Enhanced power generation through integrated renewable energy plants: Solar chimney and waste-to-energy

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ABSTRACT

In the present paper, a novel method is proposed to enhance the power production and resolve the inconsistent electricity generation of solar chimney power plants (SCPPs) during nighttime. For this purpose, an integrated renewable cycle is proposed by incorporating two technologies: solar chimney and waste-to-energy. The combination is performed by exploiting the warm air of the condensers outlet into the SCPP. The waste-to-energy (WTE) plant in Tehran is thermodynamically analyzed and the mass flow rate of the condensers cooling air is found. Results indicate that by decreasing the humidity of the municipal solid waste (MSW) from 40% to 30% or by increasing MSW feeding rate (0.934–1.146 kg/s), the mass flow rate of the condenser cooling air increases from 190.3 kg/s to 233.7 kg/s. In addition, by increasing the feeding rate or by decreasing the humidity of MSW in the mentioned range, net power output of the WTE plant increases from 1350 kW to 1650 kW. The best injection method is proposed for the warm air of the condensers outlet into the SCPP. Subsequently, the average power increase is examined in different months and parametric study is performed to assess the influence of the effective WTE parameters and meteorological variables on the power output of the SCPP. The final power of the SCPP reaches 20–70 kW (even at the hottest night of the year with 5% relative humidity) and increases 20–1200% and 65–94% (monthly average) compared to the case of without injection. Results demonstrate that in the integrated system, by a 22% increase in the MSW feeding rate (from 0.934 kg/s to 1.146 kg/s) or by decreasing the MSW moisture content (from 40% to 30%), power output of the WTE plant and SCPP increases by 22% and 7%, respectively. Additionally, relative humidity of the surrounding air can increase the SCPP power production by 25%. In addition, the results indicate that wind speeds higher than 12.5 m/s will not affect power production of the SCPP, while relative humidity of the surrounding air, ambient temperature, the MSW feeding rate, and humidity of the MSW have considerable effects on the SCPP power production. In average, total energy and useful exergy efficiency of the proposed system is increased by 0.15% and 0.12% compared to the standalone WTE plant during nighttime. The integration of SCPP with the WTE plant is an applicable method to enhance the power generation and overcome the inconsistent power production of SCPP during nighttime.

1. Introduction

Increased fossil fuel consumption and their environmental pollutants has been the major driving force for many researches on renewable energies. In 2016, total world renewable energy capacity was about 2 TW, counting for 3% of the total energy capacity; in which the share of bioenergy, renewable municipal solid waste, and solar energy was 110 GW, 16 GW, and 296 GW, respectively [1]. Electricity production using the renewable energies in Iran was reached 11 GW in the same year (32 MW, 3 MW, and 11 MW of solar, municipal solid waste, and bioenergy, respectively), showing a considerable increase of 41% from 2010 [1]. The most important advantages of using biomass resources in energy conversion systems are: continual availability, low gas emissions, and the ability to produce various biofuels [2].

1.1. Biomass gasification

Various methods are available for biomass conversion: thermochemical, physicochemical, and biochemical [3]. The only waste-to-energy plant in Tehran produces 3 MW electricity based on the gasification technology.

Recently, many researchers analyzed gasification methods, biomass-
Solar chimney power plant

Solar chimney power plants (SCPP) are among the renewable energy technologies with high potential all over the world. SCPP consists of three main parts: first, solar collector to absorb solar heat, second, tower that is generally placed at the center of the collector, and third, turbine which can be installed inside the tower or within the collector area [7]. Solar radiation heats up the air under the collector and thereafter air passes through the turbine and produces electricity. Unlike solar cells, SCPP can operate day and night, since the pressure difference always exists between the inlet and the outlet of SCPP [8]. Zanjan (Iran) and Manzanares (Spain) are examples of such SCPP models with the basic components.

Recently, many researchers studied the design, energy and exergy aspects and power enhancement methods of the SCPP [9–12]. Haaf et al. [13] are among the first researchers who tested the SCPP prototype in Manzanares in 1983. They reported that the SCPP power output would be 50 kW at 1000 W/m² solar irradiance.

Patel et al. [9] optimized the SCPP by varying the collector inlet and outlet diameters from 0.05 m to 2 m and 0.6 m to 1 m, respectively, at different chimney divergent angles (0° to 3°) and diameters (0.25 m to 0.6 m to 1 m), respectively. Also, a CO₂ emission of 4.99 × 10⁻² t/MWh and 4.95 × 10⁻² t/MWh was calculated for wood and paper, respectively.
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