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PERFORMANCE OF A PORTABLE THERMOELECTRIC WATER COOLING SYSTEM

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ABSTRACT

A water cooling system based on Peltier Effect has many benefits as being small in size, portable, noiseless, environmental friendly and economical compared to conventional cooling systems. This research focuses on the thermal performance experimental study of a portable thermoelectric water cooling system. During this study, the applied voltage on TE was changed to determine its effect on thermal performance. When the applied voltage increases, the hot side temperature incresing, while on the contrary of that appear on the cold side. This increasing the heat absorbed by the cold side as well as the heat rejected from the hot side, while the coefficient of performance decreasing with increasing applied voltage. The thermal resistance of heat sink is inversely proportional to the applied voltage. The increasing of heat sink fan speed has improved the system performance, where it leds to an increasing in heat absorbed by the cold side and the heat rejected from the hot side. Initial water temperature has a significant effect on the performance of TE water cooling system. The coefficient of performance equal to 0.14 when using initial water temperature of 15℃, while, it increase to be 0.5 when the initial water temperature increases to 30 ℃. That is happened due to the decrease in temperature gradient between cold side and hot side.

Keywords: thermoelectric cooler, TEC, Peltier Effect, Coefficient-of-performance, heat sink.

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1. INTRODUCTION

In the Middle East, the temperatures rise significantly especially in summer, therefore cold water is an urgent necessity. Since the means of cooling the water is not readily available in all places, therefore, the provision of a way to cool the water being a small and can be carried easily became a necessary. A cooling system based on Peltier Effect is the best solution where it uses a very thin thermoelectric module through which the required heat transfer can be achieved. The idea of thermocouple known since 1820 has been based on the resultant of an electric voltage difference between two different metals when they come in contact. If two different metals are connected together to be a closed circuit and maintain one of the contact points between the metals at a temperature higher than that of the other contact point, an electric current will be directly produced in the circuit by the voltage difference generated between the two metals. The voltage difference depends on the thermoelectric properties of the metals and the temperature of the two joints[1]. Peltier effect is the opposite of the thermocouple working principle. That is, when the circuit is exposed to external voltage difference, the temperature on one of the contact point increase while it decrease on the other contact point. In another meaning, the electric energy processed for the system has led to a temperature difference between the two joints, which is the opposite of the thermocouple effect[2]. The Platter's effect is used in the construction of thermoelectric cooling systems, where the cooled contact point is placed in the space to be cooled and the heated contact point placed outside. The cold point absorbs the heat from the space to be cooled and then the heat is rejected out through the hot point. The system in this way pumps heat from the cold medium to the hot medium through electric electrons instead of the working fluid(refrigerant) in the vapor compression refrigeration systems [3]. Recently the semiconductors have been used instead of metal connectors. These semiconductors are processed, so that at a particular process the semiconductor can conduct the electricity through the flow of negative charged particles or positive charged particles

Lee et al. [4] used various flat rectangular plates to investigate the effect of different surface heat transfer coefficients on the spreading resistances. The simulation results were in a good agreement with other existing theories. The results showed that, when the plates relatively thick, the constriction thermal resistance will be dependent on the relative contact size between the heat source and heat sink only, as well as it is not insensitive to Biot number and the plate thickness.

In 1996, Sofrata [5] investigated experimentally a half litter capacity refrigeration system using two different numbers of Peltier module. A heat sink with fan assembly has been used to increase heat rejection from the hot side of the module. In their results, when the ambient temperature equal to 32oC, the temperature reduction of 24oC in 7 minutes obtained. The calculated COP of the thermoelectric was found to be between 0.35 and 0.69.

In 2005 Chein and Chen [6] studied experimentally and theoretically the performance of thermoelectric cooler on water in a tank working as cooling a refrigerated system. To increase the heat rejected from the hot side, a micro channel heat sinks have been used with etched silicon wafers. TEC Model cp 1.4-127-06L was used in their study, which has a maximum temperature difference of 67.8 oC and maximum cooling rate of 51.4W. The result shows that; when the flow rate increase, the temperature decrease and also it decrease with time. The results also showed that when compared the micro channels heat sink with fin type heat sink with the difference in temperature is not significant, but its advantage is that it is small in size.

Esfahani et al [7] made a portable solar still system. To improve the performance of the still, water spray device along with thermos-electric cooler is added. The experiment carried out in nine summers and winter days in Iran. The temperature of the air and the solar radiation intensity in the summer is greater than the winter in Iran, therefore, the results were having a significant difference. The experiment result shows that; the solar radiation intensity heavily effects on the productivity of portable solar still. Mayank Awasthi [8] designed, built and test a prototype thermoelectric cooler. Melcor form thermoelectric module is used for the experiment. The experimental test was done at fourth different ambient temperatures

(15,21,32, and 43)°C. From the results they showed that a lower temperature can achieve with improvement in prototyping.

2. MATHEMATICAL MODELLING

In this study, different parameters have been used to evaluate the performance of a thermoelectric cooling device which are; the maximum temperature difference (ΔT_{max}), coefficient of performance (COP) and cold side heat pumping rate (Q_c).

Heat transfer rate from the cold side "cooling effect" (Qc) consist of the sum of three terms: (a) the Peltier effect, (b) one half of the total Joule heating and (c) the heat transfer rate between the two sides when current is equal to zero. It is given in equation below [9]:

$$Q_c = S_{te} I T_c - {}^1/_2\, I^2 R - \frac{(T_h - T_c)}{R_{te}}$$

The heat transferred from the hotter side into the heat sink(Q_h) is :

$$Q_h = S_{te} I T_c + {}^1/_2\, I^2 R - \frac{(T_h - T_c)}{R_{te}}$$

Where $S_{te}$the thermo- electric Seebeck coefficient is R_{te} is the TE thermal resistance and R is electrical resistance.

The thermoelectric thermal resistance R_{te} can be written as:

$$R_{te} = \frac{\alpha}{2 K_{te} N_c}$$

Where K_{te} is the material thermal conductivity and α is the ratio of the elements length (l) to the area (A): $\alpha = \frac{l}{A}$ or can be written as: $G = \frac{1}{\alpha}$

Where G: is the area factor, and N_c is the number of the P-N elements

The thermo- electric Seebeck Coefficient (S_{te}) is given by:

$$S_{te} = 2 S_m N_c$$

Where S_m is the Seebeck Coefficient of the material.

The electrical resistance (R) equal to: $R = 2\rho_m\, \alpha\, N_c$

Where ρ_m is the material electrical resistively, then:

$$Q_c = 2\, N_c [S_m I T_c - \frac{I^2 \rho_m}{2G} - K_{te}\, G(T_h - T_c)]$$

And

$$Q_h = 2\, N_c [S_m I T_c + \frac{I^2 \rho_m}{2G} - K_{te}\, G(T_h - T_c)]$$

The electrical voltage across the thermo-electric is given by:

$$V = 2 N_c [\frac{I \rho_m}{G} + S_m (T_h - T_c)]$$

The power input to thero-electric is given by:

$$P = V \times I = 2 N_c [\frac{I^2 \rho_m}{G} + S_m I (T_h - T_c)]$$

The coefficient of performance (COP) of thermo-electric cooling system can be stated by: [10]

$$COP = \frac{Q_c}{P} = \frac{S_m I T_c - \frac{I^2 \rho_m}{2G} - K_{te}\, G(T_h - T_c)}{\frac{I^2 \rho_m}{G} + S_m I(T_h - T_c)}$$

3. METHODOLOGY AND EXPERIMENTATION

The experimental apparatus for thermoelectric water cooling system have been presented Figure 1. It consists of heat sink, TEC, water container, fan, and two power supplies. In this study, a thermoelectric module TEC1-12706, which specifications in Table 1 have been used. The thermoelectric module consists of 127 thermocouples. It connected in series and sandwiched between two ceramic plates. After applying electricity on the system, a ceramic plate works as a heated plate, while the other one works as a cooled plate. The direction of the current determines which plate is heated.

The goal was to supply power to the thermoelectric modules using a DC power supply. The modules in turn will cool a container wherein water will be filled and tests be done. A container had to be fabricated of a material, which would easily conduct heat. The container has a cylindrical shape with diameter (100 mm) and high of (120mm). The base of the container is attached directly to the cold side of TE with thermal grease. The water containers have been insulated to diminish heat loss. To ensure best performance of TEC, the heat reduce from the hot side should be put out as much as possible. To dissipate this heat, a heat sink attached to the hot side in our module. The heat sink was used is the one, which is used typically in CPU's of the computers. It consists of two parts; one is a 12-volt dc fan and the other an aluminum finned surface.

Below the TEC sets of the module of the heat sink with proper thermal paste to ensure proper thermal contact. It has been made from aluminum. the size of the base is $(77\times68\times10)mm^3$, and the length of the fins equal to (68mm) , where the height and thickness of the fins equal to (25mm) and (1mm) respectively. On the base of heat sink, 35 fins have been used with 1.2mm distance between then. A 12V fan is set below the heat sink and connected with another power supply.

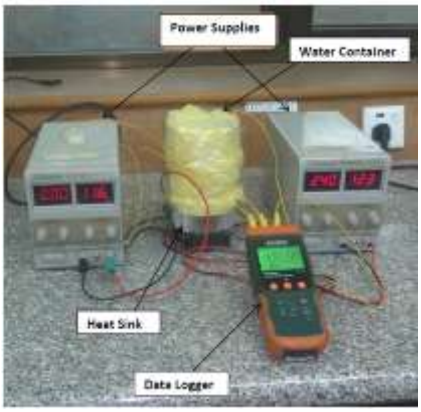


Figure 1 the photograph of the experimental model

Table 1 The specification of the thermoelectric module TEC1-12706

Hot side temperature	27	50
$\Delta T_{max}(T_h - T_c)$ ℃	70	79
$V_{max}(volts)$	16	17.2
$I_{max}(amps)$	6.1	6.1
$Q_{c\,max}(watts)$	61.4	66.7
Resistance(ohms)	2	2.2

The problem here addressed consists of cooling 0.25 liters of water, from an initial temperature T_i to a final temperatureT_f, in a 0.5 hour time period. Assuming a perfect insulation of the container, the heat removed can be calculated as:

$$Q_C = \frac{mC_{p,w}(T_i - T_f)}{\Delta t}$$

Shows the cross-section of the Fin heat sink -Thermoelectric - water container assembly. The TE module is sandwiched between a conventional Fin heat sink and a water container. *Rt* is overall resistance which is the heat sink resistance (*RHS*) and the *TEC* resistance. The overall heat passes through these resistances in our module and can be defining as following:

$$Q_h = Q_c + P_{TE}$$

$$R_{FHS} = \frac{T_h - T_a}{Q_h}$$

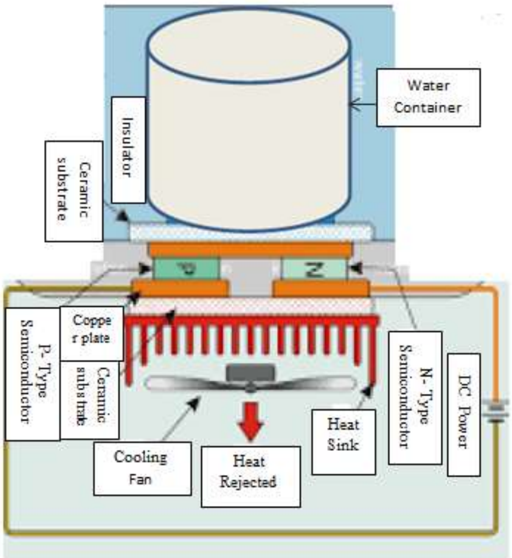
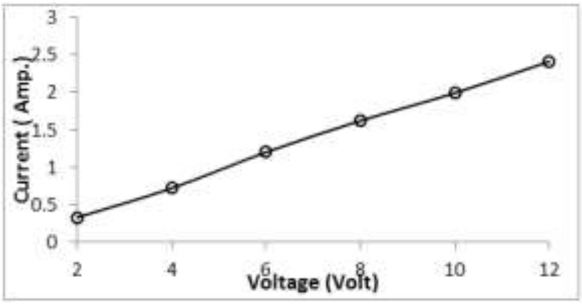


Figure 2 shows the sketch of the experimental model

4. RESULT AND DISCUSSION

4.1. Effect of Applied Voltage

In these experiments the applied voltage on the thermoelectric was varying from 2v to 12v with 2v period each time. Figure 3 shows the relationship between voltage and current of TE. It can be seen from this Figure a linear relation between them. TE power consumption variation with applied voltage is shown in Figure 4 it can be noted that as the voltage increase, the power increase also. Applied voltage effects on cold side temperature hot side temperature and water temperature difference are given in Figure 5. It can be seen that, as the applied voltage increase the cold side temperature decrease and the hot side temperature increase. As result of that, the water temperature difference increased and that led to increase the heat transfer Q_C as shown in Figure 6.



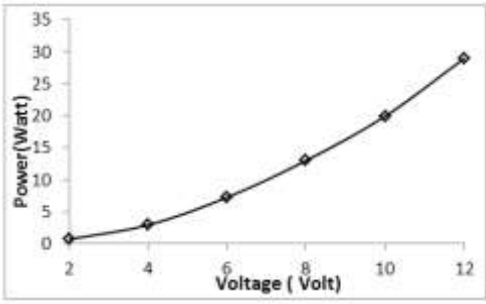
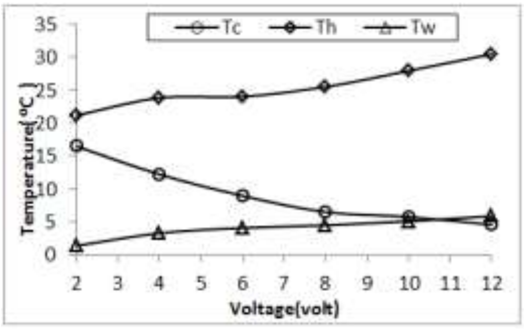


Figure 3 the variation of current with voltage on TE **Figure 4** the variation of power with voltage on TE



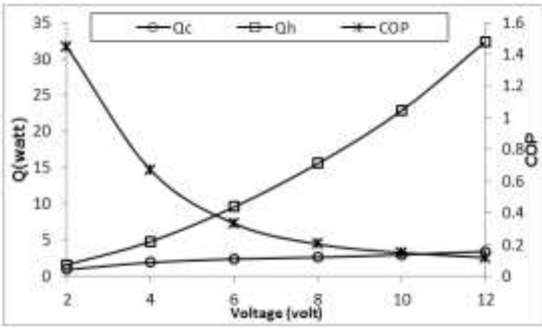
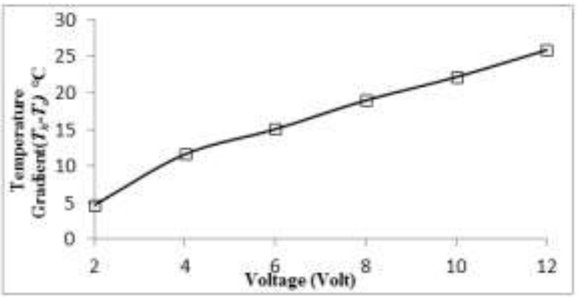


Figure 5 the variation of temperature with voltage on TE **Figure 6** the effect of input voltage on heat transfer

Figure 6 shows the effect of input voltage on Qc, Q_h and COP. It can be seen that although Q_C and Q_h increases with increasing applied voltage, while the COP decrease because of the percentage increases in Qc is less than that of power consumption as the voltage increase. Figure 7 Shows the effect of increasing in the applied voltage on the TE, Temperature Gradient (T_h-T_c)*, and COP*.



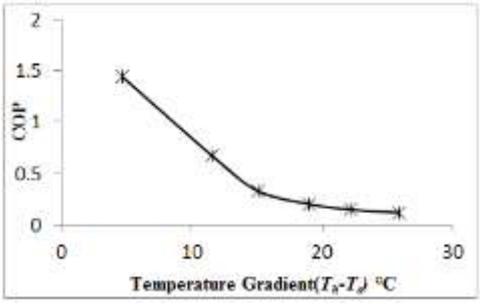


Figure 7 the temperature gradient variation with voltage on TE **Figure 8** the temperature gradient variation with COP of TE

4.2. The Effect of Water Initial Temperature

The testing on the effect of initial water temperature on performance of the TE water cooling system was carried out under constant heat sink fan speed and applied voltage. Figures 9-12 shows the variation of COP, Qc , Qh , DTw under different initial water temperature. It can be seen from Figure 9 that; the DTw increase with increasing initial water temperature where DTw increase from 3 to 10.8 C^o as the initial water temperature increase from 15 to 30 C^o

Figure 10 shows the effect of initial water temp on Qc and Q_h. It can be noted that; the Qc and Q_h increase with increasing initial water temperature due to increasing DTw . the power consumption by TE is nearly constant as the initial water temperature increase, so this lead to increasing in COP of system as shown in Figure 11. At initial water temperature of 15 °C, the COP was 0.14, as the initial water temperature increased to 30 °C, the COP 0.5.

Figure 12 shows the relationship between initial water temperature and TE temperature gradient (T_h-T_c). From this Figure, it can be observed that as the initial water temperature increase, the temperature gradient (T_h-T_c) decrease.

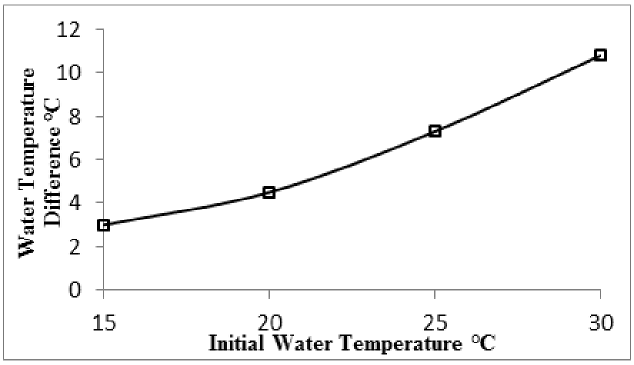


Figure 9 the effect of initial water temperature on water Temperature difference

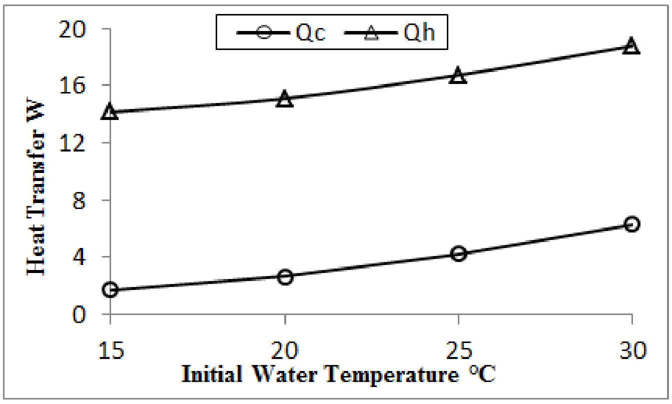


Figure 10 the effect of initial water temperature on the heat transfer

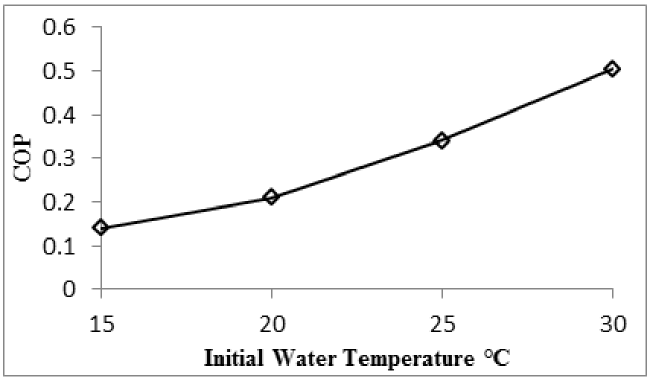


Figure 11 the effect of initial water temperature on COP

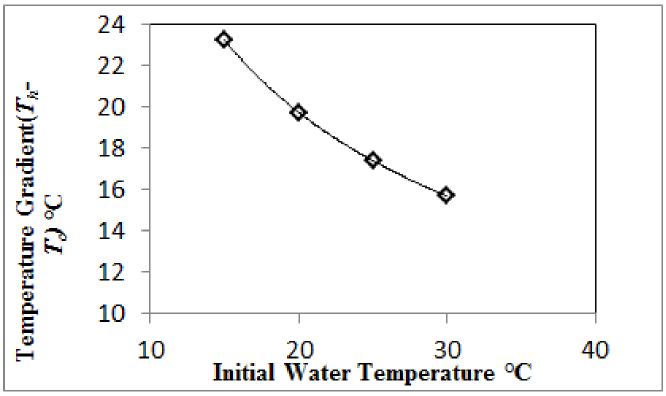


Figure 12 the effect of initial water temperature on Temperature Gradient(Th-Tc)

4.3. The Effect of Cooling Air Speed

TE works more efficiently as the amount of heat dissipated from heat sink increase, to ensure that the fan is added. To shows the effect of cooling air speed on performance of TE, the fan speed is varying by vary the voltage applied on it. Figure 13 shows the effect of increasing air velocity on T_c, T_h and ΔT_w. From this Figure it can be observed that T_c, T_h is reduced by increasing the air speed, on contrast, ΔT_w will increase with increasing air velocity and this leads to an increase in Q_c, Q_h and *COP* of system as shown in Figure 14. The effect of increasing air velocity on heat sink thermal resistance is shown in Figure 15. From this Figure it can be observed that the higher air speed lead to reduce heat sink thermal resistance due to increase convective heat transfer coefficient.

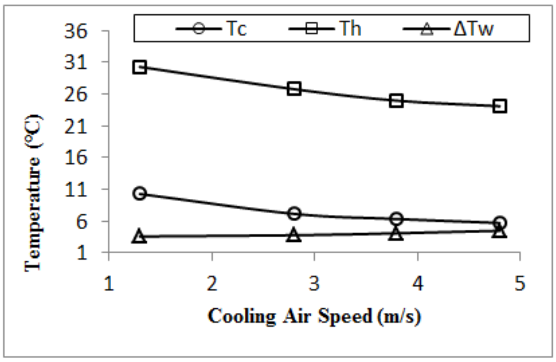


Figure 13 the effect of the effect of air velocity on temperature

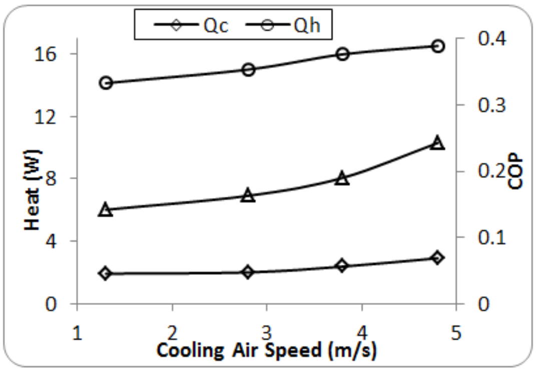


Figure 14 the effect of the effect of air velocity on heat transfer

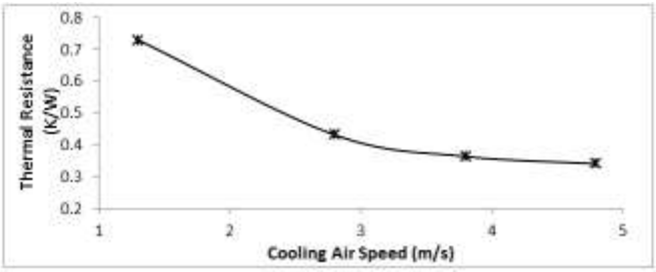


Figure 15 the effect of the effect of air velocity on Thermal Resistance

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