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The impact of aging and mechanical destruction on the performance of the flat plate solar collector in Tafila city climate in Jordan

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Abstract:
This paper investigates the effect of aging and mechanical destruction on the performance of the flat plate solar collector. Two identical flat plate solar collectors (FPSC) are tested simultaneously under same working conditions to compare the performance of heat energy absorbed. One solar plate is painted black color and the second one is painted light grey color. The black one represents the new collector after working for short time of period while the second one (light grey collector) represents the collector after years of working. The two FPSC are used to heat water of mass flow rate 0.015 kg/s. The Maximum temperature of water was achieved using the black collector. The temperature of water output from the collectors for black and light grey absorber was 90^0C and 44 ^{0}C respectively with absorbing 470 W/m^2, whereas the output temperature for broken glazing black and light grey painted was achieved 65^0C and 34^0C respectively by absorbing 410 W/m^2. Average efficiency of FPSC for black and light grey absorber are found 55% and 12% respectively, while for broken glazing black and light grey absorber about 35% and 8% respectively.
Keywords: Renewable energy; solar heater; colored absorbers collector.

I. Introduction

The flat plate solar collector is one of the most widely used device for conversion electromagnetic wave (solar radiation) to useful energy as a form of domestic hot water in Jordan. The solar thermal energy can be used in solar water heating systems, solar pool heaters, and solar space heating systems.

The popular flat plate solar collector is an insulated metal box with a glass or plastic cover and painted absorber plate usually black color. These collectors heated the liquids or air to temperatures up to 80^0C (Strukmann et al.) [1].

Nakoa et al. [2] tested four heaters built-in-storage type solar water collectors. Maximum temperature of water is achieved when the heater is painted black. In the month of March, temperature of water is achieved 54^0C for black absorber absorbing 542 W/m^2, 50^0C for blue absorber absorbing 448 W/m^2, 430 º C for red brown absorber absorbing 341 W/m^2 and 41^0C for colorless absorber absorbing 336 W/m^2. Monthly average efficiency of BSWH with black absorber is 57% in February and 56.5% in March, the blue absorber is 53% in February and 50% in March, the red brown absorber is 41% in February and 40% in March and with colorless absorber is 35% in February and 35% in March respectively.

Y. Tripanagnostopoulos et al. [3] designed and tested flat plate solar collectors with different colors of absorber works for heating water. The comparison of the yearly efficiency of glassed, insulation type collectors. This study showed that for usual temperature (40^0C) the collectors of blue color α = 0.85 and red brown α = 0.75 have a 20% and 40% lower efficiency, respectively, but the collector of black absorber α = 0.95.

Sakhrieh et al. [4] tested five types of solar collectors. The system involved in this study are blue and black coating-selective copper, copper, and aluminum collectors in addition to evacuated tubes collectors. The ambient temperature in the range 18-26^0C, and solar radiation intensity ranged from 154 to 1004.33 W/m^2. Results showed that evacuated tube, blue and black coating-selective copper collectors are recommended for medium and large scale applications due to their long life, high efficiency and easy of maintenance. Aluminum collectors are recommended for small applications.

Kalogirou et al. [5] tested solar collectors with different colored absorbers in a large hot water system. The collectors are analyzed with respect to their performance and practical applications. The results showed that although the colored collectors present lower efficiency than the typical black. The colored collectors (α = 0.85) give satisfactory results regarding of the drop of the amount of collected energy for the different location (about 7-18%), compared to collectors with black absorbers (α = 0.95). This implies the use of proportionate larger collector aperture are to have the same energy output as that of typical black colored collectors.

Streicher et al. [6] - represents a comparison of characteristic collector efficiency for the new and the exposed (aged) collectors. The comparison of the conversion factors in new state after the exposure results in an average reduction of 2.6%.

Fan et al. [7] tested of 12.5 m^2 flat plate solar collector exploited since 1983. From that period of time the efficiency of collectors increased due to technical improvements in terms of collector design. The thermal performance increased by 29%, 39%, 55% and 80% for a mean solar collector fluid temperature of 40^0C, 60^0C, 80^0C and 100^0C respectively. Due to the aging turned out that the Ottrupgard collector has a yearly thermal performance which is 4% lower than for the collector tested in 1991 for a solar fluid temperature of 45^0C, while the Marstal collector has a yearly thermal performance which is 1% lower than the collector tested in 1991.

Unfortunately, there are a limited amount of literature tested the collector lifetime and deterioration of the collector thermal performance due to aging.

Carlsson et al. [8] watched actually and predicted of degradation of solar collector in-service of nickel pigmented anodized aluminum absorber coating for solar domestic hot water systems for collectors used for a period of 10 years or more. Its expected that the service life for the coating is of the order of 30-40 years in an airtight, while in a non-airtight collector the life is shortened to 5-10 years.

In practice the main collector lifetime problem in Jordan has been damage by children throwing stones at the glazing, a problem also associated with low quality materials used for the paint of the absorber, so after a short time, the paint begins to peels off, and leaves the collector with almost light grey even white color.

When it comes to statistical data, we note that, more than 24% of domestic homes in Jordan, uses solar energy by conversion it in flat plate solar collectors to an useful energy as a domestic hot water, Jordan in Figures [9].

The aim of this study is to investigate the degradation of paint on the performance of the flat plate solar collector used in Jordan in climate condition of the Tafila City. The problem presented above is a serious problem. Figures below depict four collectors used in Tafila City. Figure 1. (A) represents a new collector working one month, while figure (B) represent collector after 5 years of exploitation, whereas figure (C) shows the collector exploited 10 years, while (D) represents collector working 10 years and on the last two years the glazing partially has been destroyed.

Most people in the country do not inspects these collectors for a long time even they have no idea how these changes in color of absorber and partially destroyed glazing affects the efficiency of the system. The structure of this paper starts by surveying the published paper of the effect of aging on the performance of the flat plate solar collector in section one. The experimental approach and setup was presented in section two. Section three shows the result and discussion. Finally, section four summarizes the study findings through the conclusion.

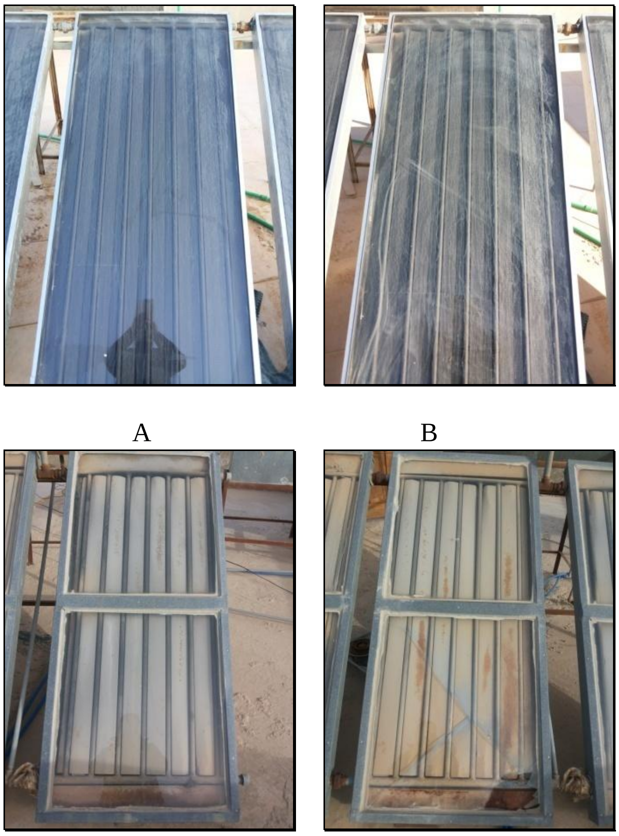

Figure 1. Authentic exploited and operated flat plate solar collectors for domestic hot water in Tafila City (A- exploited one month; B- exploited 5 years; C- exploited 10 years; D- exploited 10 years and partially destroyed glazing)

II. Experimental setup and test procedure

Several experiments were carried out to study the effect of aging on the performance of the flat plate solar collector in Tafila Technical University, Mechanical Engineering Department, Tafila, south of Jordan (30° 50′ 9″ N, 35° 36′ 44″ E). This location is suitable to run the experiment because it receives sufficient amount of sun radiation to conduct the experiment. The figure 2. shows the experimental apparatus and measurement devices. The two solar collectors flat plate of the same size have been used for the test. The existing solar collectors has a dimensions of 70 x 60 cm, volume of each collector tube 0.32 ltrs and is a single glass cover. The plates consist of tubes made of copper. While the absorber (named as black) made of copper with a black chrome selective surface, while the second collector (named as light grey) also made of copper with a white chrome selective surface, the plates has 3 cm Rock Wool insulation, and cased by a frame of Aluminum. The flat plate solar collectors mounted on a frame at 45 degree angle. The water flow on the flat plate collectors is natural circulation, These collectors are working in an open system, almost constant water temperature (about 20^0C) and constant flow rate from the upper reservoir flow through collectors, and flow out from the collectors.

Type K thermocouple was used to measure inlet and outlet of the solar collector temperatures. The thermocouple at the inlet placed in the flow stream one centimeter before collectors, and the thermocouple at the outlet placed in the flow stream one centimeter after the collectors. To account the intensity of solar radiation, the pyranometer is used. The water inlet and outlet temperature, water flow rate, solar radiation, ambient temperature are recorded hourly.

The feed water tank filled with fresh water. The uncertainty analysis for experimental measurements is given as follows:

Error due to thermocouple wire calibration = ± 1.0%
Error due to thermocouple wire itself = ± 0.80%
Error due to wind speed measurement = ± 2.0%
Error due to solar insolation measurement = ± 1.1%
So the total error in the study is = ± 4.9%.

Fig. 2. The used system for implementing the experiment

Data are collected and plotted in a graph. Data analysis from the graph is essential to obtain the efficiency of the flat plate solar collector. The efficiency of flat plate solar collector is determined by the quantity of the solar energy absorb by absorber plate and delivered as a useful energy to the working fluids[D. Yogi Goswani, F. Kreith, F. Kreider, 1999] [10]. For flat plate solar collector, the useful heat gain (Q_u) can be calculated by the formula:

$$Q_u = m\, C_p\, (T_{outlet} - T_{inlet})$$

Where:

Q_u : Useful heat gain and absorbed by flat plate solar collector (W)

m : Mass flow rate (kg/s)

Cp : Water heat capacity at constant pressure (kJ/kg K)

T_{outlet} : Water outlet temperature (^{0}C)

T_{inlet} : Water inlet temperature (^{0}C)

After calculation the useful heat gain, (Qu), the efficiency of the flat plate solar collector calculated using the following formula:

$$\eta = Q_u / I_t A_C$$

Where:

I_t : Energy gain from solar radiation (W/m^2) - measured by Pyranometer

Ac : Collector absorber area (m^2)

III. Results and discussions

Two solar flat plate collectors with different colored absorber plates and having plate glazing cover were tested experimentally. Various curves are plotted as shown from figure 3 to 6.

Figure 3. shows the solar radiation in the two days of 13, 16 Nov. 2013. versus period of time.

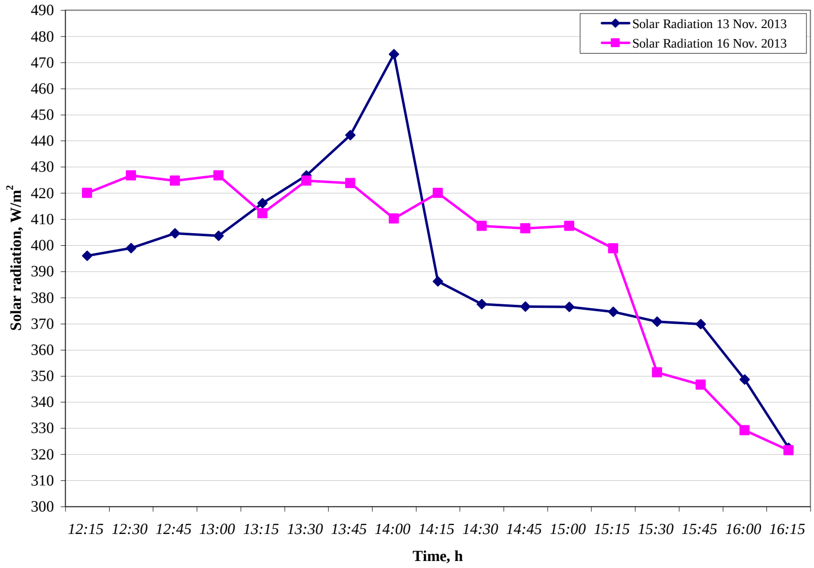

Fig. 3. The changing of solar radiation within the time (data collected 13, 16 Nov. 2013)

It was shown after (14:00) and for (13 Nov. 2013) when the weather becomes cloudy, the radiation decreasing to about 375 W/m^2, and before sunset reached minimum about 320 W/m^2 (16:15). Fluctuation of solar radiation on (16 Nov. 2013) more regularly, because the weather was not cloudy.

Ambient temperatures and output water temperature for all flat plate collectors are shown on figure 4.

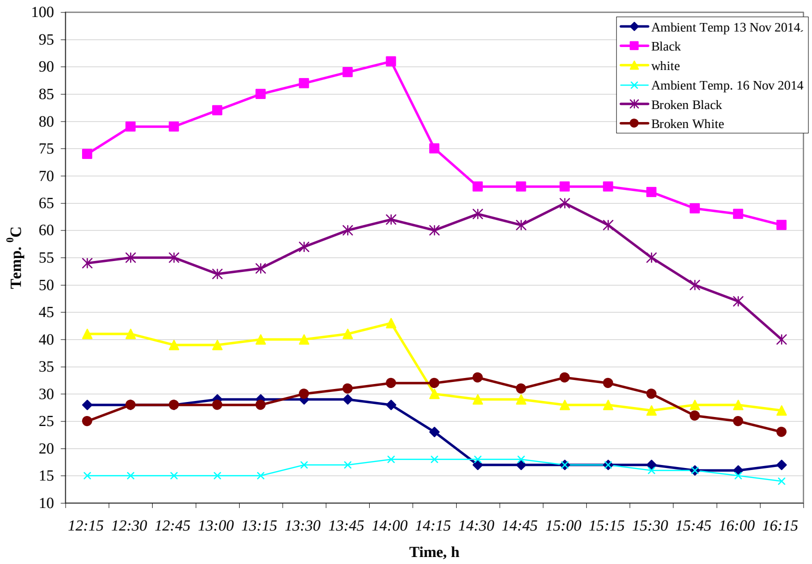

Fig. 4. The changing of output temperature from the flat plate within the time (data collected 13, 16 Nov. 2013)

Its observed from this figure that as the time increases and at (14:00) the outlet temperature for collector with black absorber increases sharper than the collector with light grey absorber. A maximum temperature was achieved for the black absorber and light grey 91^{0}C and 43^{0}C respectively. During the experiment water temperature for both collectors at the output suddenly decreased after (14:00). The reason of this phenomena is that the weather changes to cloudy state and by the end of the experiment was also almost cloudy, so the temperature reached value for black and light grey absorbers about 65^{0}C and 30^{0}C respectively. Another observation it despite the changes in weather, the temperature difference for both collectors remains almost constant.

Also from the figure 3. we observed that the solar radiation at (13:30) is conforming for the days (13, 16 Nov. 2013) and reached value about of 412 W/m^2. Figure 4 shows when the glazing covering the collector is destroyed compared with undestroyed collector, the temperature at the output of black plate about 86^0C; light grey plate 40^0C; destroyed black plate about 67^0C and about 30^0C for destroyed light grey plate (named as white in figures). Figure 5. shows one of the most important parameters characterized for flat plate solar collector, its capacity.

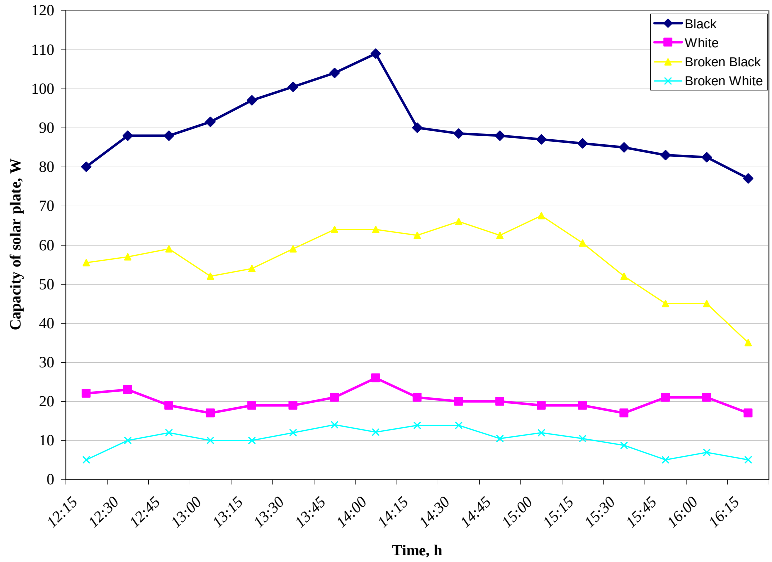

Fig. 5. The changing of capacity within the time (data collected 13, 16 Nov. 2013)

From the above figure, we can conclude that the black absorber capacity strong fluctuated, obtaining values of 80 to 110 W, but in the case of light grey absorber variations are smaller and gets the values of about 20 W. In the case of the destroyed glazing of black plate the variation receives on the level 50 to 70 W up to time (15:00) after that the capacity dramatically decreasing, achieves value about 35 W at (16:15), while for the destroyed glazing of light grey plate, these fluctuations are smaller and receives on the level of 10W.

Figure 6. displays the most important indicator, that means efficiency. It has been calculated for both solar collectors smooth and destroyed.

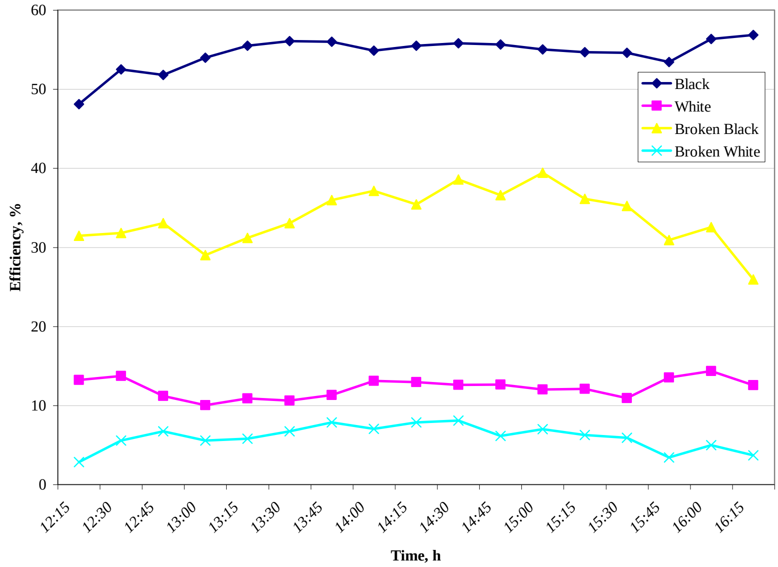

Fig. 6. The changing of collectors efficiencies within the time (data collected 13, 16 Nov. 2013)

From the figure 6. its evident that the efficiency of collector with black absorber obtained maximum value reached 57%, and on the same time the fluctuation is minimum. For the light grey absorber collector the efficiency receives on the level of 12%, also the fluctuation are minimum, while the variation is bigger for destroyed glazing of black plate, varies between 29 – 39 %, likewise for destroyed glazing of light grey plate, varies between 3 – 8 %.

IV. Conclusion

This manuscript describes an experimental investigation of the impact of aging and mechanical destruction on the performance of the flat plate solar collector. The two solar collectors flat plate of the same size have been used for the test. The main results are summarized as follows:

- From the presented graphs and for period from (12:15 to 14:00) , can be noted that the paint of absorber influences very strong at the temperature of hot water at the output of collector, which reaching difference about 45^0C between black and light grey absorber. At the same time this difference about 35^0C for smooth and destroyed collector with black absorber.
- The capacity of black absorber, obtaining average value of 95 W, and decreasing significant for light grey absorber reached average value about 20 W. For destroyed glazing of black plate the receives average value of capacity about 55 W, and for the destroyed glazing of light grey plate reached capacity only 10W.
- The efficiency of collector among all the period (12:15 to 16:15) with black absorber reached average value 57%, and 37% for destroyed glazing of black plate. For the light grey absorber collector the efficiency receives on the level of 12%, and 6% for destroyed glazing of light grey plate.
- Consequently the losses in the event of negligence’s the paint of absorber plate reached 45% and reached 20% for destroyed glazing.

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