ADVANCES IN THE SHELL COAL GASIFICATION PROCESS

E. L. Doering
Shell Oil Company
and
G. A. Cremer
Shell Synthetic Fuels Inc.
P. O. Box 2099
Houston, Texas 77252-2099

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Process Summary

The Shell Coal Gasification Process (SCGP) is a dry-feed, oxygen-blown, entrained flow coal gasification process which has the capability to convert virtually any coal or petroleum coke into a clean medium Btu synthesis gas, or syngas, consisting predominantly of carbon monoxide and hydrogen.

In SCGP, high pressure nitrogen or recycled syngas is used to pneumatically convey dried, pulverized coal to the gasifier. The coal enters the gasifier through diametrically opposed burners where it reacts with oxygen at temperatures in excess of 2500°F. The gasification temperature is maintained to ensure that the mineral matter in the coal is molten and will flow smoothly down the gasifier wall and out the slag tap. Gasification conditions are optimized, depending on coal properties, to achieve the highest coal to gas conversion efficiency, with minimum formation of undesirable byproducts.

The hot syngas exiting the gasifier is quenched to below the softening point of the slag and then cooled further in the syngas cooler. Entrained flyash is removed to less than 1 ppm using ceramic candle filters. Downstream syngas treating includes low level heat recovery and conventional cold gas cleanup to minimize trace metal emissions and to remove chlorides, and sulfur and nitrogen compounds. Essentially all of the nitrogen is ultimately converted to molecular nitrogen, and essentially all of the sulfur is recovered as salable, elemental sulfur. Slag and flyash are also recovered as marketable by-products. A simplified SCGP flow scheme is shown in Figure 1.

Technology Development

Research on the Shell Coal Gasification Process began in 1972, based on Shell's extensive experience with oil gasification. In 1976, a 6 TPD process development unit was placed in operation at Shell International's Amsterdam laboratory, and in 1978, a 150 TPD pilot plant was started up near Harburg, Germany. The Harburg unit, which operated until 1983, demonstrated the key technical features of the SCGP technology.

A very important element in the SCGP development program was the construction and operation of SCGP-1, the 250 TPD demonstration unit which operated between 1987 and 1991 at Shell Oil's Deer Park Manufacturing Complex near Houston, Texas. SCGP-1 was based on a scaled down version of commercial unit. During its 15,000 hours of operation, SCGP-1 clearly demonstrated the reliability, flexibility, efficiency, and environmental superiority of SCGP. Coal to clean gas efficiencies were typically above 80% and sulfur removal efficiencies were consistently above 99% for the 18 diverse feedstocks gasified at SCGP-1. The SCGP-1 feedstocks included domestic coals ranging from lignite to high sulfur bituminous coals, three widely traded foreign coals, and petroleum coke.

The extensive environmental, engineering and operating data collected during the SCGP-1 operating program provide the basic information necessary to permit, design, construct, and operate future SCGP plants. Moreover, the SCGP-1 program yielded a number of process improvements and innovations which have since been incorporated into commercial designs.

The Demkolec Project

The first commercial application of SCGP is the Demkolec Project, a 253 MW integrated gasification combined cycle (IGCC) power plant located in the Netherlands. Demkolec B.V., a wholly owned subsidiary of the Dutch Electricity Generating Board, selected SCGP as the coal gasification technology for their project in 1989 and executed an SCGP license agreement with Shell International later that year. Environmental permits based on NO_x emissions of 0.17 lb/MM Btu and SO_2 emissions based on 0.06 lb/MM Btu of design coal were obtained in April 1990. Construction began in July 1990, commissioning was completed in 1993 and startup was initiated in late 1993. An extensive, three-year demonstration program has been identified and is underway.

The Demkolec Project employs a single SCGP gasifier to fuel a Siemens V94.2 combustion turbine coupled with steam turbine and generator. The SCGP plant is fully integrated with the combined cycle plant, including the boiler feed water and steam systems; additionally, the compressed air for the high pressure air separation unit is supplied by extraction air from the combustion turbine air compressor.

The Demkolec Project features a multiple burner gasifier scaled up from the SCGP-1 gasifier to 2000 TPD coal. Also, the Demkolec Project includes a number of process improvements which were successfully demonstrated during SCGP-1 operation. Among these are:

- increased slagging efficiency and a reduction in slag entrainment;
- dry solids removal which offers higher flyash removal efficiency and lower cost;
- dry flyash recycle to improve carbon conversion and slagging efficiency;
- flux addition to promote slag flow and optimize gasification conditions, depending on coal properties;
- catalytic hydrolysis of hydrogen cyanide (HCN) and carbonyl sulfide (COS) to reduce corrosion, reduce emissions and simplify gas treating;
- zero aqueous process discharge for environmental considerations; and
- a turbine lead/gasifier follow control system for load following.

Additional SCGP improvements and innovations have been developed since the Demkolec design was completed with the aim of further reducing costs and improving performance. In the last several years, a number of design and optimization studies and capital cost estimates have been carried out for Shell-based IGCC systems with different engineering firms and equipment suppliers, including General Electric, Westinghouse, Air Products, Fluor/Daniel, Black & Veatch, and Bechtel, and with support from the Electric Power Research Institute. Developments in SCGP, improvements in gas turbine performance, and the ongoing experience of equipment manufacturers have all contributed to the Shell Synthetic Fuels' commercial design for SCGP.

Shell Synthetic Fuels' SCGP Commercial Design

The SCGP commercial design is the latest effort by Shell Synthetic Fuels Inc. to combine SCGP technology developments subsequent to the SCGP-1 program and the Demkolec Project design with other related IGCC improvements. The SCGP commercial design is based on a single train SCGP plant coupled with a high pressure air separation unit (ASU) to fuel a single combustion turbine operating in combined cycle service. If the GE frame 7FA combustion turbine is used, IGCC net power output is estimated to be approximately 265 MW. With a high sulfur Illinois coal, heat rate is estimated at slightly less than 8150 Btu/kWh. Even lower heat rates can be expected with most other bituminous coals.

The principal objective of the SCGP commercial design is to deliver competitive capital and maintenance costs with superior efficiency and environmental performance. Each of the main systems associated with a Shell-based IGCC plant is reviewed below.

Coal Pulverizing and Drying

Roller or bowl mill pulverizers have been demonstrated in higher capacity service in the last several years. The SCGP commercial design includes two large commercial scale pulverizers for a single gasifier/gas turbine train. (Three pulverizers would be premised for a two gasifier/gas turbine system.) Each pulverizer has excess capacity so that sufficient availability is provided without the need for an additional pulverizer. Heat and nitrogen savings have also been designed into the drying system for higher moisture content coals.

SCGP Gasifier

The SCGP-I unit was shutdown in March 1991. Considerable analyses of the later stages of the SCGP-I operation showed that the cold gas efficiency could be further increased and that the scaleup/severity parameters were less restrictive than anticipated. These less conservative scaleup rules allow reduced gasifier physical dimensions for a design coal/syngas rate. Further engineering studies into the results of the gasifier scaleup tests at SCGP-I have led to a more compact gasifier design, while at the same time leading to increased syngas production. Gasifier materials' life is extended by operating the gasifier cooling medium at lower pressure.

Syngas Cooling and Dry Solids Removal

The SCGP dry coal feed system leads to very high coal to gas conversion efficiencies as well as gasifier exit temperatures which are higher than those from coal slurry feed systems. The high gasifier exit temperature and low moisture content of the raw syngas allow most of the waste heat to be recovered at high levels through syngas cooling, at a relatively modest cost. Extensive low level heat utilization is not required to achieve high thermal efficiencies, Consequently, for SCGP, the cost of syngas cooling will almost always be justified by the value of the high level steam produced. Clearly, however, the benefits of syngas cooling can be enhanced by reducing equipment capital and maintenance costs.

The syngas cooling equipment demonstrated at SCGP-I and employed in the Demkolec Project is a series of water wall exchangers including superheat, evaporation and boiler feed water economizers. Cost/benefit studies led to the conclusion that, where SCGP can be closely heat integrated with the combined cycle plant, the SCGP steam should be superheated in the combined cycle heat recovery steam generator (HRSG) rather than in the syngas cooler. In the Demkolec IGCC Project, the SCGP syngas cooler steam will be mildly superheated, then sent to the HRSG for further superheating.

Second, early plant performance at SCGP-I and subsequent engineering studies identified that dry solids removal with ceramic candle filters at an intermediate temperature offered SCGP the opportunity to change the economizers from water wall to shell and tube exchangers. Further equipment developments in hot gas particulate removal identified that the evaporator of the syngas cooler could be located downstream of the filter and utilize relatively dust free firetube exchange. Each study led progressively to a better understanding of the tradeoffs between the costs of the filter system and the high temperature exchange surfaces.

The SCGP commercial design uses a dust laden, raw gas firetube exchanger downstream of the conventional recycle gas quench section, followed by dry flyash removal. Further cost reductions were achieved in the lockhopper system used for flyash recycle through scaleup studies on the continuous ash pressure letdown system demonstrated at SCGP-I. Additional low level heat recovery sources have been identified downstream of dry solids removal and may be included in the integrated boiler feed water/steam cycle if the capital costs are justified by the efficiency gains.

Dry Chloride Removal

Chloride in the coal vaporizes in the reducing atmosphere of the gasifier and most of it appears in the form of hydrogen chloride. Past practice has been to wash out the chloride and neutralize the acid in a wet gas cleanup section downstream of the syngas cooler/dry solid removal sections. Depending on the level of chloride in the coal, it can be more cost effective to utilize a dry chloride removal technique with a sorbent. Dry chloride removal offers the additional advantages of reducing catalyst poisons for downstream catalyst beds and of allowing more low level heat recovery from the raw gas.

Cold Gas Cleanup

Very high sulfur removal efficiencies are achievable with the SCGP cold gas cleanup system. Either of two Shell solvents can be used to hydrolyze trace amounts of carbonyl sulfide in the syngas to hydrogen sulfide and then remove the hydrogen sulfide through absorption. Recent studies have premised a total sulfur level of 20 ppm or less in the clean syngas, which allows additional low level heat recovery in the HRSG. In the SCGP commercial design a proprietary system for removing volatile metals such as mercury and arsenic has been combined with the SCGP cold gas cleanup system to further reduce emissions of hazardous air pollutants (HAPs).

Integration of SCGP with Combined Cycle and Air Separation Units

The General Electric 7F and the Westinghouse 501F gas turbines provide high fuel gas to electricity generating efficiency and improved combined cycle performance. The increased gas turbine performance has served to increase net IGCC power output which has in turn helped to reduce the IGCC $/kW cost. Additional IGCC cost and performance benefits can be realized through careful integration of the three basic technologies: SCGP, air separation, and combined cycle power generation. Figure 2 illustrates a highly integrated Shell-based IGCC power plant.

Turbine simulation studies have shown that the clean SCGP coal gas can be diluted with either nitrogen or water to reduce NOx formation and at the same time provide low CO emissions over a wide range of performance conditions. Recent studies have concluded that return of the excess nitrogen from the air separation unit to the combustion turbine is most advantageous for a Shell-based IGCC plant and that saturation of the return nitrogen to the degree desired for gas turbine operation is more attractive than fuel gas saturation and can assure a more reliable fuel gas composition for combustor design and control. Since there is little low level heat for fuel gas saturation in SCGP, the lowest overall IGCC heat rate is obtained with 100% air extraction from the gas turbine for a pressurized air separation unit (ASU), as will be practiced in the Demkolec Project. However, higher net IGCC power output can be achieved by providing the ASU with its own air compressor. The optimum level of air extraction will in fact depend on the specific situation and must be determined as part of an optimized Shell-based IGCC plant design.

Another recent development in Shell-based IGCC plant design derives from the fact that the SCGP syngas composition is very constant over a wide operating range. Combined with new gas turbine control systems, this has led to reductions in turbine fuel gas control valve pressure, which in turn leads to similar reductions in gasifier design pressure and cost.

Environmental Attributes

Environmental emissions of Shell-based IGCC are estimated to be extremely low. Total SO_2 emissions of 0.05 lb/MM Btu or less are achievable, corresponding to greater than 99.5% sulfur removal efficiency. NO_x emissions can be controlled to 0.09 lb/MM Btu (corresponding to 25 ppmv in the HRSG flue gas) or less, and hazardous air pollutant emissions as defined in the 1990 Clean Air Act Amendments are expected to be less than 0.5 tons/year for a nominal 265 MW Shell-based IGCC plant.

As shown in Figure 3, the estimated air emissions from a Shell-based IGCC power plant are well below the regulatory limits and in fact are much closer to those from a natural gas-fired power plant than from a typical coal-based facility. Moreover, long term, on-site storage of solid byproducts is not required since slag, flyash and elemental sulfur are all marketable products.

Conclusions

The first commercial application of the Shell Coal Gasification Process and the world's first fully commercial IGCC facility is Demkolec's 253 MW IGCC power plant in the Netherlands. Experience from the Demkolec Project has provided the foundation for other Shell-based IGCC commercial projects.

The Shell Synthetic Fuels' SCGP commercial design, which includes a number of technology improvements contributing to lower costs, higher efficiency and reduced emissions compared to earlier designs, is now available. Improvements include:

- a more compact gasifier design, aimed at reducing capital cost and increasing coal to gas conversion efficiency;
- revised syngas cooler design to reduce capital costs and maintenance requirements;
- continuous flyash letdown to improve reliability and reduce maintenance requirements;
- dry chloride removal to further simplify downstream gas treating;
- techniques to increase efficiency and reduce formation of undesirable byproducts in the gasifier;
- methods for improved removal and recovery of volatile metals such as mercury and arsenic to reduce HAP emissions; and
- integration of SCGP with the combined cycle and air separation units to minimize $/kW cost, while maintaining performance and operability requirements.

FIGURE 1
SHELL COAL GASIFICATION PROCESS
PROCESS FLOW SCHEME

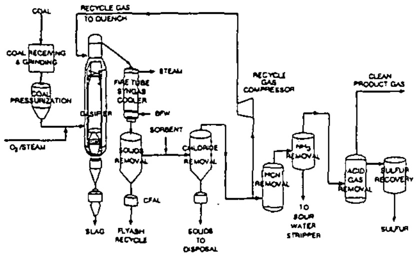

FIGURE 2
HIGHLY INTEGRATED SHELL COAL GASIFICATION
COMBINED CYCLE POWER PLANT CONFIGURATION

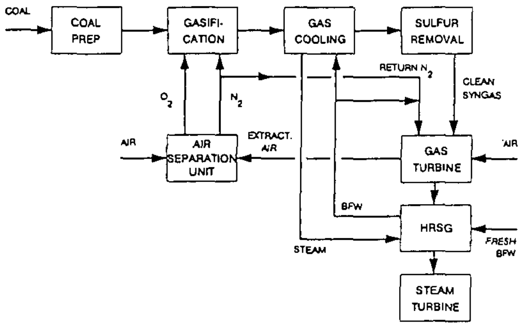

FIGURE 3
SHELL-BASED IGCC AIR EMISSIONS