Renewable and Sustainable Energy Reviews 32 (2014) 486–503

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of thermoelectrics research – Recent developments and potentials for sustainable and renewable energy applications

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ARTICLE INFO

Article history:
Received 23 October 2011
Received in revised form
4 December 2013
Accepted 29 December 2013
Available online 1 February 2014

Keywords:
Thermoelectric application
Green technology
Heat pump
Power generator
Thermal energy

ABSTRACT

In recent years, thermoelectric (TE) devices have emerged as promising alternative environmental friendly applications for heat pumps and power generators since the environmental issues such as the global warming and the limitations of energy resources gradually drew worldwide attentions. Due to the green feature and distinct advantages, the thermoelectric technology have been applied to different areas in an effort of designing simple, compact and environmental friendly systems. The applied areas are extended from the earliest application on kerosene lamp to aerospace applications, transportation tools, industrial utilities, medical services, electronic devices and temperature detecting and measuring facilities. The application potentials of TE in directly conversing thermal energy into electrical power have been identified, especially for where the cost of thermal energy input need not to be considered, such as waste heat utilization, in the light of the present low efficiency of thermoelectric conversion. The capability of TE in producing thermal energy (in terms of cooling or heating) with the use of electrical power is also well identified. This paper reviews the status of the material development and thermoelectric applications in different areas and discusses the difficulties in terms of the commercialisations of advanced materials. Other than this, the main purpose of this paper is to present the great potential of achieving both environmental and economic benefits by exclusively utilizing thermoelectric applications in different areas. It also comes to the conclusion that the thermoelectric applications with the current conversion efficiency are economically and technically practical for micro/small applications. However, it would be transformed to a more significant green energy solution for improving the current environment and energy issues by using medium/large scale thermoelectric applications when the thermoelectric materials with a figure-of-merit over 2 come into commercial practice.

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http://dx.doi.org/10.1016/j.rser.2013.12.053

1. Introduction

Greenhouse gas has been increasingly emitted globally due to the increasing demand for electricity, heating, refrigerating, air-conditioning, etc. In the last few decades, immense efforts have been made to explore and develop alternative technologies to meet the increasing demand for energy. Green technologies, such as solar photovoltaic, wind turbine, hydrogenation and biomass, have started to play an important role in tackling the energy and environment issues arising in this technology oriented world. These technologies have brought us the undeniable benefits due to their clean style of power generation, which, to some extent, contributes to lessening the environment related issues. However, the greenhouse gas emission during the manufacturing process of these technologies cannot be ignored especially when a large amount of them is required. As we are all deeply aware inside, the overall energy demand of the world has never stopped climbing. The effort in developing the current green technologies and exploring new energy technologies only switches the pressure from traditional power technologies to different technologies. Something has not been changed, which is the increasing demands for energy. Turning our head back, we would be overwhelmed by the way how the resources are consumed. It is excessive and highly inefficient. This makes us wonder the essential cause of all related issues of global energy which have been seizing our attentions intensively. It is not the technologies themselves that give birth to the worries and anxiousness that the world is loaded with. Instead, it is ourselves, who have been consuming our finite resources in an excessive and wasteful style. We must appreciate the beauty of simplicity and reconsider the necessity of energy usage in many areas. Being equally important, the energy efficiency also needs to be enhanced by improving the system efficiency and recovering waste heat. In this paper, the thermoelectric (TE) technology, one of many green technologies, is reviewed to demonstrate its potential in improving the energy efficiency and point a possible direction of alleviating our energy demand.

2. Material development

Due to their low efficiency, the extensive applications of thermoelectric materials have been limited to specialised fields where the reliability rather than the cost is a major consideration. Considering the initial cost of establishing a thermoelectric system, thermoelectric applications with the current conversion efficiency are more suitable for small scale applications. The development of new thermoelectric materials with high efficiency is one of the key factors for expanding the range of thermoelectric applications to the medium/large scale. A “breakthrough” is needed for enhancing the figure-of-merit which is the thermoelectric characteristic that describes the thermoelectric performance of the materials. A great deal of efforts has been made in researching and developing materials with high efficiency and several typical methods have been used. These include super-lattice structure, plasma treatment, material segmentation and nanotechnology. Despite the success of achieving thermoelectric materials with high figure-of-merit, the commercialization difficulty is the barrier for most of the thermoelectric materials developed in research laboratories. This cause is attributed to the insufficient accuracy and difficult fabrication in material research and the practicality in material fabrication and device construction.

2.1. Function

Thermoelectric materials can be used for either cooling or power generation, as shown in Fig. 1. Its construction consists of arrays of N and P type semiconductors in which, by applying a heat source on one side and a cooler heat sink to the other side, electric power is produced and vice versa. Namely, electric power can be converted to cooling or heating by reversing the current direction.

Despite the low conversion efficiency of around 10% when used as power generators, they are strongly advantageous due to no moving parts. This made them both more reliable and durable compared to conventional energy technologies. Apart from that, they are scalable without releasing any pollutant to the environment during the operations. Hence, they would be ideal for applications in many areas at different scales replacing the traditional cooling and power generation methods.

In typical TE devices, the N and P materials are electrically connected in series and thermally connected in parallel in the form of flat arrays called modules. Fig. 2 shows a pair of thermocouple in a thermoelectric module working as a power generator. When there is a temperature gradient across the couple, the negatively charged electrons (e^-) in n-leg and the positively charged holes (h^+) in p-leg move from the heat source to the heat sink and conduct heat to the cold end. Consequently, a current flow is resulted from the initially uniform charge carrier distribution [1].

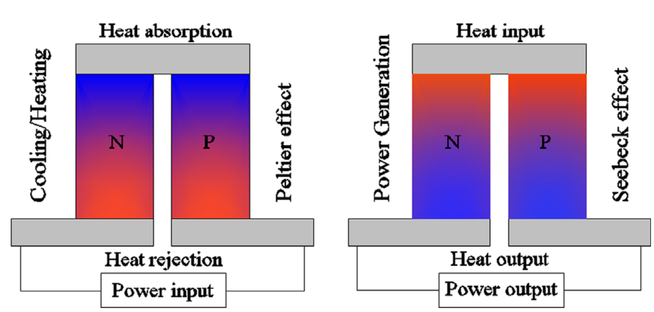

Fig. 1. Cooling/heating and power generation thermoelectric heat engines.

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