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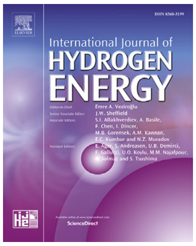

Design and analysis of a waste gasification energy system with solid oxide fuel cells and absorption chillers

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ABSTRACT

Energy saving is an open point in most European countries where energy policies are oriented to reduce the use of fossil fuels, greenhouses emissions and energy independence, and to increase the use of renewable energies. In the last several years, new technologies have been developed and some of them received subsidies to increase installation and reduce cost. This article presents a new sustainable trigeneration system (power, heat and cool) based on a solid oxide fuel cell (SOFC) system integrated with an absorption chiller for special applications such as hotels, resorts, hospitals, etc. with a focus on plant design and performance. The proposal system is based on the idea of gasifying the municipal waste, producing syngas serving as fuel for the trigeneration system. Such advanced system when improved is thus self-sustainable without dependency on net grid, district heating and district cooling. Other advantage of such waste to energy system is waste management, less disposal to sanitary landfills, saving large municipal fields for other human activity and considerable less environmental impact. Although plant electrical efficiency of such system is not significant but fuel utilization factor along with free fuel, significant less pollutant emissions and self-sustainability are importance points of the proposed system. It is shown that the energy efficiency of such small tri-generation system is more than 83% with net power of 170 kW and district energy of about 250 kW.

Introduction

European countries are working to improve their energy policies of which main themes are energy saving and less pollutions. Installation of more efficient technology (such as condensing boilers, heat pumps, district cooling and district heating related to a cogeneration power plant) could help to achieve these goals. There is currently an increased interest in developing a distributed system of smaller-scale facilities at a single location, allowing electricity heat/cool to be produced and distributed close to the end user and thereby minimizing the costs associated with transportation [1] and [2]. Micro CHCP (combined heat, cool and power) for niche application falls also within this category. However, micro CHCPs face the problem of heat/cool-to power ratio that varies during the day as well as between the seasons due to the different consumption profile [3].

Municipal waste (MW) is one such type of biomass and is suitable for use in power plants. It presents some advantages

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such as the reduction of pollutants and greenhouse gas emissions and the possibility of reducing storage in landfills, as a result of which these spaces can be devoted to other human activities Waste management is becoming a matter of crucial importance for our societies. The massive increase in the production of waste during the last decades is followed by negative consequences in the environment, whereas also there is a vital amount of raw materials that are lost due to the lack of efficient waste treatment strategies. Hence, there is an urgent need for establishing efficient and innovative public policies concerning the handling and exploitation of waste. Traditionally waste disposal in sanitary landfills was the prevalent method related to waste management. Today this method is considered outdated due to the negative environmental impact that arise, as well as because of the high demand of large fields available for the waste disposal. A very good alternative to waste landfilling comprise the waste-to energy plants [4]. Currently the most mature technology is incineration, while gasification is still in the early stages of development. The remaining waste after established separation and recycling technologies in many countries (such as metals, plastics, hard papers, glass bottles and papers) would be very suitable for gasification. This is forming the basis idea of the current study.

Numerous studies have been investigated in the literature on SOFC-based hybrid systems that suggest high thermal efficiency. The majority of these studies use gas turbines as the bottoming cycle for SOFCs resulting in pressurized SOFC systems see e.g. Ref. [5]. Steam turbines and organic Rankine cycles (ORC) have also been used as a bottoming cycle, which resulted in non-pressurized SOFC stacks, see e.g. Ref. [6]. A few studies have been performed that utilize a Stirling engine as the bottoming cycle and the fuel cell as the topping cycle, see e.g. Ref. [2].

However, studies on combined SOFC-absorption chillers are very rare (e.g. Ref. [7]) considered the potential of combined SOFC–Absorption Chiller (AC) systems in Japanese office building without undergoing the detailed plant design and system operating performance. The emphasis was to indicate the market potential, CO_2 emissions and decentralized energy system, rather than the detailed analysis and performance of the units [8]. Studied the economics of such system in Hong Kong without experiencing fuel type and system design. [9], [10], [11], and [12] considered such system with pure methane, reformed gas and biogas as fuel. None of these works address (or looked into) integrated waste gasification with SOFC–AC combination. Other studies in SOFC for residential applications as cogeneration system can be found in e.g. Ref. [13], in which the feasibility of a 5 kW SOFC from economical view was considered. A micro CHP with SOFC for single-family detached dwellings was studied in Ref. [14], while the impact of heat-to-power ratio for a SOFC based micro CHP for residential application in European climate was elaborated in Ref. [15]. Variation of the heat to power output ratio to match the electric and hot water demands of a Japanese residence can be found in Ref. [16].

[17] Conducted a study of flue gas condensation for heat recovery of biomass boilers. An increase between 3 and 21% in primary energy efficiency was found depending on the flue gas outlet temperature. Temperatures as low as −10 °C was utilized in their analysis. They also concluded that even tough for large scale systems (more than 10 MW) flue gas condensation is economically viable, but also for much smaller systems in particular if the added heating production can replace electric heaters.

This article presents a pioneering system based on an integrated waste gasification with SOFC and an absorption chiller for producing electricity, heat and cool. The study on such hybrid combination of a waste gasification plant integrated with a SOFC plant and an absorption chiller device is new and has not been deliberate elsewhere. A LiBr (Lithium Bromide) absorption chiller is chosen as a backup device to cover the cool demand while the SOFC and a heat recovery device cover the heat and electricity demands. The aim of this study is not only to present a system suitable for special applications (such as hotels, resorts and hospitals) but also to design a self-sustainable system that utilize the produced waste into energy (power, heat and cool). The waste should be handled after basic proven methods of recycling, which is considered as a critical problem for such particular applications.

System overview

The main components of the system proposed here are a solid oxide fuel cell (SOFC) plant, an absorption chiller and a heating system (through water tank). The SOFC plant is fed by municipal waste for electricity production and at the same time to use its waste heat for production of district (domestic) heating and cooling. Fig. 1 displays the integration of these components with each other. The waste heat drives firstly through an absorption chiller to produce district (or domestic) cooling. A district (or domestic) heating heat exchanger utilizes the rest of the energy as shown in the figure. Finally, a flue Gas Condensation (FGC) technique allows to further cooldown the waste heat and thereby increasing the cooling effect. A smart design may include a valve to regulate how much of the waste energy to be used for producing cooling or heating.

Methodology and modeling

The thermodynamic results in this study are obtained from the Dynamic Network Analysis (DNA) simulation tool (see, e.g. Ref. [18]). This software is a result of an ongoing development process in the Thermal Energy Section of the Mechanical Department of the Technical University of Denmark. The program includes a component library, thermodynamic state models for fluids and standard numerical solvers for differential and algebraic equation systems. The component library models include heat exchangers, burners, turbo machinery, dryers, decanters, energy storages, valves and controllers, among others. The thermodynamic state models for fluids cover most of the basic fluids and such compounds as ash and tar for use in energy system analyses. DNA is a component-based simulation tool, meaning that the model is formulated by connecting components with nodes and adding operating conditions to build up a system. Next, the physical model is

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