Review on Thermoelectric materials and applications

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Abstract— In this paper thermoelectric materials are theoretically analyzed. The thermoelectric cooler device proposed here uses semiconductor material and uses current to transport energy (i.e., heat) from a cold source to a hot source via n- and p-type carriers. This device is fabricated by combining the standard n- and p-channel solid-state thermoelectric cooler with a two-element device inserted into each of the two channels to eliminate the solid-state thermal conductivity. The heat removed from the cold source is the energy difference, because of field emitted electrons from the n-type and p-type semiconductors. The cooling efficiency is operationally defined as where V is the anode bias voltage The cooling device here is shown to have an energy transport (i.e., heat) per electron of about500 me V depending on concentration and field while, in good thermoelectric coolers, it is about 50–60 me V at room temperature.

Keywords: Thermoelectric cooler, bismuth telluride, antimony telluride

I. INTRODUCTION

Currently the world's energy resources are shifting away from a fossil fuel driven economy and towards a renewable resource economy. The world's petroleum resources are a prime example of constricting supply coupled with increasing demand. The rising price of oil, which is spurring research into alternative fuels and energy efficient practices. Hybrids, flex fuel vehicles, and fuel cells are just a few of the possibilities to decrease the environmental impact of automobiles. This move towards clean power generation is an attempt to minimize the carbon footprint burning fossil fuels generates and reduces the amount of carbon dioxide emissions in the future.

Concern over global warming and depletion of the ozone layer has stimulated research to develop cooling methods that do not employ environmentally damaging working fluids such as CFCs and HCFCs. Two methods that have been considered are absorption and thermoelectric `Peltier' cooling systems. Absorption systems, using H2O/LiBr have the advantage of being able to use low-grade waste heat. However, the large volume, high capital cost and low performance of these systems have inhibited their widespread application.

TER is new alternative because it can convert less electricity into useful cooling, is expected to play an important role in meeting today's energy challenges. Therefore, TER are greatly needed particularly for developing countries where long life and low maintenance are needed.[2]-[7] TER are applied of TEC with base on Peltier effect for removing heat by DC current applied across two dissimilar materials causes a temperature differential[8].

The main objective of the refrigerator service is to be suitable for use by the Bedouin people who live in the remote areas of Oman where electricity is not available. The refrigerator can also be used for remote parts of the world or outer conditions where electric power supply is not readily available.

Recently, the global increasing demand for refrigeration, e.g. air-conditioning, food preservation, vaccine storages, medical services, and cooling of electronic devices, led to production of more electricity and consequently more release of CO_2 all over the world which it is contributing factor of global warming on climate change[1].

II. THERMO ELECTRIC REFRIGERATOR CONCEPT

Thermoelectric systems were developed in the 1950s and use of this for air- conditioning applications was investigated as early as the 1960s. However, the continued development of thermoelectric systems was slow owing to technical difficulties and the superior performance of vapour compression systems in terms of coefficient of performance (COP).

III. PRINCIPLE OF WORKING

Refrigeration means removal of heat from a substance or space in order to bring it to a temperature lower than those of the natural surroundings. In this context, my topic, Thermoelectric Refrigeration aims at providing cooling effect by using thermoelectric effects rather than the more prevalent conventional methods like those using the 'vapour compression cycle' or the 'gas compression cycle'.

When electric current is passed between two electrically dissimilar materials heat is absorbed or liberated at the junction. The direction of the heat flow depends on the direction of the applied electric current and the relative Seebeck coefficient of the two materials. The amount of Peltier heat absorbed by the cold junction (the cooling power) is given by

$$Q = (\Pi_B - \Pi_A)I$$

The terms, ΠA(B), are the Peltier coefficients, in units of Watts per Amp (W/A). The perceptive reader will notice that the two previous effects are closely tied together. In fact, the coefficients can be related in the following equation:

$$\Pi = \alpha T$$

Like the Seebeck effect, each couple will absorb and reject a certain amount of energy, and thus, N couples will absorb N times the amount of heat of a single couple, assuming they are all at the same temperature. Figure 1 shows a module with multiple junctions connected electrically in series, and thermally in parallel.

The total heat absorbed or liberated at either the hot side or cold side of the module is given as:

$$Q = N(\Pi_B - \Pi_A)I$$

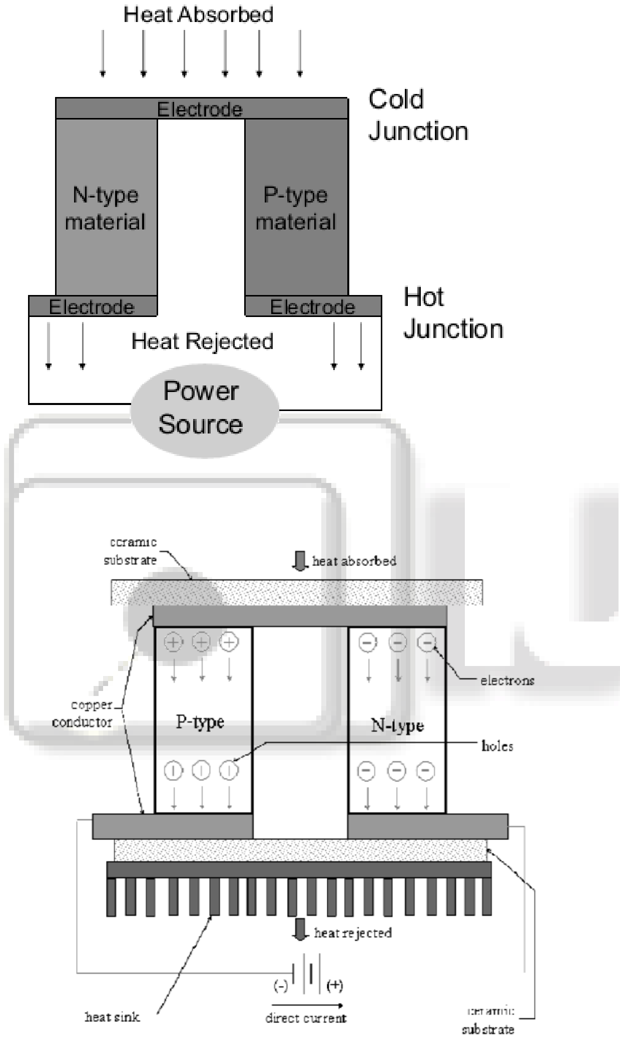


Fig. 1: simple peltier heating/cooling design

IV. LITERATURE REVIEW

In 1995 selahattin goktul[9] , He developed theoretical model for the thermoelectric module as shown in Fig.2 he shows the heat transfer at a finite rate and electric resistive losses are necessarily irreversible processes and unavoidable in thermoelectric device. It is shown that external and internal irreversibilities in a thermoelectric refrigerator may be characterized by a single parameter; named device design parameter. The presence of this parameter in equations for refrigeration effect and maximum input power shows that a real refrigerator has a smaller cooling capacity and needs more input power than a ideal refrigerator.

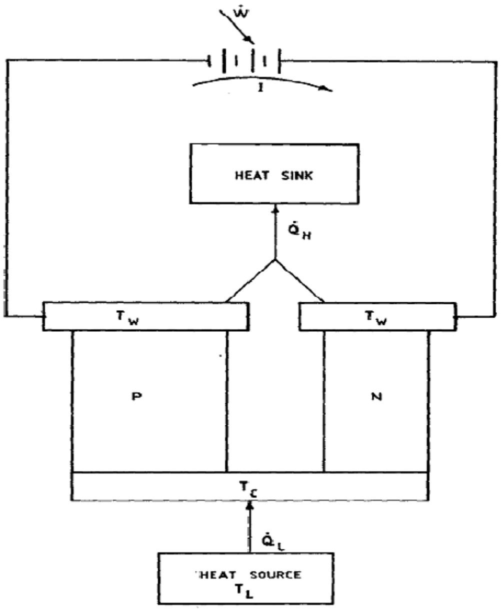


Fig. 2 A thermoelectric refrigerator

In 2010 Suwit Jugsujinda, Athorn Vora-ud, and Tosawat Seetawan[10] The refrigeration system of thermoelectric refrigerator (TER; 25 × 25 × 35 cm3) was fabricated by using a thermoelectric cooler (TEC; 4 × 4 cm2) and applied electrical power of 40 W. The TER has not cooling fan for the coldness circulates in the refrigerator.

TEC cold plate temperature (Tc) was decreased from 30ºC to –4.2 ºC for 1 hr and continuously decreasing to –7.4 ºC for 24 hrs and 50 ºC for hot plate temperature (Th). The TER temperature was decreased from 30ºC to 20 ºC in 1 hr and slowly decreasing temperature for 24 hrs. The maximum COP of TEC and TER were 3.0 and 0.65, respectively.

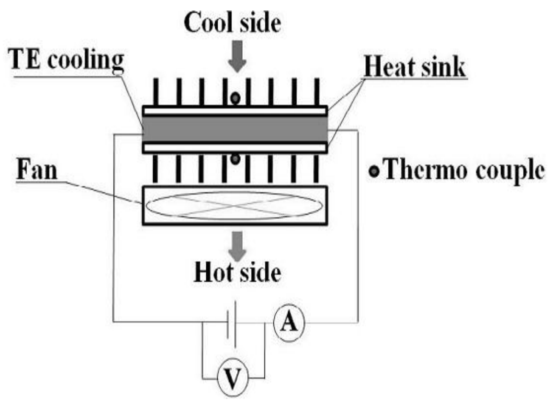


Fig. 3 : diagram for electric values measure

V. THERMOELECTRIC MATERIALS

Lead telluride (P_bT_e), Bismuth telluride (C specific heat capacity (J/kgK). ($B_{i2}T_{e3}$), Bismuth sulfide ($B_{i2}S_3$), Antimony telluride ($S_{b2}T_{e3}$), Tin telluride (S_nT_e), indium arsenide, germanium telluride (G_eT_e), cesium sulfide (C_eS), zinc antimonied (Z_nS_b) Lead telluride (P_bT_e), a compound of lead and tellurium, containing small amounts of either bismuth (n-type) or sodium (p-type) has been commonly used in recent times for thermoelectric converters.

Materials	Z(°K^{-1})
1. Bismuth telluride	4×10^{-8}
2. Lead telluride	1.5×10^{-3}
3. Germanium telluride	1.5×10^{-3}
4. Zinc antimonied	1.5×10^{-3}
5. Cesium sulfide	1.0×10^{-3}

Table . 1 : Figure of merit for thermoelectric materials

VI. CONCEPTUAL DESIGN

The thermal performance of a thermoelectric refrigerator depends on the thermoelectric module performance and heat sink design. The heat released from a heat element is absorbed by the cold side of the thermoelectric module and pumped to the hot side of the module. The pumped heat together with the input power to the module is then dumped to the ambient through heat sink. We can draw a thermal network to represent the heat transfer process to thermoelectric refrigerator as shown in fig. assuming no contact resistance.

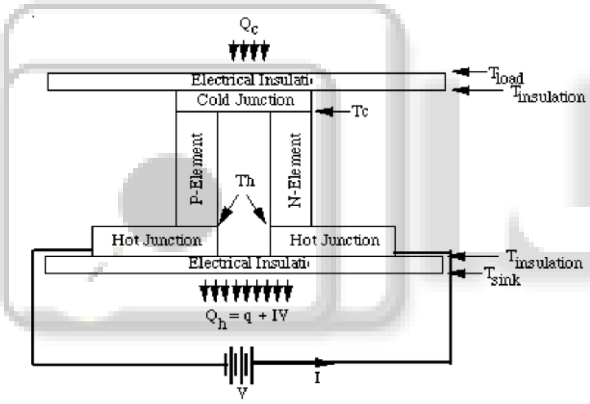


Fig. 6: Thermal network model of TER

VII. NOMENCLATURE

- A Cross sectional area
- COP Coefficient of performance
- ΔE EMF output
- I Current
- K Thermal conductivity
- L Lenght
- L_e & L_{ph} Dimensionless Lorenznumber
- NS Dimentionless entropy generation
- Q heating and cooling rate
- qh heat rejection
- qc heat absorbtion
- R Electric Resistance
- R_f heat sink resistance factor
- Sg Entropy generation rate
- T Tempreture
- ΔT Tempreture Difference
- TER Thermoelectric refrigerator
- TEC Thermoelectric cooler
- U Overall conductance
- UA cabinet thermal conductance
- P power consumption
- Z Figure of merit
- Greek letters
- α Seebeck coefficient
- τ Thomsion coefficient
- ρ Specific resistance
- π_{ab} Peltier coefficient
- ε_c ideal coefficient of performance
- ε_{ii} internally ideal coefficient of performance
- ε_s actual coefficient of performance
- η_e external thermodynamic efficiency
- η_i internal thermodynamic efficiency
- η_s Overall thermodynamic efficiency

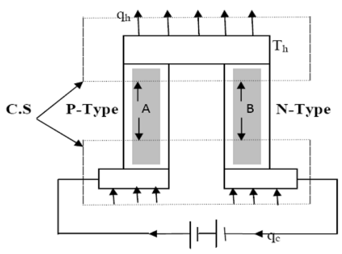
VIII. MATHEMATICAL MODELING

For analyzing the system to obtain refrigeration effect, cop, etc. Following assumptions are made:

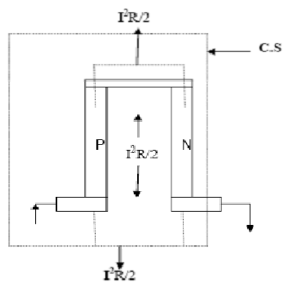
– Heat transfer takes place through semiconductors at the end only.

– No energy exchange between elements through space separating them.

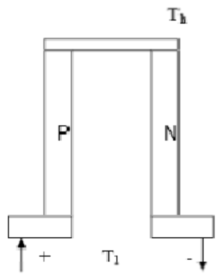
– Property such as conductivity, resistance etc. Are invariant with temperature.



(a)



(b)



(c)

Fig. 7 : Energy transfer in thermoelectric system

Now cooling and heating due to thermoelectric effect is given as:

$$q_c = \alpha_{ab} I T_l \qquad [1]$$

$$q_h = \alpha_{ab} I T_h \qquad [2]$$

As the Fig.b Shown the heat generation in the absence of other effects will lead to beat transfer from both hot and cold ends equal to $1/2I^2R$. The conduction effect along the element leads to heat transfer at the cold junction from hot one. Now from Fig b for the control volume, And for the cooling junction;

$$q_c + \frac{I^2R}{2} + U(T_h - T_l) = \alpha_{ab} I T_l \qquad [3]$$

And for the hot junction;

$$q_h + U(T_h - T_l) = \alpha_{ab} I T_l + \frac{I^2R}{2} \qquad [4]$$

Thus the thermoelectric cooling is

$$q_c = N[\alpha_{ab} I T_c - U(T_h - T_c)] \qquad [5]$$

And For heating

$$q_h = N[\alpha_{ab} I T_h + \frac{I^2R}{2} - U(T_h - T_c)] \qquad [6]$$

Now using first law, one obtains energy input to the system from outside as:

$$\phi\delta_q = q_{net} = -q_h + q_c$$

$$= -[\alpha_{ab} I (T_h - T_c) + \frac{I^2R}{2}] \qquad [7]$$

Where negative sign indicates energy supplied to the system.
The required COP is:

$$COP = \frac{qc}{\text{Energy supplied}}$$

$$= \frac{[\alpha_{ab} I T_c - \frac{I^2R}{2} - U(T_h - T_c)]}{[\alpha_{ab} I (T_h - T_c) + I^2R]} \qquad [8]$$

Where the overall conductance for both the conductors is given as

$$U = \frac{A_a K_a}{L_a} + \frac{A_b K_b}{L_b} \qquad [9]$$

And the total resistance for both conductors is given as:

$$R = \frac{L_a \rho_a}{A_a} + \frac{L_b \rho_b}{L_b} \qquad [10]$$

$$= \frac{L_a}{A_a \sigma_a} + \frac{L_b}{A_b \sigma_b}$$

Where ρ is the specific resistance and given as;

$$\sigma = \frac{1}{\rho}$$

Now from the equation [8] , the figure of merit, Z can be defined as:

$$Z = \frac{\alpha_{ab}{}^2}{UR} \qquad [11]$$

Mathematical analysis shows figure of merit is maximum when:

$$\frac{\frac{A_a}{L_a}}{\frac{A_b}{L_b}} = \sqrt{\frac{\sigma_a K_b}{\sigma_b K_a}} \qquad [12]$$

Then the maximum value of figure of merit Z will be:

$$z = \left[\frac{\alpha_{ab}{}^2}{\sqrt{(\sigma_a K_a) + (\sigma_b K_b)}}\right]^2 \qquad [13]$$

Using equations as given in [12] & [13] we obtain the current which corresponds to maximum COP from the equation 3.8 with the condition is:

$$\frac{dCOP}{dI} = 0.$$

And now the other quantity turns in

$$I' = \frac{\alpha_{ab}(T_h - T_l)}{R\sqrt{[(1+ZT_m-1)]}} \qquad [14]$$

Where T_m is mean temperature and given as:

$$\frac{(T_h + T_l)}{2}$$

The maximum COP is given by:

$$COP_{max} = \frac{T_l}{(T_h - T_l)} \frac{\sqrt{1+ZT_m} - \frac{T_h}{T_l}}{\sqrt{1+ZT_m} + 1} \qquad [15a]$$

$$= COPc(COP_{ref})_{rel} \quad [15b]$$

Where COP_c is the carnot value for a given refrigeration system operating between upper and lower temperature limits and

$$(COP_{ref})_{rel} = \frac{\sqrt{1+ZT_m} - \frac{T_h}{T_l}}{\sqrt{1+ZT_m}+1} \quad [16]$$

In eq.[15b] the $(COP_{ref})_{rel}$ stands for the actual thermoelectric behaviour. Now from the eq.[16]. it is found that the $(COP_{ref})_{rel} \sim 1$ when figure of merit $Z \sim \infty$ then

$$COP_{max} \longrightarrow COP_c$$

$$COP_{max} = \frac{T_l}{(T_h - T_l)} \quad [17]$$

For the maximum cooling condition is

$$\frac{dqc}{dI} = 0$$

So,

$$I_{opt} = \frac{(T_l)(\alpha_{ab})}{R} = T_l\sqrt{\frac{ZU}{R}} \quad [18]$$

The corresponding cooling is given by

$$q_{cmax} = U\left(\frac{ZT_l^2}{2} - (T_h - T_l)\right) \quad [19]$$

And,

$$COP_{opt} = \frac{\frac{ZT_l^2}{2} - T_h + T_l}{(ZT_hT_l)} \quad [20]$$

If heat source is removed then COP_{opt} will be zero, then maximum temperature difference is

$$(T_h - T_l)_{max} = \frac{T_l^2 Z}{2} \quad [21]$$

From the above equations it is derived that Z should be as high for reasonable amount of COP and maximum amount of refrigeration effect.

IX. CONCLUSION

The present study develops an optimization design method for thermoelectric refrigerator. The proposed simple model is used in the optimization of real thermoelectric refrigerator. Theoretical analysis results have indicated that under given conditions, there are optimal allocation ratios of the total thermal conductance that can maximize the TEC cooling capacity and COP, respectively. The energy efficiency of thermoelectric refrigerators, based on currently available materials and technology, is still lower than its compressor counterparts. However, a marketable thermoelectric refrigerator can be made with an acceptable COP. More-over, further improvement in the COP may be possible through improving module contact-resistances, thermal interfaces and heat exchangers. With its environmental benefit, a thermoelectric refrigerator provides an alternative to consumers who are environmentally conscious and willing to spend a little bit more money to enjoyed their quiet operation, and more precise and stable temperature control. The results obtained here may provide some guides for the optimal design and operation of practical thermoelectric cooling systems.

REFERENCES

[1] X. Hongxia , L. Lingai, G. Fraisse: Renew. Sust. Energy . Rev. Vol. 11,2007,pp. 923-926.
[2]. T.M. Tritt and M. A. Subramanian, Master. Res. Soc. Bull. Vol. 31, 2006, pp. 188-1910.
[3]. H. Sofrata, Energy Convers. Mgmt. vol.no.3 1996,37,1994,pp. 269-272.
[4]. H. Sofrata, J Appl. Energy . Energy .vol. 18, 1984,pp. 137-140.
[5]. R. L. field, Solar Energy. Vol. 25, 1980,pp. 445-448.
[6]. L. A. Staebler, ASHRAE. Vol.60,1959,pp.39-43.
[7]. S. Godfrey, An introduction to thermoelectric coolers, Online: http://www.electronicscooling.com2010.
[8]. S. B. Riffat, and X. Ma: app. Therm. Eng.,vol. 23, 2003,pp.913-917.
[9]. Selahatting Goktun, "Design consideration for thermoelectric refrigerator" Energy conversion management, vol.36 No 12,1995,pp. 1197-1200.
[10] Suwit Jugsujinda, Athorn Vora-ud, and Tosawat Seetawan "Analyzing of Thermoelectric Refrigerator Performance", Procedia Engineering, vol.8,2010,pp.154-159.