EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(6), 275–282
https://doi.org/10.12912/27197050/153418
ISSN 2719-7050, License CC-BY 4.0

Received: 2022.08.02
Accepted: 2022.08.24
Published: 2022.09.17

Investigating the Potential of Steam Hydro Capacitor – Prototype

Sameh Alsaqoor[1,2*], Hussein M. Sarayreh[3], Artur Andruszkiewicz[4], Gabriel Borowski[5], Ali Alahmer[1,6], M. Abu-Zaid[3],

[1] Mechanical Engineering Department, Tafila Technical University, , P.O. Box 179, Tafila, 66110, Jordan
[2] Renewable Energy Technology, Applied Science Private University, P.O. Box 166, Amman,11931, Jordan
[3] Mechanical Engineering Department, Mut'ah University, Jordan
[4] Department of Thermal Science, Wrocław University of Science and Technology, ul. Wybrzeże Wyspiańskiego 27, 50-370, Wrocław, Poland
[5] Faculty of Environmental Engineering, Lublin University of Technology, ul. Nadbystrzycka 40B, 20-618 Lublin, Poland
[6] Department of Industrial and Systems Engineering, Auburn University, Auburn, AL 36849, USA
* Corresponding author's email: sameh@ttu.edu.jo

ABSTRACT
Recently, hydropower energy resources become an attractive means of generating electricity for, off-grid networks, especially in rural areas. This work aims to design a suitable prototype of an energy-storing system, which is called a Potential Steam Hydro Capacitor. This system gives a manageable source of electricity, and partially provides drinkable water, at a low cost, as an alternative to comparatively high-cost electrical batteries. The system is composed of two solar collectors, connected in series. The working fluid in the first collector is Dead Sea water, and in the second fresh water, a heat exchanger, a thermosiphon solar water heater connected to a high column to pass the vapor to high altitude, and a condensation unit on the roof of the building. The system succeeds in producing a considerable amount of fresh water at a height of 3.4 m. The potential energy produced, can operate a small turbine. The capability of the system, to convert thermal energy in the freshwater, to potential energy, was high, with an efficiency of 66.7%. adding solar concentrators to the system would increase the water collected.

Keywords: renewable energy, Dead Sea, potential energy, rural areas, energy storage

INTRODUCTION

The use of renewable energy sources, such as solar, wind, and hydraulic energies, from the dawn of time; they have been used, for many centuries and their applications continued throughout history. In recent years, due to the increase of the environmental issues caused by using conventional fuels, in addition, to the increase, of world demand for energy, due to the increase of world populations, and amended quality of life. The-humaneness reverting to renewable energy sources. It is estimated that the world's energy demand will increase by 62% before 2050. Thus, it is expected that a large part of the growth is installed power throughout the world will be linked to the rise of renewables which will become the main source of energy [Alvarez et al. 2021].

On the other hand, the world is doing what it can, to reduce carbon dioxide emissions, and limit the global average temperature change, particularly after reaching a new agreement in 2015 at the Paris Climate Summit. In the 2015 United Nations Climate Change Conference, in which an agreement was reached that for the first time all nations united under a common cause of undertaking ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. And therefore, it charts a new track, in the global climate effort.

To move forward, worldwide nations need to, realize that there is not so much that can possibly be done, in limiting Greenhouse Gas (GHG) emissions, as the human population increases and puts more demands, on our energy infrastructure. To further help the environment, and secure the future of the planet, for the generations that are yet to come, we need to move to renewable sources, for our energy generation, renewable energies are inexhaustible and clean and they can be used, in a decentralized way. Also, they have the additional advantage of being complimentary, the integration between them being favorable. For example, solar photovoltaic energy supplies electricity on sunny days (in general with low wind) while on cold and windy days, which are frequently cloudy, the wind generators are able to supply more electric energy.

As the Jordanian Government, the Ministry of Energy and Mineral Resources mentioned in Jordan's Energy Strategic Plan 2015–2025, is working on developing renewable electricity generation, as one of the strategic goals, and thus in this paper focuses on the use of, one of the renewable and namely, solar energy. Solar energy as it is vital renewable energy, due to its availability, continuity, and cleanness Jordan is characterized and classified by high solar radiation among regions in the world because it is located, in the earth-sun belt area that has high potential solar energy.

While Jordan depends on imports of fossil fuels, to cover 90% of its energy requirements, in 2018. Renewable energy provides a minimal contribution to the energy supply. Moreover, energy consumers, in all economic sectors, have made limited efforts to improve energy efficiency. Therefore, high energy storage potential exists in all sectors ranging from 20% up to 40%, depending on the electrical sector.

The governmental and technical outlook, for renewable energy, In Jordan, is still not sure of the progress of this sector significantly, in the next ten years, and the government is not contenting the renewable resources, of power as a reliable choice yet, because of many reasons, starting the fluctuating energy generation in, renewable and not being totally controlled, to turn on or shut it off, for which is the production of, energy by these systems are not constant, and varies from season to season and even day to day. For that, the Ministry of Energy confirmed that the main primary concern is to provide a secure power supply every time, for every Jordanian citizen without a breakaway.

Hydropower with reservoirs is the only renewable energy storage in wide commercial use. Hydropower reserves and pumped hydro are used for storing at multiple time horizons, ranging from minutes up to several years [Hulsmann et al. 2015].

In a study [Al-Salaymeh 2006], periodic radiation calculations in different places in Jordan found that the abundance of solar energy in Jordan, is evident from the annual daily average, of global solar irradiance, which ranges between 5 and 7 kWh/m^2 day, on horizontal surfaces. This corresponds to a total annual value of 1600–2300 kWh/m^2 year. It was determined that the mean value of solar energy in Amman city equals 5324 kWh/m^2. day. As expected, Amman receives the most solar energy in June (mean value of 7995 kWh/m^2) and, July (mean value = 7875 kWh/m^2) and the least in, December (mean value = 2676 kWh/m$^{2)}$ new storage system is suggested, that is less costly than batteries and has more efficiency, than earthling electricity in the ground, as a solution for fluctuating in, renewable energy production problems. This idea is the basis of this work. It was confirmed that humans in time began, creating water storage systems, at the most convenient locations to best utilize power capacity [Chakraborty et al. 2015].

Since water evaporates, at various rates, due to its increase in internal energy, temperature increase, evaporate water at any temperature, especially when it seems to reach 100 ^{o}C, water will change from liquid to vapor (at constant atmospheric pressure). This evaporation process starts from the surface layer to the bottom gradually. This means that daily solar radiation will provide, the heat needed.

The main electricity storage technologies, available today are Hydropower Storage Schemes are the most widely used technology to store energy. They contribute to grid stability and provide ancillary services such, as standby and reserve duties, black start-up, frequency control, and flexible reactive loading. Hydro plants can also be used as synchronous condensers, to stabilize the power system voltage by, supplying reactive power to the system. Pumped-storage hydropower facilities use, off-peak electricity to pump water from, a lower reservoir into one at a higher elevation. When the water stored, in the upper reservoir is released, it is passed through hydraulic turbines to generate electricity.

Although renewable energy sources, become an important point in terms of, increasing energy source diversity and, decreasing harmful emissions, power system stability suffers from increasing renewable energy, and distributed generation penetration, to the power system. Therefore, grid-scale energy storage systems, are introduced to improve power system stability. In this paper, giant-scale energy storage technologies that is, connected to the power system, to enhance the power system stability, and power quality are reviewed and explained. Energy storage technologies, for grid-scale energy storage systems, application of energy storage systems, and control methods are discussed and summarized. In addition, some comparison results are, given regarding energy storage technologies for, grid-scale applications.

As an application of the Dead Sea water (DSW) experiments, working fluid in the solar collectors will give a better heat efficiency, and transfer, than many other working fluids such as pure water, or hydrocarbons oils because its content of minerals, and its ionic bonds, this research uses the same solar collectors and the working fluid DSW [Al Tarawneh and Abu-Zaid 2019]. In another study, it has been concluded that the heat transfer coefficient is less with salted water than with fresh one [Mu et al. 2016].

The integration of energy storage technologies is, important to improve the potential for flexible energy demand and, ensure that excess renewable energy can be stored, for use later time. Electrical generated from renewable sources, which has shown remarkable growth worldwide, can rarely provide an immediate response to demand as these sources, do not deliver a regular supply easily, adjustable to consumption needs [Spataru et al. 2015]. During the past decade, cold thermal energy storage systems have been widely used, for their significant economic benefits [Ibrahim et al. 2007].

Thus, the main objectives of this study are design a suitable prototype of an energy storing system, which is called a Potential Steam-Hydro Capacitor (PSHC), which gives a controlled source of electricity and partially drinkable water, with low initial cost, as an alternative of high-cost batteries and electrical capacitors. The prototype will be with proper dimensions and a structure that resists corrosion and thermal stresses. Studying the option of steam production and self-head transporting is more efficient and better in maintenance than head pumping, by studying the energy conversion process between parts. As proposed to work on this research, by constructing and studying a cheap, effective, reliable, and multi-function storing system. In addition, keeping energy produced in the high generation hours is stored until, the rush hours of consumption. Because many researchers proposed that, hydropower resources become an attractive means, of generating electricity for off-grid networks, especially in rural areas [Rismanchi et al. 2013]. An excellent review and analysis of hydropower systems and storing problems is presented in [Okafor 2013].

EXPERIMENTAL APPARATUS

A schematic diagram of the experimental apparatus is shown in Figures 1 and 2. It is composed of two solar collectors connected in series, the working fluid in the first is dead sea water, and in the second one is fresh water, a heat exchanger, a thermo siphon water heater, connected to a high column to pass the vapor to high altitude, and a condensation unit on the roof of the building.

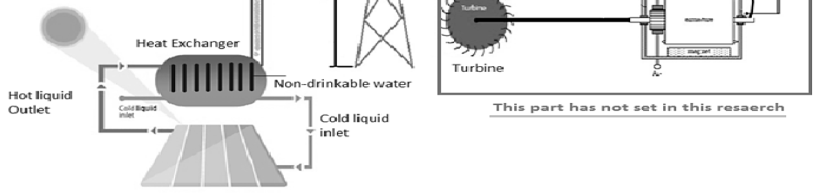

Figure 1. The proposed potential steam-hydro capacitor

Figure 2. Experimental apparatus: 1 – solar collectors, 2 – heat exchanger, 3 – condenser

In the experiments, thermo siphon solar water heaters were used, which are probably the most popular solar heating systems. Thermo siphon work is based on the principle of, physics where heated water rises, so the solar storage tank must be installed, above the solar panels. The performance test on a thermo siphon solar water heater showed the heater recorded a maximum temperature of 72 °C at an average heat gain of 24 W per hour [Chakraborty et al. 2015]. In another study, it was shown that the most efficient solar heating system is the one using a vacuum tube. Reaching a maximum efficiency of 72.33% and a maximum temperature of 62.6 °C [Hernandez and Guzman 2016].

The main components of the thermo siphon passive systems are solar storage from two solar tanks, panels, pipes, and valves. A floating head heat exchanger is, widely used for service where the temperature, is high between the shell and tube bundle, with high reliability and wide adaptability, the floating head heat exchanger has accumulated a wealth, of experience during the long – term using process, and promoted its development constantly. So far, among all kinds of heat exchangers, the floating head heat exchanger is still in a leading position, it was used in the Mut'ah University heating plant.

The heat exchanger transfers the heat of DSW dead sea water, to non-drinkable water, then return the working fluid DSW back to the solar collectors to complete the loop. Fixed and floating head heat exchanger construction finds widespread application, in the power and industry processes [Singh and Soler 1984]. The pen recorder was used to instantly record various temperatures.

Methodology

During performing several experiments, the following results of temperatures are measured, T_1 temperature at the inlet of DSW to the solar collector. T_2 is the temperature of the outlet DSW from the solar collector (we seem, to insert a schematic diagram here to explain where the measurable points are and their numbers for example T_1, T_2, T_3, etc.). T_{sat} is the temperature inside the heat transfers floating tank. In addition to the irradiance incident on the system, the irradiance on the system, the volumetric flow of water in both collectors, the amount of water collected from the heat exchanger, and the amount of water collected from the vented port.

As the system is supplied with dead sea water as the working fluid, the readings and results are taken and analyzed at each stage of the system, to study its efficiency, nature of work, and, ways of developing it, until reaching the desired result of the production of condensate water.

Nomenclature

C_p	Specific heat capacity at constant pressure (kJ/kg·K)
G_{exp}	Measured radiation (W/m²)
G_{DSC}	Data from the Dead Sea Center values for horizontal surface (W/m²)
G_{DSCC}	Values from the Dead Sea Center corrected to the tilted angle of the solar collector (W/m²)
G_t	Calculated total radiation (W/m²)
H	Height of condensation tank (m)
T_1	Inlet temperature DSW to the solar collector (ºC)
T_2	Outlet temperature DSW from the solar collector (ºC)
T_{sat}	Inside temperature of the heat transfer floating tank (ºC)

Initially, a single solar heater consisting of 30 tubes was used to heat dead sea water. A second solar collector was used after being cleaned and restarted. The heater was connected to the heat exchanger, which was connected to a chimney for the generated steam to move upward to the condensing unit. The experiments were performed during daylight time, from 8:00 AM to 5:00 PM.

RESULTS

Table 1 shows a comparison between the theoretical irradiance G_t, using [Sun earth tools calculator, 2019, and NASA calculator, 2018], experimental $G_{exp.}$ during performing the experiments, at latitude 31º, longitude 35.7º, the solar azimuth angle of 25º, inclination of the collectors 37º, and the data from Dead Sea Center at Mutah University, for horizontal surface D_{DSC}, and data from Dead Sea Center values corrected to the slope of the solar collectors G_{DSCC}. These results are shown also in Figure 3. these data are within an average difference of 11% from the other two values. This is due to the variance difference conditions in the three cases.

During performing several experiments, the following results of temperatures are measured, T_1 temperature at the inlet of DSW to the solar collector. T_2 is the temperature of the outlet DSW from the solar collector. $T_{sat.}$ is the temperature inside the heat transfers floating tank. In addition to the irradiance incident on the system. Figure 4 shows various temperatures for the single collector. It is clear from the figure, that after sunrise, all temperatures increase until 2:00 P.M., coming to a maximum value and then decreasing.

This trend is the same as the trend in Figure 5, which shows the measured irradiation incident on the system. The maximum value is between 1:00 to 2:00, with a value of 1150 (W/m²). The maximum temperature of the outlet DSW from the solar collector is 72 ºC, and the average temperature is 63 ºC.

Figure 6, shows various temperatures during daylight time, for two solar collectors connected in series. In general, the temperature profile is similar to that of using one solar collector. The

Table 1. Various data of irradiance at the location of performing the experiments

Time	G_t (W/m²)	$G_{Exp.}$ (W/m²)	G_{DSC} (W/m²)	G_{DSCC} (W/m²)	G_{DSCC}/G_{DSC}
9:00	224	200	297.4	157.6	0.530
10:00	696	750	781.2	618.0	0.791
11:00	919	900	882.4	851.9	0.965
12:00	1084	1000	902.0	1027.4	1.139
13:00	1203	1075	894.7	1153.3	1.289
14:00	1171	1069	789.3	1116.8	1.415
15:00	800	815	472.8	728.5	1.541
16:00	514	517	266.3	444.0	1.667
17:00	385	340	179.4	321.7	1.793

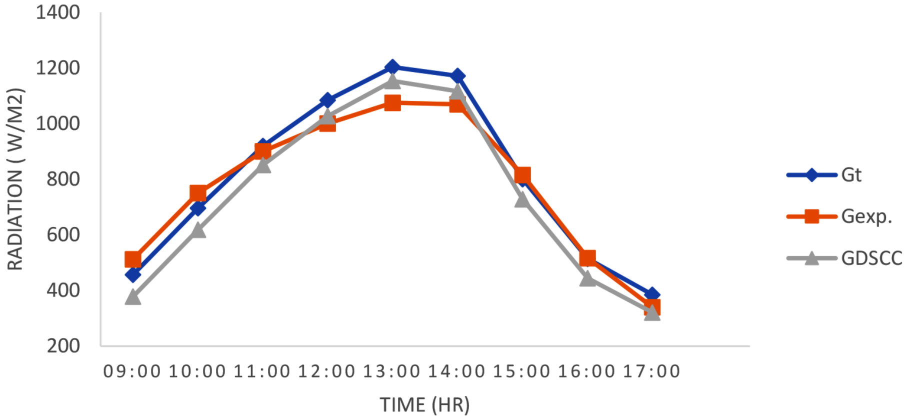

Figure 3. Various data of irradiance at the location of performing the experiments

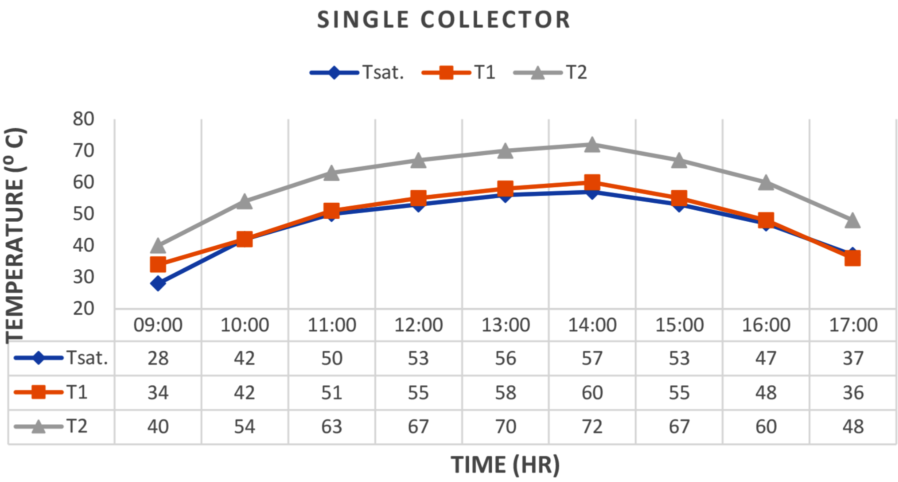

Figure 4. Various temperatures during daylight time for a single collector

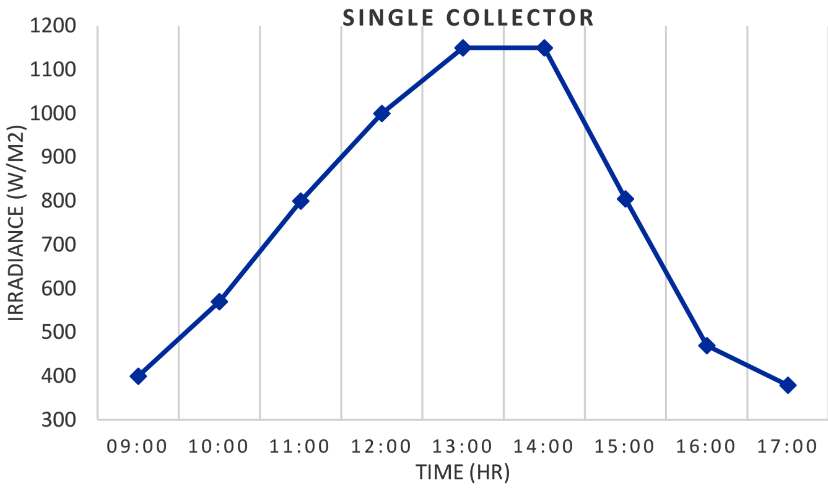

Figure 5. The incident radiation on the system for one solar collector

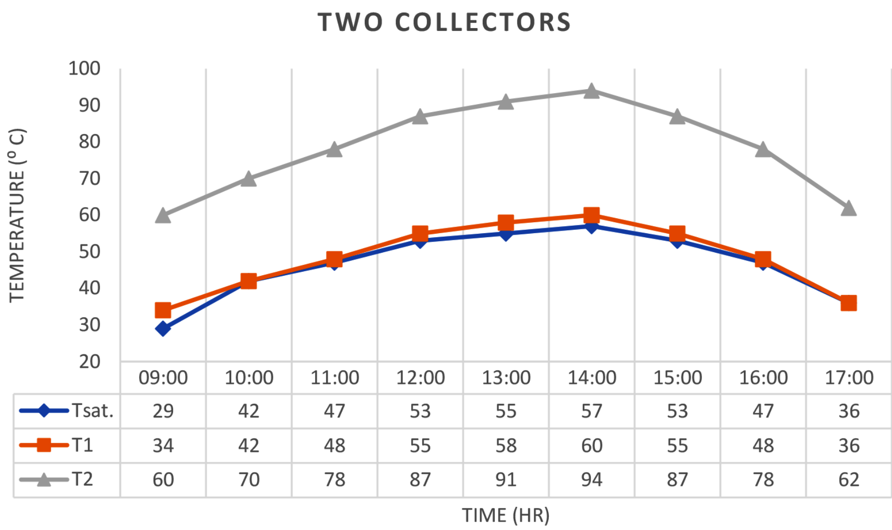

Figure 6. Various temperatures during daylight time for two collectors connected in series

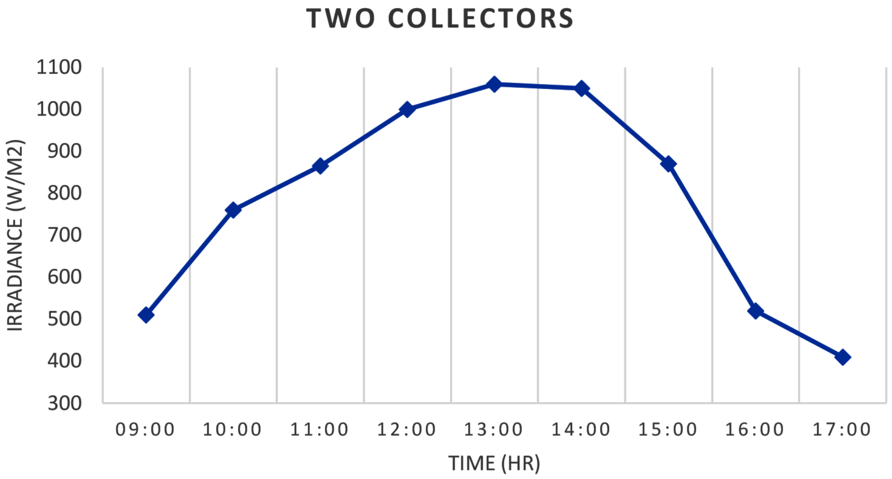

Figure 7. The incident radiation on the system for two solar collectors

figure shows that the maximum temperature attained was 94 °C, whereas for one collector was 72 °C. Figure 7, shows the irradiation for daytime, the maximum irradiance incident on the system was 1150 (W/m^2), the same as for one collector. This means that both systems (one solar collector and two solar collectors, operate at identical conditions since the two experiments were performed in two consequence days.

Sample of calculations

To calculate the thermal energy rate obtained in the collector, the following formula should be used:

$$Q_{gained} = m \cdot C_p \cdot (T_2 - T_1)$$

$$m = V \cdot \rho = (8/60) \cdot 1000 = 133.3 \text{ kg/s}$$

$$T_2 = 60.1 \text{ °C}$$

$$T_1 = 48.2 \text{ °C}$$

$$Q_{gained} = 133.3 \cdot 4.2 \cdot (60.1 - 48.2) = 6662 \text{ kW}$$

These results were accepted after performing many trails that were affected by the heat exchanger's leakage. after discovering the heat exchangers' leakage and realizing the huge amount of vapor rising from the expansion port chimney, the exiting vapor generated inside the solar collector cylinder units only was collected and condensed in the condensation unit, and the amount generated was measured, which reviled that 43 ml were produced in average per hour. The potential energy (*PE*) stored in condensed water, can be found using the following formula:

$$PE = m \cdot g \cdot h$$

where: m – mass of condensates water
h – head height of condensation tank = 3.5 m

$$Q_{potential} = 133.3 \cdot 9.81 \cdot 3.4 = 4446 \text{ kW}$$

It is obvious that the potential energy produced is less that the heat gained. The difference is because of the heat loss during the travel of the vapor to the condenser. This loss is 33.3% of the heat gained, this is since the system is uninsulated. Thus, the efficiency of the system in converting thermal energy to potential energy is 66.7%.

Table 2 shows that the energy gain, water collected from vapor of the heat exchanger, the potential energy, and the water collected from

Table 2. Energy gained in DSW collectors, Water collected the heat exchanger, potential energy for the vapor collected from the vented port

Collectors' arrangement	Experiment No.	Energy gain (W)	Water collected from vapor of the heat exchanger (l/hr)	Potential energy (J)	Water collected from vented port (l/hr)
Single solar collector	1	5710.7	0.043	1476.40	N/A
Single solar collector	2	5703.1	0.050	1716.75	N/A
Two solar collectors	1	1440.3	0.070	2403.45	0.037
Two solar collectors	2	14468.7	0.059	2025.76	0.040

the vented port, is greater than for two collectors, since the heat added to the water in the collectors is more, and that was shown in the temperatures for Figure 4 and Figure 6. All the temperatures in the two collectors' case are higher than the single collector.

The collected water could be increased by adding solar concentrators to the system and increase the mass flowrate of water in the collectors. This would increase the temperature of all collectors, which would increase the water collected for all collectors.

CONCLUSIONS

The proposed potential steam hydro capacitor was constructed, examined, and work satisfactory. The system composed of two solar collectors connected in series, heat exchanger, and condensing unit. The capability of the system to convert thermal energy in the heat exchanger to a potential energy is considerable, with an efficiency of 66.7%. A significant amount of fresh water has been collected and the generated potential energy can power a small turbine. It is recommended to study the efficiency of using this system at various areas with a very high solar irradiation in rural areas, and study using another working fluid other than dead sea water which give more efficient heat transfer characteristics. Also adding solar concentrators to the system would increase the collected water.

Acknowledgements

This article was supported by the Lublin University of Technology (Grant No. FD-20/IS-6/002).

REFERENCES

1. Al Tarawneh E.A., Abu-Zaid M. 2019. Evacuated tube solar collector using Dead Sea water. The First International Conference on Mechanical Engineering Sciences and Applications, Tafila Technical University, Jordan.
2. Al-Salaymeh A. 2006. Modeling of global daily solar radiation on horizontal surfaces for Amman City. Emirates Journal of Engineering Research, 11(1), 49-56.
3. Alvarez H., Domingues G., Ordonez A., Menedez J., Alvarez R., Loredo J. 2021. Mine water for the generation and storage of renewable energy – A hybrid hydro-wind system. Int. J. of Environmental Research and Public Health, 18(3), 6758.
4. Chakraborty S., Ahmad Md., Guin A., Mukherjee S., Goswami R., Roy R. 2015. Hydropower: its potential – A theoretical perspective. Journal of Civil and Environmental Technology, 2(12), 56-60.
5. Hernandez E., Guzman R. 2016. Comparison of three systems of solar water heating by thermo siphon. Journal of Physics, 012007.
6. Hulsmann S., Harby A., Tayler R. 2015. The need for water as energy storage for better integration of renewables. Policybrief, United Nations University, No. 01, 1-8.
7. Ibrahim H., Ilinca A., Perron J. 2007. Energy storage systems-characteristics and comparisons. Renewable and Sustainable Energy Reviews, 12, 1221-1250.
8. Mu X., Shen S., Yang Y., Liang G., Chen X., Zhang J. 2016. Experimental study on overall heat transfer coefficient of seawater on three tube arrangements for horizontal-tube falling film evaporator. Desalination and Water Treatment, 57(21), 9993-10002.
9. Okafor B. 2013. Thermo siphon solar water heater. Int. Journal of Engineering and Technology, 3(3), 313-316.
10. Rismanchi B., Rahman S., Masjuki, H., Mahlia T. 2013. Modeling and simulation to determine the potential energy savings by implementing cold thermal energy storage system in office buildings. Energy Conversion and Management, 75, 152-161.
11. Singh K.P., Soler A.I. 1984.Tube sheets in fixed and floating head heat exchangers: Mechanical design of heat exchangers. Springer, Berlin, pp. 415-516.
12. Spataru C., Kok Y., M. Barrett M. 2015. Physical energy storage employed worldwide. Energy Procedia, 62, 452-461.