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Thermoelectric Generator:A Review

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Abstract:*This paper explains a review works on thermoelectric generator using different viable solar technologies. For clean sources, thermoelectric (TE) energy converters are of increasing interest because these solid-state devices can transform heat given off from sources such as motor vehicles, power plants, computers, factories or even human bodies into electric power using the Seebeck effect in single stage. This review contains previous researches on thermoelectric based plants and also current advances on it.*

I. Introduction

The sun is the most plentiful energy source for the earth. All wind, fossil fuel, hydro and biomass energy have their origins in sunlight. Energy from the sun falls on the surface of the earth at a rate of 120 petawatts, (1 petawatt = 1015 watt). This means all the solar energy received from the sun in one days can satisfied the whole world's demand for more than 20 years [1].

There are several applications for solar energy, for example: electricity generation, solar propulsion, room temperate control, photochemical, and solar desalination. The collection of solar energy and its transfer to electricity energy will have wide application and deep impact on our society. Hence it has attracted the attention of the researchers.

The two most prominent solar energy technologies are photovoltaic (PV) and concentrated solar power (CSP). CSP systems can provide electricity as well as thermal power.

Solar thermoelectricity uses parabolic disc technology to capture thermal energy basted on the Seebeckeffect. This electricity is produced through a concentrator thermoelectric generator (CTEG). A thermoelectric device is divided into two parts which produces energy by converting differences in temperatures in the two parts into volts using a semi-conductor [1].

The many advantages of this energy-conversion phenomenon include solid-state operation, vast scalability, a long life span of reliable operation, maintenance free operation due to the lack of moving parts or chemical reactions, and the absence of toxic residuals [2].

Devices that scavenge energy from the ambient surrounding environment have become a populartopic for research. For some applications, energy scavenging eliminates the need for batteries orincrease the time between battery replacements. One ambient energy source found in ourenvironment is a temperature change (thermoelectric-Seebeck) effect. This form of ambientenergy is found in the human body, machines, buildings, bridges, furnaces, staircases, and indoor and outdoor temperature differences. The application of TEGs based on thermoelectric effects(or Seebeck, Peltier, Thomson effect) is made possible by direct conversion of temperaturedifferences to electrical power [3-8]. The Seebeck effect occurs when a temperature differenceexists between two dissimilar electrical conductors or semiconductors, producing a voltageacross two materials.

Conversely, when a voltage is applied to the thermoelectric generator, it creates a temperature gradient. At the atomic scale, an applied temperature gradient causes charged carriers in the material to move from the hot side to the cold side. This effect was knows as Peltier effect and discovered since 1982 and has been developed in recent years. Today we are able to see that it works in astronautic devices and automotive engine systems [1].

II. Thermoelectric Module(TEM)

The basic unit of a TEM is a thermocouple. As illustrated in Fig. 1(a), a thermocouple consists of a p-type semiconductor pellet and an n-type semiconductor pellet joined by metal interconnects. The two pellets of each couple and the many couples in a TE device are connected electrically in series but thermally in parallel and sandwiched between two ceramic plates, as seen in Fig. 1(b). Nevertheless, whether the contribution of the metal interconnects is ignored, there is no loss of generality in analysing a single couple [9].

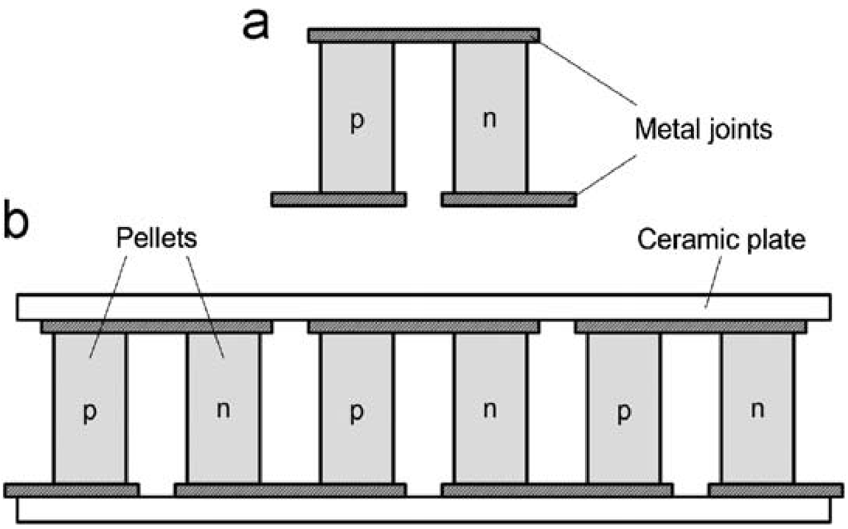

Fig.1-Schematic of a thermoelectric module: (a) basic unit and (b) multi- thermocouple module.

III. Previous Works On Thermoelectric Generator

3.1 Fabrication and performance of flat plate solar thermoelectric Generator for near-earth orbits

Auxiliary power is one of the most difficult requirements to satisfy in space. For near-earth orbital trajectories, direct solid-state energy conversion from solar radiation is one of the most advantageous techniques at power levels below 1 kW.

A unique feature of this historical work is the application of the unit couple concept in the design of solar thermoelectric flat plates. Due to this feature, the solar energy conversion panels to be fabricated by series combinations of couples. Each unit couple is soldered to the adjacent couples and mounted on a ridged lightweight aluminium radiator plate [10].

The construction of a unit couple consist the aluminium absorber and radiator plates, 0.5-mil-thick nickel disks, which are soldered to the aluminium at the thermoelectric leg locations and the four thermoelectric legs (a series connection of a pair of n- and p-type legs). The absorber and radiator plates are made from aluminium alloy 1100 foil of thickness 0.0002 inch (rolled to provide a mirror finish which reduces the internal emissivity of the plates to 0.03) formed into mechanical ridged members by special jigs. A group of unit couple types is required to form 3-by 3-inch panels of nine 1- by 1-inch unit cells connected in series which are mounted on a lightweight aluminium radiator plate.

After fabrication process, the ac resistance of the unit couple is measured at ambient temperature. Now by using the apparatus the unit couple is placed on the calibrated thermoelectric module, which in turn, rests on a thermoelectric temperature-controlling module. The control module is used to maintain the bottom of the calibrated module at a fixed temperature.

After testing of a generator, the calibrated module current is recorded for a predetermined temperature difference across the module. The tests are carried out in a vacuum of 10^{-4}torr or much better. A 150-watt, focused projection lamp is used for the radiant heat source purpose.

These performance investigations have concluded that flat plate solar thermoelectric generator panels can be fabricated to give 3 to 3.3 watts with Ar/Aa = 1, and 30 watts/pound at the unit couple (or cell) stage and 15 watts/pound at the panel stage [11].

These panels are capable of producing 3 watts/ft^2 and 15 watts/ pound when operating in a near-earth orbit, The Potential advantages of these solar energy converters over photovoltaic cells are discussed and include higher radiation resistance, improved watts/pound, and lower cost on a per watt basis.

3.2 High efficiency Thermo-Electric power generator

Thermoelectric material properties and the power generator architecture play a fundamental role in the achievement of high energy conversion efficiencies.

The research focuses on the TE module architecture design, assembly and the subcomponents manufacturing. Commercial Bismuth Telluride cells were used to fabricate TE materials. The TE generator taken into account for energy conversion efficiency calculation which is characterized by a series of TE elements placed in a counter-current heat exchanger of the hot and cold gaseous streams. A catalytic combustion chamber were designed and manufactured (SiC monolith heat exchangers, catalysts and supports for the combustion chamber, system housing) to ignite an air/fuel mixture. $Pd/NiCrO_4$ and Pt/Al_2O_3 catalysts were investigated to ignite H_2, CH_4 and H_2/ CH_4 mixtures, at different gas flow rates and fuel concentrations. This air/fuel mixture at room temperature Tin is fed to the generator flows in the cold channel where it warms up absorbing heat from the cold side of the TE element enters the combustion chamber with the regeneration temperature T_R, and here it burns reaching the temperature TH. The flue gases from the combustion chamber pass through the hot channel, in counter-current with respect to the inlet air/fuel stream. The flue gases cool down, transferring heat to the hot side of TE elements, and leave the system at relatively low-temperature Tout. Such generator can be called “U-shape” TE generator. The results led to the design of a TE generator architecture providing flexible electrical loads through a modular assembly, with an improved thermal management which enhanced the energy conversion efficiency [12].

The “U-shape” TE module was finally assembled and tested, in different operating conditions. The achieved efficiency was around 1.7% with an external oven providing the desired temperature at the TE module hot side, while a lower efficiency of 1.3% was achieved with the embedded combustion chamber. CFD simulations, which provided excellent fitting with the experimental data, predicted a maximum efficiency of 1.85% at higher gas velocities.

3.3 Parametrical analysis of the design and performance of a solar heat pipe thermoelectric generator unit

This paper describes a solar heat pipe thermoelectric generator (SHP-TEG) unit comprising a TEG module, a finned heat pipe and an evacuated double-skin glass tube. To meet the TEG operating requirement, the system takes the advantage of heat pipe to convert the absorbed solar irradiation to a high heat flux. An analytical model of the SHP-TEG unit is presented for the condition of constant solar radiation, which may lead to different performance characteristics and optimal design parameters compared with the condition of constant temperature difference usually dealt with in other studies. This analytical model presents the complex influence of basic parameters such as solar irradiation,thermoelementlength,number of thermoelementscooling water temperature, and cross section area etc. on the maximumpower output and conversion efficiency of the SHP-TEG. Mathematical simulation based on the analytical model has been carried out to study the performance and design optimization of the SHP-TEG [13].

3.4 Analysis of the internal heat losses in a thermoelectric generator

A 3D thermoelectric numerical model is used to investigate different internal heat loss mechanisms for a thermoelectric generator with bismuth telluride p- and n-legs. This model considers all thermoelectric effects, temperature dependent material parameters and simultaneous conductive, convectiveand radiative heat losses including surface to surface radiation. It is shown for radiative heat losses that surface to ambient radiation is a good approximation of the heat loss for the temperatures considered.

For conductive heat transfer the module efficiency is shown to be comparable to the case of radiative losses. The combined case of radiative and conductive heat transfer resulted in the lowest efficiency. For increased heat loss,the optimized load resistance is found to decrease. The leg dimensions are varied for all heat losses cases and it is shown that the ideal way to construct a TEG module with minimal heat losses and maximum efficiency is to either use a good insulating material between the legs or evacuate the module completely and use small and wide legs closely spaced[14].

3.5 Geometric effect on cooling power and performance of an integrated thermoelectric generation-cooling system

Geometric design of an integrated thermoelectric generation-cooling system is performed numerically using a finite element method. In the system, a thermoelectric cooler (TEC) is powered directly by a thermoelectric generator (TEG). Two different boundary conditions in association with the effects of contact resistance and heat convection on system performance are taken into account. These outputs suggest that the characteristics of system performance under varying TEG length are significantly different from those under altering TEC length. If the TEG length is changed, the entire behaviour of system performance depends highly on the boundary conditions. Other hand, the maximum distributions of cooling power and coefficient of performance (COP) are exhibited when the TEC length is altered, if the hot surface of TEG is given by a fixed temperature or heat transfer rate. Performance of the system will be reduced once the contact resistance and heat convection are considered. Whether the lengths of TEG and TEC vary, maximum reduction percentages of system performance are 12.45% and 18.67%, respectively. The numerical predictions have provided a useful insight into the design of integrated TEG–TEC systems [15].

3.6 Electric power generation from solar pond using combination of thermosyphon and thermoelectric modules

Salinity-gradient solar pond is one type of solar collector with the ability to store thermal energy for long period of time and lower cost of construction compared with the other type of solar collector. This collector can collect and store solar heat at temperatures up to 80^0C. A system in which heat from the lower zone is transferred to the hot surface of the thermoelectric modules using gravity assisted heat pipes as thermosyphons has been investigated experimentally. Temperature difference between the lower convective zone and the upper convective zone is applied across the hot and cold side of the thermoelectric modulessurface [16].

The results have been found by using water as working fluid in experiment, the temperature of the solar pond in lower convective zone is at 50^0C. This is clear that the thermoelectric generator is able to generate electricity at 36.25 mV [16].

In another place an experimental rig was developed to generate electricity from salinity gradient solar pond with 16 TEGs connected in series. The TEGs are each arranged in a tablet with 8 TEGs in each tablet unit. The tablets are made of aluminium plates with 1mm thickness to achieve good heat transfer across the TEGs surface. The two tablets are arranged such that the hot water goes through the central channel and the cold water will be channelled to the outer cold channels.

It shows that the TEGs are capable of producing power using the heat from salinity gradient solar pond and the amount of power produced is linear to the temperature difference across the TEG. This designed experimental rig was able to provide maximum power of 5.30 W which was obtained at 13.4 V and 0.24 A when the temperature difference of 75^0C was maintained across 16 thermoelectric cells. In this case, the open-circuit voltage and the short circuit current values of 26 V and 0.4 A respectively were obtained [17].

3.7 Waste heat recovery using a thermoelectric power generation system in a biomass gasifier

The aim of this study is to investigate the use of waste heat that is recovered from a biomass gasifier. In the gasification process, the low heating value of biomass can be transferred to a high heating value for combustible gaseous fuel, a form that is widely used in industry and power plants.

Conventionally, some of cleaning processes need to be conducted under higher operating temperatures that the low temperatures typically used to burn biomass. Therefore, the catalytic reactor was designed before installation the scrubber in the downdraft gasifier system to make effective use of the waste heat. The experimental result shows that the temperature of the gasifier outlet is about 623–773K; dolomite is used for tar removal in the catalytic reactor. To further improve the use of waste heat, a thermoelectric generator is added to provide for the recovery of waste heat. The thermoelectric generator system is manufactured using a Bi_2Te_3 based material and is composed of eight thermoelectric modules on the surface of catalytic reactor. The measured surface temperature of the catalytic reactor is 473–633K that is the correct temperature for Bi_2Te_3 as thermoelectric generator [18].

The result shows that the maximum power output of the thermoelectric generator system is improved to 6.1W and thermoelectric generator power density is approximately 193.1 W/m^2.

3.8 Experimental analysis of Thermoelectric Generator using Solar Energy

The performance of a 4x4 cm^2 Bismuth Telluride based thermoelectric generator with 126 thermocouples connected in series is analysed experimentally along with heat dissipater at the cold side is fixed on a stand. The terminals of the cold side are connected to multi meter and 3.3Ω load. The hot and cold junction temperatures were measured with thermometer and the corresponding voltage and current were measured with a multi meter and the power is calculated the hot junction of the thermoelectric generator is exposed to solar and candle heat and the cold side is exposed to atmosphere. With the hot junction temperature of 53^0C and cold junction temperature of 32^0C, the output power, current and voltage are measured as 0.014W, 0.042A and 0.35V respectively.

Now the hot junction of the thermoelectric generator is exposed to solar concentrator heat and the cold side is exposed to ice. If the hot junction temperature of 100.2 ^{0}C and cold junction temperature of 2.9^0C, the output power, current and voltage are measured as 0.319W, 0.1083A and 2.96Vrespectively. This power output is increased by 30.5%. The power density is 2.11μ Wcm^{-2} ◦C^{-2}[19].

It shows performance of Bismuth Telluride based TEG. With the solar and candle heat the average power output is 0.0273W. With solar concentrator the average power output is 0.134W. The power output increases with the increase of temperature gradient and the increase in temperature at the hot side. The power output can be increased further by developing vacuum at the hot and cold junction and by external cooling of the cold side.

3.9 Thermoelectric bond development for the Flat plate solar thermoelectric generator

The flat plate solar thermoelectric generator is a device that has been developed specifically to utilize direct nonconcentrated sunlight for power generation. Since the generator under consideration is designed for orbital applications, criteria applicable to other orbital power systems must be considered as well as the conventional criteria for thermoelectric systems [20].

An analysis has shown that the desirable characteristics of the optimum systems are high specific power, good radiation resistance, and small size coupled with ease of manufacture, high reliability, and low cost. In the flat plate thermoelectric solar generator module, these criteria dictate minimum element volume, lightweight shoes, and minimum radiator and absorber thicknesses.

The successful thermoelectric bond:

- **a.** Must be chemically stable under operating conditions.
- **b.** Must not produce a zone of charge carrier depletion in the element.
- **c.** Must be sufficiently strong or thermally compensated to be able to withstand shear stresses generated by thermal expansion of bond and element materials.
- **d.** Must not serve as a source of any agent that may diffuse into the element and produce poisoning or cross-doping.

In addition to these general criteria, the specific design imposed the following conditions and restraints on the bonds:

- **a.** Hot junction temperature: 520^0K.
- **b.** Cold junction temperature: 350^0K.
- **c.** Useful lifetime: 2000 to 7000 hours (to 25% degradation of electrical performance).
- **d.** Initial electrical resistance of both bonds: less than 5% of element resistance.

3.10 Effect of various leg geometries on thermo-mechanical and powergeneration performance of thermoelectric devices

This study aims to investigate possible effect of various thermoelectric leg geometries on thermomechanical and power generation performances of thermoelectric devices. Hence for this purpose, thermoelectricmodules with various leg geometries were modelled and finite-element analyses for two differenttemperature gradients were carried out using ANSYS. Power outputs, Temperature distributions, thermal stresses in the legs, conversion efficiencies were evaluated for each model. Due to changing leg geometries the differences in magnitudes and distributions of the thermal stresses in the legs are occurred significantly. Thermal stresses in the rectangular prism and the cylindrical legs were 49.9 MPa and 43.3 MParespectively for the temperature gradient of 100^0C [21].

IV. Current Research On Thermoelectric Generators

4.1 Nanostructured thermoelectric materials and future challenges

The field of thermoelectric has been recognized as a potentially transformative power generation technology.The field is now growing steadily due to their ability to convert heat directly into electricity and to develop cost-effective, pollution-free forms of energy conversion.Various types of thermoelectric materials, nanostructured materials have shown the most promise for commercial use because of their extraordinary thermoelectric performances. The article aims to summarize the present progress of nanostructured thermoelectrics and intends to understand and explain the underpinnings of the innovative breakthroughs in the last decade. We believed that recent achievements will augur the possibility for thermoelectric power generation and cooling and discuss several future directions which could lead to new excite ng next generation of nanostructured thermoelectrics[22].

Low-dimensional thermoelectric materials are believed to have higher thermoelectric properties than their bulk counterparts, because the DOS near Fermi level can be enhanced via quantum confinement therefore leading to the increase of thermopower and because phonons over a large mfp range can be effectively scattered by high density of interfaces, hence resulting in the decrease of the lattice thermal conductivity. Significant ZT enhancement has been found in two-dimensional (2D) and one- dimensional (1D) thermoelectric materials.

4.2 Recent advances on $Mg_2Si_{1-x}Sn_x$ materials for thermoelectric generation

Thermoelectric generators (TEGs) have been identified as a viable technology for waste energy harvesting, from heat in to electricity. The realization of this technology on a commercial scalelies largely with the thermoelectric material which drives this technology successfully. While bismuth telluride based TEGs dominate the current market, liabilities such as high production costs, depletion of raw resources and toxicity have triggered the search for alternative thermoelectric materials. Today one of the contenders as thermoelectric materials in the mid-temperature range is the family of Mg–Mnsilicides, given the advantages of lowered production costs, environmental compatibility, abundance of raw resources, and relatively high thermoelectric performance. In this research, the thermoelectric performance of this class of materials is first reviewed through the key thermoelectric parameters: thermal and electrical conductivity, power factor and Seebeck coefficient. The development fabrication processes for this class of materials which are usednano structuring and element doping strategies, are then elaborated. At last, comments on the thermoelectric applications and device efficiency are made within the context of this material[23].

V. Conclusion

This paper is focused mainly on thermoelectric generator and different technologies which is used on thermoelectric generators. It includes how thermoelectricity is better than other solar based technology to make electricity. But there is a drawback of thermoelectric generators of its low efficiency or low figure of merit. In this review, different methods are presented to obtain a higher satisfactory efficiency. There is easy solution to gain this higher efficiency with the help of material changing properties and waste heat recovery on the both side junction of thermoelectric module.

In the recent years mainly last decades the considerable progresses in materials science and nanotechnologies have brought to a great improvement in the values of the dimensionless figure of merit.

References

[1]. Taleb M. Maslamani et al. Development of solar thermoelectric generator. European Scientific Journal March 2014 edition vol.10, No.9 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431

[2]. Riffat SB, Ma X. Thermoelectrics: a review of present and potential applica-tions. ApplThermEng 2003;23:913–35

[3]. The Science of Thermoelectric Materials, “The Seebeck Effect”, Thermoelectric Caltech Materials Science, Thermoelectrics. Retrieved on January 3, 2013 from http://www.its.caltech.edu/~jsnyder/thermoelectrics/#top

[4]. G. Jeffrey Snyder and Eric S. Toberer "Complex Thermoelectric Materials" Nature Materials 7, 105-114 (2008).

[5]. CRC Handbook of Thermoelectrics, Introduction, Edited by D.M. Rowe, CRC Press, 1995.

[6]. G. Jeffrey Snyder, Tristan Ursell. "Thermoelectric efficiency and compatibility" Physical Review Letters, Volume 91 p. 148301 (2003)

[7]. Thermal Radiaton: Planck’s Law. Warren M. Rohsenow Heat And Mass Transfer Laboratory. Retrieved on January 3, 2013 from http://ocw.mit.edu/courses/mechanical-engineering/2-997-direct-solar-thermal-to-electricalenergy- conversion-technologies-fall-2009/audio-lectures/MIT2_997F09_lec02.pdf

[8]. History of Thermoelectrics, Custom Thermoelectric. Retrieved on January 3, 2013 from http://www.customthermoelectric.com/History.html

[9]. D. Mitrani et al. /One-dimensional modelling of TE devices considering temperature-dependent parameters using SPICE. Microelectronics Journal 40 (2009) 1398–1405

[10]. Nicholas Fuschillo, R. Gibson, and F. K. Eggleston. Theory and performance of flat plate solar thermoelectric generator for near-earth orbits. Supplement to IEEE transactions on aerospace / June 1965.

[11]. F. K. Eggleston and N. Fuschillo.Fabrication of flat plate solar thermoelectric generator panels for near-earth orbits. Supplement to ieee transactions on aerospace / june 1965.

[12]. Speechia et al. High efficiency thermoelectric generator. International journal of hydrogen energy 37 (2012) 1385-1398

[13]. W. He et al. Parametrical analysis of the design and performance of a solar heat pipe thermoelectric generator unit. / Applied Energy 88 (2011) 5083–5089

[14]. R. Bjork et al. Analysis of the internal heat losses in a thermoelectric generator. /International Journal of Thermal Sciences 85 (2014) 12-20

[15]. W.H. Chen et al. Geometric effect on cooling power and performance of an integrated thermoelectric generation-cooling system. Energy Conversion and Management 87 (2014) 566–575.

[16]. SuraTundee et al. Electric power generation from solar pond using combination of thermosyphon and thermoelectric modules. Energy Procedia 48 (2014) 453 – 463

[17]. Baljit Singh et al. Power Generation from Salinity Gradient Solar Pond Using Thermoelectric Generators for Renewable Energy Application. 2012 IEEE International Conference on Power and Energy (PECon), 2-5 December 2012, Kota Kinabalu Sabah, Malaysia

[18]. H.-K. Ma, C.-P.Lin, H.-P.Wu, C.-H.Peng, C.-C. Hsu, Waste heat recovery using a thermoelectric power generation system in a biomass gasifier, Applied Thermal Engineering (2014), doi: 10.1016/j.applthermaleng. 2014.09.070.

[19]. Jeyashree, Vimalajuliet and Alen joseph. Experimental analysis of Thermoelectric generator using solar energy. 2014 International Conference on Smart Structures & Systems (ISSS-2014), Chennai, INDIA

[20]. J. Black, F. K. Eggleston and N. Fuschillo.Thermoelectric bond development for flat plate solar thermoelectric generator. Supplement to IEEE transactions on aerospace / June 1965.

[21]. U. Erturun et al. Effect of various leg geometries on thermo-mechanical and power generation performance of thermoelectric devices. Applied Thermal Engineering 73 (2014) 126e139

[22]. Zhi-Gang Chen and Jin Zou et al. Nanostructured thermoelectric materials: Current research and futurechallenge. Progress in Natural Science: Materials International 2012;22(6):535–549

[23]. M.B.A. Bashir et al. Recent advances on $Mg_2Si_{1-X}Sn_X$ for Thermoelectric generation. Renewable and Sustainable Energy Reviews 37 (2014) 569–584.