ARQII Publication
APPLICATIONS OF
MODELLING AND SIMULATION
http://arqiipubl.com/ams eISSN 2600-8084 VOL 3, NO. 3, 2019, 179-187

Performance Study of Different Types of Solar Water-Heaters Collectors

Maram Besheir Sidky[1*], Khaled Haroun[2], Nabil Shukri[2] and Khalil Yacoob[2]

[1]Department of Research and Development, Water and Wastewater Company in Minya, Egypt
[2]Faculty of Engineering, Mechanical and Energy Engineering Department, Minya University, Egypt

[*]Corresponding author: meram_sidky@yahoo.com

Received 26 August 2019, Revised 25 September 2019, Accepted 02 October 2019.

Abstract: People are always looking for new sources of energy to be able to meet their growing energy needs and keep pace with advanced life applications in the world. As most of the existing energy sources are at risk of depletion and expected to drain, in addition to their high cost and the negative environmental impacts resulting from using them extensively, we are now alerted to consider the potential of making use of other more sustainable sources of energy, such as the solar energy. It is an easy, effective and safe source. This study aims at evaluating three types of solar water heaters and studying the effect of wind and dust that accumulate continuously on the glass surface of these solar heaters. The work also provides suggestions to select the simple and easy way of manufacturing considering the least poor villagers with their local skills and materials. Three different types of solar heaters namely Flat Plate, Serpentine and Zigzag heaters with different forms have been designed, considering maintaining similar dimensions and the same zones exposed for the sun rays, and tested them in the same climatic conditions in Minia Province, Upper Egypt. With experiment, it is observed that Zigzag water heater is the highest in efficiency than the other two types. The experiment also shows that the dust layers accumulated on surfaces of the heaters reduce the solar heater absorption of heat and that the presence of high or reduce airflow contributes directly to heat loss, where water pipes became cooler inside, consequently, the efficiency of the solar water heater decreases by accumulating dust on the surface of the collector or increasing the wind speed targeted directly towards the collector.

Keywords: Experiment; Flat plate collector; Renewable energy; Solar energy; Solar water heater.

1. INTRODUCTION

In order to secure energy for all people and because traditional sources of energy are becoming limited and cannot meet the increasing demand of all and different people for energy [1], which means that fossil energy will be depleted quickly if energy consumption continues without providing new alternatives for the depleted sources. Fossil energy is used mainly for direct combustion, electricity and thermal energy production [2]. Some of these uses cause severe environmental problems such as air pollution and the intense emissions of carbon dioxide [3]. Expanding the use of renewable energy sources and technologies is the best way to avoid such negative effects [1].

The sun is an inexhaustible source of energy that can be converted, as needed, into electrical energy using photovoltaic solar cells or thermal energy using solar collectors [4]. The solar energy that comes from the sun in the form of solar radiation can be a good alternative source of energy. When this radiation is directed to a well-selected absorbent surface, the surface absorbs heat and we can use this heat as a source for heating water [5]. This hot water can be used for many purposes in industrial and household applications. Also, this water can be stored in water pipes or tanks that protect it from freezing in the winter [6]. For that, the increased demand for energy and the high cost of fossil fuels (i.e., gas or oil), make solar energy an important source of renewable energy by using it in systems and technologies that are easy to design and cost-effective [7].

Solar water heating systems, for example, are cheaper and consume only about 20% of the total energy consumption of a family. Taking into account the requirements of heating and environmental conditions, collectors of solar energy can be classified into fixed (non-concentrating) and concentrating [8]. Flat-plate solar collectors are fixed collectors that are typically used to heat water for domestic use, to heat swimming pools or in industrial applications. Since this type of collectors is the most widespread, we often consider the issue of increasing their thermal efficiency in research activities. Therefore, over the years, researchers have investigated how to improve the thermal efficiency of the solar collector, for example, in order to improve the thermal exchange between the absorption plate and working methods, research work led to the alternative of replacing liquid (usually water) with other liquids or thermally conductive nano fluids, or to develop new highly selective layers of absorption plate [9]. We also aim to reduce heat loss by ensuring good thermal insulation, or by using transparent caps with high permeability and low emissions [10].

From a long time ago, man knew the advantages and importance of solar energy and used it in simplified ways. For example, man benefited from the energy of solar radiation directly in many applications such as drying agricultural crops and heating houses as used in other areas as mentioned in the books of historical science [11]. Archimedes burned the Roman military fleet in the war of 212 BC by focusing solar radiation on enemy ships by hundreds of reflective metal shields. In the Babylonian era, priests used golden vessels, polished like mirrors, to focus solar radiation to obtain fire [12]. Scientists such as Chernos, Suez, Lavoisier, Mochot, Eriksson, Harding, and others used solar energy to melt materials, cook food, generate water vapor, and distill water or heat the air [13]. At the beginning of this century, the world's first solar-powered irrigation plant, which operated for five hours a day, was established in Maadi near Cairo [14]. People have long tried to take advantage of solar energy and exploit it, and with the great development of technology and scientific progress achieved in the form of innovations and techniques accomplished by research and experimental efforts, new scientific horizons have been reached in the field of solar energy exploitation [15].

It was noted that, from previous experiments and researches, no comparatives research has been made on the performance of the three types of collectors in this research. It was also observed that for a Flat Plate type, of less efficiency, is the most common, due to the ease of its design and manufacture, compared to the other two types. Although a Serpentine type is more difficult to design than the flat plate type, but it is comparatively more efficient. Also, the Zigzag type outperforms them all. We seek that this work will contribute to raising awareness among users, of the highest type in efficiency, to make its use more common to utilize solar energy and make the best use of it in different aspects of life, as one of the sources of clean and environment friendly energy, leading to energy conservation, at the lowest cost and easily accessible components.

2. SYSTEM DESIGN AND IMPLEMENTATION

This simple models designed mainly to be suitable for the least poor villagers especially they have limited skills and moderate local materials and simple working tools. Three types of solar water-heaters were tested in this work which are:

1. Flat-plate solar water- heater collector (Figure 1).
2. Zigzag solar water- heater collector (Figure 2).
3. Serpentine solar water- heater collector (Figure 3).

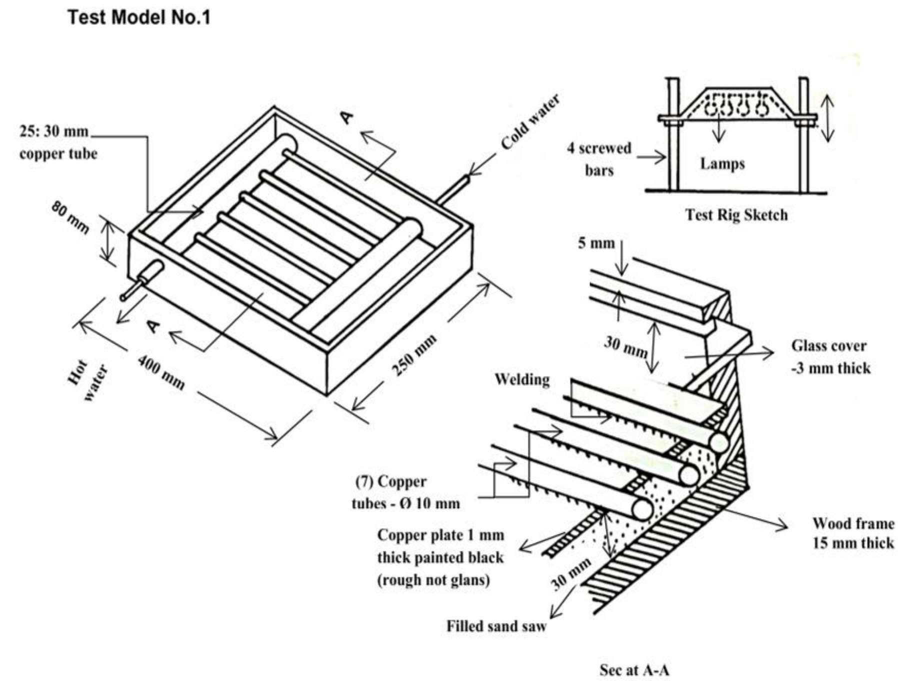

Figure 1. Flat-plate solar water heater collector

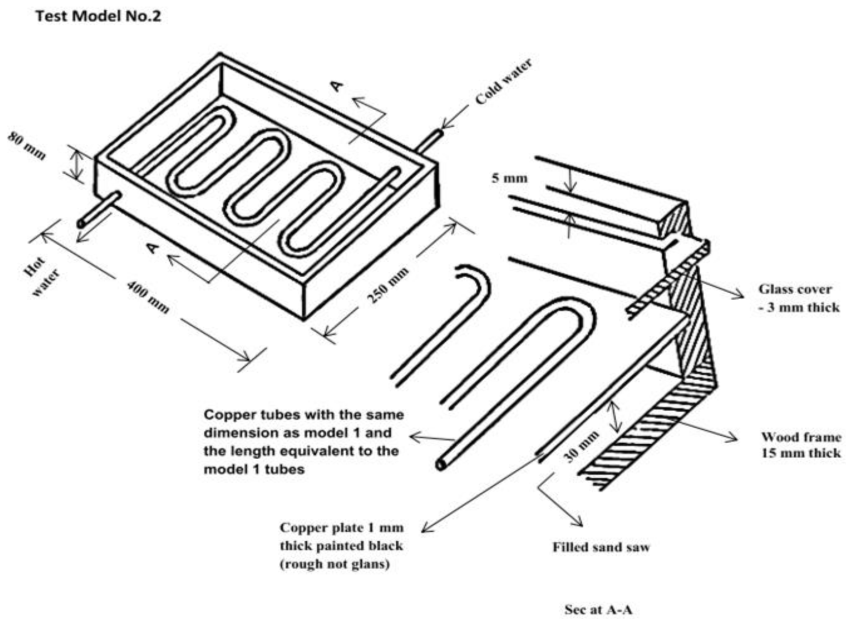

Figure 2. Zigzag solar water heater collector

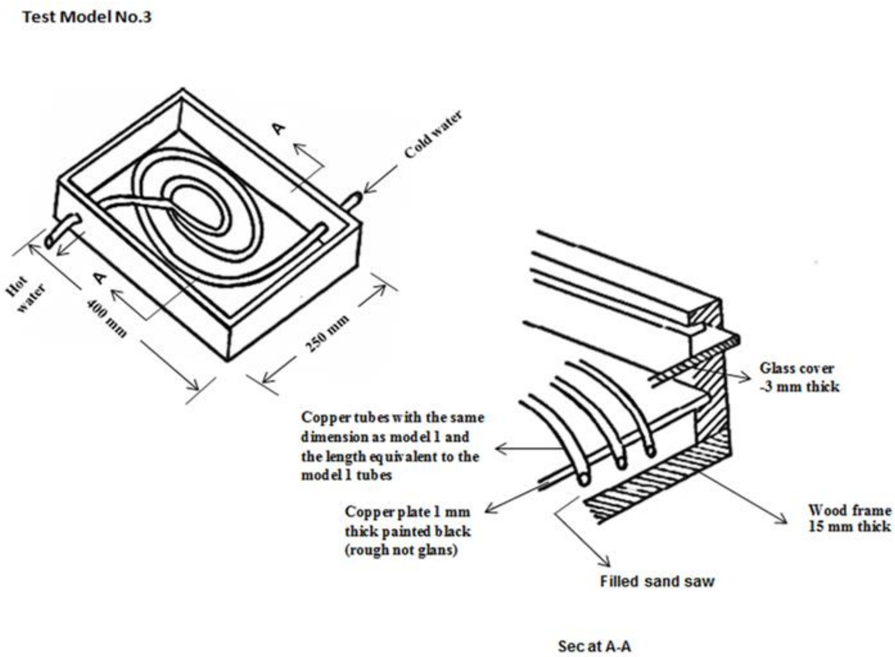

Figure 3. Serpentine solar water heater collector

2.1 Components of the Solar Heater and How It Works

The solar panels that have been manufactured to compare their efficiency in water heating, consist of a black wooden box with sawdust and a heat insulation medium, above are black copper pipes, also covered with a sheet of glass. It is painted in black, so that the surface absorbs the heat and reflects it inside, thus transforming it from a normal collector to a thermal collector that keeps the heat inside the box and thus increases the heating efficiency. The idea of its work depends on the absorption of the black glass plate of the solar radiation as heat transmitted to a network of pipes located above the absorbent copper board, heating the water it contains, then rise that hot water to the tank and transmit it to domestic uses.

The sunlight was replaced by a model to simulate the sun. It is a lamps light concentrator, made of metal plates with three Tungsten electric lamps (100 W each). According to the report of the Center for Research and Tests issued by the Authority of Electricity and Renewable Energy, the ordinary Tungsten electric lamps give 20% light and 80% heat and therefore called thermal lamps. The thermostat was also used to control the temperature intensity to simulate the temperature of the sun in different daylight hours, and thus it became easy to experiment that in a closed laboratory rather than being conducted under the direct sunlight. For the wind effect, a small 12 V fan, similar to the type used in the computer casing and installed it in the wall of the lamps concentrator was used when needed by connecting it to the electricity source. Figure 4 shows the lamps light concentrator during its installation with the rest of the system basic components. Figure 5 illustrates the system parts after they have been installed and drawn by AutoCAD 3D.

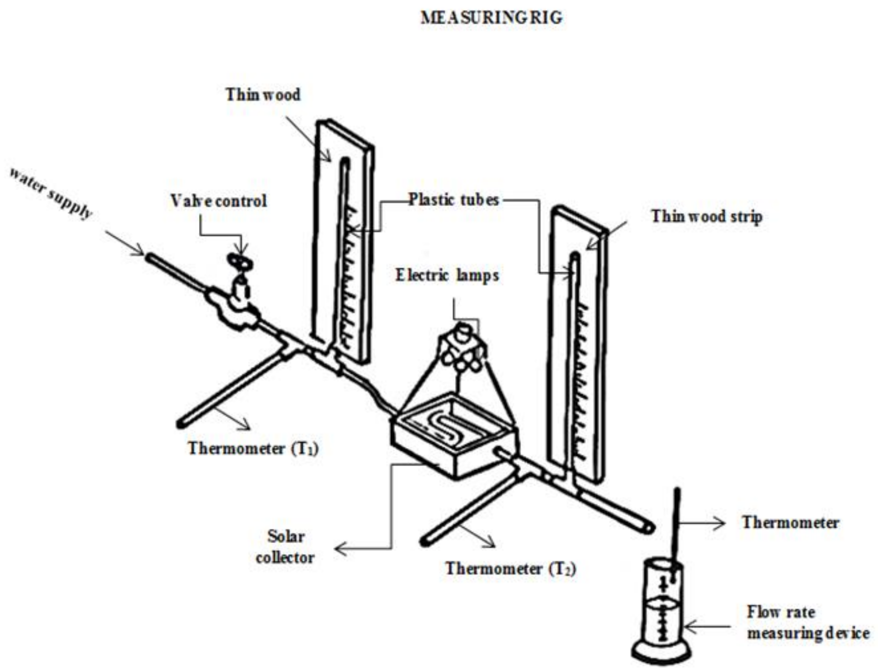

Figure 4. The lamps light concentrator and its installation with the rest of the system basic components

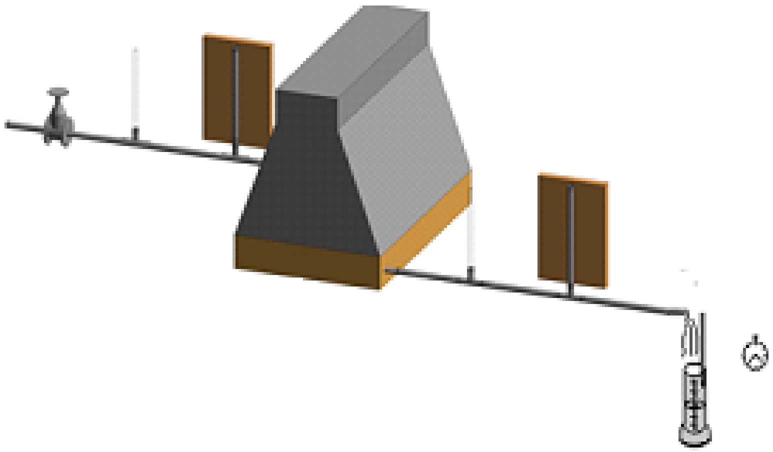

Figure 5. System parts after they have been installed

3. EXPERIMENTAL SETUP

At the onset of each experiment, the collectors were tested under steady-state conditions in which the solar intensity and the ambient temperature were considered constant for a period of time. The glass cover of collector was cleaned thoroughly, and a thermometer was placed inside a closed graduated container, so that the water inside and the outside water are poured into an insulated tank. The water is continuously administered by a small pump and the temperature reading is done periodically for water inside the tank by a thermometer, two other thermometers were also put, one for measuring the temperature of the inside water and the other to measure the water temperature directly from the solar collector. The experiments were conducted from October 2018 until June 2019, between 8 am and 3 pm at the laboratory. The average water temperature was measured at an average temperature of 24 degrees and the temperature of the water outside was taken every hour.

The study the effect of wind on the solar heater was done in two phases. The first phase included measuring the temperature of the water inside and outside before and after the operation of the fan in the case of the Zigzag heater. In the second stage, a piece of cotton screen was placed on the fan to reduce the air velocity. As for the study of the effect of dust collected on the glass surface of the solar heater, several experiments were conducted based on using an amount of fine soil, well entrenched in a piece of gauze and, weighed by a sensitive balance then scatter as different layers of dust above the glass, where it was 10 g in the first experiment and then 20, 30 and finally 40 g. Each time the water temperature was measured before and after entering the solar heater and compared with the results obtained after cleaning the glass completely. The results were analyzed on two different time periods. The first period was from October 2018 to January 2019 and the second from January 2019 to June 2019.

3.1 Mathematical Models

Theoretical analysis involves calculating the system heat losses and the quantity of energy absorbed or stored in the solar collector, as well as the efficiency. All the symbols used in this paper are listed in the Appendix. The stored energy of the heater was calculated using:

$$Q_u = \rho C(T_{av} - T_i) \tag{1}$$

The amount of energy absorbed by the solar collector can be calculated as:

$$Q_{abs} = I_b A_p F_t(\tau_g \alpha_p) \tag{2}$$

where α_p= 0.97, τ_g= 0.95, F_{sh} = 0.98, F_d = 0.97 and $F_t = F_d \cdot F_{sh}$ [16]. The amount of thermal energy stored within the solar heater is calculated as follows:

$$Q_u = MC(T_{av} - T_i)/t \tag{3}$$

The efficiency (η_s) of the heater can be calculated as:

$$\eta_s = Q_u/Q_{abs} \tag{4}$$

4. RESULTS AND DISCUSSIONS

In Figure 6 to Figure 11, the horizontal axis represents the time (in hours) and the vertical axis represents the temperature (°C). When the experiment is conducted in the first period of the year on a flat plat collector as shown in Figure 6, the temperature of the inlet water is approximately constant between 23°C and 24°C, while the outlet temperature of the water increases gradually until the temperature stabilizes after five hours from the beginning of the experiment and continues at a constant value of 42°C. In Figure 7, which was measured in the second period of the year on the same collector, the temperature of the inlet water is approximately constant between 25°C and 26°C, while the outlet temperature of the water increases gradually until the temperature stabilizes after five hours from the beginning of the experiment and continues at a constant value of 46°C.

When the experiment was conducted in the first period of the year on serpentine collector as shown in Figure 8, the temperature of the inlet water is approximately constant between 23°C and 24°C, while the temperature of the outlet water increases gradually until the temperature stabilizes after five hours from the beginning of the experiment and continues at a constant value of 47°C. In Figure 9, which was measured in the second period of the year on the same collector, the temperature of the inlet water is approximately constant between 25°C and 26°C, while the temperature of the outlet water increases gradually until the temperature stabilizes after six hours from the beginning of the experiment and continues at a constant value of 53°C.

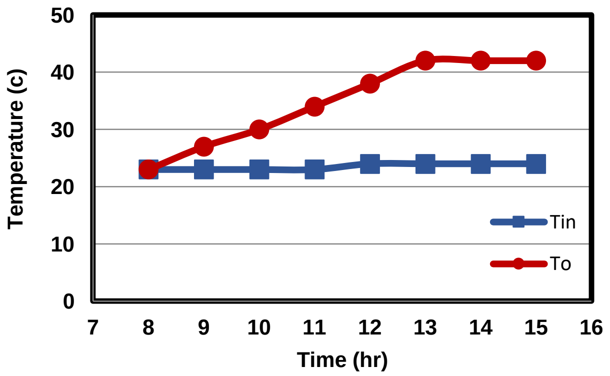

Figure 6. Flat-plate collector in first period

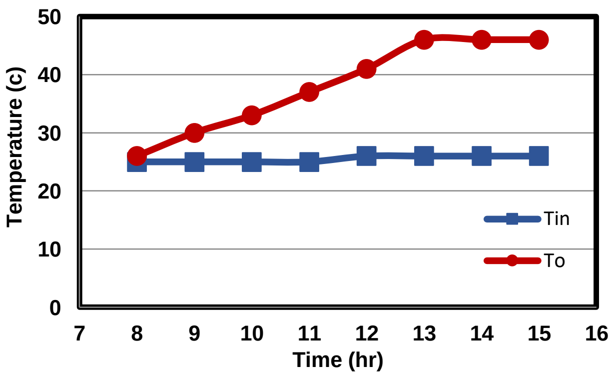

Figure 7. Flat-plate collector in second period

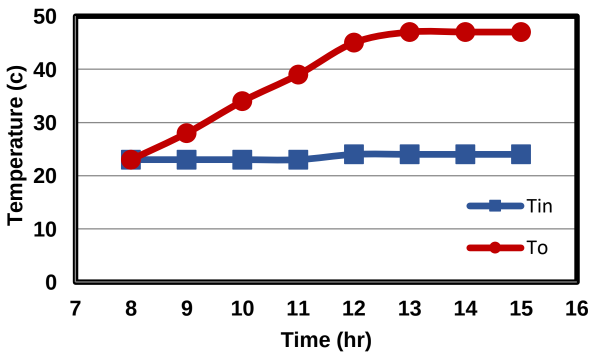

Figure 8. Serpentine collector in first period

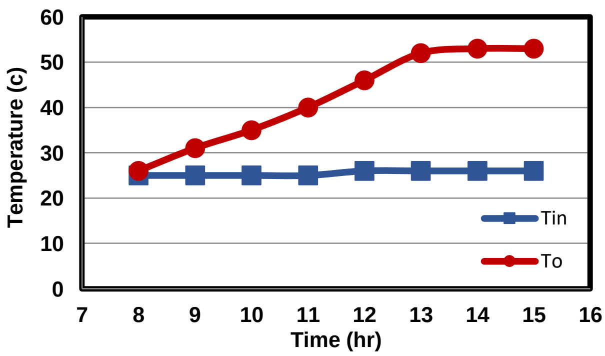

Figure 9. Serpentine collector in second period

When the same experiment was repeated in the first period of the year on a zigzag collector as shown in Figure 10, the temperature of the inlet water is approximately constant between 23°C and 24°C, while the temperature of the outlet water increases gradually until the temperature stabilizes after six hours from the beginning of the experiment and continues at a constant value of 54°C. In Figure 11, which was measured in the second period of the year on the same collector, the temperature of the inlet water is approximately constant between 25°C and 26°C, while the temperature of the outlet water increases gradually until the temperature stabilizes after six hours from the beginning of the experiment and continues at a constant value of 61°C.

The results of the three collectors were combined, where the temperature of the water inlet was almost constant in the two periods of the year. It is noted that the Zigzag solar water-heater is the one having the highest measurements compared to the other two types, see Figures 12 and 13. To calculate the efficiency of the three collectors, Equation (4) was used and it was found that the Zigzag collector is the highest among other types by 24%, see Figure 14.

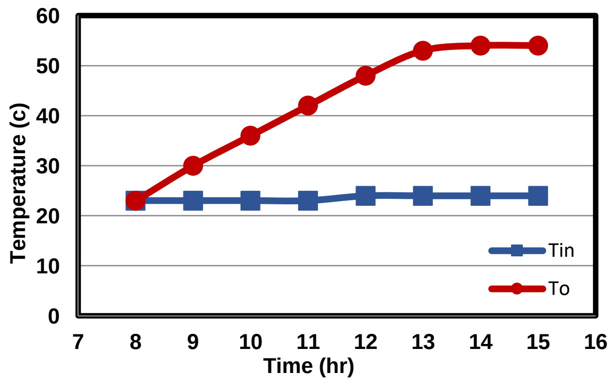

Figure 10. Zigzag collector in first period

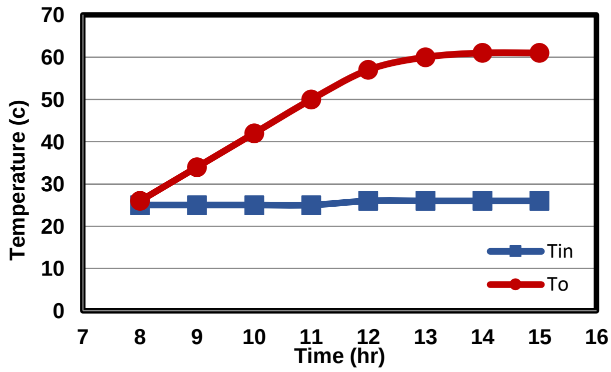

Figure 11. Zigzag collector in second period

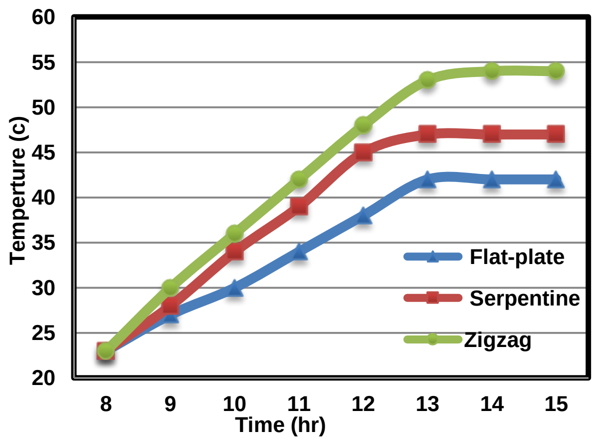

Figure 12. Temperatures that are measured in first period

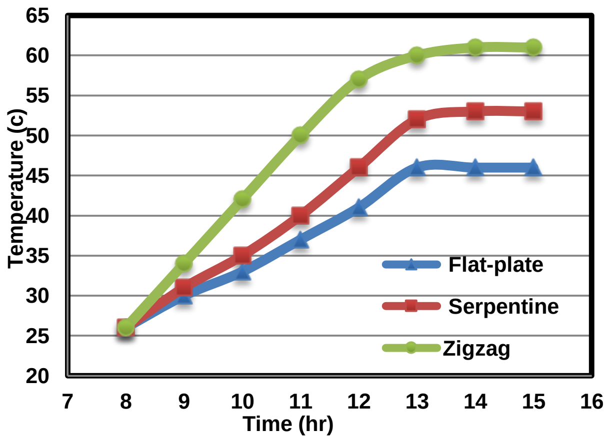

Figure 13. Temperatures that are measured in second period

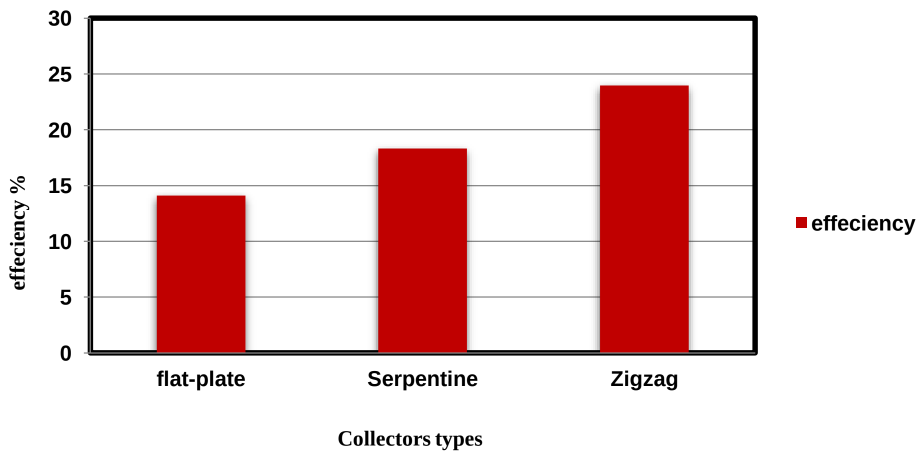

Figure 14. Test models efficiencies

To determine the effect of the air, an airflow was projected through a fan on the zigzag collector and it was observed that the temperature of the outgoing water decreased by 17°C to settle at 44°C after four hours as shown in Figure 15. By repeating the experiment after covering the fan with a piece of cotton screen to reduce the air velocity, we noticed an improvement in the outlet water temperature, where it stabilized at 48°C after four hours as shown in Figure 16. Several experiments were made to study the effect of the dust accumulation. Figure 17 to Figure 20 show the effect of several layers of dust on the outgoing water temperatures.

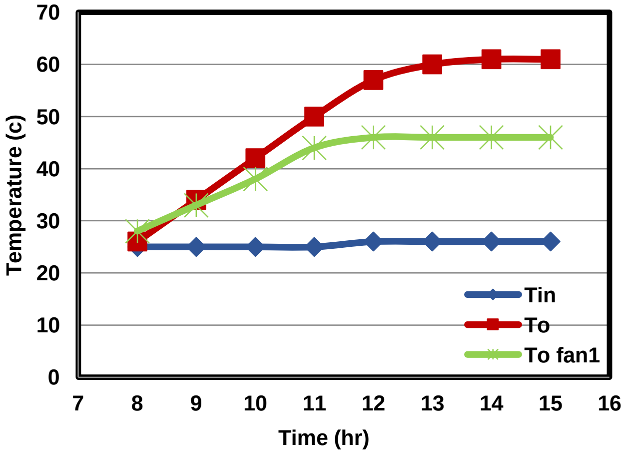

Figure 15. The difference in temperature before and after fan operation at its normal speed

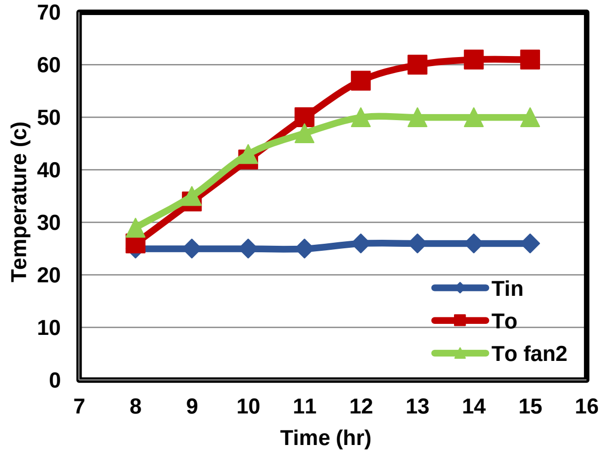

Figure 16. The difference in temperature before and after fan operation in other case

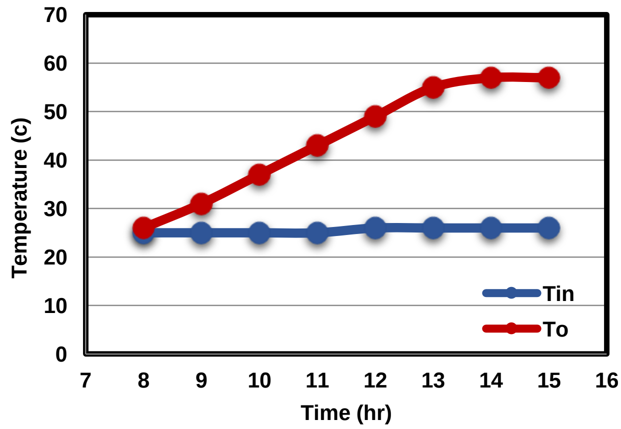

Figure 17. The difference between temperatures with a layer of soil 10 g

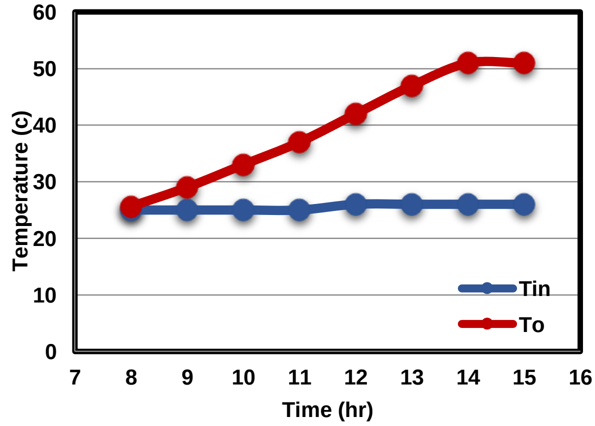

Figure 18. The difference between temperatures with a layer of soil 20 g

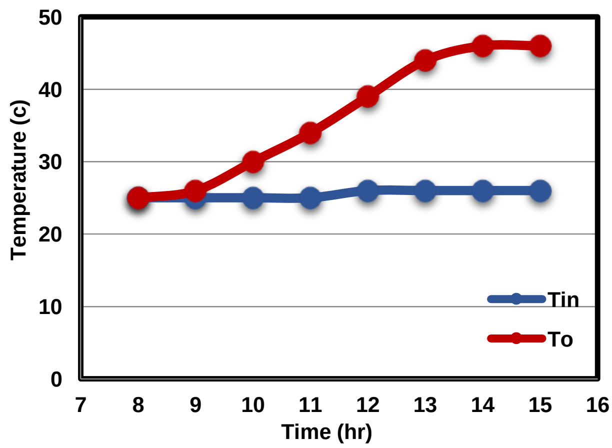

Figure 19. The difference between temperatures with a layer of soil 30 g

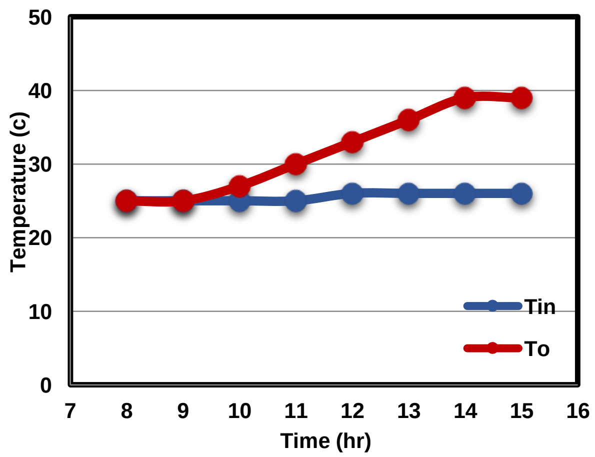

Figure 20. The difference between temperatures with a layer of soil 40 g

Figure 17 illustrates the effect of accumulation of 10 g of dust, which led to a decrease in the temperature of water coming out of the solar collector to 57°C, see Figure 18, while decreasing to 51°C when accumulated 20 g on the glass surface of the collector and continued to decline further after the accumulation of 30 g of dust to reach 46°C, see Figure 19 and then decreased to 39°C after the accumulation of 40 g of dust as shown in Figure 20, and thus effecting the efficiency of the solar heater. We noted that when the solar heater efficiency was 19% and when adding 10 g of dust, the efficiency was reduced to 16%. After dust was removed, we re-experimented with the efficiency reaching to 17.9% and then adding 20 g of dust, the efficiency decreased to 13.2%. Dust removed and taking the outing water temperature reading to calculate the efficiency of the heater. The efficiency was 16.4%, after adding 30 g of dust, the efficiency decreased to 10.6%, then dust removed and the temperature of the outing water was taken again and we got an efficiency of 12.6% and after adding 40 g of dust the efficiency was reduced to 6.9%, as shown in Figure 21.

When we run the fan in the presence of dust layers we notice a greater decrease in efficiency. In the case of a layer of dust weighing 10 g, efficiency was decreased from 16.3% to 15.3%, after the operation of the fan, as well as after the prose of 30 g of dust on the surface of the collector, the efficiency decreased from 10.6% to 9.5% after the operation of the fan. Finally, after the prose of 40 g of dust on the surface of the collector, the efficiency decreased from 6.9% to 5.9% after fan operation, as shown in Figure 22.

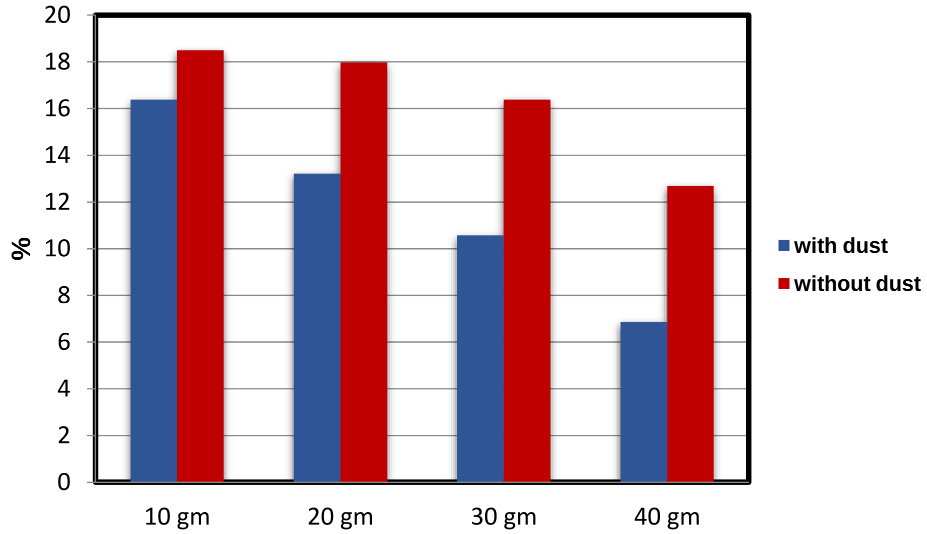

Figure 21. Effect of dust layers accumulated on the efficiency of the solar heater

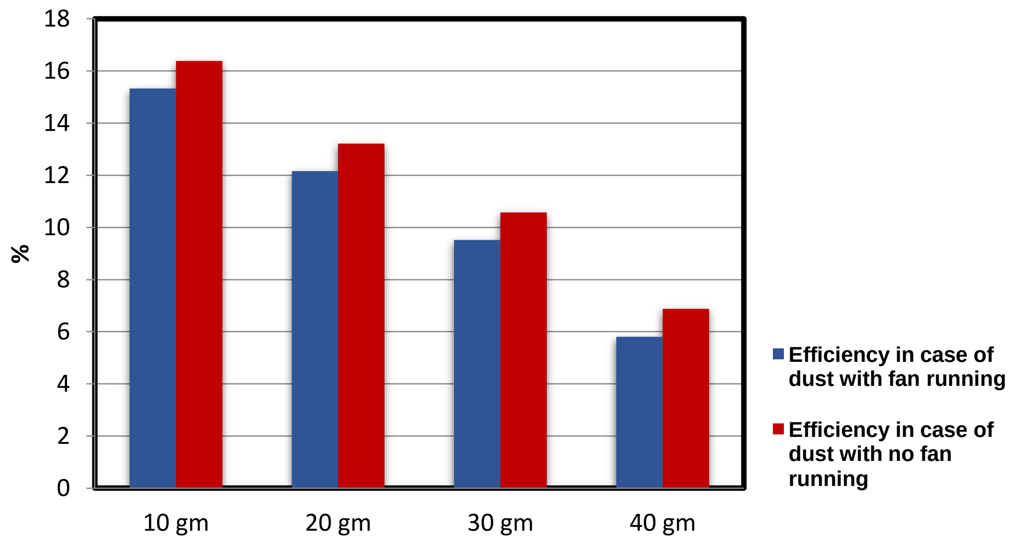

Figure 22. Efficiency of solar heater in the case of accumulation of dust with a stream of air

5. CONCLUSION

As we mentioned the aim of this present work is not only to compare these models with the well-known and conventional models but to select the simple and easy way of manufacturing depends upon the poor villagers with their local skills and materials. The experiment indicated that the Zigzag solar water heater gives the highest efficiency compared to the other types. Experiment also proved that the accumulation of dust layers reduces the absorption of the solar heater to the heat and that the presence of an air flow contributes directly to the loss of heat as it cools the pipes carrying the water inside. Thus the efficiency of the solar collector decreases faster when dust layers accumulate on the surface of the collector or with increasing wind speed.

REFERENCES

[1] H. Bhowmik and R. Amin, Efficiency improvement of flat plate solar collector using reflector, *Energy Reports*, 3, 119–123, 2017.

[2] J. Milano, H. C. Ong, H. H. Masjuki, W. T. Chong, M. K. Lam, P. K. Loh and V. Vellayan, Microalgae biofuels as an alternative to fossil fuel for power generation, *Renewable and Sustainable Energy Reviews*, 58, 180–197, 2016.

[3] T. S. Ge, R. Z. Wang, Z. Y. Xu, Q. W. Pan, S. Du, X. M. Chen, T. Ma, X. N. Wu, X. L. Sun and J. F. Chen, Solar heating and cooling: Present and future development, *Renewable Energy*, 126, 1126–1140, 2018.

[4] M. J. Muhammad, I. A. Muhammad, N. A. C. Sidek, M. N. A. W. M. Yazid, R. Mamat and G. Najafi, The use of nanofluids for enhancing the thermal performance of stationary solar collectors: A review, *Renewable and Sustainable Energy Reviews*, 63, 226–236, 2016.

[5] H. Weldekidan, V. Strezov and G. Town, Review of solar energy for biofuel extraction, *Renewable and Sustainable Energy Reviews*, 88, 184–192, 2018.

[6] M. K. A. Sharif, A. A. Al-Abidi, S. Mat, K. Sopian, M. H. Ruslan, M. Y. Sulaiman and M. A. M. Rosli, Review of the application of phase change material for heating and domestic hot water systems, *Renewable and Sustainable Energy Reviews*, 42, 557–568, 2015.

[7] J. Twidell and T. Weir, *Renewable energy resources*, Routledge, 2015.

[8] B. Jha, Non-concentrated photovoltaic and concentrated solar thermal hybrid devices and methods for solar energy collection, US Patent App. 15/269,522, 2018.

[9] Q. He, S. Zeng and S. Wang, Experimental investigation on the efficiency of flat-plate solar collectors with nanofluids, *Applied Thermal Engineering*, 88, 165–171, 2015.

[10] D. Miloştean and M. Flori, An overview on the flat-plate solar collectors and their thermal efficiency, *International Journal of Engineering*, 15(4), 123–128, 2017.

[11] Central Agency for Public Mobilization and Statistics, *Study the future of solar energy in Egypt*, March 2015.

[12] M Gadelrab, E. Badawi, E. Eltahir and W. N. Eldien, Comparison between the parabolic and dish solar collectors by using MATLAB, *International Journal of Trend in Research and Development*, 4(2), 708–717, 2017.

[13] M. A. Hossain, K. A. Kabir and M. Sarker, Mathematical modeling of the thermofluid characteristics of solar collector for variable solar radiation in climatic condition of Bangladesh, *AIP Conference Proceedings*, 2018, pp. 050022.

[14] S. Kalogirou, *Solar energy engineering: Processes and systems*, vol. 2, 2013.

[15] A. Serenelli, Solar neutrinos reveal how the Sun shines, Nature international of science news and views, 2018.

[16] A. M. Khudair and J. M. Al – Asadi, Calculate the thermal efficiency of two different designs of solar heaters, *Journal of Basrah Researches (Sciences)*, 38, 2–24, 2012.

APPENDIX

Nomenclature			
Q_u	The amount of energy stored per unit size (W)	A_p	Surface area of the absorption plate of the compound (m^2)
ρ	Water density (kg/m^3)	F_t	The total coefficient of the shadow effect and dust on the amount of solar radiation received
C	Specific water temperature (kJ/kg. °C)	F_{sh}	Shadow effect coefficient covering part of absorption sheet on solar radiation received
T_{av}	Water temperature rate (°C)	F_d	Effect of dust particles on the outer surface of the glass on the received solar radiation
T_i	Water temperature (°C)	M	Water mass (kg)
Q_{abs}	The amount of absorbed energy (W)	t	Operating time (sec)
I_b	Direct solar radiation falling on the surface of the collector (W/m^2)		