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تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

Experimental investigation of the Performance of Natural Circulation Solar Water Heater in Series

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Abstract

This research paper presents an experimental study on the performance of a natural circulation solar water heater system with two typical collectors connected in series. The paper provides a comprehensive analysis of the system's thermal performance under different load conditions, including no-load, intermittent, and continuous load. Mean storage tank, solar collector means plate (the left) temperature and thermosyphon flow rate in a vertical tank were measured. Results showed that there was variation in solar water tank and collector plate temperature under load and no-load conditions. Analysis of thermal performance of the system was conducted for each condition. The highest plate temperature (100 ˚C or even more) with no circulation of both collector and load conditions, indicate the high quality of the solar collectors even during the cold season. The collector's arrangement in series connection is of highest gain in energy and higher storage tank mean water temperature. Several characteristic equations obtained to represent the performance of the present natural circulation system under collector connection arrangement in series. In fact, when large amount of hot water was required for a certain purpose (Industrial sector for example - MSF plant or central heating), multiple collectors are to be deployed in series and in parallel to produce the required amount (quantity) and desired temperature (quality) at the same time.

Key words: Thermosyphon solar water heater, storage tank profile temperature, Solar Water Heaters (SWHs), instantaneous

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

efficiency, collector flow factor, collector efficiency factor, collector heat removal factor

دراسة عملية لاداء سخان ماء شمسي ذو الدوران الطبيعي المتصل على التوالي

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الملخص

تقدم ورقة البحث هذه دراسة تجريبية حول أداء نظام سخان ماء شمسي يعمل بالدوران الطبيعي مع وجود مجمعين شمسيين متصلين على التوالي. تقدم الورقة تحليلاً شاملاً للأداء الحراري للنظام في ظل ظروف تحميل مختلفة، بما في ذلك عدم التحميل، والحمل المتقطع، والحمل المستمر. تم قياس متوسط درجة حرارة خزان التخزين ومتوسط درجة حرارة لوحة المجمع الشمسي (على اليسار) ومعدل تدفق السيفون الحراري في الخزان الرأسي. أظهرت النتائج وجود تباين في درجة حرارة خزان المياه ولوحة المجمع في ظل ظروف الحمل وعدم التحميل. تم إجراء تحليل للأداء الحراري للنظام لكل حالة. تشير أعلى درجة حرارة للوحة (100 درجة مئوية أو أكثر) مع عدم وجود دوران للمياه في المجمع وظروف عدم التحميل، إلى الجودة العالية للمجمعات الشمسية حتى خلال موسم البرد القارص. ترتيب المجمع في التوصيل على التوالي يعطي أعلى كسب في الطاقة وأعلى متوسط لدرجة حرارة الماء في خزان التخزين. تم الحصول على العديد من المعادلات المميزة لتمثيل أداء نظام الدورة الطبيعية الحالي في ظل ترتيب توصيل المجمع على التوالي. في الواقع، عندما تكون هناك حاجة إلى كمية كبيرة من الماء الساخن لغرض معين (القطاع الصناعي على سبيل المثال – محطة MSF أو التدفئة المركزية)، فيجب نشر العديد من المجمعات على التوالي وبالتوازي لإنتاج الكمية وبجودة درجة الحرارة المطلوبين في نفس الوقت.

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

الكلمات المفتاحية: سخان المياه الشمسي ذي الدوران الطبيعي، درجة حرارة خزان التخزين، سخانات المياه الشمسية، الكفاءة اللحظية، عامل تدفق المجمع، عامل كفاءة المجمع، عامل إزالة الحرارة من المجمع

Introduction

Solar energy plants are becoming more wide-spread even in northern countries because solar energy is not subject to crisis and is delivered absolutely free. The potential saving in oil and electricity is considerable [1].

Solar thermal energy is a renewable energy source widely used worldwide [2]. Applications range from domestic solar water heaters (SWHs) to sophisticated solar farms for power generation. In particular, the relative simplicity and reliability of SWHs for hot water production in the domestic and commercial sectors has been proved to be economically viable, which has led to their widespread utilization [3–9]. The basic elements of SWHs are collectors (flat plate or evacuated tubes), connecting pipes, a water storage tank, and auxiliary heating elements. To avoid damage from freezing or boiling, indirect heating SWHs would be adopted, in which a heat exchanger is used between the collector and the tank or within the tank [10]. Further, the tank could be installed either above the collectors (thermosyphon circulation) or in a lower level (forced circulation).

Of course, the use of the solar plant offers energy autonomy, consumption of clean energy (healthy environment) and saving of other energies if it is combined with them.

As an example, layout of a typical large-scale SWHs is shown in Fig. 1 (a), while Fig.1 (b) represent an arrangement of the present natural circulation system. Four collectors (an array) are arranged in parallel (cascade) with one inlet and one outlet to heat the cold water to a desired temperature, and the arrays are connected in parallel. Note that there might be no more useful energy gained by the system as an array comprising of more than three collectors. The true parallel arrangement yields maximum efficiency, economy and more quantity of hot water [11 and 12].

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

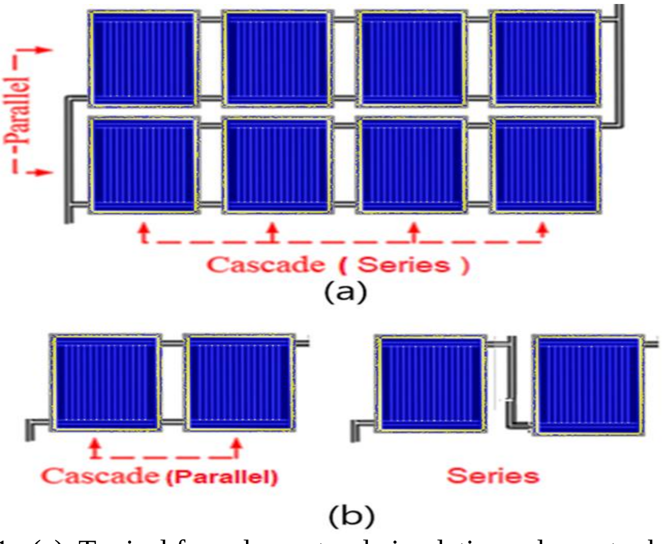

Fig.1. (a). Typical forced or natural circulation solar water heater arrangements, (b). Solar collector's arrangement connection in the present study

The basic principle of system syphonic effect (Natural circulation) operation is that the hot water rises to the top and is replaced by cold water, self-circulated (operates on the principle of different densities of cold and hot water) and mixing the collector water flow and load water consumption, which is the most common type.
The solar collectors, used in this research are non-concentrating collectors (flat plate collectors, Low temperature <100 ºC). The chosen of this type of flat plate collectors for performing the goals of the research and finding the characteristics and performance of thermosyphon circulation under series connection which comes after searching in the back ground of manufacturer impact and sounds in the area of solar water heater.

Objective of the study:
This study aims to investigate the performance of thermosyphon solar water heater in series. Two identical solar collectors are used. The characteristic equation using a statistical best trend fitting curve for each set of data performed. The objectives of the study can be

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

summarized as follows:

1. To determine the daily and instantaneous efficiencies of both system and collectors: calculating these characteristics (data reduction) using the governing equations conjunct with solar storage and solar collectors' dimensions, physical properties and other experimental data acquisition.
2. Assess the characteristic equations: Using statistical best trend curves and reassess each set of the practical data collected. The best one was the relation between the collector flow factor as a function of the collector capacitance rate.
3. Identify significant comparisons: Using different types of system arrangement and collectors' connections (forced or natural circulation with collectors connected in parallel or in series), to precisely show the differences or similarity between these types.
4. To evaluate some of practical performance limitations or optimization: Experiments conducted to clear the dust effect and collectors tilted angle on the system performance, on the other hand to optimize the system performance.

Literature review

A number of conclusion points on thermosyphon solar water heater study conducted: (1)-After a water draw-off period, the tank water would redistribute itself and temperature stratification was redeveloped within a short period under intermittent load conditions. (2)-The thermal efficiency for intermittent load conditions is about 5.8% to 7.0% higher than the value for the no-load condition. (3)-Under continuous load conditions, the temperature stratification in tanks is only preserved at flow rates less than the thermosyphon flow rate. The discharge efficiency decreases significantly for systems comprised of more than four thermosyphon SWHs, and there is no useful energy transferred to the water. The overall efficiency increases with an increase in the flow rate. Thermosyphon SWHs show more dependence on water draw-off profiles than temperature stratification in tanks. In addition, a series-parallel combination of thermosyphon SWHs would have a good performance for industrial applications [12].

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

A computer model developed for prediction of thermal performance of domestic solar water heaters, which employed thermosyphon circulation between collector and storage tank, also showed that reducing the elevation of the storage tank reduces the water flow rate [13]. The effect of storage tank elevation on the mass flow rate and system efficiencies studied, showing that reducing the elevation will reduce the water flow rate and the higher the tank position the earlier the efficiency peaks [14].

Measuring the water temperature distributions along the collector tubes, absorber plate temperature profiles at various locations along the collector studied, they clear that the absorber plate temperature is higher than the collector water temperature. This is obviously because of the heat resistance between the collector tubes and absorber plate [15 and 16].

Thermosyphon flow rate follow solar radiation trend and reach a maximum value around solar noon when solar radiation reaches its peak value studied, also they shows the system thermal efficiency and solar insolation variations with standard local time, they compares experimental and theoretical flow rates, the measured thermosyphon flow is higher than the theoretical results during the midday period because of higher velocity of flow due to higher solar radiation intensity while at the beginning and end of the day, the opposite occurred. The reason for the difference is thought to be due to the omission of a factor to allow for reflection of the collector's cover [15 and 17].

Thermal performance of thermosyphon SWHs is comparable to that of forced circulation systems [18].

The efficiency through working hours of the forced circulation system was 35% to 80% higher than that of the natural circulation system. The use of the forced circulation system may be recommended when the improvement in the system performance offsets the extra complexity and cost of the forced circulation system [19]. The connection of more thermosyphon SWHs might arise in an application when considerable hot water consumption is required, however resulting in higher mixing and less temperature stratification inside each tank and between tanks [20].

Analysis of natural circulation of compact thermosyphon solar domestic heat water system studied. They assumed that the temperature distribution in the collector is linear. The temperature rise of the water and mass flow rate are measured and calculated [21]. The maximum daily efficiency was 54% during May without water consumption and 55% with water consumption during September was concluded. The new approach can be used anywhere in the suggested months and days in a high-efficiency manner. The system also can be used commercially in industrial and domestic sectors at low cost. Their studied collector is recommended for domestic hot water use, or as an auxiliary system with a boiler system [22].

System layout

The schematic diagram of the system experimental apparatus used in this study is shown in Fig.2.

The complete solar system and apparatus are manufactured by Merloni-Company, Italy. The detail of each component of the solar water heater system are tabulated below as shown in Table 1.

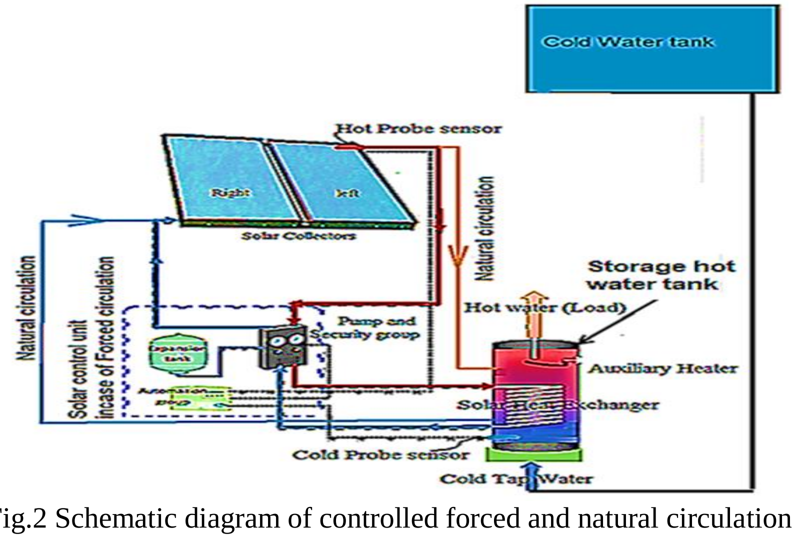

Fig.2 Schematic diagram of controlled forced and natural circulation system arrangement of the experimental apparatus

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Table 1 Specification and technical data for solar water heater system components

Item	No	Parts	Details	Remarks
Collector	2	Collector plate (Absorber plate)	0.7 mm thick, 0.92x1.86m area in total (3.42 m^2), Aluminum	Corrugated plate with Duracron S600 (PPG) acrylic paint
		Water flow pipes (risers)	0.96 cm OD and 0.8 cm ID, 1.86 m long, copper	Ten evenly spaced parallel water flow pipes (risers) bonded to plate by means of mechanical compression in semi-circular grooves formed in the collector flat-plate
		Supply and drain pipes (headers)	1.6 cm OD and 1.34 cm ID, 99.1 cm long, copper	The collectors can be connected in parallel or in series through the supply headers
		Glass cover	3 mm thick, toughened glass	Single glass cover. The space between glass cover and absorber plate is 2.8 cm
		Insulation	Polyurethane foam, 5.5 cm (back) and 1.5 cm (sides)	Space between absorber plate and back insulation 1.0 cm
		Casing	1.3 mm thick, Anodized Aluminum	
		Heat capacity	Designed collectors heat capacity in operating condition is 38.2 KJ/˚C while under no circulation is 29.3 KJ/˚C	.
Solar Storage Tank	1	Hot storage tank	Capacity of 200 Liters, cylindrical shape, 2.5 mm thick low carbon steel contains	It features a green and red light to let you know the temperature status. The digital display, the heater allows you to keep a mark on the set

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

			immersion electric heater (1.2KW capacity- single phase). Pressure 100 psi. 2.5 cm Polyurethane foam insulation covered by painted steel covers and ferrules.	temperature and display the instantaneous hot water storage tank temperature. Withstands rust and electrochemical reactions for long-term use. It is also made of premium quality materials for durability and reliability. Equipped to be used for both circulation: closed-forced circulation and open-natural circulation.
		Coiled solar heat exchanger	0.25-inch diameter, enameled steel, area of 1.11 m^2, 13.262 m long.	
		Cold Storage tank	Capacity of 2 m^3, plastic made.	supply feed water in case of any shortage of tap water
Solar Control Unit	1	Water pump	Absorbed power 36-70 Watt, 220±10%, 50 Hz, speed adjustable from 900-1300 rpm, maximum allowable pressure 7atm	Circulate solution of water, antifreeze (35 % of total circulating fluid) and corrosion proofing (2 % of total circulating fluid). In case of closed forced circulation arrangement.
		Differential thermostat	Type Ranco E 38-5000 complete with probes and probe holder, with 3 adjustable positions (Min, Med and Max)	To control the operation of the pump in relation to the difference in temperature between the hottest and coldest points in the closed solar circuit. The differential thermostat thus securing the continuous closed circulation if thermostat removed or intermittent closed flow through the collectors

		Bimetallic thermostat		To block the pump, in case the temperature of fluid inside closed circuit increases excessively
		Hydraulic air vessel	capacity of 2 Liters	To ensure the circulation without formation of bubbles or cavity occur
		Bulb water gauge		To control pressure of the closed circulating fluid
		Commutator		To exclude or connect auxiliary or heating element
		Outer box	length of 47.3 cm, width 32 cm and height of 20 cm	The whole of the control unit element is suited inside an **outer box**
Connecting pipes and Valves		Connecting pipes	½ "and ¼ "dia. Galvanized steel	All pipes coated with 2.5 cm PVC glass wool insulation
		Valves	Two gate valve ½" and check valve	To change the fluid direction and ensure non return of circulating fluid

Data acquisition:
Experiments are carried out under load and no-load, continuous and intermittent conditions. System is filled with cold water in the night before next day to perform the test. For all tests, the auxiliary heaters were not activated.
Collectors are tilted to 36˚ latitude angle within the MENA – region (Mosul city) due south.

International Science and Technology Journal
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Volume 35 العدد
Part 1 المجلد
October 2024 اكتوبر

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

This System can operate by pump (Forced circulation) without mixing the collector water flow and load water consumption -i.e. by means of coiled solar heat exchanger. In this study the system syphonic effect (Natural circulation) is investigated. It is also required that the hot storage tank to be slightly higher than the solar collectors (best average mounted 35 cm, but varied from 10 to 60 cm - above solar collectors. In this study was taken 3 5cm above collector's supply headers [23]. The feed water supplied is taken from the cold-water storage tank above it

The experimental data gathered at the end of each hour the temperature of Mean storage tank with digital gauge attached to upper third of the hot solar storage tank, while collector inlet and outlet temperature and left collector mean plate temperature observed using thermocouples connected to a digital potentiometer. Left collector thermocouple mounted at the center of plate. The collector natural mass flow rate measured by means of a dye injected in a visible tube of known inside diameter and length and hence the flow rate is derived. The solar insolation is measured by means of a sensible pyrometer connected to the potentiometer to read the value in mv then to calibrate data, where 11.5 mv is equivalent to 1 KW/m^2.

The dust effect done by following procedure steps: a quantity of fine dust taken and sift with a fine sieve over the glass surfaces at a distance of two meters above them until to be sure that there is a thin layer and fine distribution of dust is covering the glass surfaces.

All the experiment was performed under clear skies condition, no wind effect, at or around the mid-month either in winter or summer and the solar insolation are taken at the same collectors tilted angle. Also, at the start of each experiment the collectors glass covers are cleaned. Collectors are connected in Series otherwise if stated.

Results and Discussion

The experimental data listed, tabulated and charted using Excel program to be reduced and presented in the form of graph and processed using the performance data analysis characteristics equation for more valuable and important results.

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

System performance is categorized according to the influence of the following factors. The equations governing the derived characteristics, the comment and discussion on each of these variations as follows:

A. Characteristics variation with local time:

Several Figures reflected this effect. First of all, distribution of the ambient temperatures and insolation with local time, as shown in Fig. 3. It is clear that April was of highest solar insolation and that is due to clear, visibility, purity of sky from dust particles and small-scattered radiation portion.

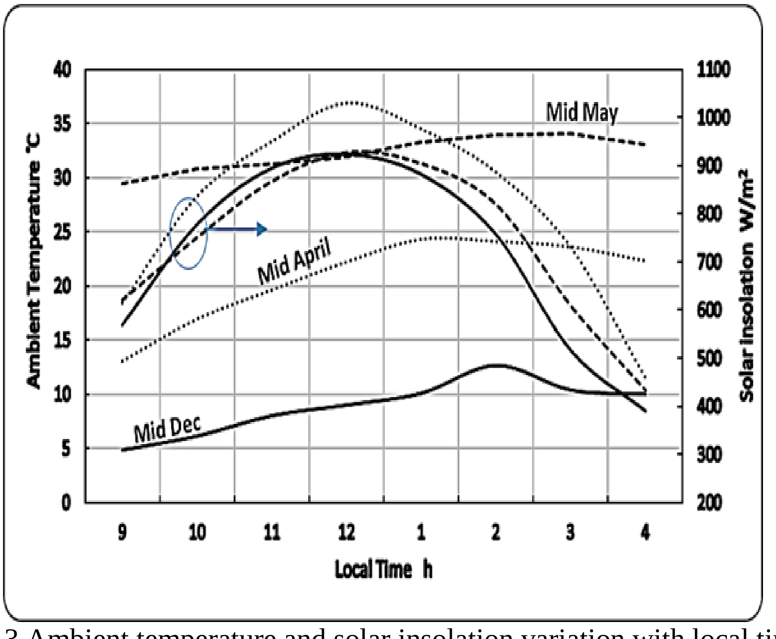

Fig.3 Ambient temperature and solar insolation variation with local time at mid-month

Fig. 4 show the temperature distribution of the left collector mean plate temperature and collector water inlet and outlet temperature with local time under constant continuous load (m_L= 60 Lit/h) and no-load condition.

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

The highest plate temperature (100 ˚C or even more) with no circulation of both collector and load condition, indicate the high quality of the solar collectors even during the cold season. The gradual change in either collector inlet or out let is so clear and obvious around the season. It is effectiveness becomes so vigorous as with water consumption rises, due to more transfer of heat to circulated water.

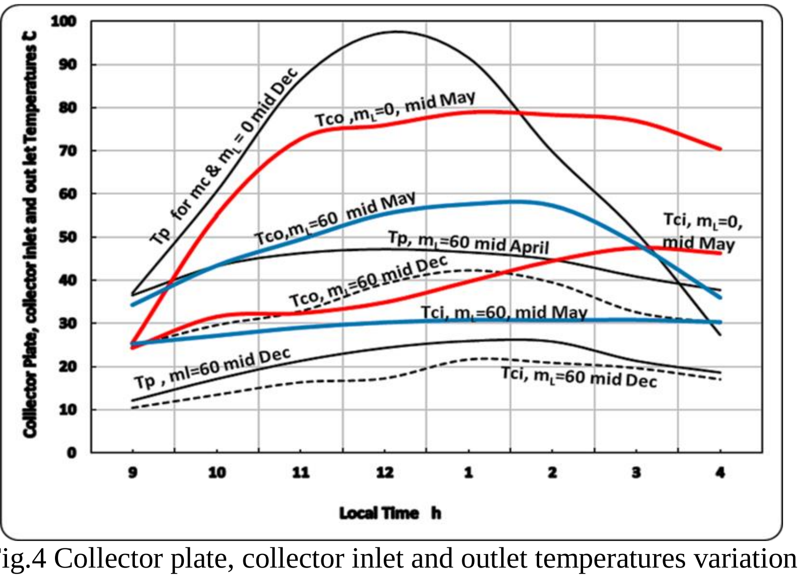

Fig.4 Collector plate, collector inlet and outlet temperatures variation with local time at mid/around mid-month at Load =0 and 60 L/h

Figures 5-8 indicate the variation of the mean storage tank temperature around or at a mid of several months starting from December towards May under load either constant continuous or intermittent load and no-load condition with local time, the effect of season and load to enhance the capacity of solar collectors to gain more amount of useful heat to be added to the consumed water for users. Mid-June was the highest month in storage tank accumulation of hot water under intermittent use of supply hot water as it is reflecting the applicable condition. Reaching the temperature of the mean storage tank above 60 ˚C for other cases or no load will give

opportunity for good saving with other auxiliary heating when it can be used in any other time especially at night time.
Symbols to be defined to eliminate the size of words repetition:

SF- Series forced circulation arrangement
PF- Parallel forced circulation arrangement
SN- Series natural circulation arrangement
NWOD- Natural series circulation without dust
NWD- Natural series circulation with dust.

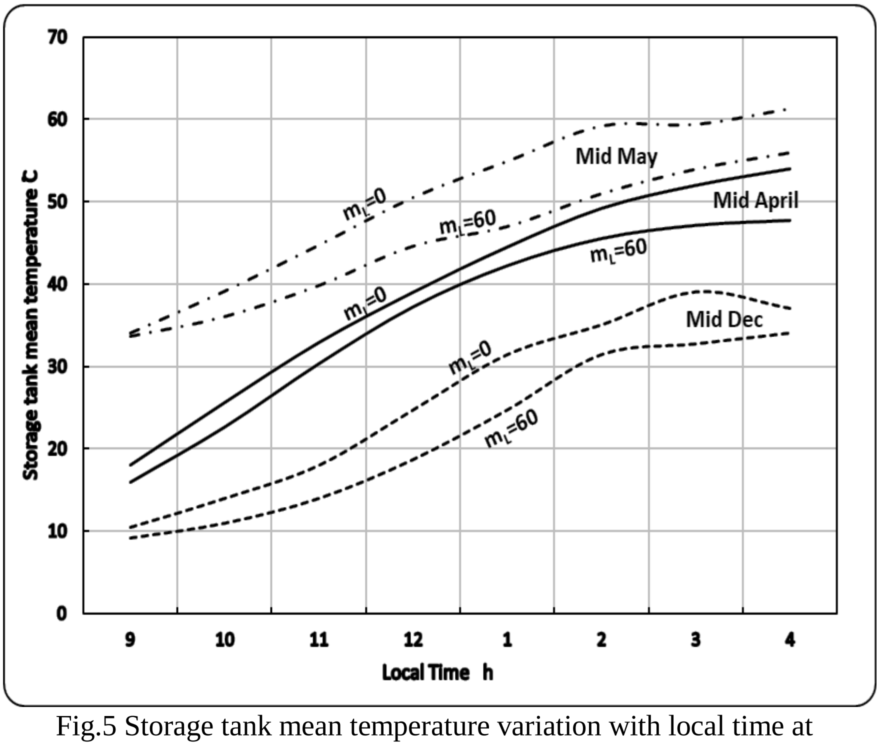

Fig.5 Storage tank mean temperature variation with local time at mid/around mid-month at Load = 0 and 60 L/h

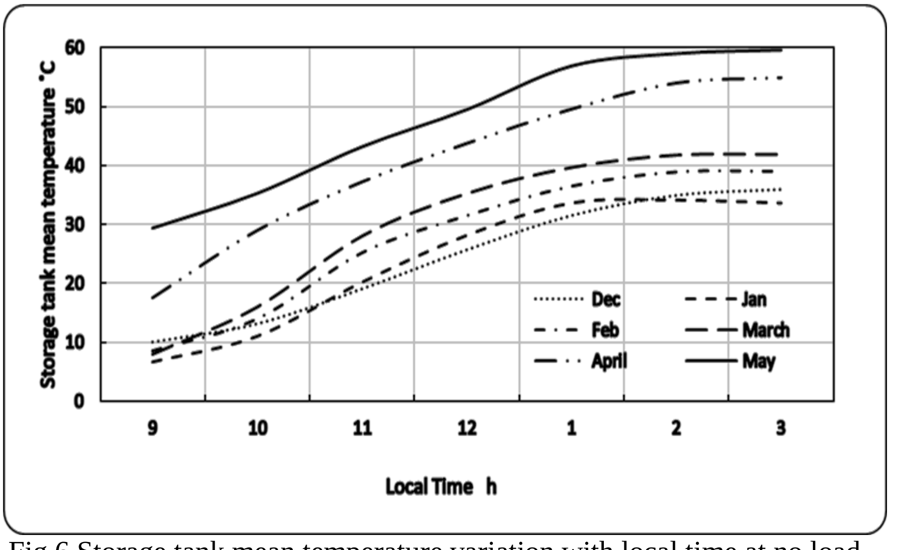

Fig.6 Storage tank mean temperature variation with local time at no load and mid-month

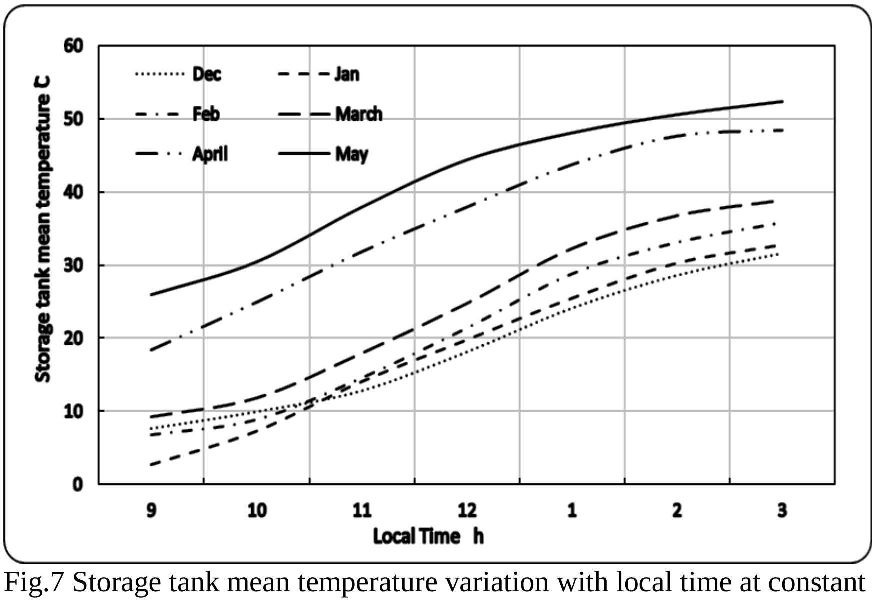

Fig.7 Storage tank mean temperature variation with local time at constant continuous load 60 L/h and mid-month

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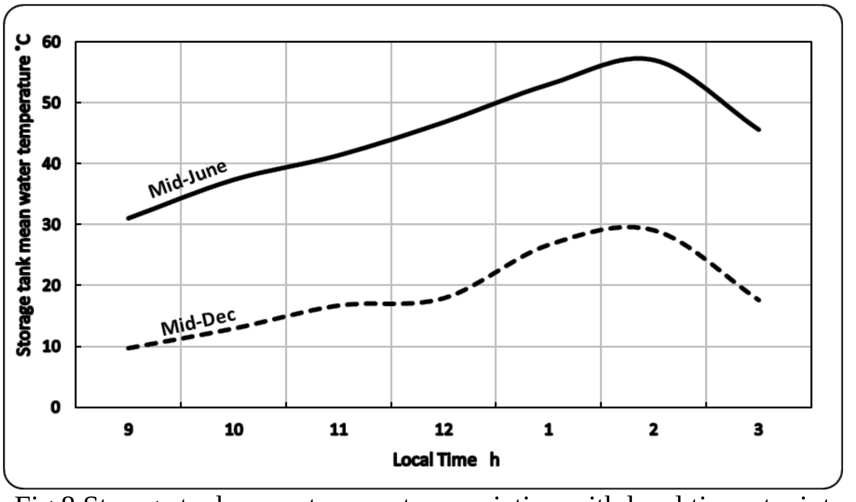

Fig.8 Storage tank mean temperature variation with local time at winter and summer under different intermittent load

Fig. 9 gives a good comparison between different system arrangement to pick the best one for domestic purpose. As shown, the comparison case of Sf with PF, it is clear that series collector connection arrangement is better.

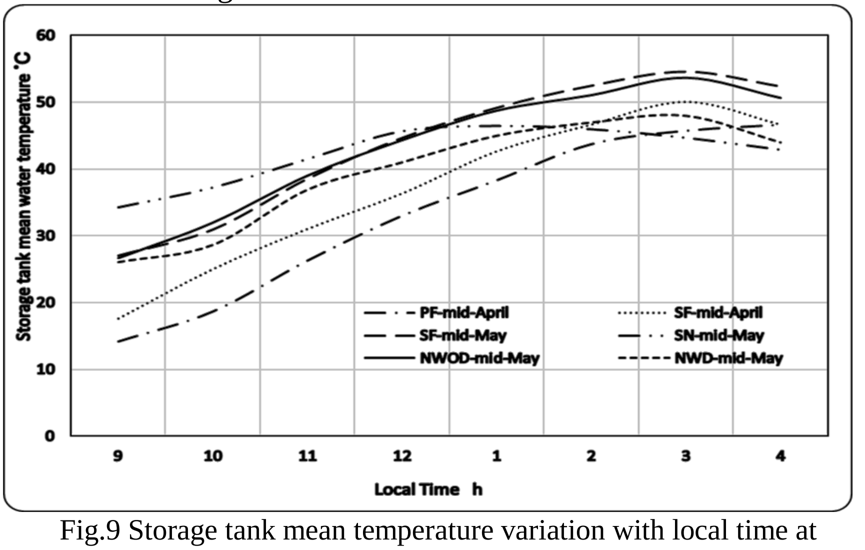

Fig.9 Storage tank mean temperature variation with local time at mid/around mid-month for various system operation and constant continuous load 60 L/h

وتم نشرها على الموقع بتاريخ: 15/ 2024/10م تم استلام الورقة بتاريخ:2024/9/20م

The case of comparison Sf with SN, it is clear that the effect on mean storage tank temperature (Tsm) are interchanged at Noon (SN better working before Noon) and vice versa. The reason for that might be because of lower thermosiphon collector flow rate due to lower difference in temperature between collector headers.
The case of dust comparison, it is obvious from the traces of temperature profile the effect of dust reduction and drop in (Tsm). The maximum reduction evaluated from the experimental data as shown:

$$\% \, Reduction \; in \; Tsm = \frac{(Tsm_{NWOD} - Tsm_{NWD})}{Tsm_{NWOD}} x \; 100 = \frac{53.6 - 48}{53.6} x100 \sim 10\% \qquad 1$$

From this figure percent, it is strongly recommended to clean the collectors glass cover surfaces by the house holder at least once per week, while in case of industrial users should be done using a digital swiped controlled motor, similar to that used in vehicles cleaner.
Fig. 10, clear the variation of the system instantaneous efficiencies ($\eta_{inst.}$) and collector mass flow rates (m_c) with local time, at mid or around mid-May.

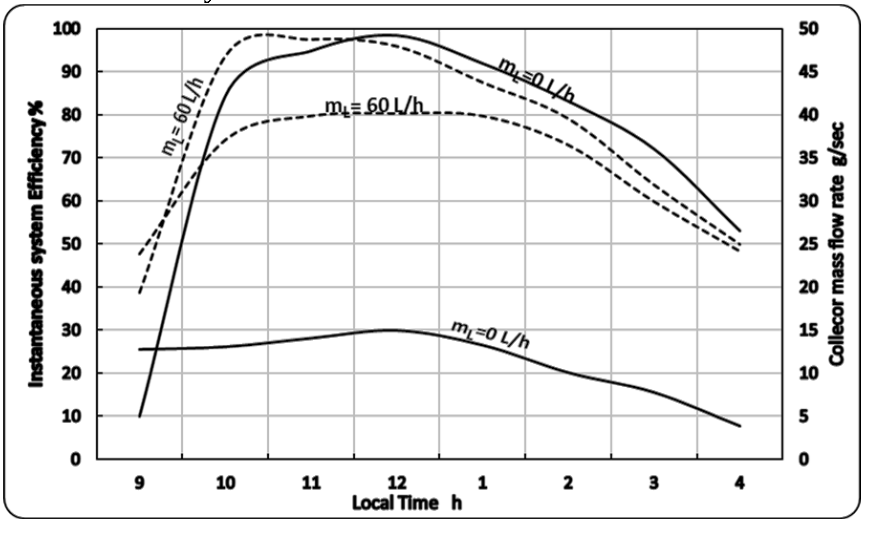

Fig.10 instantaneous system efficiency and collector mass flow rate with local time at mid/around mid-May under no load and load 60 L/h

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

Higher collector flow rate for higher load condition and vice versa. The instantaneous system efficiencies interchanged as stated before in Fig. 9, keeping the same difference and quality, due to the same reasons.

B. Characteristics variation in between

Before going furthermore, it is suitable to clear the definition of some important factors that govern this system performance and derived from the current experimental data obtained .Thus, at least two factors are joined together to predict a suitable governing equation and to reflect more valuable and important characters. The new characters are:

– **Efficiency η**

Efficiencies related to this natural circulation system are of two types:

1- System efficiency η_S:

The ratio of heat gained by solar storage tank to the tilted solar insolation multiplied by solar collectors' area over a period of time say an hour or a day. Mathematically:

$$\eta_s = \frac{Q_u}{A_c . I_t} = [\frac{m_L\, C_P\, \Delta T_{Storage\ tank}}{A_c . I_T}]_{over\ a\ period\ of\ time} x100 \qquad 2$$

Where:

m_L: Mass flow rate of drained water (useful hot water consumed); (Kg/sec)

Qu: Useful energy gained by solar storage tank; (W)

Cp: Specific heat of water; (J/Kg. ˚K)

$\Delta Ts_{torage\ tank}$: Difference in water temperature between outlet and inlet of storage tank [; (˚K)

Ac: Net collector surface area; (m^2)

I_T : Tilted insolation on surface of collector;(W/m^2)

So, you could say **system hourly efficiency or daily efficiency** …etc. but if taken all at one time say at noon, then it will be called **Instantaneous System efficiency** (η_{inst}-s) because there is no period of time.

2- Collector efficiency η_C:

The ratio of heat gained by solar collectors to the tilted solar insolation multiplied by solar collectors' area over a period of time say an hour or a day. Mathematically:

$$\eta_c = \frac{Q_u}{A_c \cdot I_t} = \left[\frac{m_C\, C_P\, \Delta T_{Solar\ collectors}}{A_c \cdot I_T}\right]_{over\ a\ period\ of\ time} x100 \qquad 3$$

Where:
m_C: Mass flow rate of circulated water through collectors (Kg/sec)
Qu: Useful energy gained by Solar collectors; (W)
$\Delta T_{Solar\ collectors}$: Difference in water temperature between outlet and inlet of collectors [Tco – Tci]; (˚K)
So, you could say **<u>collector hourly efficiency or daily efficiency</u>** …etc. but if taken all at one time say at noon, then it will be called **Instantaneous Collector efficiency** (η_{inst}-c) because there is no period of time.

– **Dimensionless collector flow capacitance rate** $\frac{G \cdot C_P}{U_L \cdot \bar{F}}$

This dimensionless term is involved with several other terms, first to define the **collector flow factor** (F'') which is the ratio of the collector **heat removal factor** (F_R) to **collector efficiency factor** (F') [10]. These factors can be verified in details, which has strong relation with the dimensionless collector flow factor as follows:

$$F_R = \frac{G \cdot C_P}{U_L \cdot \bar{F}}\left[1 - e^{\left[-\frac{U_L \bar{F}}{G \cdot C_P}\right]}\right] \qquad 4$$

$$\bar{\bar{F}} = \frac{F_R}{\bar{F}} \qquad 5$$

$$\bar{F} = \frac{U_o}{U_L} \qquad 6$$

Where:

وتم نشرها على الموقع بتاريخ: 15/ 10/2024م   تم استلام الورقة بتاريخ:2024/9/20م

G: Ratio of collector mass flow rate (m_c) to collector surface area (A_c); (Kg/sec.m^2)
U_L: Over all heat transfer coefficient from whole collector;(W/m^2. ˚C)
U_O: Heat transfer coefficient from collector plate to ambient through glass cover (i.e due to temperature difference {Tp – Ta}; (W/m^2. ˚C)
Fig. 11, shows the variation of the collector daily efficiency with collector tilted angle, it is clear that the efficiency increases and reach the maximum value at an angle equal to the latitude angle of a place plus 10 deg. A linear trend fitted to the data and get a characteristic equation.

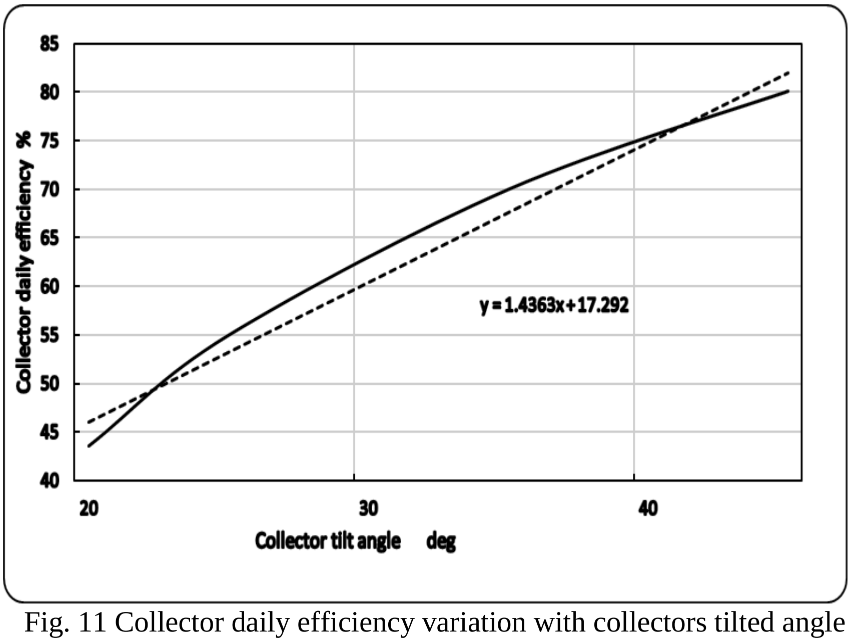

Fig. 11 Collector daily efficiency variation with collectors tilted angle

All the remaining figures 12-14 being plotted and a best linear or logarithmic trend curve were fitted to the experimental data which is quite clear without any doubt the certainty of data collected and the accuracy, as the trend fitted very highly or with small fraction deviation.

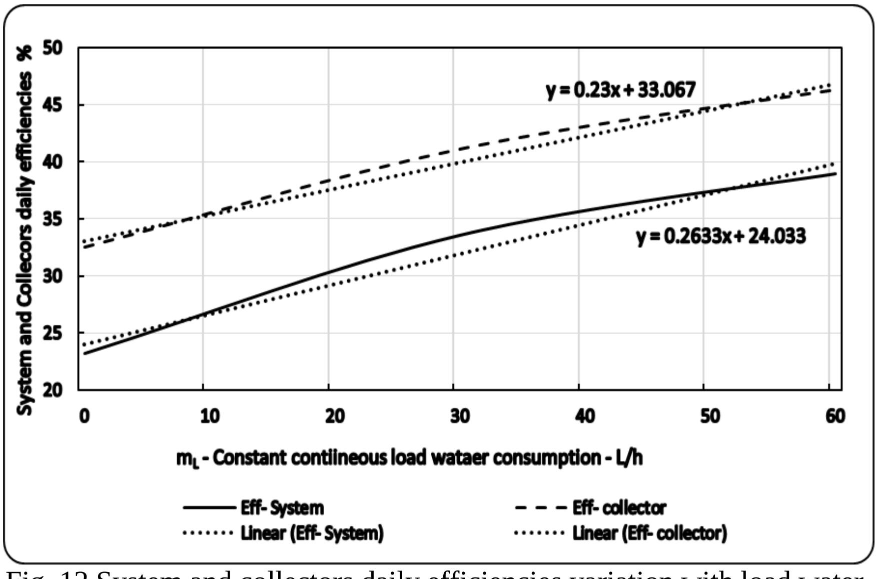

Fig. 12 System and collectors daily efficiencies variation with load water consumption

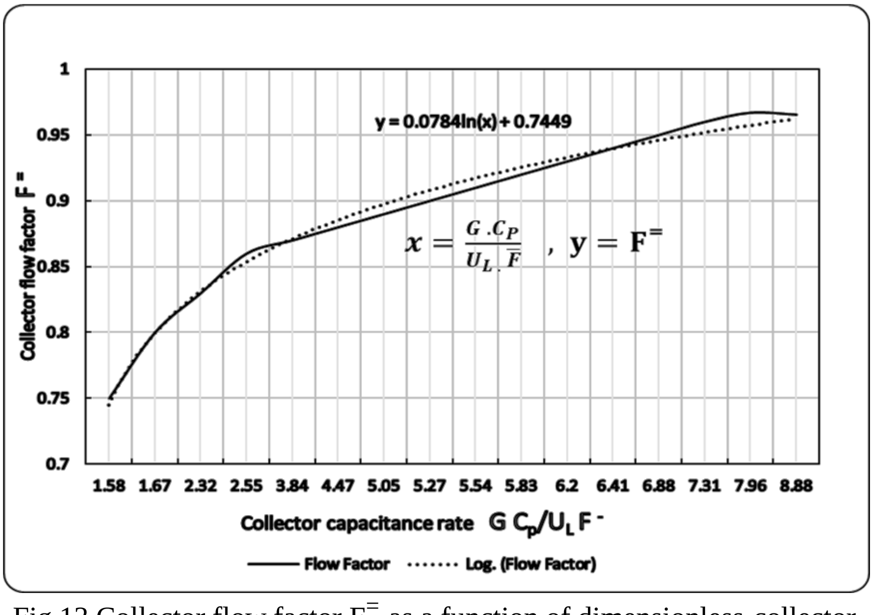

Fig.13 Collector flow factor $F^{=}$ as a function of dimensionless collector capacitance rate

تم استلام الورقة بتاريخ:20/9/2024م وتم نشرها على الموقع بتاريخ: 15/ 10/2024م

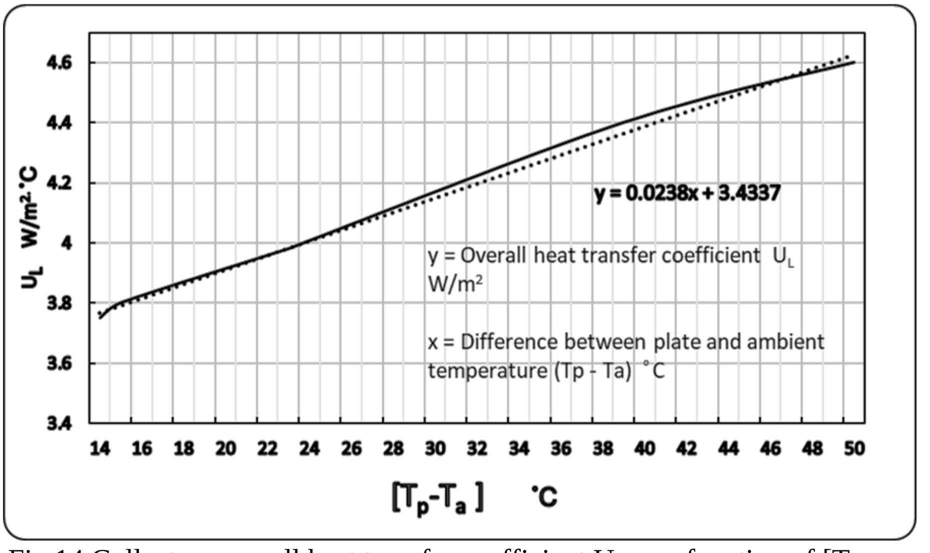

Fig.14 Collectors overall heat transfer coefficient U_L as a function of $[T_P - T_a]$

The best trend linear or logarithmic equations fitted to the experimental data are as follows:

1. **Collector tilted angle**

$$y = 1.4363\ x + 17.292 \qquad 7$$

where y = collector daily efficiency %
x = collector tilt angle deg

2. **System daily efficiency η_S**

$$y = 0.2633\ x + 24.033 \qquad 8$$

where y = system daily efficiency %
x = load water consumption L/h

3. **Collector daily efficiency η_C**

$$y = 0.23\ x + 33.067 \qquad 9$$

where y = collector daily efficiency %
x = load water consumption L/h

4. **Collector flow factor F″**

$$y = 0.0784\ ln(x) + 0.7449 \qquad 10$$

where y = collector flow factor F”
x = collector capacitance rate $\frac{G\ .\ C_P}{U_L\ .\ F}$

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

5. Collector overall heat transfer coefficient U_L

$$y = 0.0238\,x + 3.4337 \qquad 11$$

where y = overall heat transfer coedfficient from collector W $/m^2$.°C

x = temperature difference between collector plate and ambient temperature (Tp – Ta),°K

The last two characteristic equations are of important and potential effect on the design of both solar collectors and storage tank capacity. The basic relation to estimate the storage tank capacity volume is that: 1m^2 of collector area will need a 60 Lit of storage tank volume capacity. Furthermore, it can calculate the required collector area for any certain purposes as the temperature difference between mean plate and the mean ambient temperature of place are known. In addition, these characteristic equations can also calculate any desired values and compared with graph.

For example:

Using equation 7 with value of. x= 30 degree the value of y = collector daily efficiency = 60 %. Compare this value with graph plotted in Fig.9. the same value will be obtained, similarly with other characteristic equations with either fit or less than 2-3 % of discrepancy.

The limitation factors which are not evaluated in this study, have also strong influence and reduction on the system performance among these were: wind velocity, cloud weather which has to be considered and highlighted, meanwhile the places located within MENA region has of little influence on the performance of such a system as the latitude angles vary between 30-36 which has nearly the same solar insolation profiles.

Conclusions and Recommendations:

The results obtained from this study lead to a number of observations as follows:

تم استلام الورقة بتاريخ:2024/9/20م وتم نشرها على الموقع بتاريخ: 15/ 2024/10م

1. For the existent natural circulation solar water heater of 3.4 m^2 area and load of 360 Lit/day of hot water at a mean water temperature at least 60 ˚C around whole year, it can be of good quality to be used in domestic hot water with large amount of energy saving
2. The height of the hot water storage tank installation above the solar collector's upper header should not exceed 60 cm, to ensure the thermosiphon effect. The best average height is 35 cm.
3. To assure the high efficiency and best natural solar heater performance, the collectors in MENA region must be tilted in winter season plus ten degree of the place latitude angle and minus 10 degrees in summer season.
4. The collector arrangement in series connection for both natural or forced circulation are of high gain in energy and higher of storage tank mean water temperature.
5. Dust effect is a strong parameter in MENA region where the highest effect during May month were vigorous sandy storm born and result in drop down of the solar system efficiency about 10% at least.
6. Characteristic predicted equations for several solar systems parameter is obtained to facilitate and simplify the future research and more focus on other parameters.
7. Possibility using this kind of Natural or forced circulation with series connection with suitable arrangement on large scale to produce high quality in temperature and high quantity amount of water for MSF desalination purpose or for central heating or cooling in industrial sectors.
8. Investigating the performance of the system under different climatic conditions, exploring alternative collector configurations, or examining the impact of different storage tank designs.

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