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Performance of Water Thermoelectric Cooler Connected in Series: An Experimental Study

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Abstract:- This paper represents the results of a capstone project that took place in the mechanical engineering department at Abu Dhabi Men's College. Emphasis was placed on determining how much cooling can be stored in a 10 L water tank from 3 water thermoelectric coolers (WTCs) connected thermally in series. The results obtained were analyzed for 3 different connecting scenarios, a) one WTC, b) 2 WTCs connected in series, 3 WTCs connected in series and two different mass flow rates of 0.02 kg/s and 0.04 kg/s. A decrease in the water storage tank temperature with time was shown under all the conditions and scenarios the experiments were conducted. On the other hand an increase in the amount of cooling capacity in the water storage tank was observed with time. Of interest the results showed that the rate with which the storage tank temperature gradient and consequently the amount of cooling stored decreased as the number of the WTCs used increased.

Keywords:- *Thermoelectric water cooler, Cooling capacity, Stored energy.*

I. INTRODUCTION

Thermoelectric cooling (TEC) is an alternative source because it converts electricity into useful cooling with the help of the Peltier effect. The use of the TEC includes smaller residential, commercial and industrial applications, where temperatures are to be kept at certain controlled values. Fields of refrigeration air-conditioning, food preservation, vaccine storages, medical services, fresh water production and cooling of electronic devices are considered to be potential applications of it as summarized in the literature below.

In their study, **[1]** attempted to design a new type of portable thermoelectric solar still (PTSS). The PTSS, was tested under different climatic conditions in Iran for few days. The results showed that ambient temperature, solar radiation and wind speed have a direct effect on the amount of water production with a maximum daily efficiency of 7%.

In **[2],** a water-cooled thermoelectric cooler (TEC) for central processing unit (CPU) was developed. Effects of air velocity and water mass flow rate for the heat sink were investigated under severe environment. A COP larger than

0.65 was obtained at air velocity and water mass flow rate above 0.8 ms−1 and 0.042 kg s−1, respectively.

To achieve the simultaneous cooling of the human head andneck, **[3]** designed a new helmet which is cooled by a thermoelectric refrigerator that uses a combination of water and air. The effects of wind speed, water flow rate and refrigerator power on the cooling capacity and efficiency on the refrigeration characteristics are obtained under different experimental conditions. **[4]** designed and developed a thermoelectric refrigerator with interior cooling volume of 5

L. Two geometries (shapes) for the device namely a rectangle and a cylinder were investigated. The time required to cool this 5 L to a temperature of 5 ºC is approximately 6 hours. In **[5]**, experimental and theoretical studies on thermoelectric cooler (TEC) performance for cooling a refrigerated object (water in a tank) were performed. The theoretical predicted temperature variation was in good agreement with the measured data. The minimum temperature can be obtained by increasing the electrical current input and decreasing the heat sink thermal resistance conducted an experimental study on the thermal performance of a portable thermoelectric water cooling system. In this experiment, the applied voltage was changed. It was found that the hot side temperature increased while the cold side decreased when the applied voltage increased. It was also found that. Initial water temperature has a significant effect on the performance of a thermoelectric water cooling system. When the initial water temperature is XXX-X-XXXX-XXXX-X/XX/$XX.00 ©2022 IEEE 15 ºC, the Coefficient of Performance is equal to 0.14. Thisvalue is increased to 0.5 when the initial temperature is 30 ºC.

Obtained the total Coefficient of Performance (CoP) of a thermoelectric module when it is operated in combined modes (heating and cooling) through experiments and thermodynamics mathematical model. A total CoP of 4.5 was achievable in their investigation investigated experimentally the effect ofthermoelectric positions on its performance. The positions ofthe thermoelectric were at the top, on the bottom, and on thewall. The inner cooler box size employed was 215 mm _ 175 mm _ 130 mm, and the thickness of the cooler box walls was 50 mm. The COP decreased with the times, and the best position of the thermoelectric placement in this study was onthe wall.

The literature show a lack of data and understanding on the performance of water thermoelectric cooler on the cooling energy that can be stored and/or used for cooling loads purpose in small applications. Therefore, the objective of the present investigation is to record such data by conducting a series of experiments under limited operating conditions. These conditions are limited to the water mass flow rates andto the number of water thermoelectric coolers (WTCs) connected in series.

II. EXPERIMENTAL APPARATUS

Below is a brief description of the experimental apparatus and its main components.

As shown in Figure.1 the apparatus consists of ***(a)*** *Water thermoelectric cooler* ***WTC****,* ***(b)*** *Flowmeter* ***FLM****,* ***(c)*** *A stainless steel body and ball handle valve type* ***VV****,* ***(d)*** *A DC water pump* ***Pmp****,* ***(e)*** *digital Thermometer* ***TH****,* ***(f)*** *Electric Switch* ***SW****,* ***(g)*** *Power Supply* ***PS****,* ***(h)*** *Water tank* ***WT.***

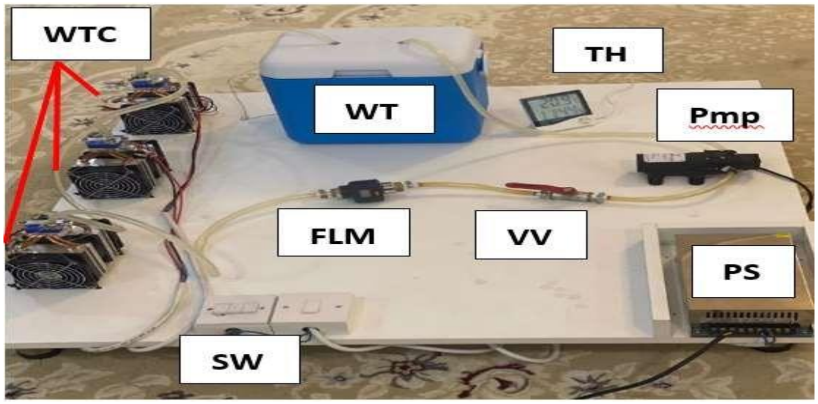

Fig. 1: Experiment apparatus components

A. Principles of Operation

Initially, the water in the storage tank (WT) was at a room temperature of 27ºC. The 12V DC pump was powered up to circulate the water between the water storage tank and the thermoelectric coolers. A total of six experiments were conducted under two mass flow rates of 0.02 kg/s, 0.04 kg/s and three different combinations of WTCs. During the first combination only one WTC was powered on to provide cooling to the water in the storage tank. During the second and third combinations, two and three WTCs connected in series were powered on for cooling purposes. Consequently, the effects of the mass flow rates of water and the number of WTCs used on the change in the storage tank temperature were investigated experimentally under ambient conditions.

The change in the cooling capacity stored in storage tank with time was also investigated under the same operating conditions.

B. Experimental Procedure

Below is a summarized general procedure description of all the experiments conducted.

- The water in the storage tank is filled with water atan ambient temperature of **27ºC.**
- The pump is switched on to ensure water circulation by observing the flowmeter reading.
- The valve is adjusted to ensure a required water mass flow.
- The switch(es) of One , two or three TWCs (are) put on depending on the experiment be conducted.
- The change of the water temperature in the storage tank is recorded every 2 minutes fro a period of 20 minutes for this part I of this investigation.
- Typical recorded data are shown in Table. I.

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Table 1: Typical Data Recorded for 2 and 3WTCs and Mass Flow Rates MFR

	2 WTCs		3 WTCs	
Time [min]	MFR 0.02 [kg/s]	MFR 0.04 [kg/s]	MFR 0.02 [kg/s]	MFR 0.04 [kg/s]
0	27	27	27	27
2	26.3	25.8	25.6	25.6
4	25.5	25.1	24.7	24.6
6	24.6	24.2	23.6	23.6
8	23.9	23.3	22.8	22.4
10	23.2	22.5	21.7	21.5
12	22.3	21.7	20.8	20.5
14	21.6	21	19.8	19.5
16	21.1	20.1	19.1	18.6
18	20.3	19.4	18.3	17.9
20	19.6	18.8	17.5	17.1

III. RESULTS AND DISCUSSION

Figure 2 shows variations of the water temperature with time under different mass flow rates of 0.02 kg/s and 0. 04 kg/s with 1 WTC used. The temperature decreases faster as the mass flow rate is increased. As expected, it can be noticed that the temperature decreases with time almost linearly within the 20 minutes of the experiment. Different curve profiles are expected with longer time. This will be a recommended series of experiments in part II of this investigation. The same can be observed in Figure 3 and Figure 4 when 2 and 3 WTCs are used respectively. A 3.6°C and 4.6°C difference between the initial water tank temperature of 27°C and the recorded one after 20 minutes can be noticed at 0.02 kg/s and 0.04 kg/s respectively, when 1 WTC is used as shown in Figure 2. Figure 3 shows bigger differences of 7.5°C and 8.5°C at 0.02 kg/s and 0.04 kg/s respectively when 2 WTCs are used. Figure 4 shows even bigger values of 9.0°C and 10.0°C at 0.02 kg/s and 0.04 kg/s respectively when 3 WTCs are used.

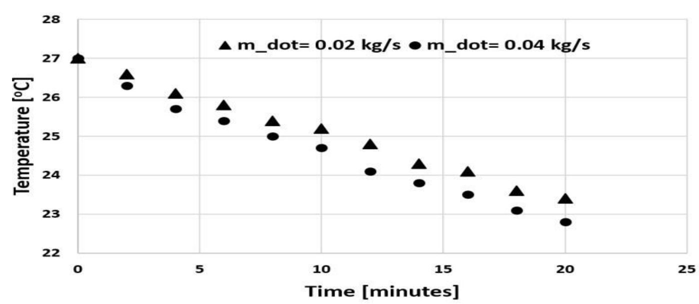

Fig. 2: Temperature vs Time

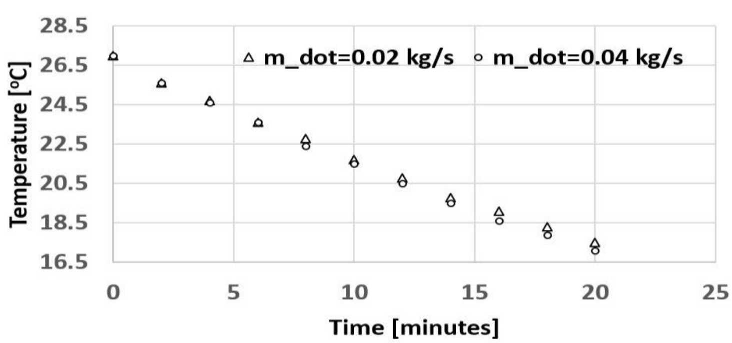

Fig. 3: Temperature vs Time

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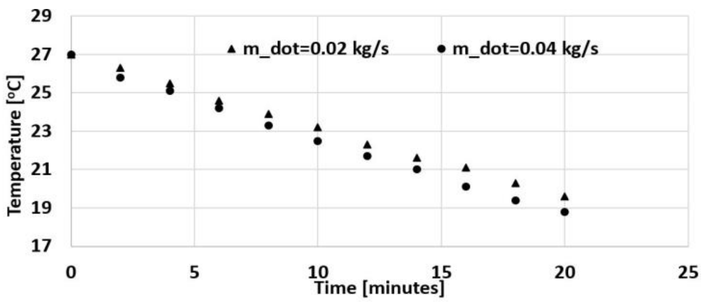

Fig. 4: Temperature vs Time

Figure 5 shows the variation of the cooling capacity, calculated using equation 1, under the mass flow rates of 0.02 kg/s, 0. 04 kg/s and 1 WTC used.

$\dot{Q} = \dot{m}.c_p(T_i - T_r)$ (1)

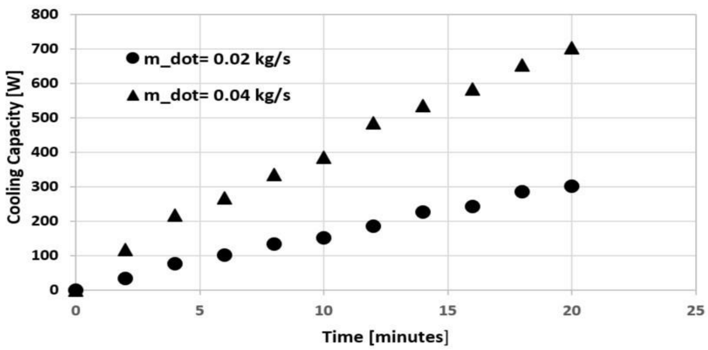

Fig. 5: Cooling capacity vs Time

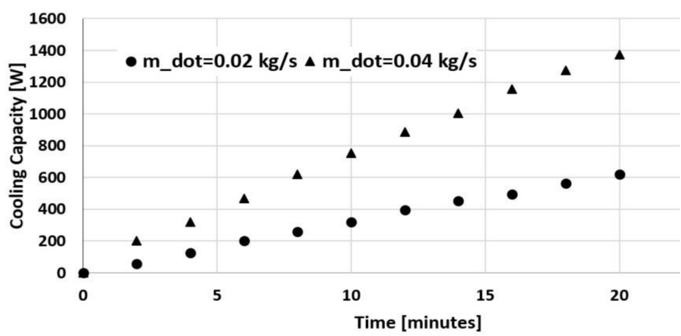

Fig. 6: Cooling capacity vs Time

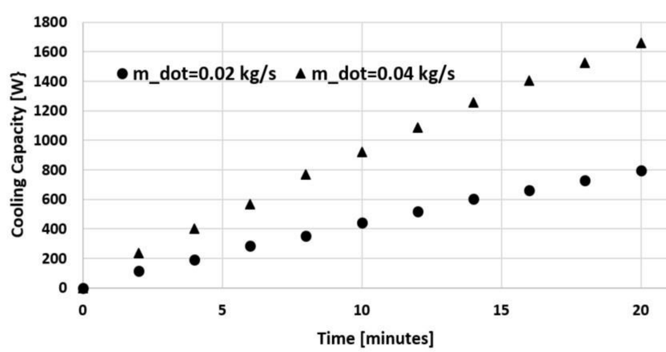

Fig. 7: Cooling capacity vs Time

Figure 8 shows the variation of water storage tank temperature with time when one, two and three WTCs are used. The difference between the two last recorded temperatures for 1 WTC and 2 WTC is 3.8 ºC. However, for 2 WTC and 3 WTC the difference is about 2.1ºC. The same analysis can be made for the results shown in Figure 9 where the differences are approximately 4 ºC and 1.7 ºC respectively. This result is of great interest as it was not expected. The reason behind remains unclear and further investigation is needed for better understanding.

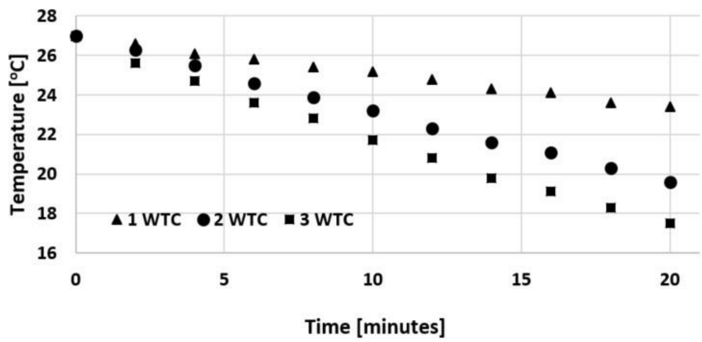

Fig. 8: Temperature vs Time with m_dot= 0.02 kg/s

Where
$\dot{Q}$: Cooling capacity in [W]
$\dot{m}$: mass flow rate in [kg/s]
c_p : the water specific heat in [J/kg.K]
T_i :the storage tank initial temperature in [ºC]
T_r: The recorded storage tank temperature in [ºC]

The cooling capacity is clearly shown to increase with time. More cooling is obtained as the mass flow rate is increased from 0.02 kg/s to 0. 04 kg/s.

Similar analysis can be made when 2 and 3 TWCs are used as shown in figure 6 and figure 7 respectively.

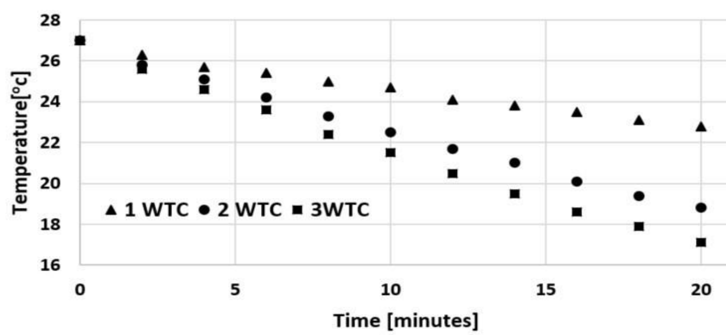

Fig. 9: Temperature vs Time - m_dot=0.04 kg/s

Figure10 shows the variation of the cooling capacity with time when one, two and three WTCs are used for cooling for a mass flow rate of 0.0 2 kg/s. The difference between the two last calculated cooling capacity for 1 WTC and 2 WTC is around 320 W. However, for 2 WTC and 3 WTC the difference is about 670 W. The same analysis can be made for the results shown in Figure 11 for a mass flow rate of 0.04 kg/s where the differences are approximately 176 W and 285 W respectively. This is an interesting observation that needs further investigation as noted previously.

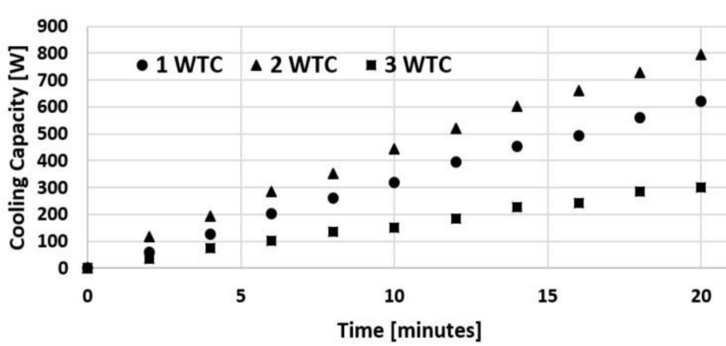

Fig. 10: Cooling capacity vs Time for m_dot=0.02kg/s

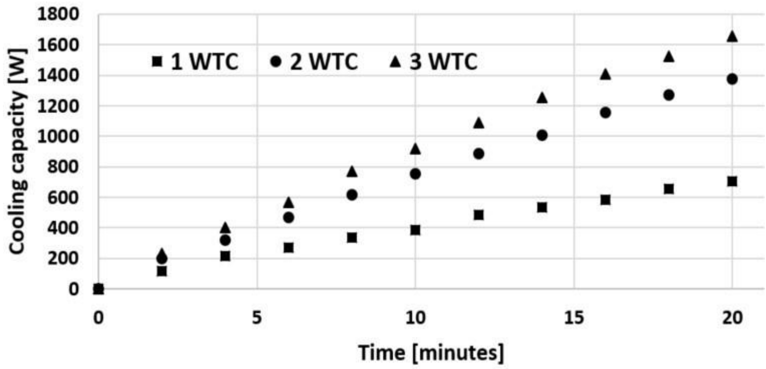

Fig. 11: Cooling capacity vs Time- m_dot= kg/s

IV. CONCLUSION AND RECOMMENDATION

Due to the limitation of time for the students, limited objectives were met under this study. The more water thermoelectric coolers connected in series are used, the lower the water storage temperature will be. Consequently more cooling energy is stored. It is believed that the cold stored energy can be used for small cooling applications. More experiments can be conducted to achieve better understanding of the performance of the water thermoelectric modules and different operating conditions as summarized below:

- Conducting experiments to figure out the lowest possible temperatures that can be achieved.
- Instead of a water storage, small loads, like a coolingcoil for a mini air conditioning would give better understanding on the limitations and feasibility in HVAC application
- Conducting experiments outdoors instead of indoor.

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