Waste heat energy harvesting using thermo electric generator

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Abstract: **-** In the conventional method for generate electricity is converting thermal energy into mechanical energy then to electrical energy. In recent years, due to environmental issues like emissions, global warming, etc., are the limiting factor for the energy resources which resulting in extensive research and novel technologies are required to generate electric power. Thermoelectric power generators have emerged as a promising another green technology due to their diverse advantages. Thermo Electric Power Generator directly converts this Thermal energy into Electrical energy. So number of moving and rotating part has been eliminated. By this it eliminated emission so we can believe this green technology. Thermoelectric power generation offer a potential application in the direct exchange of waste-heat energy into electrical power where it is unnecessary to believe the cost of the thermal energy input. The application of this option green technology in converting waste-heat energy directly into electrical power can too improve the overall efficiencies of energy conversion systems. Heat source which is need for this conversion is less when contrast to conventional methods. In this paper, a background on the basic concepts of thermoelectric power generation is presented and recent patents of thermoelectric power generation with their important and relevant applications to waste-heat energy are reviewed and discussed.

Keywords: - Thermoelectric power generator, waste-heat recovery, alternative green technology, direct energy conversion, thermocouple , thermal shield, thermoelectric materials, thermo electric module, thermal fin

I.   INTRODUCTION

A Thermoelectric power generator is a solid state device that provides direct energy conversion from thermal energy (heat) into electrical energy based on "Seebeck effect". The thermoelectric power cycle, with charge carriers serving as the working fluid, follows the fundamental laws of thermodynamics and intimately resembles the power cycle of a conventional heat engine. Advantages of Thermoelectric power generators over other technologies.

- They are extremely reliable and they have no mechanical moving parts and require considerably less maintenance.
- They have very small size and weightless.
- They have the capacity to operating at elevated temperatures.
- The source for the power generation is Heat not Light, so day and night operation is possible.
- They are mostly used for convert the waste heat so it is considered as a Green Technology.
- We can increase the overall efficiency of the system (4% to &7%).
- They can be alternative power sources.
- When compare to exciting conventional power system it require less space and cost
- Less operating cost.

The Drawback of thermoelectric power generator is their relatively low conversion efficiency (typically ~5%) and Less power output. Application over the past decade included industrial instruments, military, medical and aerospace and home reason and applications for portable or remote power generation. Though, in recent years, an increasing anxiety of environmental issues of emissions, in particular global warming has resulted in extensive research into nonconventional technologies of generating electrical power. Thermoelectric power generation offers a promising technology in the direct conversion of low-grade thermal energy, such as waste-heat energy, into electrical power. Perhaps the earliest application is the use of waste heat from a kerosene lamp to provide thermoelectric power to power a wireless set. Thermoelectric generators have also been used to provide small amounts electrical power to remote regions for example Northern Sweden, as an alternative to costly gasoline powered motor generators. Oldest technology behind this technology is seebeck effect on Thermocouple now this tech using in seebeck effect on semiconductors so it can eliminate wires, so wireless technology is possible. An important purpose in thermoelectric power generation using waste heat energy is to decrease the cost-per-watt of the devices. Moreover, cost-per-watt can be reduced by optimizing the device geometry, improving the manufacture quality and simply by operating the device at a larger temperature

difference. Analyze the thermoelectric property of the module material is very important. Good thermoelectric material has seebeck property in between 200-300µV/K. Material thermoelectric material figure-of-merit property should be near or more than 3×10^{-3} for good material. This TEG is used to convert the waste heat emitted from Jet Engine, IC Engines, Furnace, Heat water conveyor tubes.

II.   THEORY BEHIND THERMOELECTRIC POWER GENERATOR

The basic theory behind this TEG is "seebeck effect". Seebeck effect was discovered by Thomas Seebeck in 1821. When a temperature difference is recognized between the hot and cold junctions of two dissimilar materials (metals or semiconductors) a voltage is generated, this voltage is called Seebeck voltage. Indeed this phenomenon is applied to thermocouples that are extensively used for temperature measurements. When a Thermoelectric material (Thermoelectric Module or Thermocouple) held in-between temperature gradient it generate some voltage . In fact, this phenomenon is applied to thermocouples that are extensively used for temperature measurements. Base on this Seebeck effect, thermoelectric devices can act as electrical power generators.

III. THERMO ELECTRIC POWER GENERATOR PERFORMANCE CALCULATION

The performance of the Thermo Electric Calculation

$$Z = \alpha^2 / kR$$

where Z- is the thermoelectric material figure-of-merit
α-is the Seebeck coefficient
k-Total thermo electric conductivity
R- is the electric resistivity

This figure of merit can be multiply by $\overline{T}$ average absolute temperature of hot and cold plates of the thermoelectric module

$$Z\overline{T} = \alpha^2\overline{T} / kR$$

Here $$\overline{T} = \frac{T_H + T_L}{2}$$

Where T_H- Temperature at Hot end
T_L- Temperature at cold end

Seebeck coefficient

$$\alpha = -\frac{\Delta V}{\Delta T}$$

Where ΔV is voltage difference
ΔT is Temperature Difference

Limited by the second-law of thermodynamics, the ideal (absolute maximum) efficiency of a thermoelectric power generator operating as a reversible heat engine is Carnot efficiency,

$$\eta = \frac{\dot{W_e}}{\dot{Q_H}}$$

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$$

The maximum conversion efficiency of an irreversible thermoelectric power generator can be estimated using

$$\eta = \eta_{Carnot}\left[\frac{\sqrt{1+Z\overline{T}}-1}{\sqrt{1+Z\overline{T}}+T_L/T_H}\right]$$

Here ZT- Figure of Merit

IV. THERMOELECTRIC POWER GENERATOR

Thermoelectric Power Generator (TEG) is a solid state device which converts Heat Energy into Electrical Energy. All the exciting conventional power generators convert Thermal Energy into Mechanical Energy then to Electrical Energy. So here no mechanical work (no moving parts). So it produce less noise and no pollution when compare to conventional power generators. TEG is working by Thermo Electric Effect

(seebeck) effect. When TEG held between temperature gradients (Hot end, Cold end) it produce some voltage this voltage is called seebeck voltage.TEG has Modules which is semiconductors (p,n). Here electrons acting as a thermoelectric power fluid (working medium). Pair of p-type semiconductor and n-type semiconductor is called as a Module. These semiconductors highly doped by pollutants in order to increase the Electric conductivity.TEG has shield it avoid modules damaging due to high temperature. The efficiency of TEG and voltage generated by TEG is directly proportional to semiconductor material and temperature gradients. So selections of semiconductor based on electric conductivity of the material and try to increase the temperature difference value. This semiconductor is coupled by copper electrode. Increasing no of modules and no of stages and coupling no of TEG increase overall efficiency and voltage output. Exciting efficiency of TEG is 4.2% to 6%. When using stages it increases the efficiency to7%.

V. TEG HAS FOLLOWING COMPONENTS

1. Thermoelectric Module
2. Thermoelectric shield
3. Thermal Fin
4. Copper electrode

V.1 Thermoelectric Module

It is semiconductor which is highly doped by pollutants to increase the electric conductivity of the semiconductor. Good semiconductor has electric conductivity in between 200μV/K - 300μV/K. When choosing semiconductor it has to withstand that much high operating temperature. Some of the good thermoelectric module semiconductors are Bi2Te3, CaMnO, Ca3Co4O9, Sb2Te3, and PbTe

Bi_2Te_3 based materials shown to have seebeck coefficient (voltage per unit temperature difference) of −287 μV/K at 328K, However, one must realize that Seebeck Coefficient and electrical conductivity have a tradeoff; a higher Seebeck coefficient results in decreased carrier concentration and decreased electrical conductivity. In another case bismuth telluride has high electric conductivity of 1.1×10^5 S·m/m^2 with its very low lattice thermal conductivity of 1.20 W/(m·K). For 100K temperature difference and 200 modules it produces 4.2% efficiency and 15volts it is commercially available TEG.

$CaMnO_3$ bulks were prepared by a solid state reaction. They show metallic behavior at temperatures higher than about 400 K and electrical resistivity Ω is lower than 12 mΩcm at 1000K in air. For $CaMnO_3$, S value reaches -130 muV/K at 973 K. Both thermoelectric properties are dominated mainly by crystallographic structure. Thermal conductivity samples is as low as 1.5 W/m-K^2 and dimension-less figure of merit ZT reaches 0.16 at 973 K for $CaMnO_3$ in air . It generate 3.9% efficiency 2.6 V for 200 modules and 100K temperature difference. This TEG is prefer for High operating temperature.

We have Ca3Co4O9 semiconductor for high temperature withstanding property. Ca3Co4O9 has some good thermo electric properties. It can withstand 800ºc . Seebeck property 206μV/K, Electrical resistance 11.6 mΩcm. figure of merit ZT=0.23. Thermal conductivity 1.2Wm-1K-1. This property taken for 880K. This TEG generates 4.2 % efficiency 4.2 volts for 200 modules and 100K temperature difference.

V.2 Thermoelectric Shield

It is a material which protects the modules damage due to high Temperature. Mostly Ceramics material for this which is Al2O3. It also transfer temperature to the modules from hot side. It should be thick.

V.3 Thermal Fin

It is used here for increase the thermal gradient value. When we increase the Thermal gradient value it increase the seebeck voltage generated by TEG. This FIN also transfers the heat from Thermoelectric Module. It is made by Aluminum metal. When we include Thermal fin it increase the efficiency of the TEG

Fig 1. Thermoelectric power generator with fin

VI.   CONCLUSION AND FUTURE WORK

- Include Fin Effect to increase cooling rate (cold end side temperature). By reducing the temperature as we can increase the (Th-Tc)
- Using long fin and avoid accumulation of heat in between fins (Gape between fins)
- Coupling more TEG in SERIES connection to increase the voltage generated by TEG.
- Increase no of modules in TEG to increase power generation and Increase the size to increase heat withstanding capacity.
- By using multiple stages of TEGs both the high temperature with standing TEG and low temperature with standing TEGs
- Use different types of heat with standing materials for making TEG modules. For example Bi2Te3,PbTe,CMO
  Bi2Te3- Bismuth Telluride
  PbTe-Led Telluride
  CMO- Calcium Manganese Oxide
- Bi2Te3 module TEG is high efficient in room temperature (50 c-200 c, 4.5%-6%)
- But heat withstanding capacity of Bi2Te3 is less than PbTe and CMO
- PbTe and CMO modules less efficient than Bi2Te3
- So use combination of both material, Which means multistage Hot side Th area use PbTe and CMO modules after that less temperature area Tc use Bi2Te3 module TEG.

REFERENECE

[1]. P P Pradyumnan& Swathikrishnan, Indian journal of pure & Applied physics, Vol.48,   February 2010,pp.115-120

[2]. Natkrita Prasoetsopha, Supree Pinitsoontorn, Vittaya Amornkitbamrung, Department of Physics, Faculty of Science, Khon Kaen University, Khon Kaen 40002, Thailand

[3]. D. Flahaut, T. Mihara and R. Funahashi, N. Nabeshima, K. Lee, H. Ohta and K. Koumoto, JOURNAL OF APPLIED PHYSICS 100, 084911 (2006)

[4]. Il-Ho Kim1, Soon-Mok Choi, Won-Seon Seo and Dong-Ik Cheong, Kim et al. Nanoscale Research Letters 2012, 7:2

[5]. Driss Kenfaui, Guillaume Bonnefont , Daniel Chateigner , Gilbert Fantozzi ,Moussa Gomina, Jacques Guillaume Noudem, Materials Research Bulletin 45 (2010) 1240–1249

[6]. Basel I. Ismail, Wael H. Ahmed, *Recent Patents on Electrical Engineering* 2009, *2,* 27-39 R. Saidur , M.Rezaei , W.K.Muzammil , M.H.Hassan , S.Paria , M.Hasanuzzaman, Renewable and Sustainable Energy Reviews 16 (2012) 5649–5659

[7]. Nicolas Bailly, Jean-Marie Dilhac, Christophe Escriba, Claude Vanhecke, Nicolas Mauran1,Marise Bafleur, Author manuscript, published in "8th International Workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Applications (PowerMEMS 2008), SENDAI : Japan (2008)"

[8]. Ganni Gowtham, Ksitij Kumar, S.S Charan, K Manivannan, International journal of mechanical engineeringand technology (ijmet) ISSN 0976 – 6340 (Print) ISSN 0976 – 6359 (Online) Volume 3, Issue 3, September - December (2012), pp. 471-482