An Extensive Review on Thermoelectric Refrigerator

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Abstract-In this review paper we have studied the thermoelectric refrigerator. It was based on the integration of thermoelectric modules, heat pipes and phase change material into one unit. The heat pipes used in this system include thermal diode and "wicked" heat pipe. Unlike thermal diode, the "wicked" heat pipes return the liquid refrigerant to the evaporator via the wick. The thermoelectric systems were developed in the 1950s and use of this technology for air conditioning applications was investigated as early as the 1960s. 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). 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. Investigation of novel thermoelectric refrigeration systems from different researchers has been studied in this research.

Keywords - Peltier effect, Thermoelectric module, Figure of merit, Coefficient of Performance, Solar Photo voltaic cells.

I. INTRODUCTION

In thermoelectric materials, electrical energy can be directly converted into thermal energy and thermal energy into electrical energy. Direct conversion between electrical and thermal energy is possible because of two important thermoelectric effects: the Seebeck effect and the Peltier effect. The Seebeck effect refers to the existence of an electric potential across a thermoelectric material subject to a temperature gradient. The Peltier effect refers to the absorption of heat into one end of a thermoelectric material and the release of heat from the opposite end due to a current flow through the material. Thermoelectric materials are used in the construction of refrigerators and power generators. Direct conversion of thermal and electric energy means that the thermoelectric devices are often more reliable than traditional mechanic devices and suffer less wear. However, thermoelectric devices have a much lower efficiency than traditions devices. To raise the efficiency of these devices, materials with enhanced thermoelectric properties need to be found. One method of increasing the thermoelectric performance of materials is to manufacture materials with a very fine grain structure. If the characteristic length scale of the grains in a polycrystalline material is comparable to or less than the phonon mean free path, approximately 200-300 nm, phonons will be scattered off the grain boundaries, leading to a reduction in the thermal conductivity. Since the thermoelectric performance of a material is inversely proportional to the thermal conductivity, lowering a material's thermal conductivity could enhance its thermoelectric performance.The samples were made by hot pressing particles of thermoelectric materials. There were two sizes of particles that were used: nanometer-sized particles and micrometer-sized particles. The samples made from the nano-sized particles should have a finer grain structure than those produced from the micro-sized.

The theoretic background behind the theory and the basic thermoelectric principals and how they can be applied to energy conversion devices. It will also cover recent developments in the field thermoelectrics, including the theory behind increased thermoelectric performance due to grain boundaries. The study then will explore the detail of the actual experiment and examine the results. Finally, the results will be discussed and conclusions drawn.

II. THERMOELECTRIC PROPERTIES

The theories behind thermoelectric effects and possible methods for altering thermoelectric properties have been extensively studied over the years. These theories have led to great improvements in the performance of thermoelectric materials since research began and current theories predict even greater improvement in performance can be achieved.

An isolated conductor, subject to a temperature gradient, will develop an electric potential between the two extreme temperatures. The generated voltage is due to the diffusion of charge carriers from the hot side of the conductor to the cold. The charge carriers will continue to move from the hot side to the cold until an electric potential of equal magnitude to the thermal potential is established. In n-type materials the change carriers are electrons, while in p-type materials the charge is carried by the movement of holes.

This effect is called the Seebeck effect after Thomas J. Seebeck, who first observed this behavior in 1823. The magnitude of the potential difference along the material, E_A, is proportional to the temperature difference, ΔT, between the two ends according to

$$E_A = S_A \Delta T \qquad (1)$$

where S_A is the absolute Seebeck coefficient of the material. In a closed circuit of two dissimilar conductors, as shown in Figure 1, the temperature difference between the two junctions will impose an electromagnetic force (emf) around

the loop. The relationship between the induced emf, V, and the temperature difference is

$$V = S_{AB} \Delta T \qquad (2)$$

where SAB is the relative Seebeck coefficient, defined as

$$S_{AB} = S_A - S_B \qquad (3)$$

SA and SB are the absolute Seebeck coefficients of conductor A and conductor B, respectively.

The temperature difference between the two junctions drives the voltage around the loop.

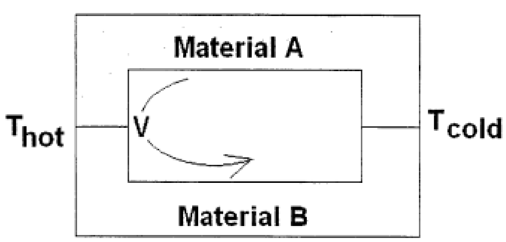

Fig 1: The Seebeck effect in a closed circuit of two dissimilar conductors.

The Peltier effect is related to the ability of charge carriers to carry thermal energy as well as charge as they move through a conductor. The heat flow, QA, moving through a material is proportional to the electric current, I, according to

$$Q_A = \Pi_A I \qquad (4)$$

where Π_A is the absolute Peltier coefficient of material A.

As a given current passes from one conductor to another, the amount of heat energy transported per unit current may either increase or decrease depending on the difference in absolute Peltier coefficients of the materials. Therefore, at the junction of a currentcarrying circuit comprised of dissimilar conductors, heat is either absorbed or released in order to balance the heat flow into and out of the junction. Figure 2 shows a schematic of the Peltier effect in a closed circuit of conductor A and conductor B.

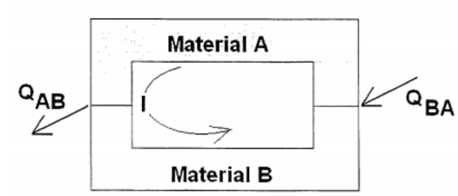

Fig 2: The Peltier effect in a closed circuit of two dissimilar conductors.

As the current flows through the loop, heat is liberated from one junction and absorbed at the opposite. The heat liberated at one end, QAB, is equal in magnitude to the heat absorbed at the opposite, QBA.

The amount of heat released or generated at each junction is proportional to the current through the circuit according to

$$Q_{AB} = \Pi_{AB} I \qquad (5)$$

where Π_{AB} is the relative Peltier coefficient. The relative Peltier coefficient is related to the absolute Peltier coefficients of both conductors as

$$\Pi_{AB} = \Pi_A - \Pi_B \qquad (6)$$

The Thompson effect describes the process by which heat is absorbed or liberated by a homogeneous conductor, conducting a current through a temperature gradient. The heat flow per unit length of the conductor, Q_A/I, is related to the current and the temperature gradient as

$$Q_A/_l = \beta_A I \frac{dT}{dx} \qquad (7)$$

where β_A is the Thompson coefficient of conductor A.

Both the Peltier and the Thompson effects are thermodynamically reversible. There is a simple relationship between the Seebeck and Peltier coefficients,

$$\Pi_{AB} = S_{AB} T$$

III. LITERATURE REVIEW

Sabah A. Abdul-Wahab, Ali Elkamel and Ali M. Al-Damkhi investigated an affordable solar thermoelectric refrigerator for the Bedouin people living in remote parts of Oman where electricity is still not available. The refrigerator could be used to store perishable items and facilitate the transportation of medications as well as biological material that must be stored at low temperatures to maintain effectiveness. The design of the solar-powered refrigerator is based on the principles of a thermoelectric module to create a hot side and a cold side. The cold side of the thermoelectric module is utilized for refrigeration purposes; provide cooling to the refrigerator space. On the other hand, the heat from the hot side of the module is rejected to ambient surroundings by using heat sinks and fans [3].

Y.L. Ju a,*, L. Wang developed and designed, based on theoretical considerations, a new type of 4 K GM/PT hybrid refrigerators. The upper warm stage of the hybrid refrigerator is a typical GM refrigeration cycle, and the cold stage is a pulse tube refrigerator (PTR), on which is thermodynamically coupled the upper warm stage. Four different types of phase shifting assembly: (1) a cold auxiliary piston that is connected to the displacer of the upper GM refrigerator stage, (2) an orifice with reservoir encircled the cold head of the upper stage, (3) an orifice with double-inlet, and (4) in combination with the cold auxiliary piston, orifice and double-inlet, has been proposed and analyzed for the adjustment of the phase shift between the gas mass flow and pressure in the pulse tube. Numerical simulation was performed to understand the unique thermo-physical features, to reveal the time-dependent dynamic parameters and to quantify the overall cooling performance of the hybrid refrigerator [4].

F. Meng, L. Chen¤ and F. Sun developed model of commercial thermoelectric refrigerators with finned heat exchanger had been established by introducing finite time thermodynamics. A significant novelty is that physical properties, dimension parameters, temperature parameters and flow parameters are all taken into account in the model. Numerical studies and comparative investigation on the performance of a typical commercial water-cooling thermoelectric refrigerator which consists of 127 thermoelectric elements, are performed for cooling load and coefficient of performance. The results show that the maximum cooling load is 2.33 W and the maximum coefficient of performance is 0.54 when the cooling temperature difference is 10 K. The performance can be improved by optimizing the length and cross-section area of thermoelectric elements. The model and calculation method may be applied to not only the analysis and performance prediction of practical thermoelectric refrigerators, but also the design and optimization of heat exchangers [5].

Ajitkumar N. Nikam1, Dr. Jitendra A. Hole developed and carried out by different researchers on development of novel thermoelectric R&AC system has been thoroughly reviewed. In recent years, with the increase awareness towards environmental degradation due to the production, use and disposal of ChloroFluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as heat carrier fluids in conventional refrigeration and air conditioning systems has become a subject of great concern and resulted in extensive research into development of novel refrigeration and space conditioning technologies. Thermoelectric cooling provides a promising alternative R&AC technology due to their distinct advantages. Use of Thermoelectric effect to increase the COP of existing cooling system has been also reviewed in this paper [6].

Manoj Kumar Rawat and Himadri Chattopadhyay tested the hoped for reduction of thermal conductivity for any of the materials tested. No enhancement of thermoelectric performance was seen for the small grain sizes, as classical size effects would suggest. It is likely that the actual grain sizes in the samples are much larger than their original particle size, for both the nano-sized and the micro-sized particles. Grain growth can occur during the hot press stage of the manufacturing process, yielding materials with grains several orders of magnitude greater than the size of the particles used [7].

Onoroh Francis, Chukuneke Jeremiah Lekwuwa researched on simulation of a thermoelectric refrigerator maintained at 4^{o}C. The performance of the refrigerator was simulated using Matlab under varying operating conditions. The system consisted of the refrigeration chamber, thermoelectric modules, heat source and heat sink. Results show that the coefficient of performance (C.O.P) which is a criterion of performance of such device is a function of the temperature between the source and sink. For maximum efficiency the temperature difference is to be kept to the barest minimum [8].

Mohan M. Tayde, Lalit B. Bhuyar and Shashank B. Thakre presented Cooling for military, civilian and aviation applications and other electronic equipment has become an important issue. Many electronic systems, components, and processors create heat which must be effectively removed in order to ensure lower temperatures. Classical refrigeration using vapour compression has been widely applied over the last decades to large scale industrial systems. The mini-scale (miniature) refrigerator using VCR seems to be an alternative solution for the electronic cooling problem. Fabrication of very small devices is now possible due to advances in technology. In this investigation a mini-scale refrigerator of 300W cooling capacity using R-134a as refrigerant is designed, built and tested [9].

Chakib Alaoui presented a model for the Peltier effect heat pump for the transient simulation in Spice software. The proposed model uses controlled sources and lumped components and its parameters can be directly calculated from the manufacturer’s data-sheets. In order to validate this model, a refrigeration chamber was designed and fabricated by using the Peltier modules. The overall system was experimentally tested and simulated with Spice. The simulation results were found to be compatible with the experimental results. This model will help designers to better design thermal systems using the Peltier modules [10].

Jonathan Winkler, Vikrant Aute and Bao Yang investigated the application of thermoelectric devices to enhance the performance of conventional vapor compression based air conditioning systems. Thermoelectric devices are capable of converting electrical energy into thermal heat-pumping at a very high efficiency. A validated air-cooled heat exchanger simulation tool is used to study the effect of adding thermoelectric devices between the fins and tubes to enhance heat transfer. The validated system simulation tool is used to study the effect of using a thermoelectric device to increase the refrigerant sub-cooling at the outlet of a condenser. The study was conducted for several refrigeration and air conditioning applications with various refrigerants [11].

Manoj Kumar Rawat, Prasanta Kumar Sen and Himadri Chattopadhyay designed methodology of thermoelectric refrigeration has been explained in detail also the theoretical physical characteristics of thermoelectric cooling module used in this research work have been investigated. Outcomes show a temperature reduction of 11^{o}C without any heat load and 9^{o}C with 100 ml water kept inside refrigeration space in 30 minute with respect to 23^{o}C ambient temperature. Also the COP of refrigeration cabinet has been calculated and it is 0.1 [12].

IV. CONCLUSION

Form our investigation we found that in thermoelectric materials research, it is more convenient to look at the thermoelectric performance of each material singularly, rather than as a component within a device. Thermoelectric coolers and power generator to be practical and competitive with more traditional forms of technology, the thermoelectric devices must reach a comparable level of efficiency at converting between thermal and electric energy. The total efficiency of the device will naturally be related to a combination of the thermoelectric properties of both the p-type and the n-type legs. As a thermoelectric cooler with the same efficiency of that of a Freon cooler would need to be constructed with 22 thermoelectric materials with ZTs of three to four. To increase ZT, expressed as S2a, also known as the power factor needs to be increased in relation to the thermal conductivity.

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