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Effect of Cascading the Thermoelectric Peltier Cooler on COP and Cooling Load

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Abstract: This paper comprises the Numerical study of various modules of first and second stage of peltier cooler to analyze that how the performance enhances when we shift from single stage to cascade thermoelectric peltier cooler. Multistage thermoelectric coolers have been used from long back as they offer a larger temperature difference than single-stage thermoelectric coolers. Apart from this multistage also helps in improving the COP and cooling load. The COP and heat load were analyzed for various temperature difference and it has been observed that they decrease with increase in temperature difference. For first stage COP ranges from 0.1 to 0.34 and cooling load maximum as 41.9 whereas for second stage COP maximizes to 0.56 and cooling load to 136.45.

Nomenclature

Q	heat flow per unit time, heat power (W)
COP	coefficient of performance
I	electric current (A)
Q_h	Peltier pellet hot side heat flow (W)
Q_c	Peltier pellet cold side heat flow (W)
P_{in}	electric power supplied (W)
R_M	thermal resistance (ohm)
V_{in}	voltage to the thermoelectric module (volt)
S_M	Seeback coefficient (V/K)
DT	The temperature difference of cold and hot side
T_h	hot side temperature (K)
T_{12}	Intermediate temperature between first and second stage in two stage cooler
T_c	cold side temperature (K)
T_a	ambient temperature (K)
K_M	total thermal conductance (W/K)
T	module temperature for hot and cold side respectively (K)
COP_c	coefficient of performance of thermoelectric cooling system
S_{mth}	module Seebeck coefficient at the hot side temperature T_h
S_{mtc}	module Seebeck coefficient at the cold side temperature T_c
S_1	Seebeck coefficient of the 1st stage in volts/K
S_2	Seebeck coefficient of the 2nd stage in volts/K
R_{mth}	module resistance at the hot side temperature T_h
R_{mtc}	module resistance at the cold side temperature T_c
R_1	resistance of the 1st stage in ohms
R_2	resistance of the 2nd stage in ohms
K_{mth}	thermal conductance at the hot side temperature T_h
K_{mtc}	thermal conductance at the cold side temperature T_c
K_1	thermal conductance of the 1st stage in watts/K
K_2	thermal conductance of the 2nd stage in watts/K
S_{new}	Seebeck coefficient for the new module
R_{new}	electrical resistance of the new module
K_{new}	thermal conductance of the new module
N_{new}	number of couples in the new module

I_{new} optimum or maximum current of the new module

Keywords: Thermoelectric peltier cooler, Multistaging

I. INTRODUCTION

Thermoelectric peltier cooler uses the concept of peltier effect which states that when voltage is applied across two junctions of dissimilar electrical conductors, heat is absorbed from one junction and heat is rejected at another junction. The most efficient configuration is that where P and N junction are put electrically in series but thermally in parallel. One side is connected to the heat source and other side to sink. The side facing source is cold side and side facing sink is hot.

Although COP of the thermoelectric peltier coolers is lesser than conventional vapour refrigeration and refrigeration system but continuous research and development work has been done in VCRS system which has led to appreciable improvement in their performance and efficiency. In same manner there is vast scope of improvement in performance of thermoelectric peltier cooler. They are better than VCRS in many aspects. They are compact in size so can be employed where we have space constraint. They do not use harmful refrigerants like Freon for cooling. They do not have any moving part.

II. LITERATURE REVIEW

Matthieu Cosnier et al (2008) [1] presented a paper on experimental and numerical study of air cooling and heating system based on thermoelectric effect. The cooling power achieved per module was around 50W, with COP ranging from 1.5 to 2, by supplying electricity of 4 ampere and maintaining the temperature difference of around 5ºC between the hot and cold sides.

Suwit Jugsujinda et al (2010) [2] conducted a study on analysis of performance of thermoelectric refrigeration system. The thermo-electric refrigeration system (dimension; 25 × 25 × 35 cm^3) was constructed by using a thermoelectric cooler (dimension; 4 × 4 cm2) and electrical power applied was 40 W. The temperature decreased from 30 ºC to 20 ºC slowly in around one hour. The maximum COP of refrigerator was 3.0 whereas for cooling system was around 0.65.

Wei He et al (2013) [3] worked out on Theoretical analysis and experimental analysis of a thermoelectric heating and cooling system getting its energy requirement through solar energy. In summer, this device works as a Peltier cooling system running on solar power through photo voltaic modules. The minimum temperature achieved was 17^0C, with COP above 0.45.

Riffat and Guoquan et al (2004) [4] carried out comparative analysis of thermoelectric air conditioning system, and conventional systems which includes vapour compression and vapour absorption air conditioning system. Comparison of all of these air conditioning systems was done and a compact air conditioner was constructed.

Astrain, Vian & Domınguez et al [5] carried out an experimental investigation of the COP of a thermoelectric refrigerating system by the optimizing heat rejection. They presented the system based on the principle of a thermo syphon with phase change. In their experiment, a prototype of a thermo syphon system was developed having thermal resistance around 0.11 K/W, dissipating the heat of a Peltier module having dimension of 40×40×3.9 mm. They experimental analysis revealed that by using thermo syphon with phase change, an increase of about 32% can be achieved in coefficient of performance.

Shen, Xiao et al (2012) [6] worked out an investigation study on thermoelectric radiant air-conditioning system and presented review paper. In the analysis they employed 51 thermoelectric modules in a panels for indoor cooling, as well as heating by just reversing direction of current. After experimental investigation of their system, they reached the maximum cooling COP of 1.77 by supplying 1.2 and maintaining the colder side temperature to around 20°C.

Virjoghe, Diana et al (2009) [7] carried out a numerical simulation of thermoelectric System. Increase in awareness, for protection of environment, against degradation, rejuvenated interest towards thermoelectric system for efficient utilization of energy. Numerical simulation of various thermoelectric materials has been presented in this paper. These simulations have been carried out by using finite element analysis through ANSYS software.

Maneewan et al (2010) [8] carried out an experimental investigation of compact thermoelectric air conditioning on the basis of thermal compact study. First stage thermoelectric moduleTEC1-12708 was used for the process of heating and cooling application. Then the COP was calculated and analyzed with respect to time under different conditions.

Manoj and Walke et al (2011) [9] carried out an experimental analysis of thermoelectric air conditioning system for cars. They have been trying to overcome the limitations of existing vapour compression system by replacing with non-conventional air conditioning system working on principle of Peltier and Seebeck effect.

Yadav and Mehta et al (2013) [10] worked out and presented a combined paper on experimental and theoretical analysis of thermoelectric materials and their application. They focused their study on optimization of thermoelectric refrigerator design. The device was constructed by combining thermoelectric cooler with two element device inserted in n-channel and p-channel of the device to reduce its solid state thermal conductivity.

Manoj Kumar et al (2013) [11] worked out and presented an experimental analysis on green refrigeration and air-conditioning systems. They firstly analyzed various aspects of the existing air-conditioning system, then they compared that with thermoelectric cooling system. Their results concluded that thermoelectric cooling systems generally have efficiency between 5–15% compared to 40–60% achievable by vapour compression system.

Huang. B et al (1999) [12] carried out an experimental study on methods to design the thermoelectric cooling system. They firstly fabricated the thermoelectric system and analyzed it under various conditions. The model simulation revealed that better design of heat sink helps in improving the performance of thermoelectric cooling system.

Jatin Patel, Matik Patel, Jigar Patel, Himanshu Modi [13] worked out numerical study and performed experimental analysis for improvement in COP of Thermoelectric peltier cooling system. They analyzed the performance of thermoelectric cooling system having single stage and multi stage modules. Their result revealed that system using single stage module has lower COP whereas system with multistage (three stages) have higher COP. But the main problem associate with multistage module is their cost. They are expensive compared to the single stage module. With recent developments in field of thermoelectric and nano science, various other thermoelectric materials have been explored which provide higher temperature difference and have lower price. This can help in cot reduction of multistage in near future.

Yamanashi [14] applied heat balance equations in analyzing the coefficient of performance of thermoelectric cooling system by addition of heat exchangers at both side of the device. The balancing equations follow non-equilibrium thermodynamics. For optimizing the two-stage thermoelectric coolers, two different configurations were presented. These configurations are cuboidal pyramidal shaped modules. These arrangements were studied by using COP as an optimization criterion. In the case of the pyramidal shaped module, number of thermocouples between two stages is in ratio of 2.5-3 with lower stage having more modules. The current flowing in the module also follows the same ratio. In the case of cuboidal type module both first and second stage has same number of thermocouples.

Hermes & Barbosa (2012) [15] theoretically analyzed and did the comparison of performance of compact and portable cooling system, which provide cooling through thermoelectric peltier effect, sterling cycle and vapour compression cycle. In their study, Sterling and vapour compression refrigeration system have an overall thermodynamic efficiencies ranging between (14-15)%, whereas the thermoelectric system have about 5%.

Bansal & Martin (2000) [16] carried out investigative study on performance analysis of conventional and non-conventional refrigeration system including vapour compression system, vapour absorption system and thermoelectric system. Their study revealed that the vapour compression refrigeration had highest COP around (2.59), thermoelectric system had (0.69) and absorption refrigeration system had (0.47).

Astrain et al. (2016) [17] aimed at investigation of the effect of various types of heat exchangers (water-air heat exchanger, natural convection heat exchanger, forced convection heat exchanger, liquid cooled heat exchanger) on the efficiency of thermoelectric refrigeration system. Their study concluded that higher value of COP is achievable through optimal designing of the heat exchangers.

III. NUMERICAL METHODOLOGY

The focus of this study is to investigate the performance of various first stage thermoelectric modules and their comparison with second stage modules

This study has been done for six first stage thermoelectric modules which include:

TEC1-03103, TEC1-07103, TEC1-12705, TEC1-12706, TEC1-12708, TEC1-12710

The nomenclature of the module as example of [TEC1-03103]

TEC- Thermoelectric cooler, 1- first stage, 031- no of couples, 03- for current

And study is done on three second stage thermoelectric module which includes:

TB-2(127-127)1.15, TB-2(127-127)1.15 Bullfinch, TB-2(199-199)0.8

The nomenclature of module as example of [TB-2(127-127)1.15]

TB- product abbreviation for thermoelectric cooler.

127-127 - number of couples in first and second stage of thermoelectric cooler.

1.15- height of the element in the bottom stage.

Various parameters are associated with thermoelectric material and module which are to be considered in mathematical modal. Elements that must be incorporated include seebeck coefficient [SM], Electrical Resistance [RM], and Thermal Conductance [KM]. The specified coefficients are applicable over range of -100^{0}C to+150^{o}C, and derived from 71 couple 6 ampere module.

1) Seebeck coefficient [SM]- Referred as a function of temperature

Smth or Smtc = $(s1T)+(0.5\times s2\times T^2)+(0.33\times s3\times T^3)+(0.25\times s4\times T^4)$ (1)

SM= (Smth –Smtc)/DT (2)

Coefficients for a 71-cpl, 6-amp module

s1 = 1.33450 × 10-2, s2 = -5.37574 × 10-5, s3 = 7.42731 × 10-7, s4 = -1.27141 × 10-9

for DT>0 (3)

2) Module resistance [RM]

Rmtc or Rmth= $(r1T)+(0.5r2\times T^2)+(0.33r3\times T^3)+(0.25r\times 4T^4)$ (4)

RM= (Rmth-Rmtc)/DT (5)

Coefficients for 71 couple 6 ampere module

r1 = 2.08317, r2 = -1.98763 × 10-2, r3 = 8.53832 × 10-5, r4 = -9.03143 × 10-8 (6)

3) Module Thermal conductance [KM]

KMTh or KMTc = $(k1T)+(0.5\times k2\times T^2)+(0.33\times k3\times T^3)+(0.25\times k4\times T^4)$ (7)

KM= (Kmth-Kmtc)/DT (8)

4) Parameter of conversion for other module

Snew = (SM × Nnew)/71 (9)

Rnew = (RM×6×Nnew)/(Inew×71) (10)

Knew = (KM× Inew×Nnew)/(6×71) (11)

5) Single Stage module equations

a) Temperature difference(DT) across module in K.

DT= Th-Tc (12)

b) (Qc) cooling load by the module in watts

Qc = (Snew×Tc×I) - (0.5×I2×Rnew) - (Knew×DT) (13)

c) The input voltage(Vin) to the module in volts

Vin = (Snew×DT) + (I×Rnew) (14)

d) The electrical input power(Pin) to the module in watts

Pin = Vin×I (15)

e) the coefficient of performance(COP)

COP= Qc/Pin (16)

Here numerical analysis of those modules have been done which have maximum cooling load and maximum COP.
All the modules are having similar maximum COP around 1.61
Here analysis has been done for TEC1-12706

i) DT = 303K-293K= 10K
ii) SM = 0.0296V/K ,Snew=0.053 V/K
iii) RM = 1.3525ohm Rnew= 1.0708ohm
iv) KM = 0.2919W/K Knew= 0.5309W/K
v) I = 6.1 ampere (from specification)
vi) Qc = (0.053×6.1×293)-(0.5×6.1×6.1×1.0708)-(0.5309×10)= 109.35watt
vii) Vin = (0.053×10)+(6.1×1.0708)= 7.0621volt
viii) Pin = 7.0621×6.1= 43.0788watt
ix) COP = 1.6134

WE are getting maximum cooling load for TEC1-12710

i) DT = 303K-293K= 10K
ii) SM = .0296V/K ,Snew = 0.053V/K
iii) RM = 1.35251ohm Rnew = 0.6467ohm
iv) KM = 0.2919W/K Knew = 0.8791W/K
v) I = 8.2 ampere (from specification)
vi) Q c= (0.053×8.2×293)-(0.5×8.2×8.2×0.6467)-(0.8791×10)= 115.08
vii) Qc(in TOR) = Qc/3500= 0.0328

6) Second stage module calculation

There are two different designs of second stage of thermoelectric peltier cooler namely pyramidal shape and cuboidal shape. In the pyramidal shape there is decrease in number of couples in second stage whereas in cuboidal shape both first and second stage have same number of couples. We done the study for cuboidal shape of second stage thermoelectric module

Modeling of cascaded or multi-stage thermoelectric coolers is somewhat more complicated than for single-stage devices. With multi-stage coolers, the temperature between each stage is critically important and module performance cannot be established until each inter stage temperature value is known.

a) T12 = (Th+Tc)/2 (17)
b) heat pumped by module(Qc) in watts:
Qc = (S2×Tc×I)-(0.5×I×I×R2)-(K2×(T12-Tc)) (18)
c) The input voltage(Vin) to the module in volt:
Vin = (S2×(T12-Tc))+(I×R2)+(S1×(Th-T12))+(I×R1) (19)
d) The input power (Pin) to the module in watts:
Pin = Vin×I (20)
e) coefficient of performance(COP):
CO P= Qc/Pin (21)

We got the maximum COP for the module **TB-2(127-127)1.15**

i) DT = 303K-293K= 10K
ii) S1 =0.053006V/K, S2 = 0.053006V/K (as both stage have same number of couples)
iii) R1 = 0.52ohm, R2 = 0.52ohm
iv) K1 = 0.2019W/K, K2 = 0.2019W/K
v) I = 8.8ampere
vi) T12 = (293+303)/2 = 298K
vii) Qc = (0.053006×8.8×293) - (0.5×8.8×8.8×0.52) - (0.2019×(298-293)) =80.3218watt
viii) Vin = (0.0530069×(298-293))+ (8.8×0.52)+(0.053006×(303-298))+(8.8×0.52)= 6.562volts
ix) Pin = 6.562×8.8= 38.0599
x) COP = 2.11

Maximum cooling load is achieved for TB-2(199-199)0.8

i) DT = 303K-293K= 10K
ii) S1 =0.08305V/K, S2 = 0.08305V/K (as both stage have same number of couples)
iii) R1 = 0.64ohm, R2 = 0.64ohm
iv) K1 = 0.2782W/K, K2 = 0.2782W/K
v) I = 10.2 ampere
vi) T12 = (293+303)/2= 298
vii) Qc = (0.08305×10.2×293) - (0.5×10.2×10.2×0.64) - (0.2782×(298-293)) =213.538watt
viii) Qc(in TOR) = 213.538/3500= 0.061

From this analysis it can be inferred that higher COP and cooling load can be achieved by multi staging the thermoelectric module and we can even achieve higher COP with third and fourth stage.

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IV. RESULTS & DISCUSSIONS

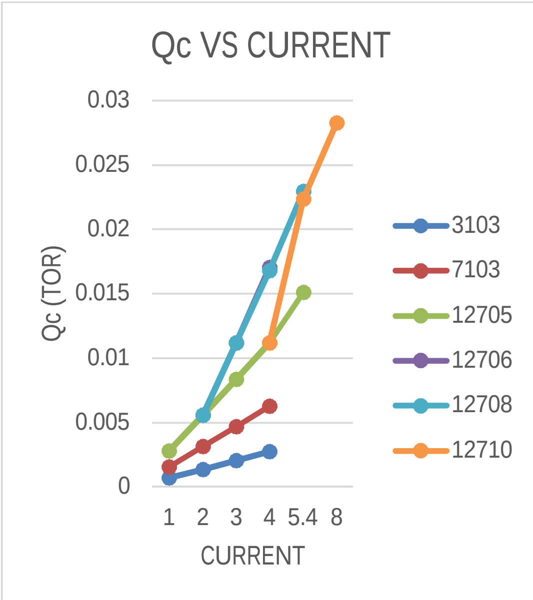

Figure.1- Qc(TOR) Vs Current

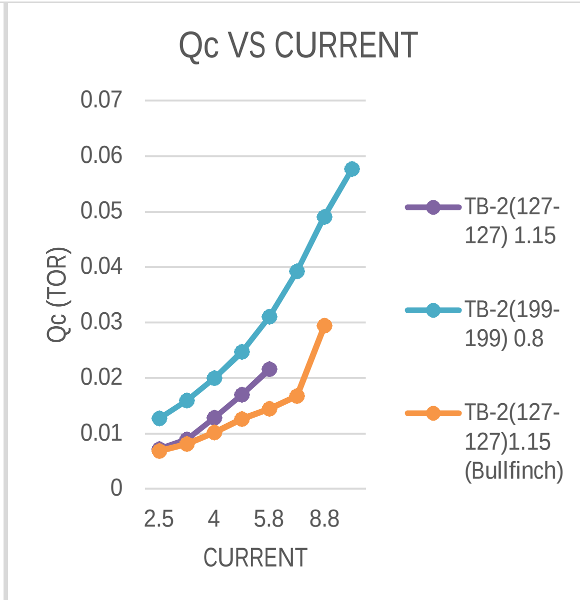

Figure.2- Qc(TOR) Vs Current

1) From figure 1 and 2, it can be interpreted that the cooling load increase with increase in the current.
2) Cooling load of the module increase due to thermal conductivity of the module.
3) For first stage we are getting maximum Qc(TOR) forall modules and, second stage maximum Qc(TOR) for TB-2(199-199)0.8.

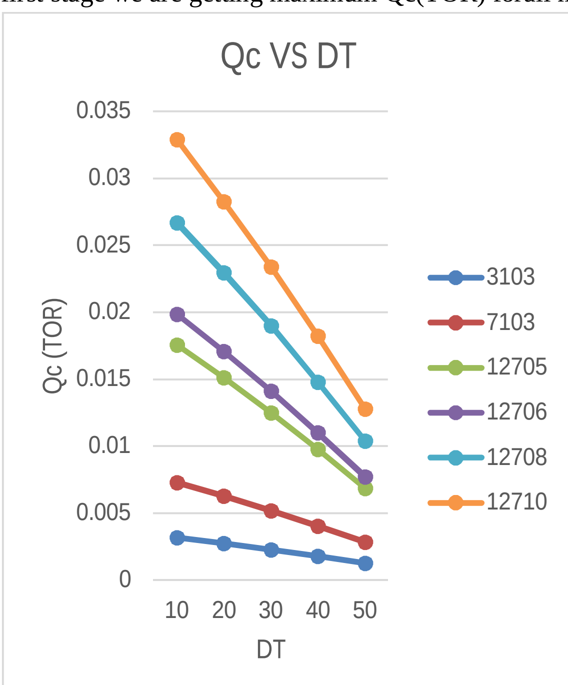

Figure.3- Qc Vs dt

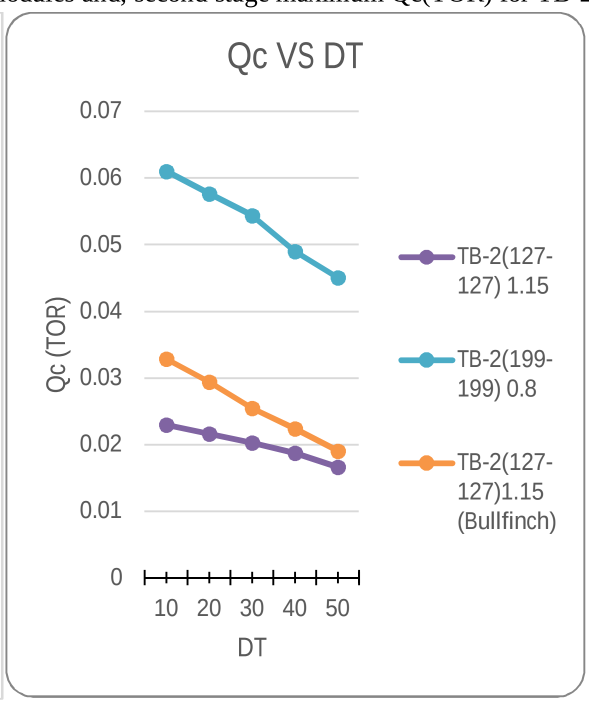

Figure.4- Qc Vs dt

4) In all the modules cooling load decrease with increase in the temperature difference between hot and cold side.
5) As the temperature difference increases the efficiency of heat exchanger system decreases. The efficiency of heat exchanger strongly influence performance parameters including COP. That's why cooling load as well COP decrease with increase with temperature difference.

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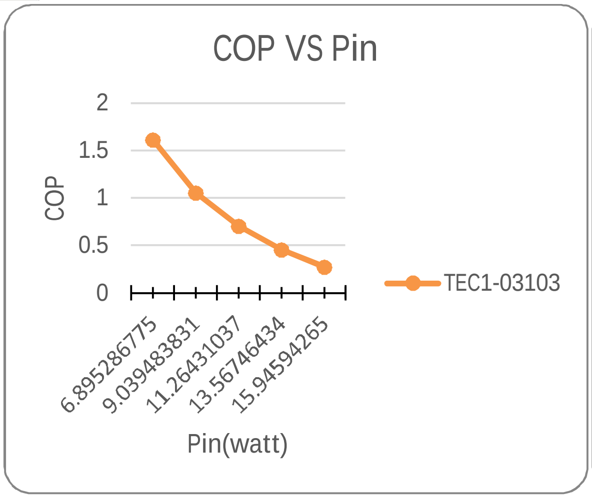


Figure.5- COP Vs Pin

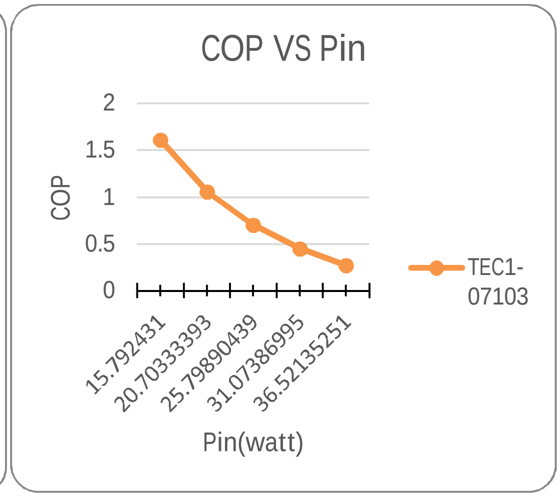


Figure.6- COP Vs Pin

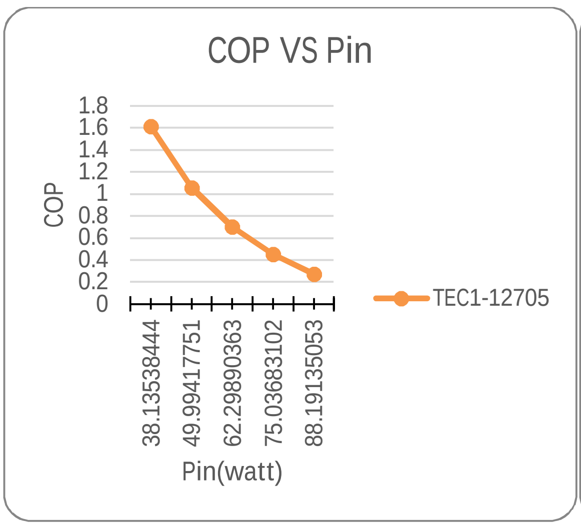


Figure.7- COP Vs Pin

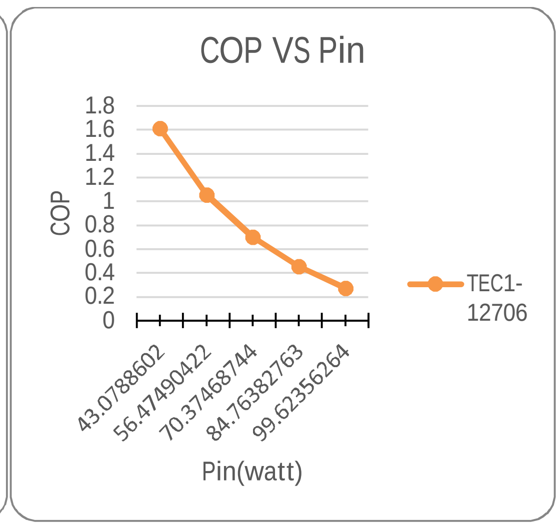


Figure.8- COP Vs Pin

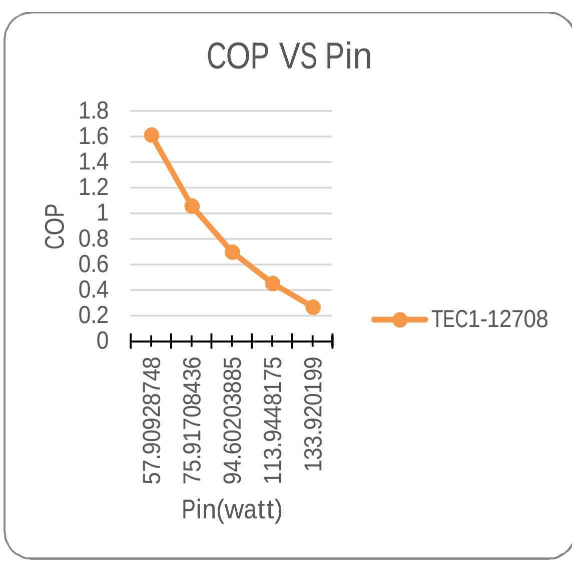


Figure.9- COP Vs Pin

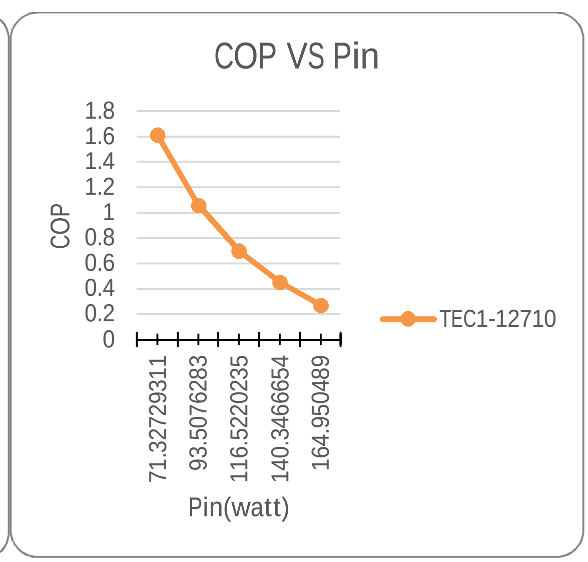


Figure.10- COP Vs Pin

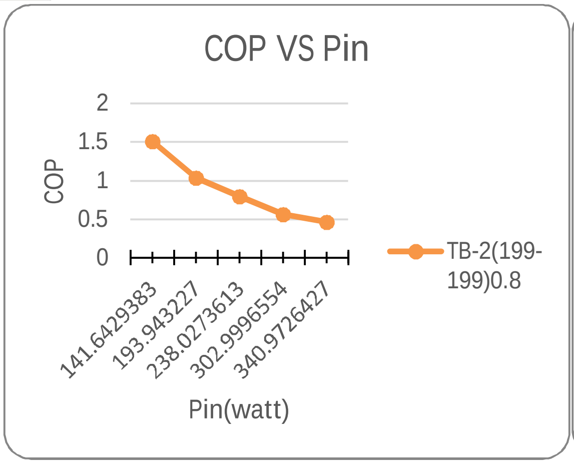


Figure.11- COP Vs Pin

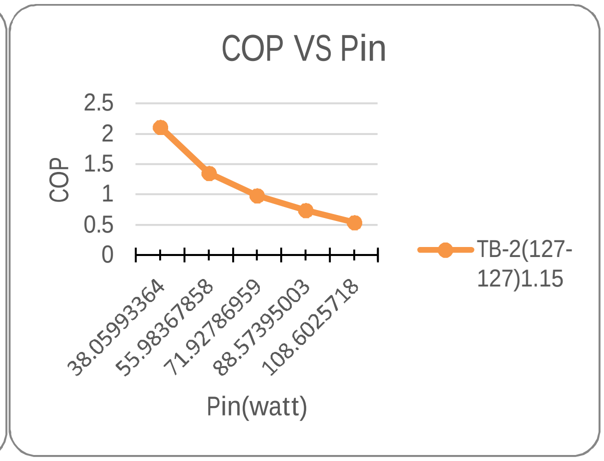


Figure.12- COP Vs Pin

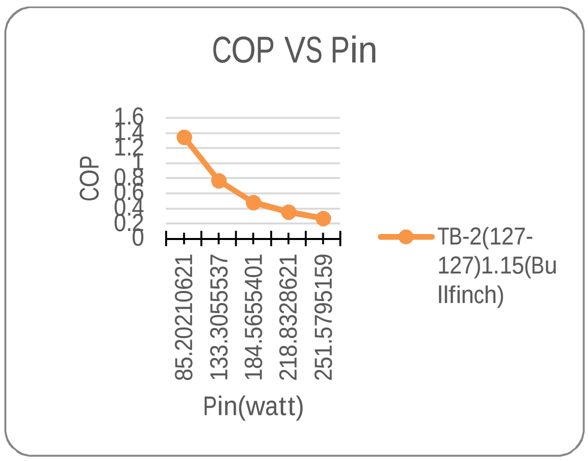


Figure.13- COP Vs Pin

6) From figure 5 to 13 we observe the variation of COP with input power.
7) COP increase with decrease in input power so we can say less power is required to achieve higher power.
8) In first stage we get maximum COP for all module is similar and around 1.61
9) In second stage we are getting maximum COP for TB-2(127-127)1.15, interpreted from figure 12, which is 2.1.

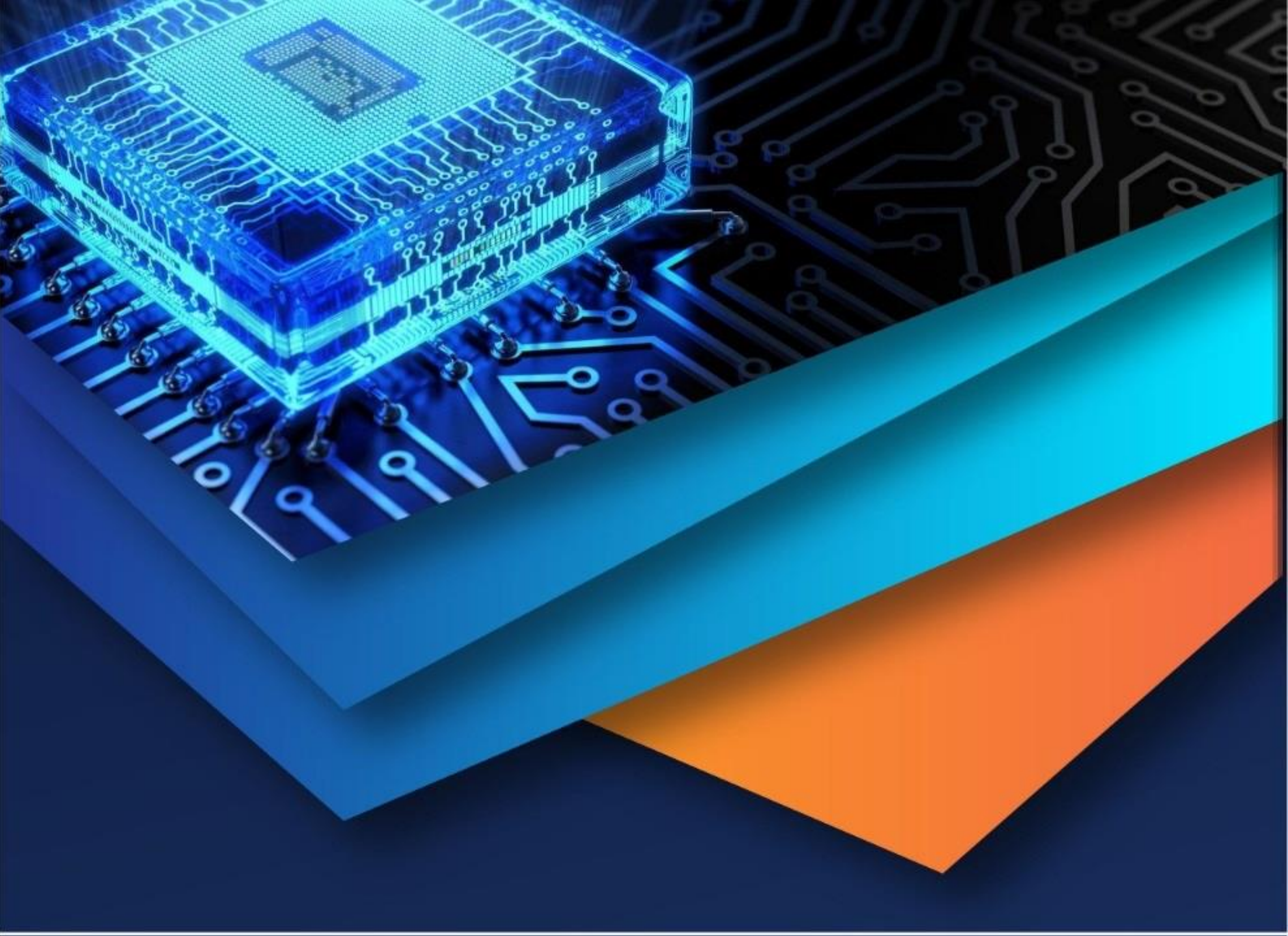
V. CONCLUSION

From the above analysis it can be concluded that cascading or multi staging helps in enhancing various parameters like COP and cooling load of thermoelectric peltier cooler.

A. Maximum value of COP is 1.61 for a first stage whereas it is around 2.11 for the second stage. Around 31% improvement in COP can be obtained by multi staging.
B. As COP increases with lesser power input means rate of consumption of energy also decreases with COP increase.
C. The maximum value of cooling load for first stage is 115.082 whereas for second stage it is around 213.538.
D. The graph indicates that both the COP and cooling load decrease as the temperature difference increases.
E. Where larger temperature difference is required COP can be greatly improved by using multistage or cascade thermoelectric peltier module.
F. One problem with the multi staging is that price of the module are high. But researches are going on in the field of thermoelectric and nanoscience to make material with good thermal performance at a cheaper price.
G. There is vast scope of further development in design of the thermoelectric cooler setup. As an alternative for normal axial fan used, if a blower fans is selected, the cooling system would provide better airflow. Advancement in design for hot and cold side heat sink can effectively help in achieving better performance parameters.

REFERENCES

[1] ElCosnier W., Gilles M., Lingai., Experimental and numerical study of thermoelectric air cooling and heating system. International journal of refrigeration, 31, 1051 – 1062 (2008).
[2] Analysing Thermoelectric Refrigeration Performance Suwit Jugsujinda et al Procedia Engineering 8(2011) 154-159.
[3] Wei., Jinzhi., Jingxin & Chen.,Theoretical and experimental analysis of thermoelectric cooling and heating system getting its power through solar energy. Applied Energy, 107, 89–97, (2013).
[4] Riffat and Guoquan., Comparitive investigation of thermoelectric air- conditioning system and conventional vapour compression and absorption air-conditioning system. Journal of Applied Thermal Engineering, 24, 1979-1993, (2004).
[5] Astrain D .,Vian J.G., & Domınguez M., Increase of COP in the thermoelectric refrigeration by the optimization of heat dissipation. Applied Thermal Engineering, 23, 2183–2200, (2003).
[6] Shen., Xiao., Chen & Wang., Investigation of a novel thermoelectric radiant air-conditioning system. Journal of Energy and Buildings, 59, 123–132, (2012).
[7] Virjoghe., Diana., Marcel & Florin., Numerical simulation of Thermoelectric System. latest trends on systems,15(2) , 630-635,(2009).
[8] Maneewan. , Tipsaenpromand Lertsatitthanakorn., Thermal comfort study of a compact thermoelectric air conditioner. Journal of electronic materials, 39(9), 1659-1664, (2010).
[9] Manoj S., & Walke., Thermoelectric Air Cooling For Cars. International Journal of Engineering Science and Technology, 40(5), 2381-2394, (2011).
[10] Yadav and Mehta, Review on Thermoelectric materials and applications. International Journal for Scientific Research & Development, 1,413-417, (2013).
[11] Manoj Kumar., Chattopadhyay and Neogi., A review on developments of thermoelectric refrigeration and air conditioning systems: a novel potential green refrigeration and air conditioning technology. International Journal of Emerging Technology and Advanced Engineering, 38,362-367, (2013).
[12] Huang B., Chin C.J., and Duang C.L., A design method of thermoelectric cooler. International Journal of Refrigeration, 23,208-218, (1999).
[13] Improvement in COP of Thermoelectric cooler by Jatin Patel, Jigar Patel, Himanshu Modi, Matik Patel International Journal of Scientific & Technology Research Volume 5 , Issue 05, May 2016.
[14] Yamanashi, M. A new approach to optimum design in thermoelectric cooling systems. J.Appl. Phys. 1996, 80, 5494–5502.
[15] Hermes, C.J. , Barbosa, J.R. , 2012. Thermodynamic comparison of Peltier, Sterling, and vapor compression portable coolers. Appl. Energy 91, 51–58.
[16] Bansal, P. , Martin, A. , 2000. Comparative study of vapour compression, thermoelectric and absorption refrigerators. Int. J. Energy Res. 24, 93–107.
[17] Astrain, D. , Aranguren, P. , Martinez, A . , Rodriguez, A . , Perez, M.G. , 2016. A compar- ative study of different heat exchange systems in a thermoelectric refrigerator and their influence on the efficiency. Appl. Thermal Eng. 103, 1289–1298.



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