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Combined Cooling Heating and Power System with Integration of Middle-and-low temperature Solar Thermal Energy and Methanol Decomposition

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Abstract

In this paper, a novel distributed energy system, which contains the process of mid-and-low temperature solar energy thermochemical hybridization with methanol is proposed. Through the solar energy receiver/reactor, solar thermal energy collected by a parabolic trough concentrator, at 250°C -300°C, drives the decomposition reaction of methanol into solar fuels of syngas, thus converts to chemical energy. The chemical energy of syngas releases in the combustion chamber of a micro gas turbine to drive the combined cooling heating and power systems. Extra produced solar fuel reserves a gas tank. Energy analysis and exergy analysis of the system are implemented, and the design and off-design performance of the system and the character of chemical energy storage under variable solar radiation are discussed. As a result, the primary energy ratio of the system is 76.40%, and the net solar-to-electricity rate reaches 22.56% much higher than the exited large-scale solar thermal power plant. As the solar thermochemical energy storage contained in the system, the generating efficiency becomes insensitive to the solar radiation, and thus the efficient and stable utilization of solar thermal energy is achieved at all work condition.

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Keywords: Solar Fuels; Mid-and-low temperature solar thermal energy; Solar thermochemical hybridization system; Distributed energy system

1. Introduction

Solar energy is clean and renewable with infinite reserves, the utilization of solar energy is an important approach to the solution of the shortage of energy supply and the greenhouse effect caused by the fossil fuel power generation. Common solar thermal power generation technologies face such dilemmas such as the high cost of electricity, low solar-to-electricity efficiency and technical problem for energy storage. Solar thermochemical process is considered as a promising path for the efficient utilization and low cost storage of solar energy. Through solar thermochemical process, the solar energy with low energy density is transfered to the chemical energy of fuel, and thus the energy level is updated greatly. At the same time, collected solar energy can be stored in a container easily in form of the chemical energy of fuel. Jin and co-workers proposed a combined cycle that integrates mid-and-low temperature solar thermal energy with

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Nomenclature

C	Cooling energy (kW)	T_0	Ambient temperature (K)
G_M	Mole flow rate of methanol (mol/s)	T_{col}	Collected solar heat temperature (K)
H_{uM}	Heat value of methanol (kJ/mol)	T_h	Heating temperature (K)
P	Power (kW)	η_{ex}	Primary energy ratio
Q	Heat (kW)	η_{th}	Exergy efficiency

methanol decomposition[1], experimental researches on mid-and-low temperature solar receiver/reactor were implemented[2]. Solar energy at 200–300 °C heats the endothermic reaction of methanol decomposition into syngas by the following chemical action:

$$CH_3OH \rightarrow 2H_2 + CO, \quad \Delta H_{298K} = 128.1 \text{ kJ/mol} \tag{1}$$

In this paper, a novel distributed energy system, which contains the process of mid-and-low temperature solar energy thermochemical hybridization with methanol is proposed. Based on the fundamental laws of thermodynamics, the energy analysis and exergy analysis of the system were implemented, and the design and off-design performances of the system and the characters of chemical energy storage under variable solar radiation and load were achieved.

2. System description

As depicted in Fig. 1, the system consists of the solar thermochemical process unit, the micro gas turbine generator unit, the cooling unit and the energy storage unit. Methanol is pumped into heat exchangers, evaporated by the waste heat of the solar fuels of syngas and the exhaust flue gas. Methanol vapor converts to syngas in the solar receiver/reactor via endothermic reaction driven by the collected solar heat of 260 °C. Syngas releases chemical energy as the fuel of the micro gas turbine, the exhaust flue gas drives double- effect Li-Br absorption refrigerator. When the solar radiation is sufficient, extra solar fuels of syngas is reserved in a gas tank.

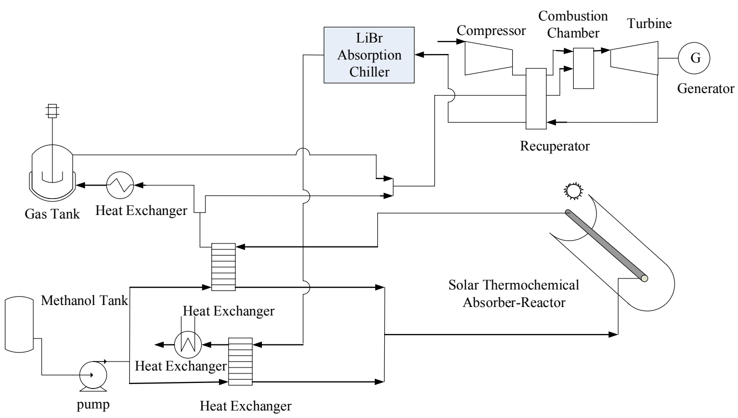

Fig. 1. Schematic diagram of the system

3. Thermodynamic performance evaluations

Primary energy ratio and exergy efficiency are used to evaluate the energy conversion efficiency of the whole energy utilization system, which can be formulated as:

$$\eta_{th} = \frac{P + |C| + Q}{G_M H_{uM} + Q_{sol}} \tag{2}$$

$$\eta_{ex} = \frac{P + C \cdot (\frac{T_0}{T_C} - 1) + Q \cdot (1 - \frac{T_0}{T_h})}{G_M H_{uM} + Q_{sol} \cdot (1 - \frac{T_0}{T_{col}})} \tag{3}$$

The energy analysis and exergy analysis result are listed in Table 1 and Table 2. Assuming the thermal efficiency of the solar collector is 0.67, COP of the LiBr absorption refrigerator is 1.26 accordign to the reference.

Table 1. Energy analysis

	Energy (kW)	Ratio (%)		Energy (kW)	Ratio (%)
Total input	2123.03	100	Total output	1351.57	76.40
Chemical energy of methanol	1817.14	85.59	Power output	600	28.26
Solar energy input	294.79	13.89	Cooling energy	587.08	27.65
Power input	11.10	0.52	Heating energy	164.49	7.75

The primary energy ratio of the system is 76.40%, the net solar-to-electricity rate reaches 22.56%. Of all the energy input, 13.89% is solar energy. The exergy efficiency of the system is 48.81%.

Table 2. Exergy analysis

	Exergy (kW)	Ratio (%)		Exergy (kW)	Ratio (%)
Total exergy input	2086.9	100	Heating	16.1	0.77
Methanol	1969.8	94.39	Others	1.2	0.06
Solar heat	117.1	5.61	Total exergy output	1018.6	48.81
Total exergy loss	1076.3	51.58	Power	600	28.75
Preheat	17.1	0.82	Cooling exergy	35.4	1.70
receiver-reactor	32.8	1.57	Heat exergy	29.4	1.41
Micro gas turbine	822.9	39.43	Chemical exergy	353.8	16.95
LiBr absorption refrigerator	186.2	8.92			

Based on typical 20,000 m^2 office building load and solar radiation data from Langfang experiment base of Institute of Engineering Thermophysics, Chinese Academy of Sciences, an analysis of variable conditions of a summer day was taken, the result is shown in Fig. 2.

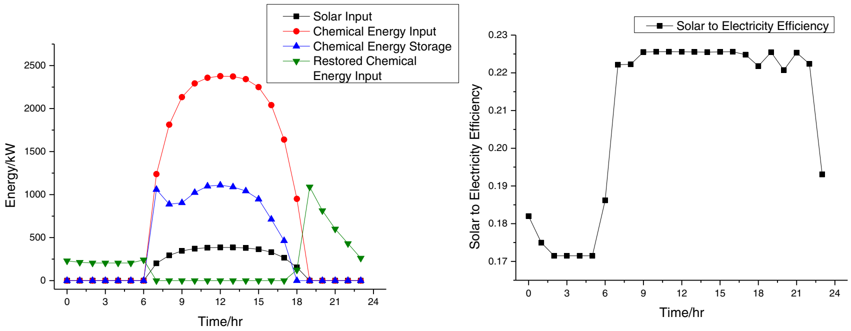

Fig. 2. (a) Energy stream of the system; (b) Solar to electricity efficiency

It is found from Fig. 2 that the novel system meets the power demand of the building, and achieves 54.62% of the cooling energy. Since the existence of the energy storage unit, the solar to electricity efficiency of the system is insensitive to the solar radiation changing.

4. Conclusion

In this paper, a novel distributed energy combined cooling power and heat with mid-and-low temperature solar energy thermochemical hybridization with methanol is proposed. the primary energy ratio of the system is 76.40%, the exergy efficiency of the system is 48.81%, and the net solar-to-electricity rate reaches 22.56%. Owing to the fact that the solar thermochemical energy storage is integrated to the system, the generating efficiency is insensitive to the solar direct radiation, and thus the efficient and stable utilization of solar thermal energy is achieved.

Acknowledgements

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Biography

Qibin Liu is an Associate Professor of Engineering Thermophysics at the Chinese Academy of Sciences (CAS). Dr. Liu's current research includes: solar thermal power, solar thermochemical technology, and analysis and optimization of energy systems. He has published more than 50 papers, and received the best paper award of The 3rd International Green Energy Conference (Sweden) in 2007.