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A polygeneration system for methanol and power production based on coke oven gas and coal gas with CO_2 recovery

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ABSTRACT

Polygeneration system for chemical and power co-production has been regarded as one of the promising technologies for fossil fuel sustainable utilization. In this paper, a new polygeneration system with carbon capture is integrated, based on coal gas and coke oven gas inputs for methanol and power co-production. New system can achieve more than 5% of primary energy saving ratio, and more than 50% of exergy efficiency. Exergy balance and Energy Utilization Diagrams (EUDs) are applied to show the performance improvement. In the system, pressure swing adsorption process is used to remove hydrogen from coke oven gas to enhance methane concentration, which reduces energy consumption and exergy destruction of reforming process. And for the methane reforming process, thermal energy for reforming is sensible thermal energy of syngas out of gasifier instead of fuel gas combustion. Furthermore, fresh syngas for methanol synthesis is the mixed gas of reformed coke oven gas and coal gas, which means that syngas components are adjusted without energy consumption. Lastly, CO_2 is recovered during chemical energy discharge and at the highest concentration resulting in less energy penalty. All of these energy integrating characteristics result in good thermal performance, which supplies a new direction for clean energy technology.

1. Introduction

Energy sustainable utilization has been an important subject for economic development of the world. With economic development, energy resource consumption increases sharply, and which worsens environmental problem. The recent report of International Energy Agency (IEA) shows that coal will be the main primary energy resource instead of crude oil anymore in five years, as there is an increasing demand for electricity generation, steel and cement productions in China, India and other emerging nations of Asia [1]. Furthermore, the region is always with lower efficiency of energy utilization, which leads to more greenhouse gas emissions. So, sustainable utilization of energy resources is necessary and important [1].

Conventionally, Chemical production and power generation are both with higher energy consumptions, and play important roles in economic development. Power system almost focuses on improvement of thermal energy utilization, and chemical production focuses on max product outputs. According to coke oven gas (COG) for chemical production, it must be transferred into CO and H_2 first, but because hydrogen component is higher than that of methane in COG, COG reforming process always consumes large of energy. Furthermore, because syngas out of reformer is rich in hydrogen, and syngas from coal is rich in CO, both of them must be adjusted to fit for chemical production with large of energy consumption. Higher energy consumption for chemical production based on coal or coke oven gas by traditional way is a critical problem [2–4].

Data of IPCC reports also show that carbon capture always leads to large of energy penalty. For pulverized-coal power plant, carbon capture from flue gas causes the thermal efficiency with more than 12 percentage points' drop, and for IGCC power plant, it decreases more than 8 percentage points. Due to less energy penalty, polygeneration system, integrating chemical production with power generation, has attracted more attentions, and some science researches and pilot projects have been carried out [2–9].

This paper is to integrate a new system for both COG and coal efficient utilizations, and to recover CO_2 with low energy penalty. The internal phenomena of energy use in the system are disclosed by energy utilization diagram method (EUD). And the results are to supply theory reference for the integrated utilization of COG and coal.

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Nomenclature

A	energy level
E	exergy [MW]
H	enthalpy [MW]
PES	primary energy saving ratio [%]
Q	low heat value [MW]
S	entropy [kJ/kg K]
T	temperature [K]
R_f	reformed rate of methane
Ru	ratio of recycled syngas to the fresh gas
W	work or electricity [MW]
x	coefficient of energy level difference
η	efficiency [%]

Acronyms and subscripts

0	the reference state
ASU	air separation unit
C	coal
CC	carbon capture
CG	coal gas
COG	coke oven gas
CO_X	carbon oxides
DISTIL	distillation
ea	energy accepter
ed	energy donor
HRSG	heat recovery steam generator
ME	methanol
M.S.	methanol synthesis
P	electric power
PSA	pressure swing adsorption

2. New polygeneration system based on COG and coal

2.1. Conceptual design of the new system

The traditional reforming process is shown in Fig. 1. COG is as fuel to supply thermal energy for COG reforming, but COG is rich in hydrogen and methane, just to supply thermal energy must lead to large exergy destruction and lower efficiency. Furthermore, because hydrogen is the main product of reforming, its high concentration in COG is a main reason of higher energy consumption for reforming process.

In traditional steam-methane reforming, methane is always totally reacted. But when about 90% methane reacted, the energy consumption increases sharply, which means that the reaction irreversibility increases. So Prof. H. Jin and his co-workers have proposed the system integration theory of partial reaction, which means that methane is unnecessary to be totally transformed into syngas, when the energy consumption begins increasing sharply, the reaction can be stopped, and un-reacted gas can be utilized in other ways. It can realize the couple between the composition transformation and energy utilization from the viewpoint of chemical energy cascade utilization [10–15].

For coal-based chemical process, the temperature of coal gas (CG) out of the gasifier can be about 1400 °C, and it is thrilled directly by cold water. In some cases, waste heat boiler is used to recycle the syngas thermal energy, by recovery steam about 550 °C. Both of which lead to higher exergy destruction.

Based on the situations of COG and CG utilizations, we propose a conceptual design of the new system, as shown in Fig. 2. Because hydrogen in COG is near 60%, 90% of hydrogen is separated via pressure swing adsorption process (PSA) firstly. And in the reforming process, thermal energy is supplied by sensible thermal energy of CG. Furthermore, methane is partially reacted. After the reaction, CG and the syngas out of reformer are mixed together, and as fresh gas for methanol synthesis. In methanol synthesis process, about 80% un-reacted syngas is recycled into the reactor, and CO_2 is captured from the un-recycled syngas. After CO_2 recovery, the left syngas and hydrogen out of PSA is as fuel of combined cycle for power generation.

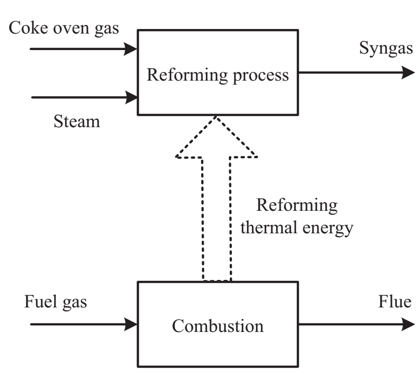

Fig. 1. Traditional reforming process.

The new reforming process is shown as Fig. 3, although PSA is adopted, fresh gas is produced with less exergy destruction due to: syngas mixed to adjust components, ratio changed of steam to methane, sensible thermal energy displacing fuel gas in reforming, partial methane reformed, and it is more important that sensible thermal energy of coal gas is converted into chemical energy of syngas.

2.2. Configuration of the new system

Flow sheet of the new system is shown in Fig. 4. By PSA process, 90% hydrogen is separated, and the rich-methane gas is put into reformer. Coal gas out of gasifier is put into the reformer to supply reacting thermal energy. About 70% methane is reacted with steam, which is more different to that mentioned in Ref. [16]. After clean-up unit, the low temperature CG is mixed with reacted coke oven gas. Then the mixed gas is put into the methanol synthesis reactor. There are about 80% un-reacted syngas is recycled to the reactor, and the left is put into shift process after recycled pressure energy. After CO_2 capture, the rich-H_2 gas and hydrogen out of PSA are put into combined cycle as fuel.

3. Evaluation of the new system

3.1. Traditional methanol production based on COG and coal

Methanol production system can be divided into two subsystems, fresh gas preparation subsystem and methanol production subsystem. For coal-based system, as shown in Fig. 5, coal is transformed into syngas via gasifier, and with a series of processes, constituents of syngas are adjusted to match the stoichiometric ratio of methanol synthesis as fresh gas. In methanol synthesis process, un-reacted syngas out of synthesis reactor is totally recycled into the reactor. With this synthesis configuration, more than 90% of the fresh gas can be transformed into methanol. In the coal-