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Experimental Study of the Efficiency of a Solar Water Heater Construction from Recycled Plastic Bottles

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ABSTRACT

A solar polymer heat exchanger is designed to heat water; its primary materials are plastic water bottles with a capacity of 1.5 liters. These materials were recycled to preserve the environment and to make use of it again. The thermal insulation properties are adopted for the characterization of polymeric materials. These properties concern the conservation of energy for the longest period of time and the absence of problems caused by rust and corrosion, which are usually encountered in traditional heat exchangers. The heat exchanger experiments start by tracking the flow of water inside the pipes by a valve. The water temperature and flow rates are determined at the inlet and outlet surfaces of the exchanger. The obtained results indicated an increase in water temperature exceeding 10°C in an ideal spring day. The thermal efficiency of the solar collector was about 62% under the sunlight, and 44% in the laboratory where halogen lamps were used as an industrial light source.

1. INTRODUCTION

Recently, it has been noticed an increase in alternative energy sources demand such as wind, water and solar radiation, instead of using traditional sources of energy such as fossil fuel. This is caused mainly by to its high price, the damage that it can cause to the environment and the risk of running out earlier.

Solar energy, which is almost available around all the world, is one of the most inexhaustible, renewable, clean, and powerful energies with a maximum of solar radiation of about 950W/m^2 on the ground. The carbon emission may be reduced through the substitution of traditional fuel sources by solar energy.

Furthermore, the stress on depleted forests may be relieved through the reduction of biomass consumption [1, 2]. The technology of solar water heating (SWH) is widely employed in various profitable applications [3-5]. This technology provides many benefits to households in developing communities, such as the a low-cost and the elimination or reduction of the need for electricity, gas, or wood to heat water.

A solar water heater design from polymer (SWHP) plays the role of global warming by absorbing the heat through aluminum sheets and using plastic bottles. This polymer has some interesting properties: transparency, high clarity with a shiny appearance, exceptional optical properties (light transmission in the polymer is higher than that in the glass), excellent resistance for corrosion and weather conditions, besides it is much lighter than the glass [6, 7]. The design of this polymer was made from plastic bottles, which act as glazing. Many parameters may influence the heat transfer phenomenon through a polymer such as the orientation of the macromolecules, temperature, and crystalline [8-10].

Phonons are carriers of heat transfer in polymers, due to the presence of a mere free-electron [11, 12]. The thermal transfer from a heat source to a polymer is achieved through a slow diffusion and not by propagation as a wave. The heat energy is received by the first atom of polymer molecular chain in a form of vibration, then it is transferred to the next atoms. The polymer thermal conductivity may be reduced by the disordered rotation and vibration of atoms that is caused by the thermal transfer [13, 14].

Other works can be found in the referenced analysis [15-22] for various situations of solar heat exchangers.

Some research works have been performed on the enhancement of thermal efficiency of solar water heaters (SWHs). Among other studies, Hassan and Abo-Elfadl [23] explored the thermal performance of double pass SAH using various situations of the absorber plate.

Bhowmik and Amin [24] used a reflector having an ability to vary its position according to that of the sun. The used setup has allowed an enhancement of the collector performance by about 10%.

Sivakumar et al. [25] explored the effect of zig-zag arrangement of riser tubes from the existing collector as well as the number of riser tubes. Performances of 62.90 and

59.09% were obtained for the zig-zag arrangement and the number of riser tubes, respectively.

The thermal conductivity influence of the absorber plate of a thermosiphon SWH was investigated by Hossain et al. [26]. Compared to the conventional system, the thermosiphon proved its superiority in terms of thermal efficiency by about 18%. During the winter months and for two SWHs of 100 and 200 liters, Khan and Islam [27] found that the incoming hot water was higher by about 300℃ than the temperature inside the room. Kulkarni and Deshmukh [28] investigated the effect of tube arrangements on the overall performances of a SWH. The highest performance of 57% was reached at the time of 1.00PM. Ramasamy and Balashanmugam [29] interested in SWHs with rectangular and circular absorber fin. They tried to enhance the thermal transfer by increasing the area, while maintaining the pressure reduction and the outlet velocity.

A detailed review on the various kinds of air source heat pumps (ASHP) was presented by Wang et al. [30]. They focused in their review on the research methodologies, efficiency indicators, boundary conditions, and system configuration. Their comparison that the PV-ASHP may provide highest techno-economic efficiency. Rukman et al. [31] reviewed the energy and exergy for various kinds of water-based PV systems operating under several conditions. Sudhakar et al. [32] utilized four types of solar cell arrays and various shapes of receiver to enhance the efficiency of trough concentrating photovoltaic SWH. The highest efficiency was obtained with the GaAs triple junction, compared to the other kinds of cell arrays. Furthermore, and in terms of solar power, the mirror reflectivity 0.92 was found to be more efficient than 0.69.

Herrando et al. [33] made a comparison between a hybrid PV/T collector and an evacuated tube collector. They reported that the hybrid PV/T system can meet up 16.3%, 55.1%, and 20.9%, and of the electrical, cooling, and space heating demands of the studied place. Saxena et al. [34] achieved a photovoltaic thermo control by changing the parameter that affects the temperature and performance of the solar panel. For various flow rates, the irradiation over the PV panel was ranged from 87.38W/m^2 to 359.17W/m^2. Values of the flow rate were 3, 5.3, and 6.2lit/min for an intermittent cooling state, and 0.6lit/min for a continuous cooling. Compared to the no cooling state, the efficiency was raised by 18 and 29% during the intermittent and continuous cooling states, respectively. In the novel system suggested by Brice Lecoeuvre et al. [35], the so-called SRLO (Orientable Blades Reflective System), the electrical and thermal energies may be produced in combination. Several parameters were considered to control the command of the location.

The technique of SWH may be considered as an efficient alternative in countries having high energy consumption and sufficient irradiation. In our study, we are interested in the analysis of the energetic performance a solar heat exchanger using recycled plastic bottles. The study is achieved by experiments.

2. METHODOLOGY

2.1 Solar collectors

The main element in SWHs is the collector, which transforms the gathered radiation energy of sun into heat, and then transfers this heat to the fluid. Many systems exploiting the solar thermal energy are developed, such as pool heaters, water heaters, and space-heating systems [36]. The different designs of collectors that are available may be classified into two main kinds: flat plates and concentrating collectors.

2.2 Flat-Plate collectors

This kind of collectors, which heats air or liquid at temperatures less than 80°C, is the most used in domestic applications, as well as for the space heating [36]. It is found under an insulated metal box covered with the plastic or glass cover (the so called glazing) and having a dark-colored absorber plate (Figure 1).

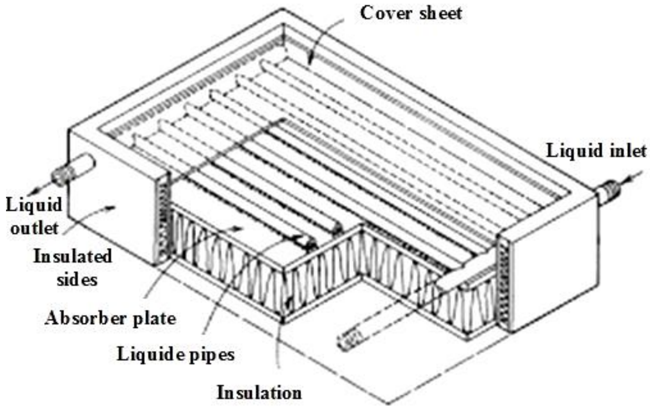

Figure 1. The typical solar energy collection system [37]

2.3 Governing parameters

The collector efficiency is defined as:

$$\eta = \frac{\int Q_u dt}{A\int DNI.dt} \tag{1}$$

where, Q_u is the useful energy gain, A is the total collector area, m^2, DNI is the direct normal irradiation, W/m^2, and t is the time, s. The instantaneous thermal efficiency of the collector is defined as:

$$\eta = \frac{Q_u}{DNI.A} \tag{2}$$

The solar collector receives the incident solar radiation energy:

$$Q_s = DNI.A \tag{3}$$

The rate of extracted heat from the collector is determined as:

$$Q_u = m.C_p\left(T_0 - T_i\right) \tag{4}$$

where, m is the mass flow rate, kg/s, C_p is the heat capacity, j/kg K, T_i is the inlet fluid temperature, °C, and T_o is the outlet fluid temperature, °C. In each experiment, a water mass flow rate (m) of 0.03 kg/s was used.

3. SOLAR COLLECTOR REALIZATION

These systems allow the total autonomy of the water heater. Some modifications of its initial design were made, in order to improve the system performance, using materials available in the domestic market: copper tubes, square tubes, Aluminum foils and plastic water bottles of 1.5 liters. The components that are used during the project implementation are summarized in Table 1.

Table 1. Components of the solar collector

Components	Quantity
Copper tubes (22 mm)	13 m
Thermometer	4
Pump (with a manual pressure regulator)	1
Metal elbow	20
Check valve	2
Aluminum square tube	10 m
Aluminum foil	2
Iron Support	1
Trolley wheel	4
Plastic bottles (1.5 L)	60
Tank	1

The solar collector under investigation is installed on the one laboratory roof of the University of M'sila in Algeria. The geographic coordinates of this site are shown in Table 2.

Table 2. Components of the solar collector

Latitude (deg)	Altitude (m)	Longitude (deg)
35.42 N	477	4.32 E

Figure 2 presents the experiment prototype weighing about 15kg and solar plane (Metal-Polymer). Area of the flat plate collector, A = 117.6 cm^2.

Figure 2. Solar collector under study

4. RESULTS AND DISCUSSION

After mounting the experimental setup, the tests were made through two steps as follows:

4.1 Experimental study within the laboratory

In this step, two experiments are conducted using a radiant source of 300 W halogen lamps (Figure 3). The number of lamps in the first experiment was 7 (7 × 300 = 2100 W), with the perpendicular incidence projection of radiations on the surface of the collector (angle of 0°).

The number of lamps in the second experiment was 7 with an incidence angle of 50° and 0° on the collector surface. The findings of this step are shown in Figure 4.

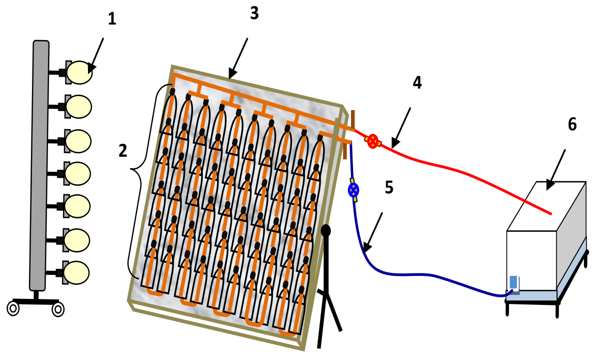

Figure 3. Installation inside the laboratory (1: halogen lamps, 2: plastic bottles, 3: installation structure, 4: water inlet, 5: water outlet, and 6: the tank)

The temperatures (Te, Ts) increased with time, on parallel with the two angles $\gamma = 0°$ and $\gamma = 40°$. However, the values of Ts in the case of $\gamma = 40°$ were less than that for $\gamma = 0°$. For $\gamma = 50°$, the minimum exit temperature after 10 min is 24°C, but for the angle $\gamma = 0°$ it was 31°C.

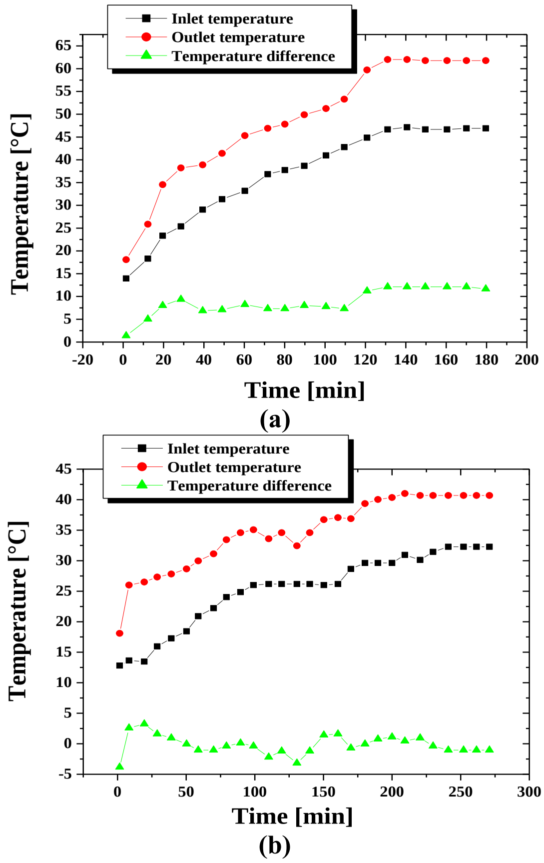

Figure 4. Variation of the inlet and outlet temperatures of the collector vs. the time (Inside the laboratory)

4.2 Experimental study outside the laboratory

The collector was exposed to the solar radiation in the technological hall at the University of M'sila in Algeria (Figure 5). Three typical days were chosen according to the availability of sunshine, a clear sky and a wind speed suitable to the experiment. The experiment started at 9 am and ended at 3 pm.

Three experiments were performed with γ = 40˚ and γ = 0˚, with a continuous reorientation of the collector to the sun to capture the maximum radiation.

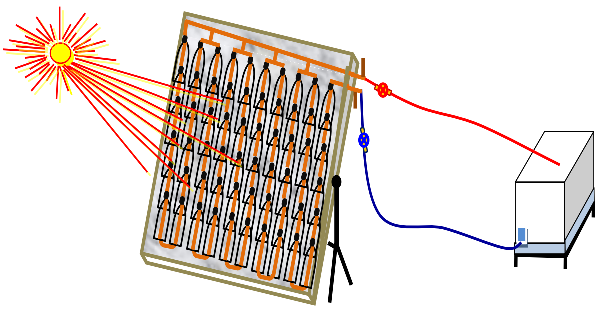

Figure 5. Installation outside the laboratory

Figure 6 illustrates the obtained results. The analysis of experimental temperature curves (Te and Ts) shows an increase in temperatures over time to a point where they become constant. This point was obtained after 4 hours. It is pointed out that the temperature difference of outside water is significantly higher than that that inside the laboratory where the pumps were used, which shows that the source of the heat absorbed by the heat transfer fluid is the photons of sunlight.

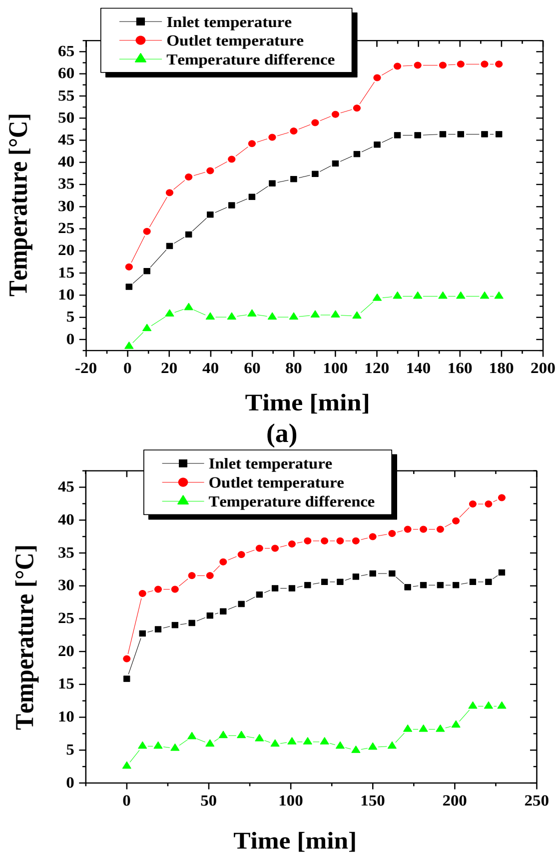

Figure 6. Variation of the inlet and outlet temperature of the collector vs. time (Outside the laboratory)

The study shows that the instantaneous yield (η) variation depends on the inclination (γ) of the collector and the best yield was 69% for the angle of incidence γ = 0°. Besides the best performance obtained by exposing the collector to the sun was greater than that when using the lump, as shown in Figure 7. This study shows that the tank must be placed above the collector so that when the water heats, it becomes lighter and rises naturally into the tank above. Meanwhile, the cooler water in the tank flows down the pipes, causing circulation throughout the system.

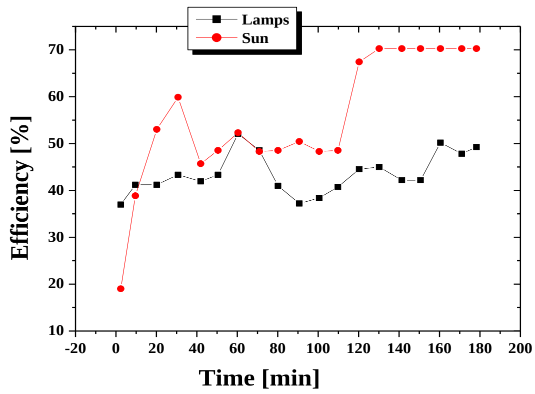

Figure 7. Comparison of collector efficiency

5. CONCLUSION

The polymer related to recycled water bottles has been invested for the purpose of use in the design and construction of a polymer heat exchanger for heating water. A collector SWHP was made using materials available in the local market: copper tubes, square tubes, Aluminum foil and 60 the plastic water bottles of 1.5 liters. The polymer heat exchanger we designed is distinguished from other commonly used exchangers by the preservation of energy for a period of more than three hours per day, due to the flow coefficient of thermal conductivity in plastic materials. The study of the temperature difference between the outlet and inlet water of the collector showed that:

- ✓ Inside the laboratory, where halogen lamps were used, the ΔT was above 7°C.
- ✓ Outside the laboratory, where the collector perpendicular was exposed to the sun's rays, the ΔT exceeded 10°C.

Calculation of the efficiency of our collector gave acceptable results and the best efficiency was 62% by exposing the collector to the sun at an angle of 0°.

From an economic viewpoint, SWHP is an energy efficient technology, which is beneficent for the community in the long run. Generally, residential our systems cost $300.

Therefore, this generation of exchanges meets the economic feasibility requirement in engineering design, considering the origin of the manufacturing materials.

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