UNIVERSITI TEKNOLOGI MARA

STUDY OF AN ULTRA-LOW TEMPERATURE FUEL CELL WASTE HEAT RECOVERY SYSTEM USING THERMOELECTRIC GENERATOR

MUHAMMAD SAUFI BIN SULAIMAN

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ABSTRACT

Polymer Electrolyte Membrane (PEM) fuel cells generates electrical power from the exothermic electrochemical reaction between hydrogen and oxygen. The thermal power generated are partly consumed by the fuel cell stack to maintain a suitable thermal environment while the bulk of the heat has to be removed as waste heat. Waste heat recovery is a method in the research on improving fuel and energy utilization of energy systems. For PEM fuel cells, waste heat recovery research is concentrated on high temperature fuel cells using advanced thermodynamic cycles due to the high quality of waste heat. For low temperature fuel cells, such as used in small-scale applications for example a mini fuel cell vehicle, these cycles are not efficient and economical. For low temperature fuel cells, thermoelectric generators (TEG) is a suitable technology to directly convert the low quality waste heat energy to electrical energy. This research explores the fundamental characteristics of a TEG waste heat recovery system for a mini vehicle PEM fuel cell stack that operates at ultra-low waste heat temperature. A system consisting of a 2 kW PEM fuel cell and a single unit of TEG assisted by an air cooled finned heat pipe was developed. A mathematical model of the fuel cell-TEG-heat pipe system based on the thermal resistance network heat transfer analogy was also developed and experimentally validated. The experimental variables were fuel cell power output, waste stream temperature, TEG cooling modes (natural and forced convection) and orientation of the TEG towards the heat flow (normal and parallel flow relative to the TEG surface). The cooling modes were applied to simulate a limited scenario of a vehicle at rest and in motion (20 km/h). The highest TEG voltage and power output of 25.7 mV and 218 mW respectively were obtained via forced convection TEG cooling mode and by orienting the TEG surface normal to the hot air flow from the heat source. The thermal resistance network model was in good agreement with the experimental results. The results positively showed that the combined use of TEG, heat pipe and heat sink on a vehicle could offset the ultra-low waste heat temperature from a PEM fuel cell. Successful characterization of this system and validation of the model would allow the system to be further developed for higher performance and contribute to fuel cell system sustainability

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CHAPTER ONE
INTRODUCTION

1.1 Background

1.1.1 Waste Heat

Demand in energy consumption is increasing and becomes a major problem faced by world nowadays. Common types of energy sources are fossil fuels which include coal, natural gas and oil, nuclear and also renewable energy sources for example hydropower, wind, sun, geothermal power, biomass etc. [1]. However, most of the energy produced were rejected as waste heat and only one third of energy were utilized effectively [2] .

Waste heat are mostly generated from industries or transportation that relates to machinery, electrical apparatus or process that generates heat. Almost 33% of energy produced have been released to the surrounding due to the failure to properly capture or recycle the energy. In the United States, about 32 quadrillion Btu (10^{15} Btu) of energy have been consumed annually in its industrial sector. Thus, 1680 million metric tons of carbon dioxide were emitted in consequences to this energy usage. It was also estimated that around 3000 TWh/year of waste heat produced which is equivalent to more than 1.72 billion barrels of oil were from United States manufacturing industries. In addition, about 5% from total heat consumption which is 11.4 TW h/year of energy was rejected as waste heat in the United Kingdom [3].

Approximately 20 to 50% of energy produced in hot exhaust gases and liquids streams were rejected as waste heat during manufacturing processes, including conduction, convection and radiation from hot equipment and streams. This concludes that there is a vast amount of available waste heat that can be reused, recovered and converted into useful energy and reduce the purchase of fuels or electricity costs [4].

1.1.2 Fuel Cells

A fuel cell is a power generating device that have high energy conversion efficiency (about 40% to 50%) where it generates a nearly equivalent amount of