

Smart Road Generative Systems: The Future of Renewable Energy Production

A. R. Vishwanath*

Department of Electrical and Electronics Engineering, Bannari Amman Institute of Technology,
Tamil Nadu, India

ABSTRACT

This project aims to produce electricity with the help of roads, hot water and thermoelectric pipes which are renewable resources. This involves zero emission in all forms of pollution. The heat absorbed by the roads due to their black colour is put in use to heat the water which is passed underneath the road with the required conditions and structures. The hot water produced by this method is collected and brought to the generation plant through the same pipeline system and a thermoelectric tube is used to generate electricity from the hot water. Here the Seebeck effect is used to generate electricity from hot water. Instead of the conventional steam turbine method here thermoelectric tubes are used which has high efficiency and low installation cost. The hot water is passed through the thermo electric tube and simultaneously cold water is passed above the tube which causes a change in temperature and loss of heat producing electricity. A generator with four thermoelectric tubes can generate a current of 10 W which can power a LED light, a fan, a portable TV etc.

KEYWORDS: electricity, renewable resource, road, hot water, thermoelectric pipe.

INTRODUCTION

World is in need of Green Energy, refers to non-polluting means of energy production. This is an attempt to utilize the resources which are unattended and our contribution to the need which may be one among the potential solutions. Generating electricity from renewable resources is very much necessary for the present and future generations. Pollution free methods are the most sought after ones. The aim is to generate electricity with the help of hot water. Though there are different ways for generating electricity from hot water, the important challenge is always to heat the water. Though the method of using solar panel or solar heater can be adopted for the same purpose, this method aims to be ten times cheaper than the solar panel method. After the laying of roads by the required method the roads quality and lifetime are increased.

This method aims to absorb heat from roads. Generally the roads which are black tend to absorb more heat from the sun. Thus the heat that is lost in vain is aimed to be generative. Thermoelectric technology is the direct energy conversion from heat into electricity and has attracted much attention as a renewable energy solution. The generation of electricity using the conventional thermoelectric generator method has very low efficiency and practical challenges. Hence this system uses thermoelectric tube, which was developed by the Panasonic Corporation, Japan. The generation of electricity is done from hot water with the help of thermoelectric tubes. The tube structure increases the efficiency much more than the previous methods.

Figure.1 Thermoelectric tube developed by Panasonic Corporation



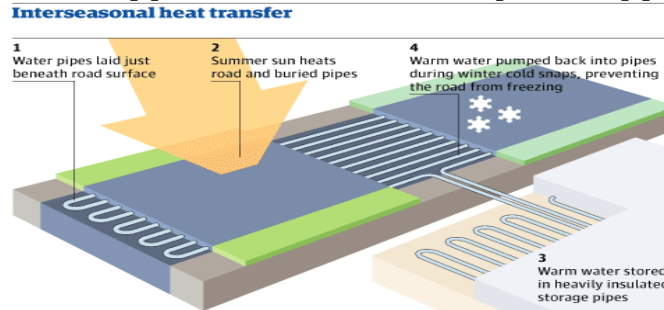
Since conventional thermoelectric generators are complicated in structure and restricted in planar shape, they are difficult to scale-up and implement. Thermoelectric tubes solve these problems by using unconventional phenomena called transverse thermoelectric effect, which takes place in tilted multilayer made of thermally-resistive thermoelectric materials and thermally-conductive metals. This effect makes it possible to control heat flow and electric current independently in materials, and realizes quite simple solution. Thus, the usage of these tubes involves zero emission in all forms of pollution.

CONSTRUCTION OF ROADS

The roads used for this system comprises an asphalt concrete layer with reinforced structure and a water-bearing medium. Asphalt concrete's dark colour has an excellent heat-absorbing property. Tar may also be used for the

same purpose. Water is allowed to flow through the water bearing medium in a slow pace. The water gets heated up and is used for the generation of electricity in the respective method. The advantage for using Asphalt in road construction is it improves the overall strength of the road and its lifetime. Secondly, Instead of laying these for sole purpose we can use this method to relay the road that are damaged and requires relaying.

Figure.2 Water pipelines under road, sun heats up road and pipelines.



The asphalt forms the top layer while a network of flexible pipes held in place is kept underneath it which helps magnify solar heat. The presence of pipes in asphalt influences the durability of the structure negatively because of the peak stresses near the tube which can lead to crack initialisation. The prevention of this phenomenon was one of the reasons to develop the reinforcing grids. The asphalt is generally 40mm thick. The water carrying system consists of a three dimensional polypropylene grid with polyethylene pipes at a centre-to-centre distance of 150 embedded in the asphalt. Metal or iron pipes may not be used because the excessive heat and pressure over the roads may cause cracks and pores on the stiff metal and iron pipes along with the property of rusting.

Figure. 3 Pipes in form of Reinforce grid to avoid peak stress.



A high quality polymer modified bitumen between the base layer and the top asphalt layer provides a flexible but firm adhesion, which is capable of withstanding the thermal movements of the base layers. Depending on the expected movement the thickness of the interface can be varied between 1.0 and 3.0mm. The grid and tube also sprayed with 1.5mm bitumen to provide good adhesion of the asphalt. No huge air gaps should be present between the pipe and the top layer. The rigid structures ensure to hold the pipeline without any damage when the loads move over the road.

PRODUCTION OF HOT WATER

The basic principle employed here to heat the water is the Seebeck effect and the Inter-seasonal heat transfer. The heat absorbed by the roads due to their black colour is put in use to heat the water which is passed underneath the road with the required conditions and structures. Water is continuously passed through the pipeline in a slow speed, enough to absorb the heat. Then the heated water is brought through the pipeline to the generation area where electricity is generated from hot water. The movement of water through the pipes can be adjusted accordingly to the heat available in the atmosphere. The cold water required for the thermoelectric generation does not require any special cooling units but a cool storage tank which maintains the water temperature from 10 degrees to 15 degree Celsius.

THERMOELECTRIC TUBES AND ITS WORKING

Instead of generation of steam from hot water, power is aimed to be generated directly from hot water. The latest invention of thermoelectric tubes satisfies the required needs. It functions through basic Seebeck effect and electricity is generated from loss of heat and difference in temperatures. It replaces the conventional thermoelectric

generators as their structures are complicated, structure is only planar and hot water cannot be used directly. The tubular shape enables direct and efficient heat transfer without additional heat exchangers, yielding high density of generated power. It acts as a heat exchanger which produces electricity. Each thermoelectric tube measures 10cms. The structure of thermoelectric tube is simple with a thermoelectric material of low thermal conductivity and a metal (copper) of high thermal conductivity. Here Bismuth (III) telluride [$\text{Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3$, (BST)/Ni] is used as the thermoelectric material in the thermoelectric tube. The thermoelectric tube is constructed by stacking conical rings of bismuth telluride as thermoelectric material and nickel as metal. Panasonic has developed processing technologies in fabricating conical rings of brittle thermoelectric materials and bonding rings with minimum parasitic electric and thermal losses.

As mentioned above, the thermoelectric tube works with the principle of Seebeck effect. Seebeck effect generates a voltage signal between two arbitrary points by introducing a temperature difference ΔT . Thus, attaching one side of the TE device to hot water and the other side to cold water enables electric power generation with an output proportional to ΔT^2 .

Figure .4 Cross-sectional view of thermoelectric tube.

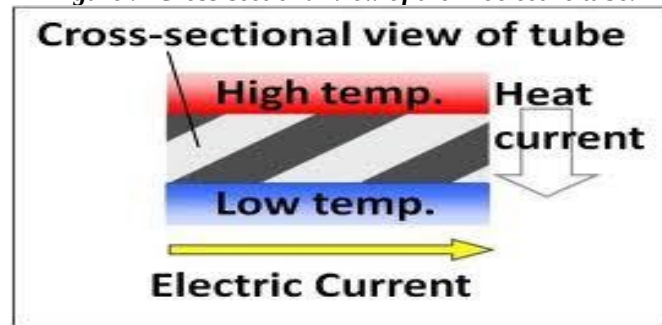
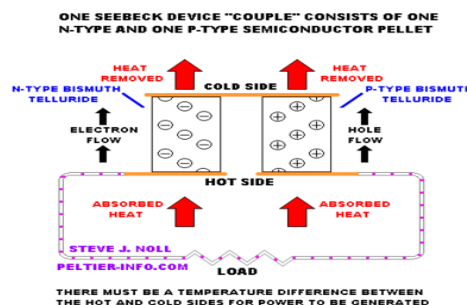
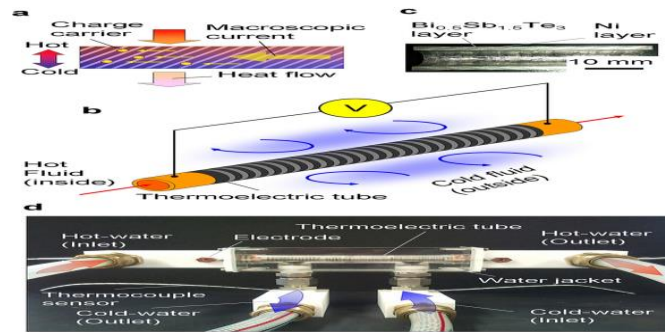


Figure .5 Generation of voltage using seebeck effect by introducing temperature difference



However, it is noticed that conventional thermoelectric devices are prototyped with high thermal resistances to sustain large $-\Delta T$. This means cooling of the exhaust heat which has higher priority than additional power generation. So, to overcome this abnormality off-diagonal thermoelectric effect is introduced, which essentially develops in tilted layered materials and the result is gigantic voltage generation and enhanced power factor for tilted multi-layered materials. So, the BST/Ni is fabricated into multi-layered material and it is used as a thermoelectric material in the thermoelectric tube.

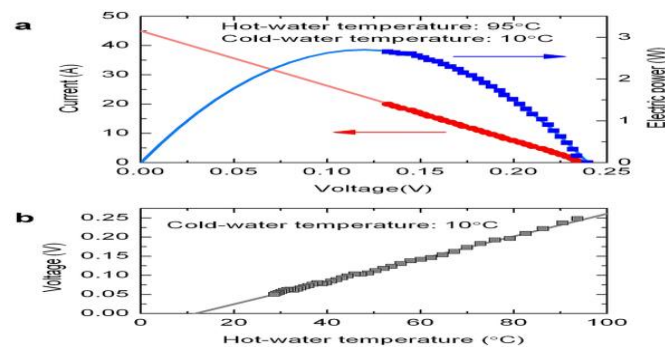
Figure .6 Operation environment of the tubular TE device made of tilted layered material. (a) Schematic of the transverse TE (off-diagonal TE) effect in a tilted layered material. The voltage develops perpendicular to the applied temperature gradient. (b) Schematic of the operation of the TE tube. Temperature difference along the tube radial direction generates an electric signal along the tube axial direction. (c) Cross-sectional picture of the BST/Ni tube. The tilted stripes at the top and the bottom represent the tilted layered structure of BST and Ni. (d) Picture of the experimental setup to evaluate the heat exchange properties and the power generation properties of the TE tube.



Reflecting the tilted layered structure, it is found that a voltage signal uniquely develops in the tube-axial direction by introducing ΔT between the inner side and the outer side of the tube. Namely, the BST/Ni tube can generate electricity by running hot fluid inside the tube and immersing itself inside cold fluid as shown in Fig. 7b. The peculiar tubular shape is practical, which allows the BST/Ni tube to be used as one of the plumbing components in water supply lines in various features. Due to efficient heat exchange and simultaneous high electric power generation from the BST/Ni tube at various water flow conditions the bi-functional BST/Ni tube shall provide practical waste heat recovery solution as an alternative to the existing heat exchangers.

For instance consider an 11cm long BST/Ni multilayer tube with an outer diameter and an inner diameter of 14mm and 10mm respectively. The tilt angle and the thickness of each BST/Ni layers were approximately 35° and approximately 1.3 mm respectively. The electrical resistance R_e of the BST/Ni tube was 4.5 mV. The BST/Ni tube was placed inside an acrylic water jacket with a diameter 18 mm-flow channel. Hot-water was introduced inside the BST/Ni tube, while the outer side was cooled by introducing cold-water inside the acrylic water jacket. The operation environment of the BST/Ni tube explained here is similar to that of the standard shell and tube heat exchangers. It is confirmed that the BST/Ni tube was sealed tightly and that there was no direct intermixing between the hot-water and the cold-water. The hot water and cold water temperatures are 95° and 10° respectively, both at a flow rate of 20L/min. The end result is the open circuit voltage V_{op} is 0.24V and the maximum electric power generated is 2.7W.

Figure .7 TE generation property of the BST/Ni multilayer tube.(a) Current-voltage plot (closed squares) and power-voltage plot (closed circles) of the BST/Ni tube measured by introducing hot-water of 95°C and cold-water of 10°C at F_{cw} and F_{hw} of 20 L/min. The linear fit and the quadratic fit to each data are also shown by the solid lines. (b) V_{op} of the BST/Ni tube measured as a function of T_{hw} . Note that T_{cw} is fixed at 10°C and F_{cw} and F_{hw} is both fixed at 20 L/min.



Using the measured T_{diff} values, the calculated thermal power Q exchanged by the 11 cm tube at each water flow conditions. Defining C_w and ρ_w as the heat capacity and density of water, Q can be expressed as,

$$Q = \rho_w C_w F_{cw} T_{diff}$$

The heat transfer coefficient α of the BST/Ni tube can be calculated as,

$$\alpha = Q / A (T_{hw} - T_{cw})$$

Where A is the heat transfer area. Based on the measured Q values, α is calculated to be as large as $4.0 \text{ kW/m}^2\text{K}$. This is only about half the value (or the same) when a pure Cu tube (or a stainless-steel tube) is substituted into this system, but more than 5 times larger than that achieved by the conventional “ π -shaped” TE devices, which represents that effective heat exchange can indeed be realized by the BST/Ni tube. The conversion efficiency η of the BST/Ni tube was also estimated by using the measured quantities as, $\eta = P_e / Q$.

In artificial tilted multilayer materials, the tensor components of the Seebeck coefficient S , electrical resistivity ρ , and thermal conductivity κ can be calculated by using the physical quantities of the constituent materials. S_{xy} , ρ_{xx} , and κ_{yy} , where x and y corresponds to the direction along the radial direction and the axial direction of the tube, respectively. The transverse ZT ($= S_{xy}^2 T / \rho_{xx} \kappa_{yy}$) of the BST/Ni tube at room temperature is estimated to be 0.144. However, since the equivalent circuit model considers stacking of an infinitely thin layers of BST and Ni, ZT of the actual layered structure, which has a finite layer thickness, is reduced from the above mentioned value. In the present case, with the layer thickness and tube thickness of 1.3 mm and 2 mm, respectively, the reduction factor is estimated to be 0.4. Thus, ZT of the present BST/Ni tube is corrected to be 0.057. Using this calculated ZT , we can further calculate the theoretical η of the BST/Ni tube as,

$$\eta = \frac{\Delta T_{TE}}{T_{h,TE}} \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+T_{c,TE}/T_{h,TE}},$$

where $T_{h,TE}$ and $T_{c,TE}$ is the temperature of the hotter side and the colder side of the tube, respectively, and ΔT_{TE} is $T_{h,TE} - T_{c,TE}$. The values of $T_{h,TE}$ and $T_{c,TE}$ were chosen here as 78°C and 26°C, respectively. This was determined by ΔT_{TE} ($= QR_t$) calculated by the Q measured at F_{hw} and F_{cw} of 20 L/min and the bulk- R_t deduced from the equivalent circuit model. The theoretical η is then calculated to be 0.216%. This value fairly agrees with that of the measured value of 0.189% at F_{hw} and F_{cw} of 20 L/min. The good agreement supports that the present tubular TE device operates on the basis of the transverse TE effect.

It is evident from the theory that the theoretical η is relatively low. Nevertheless, the power density per heat transfer area achieved here (870 W/m²) from the low-grade heat source below 100°C. The low η of the present BST/Ni tube is not much of a problem for practical use considering that the enormous. Furthermore, in many of these facilities, TE generation is expected to be a residual product of cooling of a thermalized object. In this sense, the BST/Ni tube should be more advantageous for application as a heat exchanger aimed for cooling, and also a power generator making electricity at the same time.

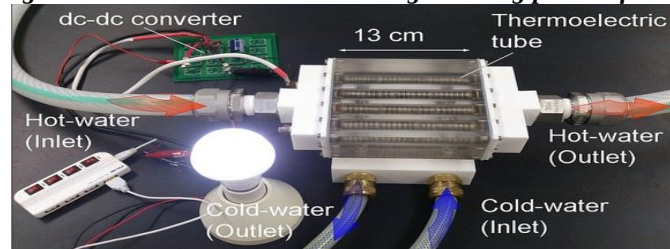
THEMOELECTRIC GENERATION PLANT

The generation plant involves the thermoelectric pipes. The thermoelectric pipes generate electricity from hot water through temperature differences. Each thermoelectric tube measures 10cms. The structure of thermoelectric tube is simple with a thermoelectric material of low thermal conductivity and a metal (copper) of high thermal conductivity. They both are structured in angles to for the tube. The tubular shape enables direct and efficient heat transfer without additional heat exchangers, yielding high density of generated power.

Four thermoelectric tubes are joined parallel with each other and they are placed in a container which can allow the flow of cold water (5-10 degree Celsius) above the tube's surface. Now hot water from the roads is passed through the thermoelectric tubes while at the same time cold water (5-10degree Celsius) is allowed to flow over the surface of the tube. Generally thermoelectric generation accounts to high loss when heat is taken in because thermoelectric materials are attached to the outside pipes such systems had also issues with reliability but the later had been overcome by designing the thermoelectric pipe in a tubular shape. This helps in high heat efficiency with the same size thus the results are four to five times higher than the conventional method.

Having the metal and thermoelectric materials in angles enables the heat flow perpendicular to the direction of flow of water and hence the current generated also flows in the direction of the water flow. So heat flow from inside of the tube to outside while the current flow along the length of the tube.

Figure .8 Four Thermoelectric tubes generating power of 10W.



The 10 cm-long thermoelectric tube generates 2.7 W of electricity from hot running water of 90 °C. When this process is executed with a generator with 4 thermoelectric tubes electric power of 10W is generated. It may be used to power a LED light, a fan, a portable TV etc. The production of thermoelectric tube aims to make it commercially available in the market in the year of 2018. The size of the thermoelectric tube can be varied in future and the heat required to bring about the production of electricity can be reduced and the efficiency can be increased to higher levels. The generation plant can be set up at the required places and the power can mostly be used in powering the street lamps and other nearby consumers.

CONCLUSION AND FUTURE DEVELOPMENTS

The power output can be increased in practice by increasing the size of the generator with many thermoelectric tubes. In the future compactly efficient and economically generative methods from factory waste heat and geothermal springs are also possible. The hot water used can be generated from roads, parking lots, airport runways, etc. This method offers generation of electricity with emission free and renewable methods. The production of hot water from pipelines under roads is 10 times cheaper than the same amount of hot water produced with the solar panel. Though the hot water produced is only 75% as that of the solar panel or solar heater method the initial cost involved in this process is much less than that of the solar panel method of generation of hot water. Thus this method proves to be economically efficient.

This method can be adopted to lay new roads than reconstructing the existing ones. It helps the method to be economically efficient. This system proves to be a major helping hand in powering the electrical devices along the road ways. Its efficiency is high in summer season. The further development of this system may lead to generation of high quantity electricity through renewable and non-polluting means. The future developments are:

- To develop an improved simulation for the project.
- To improve the heat absorbing capacity of the roads, and to develop a working model.
- To experiment the restructuring of the thermoelectric tubes.
- To develop required relations to calculate the flow rate required.

REFERENCES

- [1] Faruk Yildiz, "Potential Ambient Energy-Harvesting Sources and Techniques", The Journal of Technology Studies, Sensors Peterborough NH (2009), vol. 7288, March 2009, pp. 1-7.
- [2] THERMOELECTRIC GENERATOR Filed May 2, 1966 United States Patent O 3,458,356 THERMOELECTRIC GENERATOR Joseph T. Kummer, Ann Arbor, and Neill Weber, Dearborn, Mich., assignors to Ford Motor Company, Dearborn, Mich., a corporation of Delaware Continuation-in-part of application Ser. No. 458,596.
- [3] Bell, L. E. Cooling, heating, generating power, and recovering waste heat with thermoelectric systems. Science 321, 1457–1461 (2008).
- [4] Snyder, G. J. & Toberer, E. S. Complex thermoelectric materials. Nature Mater. 7, 105–114 (2008).
- [5] Dresselhaus, M. S. et al. New directions for low-dimensional thermoelectric materials. Adv. Mater. 19, 1043–1053 (2007).
- [6] Majumdar, A. Thermoelectricity in semiconductor nanostructures. Science 303, 777–778 (2004).
- [7] Goldsmid, H. J. Application of the transverse thermoelectric effects. J. Electron. Mater. 40, 1254–1259 (2011).
- [8] Fischer, K., Stoiber, C., Kyarad, A. & Lengfellner, H. Anisotropic thermopower in tilted metallic multilayer structures. Appl. Phys. A 78, 323–326 (2004).
- [9] Snyder, G. J. & Ursell, T. S. Thermoelectric Efficiency and Compatibility. Phys. Rev. Lett. 91, 148301 (2003).
- [10] Takahashi, K. et al. Bi-functional thermoelectric tube made of tilted multilayer material as an alternative to standard heat exchangers. Sci. Rep. 3, 1501-1–1501-5 (2013).
- [11] Thermoelectric tube developed by Panasonic (Japan), [online] Available: <http://www.panasonic.com/global/corporate/technology-design/technology/tec.html>.
- [12] Small Thermoelectric Generators by G. Jeffrey Snyder.