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Waste heat recovery using a thermoelectric power generation system in a biomass gasifier

Hsiao-Kang Ma [a, *], Ching-Po Lin [a], How-Ping Wu [a], Chun-Hao Peng [a], Chia-Cheng Hsu [a, b]

[a] Department of Mechanical Engineering, National Taiwan University, Taipei 106, Taiwan, ROC
[b] Material and Chemical Research Laboratories, Industrial Technology Research Institute, Hsinchu 31040, Taiwan, ROC

HIGHLIGHTS

- Set up the thermoelectric power generation system to recover waste heat from biomass gasifier.
- Bi_2Te_3 based material is suitable for choosing as a thermoelectric generator in the waste heat recovery temperature range of 473–633 K form gasifier.
- The maximum power density can reach 193.1 W/m^2 for waste heat recovery.

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ABSTRACT

The aim of this study is to investigate the use of waste heat that is recovered from a biomass gasifier. In the gasification process, the low heating value of biomass can be transferred to a high heating value for combustible gaseous fuel, a form that is widely used in industry and power plants. Conventionally, some of cleaning processes need to be conducted under higher operating temperatures that the low temperatures typically used to burn biomass. Therefore, the catalytic reactor was designed before installation the scrubber in the downdraft gasifier system to make effective use of the waste heat. The experimental result shows that the temperature of the gasifier outlet is about 623–773 K; dolomite is used for tar removal in the catalytic reactor. To further improve the use of waste heat, a thermoelectric generator is added to provide for the recovery of waste heat. The thermoelectric generator system is manufactured using a Bi_2Te_3 based material and is composed of eight thermoelectric modules on the surface of catalytic reactor. The measured surface temperature of the catalytic reactor is 473–633 K that is the correct temperature for Bi_2Te_3 as thermoelectric generator. The result shows that the maximum power output of the thermoelectric generator system is 6.1 W and thermoelectric generator power density is approximately 193.1 W/m^2.

1. Introduction

Governments worldwide are dealing with energy shortages; this serious problem causes everyone to actively seek alternative to fossil fuels. Therefore, gasification has been developed as a way to convert biomass to a higher heating value syngas. Three main types of gasifiers exist: fixed bed, moving bed and fluidized bed gasifiers based on fuel type and temperature. Downdraft gasifiers of a fixed bed type are regarded as a good solution to generating syngas with high heating value [1]. Many researchers have explored this technology. Jain et al. [2] used four open core throatless rice husk gasifiers to complete ten runs of experiments. Several factors including optimum equivalence ratio, optimum specific gasification rate, lower heating value and efficiency were determined. Yin et al. [3] introduced an empirical formula that can be used to determine the optimal diameter of a gasifier and various gasification parameters. A circulating fluidized bed (CFB) gasifier has also been applied to gasified rice husks to compare actual results with a mathematical model. Yoon et al. [4] gasified two different types of rice husks to study gasification results. Syngas produced from gasification were analyzed, compared and supplied to an engine to generate power. Ogi et al. [5] conducted experiments in an entrained-flow gasifier to gasify oil palm residues (empty fruit bunch). The relationship between the water–carbon and hydrogen–carbon monoxide ratios under different water and oxygen concentrations were discussed. Gasification results were also compared to a thermo-gravimetric analysis.

* Corresponding author. No. 1, Sec. 4, Roosevelt Road, Taipei 10617, Taiwan, ROC. Tel.: +886 2 3366 2725; fax: +886 2 2362 1755.
E-mail addresses: skma@ntu.edu.tw, hkma78@gmail.com (H.-K. Ma).

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Thermoelectric generators (TEG) have become popular devices because of their ability to transform a low-level heat source into higher power output unit. Three major theories can be used to describe their working principal, including the Seebeck, Peltier, and Thomson effects. The Seebeck effect theory states that two different but connected metals with different temperatures will cause an electromotive force between these materials. The Peltier effect is an inverse of the Seebeck effect, in that a temperature gradient may be produced from applying an electrical potential between two different connected metals. When electric current passes through heterogeneous conductors, and aside from generating irreversible Joule heat, the conductors will absorb or create a fixed amount of heat. This is called Thomson effect.

Many kinds of materials can be applied to a thermoelectric modulus. Different materials lead to different working temperature of TEG [6,7]. Therefore, many studies have focused on this topic. Cheng et al. [8] constructed a three-dimensional model that can be used to simulate the transient thermal condition of TEG. The TEG was simply separated into four regions, including semiconductor materials, hot junction and cold junction. It has been shown that current, heat loss and heat transfer coefficient strongly influence the coefficient of performance (COP). Gou et al. [9] established a steady-state dynamic model to predict behaviors of TEG with finned heat exchanger. The results showed that the heat dissipation rate on a cold junction has a strong effect on power output and fluctuation of the hot reservoir leads to variation of output power. Jang et al. [10,11] founded out that TEG modulus spacing has a great impact on the output power density. By using the finite difference and simplified conjugate-gradient methods, the optimized spacing and spreader thickness problems were solved. Montecucco et al. [12] applied a Simulink-Matlab program to simulate large-scale thermal and electrical dynamics of TEG. The results were also compared with an experiment to confirm accuracy and capability.

Because the TEG modulus converted heat to electrical power, it has many applications such as recovering heat from a car engine and boiler to make better use of waste heat produced from those types of equipment. Previous studies have shown that this method has been widely used with the heat generating equipment. Choi et al. [13] combined TEG with a car-seat system, installing an air conditioning system with a fan and ductwork to control the temperature on the warm side. A mathematical model was also created to predict the results. Chang et al. [14] established a thermal analogy network designed to predict the thermal condition of a TEG. When compared to a heat sink in an air-cooled system, a TEG has better performance under a low heat load. Champier et al. [15] combined a biomass cook stove with a TEG to recover waste heat and generate electric power. The optimal placement of the TEG on the stove was also investigated. Hsiao et al. [16] compared an exhaust pipe and radiator of automobile to find a better place to locate a TEG. A one dimensional thermal resistance model was applied to predict results. Zheng et al. [17,18] constructed a thermoelectric cogenerating system to generate power from a TEG and produce hot water simultaneously.

Ma et al. [19] applied an Umberto Life Cycle Assessment (LCA) model to investigate gasification of coal and petroleum coke, and evaluated the environmental impact from the process of gasification. Shie et al. [20] gasified rice straw in an attempt to provide a potential biofuel in Taiwan. The Energy Life Cycle Assessment (ELCA) model was used to simulate gasification conditions. Ma et al. [21] introduced Fire Dynamics Simulator (FDS) model to predict the temperature profile of a gasification system. Furthermore, a TEG modulus was also applied to study parameters such as output voltage and power generation. Hsu et al. [22] studied the effect of grin refinement to the ZT value of new thermoelectric material, with high temperature working conditions.

The aim of this study is to examine the use of waste heat that is recovered from a biomass gasifier. Also, the low heating value of biomass can be transferred to the high heating value of a combustible gaseous fuel during the gasification process. The experimental results show that the temperature of the gasifier outlet is about 623–773 K. To further improve the use of waste heat, the thermoelectric generators system (TEG) is attached to the surface of a catalytic reactor, which is used for cleaning (Fig. 1). Due to its high temperature, it can serve as a heat source of hot junction on the TEG. The measured surface temperature of a catalytic reactor is 473–633 K which is suitable for choosing Bi_2Te_3 as a

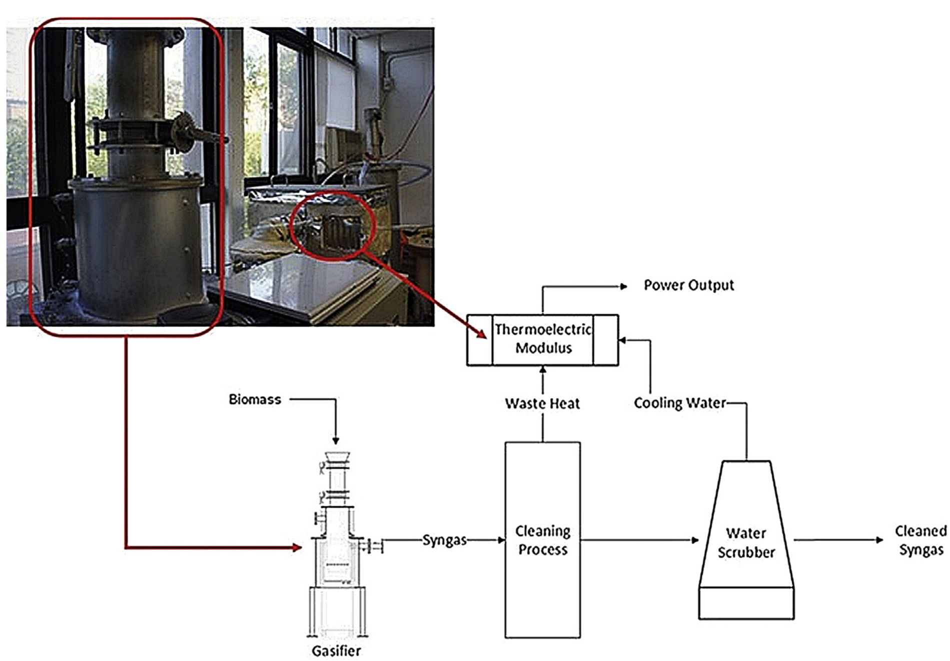

Fig. 1. Schematic diagram of the waste heat recovery system.

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