TECHNO-ECONOMIC ANALYSIS OF COAL BASED HYDROGEN AND ELECTRICITY CO-GENERATION PROCESSES WITH CO_2 CAPTURE

Fanxing Li, Liang Zeng, and L.-S. Fan*
Department of Chemical and Biomolecular Engineering
The Ohio State University
140 West 19th Avenue
Columbus, Ohio 43210
U. S. A.

Summary

The techno-economic performances of various coal based hydrogen and electricity co-generation processes are examined under a carbon constrained scenario. Both the conventional coal gasification – water gas shift process and the novel membrane and syngas chemical looping processes are evaluated. Aspen Plus® simulation is first performed to analyze the process efficiencies based on a common set of assumptions. This is followed by economic analysis using the cost analysis principles suggested by USDOE. The results indicate that the novel membrane and chemical looping strategies have the potential to reduce energy and cost penalties for CO_2 capture in coal conversion processes.

Keywords

Clean coal, CO_2 capture, membrane reactors, hydrogen production

Introduction

As the most abundantly reserved fossil fuel, coal accounts for 40% of the electricity generated worldwide and is projected to remain as an important fossil energy source within the foreseeable future [1]. Compared to other fossil fuels such as crude oil and natural gas, coal is more carbon intensive and difficult to convert. Conventional pulverized coal combustion (PCC) plants convert approximately a third of the energy in coal into electricity. Such an energy conversion efficiency can be further reduced by up to 40% when a mono-ethanol amine (MEA) based carbon capture system is retrofitted to the plant [2]. With CO_2 regulation looming over the horizon, efficient coal conversion and CO_2 control strategies are highly desired.

Hydrogen and electricity are produced commercially through coal gasification. Compared to PCC, coal gasification can potentially be more efficient with less energy penalty for CO_2 capture. However, CO_2 capture will nevertheless reduce the efficiency of a conventional coal gasification plant by up to 24% [2]. More advanced approaches such as membrane enhanced water gas shift (WGS) processes and syngas chemical looping process are being developed to improve the performance of coal gasification under a carbon constrained scenario [3,4]. The membrane enhanced WGS process integrates hydrogen or CO_2 selective membrane to the WGS reactor to simultaneously remove the WGS reaction product, thereby increasing the reaction yield. The chemical looping approach, on the other hand, indirectly converts coal derived syngas into separate streams of concentrated CO_2 and H_2 through the assistance of a reactive reaction medium, avoiding the CO_2 separation step. Previous studies focus on analyzing the efficiencies of either the membrane enhanced WGS processes or the chemical looping process [2-5]. Comprehensive techno-economic analyses on the conventional and novel processes based on a common set of assumptions, however, have not been performed to date. In order to impartially evaluate relative performances of the various options for coal conversion under a carbon constrained scenario, the present study analyzes all the aforementioned processes using the cost and performance baseline published by US Department of Energy (USDOE) [6]. The results of the present study can be useful for the development of next generation clean coal conversion processes under a carbon constrained scenario.

Process Overviews

The four conventional and novel coal gasification processes analyzed in the present study, i.e. conventional coal gasification – WGS process, H_2 selective membrane enhanced WGS process, CO_2 selective membrane enhanced WGS process, and syngas chemical looping process, are introduced in this section.

Conventional Coal Gasification – WGS Process

* To whom all correspondence should be addressed Tel.: 001-614-688-3262; Email: Fan.1@osu.edu

The schematic flow diagram of the conventional coal gasification – WGS process is given in Figure 1.

H_2 Selective Membrane Enhanced WGS Process
The schematic of the H_2 selective membrane enhanced WGS process is given in Figure 2.

CO_2 Selective Membrane Enhanced WGS Process
The schematic flow diagram of the CO_2 selective membrane enhanced WGS process is given in Figure 3.

Syngas Chemical Looping Process
The schematic flow diagram of the syngas chemical looping process is given in Figure 4.

Process Analysis Models and Methods

Aspen Plus® simulation is performed to compare the energy conversion efficiencies of the four processes. A common set of assumptions for coal type, coal processing rate, carbon conversion of the gasifier, reactor heat loss, CO_2 capture rate, etc are used. The assumptions are consistent with those in the process analyses performed by USDOE. This is followed by cost analysis based on the USDOE cost and performance analysis baseline.

Results and Discussion

The techno-economic performances of the four aforementioned gasification processes are analyzed. Effects of key process parameters such as the membrane permeability and cost and the chemical looping medium conversion on the process performances are evaluated through sensitivity analysis. The results indicate that, compared to the conventional coal gasification process, the novel processes can capture CO_2 more effectively, leading to higher process efficiencies and lower product costs.

Conclusions

Four conventional and novel coal based hydrogen and electricity co-production schemes are studied. From energy conversion efficiency standpoint, the SCL process has the potential to deliver the highest efficiency. The two membrane enhanced WGS processes can also improve the energy conversion efficiencies for coal gasification when CO_2 capture is mandatory. All three novel processes have shown cost advantage compared to the conventional coal gasification – WGS scheme under a carbon constrained scenario.

References

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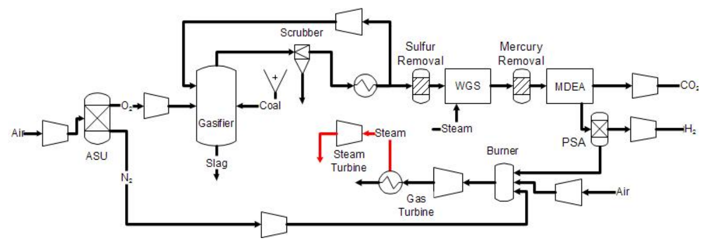

Figure 1. Conventional Gasification – WGS Process

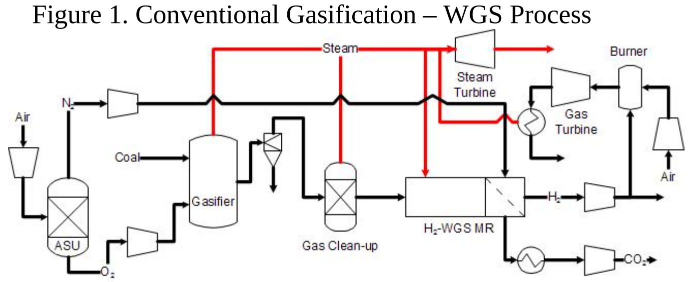

Figure 2. H_2 Selective Membrane Enhanced WGS Process

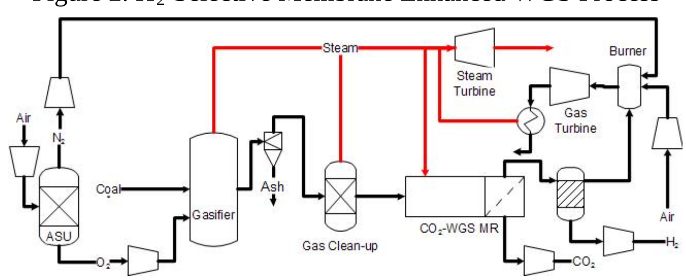

Figure 3. CO2 Selective Membrane Enhanced WGS Process

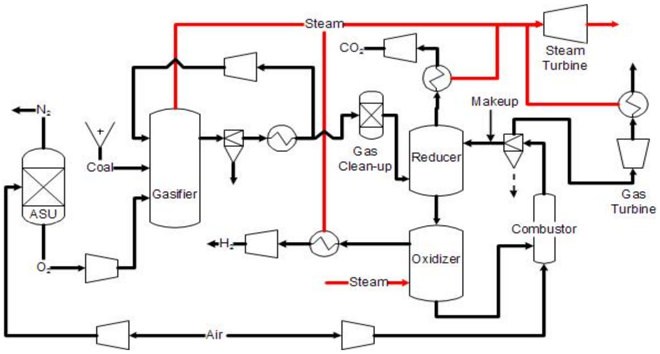

Figure 4. Syngas Chemical Looping Process