Experimental study of a New-Design Air Solar Plate Collector used in relation with the operating conditions in a solar Desalination Process

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Abstract

In the course of the actual work, the efficiencies of this collector design have been experimentally investigated using an existing set–up for an indoor and an outdoor testing of collectors. Indoor experimental results of the performance of the collector will be presented. Graphs of efficiency as a function of the collector's reduced temperature were established for variable collector operating conditions. Solar irradiation intensity, airflow rate, wind velocity and temperature and air inlet temperature were variable and adjusted to get the collector efficiency at every possible location in a new solar desalination process .The response of the collector outlet temperature and the endurance–test on the collector has also been done.

Keywords: Solar Desalination, Recoverable Energy, Solar Collector

1. INTRODUCTION

The main investment costs' of a solar desalination plant are due to the large area of solar collectors that is required. Therefore, it is economically essential for the desalination process to minimize the costs of the collectors used. However, an important criterion in this issue is the efficiency of the collectors and its dependence on the average operating temperature. The material of the collectors will also play an important role in relation to the optimization of the plant economy. A new collector was specially designed for such aim. The present new design of the solar air collector was developed and patented in order to use it in the new solar desalination process as a heat carrier. The new desalination process using stepwise heating-humidifying procedure was developed based on low-cost air solar plate collectors (Brendel, T.2003- Chafik, E.1996 – Chafik, E.2002). The solar heat will be transferred to air stream flowing in the plate collector. A second impact of the present process is the successive loading of air up to a relative high amount of vapor such as 20 weight percent. Such a high concentration is usually attainable by spraying water in air heated up to 500°C. The present process achieves the same effect at operating temperature not exceeding 100°C. The current new desalination technique by Multiple-Effect-Humidification was experimentally investigated and its principal operating parameters were optimized (Ben Amara, M.2001).

The new-design of solar plate collectors has been developed in order to use to heat the air in the present new desalination process (Chafik, E.2002- Ben Amara, M et all. 2002). The present new design of the solar air collector was developed and patented by Chafik (Chafik, E.1999) in order to use it in the new solar desalination process as heat carrier. As published in (E.Chafik 2002) the cross-section of the air collector design is presented in Fig.1. It consists of a poly-web channels polycarbonate plate of 5 m long with inserted darkened aluminum strips. The absorbing strips are inserted in the bottom channel, which is considered as the airflow channel. The upper two chambers rows serve as two insulating layers where air stagnates. The main advantage of this new arrangement is to reduce heat losses by upward convection. On the other hand it was suspected that, with such an arrangement of two air stagnating upper chambers, the upper polycarbonate layers could absorb more irradiants, and as a result of this less energy is going to reach to the absorber. Experiment results showed that, with an extra stagnating air layer, energy absorption is decreased but on the other hand the collector efficiency is increased due to better insulation from upward. The isolation of the collector was made firstly by covering the bottom side of the collector by an Aluminum folio layer, in order to ensure that won't be any irradiation leakage from the absorber, by reflecting those irradiants again to the absorber by that layer. Secondly, a polyurethane layer of 60 mm thickness is then caught behind the Aluminum folio layer and well fixed. This polyurethane layer is considered to be the main isolation material of the collector. In fact polyurethane has shown a good isolation properties (thermal conductivity $\lambda = 0.028$ W.m^{-1}.K^{-1}, Cp = 1.38 kJ.kg^{-1}.K^{-1}, ρ = 35 kg.m^{-3}). The polyurethane layer is finally coat by a silver-plated-gray painting to insulate it from rain and other climatic conditions.

The present works have tested the performance of the above developed air solar collectors in laboratory and tested their responses and endurance.

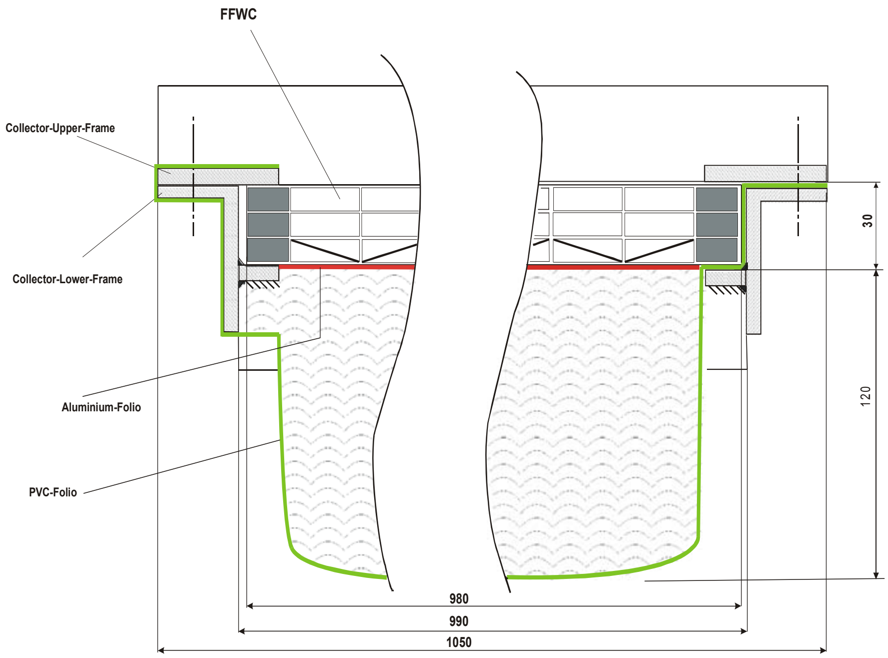

Fig.1: Cross-section of the collector

2. EXPERIMENTAL PROCEDURE

Indoor experiments were carried out on an existing the indoor set-up installed in the Bochum Ruhr University in Germany (Chafik, E. 2002) (See Fig.2). The components of the indoor collector-test set-up are the circulating air arrangement; the wind circulating arrangement; the lamp system (40 lamps of Thorn CSI type, each lamp is supplied with 1 kW power) installed in order to simulate the desirable solar irradiation and the measurement devices (inlet and outlet air temperatures, pressure difference between collector inlet and outlet, irradiation).

The efficiency of the collector as function as the reduced temperature at different surrounding conditions and operating parameters was found out.

The variable collector inlet parameters are:

- Solar irradiation, in the range of: 600, 800, 1000 W/m².
- Collector inlet temperature, in the range of: 25 – 70 °C.
- Wind inlet temperature, in the range of: 20 – 22 °C.
- Wind velocity: 1,1 – 3 m/sec.
- Airflow rate: 80, 100, 120 and & kg/h.

Fig.2: Photo of the collector prototype installed on the indoor collector-test setup. (Chafik, E. 2002)

Outdoor experiments were carried out on the collector prototype manufactured and mounted on the INRST pilot plant platform in Tunisia (Fig.3). The response of the collector and the endurance test was found out.

Fig.3: Photo of the collector prototype installed on the outdoor collectors-test setup

3. RESULTS AND DISCUSSION

To determinate the performance of the new collector design, the system was evaluated by comparing the curves of the collector efficiency (Eq.1) as function as the reduced temperature (Eq.2) for different variables parameters such us: the solar irradiation, air mass flow rate throwing the collector, the wind speed. We have also tested the outlet temperature response of the collector.

The collector efficiency was given in this equation,

$$\eta = \frac{M_{air} \,.\, C_{p,air} \,.\, (T_o - T_i)}{G \,.\, A} \tag{1}$$

Where M_{air} is the mass flow rate of the transpired humid air, $C_{P,air}$ is the air heat capacity , T_o is the outlet temperature of the air, T_i is the inlet temperature of the air G is the solar irradiation intensity and *A* is the collector area.

The reduced temperature was given in this equation,

$$Tr = U_0 \frac{\frac{(T_o + T_i)}{2} - T_a}{G} \tag{2}$$

Where we considerate that the absorber temperature equivalent as the mean temperature, T_a is the ambient temperature and we considerate U0 = 10 m²/W°C as a dimensioned number

3.1. Effect of the solar irradiation on the collector performance

Indoor experimental results are presented in the Fig.4. The graphs presents the behavior of the collector efficiency function the reduced temperature for different value of the solar irradiation and keeping constant: the air mass flow rate cooling in the collector (M_{air} = 100 kg/h) , wind velocity V~ 1 m/s, ambient temperature T_a (20 – 25 °C). In fact, the figure shows that by changing the solar irradiation values, the experimental point existing approximately in the same linear curve so we can simulate the collector efficiency us a linear function on the reduced temperature where the function coefficient are constant for different irradiation value this is mean that the solar irradiation have not influent on the optical efficiency and the loss coefficient of the collector. This result means that the outlet collector temperature flows on linearity the solar irradiation intensity. The figure shows also that the collector optic efficiency is up to 63 % and the loss coefficient is low than 5

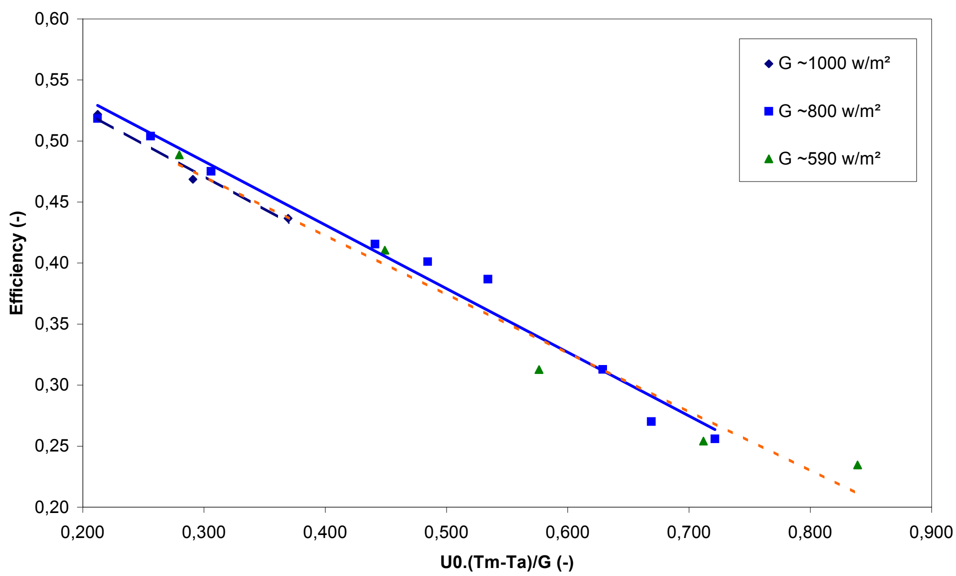

Fig.4 shows in–door test results of the solar irradiation effect on the collector efficiency

3.2. Effect of the air mass flow rate

Fig.5 illustrates the curves of collector efficiency as function as the reduced temperature for different value of the air mass flow rate and keeping constant: the solar irradiation (G ~ 800 Wm^{-2}), wind velocity (V ~ 1 m/s), ambient temperature (T_a = 18 – 25 °C). The figure shows that the cures are approximately parallel. In fact, for the used values of air mass flow rate the efficiency of the collector follow on linearity the reduced temperature. However the outlet temperature value decrease with the increases of the air mass flow rates. The figure shows also that the collector optic efficiency is up to 63 % and the loss coefficient is low than 5 for the present operating conditions.

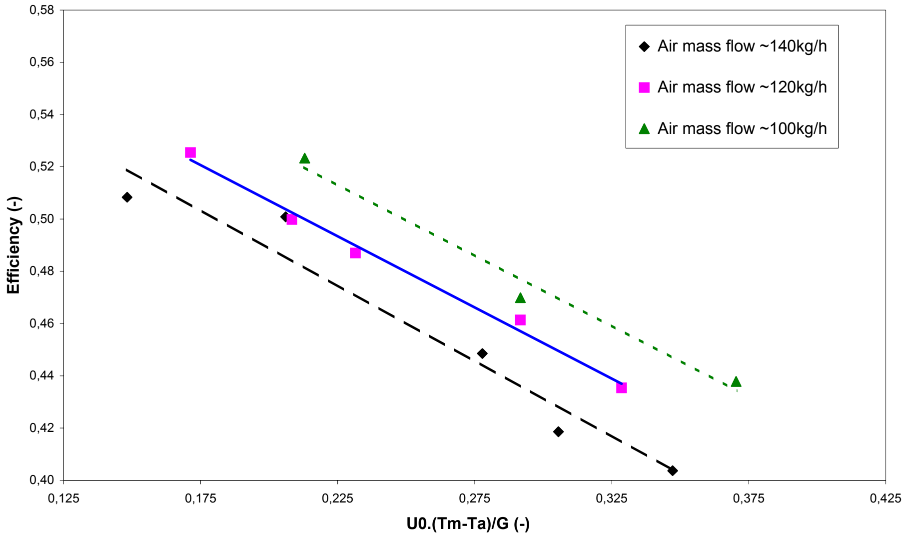

Fig.5. In–door test results of the air mass flow effect on the collector efficiency

3.3. Effect of wind velocity

Fig.6 illustrates the curves of collector efficiency function the reduced temperature for different value of wind speed and keeping constant: the solar irradiation (G ~ 800 Wm^{-2}), the air mass flow rate (M_{air} = 100 kg/h) and ambient temperature (T_a = 18 – 25 °C).

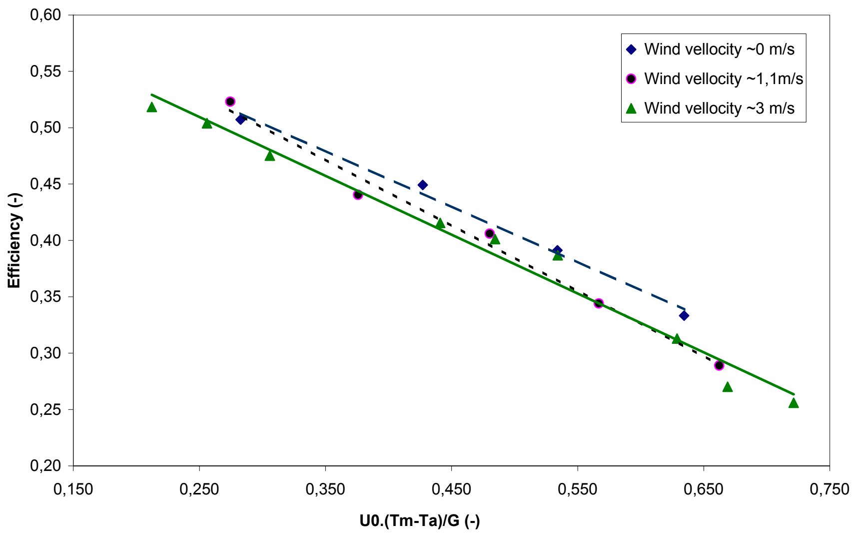

Fig.6. In–door test results of the wind speed effect on the collector efficiency

The figure shows that all the cures are approximately parallel, this mean that the curve constant of the collector efficiency as function as of the collector increasing with the decreases of wind speed, this is due that the wind influence on the transmission of solar energy in the collector. In fact wind function as a glasses cover for the collector. The figure shows also that the collector optic efficiency is up to 63 % and the loss coefficient is low than 5 for the present operating conditions.

3.4. The collector's response

Fig.7 illustrates the behavior of the collector outlet temperature during a day where the solar irradiation presents a minor fluctuation in order to refer the time response of the collector. It is clear that the collector is very sensible to the solar radiation fluctuation. This good response can be a deficiency for the mentioned solar desalination process. In fact condensation may occur inside the collector if the air temperature drops quickly.

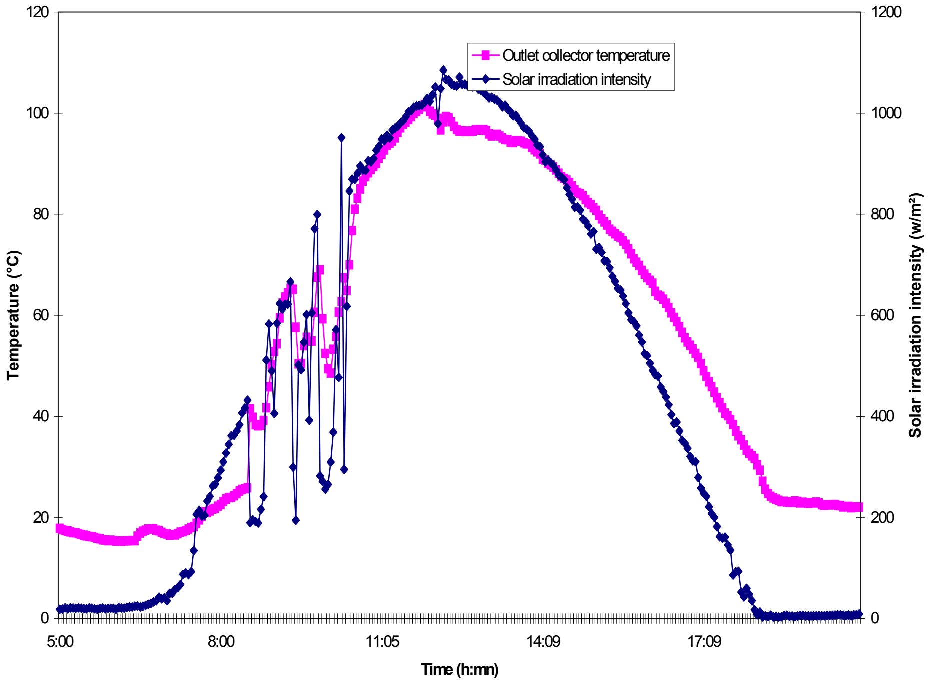

Fig.7 shows the response of the collector outlet temperature during a day

3.5. Endurance test on the collector

The collector prototype is left outdoor unprotected to test its endurance to harsh weather conditions especially excessive solar radiation in summer. The results of this test had shown that the high solar irradiation intensity and the atmospheric temperature during a month had caused a burnout in the collector channels (see Fig.8). Moreover, in different locations of the plate collector, we have remarked melted polycarbonate-folds in the absorber chamber (see Fig.9). These results could prove that this type of polycarbonate plate collector couldn't be used without a blower that ensures an air circulation in the chambers of the collector.

Fig.8: Burnout in the collector channels

Fig.9: Melted polycarbonate-folds in the absorber chamber

4. CONCLUSIONS

To sum up the experimental results obtained in the present work were used to put stress on the influence of the different operating conditions on the performance of the new collector design with low costs. In short, results have showed that the designed collector is in satisfaction with the different operating conditions in this desalination process. Such good obtained results, does not mean that the new designed collector hasn't many deficiency. Indeed, the good response of the collector can be caused a condensation may occur inside the collector if the air temperature drops quickly in the mentioned solar desalination process. Also, endurance–test on the collector shows that this type of polycarbonate plate collector couldn't be used without a blower that ensures an air circulation in the chambers of the collector.

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