Cooling Performance of Thermoelectric Water Cooler

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Abstract

Thermoelectric refrigeration is thought to be one of the alternative technologies that would help to reduce the rate of chlorofluorocarbon (CFC) refrigerants emission to the atmosphere, as this do not employ working fluids that are harmful to the environment. This article aimed to evaluate cooling performance of a thermoelectric water cooler (TEWC). The TEWC consists of two TE modules (Tianjin Lantain model TEC1-12708), a cylindrical cold water tank volume of 3 l at the cold side and two rectangular fin heat exchangers at the hot side of the TE modules. Various operating conditions were considered to assess the cooling performance of the TEAC. It was found that the cooling performance of the system depended on the electrical power supply, the ambient air flow rate of air circulated through the rectangular fin heat exchanger. At the ambient temperature about 30 °C, the suitable conditions are 4 A electric and 0.0475 $kg.s^{-1}$ and the corresponding cooling capacity is 90.33 W with an average water temperature of 19.5 °C. Therefore, the proposed concept seems to be reliable and merit further investigations towards commercial development.

Keywords: Thermoelectric water cooler, Heat exchanger, Cooling capacity

Introduction

Vapour compression (VC) refrigeration systems have been widely used in industrial or commercial products such as air conditioners, refrigerators and water coolers. The VC systems have a high coefficient of performance (COP). However, They are noisy and can only achieve their potentially high COP when the cooling power is large and the load is stable. Very important, the working fluid is compressed in these systems often escape into the atmosphere, where they are known to have harmful environment effects (Houghton, 1997). There are a number of refrigeration technologies that are not CFC based. One such technology, thermoelectric (TE) refrigeration systems. TE elements perform the same cooling function as VC system. Energy is taken from a region thereby reducing its temperature. The energy is then rejected to a heat sink region with a high temperature. TE elements are in a totally solid state, while VC systems have mechanical parts that require a working fluid. A schematic description of a TE module is shown in Figure 1. It is composed of a number of TE elements, connected electrically in series and thermally in parallel, integrated two ceramic plates, which from the cold and the hot surfaces of the module. TE modules are small, silent an “environmentally-friendly” (Rowe, 1995). TE refrigeration systems are very reliable an almost maintenance-free (Stockholm, 1991). When a DC current is supplied, the surface where heat energy is absorbed becomes cold whilst the opposite surface where heat energy is released becomes hot. If the polarity of current flow through the module is reversed, the cold side will become the hot side and vice-versa. TE cooling systems were used on railway coach (Stockholm et al., 1982), ships and submarines (Stockholm *et al*.,1988, 1989), military vehicle (Heenan *et al*., 1992) and parked aircraft (Gwilliam 1991; Gwilliam *et al*., 1992). In Thailand, we had initiated various studies on TE cooling such as Khedari (Khedari *et a*l., 2001) investigated the performance of a new domestic hot water system that combines solar energy with waste heat from TE air conditioner. The collector/ storage tank capacity was 120 litres. At water flow rate of 1.5 $l.min^{-1}$ at the hot side heat exchanger and air velocity of 2.5 $m.s^{-1}$ at the cold side, the corresponding highest COP of the hybrid system was about 3.12. The proposed system can heat up the water to 50˚C within 2 hours. A numerical model (Lertsatitthanakorn *et al*., 2000) and a lab-scale free convected TE air conditioner (Lertsatitthanakorn *et al*., 2001) was built and tested. Two types of heat exchangers were considered namely rectangular fin heat exchanger at the cold side and force convected skive fin heat exchanger at the hot side. The unit can cool the air near the fin from 31 to 9.7. The corresponding cooling capacity is 126 W with a COP of 0.89.

The aim of this study is to investigate cooling performance of a TEWC. A cold water tank was used at the cold side and forced air-cooled heat exchanger was used at the hot side of TE modules. The effect of various operating parameters namely the current supply and fan orientation and the ambient airflow rate through the heat exchanger is examined.

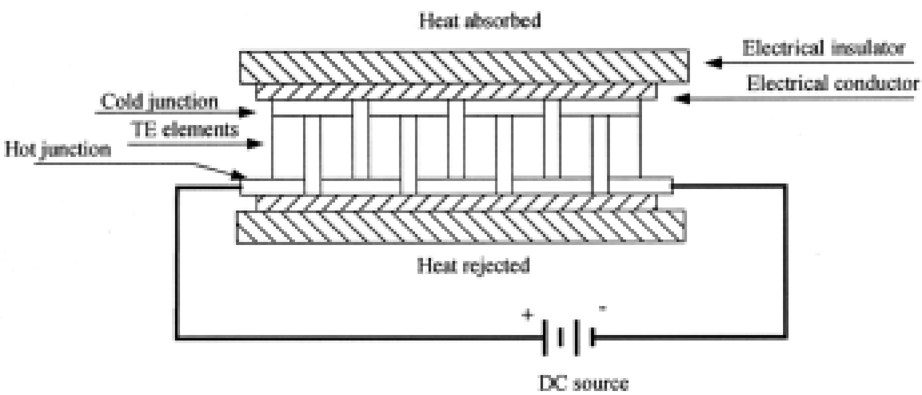
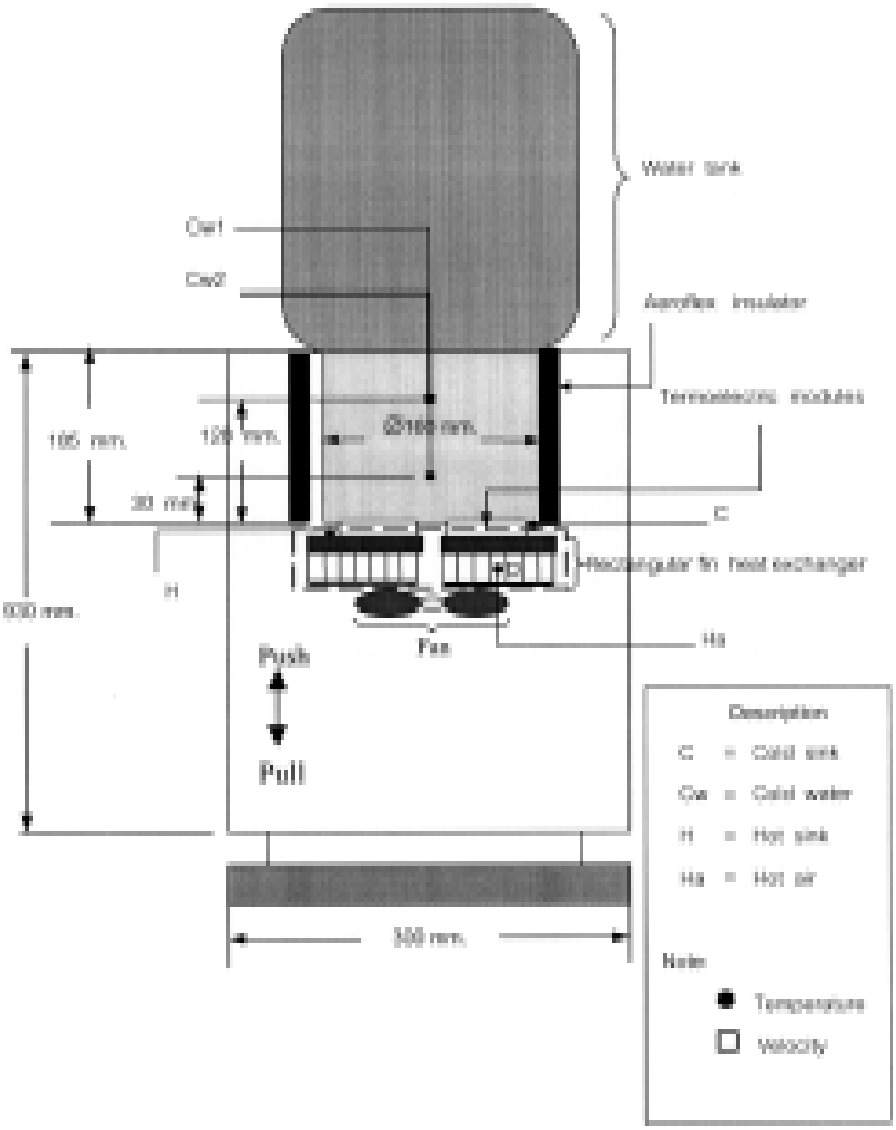


Figure 1. A schematic diagram of a typical TE cooling module

System Description and Experimental Methodology

Details of the TEWC tested in this study are shown in Figure 2. The rectangular fin heat exchanger used on the hot side was made of aluminum. The fins were 3 mm thick, 145 mm long in the horizontal direction and had a height of 40 mm from the base and a fin space of 10 mm. Therefore, two rectangular fin heat exchangers were used on the hot side. The cylindrical cold water tank volume of 3 l used on the cold side is also made of aluminum. The tank wall was insulated using Aeroflex insulator (Closed cell elastomeric thermal insulation, thermal conductivity is 0.039 $W.m^{-1}.K^{-1}$). A DC fan was used to reject the heat from the hot side of TE modules. Two TE modules (Tianjin Lantain model TEC1-12708, 127 couples) were used. Several series connections of TE modules were made to accommodate the 6 A supply current. The instrumentation in the experimental set up is consisted of temperature and flow sensors. Temperature sensors were T-Type (accuracy ± 0.1 °C) thermocouples connected to the datalogger (Testo 177-T4) and hot wire anemometer (Testo model 405V-1, accuracy ± 5 % of mV) was used for airflow measurement. The distribution of the sensors is shown in Figure 2. Two DC power supplies, which can provide variable electric current were used to power the TE modules and drive the fan respectively. A data acquisition system was used to collect the data at regular intervals every minute.



Note: $C_w = 0.5(C_{w1}+C_{w2})$

Figure 2. Schematic view and position of sensors of TEWC

Analysis

To analyse the performance of TEWC, we first consider the heat rejected at the hot side:

$$Q_h = m_a C_{pa}(T_{ao} - T_{ai}) \quad (1)$$

Where C_{pa} = specific heat of air at constant pressure
m_a = air mass flow rate at the hot side
Q_h = heat rejected at the hot side
T_{ao} and T_{ai} = outlet air and inlet air temperatures at the hot side respectively

The heat absorbed at the cold side:

$$Q_c = Q_h - P \quad (2)$$

Where Q_c = heat absorbed at the cold side
P = electrical power input to TE modules and circulating fan

The coefficient of performance of TEWC is determined from its definition:

$$COP = Q_c/P \quad (3)$$

The performance analysis of TEWC is described below

Results

Figure 3. showed an example of temperature profiles of hot heat exchanger, hot air, cold water and cold water tank at 5 A current supply. The minimum cold water tank was 15 °C. The cold water temperature decreased from 29.5 to 20 °C. Meanwhile the maximum hot heat exchanger temperature was 36.5 °C and the hot air temperature increased from 30.1 to 33.2 °C.

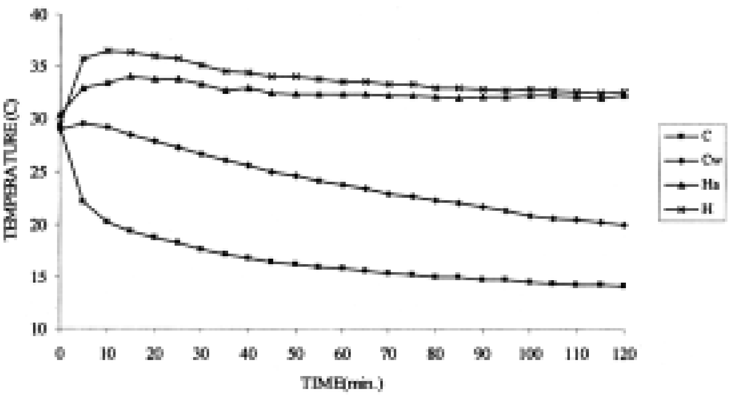


Figure 3. Temperature profiles of hot air, hot heat exchanger, cold water and cooler tank (5 A, airflow rate 0.0475 $kg.s^{-1}$, pushing air)

The effect of fan orientation on the heat exchanger performance was shown in Figure 4. Two different orientations were tested: push and pull. When the fan was pushing air through the hot heat exchanger, the cold water temperature was lower than at pulling air (about 2°C). This is thought that pushing air caused turbulence at the base of fins where as when the fan was pulling air little turbulence was created at the base of the heat exchanger. Which turbulence tends to enhance heat transfer. Thus pushing fan is recommended to use for rejected heat at the hot heat exchanger.

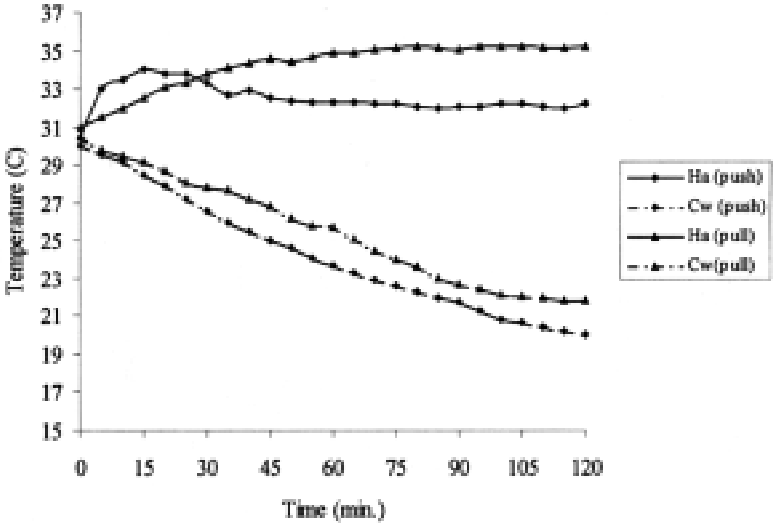


Figure 4. Hot air and cold water temperatures versus time for different fan orientations (5 A, airflow rate 0.0475 kg.s^{-1})

The effect of varying the electric current on the cold and hot fluid temperatures was shown in Figure 5. Tests were conducted at six different current: 1 to 6 A. When electric current increases, the cold water temperature decreases from 25.1 to 19.5 °C. At 6 A, the cold water temperature re-increased and was higher than at 5 A. This due to the Joule heating effect, which prevail over the Seebeck cooling i.e. too large temperature difference is applied to TE modules. The hot air temperature increases steadily as electric current increases. The maximum hot air temperature was 36.2 °C at 6 A electric current. Based on the energy balance of the system, heat rejected by the rectangular fin heat exchanger is equal to the summation of the cooling capacity and the electric power applied to TE modules. The COP is defined as the ratio between the cooling capacity to electric power applied to TE modules. Table 1 shows that the cooling capacity increases as electric current increases vary between 60 to 115.2 W. Contrary to the COP decreases significantly as electric current increases, therefore under design condition used here a 4 A electric current is recommended.

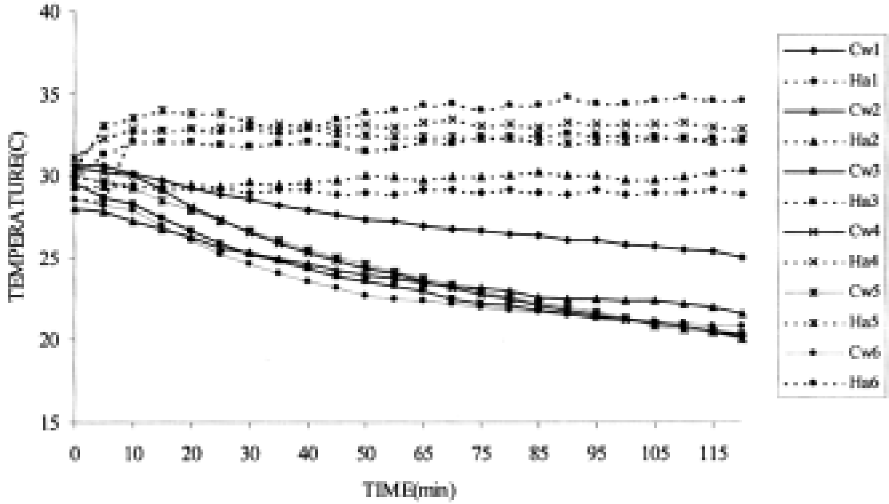


Figure 5. Hot air and cold water temperatures versus time for different supply electric current (airflow 0.0475 $kg.s^{-1}$, pushing air)

Table 1. Comparison between the cooling capacity and COP for different current supply

Current (A)	Cooling capacity (W)	COP
3	60	1.52
4	90.3	1.34
5	104.3	0.81
6	115.2	0.53

The effect of ambient airflow rate through the rectangular fin heat exchanger at the hot side of TE modules was shown in Figure 6. Tests were conducted at two different airflow rates namely 0.028 and 0.047 $kg.s^{-1}$. It was found that the cold water temperature decreases when airflow rate increases as more heat can be rejected to the ambient. Thus, when airflow rate increases from 0.028 to 0.047 $kg.s^{-1}$, the cooling capacity and COP increased from 25.6 to 104.3 W and 0.15 to 0.81 respectively as shown in Table 2. Therefore, a high airflow rate is recommended which should be considered depending on the efficiency of heat exchanger used.

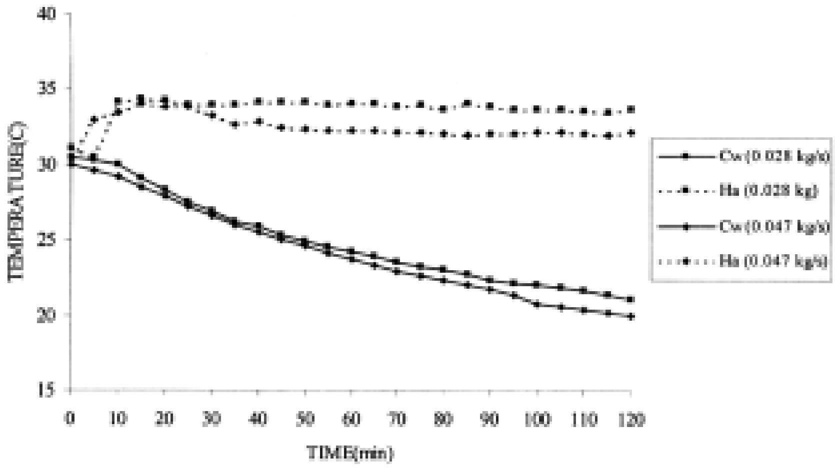


Figure 6. Hot air and cold water temperatures versus time for different ambient airflow rate (5 A, pushing air)

Table 2. Comparison between the cooling capacity and COP for different ambient airflow rate

Airflow rate ($kg.s^{-1}$)	Cooling capacity (W)	COP
0.028	25.6	0.15
0.047	104.3	0.81

Conclusions and Discussion

A TE water cooler was constructed and tested. Test results showed that the cooling performance depending on the rates of electric supply to and heat rejected from TE modules. The unit can cool the water in the cooler tank (3 l) from 29.5 to 19.5 °C. The corresponding cooling capacity is 90.3 W with a COP of 1.34. Thus, this concept seems to be reliable and merit towards commercial development. It is therefore recommended that further tests should be re-designed the cooler tank to reduce the heat loss between the bottom of the tank and the hot heat exchanger in order to improve the cooling performance of TE water cooler.

References

Gwilliam, S. 1991. Feasibility and Prototype Development of a TE Cooler for Parked Aircraft. *Proceeding of the 10th International Conference on Thermoelectric Energy Conversion*, Cardiff, UK, September, pp. 218-221.

Gwilliam, S., Entezam, B. and Tatton, S.C. 1992. TE Air Conditioning Using Evaporative Cooling of Waste Heat Air for Parked Aircraft. *Proceeding of the 11sInternational Conference on Thermoelectrics*, Arlington, USA, October, pp. 164-174.

Heenan, P. and Mathiprakasam, B. 1992. Development of Two - Man TE Microclimate Conditioner for Use in Army Ground-Vehicles. *Proceeding of the 11st International Conference on Thermoelectrics*, Arlington, USA, October, pp. 181-184.

Houghton, J. 1997. *Global Warming*. Great Britain: Cambridge University Press.

Khedari, J., Maneewan, S., Pratinthong, N. and Hirunlabh, J. 2001. Domestic Hot Water System Combining Solar and Waste Heat from Thermoelectric Air Conditioner. *International Journal of Ambient Energy*, **Vol.22**, **No.1**, pp. 19-28.

Lertsatitthanakorn, C., Sarachitti, R., Hirunlabh, J., Khedari, J. and Scherrer, H. 2000. Numerical Investigation of the Performance of Free Convected Thermoelectric Air Conditioner. *Proceeding of the19th International Conference on Thermoelectrics*, Cardiff, UK, August, pp. 481-485.

Lertsatitthanakorn, C., Hirunlabh J., Khedari, J. and Scherrer, H. 2001. Cooling Performance of Free Convected Thermoelectric Air Conditioner. *Proceeding of the20th International Conference on Thermoelectrics*, Beijing, China, June, pp. 453-457.

Rowe, D.M. 1995. *CRC Handbook of Thermoelectrics*. New York: CRC Press.

Stockholm, J.G. 1991. Reliability of Thermoelectric Cooling Systems. *Proceeding of the 10th International Conference on Thermoelectric Energy Conversion, Cardiff*, UK, September, pp. 27-31.

Stockholm, J.G. and Pujol-Soulet, L. 1982. Prototype Thermoelectric Air Conditioning of a Passenger Railway Coach. *Proceeding of the 4th International Conference on Thermoelectric Energy Conversion*, Arlington, USA, March, pp. 136-141.

Stockholm, J.G. and Schlicklin, P.M. 1988. TE Cooling for Naval Application. *Proceeding of the 7th International Conference on Thermoelectric Energy Conversion*, Arlington, USA, March, pp. 79-84.

Stockholm, J.G. and Schlicklin, P.M. 1989. Naval Thermoelectric Cooling. *Proceeding of the 8th International Conference on Thermoelectric Energy Conversion*, Nancy, France, June, pp. 235-238.