Performance analysis of a thermoelectric air conditioning

ANÁLISE DO DESEMPENHO DE UM CONDICIONAMENTO DE AR TERMOELÉTRICO

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ABSTRACT

This paper presents the theoretical development of the equations that allow to evaluate the performance of an air conditioning system based on the thermoelectric effect. The cooling system is based on a phenomena discovered by Jean Charles Athanase Peltier, in 1834. According to this when electricity runs through a junction between two semiconductors with different properties, heat is dissipated or absorbed. Thus, thermoelectric modules are made by semiconductors materials sealed between two plates through which a continuous current flows and keeps one plate hot and the other cold. The most important parameters to evaluate the performance of the device thermoelectric refrigeration are the coefficient of performance, the heat pumping rate and the maximum temperature difference between the hot side and the cold side of the thermoelectric module.

KEY-WORDS

Thermoelectric cooling. Thermo-electric air conditioning. Peltier effect.

INTRODUCTION

This paper presents the theoretical development of the equations that allow to evaluate the coefficient of performance of an air conditioning system based on the thermoelectric effect. This cooling system is based on a phenomena discovered by Jean Charles Athanase Peltier, in 1834. According to it, when electricity runs through a junction between two semiconductors with different properties, heat is dissipated or absorbed. Thus, the thermoelectric modules are made by semiconductors materials, sealed between two plates through which a direct current that keeps one plate hot and the other cold. Many researchers have studied applications of thermoelectric evices such as Gordon and Choon (1995), Göktun (1995), Sofrata (1996), Bojic et al (1997), Lindler (1998), Güler and Ahiska (2002), Chen et al (2002), Luo et al ((2003), Dai; Wang and Ni, (2003) and Astrain; Viá and Dominguez (2003).

The thermoelectric devices offer several advantages over other technologies (RIFFAT; MA, 2003): have no moving parts and, therefore, need less maintenance; contain no chorofluorocarbons; the direction of heat pumping is reversible, i.e., changing the polarity of the DC power supply a cooler can, then, become a heater; can function in environments that are too severe, too sensitive or too small for conventional refrigeration and are not position-dependent. Due to these advantages, thermoelectric devices have found very extensive applications in wide areas, such as military, aerospace, medical, microelectronics, laboratory, instrument and sensors, industrial and commercial products. Figure 1 shows a schematic of the Seebeck effect (thermoelectric generator) and the Peltier effect (cooling device).

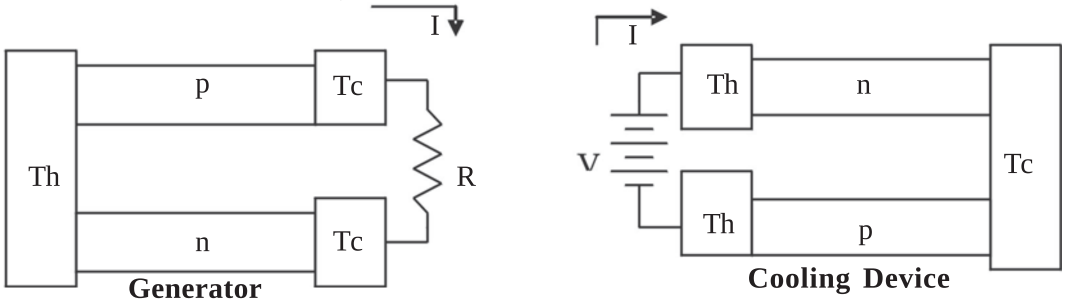

Figure 1 – Schematic of the thermoelectric generator and cooling device

COEFFICIENT OF PERFORMANCE (COP)

The parameters which are interesting in evaluating the performance of a cooling refrigerator are the coefficient of performance (f), the heat pumping rate and the maximum temperature difference which the device will produce.

$$\phi = \frac{q_c}{P} \qquad (1)$$

where q_c is the rate of heat removal from the cooled body and P is the electrical power input. The "cooling effect" is the rate of the heat removal from the cold reservoir and is the sum of three terms (HEIKES; URE JR, 1961):

$$q_c = \alpha . T_c I - \frac{1}{2} I^2 R - K\Delta T \qquad (2)$$

where: $a = a_p + a_n$, a_p and a_n are properties of the semiconductors materials, I is the current, R is a resistance () and K is the total conductivity of the thermoelectric cooling module. The power is

$$P = V.I = \alpha . I . \Delta T + I^2 . R = \frac{V(V - \alpha . \Delta T)}{R} \qquad (3)$$

where DT= (T_h-T_c), T_h and T_c are the hot and cold sides temperatures. The optimum geometry couple COP is

$$\phi = \frac{\left[mT_c - \frac{1}{2} m^2 - \left(\frac{\Delta T}{Z} \right) \right]}{\left(m\Delta T + m^2 \right)} \qquad (4)$$

$$Z = \frac{\alpha^2}{\left[\left(\rho_n K_n \right)^{\frac{1}{2}} + \left(\rho_p K_p \right)^{\frac{1}{2}} \right]^2} \qquad (5)$$

where $m = IR / \alpha$ and Z is called the figure of merit of the couple. Figure 2 shows the COP as a function of $Z\overline{T}$ or Z for three different values of $\overline{T}$ and Figure 3 compares the COP for thermoelectric and vapor compression systems.

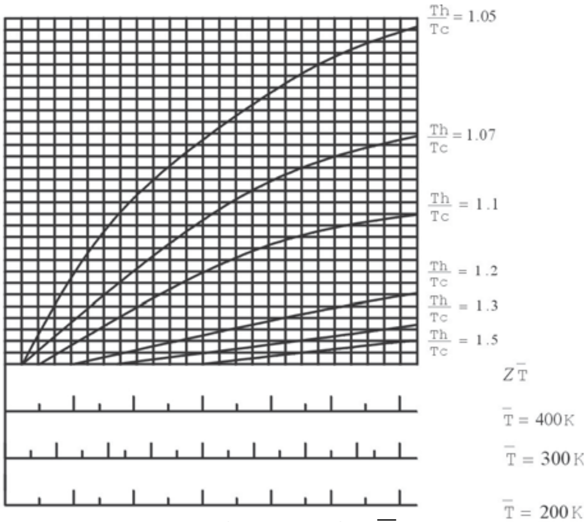

Figure 2 - COP as a function of $Z\overline{T}$ or Z

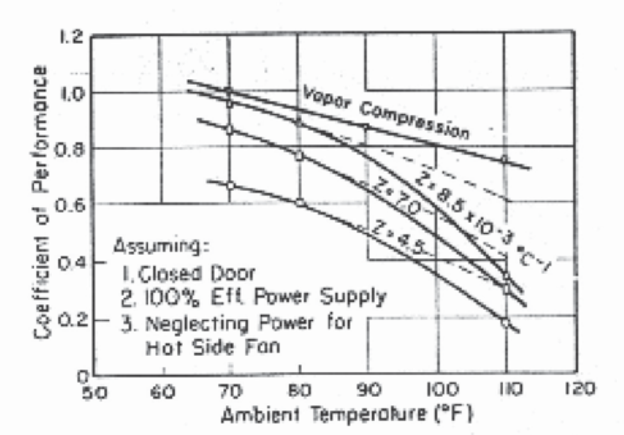

Figura 3 - COP for thermoelectric and vapor compression systems

CONCLUSION

The most important parameters to evaluate the efficiency of a thermoelectric air conditioner are: COP, transferred heat rate and maximum temperature difference possible to reach. The heat pump rate is function of the running electricity and the maximization of the COP for each temperature difference is made adjusting the applied voltage. Usually the maximum heat transfer rate and the maximum COP are not in the same point and it is needed to look for the best operation point.

Knowing the inlet and outlet temperatures of the air to be conditioned, the type and temperature of the air whirlpool, the parameters of the thermoelectric materials and the thermal load it is possible to determine the power to be provided, the total area and the thermoelectric material length for the maximum heat transfer and maximum COP conditions. From these values, the quantity of material, the number of required associations, the size of the system and the operation point that offer more advantages for the air conditioning system can be determined. The COP is strongly influenced by the "figure of merit" of the semiconductor material and it is still under the founded values for the equivalent vapor compression cooling system. The development of new thermoelectric materials with large figure of merit and appropriate technology could make a breakthrough the applications of thermoelectric devices in many fields.

RESUMO

Este artigo apresenta o desenvolvimento teórico das equações que permitem avaliar o desempenho de um sistema de condicionamento de ar baseado no efeito termoelétrico. O sistema refrigerado é baseado nos fenômenos descobertos por Jean Charles Athanase Peltier, em 1834. De acordo com este quando a eletricidade funciona através de uma junção entre dois semicondutores com propriedades diferentes, o calor é dissipado ou absorvido. Assim, os módulos termoelétricos são feitos pelos materiais dos semicondutores selados entre duas placas através da qual uma corrente contínua flui e mantêm uma placa quente e a outra fria. Os parâmetros mais importantes para avaliar o desempenho do dispositivo de refrigeração termoelétrica são o coeficiente do desempenho, a taxa de bombeamento do calor e a diferença da temperatura máxima entre o lado quente e o lado frio do módulo termoelétrico.

PALAVRAS-CHAVE

Resfriamento termoelétrico. Condicionamento de ar termoelétrico. Efeito Peltier.

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