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Realizing low life cycle energy use and GHG emissions in coal based polygeneration with CO_2 capture

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HIGHLIGHTS

- Introduce a polygeneration technology which capture CO_2 with low efficiency penalty.
- Life cycle energy use and GHG emissions are evaluated to this technology with CCS.
- Polygeneration with CO_2 capture shows 10–19% lower energy use than USC with CCS.
- Polygeneration with CO_2 capture shows 10–17% lower GHG emissions than USC with CCS.

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ABSTRACT

Cogeneration of synthetic natural gas (SNG) and power from coal can realize both high energy conversion efficiency and low energy penalty for CO_2 capture (CC). Life cycle energy use and GHG emission assessments are applied to coal based SNG and power cogeneration with CO_2 capture. Four typical pathways are considered based on the main applications of SNG in China. Results show that when SNG is produced in a single product plant with CO_2 capture and SNG is used for power generation, its life cycle energy use is averagely around 5% lower than that of supercritical coal power with CC and even can be comparable with ultra supercritical (USC) with CC pathway. Such low energy use is mainly due to much lower energy penalty for CO_2 capture in a SNG production plant than in a post-combustion coal fired power plant. The life cycle energy use of cogeneration plant with CC is 10–19% lower than that of USC with CC due to system integration, the obvious higher CO_2 concentration before separation and the consequent much lower energy penalties for CO_2 capture. The life cycle GHG emissions of cogeneration with CC range from 135 to 150 gCO_2 eq./MJ, which are obviously lower than those of all coal power pathways including USC units (10–17% lower than USC with CC). For steam and power cogeneration and pure vehicle operation pathways, the cogeneration technology with CO_2 capture also shows obvious life cycle energy use and GHG emission advantages over its competitive pathways.

1. Introduction

Production of synthetic natural gas (SNG) from coal or biomass is thought to be an efficient way for coal and biomass utilization compared to coal to other alternative fuels such as methanol and DME [1–4]. Coal to SNG can enforce the energy security considering both oil dependency and gas dependency in China are increasing quickly in these years [5]. However, the production of SNG from a traditional single product plant is thought to be not competitive to coal power pathways in terms of life cycle energy use and GHG emissions if no CO_2 capture is applied [6–8]. Previous work claimed that the life cycle energy and GHG emissions of coal to SNG (in a traditional single product plant) were both normally higher than advanced coal power pathways [6–8]. It was reported that the life cycle GHG emissions associated with converting coal to SNG were averagely 1.35–1.60 times those associated with the coal to power pathway [6]. And under best conditions, the plant efficiency of traditional coal to SNG plant can be around 60% [6], and the lower limits of its life cycle energy use and GHG emissions were reported to be comparable to the average levels of coal power pathway but still higher than ultra supercritical (USC) coal power pathway [9].

The high life cycle energy use and GHG emissions of SNG production in a traditional single product plant is mainly due to the high energy consumption for SNG production [9]. However, it was reported that cogeneration of SNG and power was more energy efficient [10–12]. In our previous work [9], the life cycle

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energy use and GHG emissions have been presented for SNG and power cogeneration technology and cogeneration shew comparable or better energy and environmental performances over other coal based alternatives. Nevertheless, the previous work did not consider the life cycle energy use and GHG emissions for SNG and power cogeneration technology with CO_2 capture (CC). It was stated that the cogeneration plant can capture CO_2 with quite low energy penalty compared to post-combustion coal fired power plants and may be the future directions toward high efficient, clean and decarbonization of coal utilization [13]. Technical and economic performances of the cogeneration technology with CO_2 capture have been evaluated in these works [12,13]. The pathway of polygeneration with CO_2 capture represent one of the most important future directions for clean coal utilization since China's energy structure is highly coal dependent and the emission reduction pressure is huge. However, it is important and necessary to evaluate the innovative PG with CC technology from life cycle viewpoint. Thus, this work aims to assess its life cycle energy use and GHG emissions, and the main outcomes may help policy makers to decide the choice of promising technologies for clean coal utilization.

2. Coal based cogeneration/polygeneration with low energy penalty for CO_2 capture

This section will introduce the proposed coal based cogeneration/polygeneration technology with CO_2 capture and its competitive pathways.

2.1. Traditional coal to SNG plant

As shown in Fig. 1, in traditional single SNG product plant, the raw syngas from a gasifier is cooled down to around 200–300 °C through a quench or a waste heat boiler (WHB) unit. Then, the syngas is sent to water gas shift (WGS) unit to convert part of CO into CO_2 and H_2 by reacting with H_2O. Fresh syngas with H_2/CO mole ratio around 3.0 is prepared to satisfy the stoichiometric requirement of the methanation reaction ($CO + 3H_2 \rightarrow CH_4 + H_2O$). Acid gases (sulfur and CO_2) need to be removed before the fresh syngas is sent to synthesis unit to avoid the effectiveness of the catalyst [13]. Fresh syngas will synthesize SNG in sequential reactors to produce the satisfactory product.

From the perspective of energy utilization, there are three main problems of single SNG product plant. One is that typically a small pulverized plant is needed to supply the power of the whole plant. And the efficiency of such kind of small pulverized plant is very low due to low steam parameters, limiting further improvement in the efficiency of the single product plant. Another energy utilization problem is that large amount of unreacted gas should be recycled to the inlet of the SNG synthesis reactors to ensure complete conversion of CO and H_2 into CH_4, resulting huge power is consumed to recompress the recycle gas and sharp energy consumption increase in chemical synthesis [10,13]. Also, large amount of steam is required in WGS unit [10,13].

In terms of CO_2 capture from a single SNG product plant, CO_2 is captured in acid gas removal unit and it is just a byproduct of syngas composition adjustment [13]. The CO_2 concentration before separation is limited by the extent of WGS reaction which is further controlled by the stoichiometric requirement of methanation reaction. Typically, CO_2 mole concentration is only around 30–40% in a traditional single SNG product plant, causing a relative high energy consumption for CO_2 capture.

2.2. SNG and power cogeneration with low energy penalty for CO_2 capture

Aiming at the main energy utilization and CO_2 capture problems of traditional single SNG product plant, a SNG and power cogeneration process with CO_2 capture was proposed by our previous work [13]. As can be seen in Fig. 2 that, part of the unreacted gas from SNG synthesis unit is recycled to the inlet of the reactor, and the left is sent to a combined cycle unit to generate power. By such integration, large amount of power consumption for recycle gas recompression is avoided and high efficient power generation is realized in a combined cycle other than in a small coal pulverized plant [13]. And WGS unit is abolished as there is no need to convert all CO and H_2 into CH_4 in a cogeneration plant, and thus steam consumption for WGS is no more required [13]. Furthermore, the sensible heat of the raw syngas from gasifier together with the heat release from SNG synthesis reactions is recovered in WHBs where steam is generated for power generation. Especially, for CO_2 capture, the CO_2 removal unit is rearranged after SNG synthesis other than before synthesis in a traditional single SNG product plant. Through the SNG synthesis reaction, CO and H_2 in the syngas are converted into CH_4, and CO_2 is left. Obviously, 1 mol CO and 3 mol H_2 just yield 1 mol CH_4, resulting less total moles of the raw product gas and the enhancement of CO_2 concentration [13]. Therefore, in this cogeneration plant, CO_2 concentration before separation can be enriched to around 55% by eliminating WGS and properly controlling the amount of recycle gas, and low energy penalty for CO_2 capture is expected [13]. It was investigated in our previous work [13] that the efficiency of the whole plant could be as high as 59.7% when the plant yields a 2.82 SNG to power output ratio (the lower heating value of SNG product to electricity product) and around 66% carbon is captured. In addition to high efficiency, the cogeneration plant with CC also shows good economic feasibility. It was studied that compared to IGCC + CC and single SNG production plant, the total annual cost of the cogeneration plant could be 3.8% lower [12]. And the cogeneration plant could realize low cost CO_2 capture (around 7.9 $/t), which is far below PC plant employing post-combustion CO_2 capture [12].

The double benefits from both system integration and CO_2 concentration enhancement can result in near zero energy penalty for CO_2 capture when the reference plants without CO_2 capture are traditional single SNG product plant and IGCC plant [13].

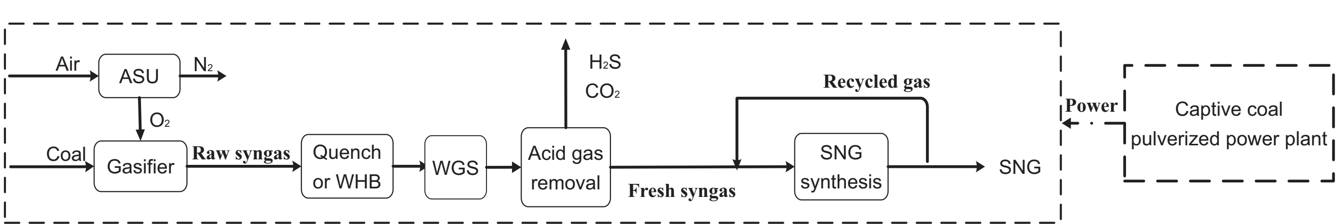

Fig. 1. Traditional single SNG product plant.