used a short length of copper pipes.

The other solar panel had the same components, surface area of 2.0 m^2, and a total length of copper pipes inside the solar panel (20 m). But, this length of copper pipes was divided into 10 pipes with length of 2.0 m as shown in Figure 2.

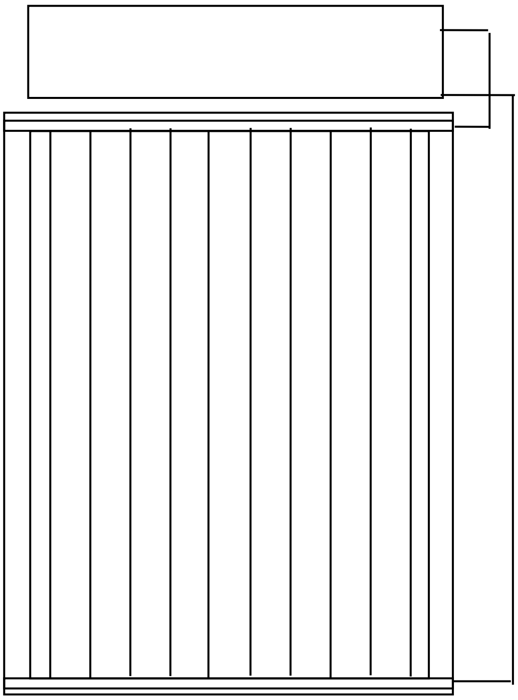

Fig. 2 : Schematic diagram of the solar energy system used a long length of copper pipes.

This solar panel used a natural system of circulation and exported from Australia (SOLCO). The flow rate was tested and adjusted twice a day using control valve and a measuring cylinder with a stop watch to be 6 L/min.

Two thermocouples (copper and constant) were evenly spaced in each solar panel to measure the absorber plate surface. To measure the water temperature two thermocouples were placed inside each storage tank at different depths. Two thermocouples were used to measure the water inlet and outlet temperatures inside each water inlet and outlet pipes of the solar panels. The data of solar radiation flux incident on a horizontal surface, the wind blowing over the place of experimental work. and the ambient air temperature were obtained from the Meteorological station (far away about 200 m). Temperatures were displayed, measured, and recorded using a data-logger system. For the rest of this research work, the solar panel with short and long length of copper pipes were referred to as system A and system B respectively.

To measure, test and compute the theraml performance of the two solar panels (System A and system B) a series of equations (Duffie and Beckman, 1980 ; Rumsey, 1982 ; Abdellatif et al., 1993 ; and many others) were employed as follows :-

$$SR = R\ A_C \quad \text{Watt}$$

$$Q_C = R\ A_C\ \tau\ \alpha \quad \text{Watt}$$

$$\eta_a = \frac{Q_C}{SR} = \tau\ \alpha \quad \%$$

$$Q_U = F_R\,[\,Q_C - A_C\,U_O\,(T_{fi} - T_a)\,] \quad \text{Watt}$$

$$F_R = \left(\frac{\dot{m}\,C_p}{A_C\,U_o}\right)\left[1 - \text{EXP}\left(\frac{-A_C\,U_o\,F'}{\dot{m}\,C_p}\right)\right] \quad \%$$

$$F' = \frac{1}{\dfrac{W\,U_o}{\pi\,D_i\,h_f} + \dfrac{W}{D_o + (W - D_o)\,F}} \quad \%$$

$$F = \frac{\tanh \dfrac{m\,(W - D_o)}{2}}{\dfrac{m\,(W - D_o)}{2}}$$

$$m = \left(\frac{U_o}{k_c\ s}\right)^{0.5}$$

$$\eta_h = \frac{Q_u}{Q_c} \times 100 \quad \%$$

$$Q_L = U_o\ A_C\ (T_p - T_a) \quad \text{Watt}$$

$$\eta_o = \frac{Q_u}{R\ A_c} \times 100 \quad \%$$

$$Q_S = m_S\ C_P\ (T_e - T_b) \quad \text{Watt}$$

$$\eta_s = \frac{Q_s}{Q_u} \times 100 \quad \%$$

NOTATION

A_C solar panel surface area, 2 m^2
C_p specific heat of water, 4186 J/kg/°C
D_i inter diameter of copper pipe, m
D_o outer diameter of copper pipe, m
h_f heat transfer coefficient between the fluid and pipe wall, 300 W/m^2/°C
k_c thermal conductivity of copper pipe material, 385 W/m/°C
m mass flow rate of water, 0.1 kg/s
m_s mass of water in the storage tank, 300 kg
Q_C absorbed solar radiation, Watt
Q_S solar energy stored, Watt
Q_U useful heat gain to storage, Watt
R solar radiation normally incident, W/m^2
s absorber plate thickness, 0.001 m
SR solar energy available, Watt
T_a ambient air temperature, °C
T_b mean tank temperature at the beginning of each hour, °C
T_e mean tank temperature at the end of each hour, °C
T_{fi} inlet temperature of water, °C
T_p mean temperature of absorber plate, °C
W copper pipes spacing, 0.1 m
τ transmittance of glass cover
α absorpttance of absorber plate
η_a absorptance efficiency, %
η_h heat transfer efficiency, %
η_o overall thermal efficiency, %
η_s storage system efficiency, %

RESULTS AND DISCUSSIONS

The thermal performance data for the two solar panels (system A and system B respectively) during this experimental work are summarized in Tables 1 and 2. Due to the two solar systems were at the same inclination and orientation under the same conditions, there was no difference in the solar energy available (SR) between systems A and B. For the duration of the experimental work, the daily average solar energy available was 12.543 kWh/day. As both systems had the same transmittance of the glass cover and absorptance of the absorber plate, the two solar panels absorbed the same amount of solar energy. The daily average absorbed solar energy (Q_C) during this experiment was 10.401 kWh/day, that gave an average absorption efficiency of 82.96%.

Table (1) : Daily average solar energy available (SR), absorbed solar energy (Q_C) and absorption efficiency (η_a) for the tow solar panels system A and system B during this experimental work.

Month	System	SR kWh/day	Q_C kWh/day	η_a %
December	**A** **B**	**11.888**	**9.937**	**83.59**
January	**A** **B**	**12.302**	**10.222**	**83.09**
February	**A** **B**	**13.438**	**11.045**	**82.19**
Mean	**A** **B**	**12.543**	**10.401**	**82.96**

The daily average solar energy which converted into useful heat gain to storage (Q_U) for system A and system B was 8.933 kWh/day and 7.667 kWh/day, which gave an average heat transfer efficiencies of 86.46% and 73.71% respectively. This difference in useful heat gain to storage between system A and system B can be attributed to the operating temperature. As the operating temperature is increased; firstly, the absorber plate temperature is increased above the ambient air temperature and heat losses are thus increased; secondly, the difference in temperature between the absorber plate and the water passing through the solar panel is reduced, making the heat transfer less efficient. As the water temperature inside the copper pipes (particularly in the last one-third of each pipe) is increased above the ambient air temperature surrounding the solar panel and heat losses are thus increased. For the reasons discussed above, system A increased the heat transfer efficiency by 17.30%. Very little useful heat was gained by the water passing through the two systems during early morning just after sunrise and just prior to sunset (when the solar radiation at those times is less than 200 W/m^2). Thus the useful heat gain to storage can be obtained in different values only when the operating temperature is greater than the water temperature. In addition, the ambient air temperature surrounding the solar panels and the wind blowing over the top of them were found to produce a significant negative effect on useful heat gain to storage. The greatest magnitudes of useful heat gain to storage can be obtained at and around solar noon when the incoming solar radiation was sufficient to increase the operating temperature over the water temperature passing through the solar panels. The daily average overall thermal efficiencies for systems A and B were 71.70% and 61.13%. Consequently 28.3% and 38.87% of the solar energy available were lost respectively. So system A increased and improved the overall thermal efficiency during this experimental work by 17.29%. This value could be increased if the difference in water inlet temperature between system A and system B had been maintained from sunrise to sunset. The daily average solar energy stored in the storage tank for system A and system B were 8.137 kWh/day and 5.743 kWh/day respectively.The storage system efficiency is directly related to the overall thermal efficiency of the solar panel, therefore the daily average storage system efficiencies for system A and system B were 90.56% and 74.90%, consequently 9.44% and 25.10% of the useful heat gain to storage were lost respectively.

Table (2) : Daily average useful heat gain to storage (Q_U), heat transfer efficiency (η_h), overall thermal efficiency (η_o), solar energy stored in the storage tank (Q_S) and storage system efficiency (η_s) for the tow systems A and B during this experimental work.

Month	System	Q_U kWh/day	η_h %	η_o %	Q_S kWh/day	η_s %
Dec.	A	8.622	86.77	72.53	8.044	93.30
	B	7.206	72.52	60.62	5.561	77.17
Jan	A	8.817	86.25	71.67	7.939	90.04
	B	7.631	74.65	62.03	5.683	74.47
Feb.	A	9.540	86.37	70.99	8.428	88.34
	B	8.163	73.91	60.74	5.965	73.07
Mean	A	8.993	86.46	71.73	8.138	90.56
	B	7.667	73.71	61.13	5.743	74.90

CONCLUSION

The solar energy systems were operated satisfactorily for over three months on sunny days only , without any malfunction. For the duration of the experimental work, there were 819 hours of actual bright sunshine of which 280 hours (34.19%) were only recorded and used in the results and tests. The specific conclusions were as follows :-

1) The thermal performance of the solar energy systems were determined by their overall efficiency in converting solar energy into stored heat energy.
2) The useful heat collected, heat transfer efficiency, and overall efficiency were found to be directly proportional to solar energy available and inversely proportional to water inlet temperature.
3) The solar panel heat losses were found to be directly proportional to water inlet temperature and operating temperature.
4) As the length of the water column passing through the solar panel is reduced, the operating temperature is reduced making the heat transfer between the water and absorber plate more efficient.

5) The thermal performance of the solar panel which exported from Australia (SOLCO) could be increased if, the flow system of operating fluid (water) had been changed from natural flow system into forced flow system with high flow rate of water.

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تأثير طول عمود المـاء المـار خلال سخان المياه الشمسى على أداءه الحـرارى

على بن مفرح العمرى
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تعتبر الطاقة الشمسية أحد صور الطاقة الجديدة والمتجددة وهى أمل كل دول العالم المتقدم منها والنامى لحل الكثر من مشاكل الطاقة، حيث تعتبر الطاقة الشمسية طاقة نظيفة غير ملوثة للبيئة ومتواجدة أينما وجدت الحياة على سطح الكرة الأرضية ولكن يعيب هذه الطاقة أنها طاقة مبعثرة وبالتالى تحتاج إلى أجهزة لتجميعها، كما أنها طاقة متغيرة تبعاً لتغير ساعات النهار طوال اليوم الواحد وتغير الفصول على مدار العام لذا فإنها تحتاج إلى أجهزة لتخزينها. من أجل ذلك كله فإن معظم الأبحاث التى تمت والتى تجرى الأن تهدف بل وتركز على كيفية تطوير نظم تجميع وتخزين وتركيز الطاقة الشمسية، وينهج هذا البحث نفس الهدف حيث أنه يقوم على دراسة تأثير طول المواسير النحاسية داخل سخانات المياه الشمسية وبالتالى طول عمود المياه المار داخل هذه السخانات على الأداء الحرارى لها.

تم تصميم وتنفيذ سخان مياه شمسي ملحق به خزان للمياه بغرض تجميع الطاقة الحرارية المحولة من الطاقة الشمسية بواسطة السخان الشمسى وذلك بورش قسم الهندسة الزراعية بمحطة البحوث الزراعية والبيطرية بجامعة الملك فيصل. المساحة الصافية لهذا السخان كان ٢م٢ (٢ × ١ م) يحتوى على ٢٠ ماسورة نحاسية (نحاس أحمر) طول الواحدة ١ م. تم الأستعانة بسخان آخر للمياه مستورد من استراليا له نفس المساحة (٢ م٢) ولكن يحتوى على ١٠ مواسير نحاس فقط، طول الواحدة منها ٢ م وذلك لإجراء دراسة مقارنة بين السخانين لتوضيح تأثير طول عمود المياه المار خلالهما على أداءهما الحرارى، وقد أوضحت الدراسة التالى :-

١- يتحدد الأداء الحرارى لنظم التسخين الشمسى عن طريق تحديد الكفاءة الحرارية الكلية فى تحويل الطاقة الشمسية إلى طاقة حرارية مخزنة.
٢- وجد أن الطاقة الحرارية المجمعة والمستفاد منها وكفاءة إنتقال الحرارة والكفاءة الحرارية الكلية كلها تتناسب تناسباً طردياً مع الطاقة الشمسية المتاحة، كما أنها تتناسب تناسباً عكسياً مع درجة حرارة دخول الماء للسخانات الشمسية.
٣- وجد أن الفواقد الحرارية لنظم التسخين الشمسى تتناسب تناسباً طردياً مع درجة حرارة دخول الماء ودرجة حرارة التشغيل (درجة حرارة السطح الماص والمواسيرالنحاسية).
٤- كلما نقص طول المواسير النحاسية وبالتالى طول عمود الماء المار داخل نظم التسخين الشمسى كلما إنخفضت درجة حرارة التشغيل كنتيجة للإزاحة الحرارية للطاقة الممتصة مما يجعل إنتقال الحرارة بين السطح الماص والماء المار داخل المواسير النحاسية أكثر كفاءة.
٥- يمكن زيادة معدل الأداء الحرارى وبالتالى الكفاءة الحرارية الكلية لسخان المياه الشمسى المستورد (ذو المواسير النحاسية الطويلة) لو تم زيادة معدل سريان الماء داخل السخان الشمسى مع تغير نظام السريان من السريان الطبيعى إلى السريان الجبرى وذلك لإزاحة أكبر كم ممكن من الطاقة الحرارية الممتصة بواسطة السطح الماص والأستفادة منها بدلاً من فقدها للوسط المحيط بنظام التسخين الشمسى.