ECONO-POWER INTERNATIONAL CORPORATION

AIR-BLOWN IGCC AND SULFUR REMOVAL - REPOWERING AND REFUELING IN 250-500 MW SIZE RANGE

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ABSTRACT

Recent developments in air-blown gasification and single-step sulfur removal systems provide repowering opportunities at coal-fired power plants and industrial power and cogeneration plants. The fixed bed gasifier and single step gas clean up plant provides economical usage of coal to syngas production for use in medium to large industrial gas turbines. The system is basically shop fabricated with a minimum of field fabrication, minimizing construction time and risk for the gasification island. For larger size plants, clean coal power will offer heat rates that are competitive with natural gas while utilizing existing or reasonably available steam turbines and cooling circuits. Past focus of air-blown gasification has been on projects of up to 75-85 MW but current developments make plant sizes of 250 MW or greater equally feasible. This technology provides for Integrated Coal Gasification Combined Cycle (IGCC) plants to be economically constructed using commercially proven gas turbines, gasification and sulfur removal systems. These plants can effectively provide base load, coal-based generation at prices competitive with conventional coal-fired plants, while offering superior environmental benefits through the unique and economical sulfur removal system.

This paper will explore the technical, environmental and economic aspects of using IGCC to refuel existing natural gas combined cycle plants in the 200 MW and up class and look at some possible options for repowering existing steam plants using the IGCC model. The paper will also review the development and construction progress of a series smaller air-blown gasification plants and sulfur removal systems.

BACKGROUND

Gas from the gasification of coal was the first fuel in the world to be distributed by pipeline. The equipment used to produce it was very primitive but although its use diminished following the discovery of natural gas, coal gas still plays a major part as an energy form in many parts of the world. Air-blown gasification has been used for many years, primarily for gas-to-liquids and fertilizer production (SASOL in South Africa, various European and Chinese systems, etc.).

Though not widely known, China has the world's most widespread use of coal gasification. EPIC, through its China office, has found a number of gasifiers and gasifier manufacturers who are very active. The majority of the gasifiers that are built operate at atmospheric pressure. The product is used both as fuel gas and as synthesis gas for the production of ammonia and urea. A large number of these gasifiers of 3.6 meters diameter have been built to provide synthesis gas for small and medium sized ammonia and urea plants. These are fixed bed gasifiers, which, for the production of ammonia, have mostly run on anthracite or coke although some have used oxygen-enriched air as oxidant.

For larger plants some manufacturers built a Chinese version of the Lurgi and other older European technology fixed bed gasifiers. The Chinese gasifier industry refined some of the older Two-stage designs by refining the 'coke oven" on the top of the fixed bed gasifier. This work was successful and led to the introduction of the Two-stage system. This gasifier design is used for fuel gas applications using bituminous and sub-bituminous coal. This paper describes the EPIC Two-stage gasifier evolution and a single stage sulfur removal system. These can be applied for use in providing fuel gas for widely available industrial gas turbines for repowering small to medium sized steam turbines, increasing the gross plant output, lowering the heat rate and lowering plant emissions. The paper also describes a Gas Clean-up process that works in a single stage and can provide gas with sulfur content of less than 30 ppm and as low as 1 ppm if required by regulations.

EPIC'S CLEAN COAL GAS SYSTEM

Coal Gasification System

In the lower part of the EPIC Two-stage gasifier, producer gas reactions take place between carbon in the coal and oxygen in the air to provide a hot gas, which is, predominantly, carbon monoxide and nitrogen. This hot gas rises through the middle level, where some level of hydro-gasification takes place, producing methane, and certain shift reactions take place producing hydrogen and carbon dioxide from carbon monoxide and steam in the gas. In the upper levels the heat causes some pyrolysis of the coal that releases oils and tars and finally dries out any water that was in the coal.

The use of coke ovens over the years has provided the experience necessary to maximize the carbon content in the char while removing no more than is necessary of the volatile matter. In this way a more or less smokeless char can be produced and lesser problems created in disposing of the tars and oil produced. See Figure 1 below for the EPIC Two-stage gasifier:

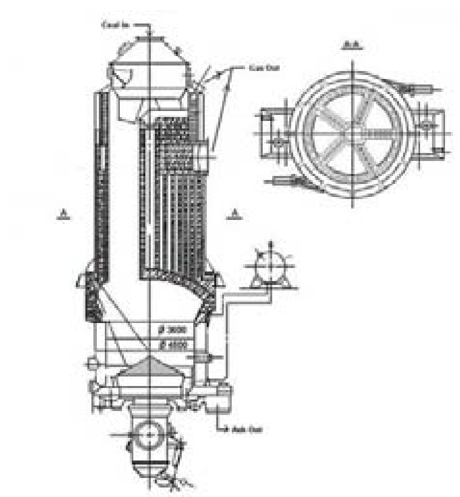

Figure 1 – Gasifier Cross-Section

A framework of refractory bricks are built in the upper part of the Two-stage that provide 5 large vertical passages through which the coal travels and narrower passages through which some of the gas produced in the lower stage feeds to a lower outlet. The rest of the gas rises through the coal and exits through the top. The gasifier internals are long lasting. The picture below (Figure 2) shows a typical gasifier after ten (10) years of continuous operation.

Figure 2 – Gasifier Internal Refractory

By adjusting the relative amounts of gas exiting the upper and lower levels the amount and quality of the oils and tars can be controlled so that the tar is relatively light and can be easily separated from the gas.

In all gasifiers there will be a quantity of hydrogen sulfide produced which is proportional to the sulfur content of the coal. The efficiency of conversion of the coal to clean gas is about 80-83%, but will depend on the amount of sulfur and ash that has to be removed.

Although there is a small loss of efficiency due to the heat lost in the removed ash, the major effect of ash content is a reduction in the output of the gasifier. Typically it is best if the ash content of the coal is no more than 10 to 12% but it can go as high as 18% without adversely affecting the performance of the gasifier. Beyond this, the throughput will be limited to the capacity of the lower grate to remove the ash.

When using Western coal the output of a single gasifier can be about 110 MMBTU/hour from 575,000 cubic feet of clean gas. The equivalent Midwest coal gas quantity can be about 95-105 MMBTU/hour.

Figure 3 below shows the gasification plant with the other components necessary to remove ash or coal fines, tars, and lighter fractions. The upper and lower gas streams are mixed, processed through a final scrubbing stage and move on to the Gas Clean-up plant (or directly to a boiler burner, if gas properties are environmentally acceptable for that use).

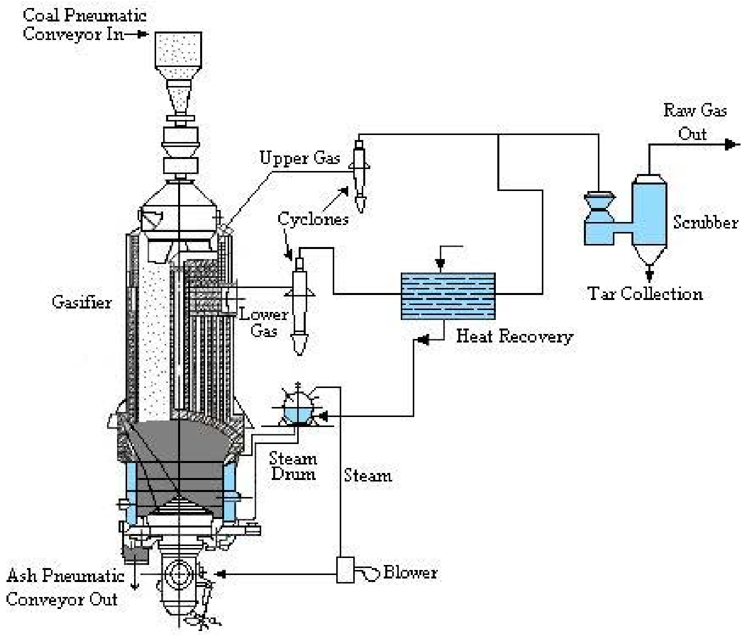

Figure 3 – Gasification Section Flow Schematic

Coal is pneumatically conveyed to the gasifier(s). Ash is pneumatically conveyed to onsite disposal or to storage hoppers for offsite disposal or sale. Using this type of system, the escape of dust or particulate is reduced to near zero. The system is shown in Figure 4 below:

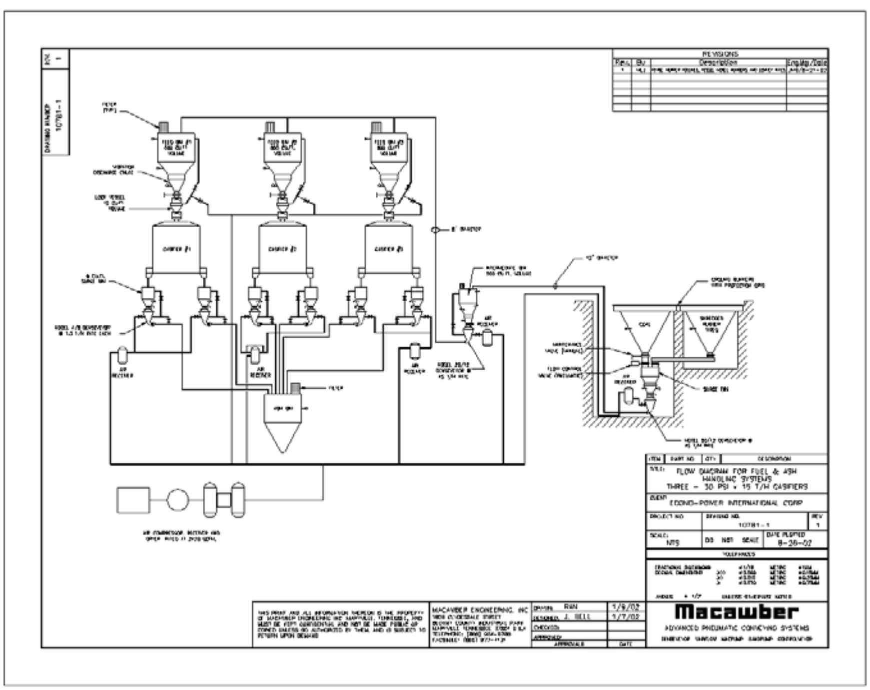

Figure 4 – Material Handling Flow Chart (Courtesy of Macawber Engineering)

Gas Clean-up Process

The second most important consideration is the removal of sulfur from the gas to an acceptably low level. EPIC uses an adaptation of the Stretford Process that was originally developed in Britain many years ago. The EPIC system (developed in China) has been used for more than twenty years. During that time it has been considerably upgraded by the use of catalysts. The improvements are such that the process today bears little resemblance to the original.

The process uses an aqueous solution of sodium carbonate and sodium bicarbonate in suitable proportions to give the solution a pH of between 8.5 and 9.5. The process is based on the principle that hydrogen sulfide is absorbed into the solution by changing the balance of carbonate to bicarbonate and by converting the carbonate and the hydrogen sulfide into sodium hydrosulfide and sodium bicarbonate.

The process has a major advantage over other clean up processes in that the gas is cleaned and the sulfur recovered in a single plant. Most other processes that remove hydrogen sulfide from gas use a second process which burns about half of the hydrogen sulfide to form sulfur dioxide. The latter and the former are reacted over a catalyst to produce elemental sulfur and water. The EPIC system uses a special catalyst to stimulate the above reactions and at the same time remove other trace sulfur compounds.

A typical process treating about 1,000,000 cubic feet per hour of gas will use from 10,000 to 14,000 cubic feet per hour of solvent, depending on the sulfur content of the gas. The resulting clean coal gas containing less than 8 ppm of sulfur may then be passed over a polishing bed when emissions regulations require a lower value. Figure 5 shows an overall flow chart of the process.

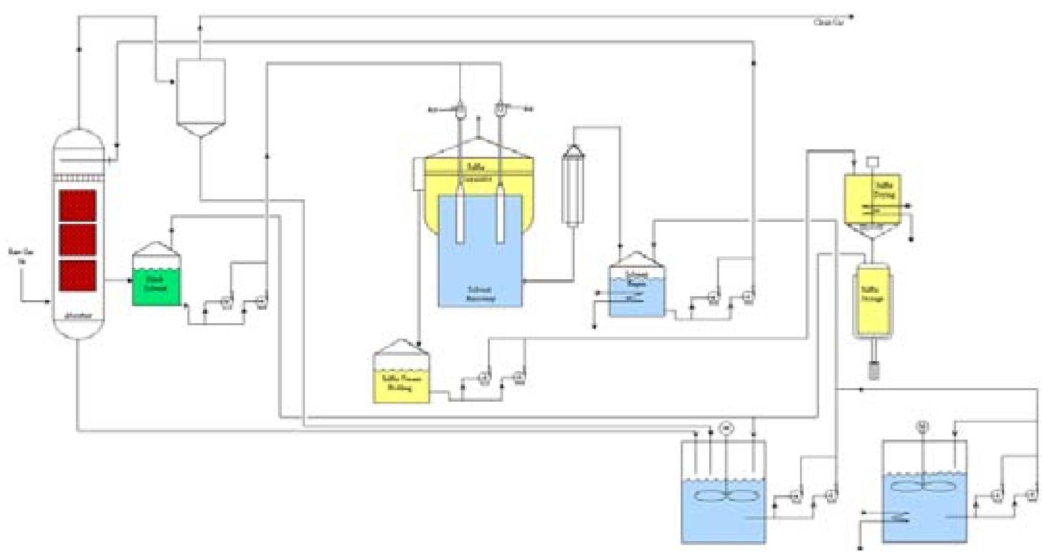

Figure 5 - Simplified Version of the Process Flowchart

Raw gas from the gasification section is passed into a packed wash tower in which it flows counter current to the solvent. Clean gas leaves the top of the tower and the sulfur-rich solvent passes to a heated degassing vessel where residual gas is driven off and mixed with the clean gas stream. The solvent is then passed to an aeration vessel where air is added before entering a liquid filter where oxidation reactions take place resulting in the separation of the sulfur as a cream on the surface of the vessel. The solvent exits from the bottom of the filter and is recycled. The sulfur cream is skimmed from the top and passes into a sulfur-polishing vessel where it is heated to drive off any remaining solvent. The sulfur, now molten, flows downward into a second vessel and into a tray where it solidifies. The only vent stream from the process is the 'used' air from the aeration vessel.

The wash tower portion of the system can operate at elevated pressures (such as those required for gas turbine combustors), which reduces the vessel size of the absorber tower. Many of the additional vessels and items, such as pumps, will be skid mounted, facilitating the modularity of the system.

The process has been used extensively in small and medium sized ammonia and urea plants for a number of years and is ideally suited to clean up gas to a quality satisfactory to any gas turbines which the EPIC syngas could use. A repowering of smaller, older steam units could provide environmental offsets to preclude major pollution retrofits on larger coal units in a generating fleet.

The clean gases from the gasifier and sulfur removal will have the approximate composition and heating value shown in Table 1:

Coal	BTU/FT_3	CO%	CO_2%	H_2%	N_2%	H_2S%	CH_4%	C_xH_Y%	O_2 %
US PRB	193	30.6	3.6	13.7	46.4	<0.1	4.6	0.5	0.5
US East	186	26.9	3.5	13.7	50.8	<0.1	4.4	0.4	0.3

Table 1 – Sample Fuel Gas Characteristics

EPIC is presently in permitting, design and construction for a smaller system to be used in a cogeneration application (approximately 50 MW combined power and thermal) in the western US using an industrial frame gas turbine. This system will provide the basis for the verification of the EPIC air-blown gasification for industrial frame gas turbines in the US. As this system is completed and operated, it will become a solid foundation for implementation on larger systems as contemplated in this paper.

The EPIC air-blown coal gasification system can be installed and operated to convert coal to clean, compressed syngas for less than $2.00 per MMBTU, depending on specific site conditions and not including the cost of coal. This rate includes operation, maintenance and capital recovery, allowing for coal-based syngas at significant discounts to present and projected natural gas costs.

Combined Cycle Plant

The syngas is compressed and directed to an industrial frame gas turbine operating in conventional combined cycle mode with a heat recovery steam generator (HRSG) and steam turbine. Figure 6 below represents a typical combined cycle plant:

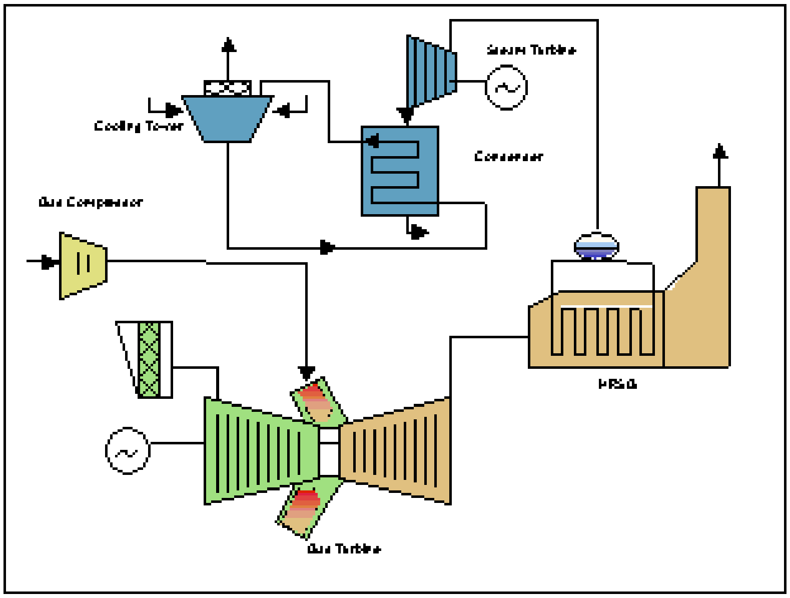

Figure 6 – Schematic Drawing of Combined Cycle Power Plant

The focus of this paper will be to look at:

1. Repowering small to medium sized steam turbine units by adding a gas turbine/HRSG system with air-blown gasification to replace the older steam generators; and

2. Refueling existing combined cycle or larger cogen systems, originally based on natural gas with air-blown gasification.

For repowering, there are many old plants with 50, 75 and 100 MW steam turbines, many in typical coal burning areas. Typically, these plants are faced with significant pollution control expenditures and economic justification for major expenditures is difficult. In many cases, the power island part of the plant (steam turbine, condenser, electrical transformers and switch gear) can have life extensions for little or no major capital expenditures.

These plants represent excellent candidates for repowering with coal gasification, particularly the older coal-fired plants. In this concept, a gas turbine and HRSG would be installed with an air-blown gasification system. The HRSG would be designed for the existing steam turbine. With air-blown gasification, a high-level of supplemental firing is desirable, making the steam and gas turbine power output approximately equal.

For this analysis, all cases are based upon the use of Powder River Basin (PRB) coal. The syngas analysis on typical PRB coals is shown in Table 1 above. To use this syngas in an industrial gas turbine, some modifications are necessary to the combustion system (fuel delivery manifold and valving, combustion liners, etc.). Additionally, some turbines may require air to be extracted from the later stages of the compressor to balance total mass flow.

The specific cases to be examined are:

- Case 1 – Frame 6B – PRB Coal - IGCC Repowering
- Case 2 – Frame 7EA – PRB Coal - IGCC Repowering
- Case 3 – S-W 501D - PRB - IGCC Repowering
- Case 4 – Frame 7FA – PRB - CCPP Refueling to IGCC

For refueling, there are many natural gas-fired combined cycle plants in operation (some even in close proximity to coal-fired plants that could minimize the installation coal infrastructure). In a refueling scenario, minimal modifications would be required to the power plant (i.e., only those necessary for syngas use).

Because the quantity of coal gas used will typically be about 5 times that of natural gas, some turbines may need to be throttled or have air extracted in order to maintain the output within the torque limits of the machine. Optimizing the extraction and using extracted air for the gasification plant may obtain improved output and efficiency.

Although a turbine such as the GE Frame 7FA could require almost twenty EPIC gasifiers using present configurations, the large number of gasifiers will provide an order of reliability and availability unobtainable with large oxygen-blown systems. As current commercial projects are implemented and the gasification system continues US evolution, it is expected that the syngas output per gasifier will be significantly enhanced, reducing the number of gasifiers required for an application. This reduction will allow the capital costs of the overall system to be reduced, thereby further reducing the cost of converting coal to syngas while still retaining extremely high availability and reliability.

Repowering - Case 1

Gas turbine model and number	-	3 x GE Frame 6B
Steam Turbine	-	2 x 50 MW or 1 x 100 MW
Coal usage	-	85 tons/hour
Ash out	-	4.8 tons/hour
Sulfur produced	-	500 pounds/hour
Net power produced	-	188 MW (gas turbine + steam turbine – aux loads)
Net plant heat rate	-	10,500 BTU/kWH (coal-in to net power-out)

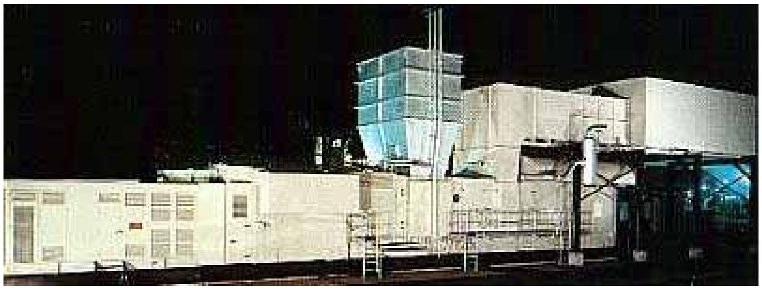

Figure 7 – GE Frame 6B

Repowering - Case 2

Gas turbine model and number	-	2 x GE Frame 7EA
Steam Turbine	-	2 x 75 MW or 1 x 150 MW
Coal usage	-	125 tons/hour
Ash out	-	6.9 tons/hour
Sulfur produced	-	720 pounds/hour
Net power produced	-	276 MW (gas turbine + steam turbine – aux loads)
Net plant heat rate	-	10,300 BTU/kWH (coal-in to net power-out)

Figure 8 – GE Frame 7EA

Repowering - Case 3

Gas turbine model and number	-	2 x S-W 501D5A
Steam Turbine	-	2 x 90 MW or 1 x 180 MW
Coal usage	-	154 tons/hour
Ash out	-	8.5 tons/hour
Sulfur produced	-	880 pounds/hour
Net power produced	-	372 MW (gas turbine + steam turbine – aux loads)
Net plant heat rate	-	9,400 BTU/kWH (coal-in to net power-out)

Figure 9 – Siemens-Westinghouse 501 D5A

Refueling - Case 4

Gas turbine model and number	-	2 x Frame 7FA
Steam Turbine	-	200 MW
Coal usage	-	198 tons/hour
Ash out	-	11.0 tons/hour
Sulfur produced	-	1140 pounds/hour
Net power produced	-	497 MW (gas turbine + steam turbine – aux loads)
Net plant heat rate	-	9,100 BTU/kWH (coal-in to net power-out)

Figure 10 – GE Frame 7FA

Even though each of these cases, particularly the larger cases, require multiple numbers of gasifiers, the reliability and availability of multiple gasifier units offer much better operational characteristics than large single and double oxygen-blown gasifier installations. Additionally, the simplicity of the air-blown gasification system removes the operation and maintenance issues associated with a large air separation plant. Continued development with the EPIC air-blown gasifier expects to raise the operating pressure from the current one atmosphere gauge to approximately five or six atmospheres gauge. This change will reduce the number of gasifiers and the associated land area required, as well as raise the efficiency of the process.

CONCLUSIONS

The installed cost of the EPIC IGCC is competitive with total installation costs of much larger, scrubbed pulverized coal plants and the net plant heat rate is at least equivalent and considerably better in some cases. By repowering at existing steam plants, the capital cost and permitting issues will be significantly minimized, allowing the repowered facility to be rejuvenated into a valuable part of the generating fleet and provide increased capacity with clean and efficient use of coal. For refueling from natural gas, fuel cost can be minimized and stabilized, leading to enhanced economic performance of many relatively young plants.

General conclusions about using air-blown gasification on repowering and refueling:

- Availability - Excellent >98%
- Heat Rate - Better than smaller coal plants, at least equal to larger coal plants
- Environmental:
  - NOx - significantly lower
  - SOx - similar to natural gas
  - Particulate - None
  - Mercury - Below detectable limits
- Economical - Clean coal syngas for less than $3.50 per MMBTU

The use of coal gasification syngas, with industrial frame gas turbines is well proven in operation. The air-blown gasification syngas offers a simple and economical option for repowering older steam plants and refueling many natural gas-fired combined cycle plants, particularly those that have a reasonable percentage of output on long-term contract. Future development and commercial operation of current EPIC IGCC plants will prove the economics of repowering and/or refueling in the 250-500 MW size range.

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