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Thermodynamics evaluation of a solar-biomass power generation system integrated a two-stage gasifier

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Abstract

A new solar-biomass power generation system that integrates a two-stage gasifier is proposed in this work, in which two types of solar collectors are used to provide solar thermal energy with different levels for driving the biomass pyrolysis (about 643K) and gasification (about 1150K), respectively. The qualified syngas produced is fed into the combined cycle system for power generation. The thermodynamic performances of the proposed system are improved with the overall energy efficiency of 26.72% and the net solar-to-electric efficiency of 15.93%. The exergy loss during the solar collection and gasification is reduced by 19.3% compared with the scheme of using one-stage gasifier.

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Keywords: solar energy, power generation, two-stage gasifier, hybrid

1. Introduction

Various renewable energies, including solar energy and biomass, are viewed as alternatives for the alleviation of the current energy and environment concerns. Moreover, the technical route of solar thermochemical is promising to deal with the low energy density and intermittent nature of solar energy [1-3].

The concentrating solar energy as the heat source of the high-temperature process can be used to drive the biomass-steam gasification, in which the solar thermal energy is converted into the chemical energy. Therefore, the solar energy is easily converted to valuable chemicals and low-carbon footprint transportation fuels [4-6].

In this work, the biomass gasification process is divided into two stages of biomass pyrolysis and char gasification. A two-stage gasifier is integrated in the proposed solar-biomass power generation system.

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Nomenclature

A	Energy level
E	Exergy
HHV	High heat value
m	Mass flow rate
P	Power
η	Efficiency

The line-focus solar collectors (LFC) and the point-focus collector (PFC) are used to provide the solar thermal energy for driving the gasification process, and the system thermodynamic performances are investigated.

2. System description

2.1. Physical Properties of Biomass

The corn straw is an abundant herbaceous biomass resource in China, which is selected as the gasification feedstock. The biomass sample of corn straw is collected as follows.

The pyrolysis experiment of corn straw is firstly conducted, by a program-control electrical furnace, with the temperature of lower than 673 K, the tar yield ratio can reach 19.5% as reported in Table 1. The chemical composition as air-dry basis of the biomass sample and the char (solid product from pyrolysis) are determined and summarized in Table 2.

Table 1. The product yield of pyrolysis / wt.%

	Tar	Water	Char	Gas
Corn straw	19.50	22.13	38.26	20.11

Table 2 Chemical compositions of the biomass sample

Sample	Proximate analysis / wt.%				Ultimate analysis / wt.%					HHV/ MJ·kg-1
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	C_{ad}	H_{ad}	N_{ad}	S_{ad}	O_{ad}	
Corn straw	3.94	7.1	69.56	19.39	41.49	6.05	2.35	0.19	38.88	16.51
Char*	0.36	18.65	22.81	58.18	59.28	3.90	4.60	0.25	12.96	25.67

* produced by pyrolysis

2.2. System description

The new solar-biomass power generation system consists of a solar-assistant biomass gasification subsystem and an advanced Brayton–Rankine combined cycle with a SGT-900 type gas turbine, as illustrated in Fig. 1. During the gasification process, the biomass pyrolysis is firstly conducted to yield tar and char with the temperature of lower than 673 K. Subsequently, the processes of tar crack and char gasification are carried out, at the temperature of higher than 1000 K, for producing syngas.

The biomass gasification reaction heat is provided by the concentrating solar energy. The LFC is used to drive the pyrolysis and generate the steam as the gasification agent, meanwhile the PFC with the