Thermoelectric application in energy conservation

Andrya Muhamad Zuhud[1,*], *Facta* Mochammad[2] and *Widayat* Widayat[2]

[1] Study Program of Magister Energy, School of Postgraduate Studies, Diponegoro University, Semarang - Indonesia
[2] Department of Electrical Engineering, Faculty of Engineering, Diponegoro University, Semarang – Indonesia
[3] Department of Chemical Engineering, Faculty of Engineering, Diponegoro University, Semarang – Indonesia

Abstract. In the becoming years, energy demand is expected to grow faster than current needs. Thermoelectric technology works through conversion process from heat energy into electricity directly and vice versa. Thermoelectric device that use for energy conversion from heat into electrical is known as thermoelectric generator (TEG). TEG is made of Bismuth Telluride, Lead Telluride and Silicon Germanium compound which contains figure of merit (ZT). In term of applications, TEG is possible to be applied in extreme condition such as a power supply in the space mission, harvesting heat from transportation vehicle, and getting waste heat from industrial sector. Furthermore thermoelectric generation is possible also to be applied as a micro power generation system which is very useful for electrical source for residential installation. In this paper, a brief review of above applications is presented. Early developed research investigation is carried out for application of thermoelectric generator in residential installation by using biomass wooden-fuel stove. The early result shows that there are amount of heat emitted from the side cylinder cook stove as energy waste. There is a chance and possibility to harvest energy waste in the stove to become electric source and finally this related research effort will increase the efficiency of the electric stove in energy conversion.

Keywords: **Thermoelectric; Thermoelectric generation; Thermoelectric applications.**

1. Introduction

In the becoming years, energy demand is expected to grow faster than current needs. How to manage the energy in a better way is the best things to do especially by increasing energy efficiency. Furthermore alternative energy resources may reduce environmental impacts [1-2]. Residual energy is one of the alternative energy from conversion process in industry and it usually presents in the heat form. This heat can be converted to electrical energy by using thermoelectric technology as a promising solution. Thermoelectric has been applied in several environments by harvesting the waste heat to increase the energy efficiency of the certain energy conversion devices/machines.

The rates of generated power from thermoelectric devices are usually low, as conversion efficiency of ~5%, but it was appropriate for low power requirements applications. Several advantages in using TEG are reliable, simple, small dimension, flexible power source, environmentally friendly and having high durability to be installed in extreme condition [3].

In this paper, we briefly presents basic technology of TEG, several application of TEG in extreme condition, industry and residential. At the end of the manuscript, we present developed work to harvest the waste heat of residential using biomass metallic cylinder cook stove with wooden pellet fuel. The early result for this developed work is that the top of the stove cylinder has a highest heat than the middle and base position. The top position the most potential position to place the thermoelectric device to harvest the heat waste of that stove.

2. Thermoelectric technology

The potential of electrical energy generation by using thermoelectric effect is available where the temperature different exist. Thermoelectricity is a physical phenomenon that changes directly heat energy into electricity or vice versa based on the material temperature. Thomas J. Seebeck in 1822 discovered the electrical generation from thermal energy directly after across of two semiconductor materials have a temperature difference [4]. Seebeck effect occurs if the electrons move from lower to higher energy level region and generates an

* Corresponding author: zuhud.andrya@gmail.com,

electric voltage caused of the temperature differences at the ends [5]. The relationship of temperature diffent and generated voltage is shown in Eq. (1). In the equiation, V is voltage, and S is the Seebeck coefficient.

$$V = S (T_1 - T_2) [V] \quad (1)$$

The *Peltier effect* is the opposite effect of *Seebeck* and discovered in 1834, by J. C. A. Peltier. This effect shows that when dc current flows in a bimetal junction circuit of the material, it brings out cooling or heating effect and it depend on the current direction. The Eq. (2) shows that the amount of heat in the junctions (Qc) is proportional to the supplied current times of Peltier coefficient [5].

$$Qc = \pi . I \text{ [W]} \quad (2)$$

2.2. Thermoelectric materials

Generally, conductors, semiconductors, and insulation are the types of thermoelectric materials that requiring a low thermal conductivity (k), high electrical conductivity (σ) and high Seebeck coefficient (S). The last three parameters above become the important properties in thermoelectric material. These properties specify the Figure of Merit (*ZT*) of the materials. High Seebeck coefficient influences the level of optimum efficiency during energy conversion [5]. The thermoelectric material is considered as a good material as that material has *ZT* value close to 1 like the bismuth and tellurium compounds at room temperature. The material performance related to *ZT* is given by Eq. (3) with k is the thermal conductivity coefficient, [W/(m·K)][6].

$$ZT = (S^2\sigma/\kappa)\ T \quad (3)$$

Low efficiency is the obstacle of thermoelectric application development, so that, there are three main issues that need to improve *ZT* value i.e. increase the operating range, work in the higher temperature difference, get the low-cost materials [1]. *Bismuth telluride*, *Lead telluride* and *Silicon germanium* are the types of compounds with the best *ZT*, and operate in some of the temperature ranges operation [5]. Most of thermoelectric research focused to find the new material compounds with the high *ZT* value [6].

3. Application of thermoelectric

According to its application, thermoelectric modules have various specifications commercially available modules with vary thickness, heat transfer range, and several temperature gradient ranges between the hot and cold side [5].

3.1. In the extreme environment conditions

Electricity generation in the extreme environments has to meet a strict specification. High reliability means the rate of maintenance must be as low as possible related to the difficulty of the access location.

In the aerospace project, the use of thermoelectric devices needed as the energy concern [5]. Photo–voltages solar panels being used, but these cannot be effective as power supply devices in the space vehicles that are far from the Sun, because of the low intensity of the solar radiation [7]. Thermoelectric generator devices combine with nuclear technology using natural radioactive plutonium-238 decay as the heat source. This combination technology is known as *Radioisotope Thermoelectric Generators* (RTGs) [8].

The first RTGs application for space mission was in 1961 to power satellites Transit 4A Spacecraft and operated for 15 years [9]. However, during the use of RTG in space mission, its power decreases gradually due to degradation of the nuclear decay and the thermoelectric materials [8].

Based on the experiments in using TEG in Space, then TEG is promising for remote locations. Electricity produced by TEG has a high reliability and minimum maintenance. Today, several of companies provide installations of electricity generators for remote location by using TEG. Although the efficiency is small i.e. around 2.3%, but TEG gives the benefits use in desert, remote well sites, offshore platforms and in the telecommunication sites which is far away in mountains.

3.2. In transportations application

TEG can contribute to the energy recovery system by using thermal energy losses conversion to the electricity directly. The high potential sector for TEGs application is to harvest heat lost in the transportation industry to become an electrical energy.

The high of engine surface temperature in the aircraft is a good place for TEG application. The heat can be utilized from the compressor, burning chamber, and exhaust pipes, but the use of TEG can also increases the weight of the aircraft. So, the constraint of the TEG design installation in the aircraft engine is probably need to overcome by searching the new light materials [1]. The thermoelectric cooling system only consume dc power makes it more efficient, lighter, compact and less energy consumption. Reduce of the electricity consumption of the aircraft is very important in the commercial aviation industry. Boeing Research & Technology showed that the low efficiency and high cost makes application of the TEGs is still limited but a reduction in airplane weight reduce more than 0.5% consumption of the fuel [5].

Shortage of oil and environmental pollution are the main factor lead to the need for the more efficient engine generation in passenger vehicles [10]. In the following years, many vehicle companies manage to implement the thermoelectric generator in their products.

Basically, only 25 percent of the energy from the fuel of car effectively becomes energy for motion, air conditioning, electronics appliances, and alternator in amount. About 75 percents of energy from the fuel of car become the losses, and mostly of energy converted into friction and heat through the exhaust system [11].

3.3. Industrial sectors

Although the waste heat is often re-used in the industrial sectors mostly they are released to the atmosphere. The Japanese integrated steel industry could increase of their effective energy use by using 896 units of TEG system [12]. One of the high energy-intensive example in the industrial process is in cement production. TEGs also possible to recover approximately 10–15% of wasted heat of the kiln in Portland cement manufacture [13].

3.4. In micro-power generation

Industry also requires sensors in the production process of the factories to be competitive. The sensors only need a few watts to operate. The power source of sensor should match with the lifecycle of sensor. The most common power source for sensor is battery. Difficulty are often found and costly in order to change the battery in some of the industrial applications according to the geographical constraints, restriction access, nuclear power plants, military facilities, and the secure data centres due to safety reason and the extreme condition where the applications present. Manufacturers are producing a few watts generators sensors and make them work autonomously using thermoelectric based of micro-power generator like electronic sensors [1].

3.5. In cooling application

The common application of thermoelectric devices is as cooler, working with the Peltier effect to keep the electronic and optoelectronic components maintained in the low temperature and dominantly used at present [11]. Thermoelectric refrigerators are considered to be applied other than conventional refrigerators because they contain no CFC coolant that supports global warming, not heavy and heavy construction, and that is low power consumption [14]. The simplicity, high reliability, and silent operation are the typical advantages of this application but it still has lower performance [15]. The technology is still not competitive yet for air conditioning system, but this refrigerant free technology can be an attractive solution to consider [16].

3.6. Renewable energy plant

Thermal photovoltaic and thermoelectric combination systems that are aimed concentrating *Solar Thermoelectric Generator* (STEG) using the optical concentration as a solar thermal absorber system. The difficulty for this system is how to concentrate the heat on the TEG elements and withstand in very high temperatures of more than 1000°C. This condition, however, makes the PV cells being too hot and reduce the lifetime of the systems [11]. This application gives more option of renewable energy conversion plant.

3.7. Thermoelectric in residential installation

The two main applications of thermoelectric modules in residential applications are as TEG and thermoelectric cooler (TEC). In the rural community, woods are burned with low thermal efficiency and directly contribute to the local problem such as deforestation and public health issues [30].

The wooden-fuel cooking stoves is possible to use as a electric power supply by applying two thermoelectric modules [19], and produced about 3.4 W maximum power. This technology also developed into biomass stoves in Malawi [20]. An 80-days field trial indicated that the stove generator fed LED lighting and charging mobile phones [37]. The stove generator technology also can use water for the heat exchanger [23].

We also conduct the possibility study to reuse the heat using TEG placed on the side of the metallic cylinder stove in Diponegoro University. The goal of this experiment is to increase efficiency of the stove with biomass wooden-pellet fuel by harvesting the waste heat using TEG. In Figure 1, the stove (1) is filled by 350 mg wooden-pellet fuel and managed to boil 1 litter of water. Three sensors of heat (2) are placed in top, middle, and base position at the wall of stove cylinder, the automatic data recorders (3) based on 8-channel thermocouple input type USB-4718 connected to computers (4). Figure 2 shows the temperature record of the stove cylinder. Position #1 is located at the top, Position #2 at the middle, and Position #3 at the lowest spot of the cylinder wall of the stove. The graph shows that the highest temperature is recorded at the top, then it is followed by the temperature of the middle and the base. By this result we can determine the most prominent potential position to place the TEG devices to harvest the heat waste of that stove and to increase the cooking stove efficiency.

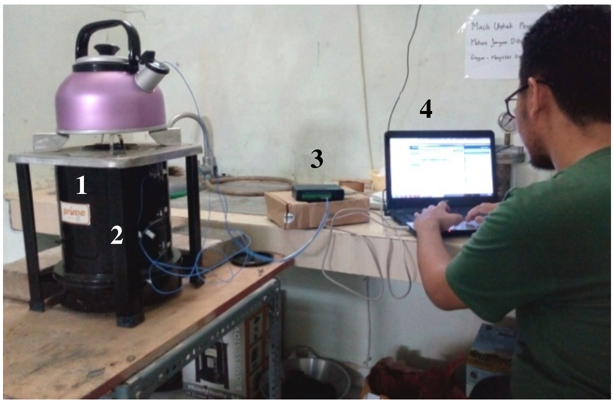

Fig.1. Experiment of the waste heat recovery system study in the wooden cooking stove using TEGs.

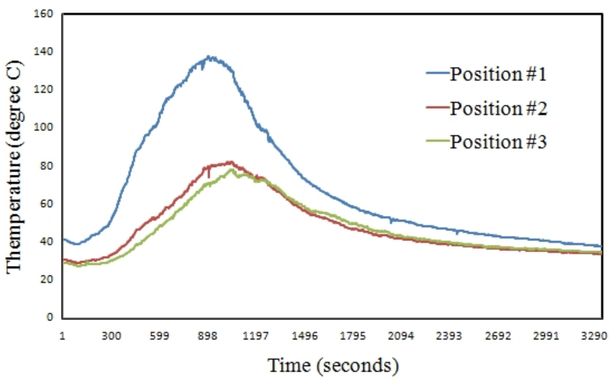

Fig.2. Preliminary experiment result.

4. Conclusion

To conduct the energy conservation for the future, energy management is one of the necessary things to do. Thermoelectric may become one of solution to recover the loss of energy especially in heat energy form. The thermoelectric technology can be used as generator and cooler devices in any systems. Thermoelectric device has large application especially in energy conservation, such as from the space mission until the electric generator in residential installation.

In domestic application, thermoelectric generator technology can be used to provide small scale electricity from harvesting the waste heat of the cooking stove. An experiment developed to investigate the use of TEG to harvest the waste heat of biomass metallic cylinder cook stove with biomass wooden-pellet fuel in Diponegoro University. The early results of this work is the top of the stove cylinder has a highest heat besides the middle and the base position. It will help us to determine of the highest potential position to place the TEG devices to harvest the heat waste of that stove and then we can see the possibility to reuse the heat. Finally the expected goal of this experiment is to increase the efficiency of the stove by using thermoelectric generator.

5. References

1. D. Champier, 'Thermoelectric generators : A review of applications', *Energy Convers. Manag.*, **140**, (2017)
2. I. Dincer, 'Renewable energy and sustainable development: a crucial review', *Renew. Sustain. Energy Rev.*, **4**, 2 (2000)
3. B. Ismail and W. Ahmed, 'Thermoelectric Power Generation Using Waste-Heat Energy as an Alternative Green Technology', *Recent Patents Electr. Eng.*, **2**, 1 (2009)
4. Enn Velmre, 'Thomas Johann Seebeck (1770–1831)', *Est. J. Eng.*, **13**, 4 (2007)
5. O. H. A. Junior et al., 'A review of the development and applications of thermoelectric microgenerators for energy harvesting', *Renew. Sustain. Energy Rev.*, **91**, (2018)
6. Z. Ren et al., 'Nanostructured Thermoelectric Materials', in *Modules, Systems, and Applications in Thermoelectrics*, 1st ed., D. M. Rowe, Ed. CRC Press Taylor & Francis Group, (2012)
7. S. V Novikov et al., 'Reliable Thermoelectric Generators for Space Missions', in *Proc. 11th Eur. Conf on Thermoelectrics*, Springer Int. Publ. Switz. 2014, (2013)
8. NASA/U.S. Departement of Energy, 'Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)', (2013)
9. R. D. Abelson, 'Space mission and applications', in *Thermoelectric Handbook: Macro to Nano*, D. M. Rowe, Ed. Taylor and Francis, (2006)
10. M. Morschel et al., 'Assessment of Thermoelectric Power Generation for Hybrid Electric Vehicles Based on Tracked Data', in *Proc. 11th Eur. Conf. on Thermoelectrics*, (2014)
11. P. Douglas, 'Thermoelectric energy harvesting', in *Concepts Towards Zero, Power Information and Communication Technology*, Intech, (2014)
12. T. Kuroki et al., 'Waste Heat Recovery in Steelworks Using a Thermoelectric Generator', *Proc. 11th Eur. Conf. Thermoelectr.*, (2014)
13. Q. Luo et al., 'A Thermoelectric Waste-Heat-Recovery System for Portland Cement Rotary Kilns', *J. Electron. Mater.*, **44**, 6 (2015)
14. R. Sutanto and D. K. Putra, 'Unjuk Kerja Kotak Pendingin Termoelektrik dengan Varuasi Laju Aliran Massa Air Pendingin', *J. Tek. Mesin*, **07**, 1 (2018)
15. G. Min, 'Improving thermoelectric cooling by light emission', in *Proc. 11th Eur. Conf. on Thermoelectrics*, A. Amaldi and F. Tang, Eds. Springer, (2014)
16. A. Zuazua-Ros et al., 'Investigation of the thermoelectric potential for heating, cooling and ventilation in buildings: Characterization options and applications', *Renew. Energy*, **131**, (2018)
17. A. Anozie et al., 'Evaluation of cooking energy cost, efficiency, impact on air pollution and policy in Nigeria.', *Energy Procedia*, **32**, 7, (2007)
18. J. Parikh et al., 'Exposure from cooking with biofuels; pollution monitoring and analysis for rural Tamilnadu, India', *Energy*, **26**, (2001)
19. R. Y. Nuwayhid et al., 'Low cost stove-top thermoelectric generator for regions with unreliable electricity supply', *Renew. En*, **28**,2, (2003)
20. S. M. O'Shaughnessy et al., 'Small scale electricity generation from a portable biomass cookstove: Prototype design and preliminary results', *Appl. En.*, **102**, (2013)
21. S. M. O'Shaughnessy et al., 'Performance analysis of a prototype small scale electricity-producing biomass cooking stove', *Appl. Energy*, **156**, (2015)
22. S. M. O. Shaughnessy et al., 'Adaptive design of a prototype electricity-producing biomass cooking stove', *Energy Sustain. Dev.*, **28**, (2015)

23. A. Montecucco et al., ‘A Combined Heat and Power System for Solid-fuel Stoves Using Thermoelectric Generators’, *Energy Procedia*, **75**, (2015)