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Modelling and optimization of low-temperature waste heat thermoelectric generator system

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Abstract

Thermoelectric generation (TEG) technology has several kinds of merits; waste heat recovery is one of its most promising applications, is becoming a noticeable area of research. The primary challenge of this technology is its relatively low heat to electricity conversion (low conversion efficiency), but low efficiency is not a major issue since this technology used waste heat; costless thermal energy input. System performance/efficiency of TEG technology is depends on module properties and system configurations. In this project, a theoretical model has been developed to analyze the different affecting factors to optimize the electric power from low grade waste heat using TEG technology. From the optimization model it can be found that waste heat temperature, arrangement of TE modules, enhancing heat transfer co-efficient and parasitic loss plays an important role to maximize the net electric power. This project is still under develop, the aim of this project is to find out all possible affecting factors to optimize the output power from low grade waste heat source and also the theoretical analysis will be used to established an experimental setup to validate the optimization technique.

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Keywords: Thermoelectric Generator, Low grade Waste heat recovery, Optimization.

1. Introduction

In 2015, 59.2 quadrillion BTU of energy was wasted mainly in the form of heat. Much of the waste heat has been characterized by its source and its temperature. A majority of the opportunity lies in the transportation or mobile sector, with an estimated work potential of 6.7 quadrillion Btu (Q) from 21.9 Q of waste heat. Waste heat can be classified into high, medium and low grade temperature ranges. The high temperature range is above 650 °C, 230-650 °C is medium temperature and low grade temperature is below 230 °C. It’s stated that, the waste heat with temperature

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below 140 °C can be a potential source of electricity[1]. Several technologies exist to realize the opportunity of lower-grade waste heat recovery—typically either mechanical, solid state, or hybrid systems. Examples of mechanical systems include the Organic Rankine cycle, and Kalina cycle. Mechanical systems are often limited by their complexity, large footprint (e.g. size/mass), and parasitic power requirements. These are particularly challenging limitations for waste heat recovery in the transportation or mobile sectors. Examples of solid-state devices include thermoelectric generators; Solid-state devices have advantages in auto-mobile applications due to their small footprint and lack of complexity and parasitic power requirement. A thermoelectric generator (TEG) is a solid state device that generates electrical energy from heat directly through the phenomenon of Seebeck effect. It has no moving parts and is compact, quiet, highly reliable and environmentally friendly. A thermoelectric module consists of two dissimilar thermoelectric materials joining in their ends: an n-type; and p-type semiconductors. A direct electric current will flow in the circuit when there is a temperature difference between the two materials. Generally, the current magnitude has a proportional relationship with the temperature difference [2]. In recent years, many scientist and researcher focusing to generate electricity from waste heat using TEG. In 2011, Singh et al. used passive heat pipe to extract the solar pond heat and investigated the power generation using TEG. This research used 16 TEG modules and able to produce 3.2 W electrical power while they maintained 27 °C temperature gradient across the modules [3]. Kim et al. [4], developed a low temperature TEG using car engine coolant and attempted to replace the car radiator. The cooling plates and hot-side block were sandwich structure to increase the effectiveness of surface area. At 80 km/h driving condition, the maximum power output from the proposed TEG with 72 4 mm X 4 mm modules was 75 W. The calculated module efficiency is 2.1% and overall efficiency of engine coolant heat to electric power was 0.3%. Nuwayhid et al. [5, 6] designed, fabricated and tested a high performance and low-cost thermoelectric generator (TEG) that fitted to a domestic woodstove. They found that the maximum power generated at matching load was 4.2 W for a single TEG.

Recently, B. Orr et al. [7-9] produced electricity from car exhaust heat (>2500C) using TEG. The idea behind the design is that exhaust gas passes through exhaust duct, extracted via fins and transferred to hot side of TEG via heat pipes. The rejected heats of TEG are transferred by heat pipes to cold duct and remove the rejected heat by ambient air flow. A theoretical model has been developed to predict the performance of the system and then validated by experimental results. The author's found that the theoretical results are valid but only when the exhaust temperature is relatively low. The maximum power generated during testing was 38 W from 8 (62 mm X 62 mm) TEG with the thermal efficiency of 2.46%. Most of these above studies have investigated power generation using TEG and some of them used heat pipe assisted TEG to produce electrical power from waste heat. A gap identified in the literature is the development of theatrical model and optimization for low-temperature waste heat thermoelectric generator system. The aim of this study is to find out all possible affecting factors to optimize the output power from low grade waste heat source.

2. Description of proposed system

In this study, an optimization model has been developed to predict the waste heat recovery and electrical power conversion performances using TEGs. Fig. 1 shows the overall conceptual model for optimization technique. Two separate rectangular ducts are used in which three sides are thermally insulated and TEG modules are placed on other side. Hot water flows through hot water duct, a pump (P) has been used for pumping the water from hot water source (HWS) and valve (V) will be used to control the flow rate. Similar arrangement is used in cold side. The thermoelectric modules are sandwiched between hot water and cold water duct to achieve the temperature gradient across the TEG surfaces to generate electricity.

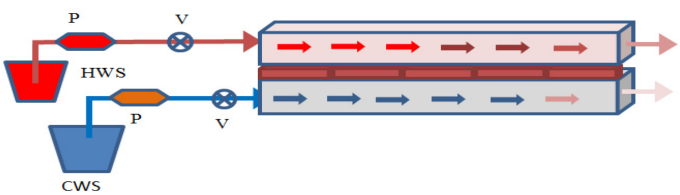

Fig. 1: Proposed conceptual model

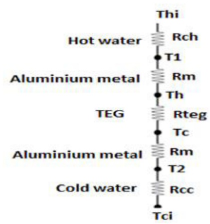

Fig. 2: Thermal resistance of each component for one module