UNIVERSITI TEKNOLOGI MARA

THEORETICAL MODELLING AND EXPERIMENTAL ANALYSIS OF SINGLE AND DOUBLE LAYERED THERMOELECTRIC GENERATOR (TEG) MODULE FOR ENERGY RECOVERY OF BREAD-BAKING INDUSTRIAL WASTE HEAT

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ABSTRACT

Thermoelectric generator (TEG) is a promising alternative in combined heat and power (CHP) generation for low-cost waste heat recovery (WHR) applications. The lack of effective and sustainable approaches to recover the excess heat and a method to assess the economic potential are the main research problems. The objective of the research is to develop a TEG-based WHR system to convert waste heat into useful CHP outputs which are electrical (PTEG) and regenerated thermal energy (PRTE). The research also aims to analyze the economic potential of the developed system for industrial implementation. The TEG module integrates TEG cells, rectangular finned heat exchangers, heat pipes, and copper block housings to enhance heat transfer and energy conversion performance. The system was evaluated through theoretical modelling for fundamental relationship analysis and lab-scale testing for physical system performance evaluation. From the theoretical results, higher waste heat temperature (TWH,IN) and low cooling supply temperature (TCS,IN) show greater potential in generating higher combined heat and power energy (PCHP) due to larger TEG temperature difference (ATTEG) and enhanced cooling rate. Extra heat pipes and TEG cells installation could lead to higher heating and cooling effect and boost the power generation. An energy recovery ratio (ERR) of approximately 14% is expected after critical parameters identification through parameter sweep analysis approach. In the experimental evaluation, double-layered (DL) TEG generated higher PTEG compared to single-layered (SL) TEG. The maximum PTEG generated under DL of 1 module is 27 mW/cm^2 (4 W) while with 2 modules, the total PTEG is 26 mW/cm^2 (8 W). Higher number of TEG modules offer higher PRTE due to the repetition of module cooling. The highest PRTE is 60 W, obtained from the cooling of 2 TEG modules (TEM), arranged in back-to-back configuration, under optimum operating conditions with a total ERR of 7%. The optimum result from the experimental assessment is applied for the economic potential analysis. Under optimum operating parameters, 10 TEG modules TEM in back-to-back arrangement provides the shortest payback period of 8 years, which confirms the technical and economic feasibility of TEG-based CHP systems for bakery waste heat recovery. The installation of more than 8 TEMs increased the payback period due to insufficient amount of annual savings to cover the increasing investment costs. Higher CHP generation could be achieved by further improving the material selection and design optimization for higher annual savings and lower payback period.

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INTRODUCTION

1.1 Research Background

Energy growth is essential in fulfilling basic human needs while building a better quality of life. However, most of the energy produced today originates from non-renewable sources including petroleum, natural gas and coal. Countries including Malaysia, Indonesia and Australia generate about 80% of their energy by using these sources [1]. Apart from producing energy from sources that could not be replenished, the process also produces harmful gas emissions that leads to climate change. The atmospheric temperature is expected to rise by 11% in the next 100 years if global warming continues [2]. The challenge lies in recovering the wasted energy as it often generated at different temperatures, by various sources and at different times. Researchers are exploring deep into energy harvesting as an effective alternative to reduce the global effects of human activities. Energy harvesting, also known as energy scavenging or power harvesting, involves the process of generating useful energy through capturing or extracting wasted energy. Waste heat is an example of the by-product released as a result of energy conversion from various industries.

The fundamental principle of the second law of thermodynamics stated that no energy conversion process is 100% efficient. Therefore, increasing global energy demand leads to more energy being converted and more waste heat is released. The uncaptured amount of waste heat holds the potential in saving costs and reduce environmental impact. These waste heats can be divided based on the temperature range. Low temperature waste heat usually comes from parts of the process unit with temperatures below 100°C, while medium temperature waste heat ranges from 100°C until 400°C which covers the heat from exhausts of most combustion units. Waste heat higher than 400°C is classified as high temperature that is normally rejected from direct combustion processes [3]. In food processing industry, particularly in bread-baking, a significant portion of thermal energy is lost through the oven exhausts, typically within the range of 120-250°C. The wasted heat is a potential source for a direct and on-site energy recovery that could reduce fuel consumption and operating costs while lowering carbon emissions.