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Design and Manufacturing of Thermoelectric Waste Heat Recovery System

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Abstract—*This paper outlines research towards the degree of Bachelor of Technology (B.tech) in the Department of Mechanical and automation engineering at Amity University Noida. This project is based on thermoelectric waste heat recovery system from power plant industries. The waste heat recovery system is based on seeback effect principal. It is focus on the conventional method for generate electricity is converting thermal energy into mechanical energy then to electrical energy. The DC current is change in AC current by using an amplifier circuit.*

In recent years, due to environmental issues like emissions, global warming etc., are the limiting factor for the energy resources. By using thermoelectric generators it is possible to develop independent electric energy source in burning and heating systems in households and industrial heating with this energy source. This system is used in the furnace. The furnace temperature is very high. The conversion of waste heat into electrical energy may play an important role in our current challenge to develop alternative energy technologies to reduce greenhouse gas emissions and also save the electric energy in auxiliary battery.

TE materials are currently under investigation by various researches for a good material on my project. As the industrial sector continue effort to improve its energy efficiency, recovering waste heat losses provide an attractive opportunity for an emission free and less costly energy resources. In research thermoelectric element current, voltage, power and efficiency are defined different temperature differences. Its utilization will remain a good prospect in future automotive engine application.

Keywords: *Thermoelectric modeling, thermal contact resistance, electrical contact resistance, Waste heat, heat recovery, heat potential, recovery technologies.*

1. INTRODUCTION

The development of thermoelectric (TE) devices, for example thermoelectric generators (TEG) large extents that predict performance .The thermoelectric waste heat recovery system is used to converting heat into electricity. The main focus is to make high efficiency air motor in the power range is 15 to 25kw. The basic TE generator consists of thermocouples, which have both p-type and n-type elements and are connected electrically in series to obtain the desired output voltage and thermally in parallel [1].

It is possible to develop independent electric energy source, which start generation in the moment when there will be temperature difference on their sides. Thermoelectric generators are devices that use Seebeck effect converting heat (temperature differences) directly into electrical energy [2].In a conventional thermoelectric generator, the hot ends of both p-type and n-type materials are connected electrically, and a load is connected across the cold junction to produce a voltage [1].The thermoelectric generator will generate DC electricity as long as there is a temperature difference across the module [2].Some of the research efforts focus on minimizing the lattice thermal conductivity, while other efforts focus on materials that exhibit large power factors [3].the direct recovery of waste heat and its conversion into useful electrical energy [3].

Three ways to increase Figure of Merit (ZT= $(\sigma S^2 t)/\kappa$) .Hard to have all three cases (high S value, high σ value, low κ value) simultaneously [4].Thermoelectric application of waste heat recovery (automobiles, utilities etc.) [6].heat recovery technologies frequently reduce the operating costs for facilities by increasing their energy productivity [7].There are certain practical limits for each of the parameters used to calculate ZT. These practical limits must be possible in order to achieve a material viable for thermoelectric applications. For example $Bi2Te3$, in order to achieve a ZT =1 at T= 320 K, σ =1 mΩ cm, α= 225 V/K, and κ=1.5 W. It is high with metals, very low with insulators, with an intermediate position taken by semiconductors [16]. The thesis focuses on experimental and analytical investigations on the dynamics of thermocouples and thermopiles reaction to low temperature (less than 400°C or waste heat) for the feasibility and purpose of generating electricity [17].Some of the goals of current research efforts are to find new materials that either raise the current efficiency of TE devices (i.e. Increase ZT) or have the capability of operating in new and broader temperature regimes, especially at lower temperatures (T=250K) and higher temperatures (T=400K) [3].

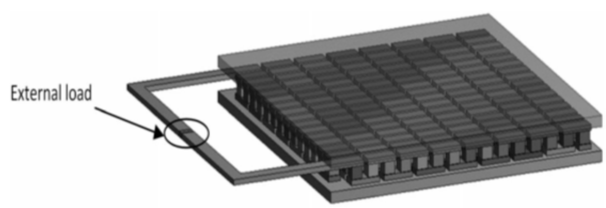
2. EASE OF USE

Thermoelectricity

So why is thermoelectricity not used more widely? The reason is that the coupling between the electrical and heat currents is weak in most materials, and the overall energy conversion efficiency is therefore very low. You need a lot of heat to generate a little electricity Advantages of TEG include free maintenance, silent operation, high reliability and involving no moving and complex mechanical parts [19].

Thermoelectric Generator

The thermoelectric effects arise because charge carriers in metals and semiconductors are free to move much like gas molecules, while carrying charge as well as heat. When a temperature gradient is applied to a material, the mobile charge carriers at the hot end tend to diffuse to the cold end. The build-up of charge carriers results in a net charge (negative for electrons, e–, and positive for holes, h+) at the cold end, producing an electrostatic potential (voltage).An equilibrium is thus reached between the chemical potential for diffusion and the electrostatic repulsion due to the build-up of charge. This property, known as the Seebeck effect, is the basis of thermoelectric power generation [10].To best assess the recent progress and prospects in thermoelectric materials, the decades of research and development of the established state-of-the-art materials should also be considered. By far the most widely used thermoelectric materials are alloys of Bi2Te3 and Sb2Te3. For near-room-temperature [10].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 [18].



The Thermoelectric Module

The thermoelectric module consists of pairs of P-type and N-type semi-conductor thermo element forming thermocouple which are connected electrically in series and thermally in parallel. The modules are considered to be highly reliable components due to their solid state construction. For most application they will provide long, trouble free service [5].

3. METHOLOGY

The experimental measurement setup used in this research enabled highly accurate determination of voltage, current, and heat flow through TEG modules exposed to different thermal gradients.[9] Select suitable thermoelectric materials (bismuth telluride) that can be used at cryogenic temperatures. This selection of thermoelectric materials is based on the figure of merit at the proposed operating temperatures [1]. How can we make a material with a simultaneously large Seebeck voltage, a large electronic conductivity and low thermal conductivity? Something that is impossible for traditional materials such as Bi2Te3. [8]

Finally the identified contact resistances were used to predict the performance of a geometrically different module, manufactured by use of the same materials, to assess the consistency of the model and the measured contact resistances [9].

Thermoelectric Material

The thermoelectric material selected for use in the generator is expected to operate at an average temperature of 300 K based upon its properties at low temperatures. The figure of merit is the best criterion by which to select a thermoelectric material. Figure of merit is a function of the Seebeck coefficient, electrical conductivity, and thermal conductivity. Bismuth telluride (Bi2Te3) alloys were the best available thermoelectric materials at room temperature and lower [1].

Calculation

Aluminium: It is the best thermal conductor.

Properties:

1. Density= 2700 kg/m3
2. Electrical resistance=26.50 at 300 K
3. Thermal conductivity=237 w/mK at 300 K

Material

Properties:

Bi_2Te_3/Sb_2Te_3 at 300K

Figure of merit (ZT)= 2.4 (maximum)

Temperature Range=300 K to 750 K

See-beck effect coefficient= n type= -230Mv/K

See-beck effect coefficient p type= +185Mv/K

Efficiency of generator:

η= ((T1-T2)/T1)*((M-1)/ (M+ (T1/T2)))

$$M = (1 + ZT)^{1/2}$$

$M = (1 + 24)^{1/2}$

M=1.844

$$\eta = \frac{750 - 300}{750} \times \frac{(1.844 - 1)}{(1.844 + \frac{300}{750})}$$

η= 0.225

η= 22.5%

Voltage:

$V= (S_p-S_n)(T_2-T_1)$

$V= (185+230)10^{-6}(750-300)$

$V=1.66V$

Time (min)	Temperature(℃)	Voltage (v)
8	35	0.4
12	40	0.8
18	45	1.2
22	50	1.55
25	55	1.87
27	60	2.1
30	65	2.25
35	70	2.45

Result And Analysis

To verify the above system design analysis, we designed and built a prototype thermoelectric cooler and perform an experiment. The Bi2Te3 is a good thermoelectric material. It is a work on low temperature. More specifically, which materials are optimal when materials properties are adjusted in nanoscale. Thus the development work should be focused on development of new efficient thermoelectric materials suitable for mass manufacturing utilizing nanoscience.

4. MODEL DESCRIPTION

The thermoelectric modules consisted of several small thermocouples connected electrically in series and thermally in parallel. The external surfaces of the modules were covered with a thin layer of graphite that had to be compressed to reduce the thermal resistance. Graphite layer also covered the interior of the modules, between the connecting bridges on the hot side and the ceramic plate. Thermal contact resistances in the model were applied to the surface between the ceramic plate and the connecting bridges. It is the temperature on the surface of the thermoelectric material that is of interest in generation of thermoelectricity, these resistances were grouped together. The Seebeck coefficient, electrical resistivity, and thermal conductivity are Temperature-dependent material data for the bismuth telluride used in the modules was obtained from the manufacturer.

The connecting bridges inside the modules were made of copper on the cold side and aluminum on the hot side. The ceramic plates enclosing the module were made of aluminum oxide. The temperature dependence of all these materials was also included in the model [10].

5. SIGNIFICANCE OF THE STUDY

Cryogenic-powered vehicles must carry an auxiliary battery for electric services. The development of a cryogenic thermoelectric generator can minimize the need for auxiliary batteries [1].Since waste heat temperature is an important quality in the feasibility of waste heat recovery, this study reports typical exhaust temperatures of all waste heat sources investigated. Additionally, the work potential or efficiency of converting waste heat to another form of energy (i.e., mechanical or electrical) was estimated. Quantifying work potential allows a better comparison of waste heat sources with different exhaust temperatures [7].

Critical Role

Thermoelectric generator harvests waste heat from the exhaust gases, which are at a temperature of 300 to 500 °c, and turns this into electricity [3].

Typical Waste Heat At Medium Temperature Range From Various Sources In India

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose. During engine run time, there are four sources of usable waste heat from a exhaust gas, engine jacket cooling water, furnace, boiler thermal power plant lube oil cooling water, and turbocharger cooling are dissipated to the atmosphere [9].

`Typical Source Of Waste Heat And Recovery Option [7]

``Waste Heat Sources	Uses for Waste Heat
• Combustion Exhausts: Glass melting furnace Cement kiln Fume incinerator Aluminium reverberator furnace Boiler • Process off gases: Steel electric arc furnace Aluminium reverberator furnace • Cooling water from: Furnaces Air compressors Internal combustion engines • Conductive, convective, and radiative losses from equipment: Hall Hèroult cells • Conductive, convective, and radiative losses from heated products: Hot cokes Blast furnace slags	• Combustion air preheating • Boiler feed water preheating • Load preheating • Power generation • Steam generation for use in: power generation mechanical power process steam • Space heating • Water preheating • Transfer to liquid or gaseous process streams

6. CONCLUSION

The recovery and utilization of waste heat not only conserves fuel (fossil fuel) but also reduces the amount of waste heat and greenhouse gases damped to environment [9].In this study 3D finite element modeling was combined with experimental results from commercial TEG Bi2Te3-based modules to measure thermal and electrical contact resistances and their effect on module performance. The experimental setup used enabled heat flow, voltage, and current to be measured with high accuracy [11]. Before applying modules, it is necessary to measure temperature range in specific furnace or flue pipe, because of power high dependence on temperature difference [2]. It is also clear that TE waste-heat recovery technology could potentially offer significant fuel economy improvements. If this is demonstrated feasibly on large scale applications such as automobiles, a significant savings in worldwide fuel consumption can be achieved by applying the technology across the board to conventional and hybrid vehicles. However, many challenges remain for large-scale development [3]. Doping studies are important in ZT optimization [6].

7. ACKNOWLEDGMENT

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