



## Study of Thermoelectric Generator Utilization to Recover Heat at Low Temperature Grade Application: A Review

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**Abstract:** Generally, the supply of heat energy is abundant in this world especially from direct solar radiation or combustion process activity. However, this energy is mostly wasted and discharged to the environment without recovery and re-utilization process. There is a potential utilization this heat to be converted to electricity using thermoelectric generator (TEG). This technology device has an ability to convert heat to electricity by difference temperature from both surfaces. This device could prevent thermal loss to environment and optimize the system to generate electricity for small and micro scale power generation. This research conducts a literature review about identifying several potential object application or equipment as heat sources from solar energy or combustion activity combine with thermoelectric generator at low grade temperature that has been worked by previous researcher for past 5 years. Current status and working principal of thermoelectric generator are presented briefly. Several parameters such as working temperature range, potential output power, and efficiency system are described and presented. Then, some implementation challenges and opportunity development combination TEGs with each object applications are discussed and analyzed to produce recommendation for further research.

**Keywords:** waste heat, TEGs, temperature gradient, power output

### Introduction

Increasing the world population and economic growth each country rises the demand of power generation. In other side, energy supply for power generation still depends on fossil fuel which the existence is not long-life span and harmful environmental impact. Searching an alternative renewable and sustainable energy sources is an option to replace fossil energy and support the demand in the future to reduce global environmental impact. Some researchers have identified in the past decade the potential of waste heat in surrounding to be a renewable energy source especially for power generation purpose using thermoelectric generator system. This waste heat usually comes from heat loss discharged and transferred through conduction, convective and radiation process from industrial products, combustion process or equipment [1].

There is classification of heat loss process based on range of temperature grade. Each process gives results different

temperature grade. S. Bruckner [2] classify high temperature waste heat with range temperature above 400°C, medium grade temperature is 100-400°C and low temperature grade is below 100°C. Other researcher has classified different range number. Based on Sohel Rana [3] experience result, it categorized for high grade temperature is greater than 650°C, medium temperature grade is 230-650°C, and low-grade temperature is lower than 230°C.

Among of waste heat recovery devices, Thermoelectric has attracted several researchers by its function to recover loss thermal energy from direct solar energy and combustion process from industrial or engine activity. These devices utilize seebeck effect for power production.

This research resumes the potential of object application that utilize waste heat by thermoelectric generator to generate power at low grade temperature (<230°C) based on previous research works and studies in published paper and scientific journal. The purpose of this work is to conduct a

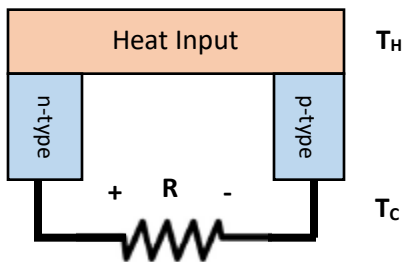


review of thermoelectric generator utilization at low temperature application in the last 5 years to generate power in micro and small-scale application.

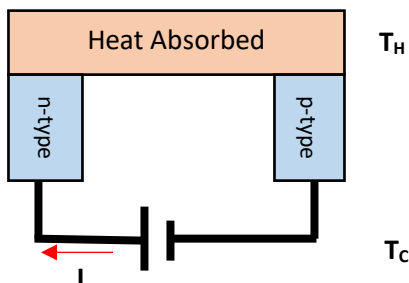
**Method / Metode**

**1. Thermoelectric Devices System**

Thermoelectric devices system is classified by 2 types which are Thermoelectric Generators (TEGs) and thermoelectric cooler (TEC). Actually, each type has similar configuration material and working principle, but different in process that it reverses each other. TEGs utilize seebeck effect to generate electricity from gradient temperature of both material surface as illustrated in **fig. 1**. Then, TEC utilizes Peltier effect to produce cooling effect from electric supply. The work schematic of TEC is drawn in **fig 2**.



**Figure 1.** The schematic of TEGs working principle [4]



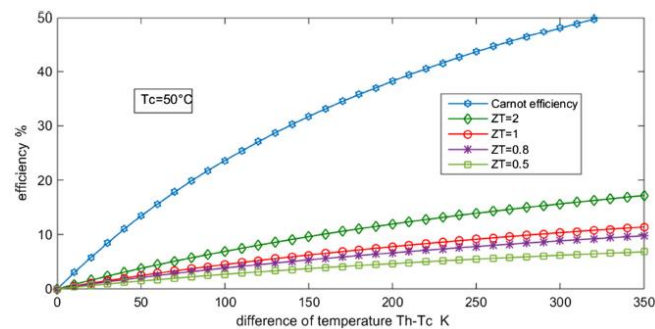
**Figure 2.** The schematic of TEC working principle [4]

To evaluate the performance of thermoelectric devices, it is used an efficiency equation for TEGs and coefficient of performance (COP) for TEC. Hence, TEGs are considered as power generation engine and TEC is considered as refrigerator [4]. The efficiency for TEGs means as ratio of the electrical energy produced with thermal energy input from hot surface as shown in **equation 1** below. COP for TEC is defined as reversed from efficiency equation as written in **equation 2** where  $T_C$  and  $T_H$  indicate the temperature of cold surface and hot surface.

$$\eta_{max} = \frac{W_{electric}}{Q_h} = \frac{T_H - T_C}{T_H} \times \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + \frac{T_C}{T_H}} \tag{1}$$

$$COP_{max} = \frac{T_C}{T_H - T_C} \times \frac{\sqrt{1 + ZT} - \frac{T_C}{T_H}}{\sqrt{1 + ZT} + 1} \tag{2}$$

Based on **equation 1** and **equation 2** above, it shown that the parameter performance of thermoelectric device is not only from temperature value, but also ZT factor. ZT is defined as the dimensionless figure of merit. This factor is strongly related with nanostructure and material properties. Based on research by Daniel [5], the current available of thermoelectric material have ZT factor is around 1 or less. For the most uses in application, Bismuth Telluride ( $Bi_2Te_3$ ) has been implemented in industrial thermoelectric module. **Figure 3** below present the influence of ZT factor to effective thermoelectric efficiency for industrial application. For  $Bi_2Te_3$  module, the average value of ZT is between 0,5-0,8. For the next research development in the couple years, it is expected to reach  $ZT = 1$ . To get efficiency at 10%, it is needed to develop thermoelectric material with value of ZT is 2.



**Figure 3.** Relation of ZT different values with thermoelectric efficiency [5]

There are several advantage of TEGs utilizations combines with other application:

- a. Direct energy conversion to electricity
- b. Minor of maintenance cost and extra cost due to no rotary or moving components and no working fluid
- c. Noiseless operation
- d. Suitable with single or embedded systems

Although this device has numerous advantages, there is still barrier to implement for commercially application. The factor of low efficiency and high cost are still big obstacle in research development. Hence, it is needed a big effort from researchers and manufacturers to improve performance

parallel with reduce the cost in order to make this device become feasible for used as economic and reliable.

## 2. Potential Object Application / Devices

### a. Solar Ponds

Ponds is a territory consist of water in land region that made by human construction or natural activity. Majority of ponds size is smaller than lake. Although the area of ponds is only few hundred square meters, it has potential to absorb and store heat from direct solar radiation during the day. Generally, Ponds divided into 3 layer, which are Upper Convective Zone (UCZ), Non Convective Zone (NCZ) and Lower Convective Zone (LCZ). Each layer has different depth, rate of salinity and temperature distribution. N. Fadliah Baso [7] has explained this layer characteristic in their publication. By this layer characteristic, Pond has potential to store an energy especially heat from sun radiation. Several researcher has identified this potential and conduct research in this sector.

Ding et al. [8-11] conducted several works regarding combination thermoelectric to utilize available heat in the solar pond. They designed [9] 120 module TEGs power generation unit that placed on the exterior of polygonal cylinder and submerged in the LCZ without using pump to flow the water.

The work schematic utilized difference temperature between interior and exterior layer. For interior layer, the cool water was flowed by siphoning effect and hot water was supplied at LCZ. From their experiment, it was produced maximum electrical power of 40.8 W at hot temperature ( $T_h$ ) = 99°C with cooling water flow rate of 11.5 LPM with thermal-to-electric conversion efficiency was 0.8%. The LCZ average temperature of a practical solar pond is estimated to be around 40 - 80°C. Therefore, an output in the range of 19–28 W is more representative for the system with heat-to electric conversion efficiency range from 0.37% to 0.68% based on their study.

Ding et al [11] proposed another design by using a plate type power generation unit (PTPGU). it was found that the system is generated 35,9 W of electricity at hot water temperature of 81°C.

### b. Asphalt Roadway

Roadway is a civil infrastructure has a large surface area that receive high solar radiation. Asphalt roadway is the most pavement that used for urban and highways road [13]. From

that solar energy, abundant of heat is absorbed directly into asphalt roadway and increase the temperature of the road surface. The heat stored inside of asphalt could damage the structure and reduce the life span of asphalt. This thermal energy could be transferred and converted to another useful energy. One of heat recovery technology is using TEGs that can produce the electricity. It is found that there are 2 configuration system [13] to collect heat from asphalt which are liquid and solid system. For liquid system, it involve piping system, pump and heat exchanger. The water is flowed inside of pipe below the asphalt. Then, heat is absorbed by the water and stored at heat exchanger. TEG is placed at heat exchanger to get temperature difference between hot and cold surface of TEG. Compare to liquid system, solid system utilize solid instrument to replace pipe as a media or module for conducting heat such as aluminium bar. This module is buried below asphalt and TEG is placed under the module. So the heat source comes from asphalt surface and transfer to the module and the cold source from soil layer in certain depth. Several work [14-16] has been conducted by researchers to review and investigate various technologies to harvest energy from asphalt roadway.

W. Jiang et al [17] has developed new RTGES prototype (Road Thermoelectric Generator System) integrate with asphalt mixture slab. They used 199 of TEGs in series connection with size of 62mm x 62mm x 4mm. The research was conducted during summer season with temperature gradient about 25-30°C. They got result about 160 kWh of maximum energy during 8 hours of experiment with road test size 1 km of length and 10 m in width.

W. Jiang [18] conducted another experimental works with same number of TEGs (199 pairs) and similar method but different prototype design. From the area about 10,000 m<sup>2</sup>, it could produce a maximum energy output around 33 kWh during 8h in the summer season.

Tahami et al [19] proposed design thermoelectric generator combines with the asphalt pavement. Initially, they designed several models and conducted simulation using computer software to determine optimal design. Then, it was fabricated as prototype and placed below the pavement. Based on their experimental research, their system was able to generate a maximum power output of 34 mW by maintaining temperature gradient at 34°C.

### c. Rooftop

Average Position of rooftop that higher or similar with trees has potential to absorb more heat due to high intensity solar

radiation during the day. Most of the rooftop material are using clay tile and only small population using zinc roof. The heat is absorbed by rooftop and passed on into the room or chamber below the rooftop. The room temperature inside the room increases parallel with high absorption of heat from solar radiation during the day. This will impact the load of Air conditioning inside the house increase and electric consumption bill also rise. The system design of heat exchanger is key role to have a maximum heat transfer to thermoelectric surface.

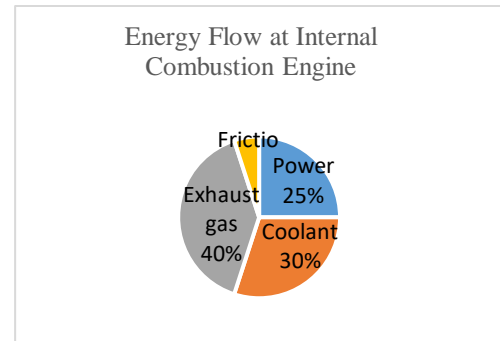
This absorption heat from the rooftop has potential to be recovered and converted by TEGs to generate electricity for self-consumption. Based on the literature review, it is few of researcher doing works in this area. A.E Putra et al,[21] research team from Indonesia has an experimental work with zinc as a material of rooftop. Several parameters are analyzed such as radiation intensity, temperature, power output and efficiency. The maximum temperature gradient was measured only 1,2°C. Their result is not significant that power output 0,00422 W and 0,00888% of efficiency. The low point was due to small difference temperature during experimental.

Nevertheless, there is an opportunity to recover waste heat from the rooftop. Higher position and larger surface of heat absorption are an advantage to get more direct solar radiation as a heat source. This concept could combine with thermal storage technology as media to store heat. Challenge to install thermoelectric into rooftop is design the system for existing rooftop. It means that it need restart and rebuild the foundation of rooftop. It takes a time and cost of money for existing rooftop.

#### d. Automotive exhaust

Recently, most automotive engine is still using Internal Combustion Engine (Spark ignition or diesel engine) as the main engine for prime mover. It means that the combustion using liquid fuel inside of the engine. This engine type doesn't convert all chemical energy into mechanical energy. From the fuel energy supply at ICE, it is only 25% that convert to power output for driving (see **figure 4**). Majority of fuel energy is indicated as an energy loss to surrounding that dissipated as waste heat through engine exhaust [22].,

Several researchers have worked to optimize the ICE system by recovering the waste heat from engine exhaust using thermoelectric to optimize the system, produce power and reduce the emission. They named it ATEG application (Automotive Thermoelectric Generator) as a combination device between thermoelectric and automotive heat exchanger equipment.



**Figure 4.** Energy Flow at Internal Combustion Engine [22]

M. Aljaghtham et al [23], performed simulation to integrate ICE engine with thermoelectric by designing oil pan shape and size. Parameters such as module geometry, quantity of TEG, oil pan shape and temperature gradient was optimized during simulation to get ideal design. The power density result was 5,77 kW/m<sup>2</sup> with temperature difference of 76°C.

S. Arumugam et al [24] also developed a theoretical model with 3 various profile of parabolic fins with different fin length using Bi<sub>2</sub>Te<sub>3</sub> thermoelectric module. The result of this simulation was 21.77 kW as the maximum power output with TEG efficiency reach 48%. The result was quite high than the reality due to the value of merit figure (ZT) was 2.4.

P. Fernández-Yáñez et al [25], conducted an experimental research to obtain power output from heat recovery process using combination TEG with both type ICE (spark ignition and diesel engine) and compared to electric turbo-generator. Based on their result, it reported that maximum power output TEG-CI engine reach 55,4 W, while TEG-SI engine reach 127 W with full load condition and no by pass.

C. T. Hsu et al [27], have constructed experimentally using 24 TEGs into automobile exhaust gas to recover waste heat and produce electrical energy. Their research could harvest maximum power output of 12,41 W with temperature gradient around 30°C.

T. Y. Kim et al [28] performed experimental research by using 40 TEG to recover heat from diesel engine. The configuration of TEGs was placed in rectangular exhaust gas channel with 4x5 arrangement. Some parameters such as various engine load and an interval of 0.2 MPa for brake mean effective pressure (BMEP) was conducted to get a maximum output and energy conversion efficiency. They got result that the maximum power output from this research was 119 W at 2000 rpm with a BMEP of 0.6 MPa. The maximum energy conversion efficiency reached approximately 2.8%

Utilization of TEGs has been worked with R. Sukarno [31] by design heat exchanger using heat sink as the main

component combine with TEG to recover heat from 110 cc of motorcycle exhaust gas. He obtained the maximum result that voltage of 2094 mV and current of 205 mA at temperature difference was 74°C.

## Results And Discussion

**Table 1** presents the resume of each potential object application with value parameters from the previous researchers during the utilization of TEGs in the low-grade temperature.

**Table 1.** Parameters of TEGs utilization

No	Potential Object Application	Range of temperature gradient (°C)	Number of TEGs	Potential Maximum Output Power	Reference
1	Solar Ponds	40-80 56	120 500	19.5-27.8 W 35.9 W	[9] [11]
2	Asphalt	25-30 25-30 34	199 199 2	20 kW 4.125 kW 34 mW	[17] [18] [19]
3	Zinc Rooftop	1,2	127	0,0042	[21]
4	Automotive exhaust	76 - 30	80 -	5.77 kW 55 W (TEG-CI) and 127 (TEG & SI) 12.4 W	[23] [25] [27]

Generally, It showed that the potential maximum output power is influenced by temperature gradient and number of TEGs. Higher number of temperature range and TEGs, more output power is produced. In this case, temperature gradient is important parameter that dependent with external factor especially from environmental surrounding such as solar radiation, humidity, and wind speed. Hence, it needs to determine from where the hot source and cold source initially. From 3 application above which are ponds, asphalt and rooftop, the hot source is from solar radiation. Higher intensity of solar radiation, temperature increase and become hotter. The cold source could be obtained from the fluid flowing directly by pump/compressor or indirectly by air natural convection cooling.

Then, for an automotive exhaust, the hot source is from engine combustion process and the cold source is obtained from lubricant or similar method with other application. To integrate between hot and cold side, optimization of configuration system is required. Several researchers have

developed each prototype for each application in order to maximize heat transfer between both sides.

## Conclusions

In conclusion, this study reviews the integration between thermoelectric generator (TEG) and several potential object that has been worked by previous researchers at Low temperature application. TEG is a promising technology device to produce electricity by recovering waste heat from active and passive application. By employing TEG into these potential application, it could reduce energy loss to environment while harvest and conserve the energy system. There are several key findings by integrating TEGs with some simple object or application from this research. The largest surface of object that receive high solar radiation such as ponds, asphalt and rooftop have potential to utilize heat absorption and recover it to produce micro and small-scale electrical power generation using thermoelectric generator. The temperature gradient as a key parameter in this application to produce a maximum power output is mostly influenced by solar radiation intensity and cooling effect to maintain the difference temperature from both side of TEGs. Potential of using TEGs to produce electricity from exhaust waste heat recovery is huge because of the high number of automotive users recently. Temperature difference from automotive application is depend on type of ICE, load engine and mass flow to generate hot side and lubricant for cold side in order to achieve maximum result.

## Conflicts of interest

There are no conflicts to declare

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