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Energy Efficienct Coal Gasification for IGCC Power Plant

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Abstract— Today we are facing the problems regarding conventional energy sources as they are depleted drastically and limited reserves. This paper enumerates technical feasibility and assessment of the integrated gasification combined cycle (IGCC) power plant which is useful for the conventional coal-fired power plant to enhance their plant performance. IGCC is one more advanced coal combustion technology available now a day to improve overall cycle efficiency of the system, for generation of electricity.

Index Terms— Conventional energy sources, power plant, coal

I. COAL GASIFICATION & IGCC

1.1 Coal Gasification

Coal gasification is a process that converts coal from a solid to a gaseous fuel through partial oxidation. Once the fuel is in the gaseous state, undesirable substances, such as sulfur compounds and coal ash, may be removed from the gas by established techniques. The net result is a clean, transportable gaseous energy source.
In contrast to combustion process which works with excess air, gasification process works on partial combustion of coal with the oxygen supply controlled (generally 20 to 70% of the amount of O_2 theoretically required for complete combustion) such that both heat and a new gaseous fuel are produced as the coal is consumed.

$C + \frac{1}{2} O_2$ (gasification) → CO
$C + H_2O$ (gasification) → $CO + H_2$

1.2 Integrated Gasification Combined Cycle (IGCC)

The integrated gasification combined cycle is a process in which the fuel is gasified in an oxygen or air-blown gasifier operating at high pressure. The raw gas thus produced is cleaned of most pollutants (almost 99 % of its sulphur and 90 % of nitrogen pollutants). It is then burned in the combustion chamber of the gas turbine generator for power generation. The heat from the raw gas and hot exhaust gas from the turbine is used to generate steam which is fed into the steam turbine for power generation.

A. Figures

As said, to insert images in *Word*, position the cursor at the insertion point and either use Insert | Picture | From File or Often, IGCC is referred to as "Cool Water" technology, a name drawn from the ranch in California's Mojave Desert that once occupied the site where it was developed. Coal all shorts burns so well with the Cool Water technology -upto 99 % of sulphur contamination is eliminated.

The main subsystems of a power plant with integrated gasification are:
1) Gasification plant
(2) Raw gas heat recovery systems
(3) Gas purification with sulphur recovery
(4) Air separation plant (only for oxygen blown gasification)
(5) Gas turbine with heat recovery steam generator
(6) Steam turbine generator

The feedstock which is fed into the gasifier is more or less completely gasified to synthesis gas (syngas) with the addition of steam and enriched oxygen or air. The gasifier can be fixed bed, entrained or fluidised bed. The selection of the gasifier to achieve best cost efficiency and emission levels depends upon the type of fuel. In the gas purification system, initial dust is removed from the cooled raw gas. Chemical pollutants such as hydrogen sulphide, hydrogen chloride and others are also removed. Downstream of the gas purification system, the purified gas is reheated, saturated with water if necessary (for reduction of the oxides of nitrogen) and supplied to the gas turbine combustion chamber.
The IGCC technology scores over others as it is not sensitive with regard to fuel quality. Depending on the type of gasifier, liquid residues, slurries or a mixture of petcoke and coal can be used. In fact, the IGCC technology was developed to take advantage of combined cycle efficiency of such low-grade fuels.

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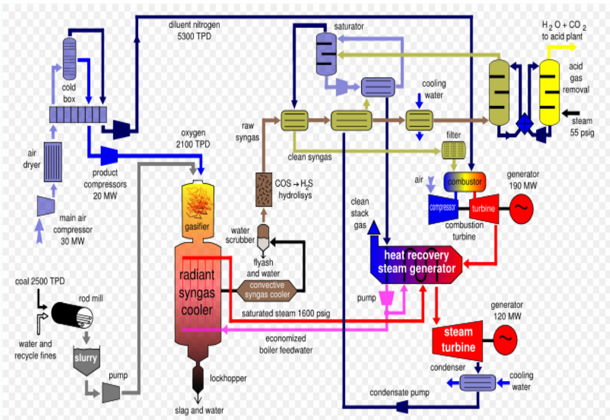

Fig 1 Integrated Gasification Combined Cycle (IGCC) Power Plant

However, IGCC is an expensive option. Some companies claim that they have found an answer to the cost issue with a new technology for producing methanol. They believe that

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fitting this system, which produces methanol at twice the rate of conventional methods, on the back end of the gasifier units on an IGCC plant can cut the capital cost by 25 %. The technology achieves this saving by reducing the number of gasifiers the IGCC plant needs - provided the full capacity of the power station is not required for base load running. This enables the operator to make full use of the gasifiers, which account for 50-60 % of the cost of an IGCC and become prohibitively expensive under part-time operation. When power is not required, they can be switched to methanol production. This provides the additional fuel to meet full power output at time of peak demand.

IGCC technology is also environment friendly. In IGCC, pollutants like sulphur dioxide and oxides of nitrogen are reduced to very low levels by primary measures alone, without down-stream plant components and additives like limestone. The low NOx values are achieved by dilution of the purified syngas with nitrogen from air separation unit and by saturation with water. The direct removal of sulphur compounds from the syngas results in the effective recovery of elemental sulphur, yielding a saleable raw chemical product. Gasification and gas cleaning are an extremely effective filter for contaminants harmful to both gas turbines as well as environment. The IGCC technology is not only environment friendly, but also efficient in power generation (upto 50 %).

The additional benefits will not make an IGCC unit competitive with a combined cycle gas turbine (CCGT) plant where there is adequate supply of natural gas. However, a 500 MW unit could compete with traditional coal-fired technology. The biggest difficulty may arise in securing a long-term purchase contract for methanol that will allow the plant operator to keep the gasifiers in continuous operation.

The use of gasification for power generation is perceived by many as a complex and expensive technology. However, recent experience in both developed and developing countries reinforces its relevance to power generation.

In India, in particular, the IGCC technology is of great relevance as we do not have huge reserves of hydrocarbons. Since coal is available, more project developers can go in for coal-based IGCC plants. The IGCC process is two-stage combustion with cleanup between the stages. The first stage employs the gasifier where partial oxidation of the solid/liquid fuel occurs by limiting the oxidant supply. The second stage utilizes the gas turbine combustor to complete the combustion thus optimizing the gas turbine/combined cycle (GT/CC) technology with various gasification systems. The SynGas produced by the Gasifiers however, needs to be cleaned to remove the particulate, as well as wash away sulphur compounds and NOx compounds before it is used in the Gas Turbine.

It is the integration of the entire system components which is extremely important in an IGCC Plant.

Various sub-systems of an IGCC Plant thus are:

i) Gasification Plant

ii) Power Block

iii) Gas Clean-up System

II. MERITS OF IGCC OVER CONVENTIONAL PC FIRED TECHNOLOGY

2.1 Potential for Higher Efficiencies

Continuous developments have been taking place in the newer materials of construction thus consequent higher gas turbine performance. Recent advances in the Gas Turbine technologies have presented great potential towards much higher gas turbine efficiencies. Increasing the firing temperatures and utilizing materials that withstand higher temperatures can increase the efficiency of gas turbine. At present the efficiency of gas turbines is in the range of 45-50% which is projected to go upto 60% with the development of H-technology by GE. The advances in gas turbines would improve the overall efficiency of IGCC plant

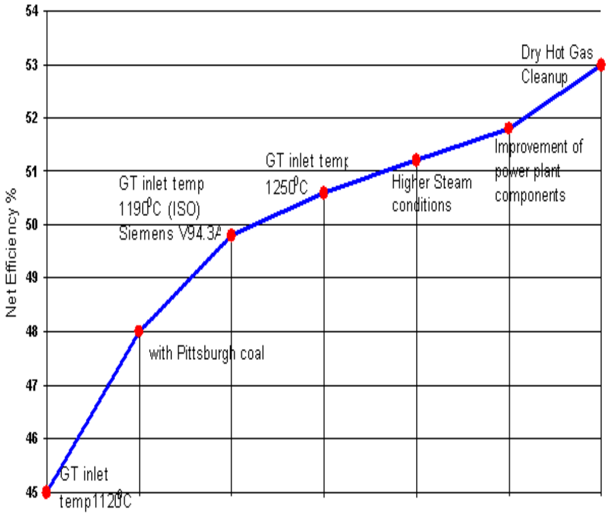

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Fig 2 Expected Improvement of IGCC Power Plant Efficiency

2.2 Lower Heat Rates & Increased Output

The heat rates of the plants based on IGCC technology are projected to be around 2100 kCal/kWh compared to the heat rates values of around 2500 kCal/kWh for the conventional PC fired plants.

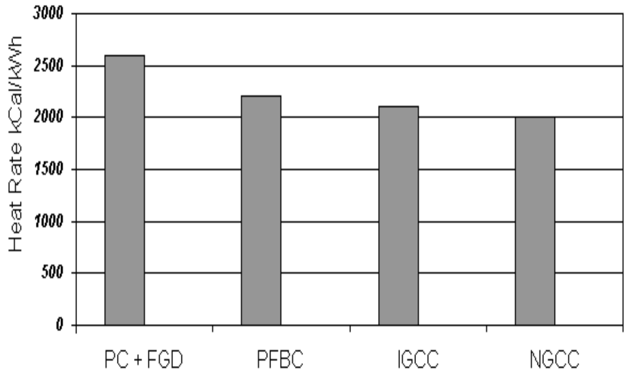

Fig 3 Heat Rates of Various Power Plants

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2.3 Flexibility to accept a wide Range of Fuels

IGCC technology has been proven for a variety of fuels, particularly heavy oils, heavy oil residues, petcoke, and bituminous coals in different parts of the globe. In fact the same gasifiers can handle different types of fuels.

2.4 Low Pollution Technology

IGCC is an environmentally benign technology. The emission levels in terms of NOx, SOx and particulate from an IGCC plant have been demonstrated to be much lower when compared to the emission levels from a conventional PC fired steam plant. In fact, no additional equipment is required to meet the environment standards.

III. GASIFIERS STRATEGIES

The Coal Gasification requires the presence of an oxidant in the process. Air or Oxygen may be used as an oxidant and the gasifiers are accordingly known as either Air-Blown or Oxygen-Blown Gasifiers.

• Moving-bed
• Fluidized-bed
• Entrained-flow

The typical operating characteristics of the gasifiers are shown as in Table 1.

	Moving Bed	Fluidised Bed	Entrained Bed
Exit Gas Temp. ^{0}C	420 - 650	920 - 1050	1200
Coal Feed size	< 50 mm	< 6 mm	< 100 mesh
Ash Conditions	Dry / Slagging	Dry / Agglomerating	Slagging

Table 1. Typical operating characteristics of the gasifiers

IV. TECHNOLOGY SUPPLIERS

Different technology suppliers worldwide have developed the gasifiers which are either air-blown or oxygen-blown and are either of the moving bed, entrained bed or fluidised bed. The choice of the type of the gasifier is purely a factor of the coal/fuel characteristics. Various technology suppliers for the gasification process are as below in Table 2.

Table 2 IGCC Technology Suppliers

Technology Supplier	Coal Feed Type	Oxidant	Gasifier Type
Texaco, USA /	Water Slurry	O_2	Entrained Flow
Shell, USA	N_2 carrier/Dry	O_2	Entrained Flow
KRW, USA	Dry	Air	Fluidised Bed
Lurgi, Germany	Dry	Air	Fluidised Bed
British Gas/ Lurgi	Dry	O_2	Moving Bed
Prenflo, USA / Krupp Uhde , Germany; Deutsche-Babcock, Germany	Dry	O_2	Entrained Flow
Destec Energy, USA	Water Slurry	O_2	Entrained Flow
IGT U-Gas, USA / Carbona, Finland; IBIL, India	Dry	Air	Fluidised Bed
Rheinbraun HTW, Germany RWE Energie, Germany	Dry	Air	Fluidised Bed
MHI, Japan / IGC, Japan	Dry	Air/O_2	Entrained Flow
ABB-CE, USA	Dry	O_2	Entrained Flow
VEW/Steinmuller, Germany		O_2	Entrained Flow
Hitachi	Dry	O_2	Entrained Flow
Noell/GSP	Dry	O_2	Entrained Flow
Ahlstrom, Sweden	Dry	Air	Fluidised Bed

V. ASSESSMENT OF SYNGAS CHARACTERISTICS

Composition of the syngas depends on the fuel as well as on the gasification process. The typical characteristics of the SynGas as generated from different fuels at some of the IGCC projects are presented below in Table 3.

Table 3 Syngas Characteristics

	Project						
	PSI Wabash	Tampa Polk	El Dorado	Shell Pernis	Sierra Pacific	IBIL	Schwarze Pumpe
Fuel	Coal	Coal	Pet Coke/ Waste Oil	Vacuum Residue	Coal	Lignite	*
H	24.8	27.0	35.4	34.4	14.5	12.7	61.9
CO	39.5	35.6	45.0	35.1	23.5	15.3	26.2
CH_4	1.5	0.1	0.0	0.3	1.3	3.4	6.9
CO_2	9.3	12.6	17.1	30.0	5.6	11.1	2.8
N_2+Air	2.3	6.8	2.1	0.2	49.3	46.0	1.8
H_2O	22.7	18.7	0.4	--	5.7	11.5	--
LHV, KJ/M^3	8350	7960	9535	8235	5000	4530	12500
T_{fuel}, ^oC	300	371	121	98	538	549	38
Oxidant	O_2	O_2	O_2	O_2	Air	Air	O_2

* Lignite/Oil Slurry with Waste Plastic & Waste Oil

VI. GAS CLEAN-UP SYSTEM

The typical steps for Gas Clean-up System aim at particulate removal, sulfur removal and NOx removal. This is achieved as follows:

(1) Particulate Removal: Combination of Cyclone Filters & Ceramic candle Filters

(2) SOx & NOx removal: Combination of steam/water washing and removing the sulfur compounds for recovery of sulfur as a salable product. Hot Gas Clean-Up technology is currently under demonstration phase and various demonstrations have not been successful so far. Wet scrubbing technology, though with a lower efficiency, still remains the preferred option for gas clean-up systems in IGCC.

Table 4. Technology Suppliers for Particulate Removal

S. No	Manufacturer	Gas Temp. (Max.)	Particle collection efficiency	Remarks
1.	Westinghouse Ceramic Candle Filter	1000^{0}C	99.99% for 0.1 mm size	Hanging Type Candles
2.	LLB Lurgi Lentjes Babcock Ceramic Candles Filter	1000^{0}C	99.99%	Supported both sides
3.	Pall Process Filtration Ceramic Candle Filter	1000^{0}C (max.)	99.99%	Supported both sides; Clay bonded silicon carbide filter
4.	Schumacher Ceramic Candle Filter	1000^{0}C	99.9%	Hanging type candles; Clay bonded silicon carbide filter
5.	Mott Metal Candle Filter	950^{0}C	99.99%	Hanging type candles; Sintered Hastelloy

VII. SULFUR REMOVAL

Sulfur from the hot fuel gas is captured by reducing it to H_2S, COS, CS_2 etc. The current sulfur removal systems employ zinc based regenerative sorbents (zinc ferrite, zinc titanate etc.) Such zinc based sorbents have been demonstrated at temperatures upto 650 ^{0}C. Sulfur is also removed by addition of limestone in the gasifier. This is Commonly adopted in air-blown fluidised bed gasifiers.

In fact, in the case of Air Blown Gasifiers, sulfur is captured in the gasifier bed itself (above 90%) because of addition of limestone. The sulfur captured in the bed is removed with ash.

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VIII. POWER BLOCK IN IGCC PLANT

The Power Block in the IGCC Plant is essentially a Gas Turbine Unit that operates on SynGas. This Gas Turbine Unit is basically the same as used for Natural Gas with certain modifications. The areas that are modified and also which need to be critically evaluated for use with SynGas is:

(1) Modification of Fuel Supply System

(2) Modification in the Burners -- Special burners are required when using SynGas because of its higher flame propagation velocity.

(3) Checking for Surge Conditions and suitability of Gas Turbine Units because of excess flow in case of SynGas on account of it being a lean gas.

The gas turbine combined cycle technology has been proven for use with natural gas as well as with syngas.

IX. STATUS OF IGCC TECHNOLOGY

The technology level for each individual system component of IGCC i.e. gasification block, gas clean-up system and power block have already been established and proven in practice at commercial level. Integrating these individual technologies for the electricity generation is the concept of IGCC. To demonstrate IGCC technology at the commercial level, a number of projects have been in demonstration/operation stage. The fact that the IGCC technology has reached maturity stage, can be seen from the following table which gives status of various IGCC projects.

X. OPERATIONAL FEEDBACK

Typical problems that have been encountered in various projects relate to the following areas:

(1) Gas Turbine Combustors: GT combustor design has been altered to handle low BTU gas with high mass flow due to problems encountered in gas turbines.

(2) Hot Gas Clean-up System: Breakage of ceramic candle filters & stress corrosion cracking in heat exchangers has also been reported.

XI. CONCLUSIONS

Integrated coal gasification combined cycle is a high efficiency power generation technology which gasifies coal to be used as the fuel for gas turbine. IGCC is an advanced technology that represents the cleanest of currently available coal technologies. Advantages of IGCC over current conventional coal-based power generation systems include higher efficiencies and lower emissions are dominate. With efficiencies currently approaching 50%, IGCC power plants use less coal and produce much lower emissions of carbon dioxide than conventional power plants. With development of new gas turbine concepts and increased process temperatures efficiencies of more than 60% are being targeted. IGCC power plants clearly show promise of being the truly environmentally benign, economically competitive method of utilizing high-sulphur coal for power generation.

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