Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 143 (2017) 649–655

Energy Procedia

www.elsevier.com/locate/procedia

World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference, WES-CUE 2017, 19–21 July 2017, Singapore

Investigation on the mid-temperature solar thermochemical power generation system

Zhang Bai[a,b,c], Qibin Liu[b,c,*], Jing Lei[d], Hongguang Jin[b,c]

[a] College of Pipeline and Civil Engineering, China University of Petroleum (East China), Qingdao,266580, P.R. China
[b] Institute of Engineering Thermophysics, Chinese Academy of Sciences, Beijing, 100190, P.R. China
[c] University of Chinese Academy of Sciences, Beijing, 100049, P.R. China
[d] School of Energy, Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, P.R. China

Abstract

A novel mid-temperature solar thermochemical power generation system with the capacity of $1MW_e$ is proposed in this work, which mainly consists of a parabolic trough solar collector, a solar receiver/reactor, a syngas storage tank, an internal combustion engine and heat exchange devices. The fed methanol that is evaporated and fed into the solar receiver/reactor for decomposition and producing syngas (H_2 and CO), the required reaction heat is provided by the parabolic trough collector with the temperature of 200-300℃. The generated syngas can be stored or directly utilized by an internal combustion engine for the power generation. The system thermodynamic performance and the off-design operation characteristics are numerically investigated. The results indicate that the introduced solar thermal energy achieves a favorable conversion efficiency, the system annual energy efficiency and the solar-to-electric efficiency reach to 33.78% and 18.29%, respectively. The monthly averaged solar-to-electric efficiencies under system off-design conditions reach to 8.73%-26.31%, an evident improvement of the efficiency is achieved compared with the typical parabolic trough type solar power system. In addition, a small scale pilot system with the capacity of 20 kW_e is constructed to achieve the operation with a full power ratio, and the developed mid-temperature solar thermochemical power concept is experimentally validated. The research findings contribute to the efficient utilization of the concentrated solar thermal energy.

Peer-review under responsibility of the scientific committee of the World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference.

Keywords: solar thermochemistry; power generation; methanol decomposition; system evaluation

1. Introduction

The renewable energies, like solar energy and biomass, are attracting more attention owing to the distinct advantages of clean and sustainability, which can contribute to the alleviation of current energy and environment concerns [1].

Peer-review under responsibility of the scientific committee of the World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference.
10.1016/j.egypro.2017.12.741

Nomenclature

A	aperture area of the solar collectors	Subscript	
HHV	high heat value	sol-elec	solar-to-electric
m	mass flow rate	sys	system
P	electric power		
η	efficiency		

Concentrated solar power (CSP) system use various solar collection technologies, like parabolic trough collector and solar tower, the molten salt and synthetic oil as the heat transfer fluid (HTF) [2]. In a typical CSP system, the solar irradiation is concentrated and used to produce high-temperature steam via HTF, then solar energy can be generate the electricity by a steam turbine.

The solar collection temperature is limited due to the physical properties of the HTF and coating material of the solar receiver, thereby, the thermodynamic performance of the CSP system can not reach to a reasonable level. Moreover, the intermittent nature (i.e. day/night cycles and periods irradiation reduction) leads to unfavorable operation behaviours and low capacity factor. Therefore, the improvement of the solar conversion efficiency is one of major challenges which needs to be overcome in CSP technologies.

The hybrid energy system provides a promising method to enhance the solar conversion performance, and diverse solar based hybrid power systems were developed. Solar energy can be hybrid with the typical coal-fired and biomass-fired power system, the introduced solar energy is used to preheat the steam or using the hybrid energy to increase solar steam temperature, therefore, the solar energy can be converted stably with enhanced efficiency [3,4]. In addition, the integrated solar combined cycle system (ISCC) system is proposed, solar energy is introduced into a heat recovery steam generator (HRSG) of the bottom cycle for generating the solar steam [5].

The solar thermochemistry is a different energy hybrid routine, including solar driving H_2O splitting, carbonaceous materials gasification and methane reforming, is a promising method [6]. The collected energy can be converted into the chemical energy which realizes readily storage and efficient conversion. In particular, regarding to the commercially applied solar collection technology, the mid-temperature solar thermochemistry with parabolic trough collector has potential to be developed. Jin et al. [7] proposed a mid-temperature solar thermochemistry concept with the temperature of 150-250℃ for driving the methanol reforming, which can integrate current parabolic trough solar collectors. Liu et al. [8] conducted the experimental research on the hydrogen production by solar-methanol reforming using a 5 kW prototype solar reactor, and developed a reaction kinetic model.

The above studies provide a promising solar conversion concept, whereas, these works more focused on the solar reaction characters, the related solar thermochemical power systems are not evaluated yet, the system thermodynamic performance and the future application potential need to be investigated. Thus, the rest of this study is organized as follows. In Section 2, a novel mid-temperature solar thermochemical power concept is proposed, and a 1 MW_e power system is constructed. The system thermodynamic evaluation and a small size pilot system for experimental validation are presented in Section 3. Finally, the main conclusions are summarized in Section 5.

2. Methanol decomposition and mid-temperature solar thermochemical power system

2.1. Mid-temperature solar thermochemistry for methanol decomposition

Methanol decomposition is an endothermic reaction to yield syngas, i.e., H_2 and CO, as listed in Eq. (1), the the main reaction temperature range is 200-300℃. The required reaction temperature can be well matched with solar collection temperature of the parabolic trough solar collectors (<400℃), thus the concentrated solar thermal energy can be utilized as the reaction heat to drive the methanol decomposition.

$$CH_3OH \rightarrow CO + 2H_2,\quad \Delta_r H_{298K} = 90.14\ \text{kJ/mol} \tag{1}$$

The equilibrium conversion ratios of the methanol decomposition decrease with the increase of reaction pressure. Correspondingly, when the reaction pressure increased to 0.5 MPa from 0.1 MPa, the required equilibrium temperature is improved to about 250℃ from 175℃ in order to achieve a reasonable methanol conversion ratio.

The concentrated solar thermal energy can be converted into the syngas by driving the methanol decomposition reaction. Meanwhile, the energy form of the solar energy is changed to the chemical energy, the energy level of the