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Low Power Generation From Waste Heat Of Internal Combustion Engines By Thermoelectric Generator

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ABSTRACT

Abundant movements on environmental and carbon emission issues have been going on formore than decades while researchers have lot of innovation to decrease carbon emission byimproving the internal combustion engine of an automobile, however, none of this prove tolesseningcarbonemissionduetomajorfactthatthenumberofvehiclesareincreasingondailybasis.

Consequently, this work delivers an inclusive review, design, and development of a Thermo-ElectricGenerator(TEG)systemthatwillproducepowerfromtheunusedheatenergygenerated by an internal combustion engine through the exhaust gas conduit. This explorationworkprovidesanenhancedstructuraldesignofthesystembyintroducingcoolingfinsaccompanied on the cold side of the TEG, in order to maintain the temperature at a constantlevel. According to the output power generated from the proposed TEG system, it is observedthat when the temperature difference between the hot side and cold side of the TEG ismaximum,theoutputpowerelectricitygeneratedfromthesystemreachesthemaximum.Thusresultinginusefullowpowergenerationfromthefuelenergywastedinexhaustedgasesbytheinternalcombustion engines.

KeyWords: TEG, Seeback effect, Waste heat, Thermoelectri

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INTRODUCTION

More than decades, public sectors and scientist are canvassing on environmental and carbonemissionissues,andthishasbroughtmajorinterestofresearchoninternalcombustionengine,waste reduction and energy consumption. However, researchers have confirmed that internalcombustionengineisconsideredasoneofthemajorconsumptionfossilfuelswhichledtoCO2emission.

In the world where 30% to 40% of heat supplied by fuel is converted into mechanical whileremaining heat energy is disqualified through exhaust gas pipe to the environment resulting toserious environmental pollution claim to continue damaging our earth according to climatechange campaign resolution. Therefore, reduction of waste heat requires utilization for usefulwork, the utilization and recovery of waste heat will not only reduce environmental pollutionbutwouldalsoconservefuelconsumptionandreducethetotalamountofwasteheatgeneratedby combustionengine.Manyresearchershavecarriedoutalotofsuccessfulenergyconversionfor efficiency, however, most limit the scope of research for the improvement of thermalefficient for combustion engine, whereas, this paper focuses on potential solution to the usageof exhaust heat resulting from internal combustion engine, exhaust gas heat recovery systemand energy utilization with increase in C02 emission yet, in cost effective way. The intensionof this work is to provide a comprehensive review, design, and development of the Thermo-Electric Generator (TEG) system to generate power from waste heat energy resulting byinternal combustion engine through the exhaust gas channel. This is a possible solution torecoverwasteusingthermoelectricgenerator,whichwillconvertthetemperaturegradientintousable voltage which can be used to power other appliances, such as auxiliary system andothers.

PROPOSEDSYSTEM

This exploration has been implemented to study about heat loss at the exhaust the automobileengine.Themainobjectiveofthisprojectisobservingthewasteheatenergythathasbeenthrownto the atmosphere as waste. A prototype of the TEG system has been built and the TEGs areplacedontheonesideoftheAluminumpipeline.OnthetopofeachTEG,theAluminumheatsink has been placed to remove the excess heat from the cold side of the TEG. All the threeTEGsare connected in series and connected with load.

Thebelowblockdiagram indicatestheexperimentsetup.

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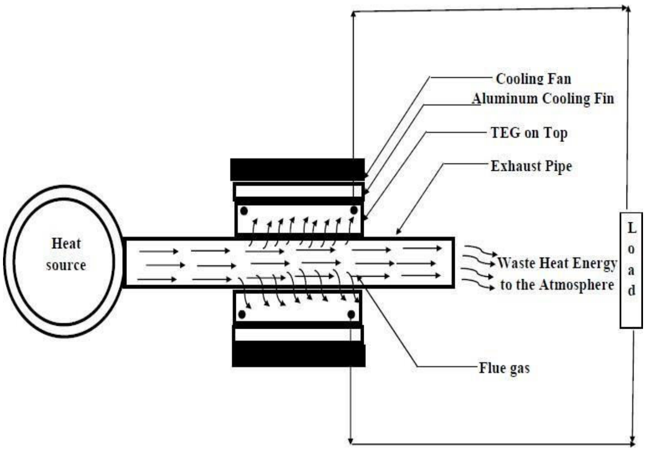

Figure1: Blockdiagramofthethermoelectricgeneratorsystemusingheatsinkand Coolingfan

TEGMODULE

InthisprojectBismuthTelluridetypeofthermoelectricdevicehasbeenused.Belowistherated power output and selected thermoelectric device dimension. This device is placed inheat environment to generate a voltage output, and also to get the sum of a total voltage oftwo or more, which is connected in series and have the ability to withstand a continuoushightemperature260°C (500F).

Rating:Umax(V):15.4V, Imax(A):6A,Voltage(V):12V,QMax(W):92W.Dimensions:40mmx 40mmx 3.6mm.

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CONCEPTDESIGNEDDERIVEDFROMFUNDAMENTALPRINCIPLES.

In order to analyses and perform the computational data of the voltage generator module,some parameters have to be considered, which includes the coefficient of Seebeck and thetotalamount of thermoelectricmodule coupled together, andthisresultsto.

$$N = \frac{\alpha}{(Seebeck\ Coefficient\ of \sin glethermoelectric \sin glecouple)} \quad (1)$$

Where

α:CoefficientofSeebeckofasinglethermoelectricmoduleN:Totalnumbercouples.

Therefore,basedonparameterscollectedfromTEC1-12706datasheet,Coefficientof Seebeckfor p-typeis270µV/K

CoefficientofSeebeckforn-typeis-270µV/K(-signmeann-type)

SeebeckCoefficientofa thermoelectricsingle couple

(2) $= 270\ \mu V/K + 270\ \mu V/K$

total number of couples used as generator, it willnow be necessary to compute voltageproducedbyoverallcombinationofthermoelectricdeviceformingasinglevoltagegeneratormodule

$$V = \alpha \times \Delta T \quad (3)$$

WhereVis voltage

ΔTIsthetemperaturedifferencebetweenT-hotandT-cold

$$T_{hot} \square 60^0 c \square 273 \square 333^0 K \quad (4)$$

$$T_{cold} = 24°C + 273 = 297K \quad (5)$$

Tocalculateamultiplecascadevoltageofthermoelectricmodule

$$V_{total} = V \times n \quad (6)$$

Where

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V total is the total voltage produced, V is the produced voltage from each cascade module andthermoelectric module number is N.[22] Considering a situation where device is used for chargingbattery, this related to ampere hour per day, that is, therate at which the current produced is tochargeabattery.

Usagehours*Currentflowingto thebattery (7)

Finally,outputpowercan calculatewith $Output\,power = IV$(8)

WhereIandVarethetotalcurrentandtotal voltageproducedrespectively.

Tocalculatethetotalpowerwhichiscomingoutfromthecar,thetemperatureat certainspeedwithspecific car must be known. [4] [5] [25] the example that has been chosen here is 1996 DodgeCaravan Sport, at speed 34mph which releasesthe Exhaust gas (in manifold) at a temperature of1134°Fwhichis usedtoconvertfromFahrenheitto Celsiususingthe followingformula:

(9) $T(°C) = (T(°F) - 32) \times 59$

Thetemperatureofthecarexhaustis1134whichis=(612)°CanditisassumedtobeT(hot)andthetemperatureoftheoutsideisassumedtobe35°CwhichcancalledasT(cold).[15]Thegasconstantsof the CO2 "R" is 0.1889 KJoule ⁄Kg*K taken from the table of ideal gas specific heats. Thefollowingformulaisto calculate theinternalenergy:

(10) $H_{(hot)} = R \times T\,(K)$

To calculate the volume flow, must chose a specific engine because each model of engine has adifferent volume flow, so according to "Continental Motors Continued" the engine model that hasbeen chosen is M330 engine under 2400rpm which is equal to 497cfm (cubic feet per minute) andafter converting from cubic foot per minute to meter cube per second the volume flow will be equalto 0.2346 m3⁄s .According to engine "Ti-AL 605 turbo" the pressure exhausted is 144.79kpa andthis pressure has been taken as the average speed which is 3500rpm cross with 21psi according tothegraphofthe exhaustsystempressure.

Thespecificvolumeisobtainedusingtheformula,

$$V_1 = \frac{RT}{P}$$

(11)

Further, the mass of flow of the gas can be calculated using the volumetric of flowrate over thespecificvolumeandthevolumetricflowratecan beobtainedonlineforachosentypeof caras,[9]

(12)

$$m = \frac{V_1}{V}$$

Totalpowercanbecalculatedbymultiplyingthemassofthegasflowwiththe differenceoftemperatures asmentionedbelow:

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(13)

THERMOELECTRICGENERATOR

A thermoelectric generator (TEG), also called a Seebeck generator, is a solid state devicethat changes heat flux (temperature differences) directly into electrical energy through aphenomenoncalledthe Seebeckeffect (aformof thermoelectriceffect)Thermoelectricgenerators function like heat engine, but are less bulky and have no moving parts. However,TEGsaretypically more expensive and lessefficient.

Thermoelectric generators could be used in power plants in order to convert waste heat intoadditionalelectrical power and in automobiles as automotive thermoelectricgenerators (ATGs)toincreasefuelefficiency.Anotherapplicationis radioisotopesthermoelectric generators which are used in space probes, which has the same mechanism butuseradioisotopes to generate therequired heatdifference.

ThermoelectricEffects- EarlystudyofThermoelectricity1820-1920

In the 100 years before the world wars thermoelectricity was discovered and developed inWesternEuropebyacademicscientists,with muchoftheactivity centeredin Berlin.

SEEBECK EFFECT

In 1821Thomas Johann Seebeck found that a circuit made from two dissimilar metals, withjunctionsatdifferenttemperatureswoulddeflectacompassmagnet.Seebeckinitiallybelievedthisw asduetomagnetisminducedbythetemperaturedifferenceandthoughtitmightbe

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related to the Earth's magnetic field. However, it was quickly realized that a "ThermoelectricForce" induced an electrical current, which by Ampree's law deflects the magnet. Morespecifically,thetemperaturedifferenceproducesanelectricpotential(voltage)whichcandriveanelectriccurrentin aclosedcircuit. Today,this is knownas theSeebeck effect.

Instrument used by Seebeck to observe the deflection of a compass needle (a) due to athermoelectricinducedcurrentfromheatingthejunctionoftwodifferentmetals(nando).Thevoltage produced is proportional to the temperature difference between the two junctions. Theproportionality constant (S or a) is known as the Seebeck coefficient, and often referred to as"thermopower" even though it ismorerelated topotential thanpower.

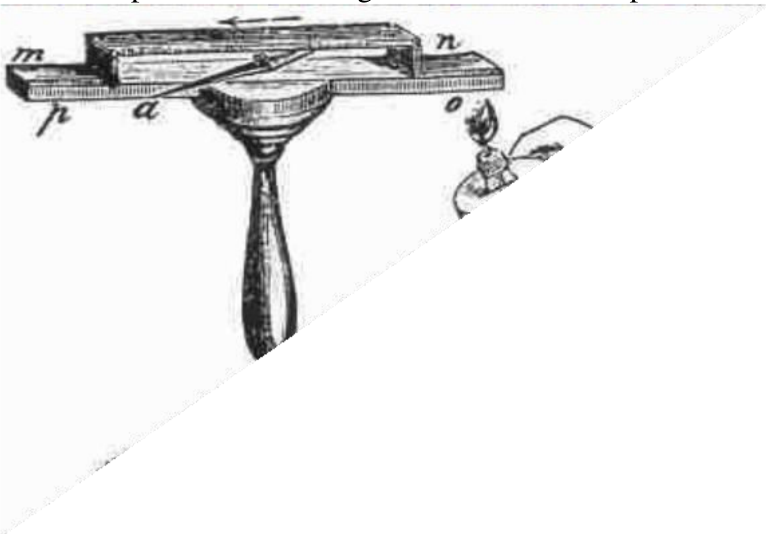

Figure:2

In1851GustavMagnusdiscoveredtheSeebeckvoltagedoesnotdependonthedistributionoftemperature along the metals between the junctions an indication that the thermo power is 7 athermodynamic state function. This is the physical basis for a thermocouple, which is usedoftenfortemperaturemeasurement.

CONSTRUCTION

Thermoelectricpowergeneratorsconsistofthreemajorcomponents:thermoelectricmaterials,thermoelectricmodulesandthermoelectricsystemsthat interfacewith theheat source.

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THERMOELECTRICMATERIALS

Thermoelectricmaterialsgeneratepowerdirectlyfromheatbyconvertingtemperaturedifferencesintoelectricvoltage.Thesematerialsmusthavebothhigh electricalconductivity(σ)andlowthermalconductivity(κ)tobegoodthermoelectricmaterials.Havinglow thermal conductivity ensures that when one side is made hot, the other side stays cold,which helps to generate a large voltage while in a temperature gradient. The measure of themagnitudeofelectronsflowinresponsetoatemperaturedifferenceacrossthatmaterialisgivenby the Seebeck coefficient (S). The efficiency of a given material to produce a thermoelectricpoweris governed by its"figureof merit"$zT=S^2\sigma T/\kappa$.

For many years, the main three semiconductors known to have both low thermal conductivityandhighpowerfactorwere bismuthtelluride (Bi_2Te_3), leadtelluride (PbTe),and silicongermanium(SiGe).Thesematerialshaveveryrareelementswhichmakethemveryexpensivecompounds.

Today,thethermalconductivityofsemiconductorscanbeloweredwithoutaffectingtheirhighelectricalpropertiesusingnanotechnology.Thiscanbeachievedbycreatingnanoscalefeaturessuchasparticles,wires orinterfacesinbulksemiconductormaterials.However,themanufacturingprocessesof nano-material is stillchallenging. AthermoelectriccircuitcomposedofmaterialsofdifferentSeebeckcoefficient(p-dopedandn-dopedsemiconductors),configured as athermoelectric generator.

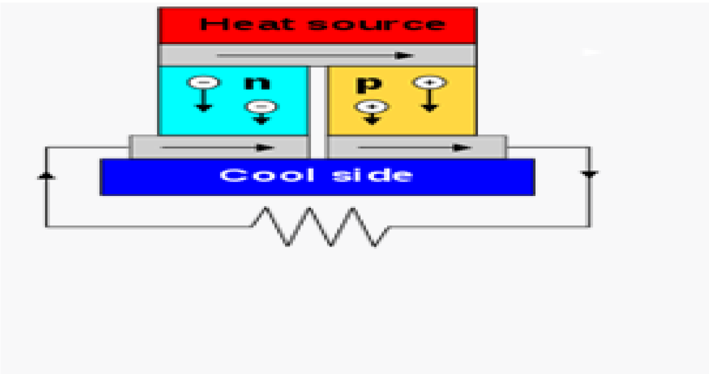

Figure:3

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THERMOELECTRICMODULE

A thermoelectric module is a circuit containing thermoelectric materials which generateselectricityfromheatdirectly.Athermoelectricmoduleconsistsoftwodissimilarthermoelectric materials joined at their ends: an n-type (negatively charged); and a p-type(positively charged) semiconductors. A direct electric current will flow in the circuit whenthere is a temperature difference between the two materials. Generally, the current magnitudeisdirectly proportional to the temperaturedifference.

Inapplication,thermoelectricmodulesinpowergenerationworkinverytoughmechanicalandthermal conditions. Because they operate in very high temperature gradient, the modules aresubject to large thermally induced stresses and strains for long periods of time. They also aresubjectto mechanical fatigue caused bylargenumber ofthermal cycles.

Thus,thejunctionsandmaterialsmustbeselectedsothattheysurvivethesetoughmechanicaland thermal conditions. Also, the module must be designed such that the two thermoelectricmaterials are thermally in parallel, but electrically in series. The efficiency of a thermoelectricmoduleis greatly affected by the geometry of itsdesign.

THERMOELECTRICSYSTEM

Usingthermoelectricmodules,athermoelectricsystemgeneratespowerbytakinginheatfroma source such as a hot exhaust flue. In order to do that, the system needs a large temperaturegradient, which is not easy in real-world applications. The cold side must be cooled by air orwater. Heat exchangers are used on both sides of the modules to supply this heating andcooling.

TherearemanychallengesindesigningareliableTEGsystemthatoperatesathightemperatures.Achievinghighefficiencyinthesystemrequiresextensiveengineeringdesigninorder to balance between the heat flow through the modules and maximizing the temperaturegradient across them. To do this, designing heat exchanger technologies in the system is oneofthemostimportantaspectsofTEGengineering.Inaddition,thesystemrequirestominimizethethermallossesduetotheinterfacesbetweenmaterialsatseveralplaces.Anotherchallenging constraintisavoiding large pressure drops between the heating and coolingsources.

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After the DC power from the TE modules passes through an inverter, the TEG produces ACpower, which in turn, requires an integrated power electronics system to deliver it to thecustomer.

MATERIALSFORTEG

Onlyafewknownmaterialstodateareidentifiedasthermoelectricmaterials.Mostthermoelectricmaterialstodayhaveaz T,thefigureofmerit,valueofaround1,suchasin Bismuth Telluride (Bi_2Te_3) at room temperature and lead telluride (PbTe) at 500-700K.However, in order to be competitive with other power generation systems, TEG materialsshould have a zT of 2-3. Most projectsin thermoelectric materials have focused on increasingthe Seebeck coefficient (S) and reducing the thermal conductivity, especially by manipulatingthe nanostructure ofthethermoelectricmaterials.Becausethethermalandelectricalconductivity correlate with the charge carriers, new means must be introduced in order toconciliate the contradiction between high electrical conductivity and low thermal conductivityasindicated.

When selecting materials for thermoelectric generation, a number of other factors need to beconsidered. During operation, ideally the thermoelectric generator has a large temperaturegradientacrossit.Thermalexpansionwillthenintroducestressinthedevicewhichmaycausefracture of the thermoelectric legs, or separation from the coupling material. The mechanicalproperties of the materials must be considered and the coefficient of thermal expansion of thenandp-typematerialmustbematchedreasonablywell.Insegmentedthermoelectricgenerators, the material's compatibility must also be considered. A material's compatibilityfactoris defined as, when the compatibility factor from one segment to the next differs by more than a factor ofabout two, the device will not operate efficiently. The material parameters determining s (aswell as zT) are temperature dependent, so the compatibility factor may change from the hotside to the cold side of the device, even in one segment. This behavior is referred to as self-compatibilityand maybecome importantin devicesdesign forlow temperatureoperation

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CONVENTIONALMATERIALS

TherearemanyTEGmaterialsthatareemployedincommercialapplicationstoday.Thesematerialscan bedividedintothreegroupsbased onthe temperaturerangeofoperation:Lowtemperaturematerials(uptoaround450K):AlloysbasedonBismuth (Bi)incombinationswith Antimony (Sb),Tellurium(Te)orSelenium (Se).

Intermediate temperature (up to 850K): such as materials based on alloys of Lead (Pb).

Highest temperatures material(up to 1300K): materials fabricated from silicongermanium (SiGe) alloys.

Althoughthesematerialsstillremainthecornerstoneforcommercialandpracticalapplicationsin thermoelectric power generation, significant advances have been made in synthesizing newmaterialsandfabricatingmaterialstructureswithimprovedthermoelectricperformance.Recent research have focused on improving the material's figure-of-merit (zT), and hence theconversionefficiency, byreducing the latticethermalconductivity.

EFFICIENCY

The typical efficiency of TEGs is around 5–8%. Older devices used bimetallic junctions andwerebulky.Morerecentdevicesusehighlydopedsemiconductorsmadefrom bismuttelluride (Bi_2Te_3), leadtelluride (PbTe), calciummanganeseoxide($Ca_2Mn_3O_8$), orcombinationsthereof, dependingontemperature.Thesearesolid-statedevices andunlikedynamos havenomovingparts, with theoccasionalexception ofafanor pump.

ANALYSISOFWORK

A thermoelectric module used for power generation has certain similarities to a conventionalthermocouple. Let us look at a singlethermoelectric couple with an applied temperaturedifference as shown in Figure

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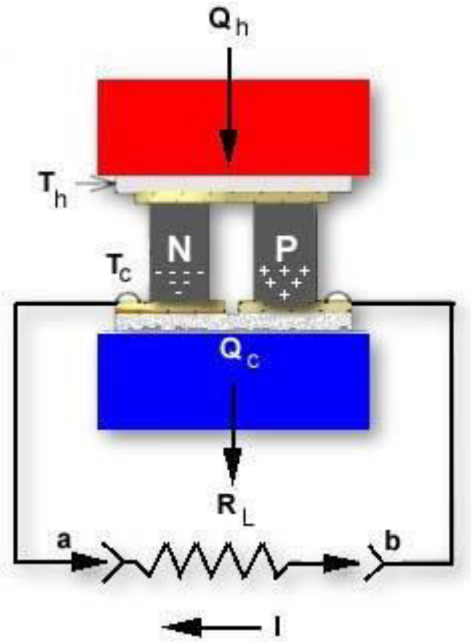

Figure:4

SingleThermoelectricCouplewhereTh>Tc

Withnoload(RLnot connected),theopencircuitvoltageasmeasuredbetweenpointsaandbis:

V=S x DT

Where:

V = the output voltage from the couple (generator) in voltsS= the average Seebeck coefficient in volts/°KDT=thetemperaturedifferenceacross thecoupleinK where DT=Th-Tc

When a load is connected to the thermoelectric couple the output voltage (V) drops as a resultofinternal generatorresistance. The currentthrough the load is:

$$I = \frac{S \times DT}{R_C + R_L}$$

Where:

I= the generator output current in amperesRc= the average internal resistance of the thermoelectric couple in ohmsRL=the load resistancein ohms

Thetotal heatinput tothe couple(Qh)is:

$Q_h = (S \times T_h \times I) - (0.5 \times I^2 \times R_c) + (K_c \times DT)$

Where:

Qh= the heat input in wattsKc= the thermal conductance of the couple in

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watts/°K T_h=the hot sideof thecouple in °K

Theefficiency of thegenerator (E_g) is:

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$$Eg = \frac{V \times I}{Qh}$$

Practicallimitations

Besideslowefficiencyandrelativelyhighcost,practicalproblemsexistinusingthermoelectricdevices in certain types of applications resulting from a relatively high electrical outputresistance, which increases self-heating, and a relatively low thermal conductivity, whichmakes them unsuitable for applications where heat removal is critical, as with heat removalfroman electrical device such as microprocessors.

- **High generator output resistance:** To get voltage output levels in the rangerequiredbydigitalelectricaldevices,acommonapproachistoplacemanythermoelectricelementsi nserieswithinageneratormodule.Theelement'svoltagesincrease,butsodoestheiroutputresistance.The maximumpowertransfertheorem dictates that maximum power is delivered to a load when the source andload resistances are identically matched. For low impedance loads near zero ohms,asthegeneratorresistancerisesthepowerdeliveredtotheloaddecreases.Tolowerthe output resistance, some commercial devices place more individual elements inparallel and fewer in series and employ a boost regulator to raise the voltage to thevoltageneeded by the load.
- **Low thermal conductivity:** Because a very high thermal conductivity is requiredtotransportthermalenergyawayfromaheatsourcesuchasadigitalmicroprocessor, the low thermal conductivity of thermoelectric generators makesthemunsuitableto recover theheat.
- **Cold-side heat removal with air:** In air-cooled thermoelectric applications, suchas when harvesting thermal energy from a motor vehicle's crankcase, the largeamount of thermal energy that must be dissipated into ambient air presents asignificant challenge. As a thermoelectric generator's cool side temperature rises,the device's differential working temperature decreases. As the temperature rises,the device's electrical resistance increases causing greater parasitic generator self-heating. In motor vehicle applications a supplementary radiator is sometimes usedfor improved heat removal, though the use of an electric water pump to circulate acoolantaddsparasiticlosstototalgeneratoroutputpower.Watercoolingthe

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thermoelectricgenerator'scoldside,aswhengeneratingthermoelectricpowerfromthehotcrankcaseofan inboardboatmotor,wouldnotsufferfromthisdisadvantage.Wateris a far easier coolantto useeffectively incontrastto air

IMPLIMENTATIONS

Thermoelectric generators (TEG) have a variety of applications. Frequently, thermoelectricgenerators are used for low power remote applications or where bulkier but more efficientheat engines such as Stirling engines would not be possible. Unlike heat engines, the solidstate electrical components typically used to perform thermal to electric energy conversionhave no moving parts. The thermal to electric energy conversion can be performed usingcomponents that require no maintenance, have inherently high reliability, and can be used toconstruct generators with long service-free lifetimes. This makes thermoelectric generatorswell suited for equipment with low to modest power needs in remote uninhabited orinaccessiblelocations suchas mountaintops, the vacuum of space,or thedeepocean.

Themainusesof thermoelectricgeneratorsare:

1. Space probes, including the Mars Curiosity rover, generate electricity using a radioisotopethermoelectricgeneratorwhoseheat sourceisaradioactiveelement.

2. Waste heat recovery. Every human activity, transport and industrial process generateswaste heat, being possible to harvest residual energy from cars, aircraft, ships, industries andthe human body. From cars the main source of energy is the exhaust gas. Harvesting that heatenergy using a thermoelectric generator can increase the fuel efficiency of the car.Thermoelectric generators have been investigated to replace the alternators in carsdemonstrating a 3.45% reduction in fuel consumption representing billions of dollars insavingsannually.Projectionsforfutureimprovementsareuptoa10%increaseinmileagefor hybrid vehicles. It has been stated that the potential energy savings could be higher forgasoline engines rather than for diesel engines. For more details, see the article: Automotivethermoelectric generator. For aircraft, engine nozzles have been identified as the best place torecover energy from, but heat from engine bearings and the temperature gradient existing intheaircraft skin have alsobeen proposed.

3. Solar cells use only the high-frequency part of the radiation, while the low-frequency heatenergy is wasted. Several patents about the use of thermoelectric devices in parallel orcascadeconfigurationwith solarcells havebeen filed.Theideais toincreasetheefficiency

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ofthecombinedsolar/thermoelectricsystemtoconvertsolarradiationintouseful electricity.

4. Thermoelectric generators are primarily used as remote and off-grid power generators forunmanned sites. They are the most reliable power generator in such situations as they do nothave moving parts (thus virtually maintenance-free), work day and night, perform under allweather conditions and can work without battery backup. Although solar photovoltaicsystems are also implemented in remote sites, Solar PV may not be a suitable solution wheresolar radiation is low, i.e. areas at higher latitudes with snow or no sunshine, areas with muchcloud or tree canopy cover, dusty deserts, forests, etc. Thermoelectric generators arecommonly used on gas pipelines, for example, for cathodic protection, radio communication,and telemetry. On gas pipelines for power consumption of up to 5 kW, thermal generators arepreferable to other power sources. The manufacturers of generators for gas pipelines areGlobal Power Technologies (formerly Global Thermoelectric) (Calgary, Canada) andTELGEN(Russia).

5. Microprocessors generate waste heat. Researchers have considered whether some of thatenergycould berecycled.(However, seebelow forproblems that canarise.)

6. Thermoelectric generators have also been investigated as standalone solar-thermal cells.Integration of thermoelectric generators have been directly integrated to a solar thermal cellwithefficiency of 4.6%.

7. The Maritime Applied Physics Corporation in Baltimore, Maryland is developing athermoelectric generator to produce electric power on the deep-ocean offshore seabed usingthe temperature difference between cold seawater and hot fluids released by hydrothermalvents, hot seeps, or from drilled geothermal wells. A high-reliability source of seafloorelectric power is needed for ocean observatories and sensors used in the geological,environmental, and ocean sciences, by seafloor mineral and energy resource developers, andby the military. Recent studies have found that deep-sea thermoelectric generators for largescaleenergy plants arealso economically viable.

8. Ann Makosinski from British Columbia, Canada has developed several devices usingPeltier tiles to harvest heat (from a human hand, the forehead, and hot beverage) that claimsto generate enough electricity to power an LED light or charge a mobile device, although theinventor admits that the brightness of the LED light is not competitive with those on themarket.

9. Thermoelectric generators are used in stove fans. They are put on top of a wood or coalburning stove. The TEG is sandwiched between 2 heat sinks and the difference intemperaturewillpower aslow movingfan thathelps circulatethe stovesheat intotheroom."

FUTURE SCOPES

While TEG technology has been used in military and aerospace applications for decades, newTEmaterials andsystemsarebeingdevelopedtogeneratepowerusingloworhightemperatures waste heat, and that could provide a significant opportunity in the near future.Thesesystemscanalsobescalabletoanysizeandhaveloweroperationandmaintenancecost.

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TheglobalmarketforthermoelectricgeneratorsisestimatedtobeUS$320millionin2015andUS$472millionin2021;uptoUS$1.44billionby2030withaCAGRof11.8%.Today, NorthAmerica captures 66% of the market share and it will continue to be the biggest market in thenear future. However, Asia-Pacific and European countries are projected to grow at relativelyhigher rates. A study found that the Asia-Pacific market would grow at a Compound AnnualGrowth Rate (CAGR) of 18.3% in the period from 2015 to 2020 due to the high demand ofthermoelectric generators by the automotive industries to increase overall fuel efficiency, aswellas the growing industrialization in theregion.

Small scale thermoelectric generators are also in the early stages of investigation in wearabletechnologies to reduce or replace charging and boost charge duration. Recent studies focusedon the novel development of a flexible inorganic thermoelectric, silver selenide, on a nylonsubstrate. Thermoelectrics represent particular synergy with wearables by harvesting energydirectly from the human body creating a self-powered device. One project used n-type silverselenide on a nylon membrane. Silver selenide is a narrow bandgap semiconductor with highelectrical conductivity and low thermal conductivity, making it perfect for thermoelectricapplications.

Low power TEG or "sub-watt" (i.e. generating up to 1 Watt peak) market is a growing part ofthe TEG market, capitalizing on the latest technologies. Main applications are sensors, lowpower applications and more globally Internet of things applications. A specialized marketresearchcompanyindicatedthat100,000unitshavebeenshippedin2014andexpects9millionunitsper year by 2030.

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REFERENCES

[1] S. H. e. Xin Bao, "Mechanical properties of thermoelectric generators," *Journal of Materials Science & Technology,* pp. 64-74, 10 June, 2022.

[2] D. A. et.al., "Enhanced behaviour of a passive thermoelectric generator with phase change heat exchangers and radiative cooling," *Applied Thermal Engineering,* pp. 1359-4311, Feb, 2023.

[3] M. G. et.al., "Effect of non-uniform heat flux on solar thermoelectric generator," *Energy Reports,* pp. 296-301, Voulme-8, Supplement-16, December 2022.

[4] P. A. M. A. D. A. Leyre Catalan, "Field test of a geothermal thermoelectric generator without moving parts on the Hot Dry Rock field of Timanfaya National Park," *Applied Thermal Engineering,* pp. 119843, Volume-222, March 2023.

[5] S. W. Y. Z. L. Y. Yanzhe Li, "Effect of thermoelectric modules with different characteristics on the performance of thermoelectric generators inserted in the central flow region with porous foam copper," *Applied Energy,* pp. 120041, Voulme-327, 1 December, 2022.

[6] Y. Z. et.al., "Influence of porous plate position on thermoelectric generator," *Energy Reports,* pp. 1045-1050, Volume-8, Supllement-13, November 2022.

[7] W. L. et.al., "Experimental research of solar thermoelectric generator based on flat heat pipe," *Energy Reports,* pp. 245-250, Volume-8, Supplement-10, Novemebr 2022.

[8] Z. L. et.al., "Performance analysis of the heat pipe-based thermoelectric generator (HP-TEG) energy system using in-situ resource for heat storage applied to the early-period lunar base," *Applied Thermal Engineering,* vol. 218, no. 119303, 5 January, 2023.

[9] Z. C. et.al., "Analysis of the influence of different thermal boundary conditions on thermoelectric generators," *Energy Reports,* vol. 8, no. 16, pp. 48-55, December 2022.

[10] Y. Z. et.al., "Experimental study of thermoelectric generator with different numbers of modules for waste heat recovery," *Applied Energy,* vol. 322, no. 119523, 15 September, 2022.

[11] K. T. W. et.al., "A testbed for performance studies of gas–liquid thermoelectric generators for waste heat harvesting," *Measurement,* vol. 203, no. 111933, 15 November 2022.

[12] T. D. et.al., "Study on supercritical carbon dioxide recompression Brayton cycle system integrated with thermoelectric generator," *Sustainable Energy Technologies and Assessments,* Vols. Volume-53, Part-B, no. 102541, October 2022.

[13] S. J. e. al., "Study of the performance of a thermoelectric generator transformation of the thermal energy conveyed by a heat transfer fluid into electrical energy," *Current Applied*

ISSN PRINT 2319 1775 Online 2320 7876

Research paper **© 2012 IJFANS. All Rights Reserved, UGC CARE Listed (Group -I) Journal Volume 11,S Iss 3, Dec 2022**

Physics, vol. 43, pp. 97-105, November 2022.

[14] R. S. R. C. Song Lan, "Performance comparison of a thermoelectric generator applied in conventional vehicles and extended-range electric vehicles," *Energy Conversion and Management,* vol. 266, no. 115791, 15 August 2022.

[15] Z. W. e. al., "Hybrid thermoelectric generators-renewable energy systems: A short review on recent developments," *Energy Reports,* Vols. Volume-8, Supplement-9, pp. 1361-1370, November 2022.

[16] B. W. K. W. G. W. Y.J. Cui, "An analytical model to evaluate influence of negative Poisson's ratio architecture on fatigue life and energy conversion performance of wearable thermoelectric generator," *International Journal of Solids and Structures,* vol. 258, no. 112000, 15 December 2022.

[17] W. Y. et.al., "Global structural optimization of annular thermoelectric generators based on a dual-finite-element multiphysical model," *Applied Thermal Engineering,* vol. 220, no. 19797, 5 February 2023.

[18] W. G. K. S. Zbigniew Rogala, "Theoretical analysis of liquefied natural gas cold energy recovery using thermoelectric generators," *Applied Thermal Engineering,* vol. 213, no. 118608, August 2022.

[19] B. R. H. S. Jaywan Chung, "Unique temperature distribution and explicit efficiency formula for one-dimensional thermoelectric generators under constant Seebeck coefficients," *Nonlinear Analysis: Real World Applications,* vol. 68, no. 103649, December 2022.

[20] M. e. B. T. E. N. Haythem Sahli, "Analysis of a hybrid solar absorption cooling system with thermoelectric generator," *Thermal Science and Engineering Progress,* vol. 35, no. 101474, 1 October 2022.

[21] M. A. M. et.al., "Effect of liquid saturated porous medium on heat transfer from thermoelectric generator," *International Journal of Thermofluids,* vol. 17, no. 100264, February 2023.

[22] D.-h. K. et.al., "Design and performance analyses of thermoelectric coolers and power generators for automobiles," *Sustainable Energy Technologies and Assessments,* vol. 51, no. 101955, June 2022.

[23] O. C.-C. Marisol Martín-González, "Thermoelectric generators as an alternative for reliable powering of wearable devices with wasted heat," *Journal of Solid State Chemistry,* vol. 316, no. 123543, December 2022.

[24] S. G. H. A. C. Farzad Tohidi, "Thermoelectric Generators: A comprehensive review of characteristics and applications," *Applied Thermal Engineering,* Vols. 201, Part-A, no. 117793, 25 January 2022.

ISSN PRINT 2319 1775 Online 2320 7876

Research paper **© 2012 IJFANS. All Rights Reserved,** **UGC CARE Listed (Group -I) Journal Volume 11,S Iss 3, Dec 2022**

[25] L. C. M. A. A. R. D. A. Patricia Alegria, "Experimental development of a novel thermoelectric generator without moving parts to harness shallow hot dry rock fields," *Applied Thermal Engineering,* vol. 200, no. 117619, 5 January 2022.

[26] Y. Z. e. .al., "Characteristics analysis of an exhaust thermoelectric generator system with heat transfer fluid circulation," *Applied Energy,* vol. 304, no. 117896, 15 December 2021.

[27] W. T. C. Dr. Terry Hendricks, "Engineering Scoping Study of Thermoelectric Generator Systems for Industrial Waste Heat Recovery," U.S. Department of Energy, Industrial Technolgies Program, Washington, DC 20585, November 2006.

[28] 2. W. PRASHANTHA.K, "SMART POWER GENERATION FROM WASTE HEAT BY THERMO," *International Journal of Mechanical And Production Engineering,* Vols. ISSN: 2320-2092, no. Special Issue, September, 2006.

[29] N. AIMABLE, "DESIGN, MODELING, AND FABRICATION OF THERMOELECTRIC GENERATOR," University of Agder, Faculty of Engineering and Science, Department of Engineering, Kristiansand, Norway, 2017.