ADVANCED CO₂ CYCLE POWER GENERATION

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Abstract

Research is being conducted under United States Department of Energy (DOE) Contract DE-FC26-02NT41621 to develop a conceptual design and determine the performance characteristics of a new IGCC plant configuration that facilitates CO₂ removal for sequestration. This new configuration will be designed to achieve CO₂ sequestration without the need for water gas shifting and CO₂ separation, and may eliminate the need for a separate sequestration compressor.

This research introduces a novel concept of using CO₂ as a working fluid for an advanced coal gasification based power generation system, where it generates power with high system efficiency while concentrating CO₂ for sequestration. This project supports the DOE research objective of development of concepts for the capture and storage of CO₂.

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1. Executive Summary

Project Overview

The linkage between global climate change and emission of greenhouse gases such as carbon dioxide (CO₂) is well documented. Modern pulverized coal-fired power plants are some of the largest single point emitters of CO₂. To assure continued U.S. power generation from its abundant domestic coal resources, new coal combustion technologies must be developed to meet future emissions standards, especially CO₂ sequestration.

This project will develop a conceptual design to determine the performance characteristics of a new IGCC plant configuration that facilitates CO₂ removal for sequestration without the need for water gas shifting and CO₂ separation and may eliminate the need for a separate sequestration compressor. The plant will introduce a novel concept of using CO₂ as a working fluid for an advanced coal gasification based power generation system, where it generates power with high system efficiency while concentrating CO₂ for sequestration. This project supports the DOE research objective of development of concepts for the capture and storage of CO₂.

A published study^{[1]*} has shown that CO₂ removal/sequestration systems applied to the back end of a pulverized coal-fired plant can reduce its efficiency by up to 11 points with a resulting \$30 per ton CO₂ removal cost. For oxygen-blown IGCC plants, carbon monoxide can be water gas shifted to hydrogen and CO₂ upstream of the gas turbine. The CO₂ can then be separated and concentrated by absorption and stripping or by membranes and then compressed for sequestration. This process is energy intensive, costly, and lowers system efficiency due to the energy losses associated with shifting. (Because the lower heating value (LHV) of hydrogen is less than carbon monoxide on a per mole basis, 15% of the LHV is lost when carbon monoxide is shifted to hydrogen. Therefore, more syngas needs to be generated from gasification to compensate for the shift loss. The low-grade heat from the shift reaction contributes to system losses.) An efficiency loss of 6% with a CO₂ removal cost of \$15 per ton is estimated for such an IGCC plant.

The proposed advanced gasification system avoids these problems by using a mixture of CO₂ recycled from the gas turbine exhaust together with oxygen as the working fluid; this facilitates straightforward concentration of CO₂ at high pressure without a shift reaction and, depending upon the required pipeline pressure, may eliminate the need for a separate compressor for sequestration. Any excess oxygen in the gas turbine exhaust is recycled along with the CO₂ back to the gasifier, thus minimizing oxygen usage. The process eliminates the need for CO₂ shifting, absorption, and stripping allowing direct collection of CO₂ at the gas turbine compressor discharge pressure. This results in a simpler CO₂ collection process than conventional oxygen-blown IGCC systems while providing additional advantages of a lower cost and a minimal loss in efficiency.

* numbers in brackets indicate reference

Progress During the Quarter (April 1 Through June 2003)

The project work during this quarter is focused on Task 1 – Cycle Analysis. The work started with a detailed review of existing IGCC cycles in the literature, including Foster Wheeler's development work of GFBCC technology.

Reference [1] presents a conceptual design along with performance and economics of two different plants incorporating 90% CO₂ removal for pipeline transport to an offsite sequestering location. The plants studied were an oxygen-blown, entrained flow gasifier IGCC and a PC fired plant. The current study uses the same project ground rules, i.e., site characteristics, Illinois #6 coal, CO₂ pipeline conditions, gas turbine, etc. as Reference [1].

Framework of an ASPEN model of oxygen-blown CO₂ cycle coal gasification plant has been set up. The conceptual plant is based on the core GFBCC technology developed by Foster Wheeler and incorporates CO₂ as the working medium. This ASPEN model is being used to predict the gasification plant's performance, including syngas and char yields, compositions, and heating values.

The initial model simulation has revealed that, to achieve the same turbine exit temperature, the cycle with pure CO₂ as the working medium would require much higher turbine inlet pressure than a base case cycle with air as the working medium. As shown in Figure 1, the required pure CO₂ inlet pressure is over 1000 psia. A mixture of 70% CO₂ and 30% H₂O would require a gas mixture inlet pressure of about 800 psia. This finding has a number of implications on the design of the proposed CO₂ cycle gasification plant.

First, the proposed plant will need an advanced Intercooled Aeroderivative (ICAD) gas turbine. The ICAD turbine has a pressure ratio of 49 and an inlet pressure of 716 psia. Second, gas turbine interstage cooling by water injection may be desirable to increase the H₂O concentration in the working medium and thus avoid an excessively high turbine inlet pressure. Furthermore, both the CO₂ and O₂ need to be compressed to above 800 psia turbine inlet pressure.

Reference [1] suggests that CO₂ will be compressed to 1200 psia for sequestration. In our case all CO₂ compression will be done by the gas turbine compressor, and a part of the CO₂ can be extracted for recycle to the gasifier.

Compressing pure oxygen requires special materials for the compressor and piping due to its reactive nature. This would lead to high capital costs in addition to the large power consumption to compress gaseous oxygen. After reviewing the operating principles of the cryogenic air separation process, it becomes clear that pumping liquid oxygen to an elevated pressure, in the ASU plant itself, is potentially a much cheaper alternative for delivering pressurized oxygen. Of course, since liquid oxygen is usually used to cool the incoming air stream, during which the liquid oxygen vaporizes, pumping liquid oxygen to a high pressure will have an impact on the ASU system arrangement, especially the heat exchanger design. We plan to work with ASU vendors to identify the solutions and potential cost impact of the liquid oxygen pumping option. Figure 2 is a flow diagram of a typical ASU plant (Reference [2]).

Figure 1 Expansion performance for different gases

Figure 2 Cryogenic air separation process (Reference [2])

2. Experimental

This work is a conceptual study and does not employ any experimental methods.

3. Results and Discussion

Preliminary cycle analysis indicates that the proposed CO₂ cycle will require the working medium to be compressed to a higher pressure than that of the current air-blown gasification combined cycle technologies. Increasing the moisture content in the working medium can reduce the inlet pressure requirement. A mixture of 70% CO₂ and 30% H₂O would require a gas mixture inlet pressure of about 800 psia.

The same gas turbine compressor will be used to prepare the CO₂ for sequestration and deliver the pressurized CO₂ to the gasifier. Instead of compressing the CO₂ to its final pressure, to reduce power consumption, the extracted CO₂ stream from the compressor for sequestration will be cooled down and condensed, and then the condensed CO₂ will be pumped to pipe line pressure. A potentially low cost option for high-pressure oxygen supply is to integrate pumping of liquid oxygen into the ASU plant. Further cycle analysis is being done to verify these initial findings.

4. Conclusion

No technical project conclusions are currently available.

5. References

1. "Evaluation of Innovative Fossil Cycles Incorporating CO₂ Removal", M. De Lallo et al, Parsons Energy and Chemical Group. Presented at 2000 Gasification Technologies Conference, San Francisco, CA, October 8-11, 2000.
2. "Kirk-Othmer's Encyclopedia of Chemical Technology – Cryogenics", 4th edition, 1993, V7, 659 – 683.