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Review On Thermoelectric Refrigeration: Materials, Applications And Performance Analysis

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Abstract
In the past 10 years, there is a rapid increment in the awareness towards environmental degradation due to release of ChloroFluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as major heat carrier fluids in traditional refrigeration systems, which has become a subject of prime concern and resulted in extensive research into development of new unconventional refrigeration technologies. Thermoelectric refrigeration serves as a best alternative in refrigeration technology due to their distinct advantages. In this paper a brief introduction of thermoelectric refrigeration, its principle and applications has been presented. The research and development work carried out by different researchers on development of thermoelectric R&AC system has been thoroughly reviewed in this paper.

I. INTRODUCTION

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. Thermoelectric cooling is a way to remove thermal energy from a medium, device or component by applying a voltage of constant polarity to a junction between dissimilar electrical conductors or semiconductors. Thermoelectric Refrigeration provides cooling effect by using thermoelectric effect i.e. Peltier effect rather than the more prevalent conventional methods like those using the ‘vapour compression cycle’ or the ‘gas compression cycle’.

In 1821, Thomas Seebeck discovered that a continuously flowing current is created when two wires of different materials are joined together and heated at one end. This idea is known as the Seebeck Effect. The Seebeck effect has two main applications including temperature measurement and power generation. Thirteen years later Jean Charles Athanase reversed the flow of electrons in Seebeck.s circuit to create refrigeration. This effect is known as the Peltier Effect. This idea forms the basis for the thermoelectric refrigerator. Scottish scientist William Thomson (later Lord Kelvin) discovered in 1854 that if a temperature difference exists between any two points of a current carrying conductor, heat is either evolved or absorbed depending upon the material.6 If such a circuit absorbs heat, then heat may be evolved if the direction of the current or of the temperature gradient is reversed. The coefficient of performance (COP) of compression refrigerators decreases with the decrease in its capacity. Therefore, when it is necessary to design a low capacity refrigerator, TER is always preferable. Also, better control over the space temperature is the major advantage of the TER. Hence, TER is good option for food preservation applications & cooling of pharmaceutical products. [3]

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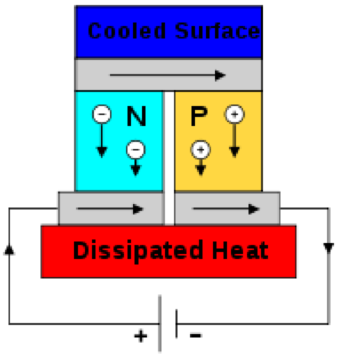
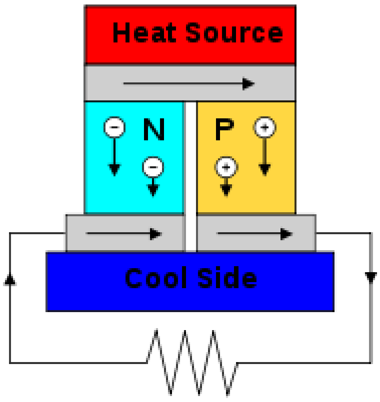
II. PRINCIPLE

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials.
Thermoelectric heating uses the Seeback effect to create a temperature difference between the junctions of two different types of materials.

Peltier Effect: It states that when electric current is maintained in a circuit of material consisting of two dissimilar conductors, one junction becomes cold and the another junction
Becomes hot.



Seeback effect: It states that when temperature difference is maintained between two dissimilar conductors, Electric voltage difference is produced between the two junctions.



III. MATERIAL REVIEW

Thermoelectric module is made of two different semiconducting materials, which generate thermoelectric cooling effect (Peltier effect) when a voltage of similar polarity & in appropriate direction applied through the connected junction. Two heat sinks & fans are attached to hot and cold sides of thermoelectric module in order to enhance heat transfer and system performance. There exists an optimum current & optimum voltage for maximum coefficient of performance (COP) for a specific module and fixed hot/cold side temperatures.
According to the primary criterion of figure of merit ($Z = \alpha 2\ RK$), a good thermoelectric material should have high Seebeck coefficient, high electrical conductivity, and low thermal conductivity. Commonly used thermoelectric materials are Bismuth Telluride (Bi2Te3), Lead Telluride (PbTe), Silicon Germanium (SiGe) and Cobalt Antimony (CoSb3), among which Bi2Te3 is the most commonly used one. These materials usually process a ZT value (figure of merit at temperature) less than one. From 1960s to 1990s,

developments in materials in the view of increasing ZT value were modest, but after the mid-1990s, by using nano structural engineering thermoelectric material efficiency is greatly improved. Thermoelectric materials such as primary bulk thermoelectric materials like skutterudites, clathrates and half-Heusler alloys, which are principally produced through doping method are developed but not exploited for commercial use. [4] The best commercial thermoelectric materials currently have ZT values around 1.0. The highest ZT value in research is about 3. Other best reported thermoelectric materials have figure-of-merit values of 1.2-2.2 at temperature range of 320-5200C. It is estimated that thermoelectric coolers with ZT value of 1.0 operate at only 10% of Carnot efficiency. Some 30% of Carnot efficiency could be reached by a device with a ZT value of 4. However, increasing ZT to 4 has remained a formidable challenge. Bell also mentioned that if the average ZT reaches 2, domestic and commercial solid-state heating, ventilating and air-cooling systems using thermoelectric material would become practical.[4]

IV. PERFORMANCE ANALYSIS

Nomenclature
V = Voltage [v]
I = Current [A]
Q = Rate of heat transfer [W]
R = Electrical Resistance [Ω]
P = Input power [W]
σ = Electrical conductivity [Ω^{-1} m^{-1}]
K = Thermal Conductivity [W m^{-1} K^{-1}]
= Seeback Coefficient [[VK^{-1}]
Subscripts
H = Hot junction side
L = Cold junction side
source = Heat source
sink = Heat sink

The theoretical equations for the thermoelectric module performance include:
Thermoelectric Voltage,

$$V = (T_H - T_L) + IR \qquad (1)$$

Power input equation,

$$P = (T_H - T_L) + I2R \qquad (2)$$

Equation for Cooling capacity

$$\dot{Q}_L = I\alpha T_{\text{source}} - (T_H - T_L) - 0.5I^2R \qquad (3)$$

Equation for heat rejection

$$\dot{Q}_H = I\alpha T_{\text{sink}} - (T_H - T_L) + 0.5\, I^2R \qquad (4)$$

And COP is given by,

$$COP = \dot{Q}_L / P \qquad (5)$$

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An important physical property for the thermoelectric module is the figure of merit Z which is given by,

$Z = \alpha^2 \sigma /$

Thermoelectric efficiency = ZT

V. APPLICATIONS

1. Thermoelectric refrigeration
2. Electronic cooling
3. Automobile cooling
4. Air conditioning appliances
5. Portable active solar still
6. Space cooling with PCM
7. Solar space power system
8. Fire fighter application

VI. THERMOELECTRIC COOLING VERSUS TRADITIONAL REFRIGERATION

Solid state design

No moving parts

Integrated chip design

No hazardous gases

Silent operation

Compact and lightweight

Low profile

Sizes to match your component footprint

No bulky compressor units

Precise temperature stability

Tolerances of better than +/- 0.1°C

Accurate and reproducible ramp and dwell times

Cooling/heating mode options

Fully reversible with switch in polarity

Localized Cooling

Spot cooling for components or medical applications

Perfect for temperature calibration in precision detection systems

Rapid response times

Instantaneous temperature change

Reduced power consumption

Dehumidification

Efficient condensation of atmospheric water vapor

VII. RECENT DEVELOPMENTS IN THERMOELECTRIC REFRIGERATION AND AIR CONDITIONING SYSTEMS

Design and Development of thermoelectric refrigeration system DC voltage generated by solar cells. Et.al Dai. In their research they developed a model consisting of a TEC module, array of solar cells, controller, storage battery and a rectifier.
Min *et al*. developed a model of thermoelectric refrigerator having dissimilar heat exchangers. Their results show that COP can be increased through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers.
Lertsatitthanakorn *et al*. carried out the performance analysis of thermoelectric ceiling cooling panel (TE-CCP) system composed of 36 TEM.
Gillott *et al*. performed an experiment of thermoelectric cooling devices for small-scale space conditioning applications in buildings. They also performed a numerical study to find the optimum working conditions, which were then applied in the laboratory testing work.
Bansal *et al*. carried out a theoretical investigation on efficiency and cost-effectiveness for vapour compression system, thermoelectric and absorption type of refrigeration system of similar capacity (about 40 litre). Their result show that vapour compression refrigerator was the most energy efficient (with a COP of 2.54) followed by thermoelectric (COP of 0.78) and absorption refrigerator (COP of 0.55).
The researchers finally concluded that the VC refrigerator was the most energy efficient and cheaper unit followed by the thermoelectric and the absorption refrigeration.

VIII. CONCLUSION

TEC modules offers so many advantages including: zero moving parts, low profile amd compact components, no maintenance,vibration free ,Acoustically silent and electrically quiet , easy temperature regulation, Highly precise temperature control (to within 0.1°C), Operation in any orientation, no gravity and zero Environmentally degradation and Sub-ambient cooling. The paper focuses on thermoelectric device principles and theory, thermoelectric Principle of Operation, thermoelectric materials,its performance analysis as well as recent developments in thermoelectric Refrigeration and Air Conditioning Systems.

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