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Performance of Solar Pond Integrated with Thermoelectric Generator: A Theoretical Study

Hayder Noori Mohammed, Mohammed Hassan Abboud, Basim Sachet Atiyah*

Mechanical Engineering Department, College of Engineering, University of Kerbala, Karbala 56001, Iraq

Corresponding Author Email: basim.s@s.uokerbala.edu.iq

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ABSTRACT

This article intends to theoretically propose and investigate the construction of a solar pond with a salinity gradient and the generation of electrical energy from it using a thermoelectric generator. It is possible to gradually add salt (magnesium sulfate salt) to the lower layer, increasing the quantity of thermal energy supplied to the pond. According to the theoretical findings, increased heat storage in the pond's bottom layer is enhanced by the addition of salt, and reflecting mirrors help to raise the quantity of solar radiation that is directed at the pond's surface, increasing the amount of thermal energy that is absorbed through the layers of the pond. Thermal energy losses are decreased by the plastic cover that has been applied to the pond's surface. When salt, a cover, and mirrors were added to the conventional pond, the amount of useable energy increased from (2 kilowatts) to (20 kilowatts), and these modifications helped the pond's thermal efficiency rise from (5 percent) to (28.4 percent). TEG Electric Efficiency was 12% at a temperature of 65℃ and a mass flow rate of 2 L/min.

1. INTRODUCTION

The importance of solar energy as being one of the major renewable energies is well known to scientists and researchers. Solar energy, which is available in the world's majority countries, can meet humanity's future energy needs. Solar energy does not, however, always exist, which is one of its limitations. It is necessary to have solar energy storage technologies because this energy is not present during overcast weather at or night. Finding a means to store this energy is required before exploring and using solar power. As a result, one technique used to store solar energy is the solar pond, which has a variety of uses [1-3]. A solar pond is a sizable body of water designed to store solar energy in heat reservoirs on the pond's bottom side, where it can later be used for practical reasons. Solar ponds are used to gather heat from the sun's rays, and the energy they contain will eventually be used for other purposes. It can run constantly all year round. A salinity gradient solar pond (SGSP) uses saltwater to capture, store, and conserve the thermal energy of the sun's descending rays. It comprises three layers: the upper convective area (surface zone), which has little salt content; solar radiation absorption; and with the excess energy being transported to the intermediate zone underneath (gradient zone). This zone can be identified by the gradient concentration of salty water, which varies with depth as measured from the upper convective zone boundaries to the lower convective zone limits. The region with the highest salt density is the lower convective zone (store zone). At the zone boundary, there is no difference in salt content. Its uniformly high salinity water is heated by solar radiation, which permeates the water's surface and saves intermediate zones at the pond's lowest point. The solar pond can be used for many purposes, including heating and cooling homes; providing heat for industrial processes; producing electricity; drying crops for business or agriculture; desalination; heating swimming pools and greenhouses; etc. [4, 5]. TEGs have been identified as a method for both large-scale electric power generation and a different source for low power generation. According to the life cycle analysis that was done, alternative power generation methods will become more popular because of their economic benefits and their environmental friendliness as fuel prices rise. Including taking externalities into account will undoubtedly favor the use of TEG as an addition for the generation of electric power. Seebeck effect and the Peltier effect are the basis for the TEG's operation because there is a temperature gradient. The former occurrence relates to the temperature differential associated with the Seebeck coefficient (V/K), and the thermoelectric potential under open-circuit conditions [6-10]. Many studies have investigated theoretical and practically the performance and productivity of solar ponds with additions, including: Heat transmission in a brackish-gradient solar pond has been theoretically and empirically investigated by Khalilian [11]. The model examines how transit energy behaves in each section of the pond, including many procedures that impact the solar pond's efficiency. The temperature in the storage region was measured both theoretically and practically. The findings showed that evaporation, rather than convection and radiation, accounts for most heat loss from the pond surface. The thickness of the lower load region can be adjusted depending on the application, while the thickness of the top load area should be as thin as possible. The stored temperature of a pond was found to be significantly impacted by wall shade, whereas a large pond's effect was determined to be minimal. The impact of the solar pond's design when covered with plastic glazing was examined by Assari et al. [12]. Solar ponds similar in size and area to one another but with a distinct geometric shape—rectangular as opposed to circular—have been examined. At the conclusion of the research, it was discovered that the maximum temperature in the rectangular pond was higher. The equations also show how variables like geographic location, radiation angle, pond size, and the day and time of year affect the shadow area produced in each of the solar ponds. So. The rectangular solar pool was shaded less than a result, according to the results. The rectangular solar pond's shaded area appears to have shrunk. The solar pond in UCZ had a temperature that was considerably different from the surrounding air because of the glass, plastic used in solar pond construction. Heat couldn't escape from the pond's surface because of the glass cover. As a result, heat was kept in the ponds, raising the temperature in the UCZ. At the conclusion of the test, it was also noted that there was a 13℃ temperature differential between the UCZ in the solar ponds and the ocean. The plastic glass handled the temperature discrepancy. The difference in temperature between the circular and rectangular solar pools at the conclusion of the testing period was 12 degrees and 9 degrees Celsius, respectively. A mathematical model was designed to simulate the performance of a solar pond used to collect thermal energy in the Iraqi city of Kerbela by Mahdi [13]. Calculating the incident solar radiation on the pond's surface required the usage of Fortran software. The water temperature was then calculated using the finite difference approach. The findings corroborated earlier meteorological data. The lower layer of the pond's water reached a maximum temperature of 90℃, and more solar radiation than 7 kW/m2 was received. The findings suggest that the city of Kerbela is suited for creating a solar pond and using it for a variety of purposes. Sogukpinar 2019's [14] used COMSOL software to determine how a solar pond with a salinity gradient and a square surface area operates and how much energy it produces. It was discovered that there was a good agreement between the numerical outcomes of this work and the experimental outcomes of earlier investigations. These findings show that the solar pond system is a successful method for supplying hot water for many uses, including the production of electricity, and that the highest temperature of the water in the solar pond is approximately 55 degrees Celsius. Rizvi et al. [15] describe how adding reflectors to the solar pond's sides and covering the water's surface with a cover can improve the solar pond's efficiency and the amount of radiation it receives. The maximum water temperature reached was about 65℃, which is a rise of about 28% over the average situation (without installing reflectors or covering the pond deck). Kumar [16] studied Theoretically, the performance evaluation and boost of a salt-gradient solar pond incorporates a thermoelectric generator in its top layer. A genetic algorithm was used to solve an inverse optimization issue in order to determine the ideal size of various zones while taking into account the minimal temperature differential throughout the TEG. To show the thermal performance and power generation under various circumstances, parametric simulations of different meteorological data from India were looked at. The developed system enabled improved performance in comparison to the literature while having an about 18.11 percent lower height. A net heat transfer coefficient was used by Verma and Das [17] to study heat extraction from the gradient layer of a solar pond with a more realistic perspective. The thermal efficiency of the solar pond was studied for research purposes, the temperature distribution in the gradient layer was established by an analytical method. The outcomes demonstrated that the idealized assumptions under-predicted the exergy destruction rate and gradient zone optimum thickness.

The current work aims to provide a theoretical study to improve the performance of the solar pond with salt (magnesium sulfate) and the addition of reflective mirrors, this to conserve thermal energy in the solar pond's bottom layer. As well as verifying the possibility of benefiting from the thermal energy of the pond to produce electrical energy using a thermoelectric generator (TEG). This is done by feeding TEG from one side with hot water produced from the solar pond in theory, while cold water is pumped from the other side TEG to create a temperature difference on both ends TEG to produce an electrical potential difference to be used in certain applications. This work is theoretically carried out in the city of Karbala, Iraq.

2. SOLAR POND CONSTRUCTION

The test rig for the current investigation is a solar pond with a salinity gradient. The solar pond's construction was raised by the following measures: Reflective mirrors are added once the plastic covering applies to the pond's sides. Finally, the inside and edges of the pond were covered with glass, mirrors, and black stones. In Figure 1, the schematic diagram is shown. The pyramidal design and salt gradient were used in the production of the solar pond. The pond is 6.25 square meters on top, 1.35 meters deep, and 0.64 square meters at its bottom. There is a 60-degree tilt in the pond's walls.

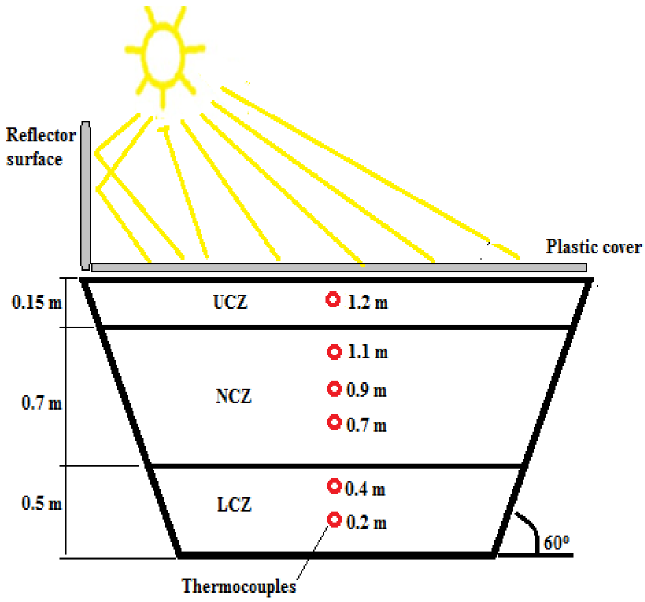

Figure 1. A solar pond schematic with secondary, measurement, and modification devices

3. MATHEMATICAL MODELLING

Heat Analysis of Lower Convective Zone:

$$H_L = Q_{cond.4} + (\frac{\partial T}{\partial t} * \rho_{LCZ} * Cp_{LCZ} * X_{LCZ}) \tag{1}$$

where, H_L is the thermal energy entered into the lower convective zone $Q_{cond.4}$ is the thermal energy exited from the lower zone $\frac{\partial T}{\partial t} * \rho_{LCZ} * Cp_{LCZ} * X_{LCZ}$ is the thermal energy kept in the lowest zone of the solar pond.

$$Q_{cond.4} = -K_{LCZ} \frac{\partial T_n^t}{\partial x}\bigg| \quad (2)$$

The finite difference of brine temperature of the pond lower zone (LCZ) can be determined by the next equation:

$$T_L^{t+1} = T_L^t + \frac{\Delta t}{\rho_{LCZ} * Cp_{LCZ} * X_{LCZ}}\left[(H_L) + \frac{K_{LCZ}(T_L^t + T_n^t)}{X_{LCZ}/_2}\right] \quad (3)$$

The solar pond useful thermal energy (Qu) can be determined by the following equation [18]:

$$Q_u = M_s\, Cp_s\, \Delta T \quad (4)$$

where, M_s is the solar pond brine mass of, Caps is the pond brine heat capacity of and ΔT is the average temperature difference between the ambient and lower zone.

The solar pond thermal efficiency (*Ŋ*) can be calculated by division of the useful energy (*Qu*) on the quantity of incident sun light on the pond surface (*I*) as follows [18]:

$$Ŋ = Q_u/I \quad (5)$$

The incident sun light on the pond surface (*I*) can be found by the following equation:

$$I = I_O * A \quad (6)$$

where, *A* is the solar pond surface area.

TEG electrical power generated is given as studies [19-23]:

$$P_{TEG} = I * V \quad (7)$$

$$V_{TEG} = \alpha * \Delta T \quad (8)$$

where, (αp–αn)=α and (Th–Tc)=ΔT, *Tc* and *Th* denote the cold and hot junction temperature. αp and αn are the Seebeck coefficient of *P* and *N* type TEG leg respectively.

The following equation may represent short circuit and open circuit relationships in a TEG with N number of couples.

$$V_{TEG} = 2 * N * \alpha * \Delta T \quad (9)$$

$$I_{TEG} = \left(\frac{\alpha}{\rho}\right) * \left(\frac{A_{TEG}}{L}\right) * \Delta T \quad (10)$$

Electrical resistivity of thermo element material, (ρ Ω cm). Area of thermo element, (ATEG mm^2). Length of thermo element, *L* mm.

The thermoelectric power is related to dimensionless figure of merit given by:

$$ZT = \alpha^2 * \sigma * T/K \quad (11)$$

where, α is the TEG Seebeck coefficient, k and σ are the thermal conductivity and electrical and T is the absolute temperature.

For calculating the efficiency of TEG, the following equation is used.

$$\eta_{TEG} = (T_h - T_C)/T_h * \frac{(1+ZT)^{0.5} - 1}{(1+ZT)^{0.5} + \left(\frac{T_C}{T_h}\right)} \quad (12)$$

4. THEORETICAL RESULTS

In theory, the study is carried out using the MATLAB program to resolve the governing equations and constrained flowcharts in this program such as theories of solar radiation falling on the solar pond surface and the mathematical calculations to compute it. It also includes analyzes of heat transfer through the lower layer of the solar pond. In addition, the mathematical equations for calculating the heat loss and the energy saved in the solar pond are shown, the mathematical equations are revealed to determine the thermal efficiency and the solar pond useful energy, the thermoelectric generator, the energy generated from it and its efficiencies. Here, magnesium sulfate salt is used at a concentration of 28 percent with the use of a plastic cover with reflective mirrors. The following results indicating the water temperatures in the pond layers in three different scenarios, were obtained by applying special equations to two types of ponds: Standard pond and salt gradient pond with addition of cover and reflective mirrors.

Water can convert solar radiation into heat energy when exposed to it, which it then stores inside its layers. Figure 2 displays numerically the water temperatures in the salt-free pond throughout a 24-hour period. The results show that during the period of solar radiation, as more radiation enters the water, the temperature rises; after sun set, as the angle of the sun's light as it strikes the pond's surface changes, the temperature falls.

Figure 3 demonstrates that the pond layer has become warmer overall, but particularly in the bottom layer. The effect of salting the water, which produces a brine solution that absorbs solar energy and converts it into thermal energy inside the pond, is what causes this.

In contrast to the previous case, where the salinity gradient pond was left exposed to the elements, Figure 4 illustrations the effects of covering the solar pond's surface with plastic. The lowest layer of the pond's temperature is clearly rising, as seen by the graph. Because of the cover's large reduction in water evaporation and consequent reduction in heat loss from the pond, the pond's functionality is affected.

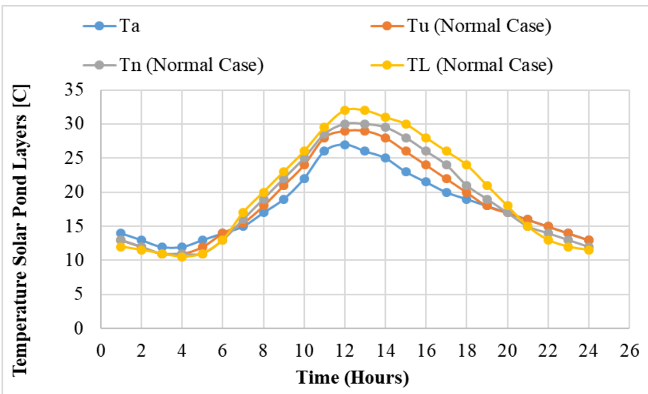

Figure 2. Temperature of the three layers of the normal solar pond

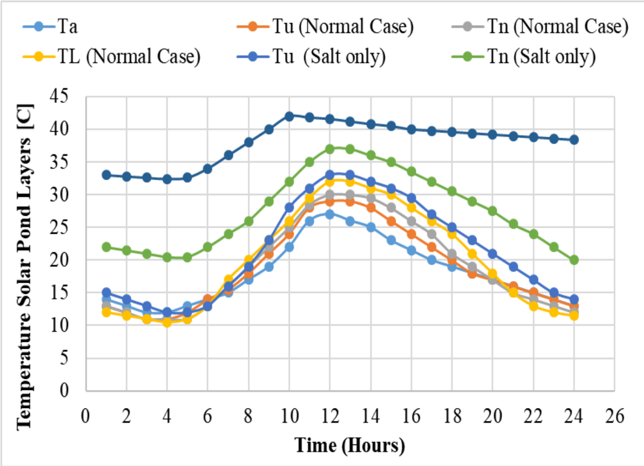

Figure 3. The three-layer salinity solar pond's temperatures

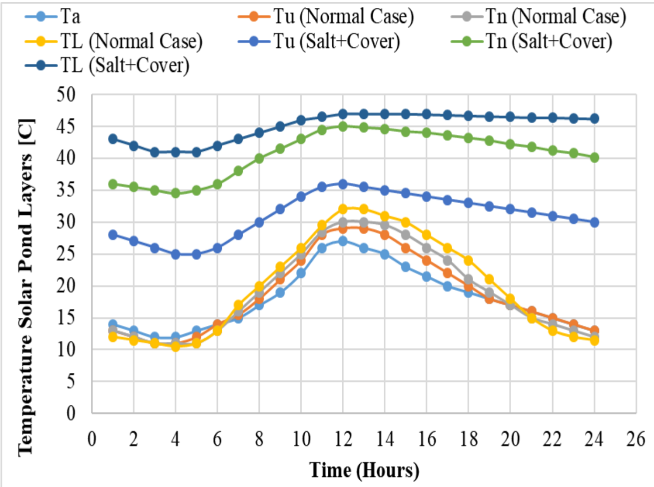

Figure 4. Temperature of the three layers of the covered salty solar pond

Because the solar radiation amount on the surface of the pond affects the quantity of thermal energy kept in the layers of the pond, any increase in the radiation shed on the pond's surface shows a growth in the thermal energy stored in the pond. This is where the reflective mirrors on the sides of the pond come into play, boosting the amount of radiation by redirecting the sun's rays away from its surface and toward the surface of the pond. This is depicted in Figure 5.

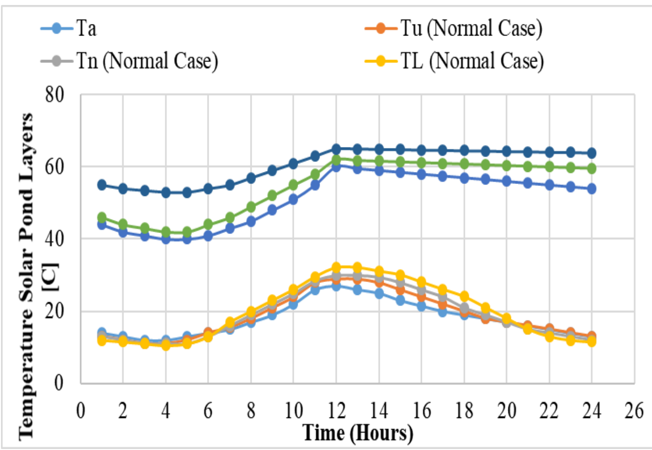

Figure 5. Temperature of the three layers of the covered salty solar pond with the reflectors

Theoretical results using additive methods are shown in Figure 6 for usable energy in a solar pond with a normal pond and a salt gradient pond. Given that the reflective mirrors and cover raised the pool's temperature, more usable energy would almost certainly be generated. This is because it is directly related to temperature. According to the theoretical results, the pond has a usable power of 2 kW. Salts are added to this quantity to reach 7.5 kilowatts. The highest value of usable energy during the study is close to 20 kW due to the increase in radiation that reaches the pond surface caused by the addition of salts, reflecting mirrors and cover. The substrate's internal heat storage system benefits from the addition of salts as well.

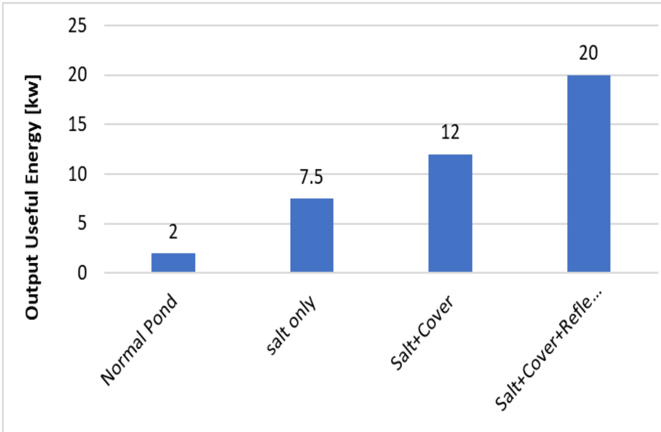

Figure 6. Output useful energy of solar pond [kw]

Figure 7 displays the efficiency outcomes of the solar-powered pond with a salinity gradient and the standard pond. Adding gravel, cover, and reflective mirrors has made the pond more efficient. The efficacy of the ponds is increased by this technique because it improves the amount of energy that can be used by the solar pond, which is directly proportional to the solar pond's thermal efficiency. The solar pond's efficiency increased with improvements, going from 5% to 28.4%.

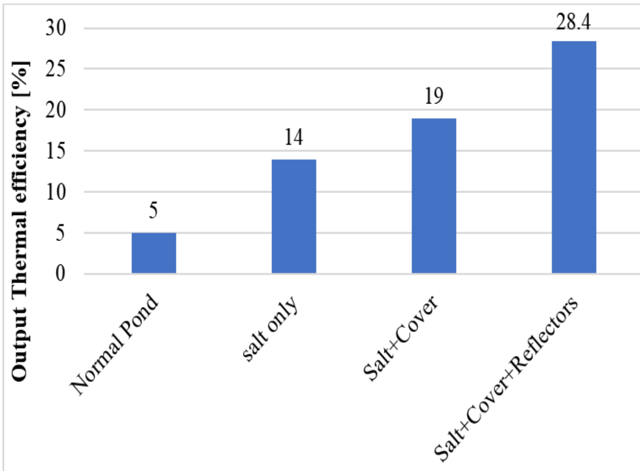

Figure 7. Output overall thermal efficiency of solar pond [%]

Figure 8 displays the current produced by TEG because of temperature differences and for three water flow rates via the tubes in contact with the electrodes. (TEG). It should be noted that the current value increases along with the flow rate. Because all the water in contact with the TEG at high speeds is of the same intensity, all the TEG chips function at the same productivity. Regarding the growth and its cause, Figure 9 shows behavior similar to that of the prior graph. The electrical potential differential (TEG) for three different water flow rates is depicted on the graph. According to the same principle, the increased flow rate happens as the electric potential difference widens. The electric power is calculated from the current and electrical potential difference induced by the flow of hot and cold water at three different flow rates on both sides of the TEG (TEG). This is depicted in Figure 10.

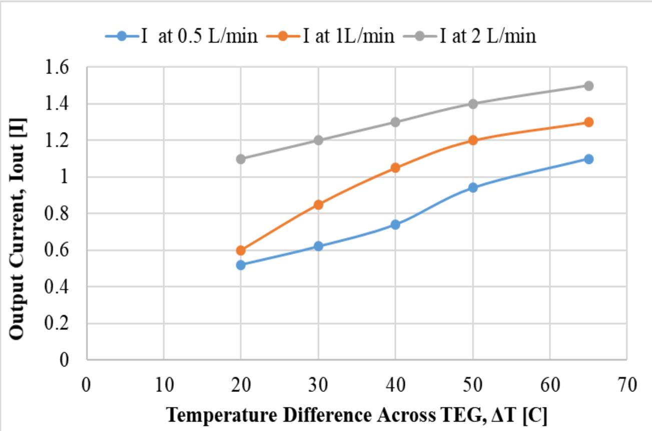

Figure 8. The output current, Iout [A] for temperature difference across TEG, ΔT [C]

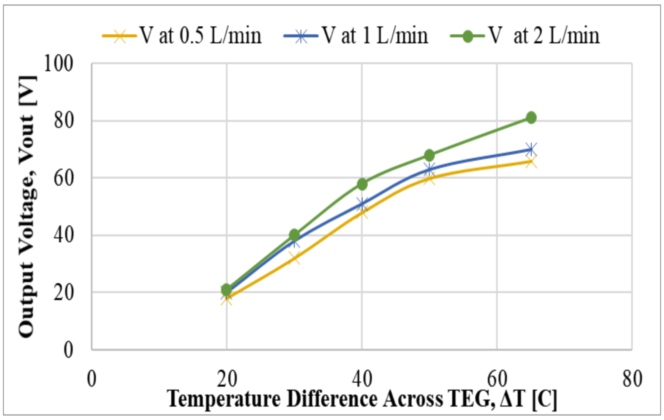

Figure 9. The output voltage, Vout [V] for temperature difference across TEG, ΔT [C]

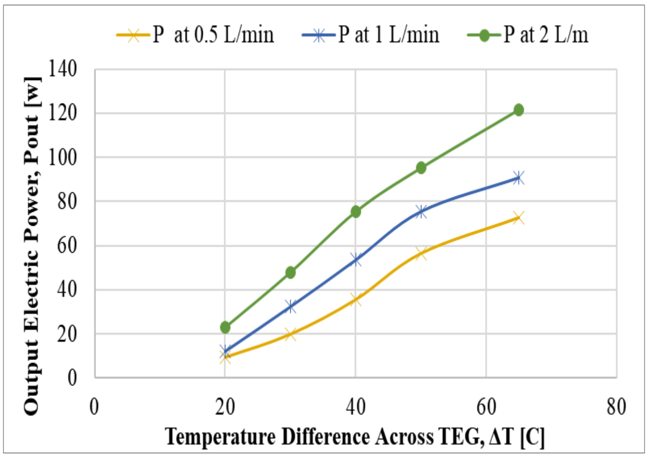

Figure 10. The output electric power, Pout [w] for temperature difference across TEG, ΔT [C]

The electrical efficiency of the TEG is calculated using the electrical energy produced by the TEG and three flow rates, as shown in Figure 11. Since it can be seen in the figure that increasing mass flow rate enhances thermal efficiency, the best mass flow rate throughout the tests was 2 liters per minute.

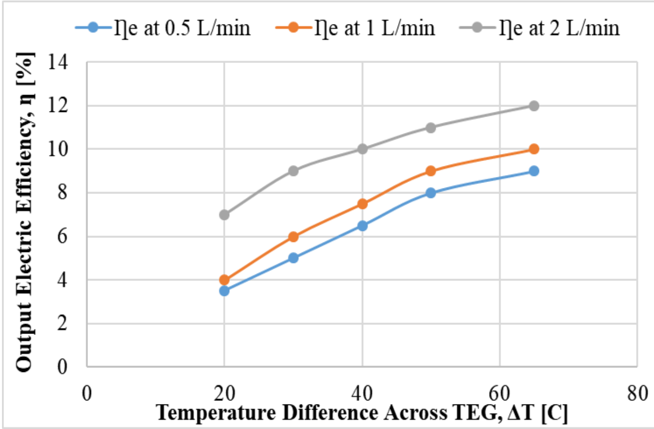

Figure 11. The output electric efficiency, η [%] for temperature difference across TEG, ΔT [C]

5. CONCLUSIONS

According to the theoretical findings got with the help of the Matlab software:

(1) While reflective mirrors help to raise the intensity of solar radiation directed at the pond's surface, which serves to raise the amount of heat energy absorbed through the pond's layers, the addition of salt helps to increase the amount of heat energy stored in the lower layer.

(2) The plastic cover that has been added to the pond's surface helps to cut down on thermal energy losses.

(3) When salt, a cover, and mirrors were added, the quantity of useful energy increased from 2 kilowatts to 20 kilowatts when compared to the conventional pond.

(4) These improvements allowed the pond's thermal efficiency to rise from 5 percent to 28.4 percent.

(5) TEG efficiency was 12% at a temperature of 65℃ and a mass flow rate of 2 L/min.

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