INTEGRATED GASIFICATION COMBINED CYCLE: Technology Overview

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I. Introduction

The world today is having some serious problems regarding to energy crisis. The energy demand is increasing in alarming rate with average 1.3 percent per year to 2030. The increase will be underpinned by economic and population growth (www.exxonmobil.com). Power generation to meet electricity needs will be the biggest driver of higher energy demand representing more than 40 percent of the increase while fossil-base fuels will continue to provide the supplies for this demand with oil and gas close to 60 percent. Demand for coal will grow as the demand of electricity in developing country rise. Figure 1 shows the world energy demand by sector to 2030.

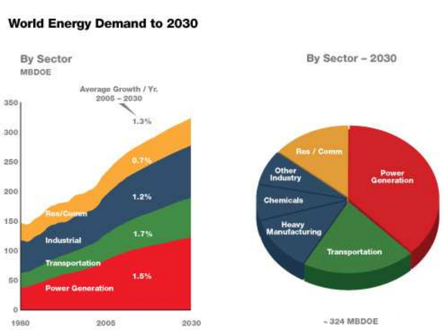

Figure 1. The world energy demand by sector (www.exxonmobil.com)

The need for mitigating the effect of greenhouse gases emissions and the rapid increase of oil price lead us to start thinking some possible solutions. One of the solutions which have been the main long term goal for The European Union is the conversion of the fossil-base fuel to the sustainable energy system to gain higher energy efficiency and reduce the emissions. Even with higher energy efficiency, the energy consumption by people around the world is growing. Thus, meeting the need for affordable and reliable energy supplies will not be easy. An effective combination of access, investment, technology and trade is necessary to deliver reliable supplies (Christou et al, 2007).

Nowadays, oil holds an important role in world energy system since it is used widely in industrial, residential and transportation sectors. In future projection, the use of oil will be limited to transportation sector while natural gas and coal will be utilized in electricity generation. Although the efficiency of coal-fired unit with modern combustion technology is considerably high, this fact has caused some concerns in terms of conservation of resources and CO_2 emissions. Over the last 20 years a great amount of work has been done to improve existing combustion technologies as well as investigating the alternatives. Of all the potential alternatives, coal gasification has come up with a very good chance to develop in the future with its Integrated Gasification

Combined Cycle (IGCC) (Higman and Van der Burgt, 2003).

IGCC produces electricity from solid or liquid fuels. The scientific community and major electricity corporation consider this technology as promising to produce cleaner electrical power in the future. First, fuel is converted to synthesis gas which is a mixture of hydrogen and carbon monoxide through gasification. Second, the synthesis gas is converted to electricity in a power block consist of a gas turbine process and steam turbine process which include heat recovery steam generator (Maurstad, 2005).

Coal based IGCC plants are not fully commercial. Although each major components of IGCC have been widely utilized in industrial or power generation, the integration of a gasification and combined cycle power plant is considerably new. The motivation to apply this technology is the potential for better environmental performance at low marginal cost (Maurstad, 2005). Several IGCC pilot plants have been built these recent years to assess the possibility in commercializing the technology.

II. IGCC Process Description

IGCC technology is a power generation process that integrates gasification process with combined cycle power plant. The gasification system converts coal into synthesis gas which consists primarily by hydrogen (H_2) and carbon monoxide (CO). The synthesis gas is then used as fuel on a combined cycle power plant for electricity generation (Christou et al, 2007). Figure 2 shows the flow diagram of IGCC technology without CCS.

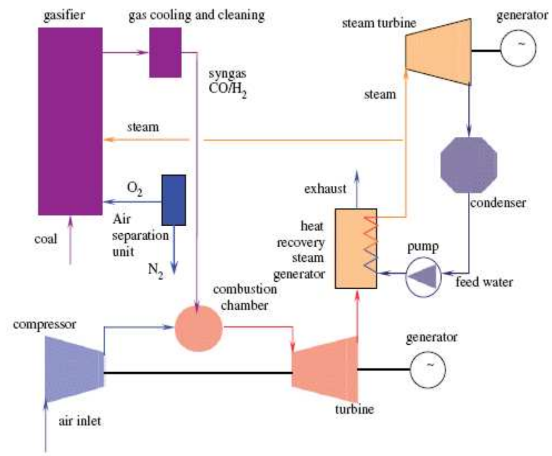

Figure 2. Integrated Gasification Combined Cycle technology (Christou et al, 2007)

IGCC system mainly consists of 4 major sections, air separation, gasification, cooling and clean up system, and combined cycle power plant. Air separation unit is responsible for separating air into its constituents and supplying pure oxygen into the gasifier. This process is held on a pressurized and cryogenic condition.

Coal gasification takes place in the presence of controlled air/oxygen and steam which maintaining a reducing condition. Gasification is a partial oxidation of the feedstock which creates heat and series of chemical reactions. The process is carried out in an enclosed pressurized reactor. Most of gasifiers have been oxygen blown because of the cost of handling large amounts of nitrogen and the effect it has in diluting the product. The air blown gasifier is less preferable since its product has low calorific value which is not desirable. But the oxygen blown itself also has disadvantage, it requires higher degree of plant integration. This means that controlling and operating the plant is more like running the whole chemical complex plant than a traditional power station (UK Clean Coal Center).

In addition to its chemical energy (heating value), the hot raw synthesis gas contains sensible heat which may be recovered in heat exchangers to produce steam for the steam turbine. The use of synthesis gas coolers for this purpose increases efficiency, but adds capital costs. In theory, it would be desirable to clean the raw synthesis gas without cooling (as the sensible heat would be utilized most efficiently when delivered to the gas turbine), but the proven technologies for gas clean up operate at near ambient temperatures. In the gas clean up process, particles, sulfur and other impurities are removed. At this point, CO_2 may also be captured. Because of the high partial pressures of the species and the low volume flow of synthesis gas, the gas clean up process is very efficient and low cost compared to traditional flue gas cleaning (Maurstad, 2005).

Recent studies have shown that an IGCC plant with CCS requires two additional pre-combustion stages than the conventional IGCC cycle plant (Figure 2) as illustrated in Figure 3. The two additional stages are the water gas shift reaction and the acid gas removal for the removal of CO2 from the synthesis gas. In addition, a CO2 compression stage is necessary to make transportation and storage of the sequestered quantity of CO2 feasible. The addition of CCS technology decreases the overall process efficiency due to the power for compressing the CO_2. Another reason for the decrease efficiency is the installation of two additional stages, the amount of coal feed required needs to be increase. On the other hand, this can result in lower steam/carbon ratio in gasifier which will need additional supply of steam, thus lower the plant output power (Descamps et al, 2007).

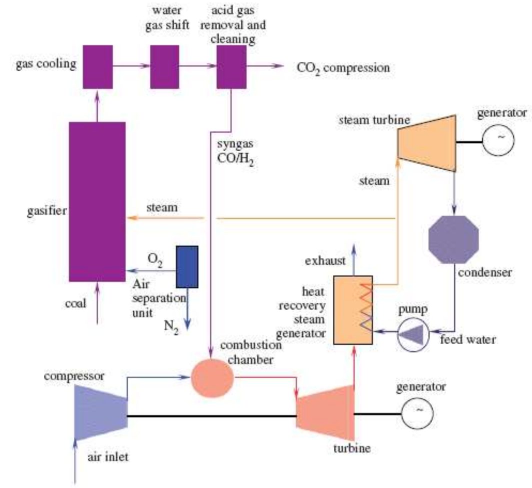

Figure 3. Integrated Gasification Combined Cycle incorporating CCS (Christou, 2007)

The clean gas is then fed to the combined cycle power plant. Combined cycle power plant consists of a combustion turbine/generator, a heat recovery steam generator, and a steam turbine/generator. The exhaust heat from the combustion turbine is recovered in the heat recovery steam generator to produce steam. This steam then passes through a steam turbine to power another generator, which produces more electricity. Combined cycle is more efficient than conventional power generating systems because it re-uses waste heat to produce more electricity (www.wci-coal.com).

III. Major IGCC Blocks and Components

This section will provide further explanation of four major sections in IGCC plant.

III.1 Air Separation Unit (ASU)

The commercial technology used for oxygen production in IGCC plants is cryogenic air separation which may be defined as the separation of air into component gases by distillation at low temperatures. Cryogenic air separation has single train O_2 production capacities of 3200 tons/day and is recognized for high reliability. Major suppliers of the technology are Air Products, Air Liquid, BOC Gases, Praxair and Linde. The major energy requirement of the process is the air compression work.

Typically, the air to the ASU is compressed to around 5 bar, and the oxygen (typically 95 % O_2, 3.5 % Ar and 1.5 % N_2 by volume) and nitrogen product streams are available at around 1 bar. However, the process may also operate at elevated pressure such that the air fed to the ASU is at a pressure closer to that of the gas turbine compressor outlet. This makes it feasible to supply part or all of the ASU air from the gas turbine compressor. In this case, the ASU product streams are at around 5 bar which reduces the recompression work (Maurstad, 2005).

III.2 Gasification

The conventional coal gasification technology, as is known today, has its origin from the 1934 Lurgi coal gasifier. Coal gas reactions, $C + H2O \rightarrow CO + H2$ and $C + CO2 \rightarrow 2CO$, are also known as steam and dry reforming reactions, respectively. Here, carbon is reformed into CO and H2 gases, called synthesis gas. Furthermore, they are chemically reductive and endothermic reactions. For the reforming reactions to proceed, it must absorb heat energy comparable to its combustion reaction *(*$C + O2 \rightarrow CO2$*)* (Yong, 2007).

There are 3 main classes of gasifiers as shown in Figure 4 while Table 1 describes their differences. In moving-bed reactors, large particles of the fuel move slowly down through the gasifier while reacting with the gasifying medium moving up through it. Several different reaction zones are created and they accomplish the gasification process. Operating temperatures are not uniform inside the reactor with the temperature of the synthesis gas leaving the reactor being as low as 400–500°C. In fluidized-bed reactors small particles of the fuel remain suspended in the gasifying medium while the gasification process takes place. The temperature inside the reactor remains uniform in the range of 800–1000°C. In entrained flow reactors the pulverized fuel goes through the various stages of gasification flowing co-currently with the gasifying medium. The feedstock can be either in dry or in water slurry form. The temperatures achieved in the reactor are very high in the range of 1200–1600°C. Entrained flow gasifiers are considered to be the most suited type for IGCC applications (Higman and Van der Burgt, 2003).

Table 1. Characteristics of different gasifier types (Higman and Van der Burgt, 2003)

Gasifier Type	Fixed Bed	Fluidized Bed	Entrained Flow
Temperature	425-600 (°C)	900-1050 (°C)	1250-1600 (°C)
Oxidant demand	Low	Moderate	High
Ash conditions	Dry ash or Slagging	Dry ash or Agglomerating	Slagging
Size of coal feed	6-50 mm	6-10 mm	< 0,1 mm
Acceptability of fines	Limited	Good	Unlimited
Other Characteristic	Methane, tar, and oils present in syngas	Low carbon conversion	Pure syngas; high carbon conversion

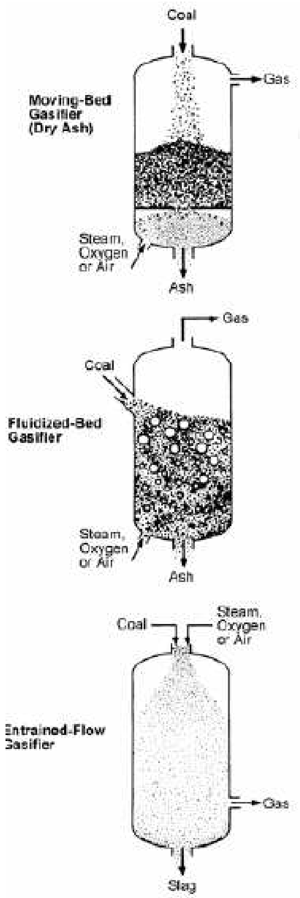

Figure 4. Types of gasifier (Maurstad, 2005)

III.3 Gas Clean-up

The raw synthesis gas may be containing some chemical components and particulates which must be removed before it is used in combined cycle plant.

III.3.1 Chemical Components

The major components of the syngas at the outlet of an entrained flow slagging gasifier are CO, H_2, CO_2 and H_2O. Some N_2, Ar and small amounts of CH_4 will also be present. Table 2 provides a summary of the components.

Table 2. Some of trace components in raw syngas (Maurstad, 2005)

Sulfur compounds	H_2S, COS
Nitrogen compounds	HCN, NH_3
Chlorine compounds	HCl, NH_4Cl, other MeCl
Fly ash/slag	Unconverted C and ash
Other compounds	Pb, Hg, As, $Ni(CO)_4$, $Fe(CO)_5$

Up to 99.8 % of the coal sulfur can be removed in the acid gas removal process. As COS in not easily removed, a hydrolysis unit (or shift reactor in case of CO_2 capture) is required to convert the COS to H_2S prior to the acid gas removal. As for nitrogen and chlorine compounds, both compounds have very high solubility in water and may be removed in water scrubbing. For the unconverted carbon and ash, after capture in a filter or scrubber, these particles may be recycled to the gasifier to increase the carbon conversion efficiency (Higman and Van der Burgt, 2003).

III.3.2 Particle Removal

Dry solids removal systems use candle filters that can remove all solids from the gas at temperatures between 300 and 500 °C. Above 500 °C, alkali compounds may pass the filters in significant amounts. Below 300 °C, the filters may be blinded of deposits of ammonium chloride (NH_4Cl) (Maurstad, 2005).

Wet solids removal systems use water scrubbers operating at a temperature lower than the dewpoint of the gas so that the smallest solid particles can act as nuclei for condensation and ensure efficient operation. Even if an IGCC plant has a candle filter it usually also adds a wet scrubbing system for removal of remaining impurities such as chlorides and ammonia.

III.3.3 Shift Reaction

This stage of clean up is optional depends on the conditions. Figure 5 shows the principle processes for gas clean up for cases with and without CO_2 capture.

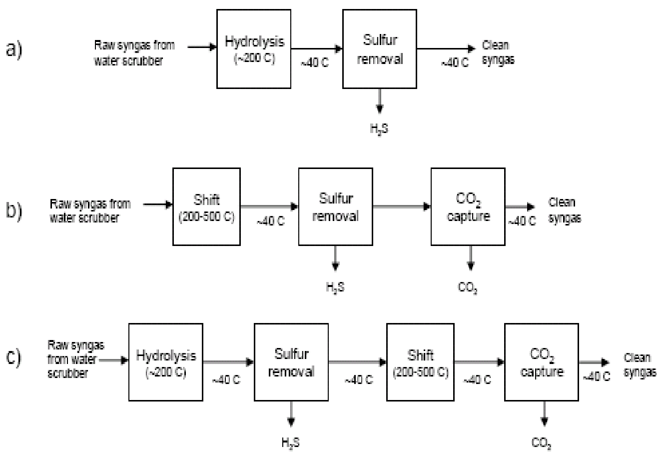

Figure 5. Gas clean up processes; a) No shift conversion, b) Sour shift conversion, and c) Clean shift conversion (Maurstad, 2005)

If CO_2 capture is not considered and the syngas is used only to feed the turbine (no chemical or fuel production), then a shift would not be included. However in this case, a separate hydrolysis reactor would be required to convert COS to H_2S for easier sulfur removal. If there is a shift reaction, this conversion takes place simultaneously and no separate reactor is needed. When CO_2 capture is considered there are two alternative processes for the shift reaction: a) Sour shift and b) Clean shift. A study has concluded that the sour shift is the preferred process with respect to costs and efficiency.

III.3.4 CO_2 Capture

Removal of CO2 from gas streams can be achieved by a number of separation techniques including absorption into a liquid solvent, adsorption onto a solid, cryogenic separation and permeation through membranes.

When considering capture of CO_2 in the IGCC design, two additional process blocks are needed (besides the compression of CO_2 for transportation):

a. A shift reactor in which the CO reacts with H_2O to H_2 and CO_2

b. An absorption process for capture using the Selexol process or other processes based on physical solvents, or an MDEA process based on chemical solvents.

CO2 separation processes with chemical solvents (alkanolamines) are industrialized since the seventies and the licensors are directed these last years toward specific solvent formulations: primary or secondary amines and anti-corrosion additives, tertiary amines with promoters or activators and with antifoaming additives. Mixing of chemical solvents, such as tertiary amines and a relatively small amount of the primary amine, aims to combine the advantages of the two solvents: the target of such mixed chemical solvents is to achieve a better absorption capacity, to avoid the solvent degradation and to limit the corrosion (Descamps et al, 2007).

As mentioned above, the use of CCS technology will decrease the plant overall efficiency for several reasons. The amount of efficiency penalty for the

IGCC plant with CCS also depends heavily on the type of gasifier used. But the efficiency often decreases in range 8-12 percent (Descamps et al, 2007).

III.4 Gas Turbines

Gas turbines were designed for natural gas and oil fuels, but are also commercially available for operation on syngas. GE, Siemens, Mitsubishi and Alstom offer gas turbines which could be applied in larger scale IGCC plants (Maurstad, 2005).

Syngas which typically has only 25 % of the volumetric heating value compared to natural gas, therefore requires roughly 4 times higher flow rate to maintain the same turbine inlet temperature (which is desirable to maintain high efficiency of the power block). Potentially, the increased mass flow of fuel and therefore the higher mass flow rate through the turbine will lead to an increased power output from the turbine.

However, depending on the gas turbine technology and fuel under consideration, there may be several limitations for the full realization of this increased power output potential:

a. Compressor surge
b. Gas turbine torque
c. Turbine inlet temperature and material lifetime

A higher mass flow rate through the turbine may increase the pressure at the compressor outlet (back pressure) too much, so that the compressor runs into surge and the air flow no longer can be maintained. The amount of pressure increase the compressor can tolerate before this occurs is referred to as the compressor surge margin which is a characteristic of the design of a given compressor. If surge becomes a problem therefore depends on the type of gas turbine, but it seems that this is an issue for the majority of available large gas turbines (Maurstad, 2005).

The mechanical ability of the gas turbine rotor to handle increased power output is another limitation for maximum GT power output. The turbine inlet temperature (TIT) is an important variable with respect to the electric efficiency of the combined cycle. It is desirable to operate with a TIT as high as possible to increase the efficiency. However, in order to protect the materials of the turbine, it is necessary to have a cooling system.

A heat recovery steam generator or HRSG is often used in the combined cycle power plant. HRSG is a heat exchanger that recovers heat from a hot gas stream. It produces steam that can be used in a process or used to drive a steam turbine. HRSG in a combined-cycle power station, exchanges hot exhaust from a gas turbine to generate steam which in turn drives a steam turbine. This combination produces electricity more efficiently than either the gas turbine or steam turbine alone.

HRSGs consist of three major components. They are the Evaporator, Superheater, and Economizer. The different components are put together to meet the operating requirements of the unit.

IV. Conclusion

IGCC technology is somehow one of the way to create more electricity to meet the world need. There are four major sections in which the electricity can be produced; air separation, gasification, gas clean up and conditioning, and combined cycle power plant. Due to the environmental problem, many future IGCC plant integrates the plant with CCS technology which will separate the CO_2 from the gas stream. But this action will highly decrease the plant overall efficiency. The reduction in electrical efficiency for a plant with CO_2 capture is explained by the following factors:

a. Exothermic shift reaction produces heat from syngas fuel and required coal feed rate to provide necessary rate of chemical fuel energy to the gas turbine increases. The produced heat is less efficiently converted to electricity than chemical energy (fuel heating value).

b. If the steam/carbon ratio is too low (as for Shell gasifiers), steam must be supplied from the steam cycle and is equivalent to an electricity production loss

c. CO_2 compression work

There is a continual research to reduce energy consumption for the overall process. The use of the new technologies of gas turbines operating with high turbine inlet temperature will increase the power production with similar fuel flow rate and so for the electric net efficiency which is a complimentary way to reduce fossil fuel consumption and therefore the CO2 emission. Research on the CO shift conversion could also reduce the steam consumption.

V. References

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