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Developmental and Experimental Study of Solar Powered Thermoelectric Refrigeration System

Manoj Kumar Rawat[1], Prasanta Kumar Sen[2], Himadri Chattopadhyay[3], Subhasis Neogi[4]

[1](PPE, CSIR-Central Mechanical Engineering Research Institute, Durgapur -09, West Bengal, India)
[2](PPE, CSIR-Central Mechanical Engineering Research Institute, Durgapur -09, West Bengal, India)
[3](Mechanical Engineering Department, Jadavpur University Kolkata-700032, West Bengal, India)
[4](School of Energy Studies, Jadavpur University Kolkata-700032, West Bengal, India)

ABSTRACT

Design and developmental 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. Authors have been designed and developed an experimental prototype of thermoelectric refrigeration system working on solar photo voltaic cells generated DC voltage. The developed experimental prototype having a refrigeration space of 1liter capacity is refrigerated by using four numbers of Peltier module (Supercool : PE-063-10-13, Q_{max}=19W) and a heat sink fan assembly used (Model No: TDEX6015/TH/12/G, R_{th}=1.157 ^{o}C/W) to increase heat dissipation rate from hot side of Peltier module.

The experimental result shows 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. The developed thermoelectric refrigeration system is having potential application of storage and transportation of life saving drugs and biological materials at remote areas of our country where grid power is unavailable.

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

I. INTRODUCTION

In recent years, with the increase awareness towards environmental degradation due to use of CFCs and HCFCs refrigerants in conventional refrigeration systems has become a subject of great concern. Besides, these kinds of refrigeration systems having limitation of use of grid power and same cannot be utilised for remote applications. Researchers are continuously giving efforts for development of eco-friendly refrigeration technologies like thermoelectric, adsorption, magnetic and thermoacoustic refrigeration. Dai et al. [1] developed a thermoelectric refrigeration system powered by solar cells and carried out experimental investigation and analysis. Researchers developed a prototype which consists of a thermoelectric module, array of solar cell, controller, storage battery and rectifier. The studied refrigerator can maintain the temperature in refrigerated space at 5–10^{o}C, and has a COP about 0.3 under given conditions. Wahab et al. [2] have designed and developed an affordable solar thermoelectric refrigerator for the desert people living in Oman where electricity is not available. In this study, they used 10 nos. of thermoelectric module in design of refrigerator. The experimental results indicated that the temperature of the refrigeration was reduced from 27^{o}C to 5^{o}C in approximately 44 min. The coefficient of performance of the refrigerator was calculated and found to be about 0.16.

Abdullah et al. [3] have carried out an experimental study on cooling performance of a developed hybrid Solar Thermoelectric- Adsorption cooling system. The developed system produced cooling via the Peltier effect during the day, by means of thermoelectric elements, and through adsorption (activated carbon-methanol) process at night. They evaluate the coefficient of performance by using derived equations, the average COP values of the hybrid cooling system were found about 0.152 for thermoelectric system and about 0.131 for adsorption.

Thermoelectric cooling works on the principle of Peltier effect, when a direct 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 applied electric current and the relative Seebeck coefficient of the two materials. A Peltier module or thermoelectric cooling module (Fig.-1) is a solid-state active heat pump which consist a number of p- and n- type semiconductor couples connected electrically in series and thermally in parallel are sandwiched between two thermally conductive and electrically insulated substrate. The performances equations (1-3) of a thermoelectric cooler are expressed as follows and are described in many handbooks and papers [4-6],

$$Q_c = \alpha_m T_c I - \frac{1}{2}(I^2 R_m) - K_m (T_h - T_c) \quad (1)$$

$$W = \alpha_m I (T_h - T_c) + I^2 R_m \quad (2)$$

$$COP = \frac{Q_C}{W} \quad (3)$$

$$\alpha_m = 2\alpha N \quad (4)$$

$$R_m = \frac{2\rho_{tm} N}{G} \quad (5)$$

$$K_m = 2NKG \quad (6)$$

In the above equations the α_m, K_m, R_m are the device Seeback voltage, device thermal conductance and device electrical resistance under the assumption of all identical couple and the unidirectional heat flow. These device parameters can be calculated from manufacturer's datasheet by using following equations as given below [7],

$$\alpha_m = \frac{V_{max}}{T_h} \quad (7)$$

$$R_m = \frac{(T_h - \Delta T_{max})}{T_h} \frac{V_{max}}{I_{max}} \quad (8)$$

$$K_m = \frac{(T_h - \Delta T_{max})}{2\Delta T_{max}} \frac{V_{max} \cdot I_{max}}{T_h} \quad (9)$$

$$Z = \frac{2\Delta T_{max}}{(T_h - \Delta T_{max})^2} \quad (10)$$

Where I_{max} is the maximum input current at Q_c=0, V_{max} is maximum DC voltage at Q_c=0 and ΔT_{max} is the maximum temperature difference at I_{max}, V_{max} and Q_c=0.

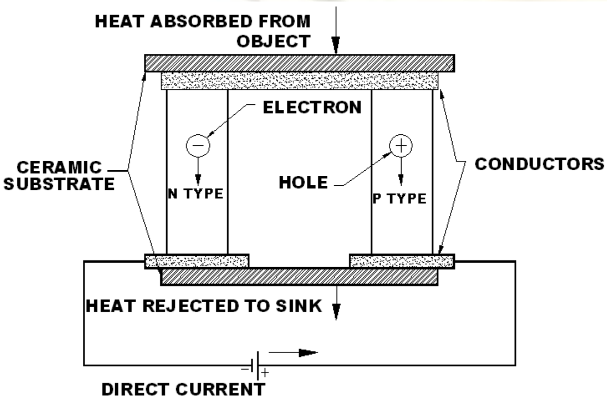

Fig.-1: Schematic diagram of a Thermoelectric Cooling Module

II. EXPERIMENTAL SECTION

A thermoelectric refrigeration cabinet (Fig.-2) with refrigeration space of (1000 cubic centimeter) or (1Liter capacity) has been developed with outer casing of MS sheet and for thermal insulation a polyurethane foam sheet has been provided inside the box to prevent reversal of heat flow. A thin cupper sheet (0.4mm) has been fixed inside the box for uniform distribution of temperature. Four numbers of thermoelectric modules (Supercool: PE-063-10-13) have been used to reduce inside temperature of refrigeration space. Cold side of TEM mounted on cupper sheet and hot side of modules were fixed with heat sink fan assembly. Four numbers of black anodized plate fin heat sink fan assembly (Model No: TDEX6015/TH/12/G) were used for each module to enhance the heat dissipation rate.

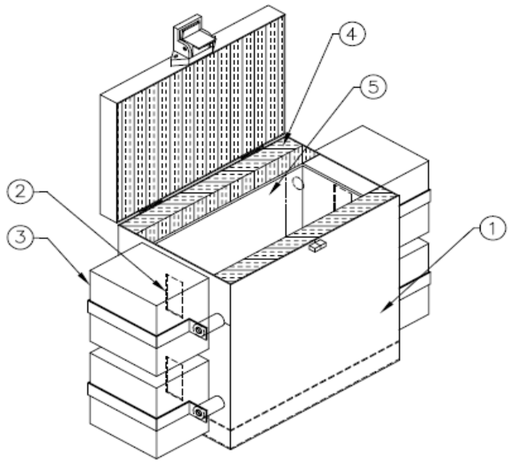

Fig.-2: Schematic Diagram of thermoelectric Refrigeration Cabinet (1) Outer casing (2) Peltier Module (3) Heat sink fan assembly (4) PUF Insulation sheet (5) Cupper lining

The thermoelectric cooling modules for development of thermoelectric refrigerator cabinet have been selected on the basis of active and passive heat removal from refrigeration cabinet.

2.1 Active heat load calculation

The active heat load is the heat released by a mass which is kept inside the cabinet during the cooling and is calculated by,

$$Q_{active} = \frac{mC_p \Delta T}{dt} \quad (11)$$

2.2 Passive heat load calculation

The passive heat load is the heat losses due to convection & conduction of the enclosed thermoelectric cabinet and calculated by,

$$Q_{passive} = \frac{A\Delta T}{\left(\frac{X}{k} + \frac{1}{h}\right)} \quad (12)$$

$$Q_{total} = Q_{active} + Q_{passive} \quad (13)$$

For total heat removal (Q_{total}) four numbers of thermoelectric cooling modules (Supercool: PE-063-10-13) (Fig.-3) have been selected with following specification,

$Q_{maxi} = 19\ w$ $T_{hot} = 25°\ C$
$I_{maxi} = 3.9\ A$ N = 10
$V_{maxi} = 7.8\ v$
$T_{h\ maxi} = 80°\ C$
$(\Delta T_{maxi}) = 74°\ K$

To enhance heat dissipation from hot side of thermoelectric cooling module a (Fig.-3) black anodized heat sink fan assembly (Model No: TDEX6015/TH/12/G, R_{th}=1.157 °C/W) has been used for each Peltier module. The heat sink fan assembly has been selected on the basis of experimentally investigated thermal resistance as given,

$$R_{th} = \frac{T_h - T_a}{Q_h} \qquad (14)$$

Where Q_h,

$$Q_h = Q_{total} + Q_{TEM} \qquad (15)$$

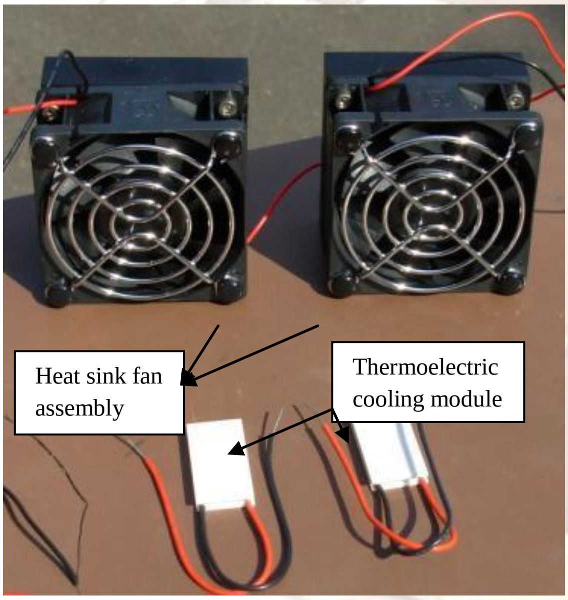

Fig.-3: Thermoelectric cooling module and heat sink fan assembly used in development of thermoelectric refrigeration cabinet

A DC power supply system (Fig.-4) was developed to power the developed thermoelectric refrigeration cabinet for remote application where grid power is unavailable. This system consist two nos. of solar PV panel (Make: Access Solar Limited, Model No: A635-3712, 12V, 40Wp) fixed on a frame with provision of angle variation for optimum solar radiation incidence on PV panel. The electric charge produced by solar cells was controlled by a charge controller and used to charge a solar PV compatible rechargeable battery (Make: Exide, Model No: 6LMS40, 12V, 40Ah).

A DC variable power supply unit (Make: Saikat Instruments) was used for supply DC voltage to thermoelectric cooling modules and heat sink fan assembly of thermoelectric refrigeration cabinet. For online performance measurement of developed thermoelectric refrigeration system an 8-Channel data acquisition system (Make: Nippon Technologies, Model No: UNSC-08μ) with PT-100 temperature sensors was used.

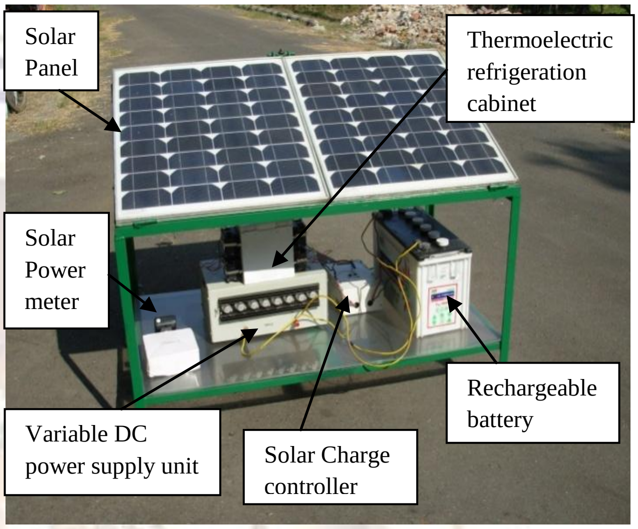

Fig.-4: Photograph of developed solar powered thermoelectric refrigeration system

III. RESULTS AND DISCUSSION

In this experimental analysis, four nos. of Thermoelectric cooling modules (Supercool: PE-063-10-13) were used for development of thermoelectric refrigeration cabinet. The cooling module specification from manufacturer's datasheet are I_{maxi}= 3.9A, V_{maxi}=7.8V and ΔT_{maxi}=74 °K at T_h=25°C and the dimensions of module are 30 mm x 15 mm x 3.6 mm. The fundamental theoretical device characteristics have been calculated by using equations (7)-(10) and the values are,

α_m=0.02617 V/K
K_m=0.1545 w/K
R_m=1.5033Ω
Z = 0.002949 1/°K.

First for the performances evaluation of single thermoelectric cooling module experiments have been conducted. The performances of TEM was evaluated at variable input electrical current conditions ($0.25I_{maxi}$, $0.5I_{maxi}$ & $0.75I_{maxi}$) and at natural as well as forced air convection condition for enhance heat dissipation from hot side of TEM. The test results (Fig.-5) showed for input electrical current $0.5I_{maxi}$ and at forced air convection condition the cooling down rate was higher than natural air convection and also the reduced temperature was maintained for a longer duration.

With these optimized operating conditions ($I=0.5I_{maxi}$) experiments were conducted on developed prototype of thermoelectric refrigeration system without any heat load and result shows a temperature reduction of 11°C in refrigeration space with respect to 23°C ambient temperature in 30 minutes (Fig.-6). Also the experiments were carried out with 50 ml and 100 ml of water inside cabinet with same operating conditions and results shows a temperature reduction of 9°C for 100 ml heat load with respect to 23°C ambient temperature in 30 minutes. The COP of thermoelectric refrigeration cabinet has been calculated for same operating conditions and for 100 ml heat load by

equation (16) and it was 0.1[8].

$$COP = \frac{Q_{cooling}}{E} \quad (16)$$

Where,

$$Q_{cooling} = \frac{mC_p \Delta T}{dt} \quad (17)$$

And E is the total input electrical energy.

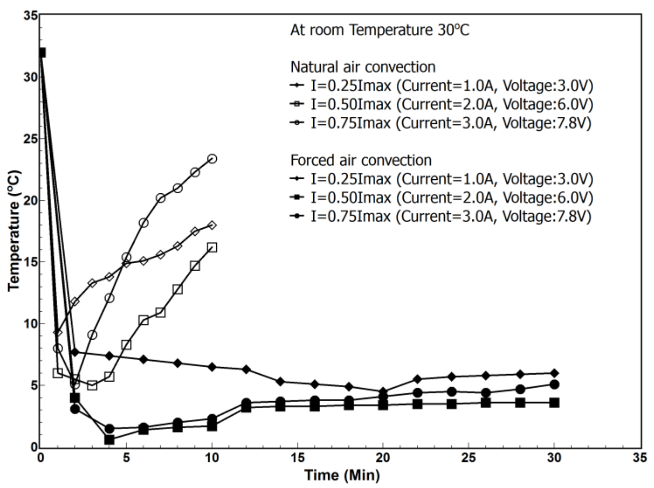

Fig.-5 Performances of single TEM at Natural and Forced air Convection

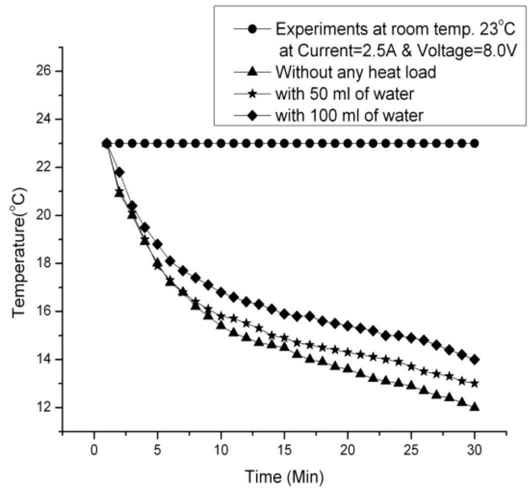

Fig.-6 Experimental results of developed TER cabinet

IV. CONCLUSION

The experimental results of developed prototype of TER system shows that the performances were optimum for a given operating conditions $I=0.5I_{maxi}$ and forced air convection heat dissipation. An 11°C temperature reduction at no load and 9°C at 100 ml water inside refrigeration space of developed TER has been experimentally found with respect to 23°C ambient temperature in 30 minutes. Also the calculated COP of thermoelectric refrigeration cabinet was 0.1.

Also it has been experimentally found that the developed thermoelectric refrigeration system gives optimum performance at 2.5A, 8V and the system can continuously work for 15 hours when battery is fully charged with solar panel. The performance of TER system can be improved further with use of increased figure of merit Peltier modules and efficient heat exchange technology.

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NOMENCLATURE

A	:	Area of refrigeration Cabinet exposed to air, m^2
CFCs	:	ChloroFluoro Carbons
COP	:	Coefficient of performance
C_p	:	Heat capacity at constant Pressure, J/kg. k
DC	:	Direct Current

G	:	Area/ Length of Thermo-electric elements, cm
HCFCs	:	Hydro Chlorofluorcarbons
h	:	Overall heat transfer Coefficient, w/m^2 ^{o}k,
I	:	Electric Current, Ampere
K	:	Thermal Conductivity of Thermo-material, W/cm.K
K_m	:	Device thermal Conductance, W/K
k	:	thermal conductivity of HDPE sheet, w/m ^{o}k
m	:	Mass of liquid, Kg
N	:	Number of couple of Thermoelectric element
PV	:	Photo voltaic
Q_c	:	Rate of heat absorbed at Cold Junction, Watt
Q_h	:	Total heat to be removed By TEM (W)
Q_{TEM}	:	Heat generated by TEM (W)
R_m	:	Device Electrical Resistance, Ω
R_{th}	:	Thermal resistance of heat Sink, ° c/w
TER	:	Thermoelectric Refrigerator
TEC or TEM	:	Thermoelectric cooler or Thermoelectric Module
T_h	:	Hot Junction temperature, Kelvin, ^{0}C
T_c	:	Cold Junction temperature, Kelvin, ^{0}C
T_a	:	Ambient temperature, ^{0}C
V	:	Voltage, V
W	:	Electrical Power, Watt
X	:	Thickness of insulation, m
Z	:	Figure of merit, 1/K

Greek letters

α_m	:	Device Seeback voltage , V/K
ρ_{tm}	:	Thermoelectric material Electrical Resistivity, Ω.cm
ρ	:	Density of water, Kg/L
α	;	Thermoelectric material Seebeck Coefficient, V/K

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