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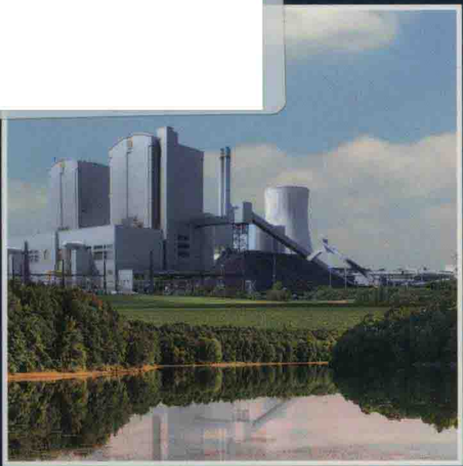

Integrated Gasification Combined Cycle (IGCC) Technologies

Edited by Ting Wang and Gary Stiegel

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List of Contributors

Claudio Allevi SARAS, Milano, Italy

Phil Amick Hard Carbon Consulting, LLC, Pearland, TX, United States

Silvio Arienti Amec Foster Wheeler, Corsico, Milano, Italy

Fátima Arroyo Torralvo ETSI-Universidad de Sevilla, Seville, Spain

Testuji Asano Joban Joint Power Co., Ltd., Iwaki-shi, Fukushima-ken, Japan

Pietro Bartocci University of Perugia, Perugia, Italy

Omar M. Basha University of Pittsburgh, Pittsburgh, PA, United States

Debangsu Bhattacharyya West Virginia University, Morgantown, WV, United States

Steven M. Carpenter Enhanced Oil Recovery Institute, Laramie, WY, United States

P. Casero ELCOGAS, Puertollano, Spain

P. Coca ELCOGAS, Puertollano, Spain

Guido Collodi Amec Foster Wheeler, Milano, Italy

Francesco Fantozzi University of Perugia, Perugia, Italy

He Fen Shell

Constantino Fernández Pereira ETSI-Universidad de Sevilla, Seville, Spain

Thomas H. Fletcher Brigham Young University, Provo, UT, United States

Oriol Font Piqueras Consejo Superior de Investigaciones Científicas (CSIC), Seville, Spain

F. García-Peña ELCOGAS, Puertollano, Spain

Alex Gorodetsky Alter NRG Corp., Calgary, AB, Canada

Dr. David Gray Noblis (Retired)

N. Hervás Universidad de Castilla-La Mancha, Ciudad Real, Spain

Herbert M. Kosstrin Leidos Engineering, L.L.C

Vijayaragavan Krishnamoorthy The Pennsylvania State University, University Park, PA, United States

Henry A. Long III University of New Orleans, New Orleans, LA, United States; Energy Conversation and Conservation Center

Giovanni Lozza Politecnico di Milano, Milano, Italy

Diane R. Madden National Energy Technology Laboratory, Pittsburgh, PA, United States

Luca Mancuso Amec Foster Wheeler, Corsico, Milano, Italy

Bernd Meyer Institute of Energy Process Engineering and Chemical Engineering (IEC), Freiberg, Germany

Badie Morsi University of Pittsburgh, Pittsburgh, PA, United States

Mustafa Ozer University of Pittsburgh, Pittsburgh, PA, United States; Istanbul Technical University, Maslak, Istanbul, Turkey

Sarma V. Pisupati The Pennsylvania State University, University Park, PA, United States

Loek Schoenmakers Nunhem, Limburg, The Netherlands

Gary Stiegel Pittsburgh, PA, United States

Veena Subramanyam Alter NRG Corp., Calgary, AB, Canada

Richard Turton West Virginia University, Morgantown, WV, United States

Rob van den Berg Shell

Ting Wang University of New Orleans, New Orleans, LA, United States

Christian Wolfersdorf Institute of Energy Process Engineering and Chemical Engineering (IEC), Freiberg, Germany

Stephen E. Zitney West Virginia University, Morgantown, WV, United States; Morgantown, WV, United States

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An overview of IGCC systems

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Ting Wang
University of New Orleans, New Orleans, LA, United States

1.1 Introduction of IGCC

IGCC is an acronym for Integrated Gasification Combined Cycle. The major purpose of IGCC is to use hydrocarbon fuels in solid or liquid phases to produce electrical power in a *cleaner* and *more efficient* way via *gasification*, compared to directly *combusting* the fuels. The hydrocarbon fuels typically include coal, biomass, refinery bottom residues (such as petroleum coke, asphalt, visbreaker tar, etc.), and municipal wastes. The approach to achieve a "cleaner" production of power is to convert solid/liquid fuels to gas first, so that they can be cleaned before they are burned by removing mainly particulates, sulfur, mercury, and other trace elements. The cleaned gas, called synthetic or synthesis gas (syngas), which primarily consists of carbon monoxide (CO) and hydrogen (H_2), can then be sent to a conventional combined cycle to produce electricity. A simplified IGCC process diagram comprising three major "islands"—gasification, gas cleanup, and power—is shown in Fig. 1.1. The ultimate goal for IGCC is to achieve a lower cost of electricity (COE) than conventional pulverized coal (PC) power plants and/or to be competitive with natural gas-fired combined-cycle systems with comparable emissions.

While "clean" power generation is the primary driving motivation for entering the business of IGCC, "increasing plant efficiency" to a level higher than that of PC plants is the second driving motivation. To achieve higher efficiency, "integration" between sub-systems becomes necessary. Integration consists of all aspects of the operation, including mechanical, thermal, and dynamic process control. For example, mechanical integration can be achieved between the compressor of the gas turbine (GT) and the air separation unit (ASU), aiming to save some compression power.

Thermal integration can be implemented by strategically interconnecting the various grades of steam generated during the syngas cooling, gas cleanup, and/or water-gas shift processes with the heat recovery steam generator (HRSG) and the steam turbine system. Full air integration does enhance the overall plant efficiency positively by about three to four percentage points, but it also increases the complexity of construction, operation, and maintenance, which may result in increased potential for construction phase delay and/or cost overrun, increased maintenance, lost availability, and degraded reliability. Thus, the concept of nonintegrated IGCC has been advocated by some developers to trade reduced efficiency for higher availability and reliability, even though the term "nonintegrated IGCC" could be confusing.

When the potential of global warming became a concern, the emission of carbon dioxide (CO_2)—a greenhouse gas (GHG)—from power plants was subjected to

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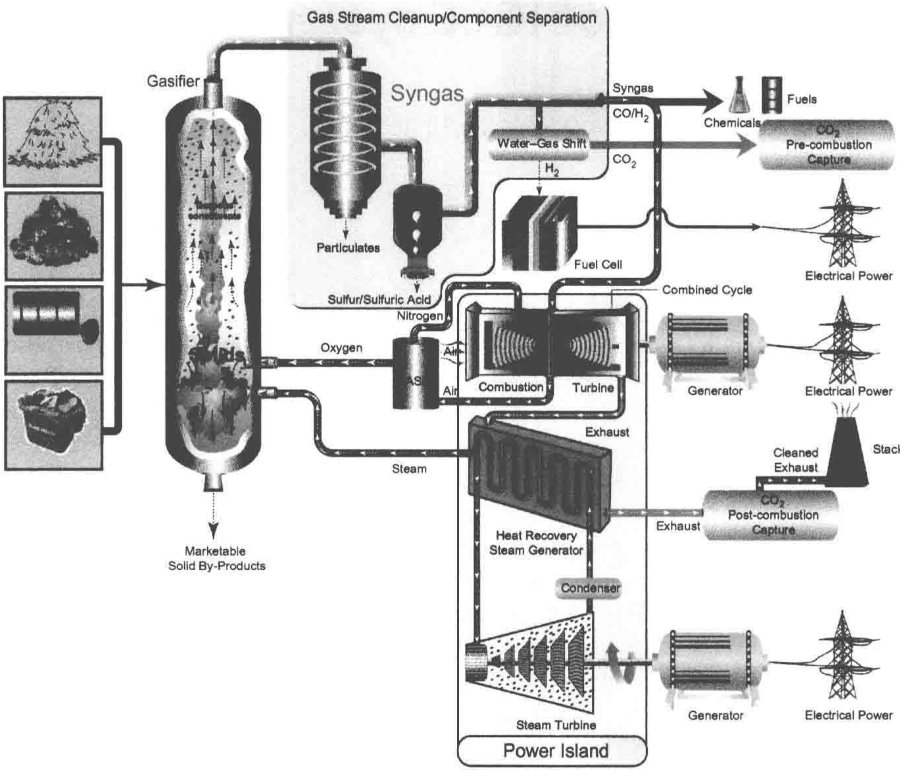

Figure 1.1 Simplified block diagram of an IGCC system.

stringent scrutinization and regulations. Usually, there are three ways to reduce CO_2 emissions: by increasing the overall system efficiency, capturing a portion of the CO_2 and sequestering it, called *CCS (Carbon Capture and Sequestration)*, or utilizing the captured CO_2 multiple times. The syngas generated via the gasification process can be more readily separated into highly concentrated H_2 and CO_2 through the water-gas shift (WGS) process (to be explained later) before the combustion stage (i.e., *pre-combustion*) in an IGCC system, as opposed to PC power plants, which have to use a *post-combustion* carbon capture method. It is significantly cheaper to perform pre-combustion carbon capture in an IGCC system than post-combustion carbon capture in a PC power plant due to the nature of the processes involved and the reduced size of equipment. CCS imposes a severe penalty on power output, plant efficiency, and COE.

The objective of this chapter is to provide an introduction of the complete IGCC system, allowing readers quickly to obtain an overall view of the IGCC system, leaving the details in each subsequent chapters, each focusing on a specific subject. Although the gasification process can be applied to various carbon fuels, since the major developments and applications have involved coal, *the descriptions and explanations in this chapter are written with coal in mind as the major feedstock unless specified.*

1.2 Layouts of key IGCC components and processes

For the convenience of explaining the IGCC systems with information of some of the flow's thermodynamic properties, the flow system diagrams obtained from an academic simulation of an IGCC plant are used. The simulation was performed using the commercial software, GT Pro, a part of the program suite, Thermoflow. The plant was designed to generate about 240 MWe of net power output, using Texas lignite as feedstock. The results of these simulated IGCC plants have been documented by Wang and Long (2012a, 2012b, and 2014). Two systems were simulated in Wang and Long's papers. The result of the one with a lower steam turbine inlet pressure (1100 psi/76 bar) and temperature (538°C/1000°F) is used in this chapter. Fig. 1.2 shows the general layout of the baseline case with and without CCS.

The feedstock is the South Hallsville Texas Lignite with a feeding rate of 4308 tons/day. The reason of using the Texas Lignite is because the simulate plant is located in Louisiana and Texas Lignite is close by. The coal is mixed with 35% water by weight to form a slurry, which is injected into a GE entrained flow gasifier together with 95% pure oxygen provided by the air separation unit (ASU). The syngas coming out of the gasifier needs to be cooled down to meet the operating conditions of the currently available gas cleanup system. Typically, either a radiant syngas cooler or a quench cooling method can be used, followed by several traditional convective heat exchanger coolers. The gas cleanup system consists of a scrubber to remove particulates and other soluble contaminants, such as hydrogen cyanide (HCN), ammonia (NH_3), and hydrochloric acid (HCl). The slight amount of carbonyl sulfide (COS) in the syngas is converted to hydrogen sulfide (H_2S) through COS hydrolysis. The syngas needs to be further cooled down to near the ambient temperature before it enters the Acid Gas Removal (AGR) unit. The heat released from the cooling process between the exit of the gasifier and the inlet of the AGR unit is used to generate superheated steam and hot water at various pressures.

The cleaned syngas is sent to the GT to generate electricity. The exhaust of the GT is at about 593°C (1100°F), which has sufficient energy to generate steam through a Heat Recovery Steam Generator (HRSG). The steam generated through the HRSG is combined with steam generated through the syngas cooling process to drive a steam turbine and generate additional electricity. This is identical to a conventional combined cycle. In this example here, a GE quench-type gasifier is used. The power block consists of a single GT, modeled after the Siemens SGT6-4000F turbine, with steam injection in the combustor to reduce NO_x formation, and a single ST, with a fixed steam inlet pressure and temperature of 1100 psi (76 bar) and 538°C (1000°F), respectively. The steam is reheated to 538°C (1000°F) at 174.5 psi (11.87 bar) to increase the output power and efficiency of the bottom steam cycle. The plant is designed exclusively for power generation, so no chemicals or energy gases are exported anywhere in the middle of cleanup.

If carbon capture is needed in a system that was initially designed without considering carbon capture, a post-combustion carbon capture system (shown as an inset in Fig. 1.2) can be implemented at the exhaust gas side exit of the HRSG. The carbon capture system makes use of an amine-based solvent to separate the CO_2 from the rest of the GT exhaust. The cost of using a post-combustion carbon capture system is

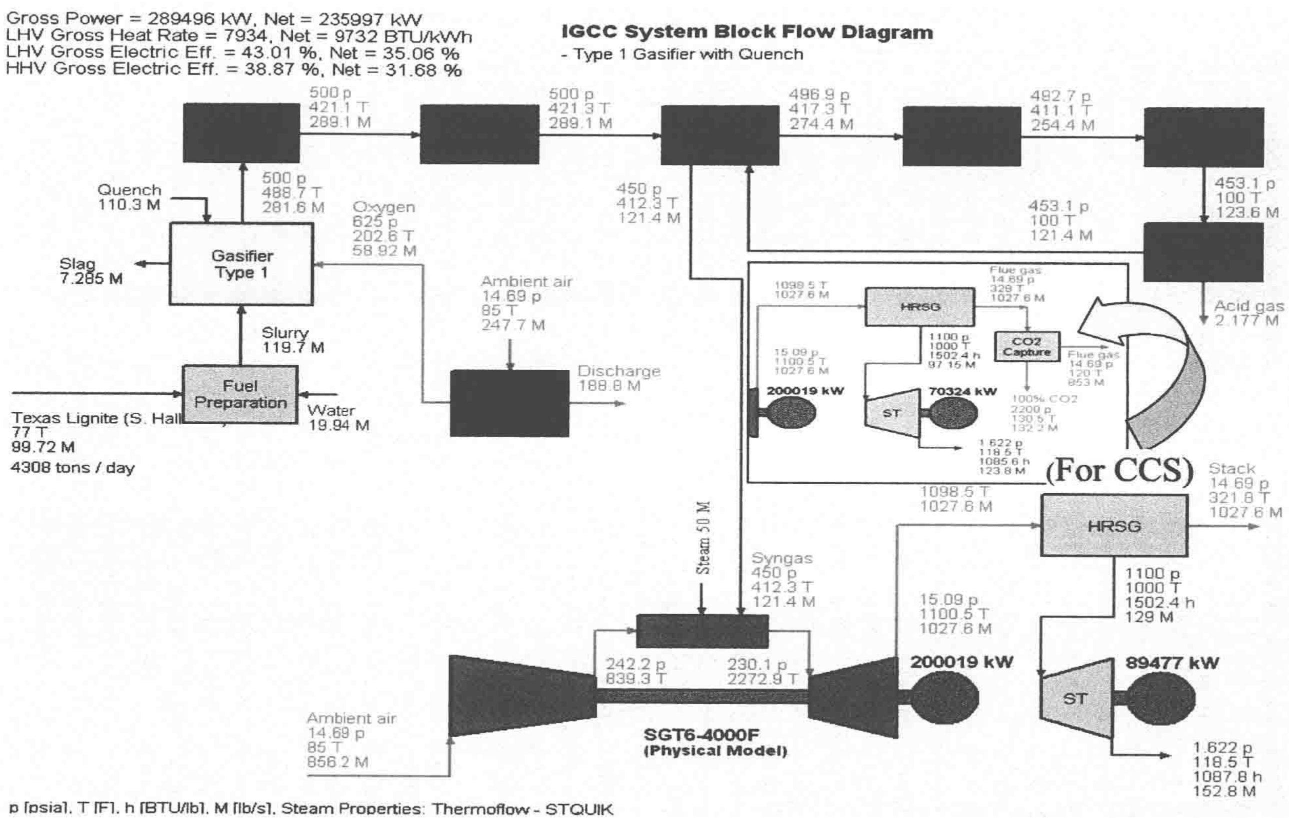

Figure 1.2 A general layout of a simulated IGCC plant without CCS with an inset showing an added post-combustion carbon capture system. The physical parameters at each nodal point is represented as pressure p (psia), temperature T(°F), enthalpy h(Btu/lb), and mass flow rate M(lb/s) (Wang and Long, 2012a).