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Thermal Management of Solar Thermoelectric Power Generation

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ABSTRACT: Solar energy utilization efficiency of solar thermoelectric generators mainly depends upon the temperature gradient available across the power module. The temperature gradient can be increased through the better performance of the thermal management system. This work reviews the thermal management of solar thermoelectric power generation by material selection for thermoelectric generators, solar absorbers, insulation, and heat exchanger to improve solar energy utilization. The proper maintenance of temperature gradient in the range of 150-300°C across the power module is attainable through the effective heat exchanger designs. Higher conversion efficiency up to 8.5% was observed in the literature due to the practical material selection and temperature gradients.
Key words: Thermoelectric generator, Parabolic dish solar collectors, Thermal energy storage, Seebeck effect.

INTRODUCTION

The energy crisis, pollution control, global warming is some of the recent significant difficulties. To overcome these difficulties, power generation through renewable energy sources is one of the promising solutions. Many renewable energy power plants are already installed throughout the world. Many research works are going to overcome the limitations of these kinds of power plants. Solar energy is one of the promising renewable energy sources. Very low efficiency is the major limitation of solar thermoelectric generators (STEG).STEGs operate by absorbing concentrated sunlight to produce a temperature gradient. Generating electricity is made using the Seebeck effect. The sunlight is converted to heat and then, thermoelectric conversion takes place. Output power generated from STEG's depends upon the temperature gradient. Increasing the temperature gradient can be achieved by increasing the energy absorbed from the sun and decreasing the system's energy loss. Thermal management plays a vital role, even deciding the efficiency of the STEG and the generated power generated. The thermal management system includes thermal insulation, heat sink.Parabolic dish solar absorbers produce heat flux at the absorber surface which can be used as the hot side of the thermoelectric modules [1]. The material aspects of solar thermal collectors are essential to the deployments [2]. For low temperature applications up to about 300 °C, α-MgAgSb-based materials were found to be attractive in terms of thermoelectric power conversion efficiency of about 8.5% at the temperature gradient of about 225 °C [3]. A hybrid-cavity photovoltaic (PV)-thermoelectric generator (TEG)showed thrice the performance of flat PV-TEG system. The efficiency improvement was 18.9% higher than the conventional system [4-6].

Various thermoelectric cooling systems were discussed regarding advances in materials and design approaches with solar thermal and photovoltaic energy systems [7-10]. The opaque PV-TEC collector was investigated [11]. Introduction of air duct was beneficial to enhance generation of electrical energy and thermal energy. The thermosyphon effect with two-phase for thermoelectric was observed with a stable working temperature in the range of 100–300°C [12]. The maximum power increased exponentially with temperature difference. The power output of 20 W obtained at a temperature difference of 210°C. A novel inverse methodology was used to optimize the dimensions of various regions of solar pond to provide the required temperature gradient towards the production of thermoelectric power annually [13]. The increase in scattering effect improves the

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power generation. In high temperature solar thermal power systems, thermoelectric modules are selectively used to harness the power from the temperature gradient. Thermoelectric power generation is effectively proposed for industrial waste heat recovery. Sometimes, the thermoelectric modules were employed on the combustion chamber walls to produce electricity. In space application, phase change material-based thermoelectric modules were investigated.

Fish-bone shaped fins were used to improve the hot and cold side heat absorption of thermoelectric modules. The integration of thermoelectric modules with cook stoves was one of the feasible options to generate power. The power generated using TEG was found to be capable of driving the fan for the operation of the stove. PV and thermoelectric hybrid systems were determined thermodynamically, and the promising results were obtained for the electrical and thermal performance improvement. Poly-generation aspect is observed with the hybrid energy systems. The maximum input heat flux varied by 42.49% with wind velocity variation from 1 to 5 m/s.The optimum inclination was determined to be about 45° for horizontal rotation. Co-based and PbS-based thermoelectric materials produced higher conversion efficiencies. Heat pipe-based thermoelectric power was found to be effective for waste heat recovery and power generation. Inorganic thermoelectric materials reviewed and parametric analysis of asymmetric thermoelectric systems for power production. In this article, the recent developments in the materials and utilization aspects of TEG-coupled with solar thermal systems are discussed to provide the insights towards the commercial deployment of TEG in various applications.

RESEARCH METHODS

The articles are selected from the Scopus database on the thermoelectric generators in the recent three years and the review is carried out based on the materials and hybrid energy systems and the year-wise distribution of the articles is shown in Fig. 1. The major findings of the researchers are discussed to provide an insight into the latest developments in the thermoelectric power generation.

THERMOELECTRIC POWER GENERATION

The concept of power generation through solar thermoelectric power generator is demonstrated in figure 2. Solar thermoelectric generator consists of three subsystems 1. Parabolic solar collector, 2. Thermoelectric generator, 3. Energy storage unit. Parabolic solar collector focuses the solar radiance to the thermoelectric generator which is placed at the focal point of the Parabolic solar collector. The thermoelectric generator consists of hot side, See beck module and cold side usually a heat sink. Higher the temperature difference, higher the power generation. Thermal management plays an essential role to increase the temperature difference. Thus, the electricity generation depends on the temperature gradient and the enhanced heating and cooling of STEG depends on the material selection and operating conditions.

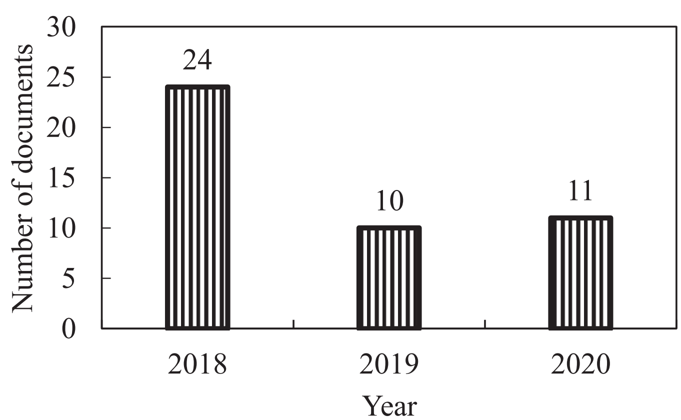

FIGURE 1. Literature discussed in the present article.

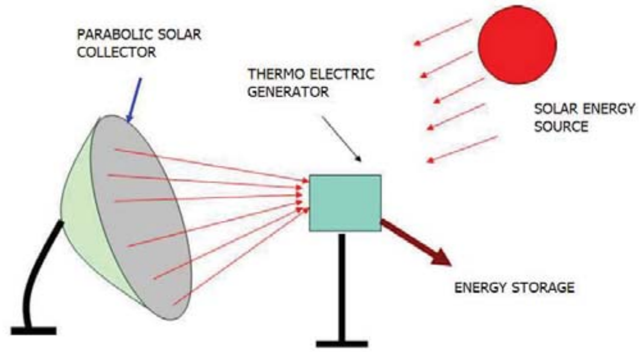

FIGURE 2. Schematic of solar thermoelectric generator using parabolic dish collector**.**

THEORY OF THERMOELECTRIC GENERATION

Seebeck effect is the base of thermoelectric generation. Fig.2 demonstrates the Seebeck effect. Consider two dissimilar metals A and B are connected to form a circuit. When one joint is maintained at a high temperature T_1 and another joint is maintained at a low temperature T_2, then the electromotive force V can be expressed in Eq. (1),

$$V = \pi \Delta T \quad (1)$$

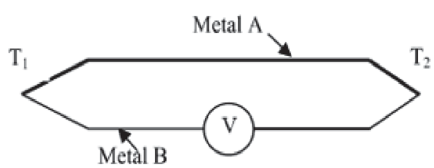

Fig.3.
Thermoelectric effect.

TEG module efficiency is expressed in Equ.2.

$$\eta = \left(\frac{T_H - T_C}{T_H}\right) \cdot \frac{\sqrt{1 + ZT_{avg}} - 1}{\sqrt{1 + ZT_{avg}} + \left(T_C / T_H\right)} \quad (2)$$

Where,

Temperature gradient (T_h and T_c),

Average temperature ($T_{avg} = 0.5\ (T_h\text{-}T_c)$)

Figure of merit (Z),

Where, $Z = S^2\sigma / k$

Seebeck coefficient (S),

Electrical conductivity (σ),

Thermal conductivity (k) of TEG materials.

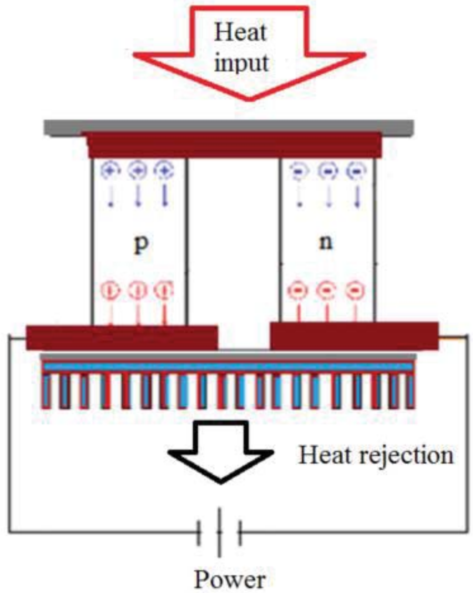

FIGURE 4. Schematic layout of TEG.

Figure 4 shows the schematic layout of TEG. Thermal insulation plays a significant role in minimizing the energy loss of the system. Thermal insulation ensures the minimal loss of the temperature from the system, which in turn maximizes the temperature gradient. Eventually, thermal insulation helps to achieve maximum efficiency and maximum output power at operating temperature. Heat flow was a natural phenomenon when two objects of different temperatures came into contact. Thermal insulation provides a region of insulation in which heat flow is reduced. Thermal insulation is achieved by the usage of bad conductors or insulators. The heat sink is placed at the low temperature side of the thermoelectric generator. Since the electricity generated is directly proportional to the temperature difference, heat sink needs to be maintained at a low temperature to increase the output power. Figure 5 shows the heat sink design. The classification of heat sinks ismade as per the final shapes. The most common types of air-cooled heat sinks include:

1. Stampings
2. Extrusion
3. Bonded/ Fabricated Fins
4. Castings
5. Folded Fins

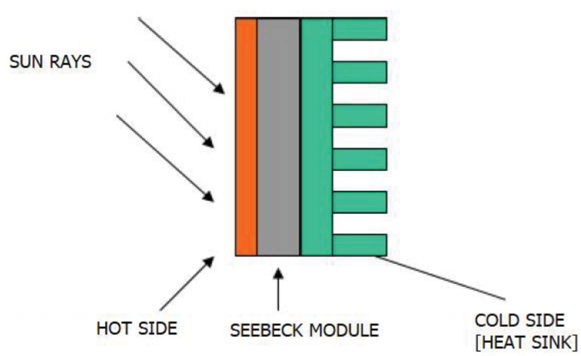

FIGURE 5. Construction of STEG.

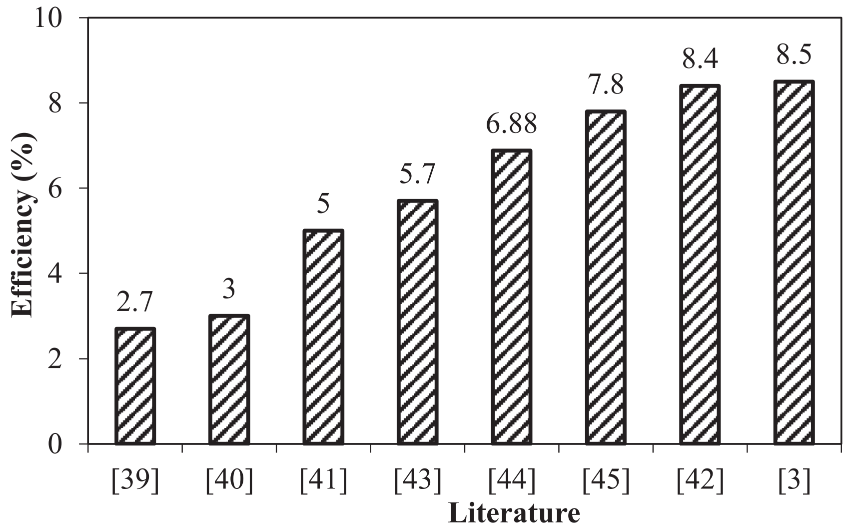

FIGURE 6. Thermoelectric conversion efficiency of previous studies.

Thermal management of the STEG is essential in maintaining and increasing the temperature difference, which in turn increases the efficiency and the output power. Thermal insulation and heat sink are the two thermal management subsystems, which are very important in deciding the output power and performance of the solar thermoelectric generator. The operation of heat sink includes air cooling, water cooling and phase change material (PCM) based cooling. A hybrid cooling concept is also suitably employed.

The thermoelectric power conversion is highly depending on the temperature gradient and the materials used in the construction. The conversion efficiencies are varying in the range of 2% to 8.5%.Figure 6 shows the thermoelectric conversion efficiency by several researchers. The temperature gradient depends on the nature of heat sources and the construction materials. Phase change materials in the high temperature solar absorbers are a suitable source of uniform energy to the thermoelectric generators. Thermal management of thermoelectric generators are selectively carried out with phase change materials due to isothermal operation and a larger latent heat. The recent development in materials science paves the way for the effective energy conversion of energy using thermoelectric devices.

CONCLUSIONS

The thermoelectric power generation typically works well with almost all types of heat recovery and solar collectors. The major conclusions drawn based on the study of the recent literature are provided here.

- Thermal insulation helps in reducing the heat loss from the hot side of the thermoelectric generator.
- Heat sink plays a vital role in maintaining the temperature gradient across the hot side and cold side. With the help of material selection and design of the heat sink, an excellent optimistic temperature gradient is achievable.
- The STEG's optimal efficiency depends upon the high thermal resistance of the insulators used in the thermal insulation unit and the thermal conductivity of the material used in the heat sink.
- Material selection and design of the thermoelectric module reflectin the heat to power conversion efficiency.
- The thermoelectric generator conversion efficiency was observed to be about 8.5% with α-MgAgSb-based materials.
- The utilization of phase change materials is one of the feasible thermal management options of solar thermoelectric generators.

Thus, the effective utilization of waste heat from power plants and industrial process heat into power shows great attention by several researchers and renewable sources as a hybrid power generation.

Abbreviations

PCM	Phase change material

PV	Photovoltaic
TEG	Thermoelectric generator
STEG	Solar thermoelectric generators

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