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Improving the Performance of a Solar Pond Using TEG: An Experimental Investigation

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ABSTRACT

A study has created a solar pond model. The pond's performance in terms of heat storage and electric power generation using TEG is analyzed using this model. The impact of various parameters, such as covering the pond's surface with plastic and using reflectors to focus on the intensity of solar radiation, will be investigated. A pyramidal pond with a base size of 0.64 square meters was used to validate the model. And it has a 6.25 square meter surface area. There's also a 1.35-meter depth. The walls are inclined at a 60-degree angle. TEG was also used to determine the pond's electrical capacity. The addition of a plastic cover and reflectors enhanced the efficiency of the pond's operation from 12.1% to 27.5%, according to the findings. At a lower layer temperature of 60 degrees Celsius, the electrical capacity reached 104 watts with a TEG operating efficiency of 8.9%.

1. INTRODUCTION

Energy plays a critical role in all aspects of a country's economic development. A nation's living levels can be correlated with its per person energy use. There is an energy crisis because of the rapid increase in the human population and the standard of living. Oil supplies will not meet rising population demand. To fulfill future energy demands, an alternative energy source had to be identified. Several green technologies, as well as methods for extracting energy, have been identified. Solar energy is one of the most extensively distributed and clean renewable energy supplies, and it is one of the most effective solutions to pollution and fossil fuel scarcity. An abundant and sustainable source of energy is solar energy [1]. There has been a surge in attention to environmental protection, resulting in using energy transference and thermal energy storage technologies (TES) that use renewable energy sources like solar energy. Thermal energy storage systems are employed in applications where the needed energy demand and supply do not coincide. There are two types of energy storage systems: sensible and latent. The fluid temperature is constant, when heat is kept or removed in the phase change part of the storing and charging duration in a sensible TES, including a solar pond, where the medium of storage does not undergo a phase transition and is added or subtracted, such as those systems that use a liquid combination of water and ice as the storage medium, where the fluid temperature is constant and heat is removed or stored in latent form in the phase change part of the charging and storing period. Solar ponds, often referred to as renewable storage systems for thermal energy (TES), are used for both storing and collecting solar energy and are gaining popularity in various thermal uses such as water desalination, space heating, and the use of biological cycles to generate power [2, 3].

The transfer process that takes place when a mixture is subjected to a heat gradient is known as thermos diffusion in physical terms [4]. It is referred to as "the Soret Effect," and a great deal of theoretical and experimental research has been done to interpret it. This article briefly discusses a one-dimensional theoretical and numerical approach to the concentration distribution of NaCl in a solar pond with a salinity gradient that is based on the first law of thermodynamics. Its fluid-thermodynamic factors are intended to be framed by the theoretical developments. Al Alawin [5] constructed a solar pond in Jordan with a 56 m^2 surface area and a 1.8 m depth. Three primary strata were present, UCZ, NCZ, and LCZ, according to the salinity scale and temperature that were measured. In the LCZ layer, the lowest specific gravitational value was 1.16. According to Al Alawin [5], the wind and the dust that accumulated on the pond's surface had a considerable impact on the pond's performance. Ongoing cleaning improved the efficiency of the pond, while the installation of a network of ropes lessened the effect of the wind. The solar pond's reflection mirrors were used to concentrate solar radiation.

Khalilian [6] has conducted both theoretical and practical research on heat transfer in a brackish-gradient solar pond. The model investigates how transit energy interacts in each area of the pond, considering several processes that affect the solar pond's effectiveness. Both theoretical and actual measurements of the storage area's temperature were taken. The results showed that evaporation—rather than convection or radiation—handles most heat loss from the pond surface. According to the application, the thickness of the lower load zone can be changed; however, the top load area should have the thinnest thickness possible. Wall shadow was shown to have a considerable impact on a pond's stored temperature, whereas a big pond had less of an impact. Al-whoosh et al. [7] constructed a 5 m^3 salty graded solar pond near the Dead Sea, which shows that after 100 hours of operation, the lower layer's maximum temperature is 85°C. Heat extracted from the solar pond can generate electric power or for desalination plants that operate under 100 degrees Celsius. Bezir et al. [8] constructed a solar pond with a surface area of 3.5x3.5 m^2 and a depth of 2m. The results revealed that reflectors during the day increased the heating area, and that these reflectors are foldable and serve as a cover at night to decrease heat loss, and that they have a great performance for the solar pool, as the heat increases by 25%. Theoretically, the larger the solar pool, the more efficient it is because heat loss from the walls and bottom is reduced per unit area. In order to prevent power supply interruptions caused by the temporary unavailability of a suitable heat source, Ding [9] discusses how most thermoelectric generator applications generate electricity from a non-stored heat source and the solar pond (SP) has been proposed as a heat source for a thermal storage system that can continuously supply enough heat for electricity generation. A low-grade heat source between 50°C and 100°C can be obtained from sun ponds, which also serve as thermal storage. The thermoelectric generator and the solar pond are also both extremely scalable in terms of size. In order to maximize the potential of the solar thermoelectric power generating system for the pool, the performance of the thermoelectric cells was integrated with the temporary heat transfer of the solar pond. An experimental solar pond model to heat water was built by Abbood et al. [10]. The pond measured 1 m in depth and 7.29 m^2 in surface area, and walls inclined at a 45° angle. In this study, potassium chloride and sodium chloride were employed as salts. Two reflecting mirrors were utilized to concentrate radiation of solar on the pond's surface. The highest temperature in the pond was 44 degrees Celsius when sodium chloride was used, while potassium chloride yielded a maximum temperature of 40 degrees Celsius. Thermal efficiency and usable energy were discovered to be 28.2 MJ/h and 11.6 percent, respectively, in the experiment. This study [11] presented a design and model for a low-cost solar sterilizer that uses hot, dry air to clean medical equipment. Sterilization of dry objects using hot air takes 60 minutes at 160°C. A box made of stainless steel measuring 60 cm × 30 cm × 12 cm is part of the design, and is used to carry surgical supplies. The system has been tested in many ways. Surgical instruments and reflective panels are present and absent. In 121 minutes, the system produced hot air at 160°C. When surgical instruments weighing 1.2 kg added, this time it increased by 23.9%. Reflective panels reduce the time required to generate the required heat by 9%.

The best method for capturing and storing solar energy is a solar pond with changeable salt density [12]. sunlight-based ponds that are permeable and impermeable are tested under various environmental situations. A 30-day period of readings was used to examine the salt density concentration, thermal energy storage measurement, and temperature cycle. Two identical 0.02 m^3 and 0.32 m tall solar basins were constructed for testing. Broken glass, weld spray, and fragments of black granite were utilized in the lowest convective zone (LCZ) as a permeable medium. The impermeable solar pond and the detachable solar pond had the greatest temperatures of 42.3 and 40.6, respectively. Temperature increased by 4.18% in the permeable median solar pond. The difference in the thermal energy reserves is 4.54 kilojoules. Compared to the impermeable solar pond, the medium permeable solar pond stores higher heat energy, according to optimization carried out using the acquired parameters [13]. Energy use increases together with the amount of underdeveloped or unusable land in developing nations. For these nations, solar energy presents a positive prospect. Solar Pond is a long-term heat storage and solar collector that can be used in open, sunny spaces. Numerous applications that call for low-grade thermal energy can be heated using solar pond technology, which can also be used to generate electricity. It is required to use systems fed by low enthalpy sources, such as thermoelectric generators (TEG) and the organic Rankine cycle, in order to generate electrical energy from solar ponds (ORC). In this study, the organic Rankine cycle and a solar pond model for power production are examined.

Goswami et al. [14]. presented research in India on an experimental analysis of a new solar pond-driven thermal power system. The aim of the experimental study was to charge a 12V battery using a 4m^2 and 1m deep solar pond insulated with ethylene black and covered with propylene. The salt used is sodium chloride in the lower area at a concentration of 24.01%. An octagonal stainless steel reflector is installed to direct solar radiation. The pond's bottom layer had a temperature of 55C, when the radiation intensity was 976 w/m^2, and here comes the role TEG, which is a material made of bismuth semiconductor, in converting thermal energy into electrical energy. Volts 1.5 were obtained at a temperature of 23°C.

The aim of this study was to examine how effectively a solar pond with a salinity gradient functioned as a source of hot water intending to use it to generate energy using TEG. In order to compare the addition of magnesium sulfate salt regarding its qualities and efficacy in thermal storage, the pond is built to use the solar radiation that falls on its surface. This has been made easier by using reflective surfaces and a plastic cover system to track how the sun affects the pond's effectiveness. The performance of a thermoelectric generator in these circumstances is another goal of the research.

2. EXPERIMENTAL SETUP

2.1 Construction of a solar pond system

A solar pond in the shape of a pyramid with a base area of 0.64 square meters. And it has a 6.25 square meter surface area. There's also a 1.35-meter depth as shown in Figures 1 and 2. The walls are inclined at a 60-degree angle. Foam is used to insulate the walls in two layers, each 5 cm thick. Nylon covered in black is used as a lining. A plastic cap is placed on top of the container. On both sides, reflectors are mounted. Thermocouples are inserted at various depths inside it. Magnesium sulfate salt was used at a 28 percent concentration, with 400 grams of salt per liter.

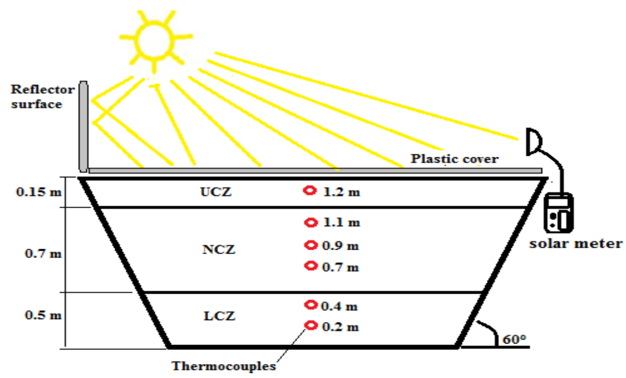

Figure 1. Schematic of the solar pond

The pond was exposed to natural solar radiation and also other weather conditions after construction. A thermocouple type 8 k were used: six of these were placed at 0.2, 0.4, 0.7, 0.9, 1.1, and 1.2 m from the lowest of the pond, with one at the pond bottom, the last thermocouple was placed to measure the outside temperature. Throughout the pond testing period, solar radiation measurements were made every day from 8 a.m. to 5 p.m. During the testing period, the temperatures of the pond layers were recorded over a 24-hour period. Reflecting mirrors were used with a cover plastic as shown in Figure 3, to lower the required surface area by increasing the sun's radiation intensity on the pond's surface.

Figure 2. Solar pond with plastic cover and reflective mirrors

Figure 3. Instruments for measuring: 1-thermocouples, 2-temperature meter, 3-solar power meter

2.2 Measurements

The intensity of solar radiation, water salt concentration, and temperature were all measured using the following equipment.

1) K-type thermocouples.
2) Temperature meter the temperature readings range of this device is from-20 to+250°C with an error ratio of±0.4% (±0.5°C).
3) Solar power meter with a manufacturing error rate of 0.4% to 0.50%, the greatest radiation range that may be detected by this instrument is 2000 W/m^2.

2.3 The procedure for the test

In February and March 2022, two months were dedicated to the present experiment. Each beta test lasts from 8 a.m. until 7 a.m. the next morning in the city of Karbala, Iraq. Table 1 contains the monthly input quantities for Kerbela city for April month. These quantities are the average daily ambient temperature (Ta), wind velocity (v), relative humidity (Ɣ), and the percentage of sunshine interval (n/N) [15].

Table 1. Weather data for the city of Kerbala in year of 2022 [15]

Month	Ta (°C)	Ɣ (%)	v (m/s)	n/N
April	23.8	28	4	0.69

The following steps can be used to characterize the experimental process of the current work:

1) Examining a group of salts using beakers to know the efficiency of each salt in collecting heat. The highest temperature is reached by any type of salt.
2) After determining the best salt (magnesium sulfate), use the same flasks to test three salt concentrations until reaching the state of saturation at a concentration of 28% with an amount of salt of 400 grams per liter.
3) After determining the best salt and the best concentration, the solar pond was worked by adding water and salt, waiting for it to settle, and recording the temperatures.
4) Installing reflective mirrors on the pond's sides, waiting for the pond to settle, and recording temperatures.
5) Add a transparent plastic cover and record the temperatures after the pond has settled.
6) After reaching the highest possible temperature in the previous steps, we now use TEG slices.
7) Installing TEG slides inside the pond and recording the voltage and the resulting amperage as shown in Figure 4.

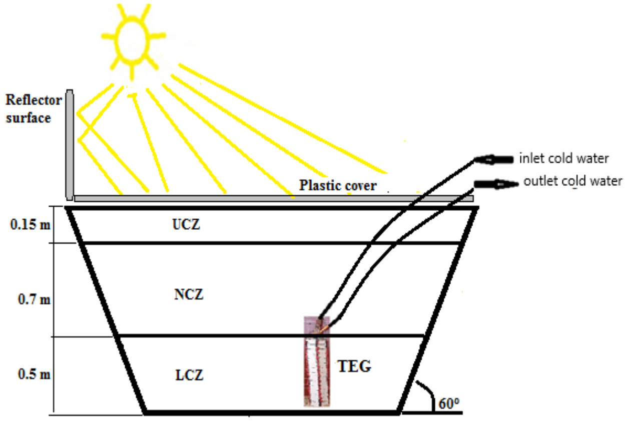

Figure 4. The location of the TEG fixation inside the pond

3. THERMAL EFFICIENCY AND USEFUL ENERGY CALCULATIONS

The amount of useable energy, computed as [16]:

$$Q_u = M_s * cp_s * \Delta T \tag{1}$$

where,

$$M_s = V_{LCZ} * \rho_s \tag{2}$$

$$\rho_s = \rho_w * (1 - C) + \rho_{salt} * C \tag{3}$$

$$cp_s = [(\rho_w * cp_w * (1 - C) + \rho_{salt} * cp_{salt} * C)]/\rho_s \tag{4}$$

The following equation may be used to determine the thermal effectiveness of a solar pond [17]:

$$\eta = Q_u / I \tag{5}$$

$$I = H_o * A \tag{6}$$

where,

C is the amount of salt in the water; V_{lcz} is the LCZ layer's volume, ρ_w=997 kgm^{-3}, cp_w=4.18 kJkg^{-1}. K^{-1}, ΔT is the difference in temperature between the lower convective zone and the surrounding air, While Ho is the solar irradiance on the solar pond and I is the solar energy incidence on the pond.

The electrical energy produced by TEG is provided as [18]:

$$P_{TEG} = I_{TEG} * V_{TEG} \tag{7}$$

where,

$P_{TEG}, I_{TEG}, V_{TEG}$ is power, current and voltage of TEG.

$$V_{TEG} = \alpha * \Delta T \tag{8}$$

$$I_{TEG} = \left(\frac{\alpha}{\rho}\right) * \left(\frac{A_{TEG}}{L}\right) * \Delta T_b \tag{9}$$

where,

α is the See beck coefficient of TEG, A_{TEG} is area of TEG.

The following equation is used to determine TEG's efficiency: [19-21].

$$\eta_{TEG} = \frac{T_h - T_C}{T_h}\left[\frac{(1+ZT)^{0.5} - 1}{(1+ZT)^{0.5} + \frac{T_C}{T_h}}\right] \tag{10}$$

where,

$$ZT = \alpha^2 * \sigma * T/K \tag{11}$$

where,

T is the absolute temperature, while k and σ are the thermal and electrical conductivities, respectively.

4. RESULTS AND DISCUSSION

Figure 5 demonstrates that the pond levels have 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.

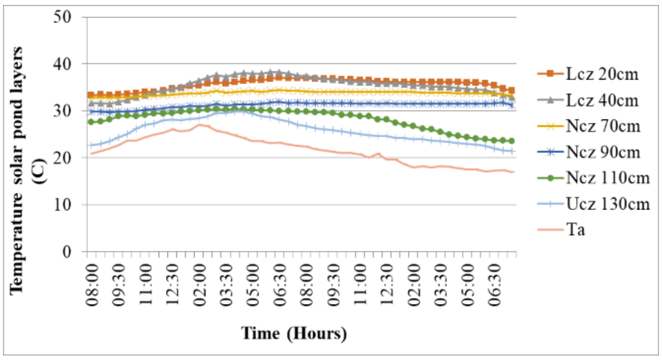

Figure 5. Three-layer salinity solar pond's temperatures

The temperature distribution on the pond levels and at different depths is depicted in Figures 7 and 8. Figure 6 shows the temperatures when using magnesium sulfate salt with the plastic cover and without mirrors. As shown in the diagram, the highest temperature in the lower layer, at a depth of 40 cm, reaches 45 degrees Celsius.

When magnesium sulfate, a cover, and mirrors are used, the temperature distribution is shown in Figure 7. The temperature rises in all layers, reaching 59 degrees Celsius in the storage layer at the bottom. The increase in temperature is because of the use of mirrors, which enhance the quantity of radiation falling on the pond's surface, hence increasing the heat energy stored in the pond.

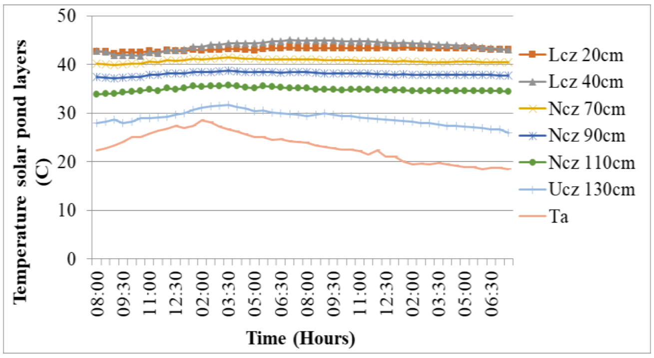

Figure 6. Temperature of the three layers of the covered salty solar pond

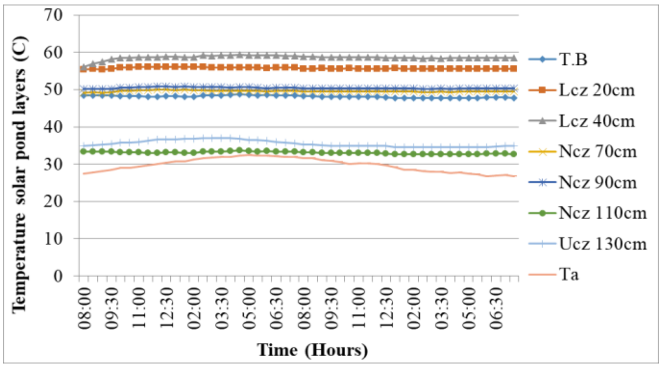

Figure 7. Temperature of the three layers of the covered salty solar pond with the reflectors

Figure 8 presents the useful energy (Qu) and thermal efficiency for three experiments: the first using simple salt (magnesium sulfate), the second using salt (magnesium sulfate) plus a plastic cover on the pond's surface, and the third adding reflectors to the pond. The quantity of useful energy was showed to be a factor in the practical results. In the first experiment, the usefulness was 6.92 kw, while in the second experiment, it was 10.35 kw, with the plastic cover helping to reduce heat losses by limiting reflection beyond the pond. The reflectors contributed to increasing the solar radiation intensity, which increased the quantity of heat absorbed and so raised the heat selected in the third experiment. The usable heat transfer is 17.32 kilowatts. This gain was reflected in the pond's efficiency, which increased to 27.5 percent when salt (salt), a plastic cover, and reflectors were used.

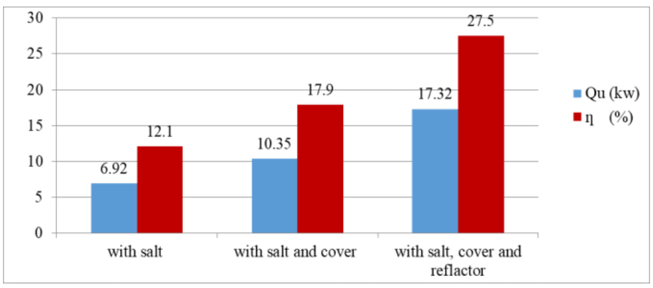

Figure 8. Thermal efficiency (η) and output useful energy (Qu) of solar pond

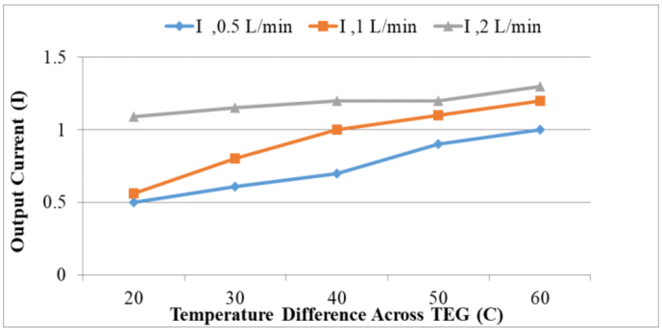

Figure 9. The output current, I_{out} [A] for temperature difference across TEG, ΔT [C]

Figure 9 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.

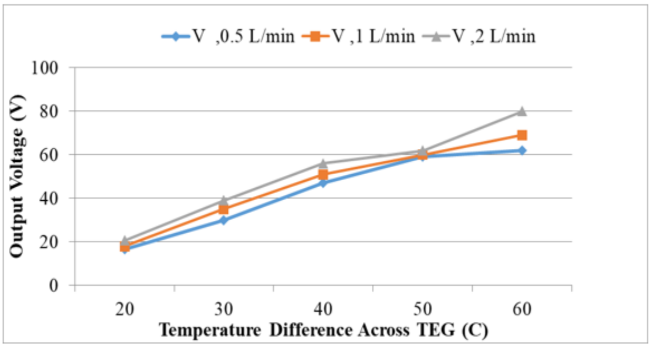

Figure 10. The output voltage, vout [V] for temperature difference across TEG, ΔT [C]

Figure 10 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.

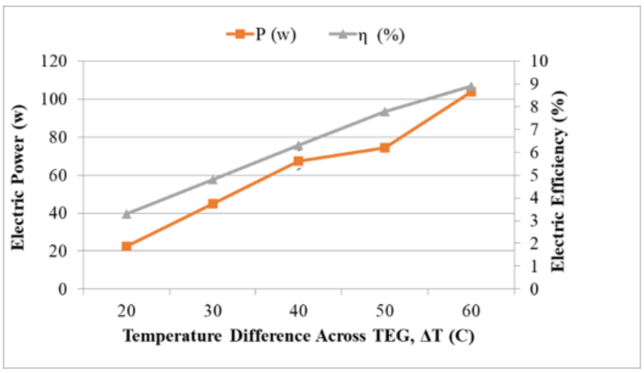

Figure 11. The Output Electric Power, Pout [w] and Electrical Efficiency [%] for temperature difference across TEG, ΔT [C]

Figure 11 depicts the electrical power generated by TEG and its work efficiency at five different temperatures (20, 30, 40, 50, and 60 degrees Celsius). It was showed through actual results that raising the temperature stored in the lower layer leads to an increase in electrical power production to its greatest value of 104 watts, therefore boosting the efficiency of TEG's work to 8.9%.

5. CONCLUSIONS

(1) Experiments show that the temperature in the pond's lower layer is influenced by several elements, the most important of which are the intensity of solar radiation, the kind and concentration of salt used, and good pond insulation to limit heat loss.

(2) The use of the plastic cover has helped to improve the pond's efficiency work by limiting heat loss from the pond's surface.

(3) Reflectors improved the quantity of heat received and stored in the pond by concentrating the intensity of solar radiation on it.

(4) Using the plastic cover and reflectors, the pond's bottom layer attained a maximum temperature of 59 degrees Celsius.

(5) When salt (magnesium sulfate), a plastic cover, and reflectors were installed, the pond's operational efficiency reached 10.3 percent.

(6) At 60°C temperature and a flow rate of 2 liters per minute, the current, voltage, and capacitance produced by TEG from the solar pond were 1.3 A, 80 V and 104 W respectively, and the efficiency of TEG was 8.9%.

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