Study on Commercialization of High Efficiency IGCC System*

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The Integrated Gasification Combined Cycle (IGCC) is regarded as a prospective winner of thermal power system in the next decade. Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) has been developing gasification technology and dry gas desulfurization technology. These are key technologies for IGCC commercialization. IHI has constructed Texaco Type coal gasification test facility and has been carrying out various tests since 1987. Also at the Japanese national IGCC development project, IHI has been in charge of a dry gas desulfurization pilot plant development for 200 coal tons/day gasification plant. This worldly largest desulfurization unit has performed successfully and concluded in February 1996. With these test results, IHI has continued to improve IGCC system through various feasibility studies with Toshiba who designed the combined cycle. We also carried out parameter survey that focused on the influence of fuel properties. These results made clear some useful features for IGCC development.

Key Words: Gasification, Power Plant, Combined Cycle, Spouted Bed, Gas Turbine

1. Introduction

The demands for both energy supply stability and environment preservation are closed up simultaneously in the world. The importance of making use of vast reserved fossil fuel with high efficiency and with low environmental pollution is getting increase. IGCC can generate electricity from coal and low quality heavy oil more efficiently and cleanly. We can propose a high efficiency IGCC system based on long term experience.

In this paper we report our IGCC improvement activities and some results of parameter survey.

2. System Configuration

Figure 1 shows the IGCC system which we propose as high efficiency power plant.

2.1 Gasifier

This gasifier is quite simple. Coal and oxygen blow in through a single burner located at the top of the gasifier and react at high temperature. The synthesis gas and molten slag are discharged from the bottom of the gasifier together by down flow. The exit throat of gasifier is always heated by synthesis gas, so the slag does not set and plug the exit. Oxygen is chosen and used as gasification oxidant because oxygen blown enables a higher gasification performance than air blown case. Oxygen converts fuel to synthesis gas at the rate of almost 100% in one stage gasification. Therefore there is no need to recycle unconverted char to the gasifier.

The synthesis gas has a higher heating value, and less volume compared with air blown synthesis gas. Because the needless nitrogen for gasification reaction can be separated before the gasifier. As the useful nitrogen for Gas Turbine (GT) can be injected directly into the GT combustor which is operated in lower pressure than gasifier, we can save the nitrogen compression power. Furthermore the equipment after gasifier can be smaller than air blown case.

The synthesis gas is cooled in a synthesis gas cooler which is located under the gasifier. The slag is caught into a water bath located at the bottom of

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Fig. 1 Schematic flow diagram of the coal gasification power generation plant

synthesis gas cooler and discharged outside smoothly.

2.2 Gas clean up system

The both of dry desulfurization system and dry dust removal system realize a high temperature gas clean up which improves the plant efficiency. The desulfurization system has a fluidized bed type desulfurizer using iron oxide as sorbent. Dust is removed by candle type filter made of ceramic or metal which is located after the desulfurizer.

2.3 Air separation unit

The main process of Air Separation Unit (ASU) is cryogenic separation system. The air provided to ASU is integrated with GT extraction air and compressed ambient air. All residual nitrogen is returned to GT. So, the additional mass flow results that GT can increase power output. The nitrogen also acts to control thermal NO_x in the GT combustor.

2.4 Combined cycle

Combined cycle is composed by GT, Heat Recovery Steam Generator (HRSG) and Steam Turbine (ST). High efficiency is realized by utilizing the 1300°C class GT. The integrated steam cycle recovers heat efficiently not only from HRSG but also from the synthesis gas cooler in gasification unit.

3. Development Activity

IHI has developed the technologies of gasification and desulfurization which were the key technologies of IGCC.

3.1 Gasification technology

We joined the worldly first IGCC project, Cool Water Project in USA, in which we obtained many

operation data of 900 t/d gasifier as well as IGCC entire operation results. With these results we recognized that the TEXACO gasification process was the best process for IGCC. Therefore we built a 6 t/d TEXACO type gasifier (Coal Gasification Test Facility: CGT) in our Aioi factory to prove and improve this technology. We confirmed that TEXACO gasifier could gasify many kinds of coals, wide range of liquid fuels and even Orimulsion™ very well with no extra reconstruction for the facility.

3.2 Gas clean up system

The development for the gas clean up has started earlier than that for gasification. At the Japanese national project, 40 t/d coal gasification pilot plant in Yubari, we took charge to develop the dry gas clean up system. And also at the 200 t/d pilot plant in Nakoso we accomplished development of the dry gas clean up system. Besides the above projects we had been doing several backup tests in CGT. The results we have obtained from the both pilot plant projects are summarized below.

3.2.1 Stable desulfurization performance We confirmed that the desulfurization system had a stable desulfurization efficiency of 90% to 98%. This resulted that the sulfur (mainly H_2S and COS) concentration of desulfurization unit outlet was always at the range of 30 to 70PPMV regardless of inlet sulfur content variation.

3.2.2 Stable operation The result of 345 hours continuous operation proved that the desulfurization performance was stable. This operation result also confirmed that iron oxide had enough attrition

resistance hardness to operate for long time.

3.2.3 Scale up We confirmed that scale up did not reduce the desulfurization performance by the result of scale up from 40 t/d to 200 t/d.

3.2.4 Stability of materials and structure
After 9 years testing at the 40 t/d gasification pilot

Table 1 Main design condition

Net Power Output	400MW Class
Air Condition	ISO Base(15°C,60%)
Vacuum Pressure	722mmHg
Sulfur Recovery	Gypsum
Environmental Condition (6%dry O ₂ base)	SO _x :~50PPM NO _x :~45PPM DUST:~10mg/Nm ³

plant, it was proved that material selections of vessels, other equipment and pipes were quite adequate.

3.3 Trial design for IGCC

Reflecting above results of development, IHI started to carry out some trial designs for commercialized scale IGCC since 1989. The main design conditions are shown in Table 1.

As a result of these trial designs we confirmed that the IGCC process would realize a broad improvement of plant performances as it was mentioned in the next chapter. The main results are summarized below.

3.3.1 IGCC with wet gas clean up system In 1991 we carried out the first stage of trial design of a commercial scale IGCC with wet gas clean up system. As a result we confirmed the performance with over

Fig. 2 IGCC flow for trial design

40% of net plant efficiency based on high heat value (HHV).

3.3.2 Study of load regulating capability of IGCC We studied the load-regulating capability of IGCC with wet gas clean up system. As a result the load regulating capability of IGCC was proved to be as same as that of the conventional coal-fired thermal power plant.

4. System Improvement

Based on the elemental technology development and previous trial design results, we started to improve IGCC plant efficiency.

We set 4 cases to study system improvement. These cases are shown in Fig. 2. The case 1 is base case comes from Cool Water Plant system⁽¹⁾ with wet gas clean up system. The case 2 adopts ceramic type dry particulate filter, wet type gas desulfurization and air/nitrogen integration. The case 3 adopts complete dry type gas purification which involves our dry gas desulfurization system. And the case 4 is same with the case 3 but using next generation 1500°C class GT has air cooled blades. The main design conditions and design bituminous coal properties are shown respectively in Table 1 and Table 2. The results of trial design are summarized in Table 3. Bigger improvement on net plant efficiency was achieved in comparison with base case 1. Consequently we analyzed these results as follows;

4.1 Dust collection type

We adopt a ceramic candle type filter from the case 2 instead of water scrubber. Nearly in year, a high performance filter made of ceramic or metal was developed and has been applied to remove dust certainly with a small pressure loss in high temperature range. The water scrubber that is adopted in the case 1 accompanies a large pressure drop. This energy loss in pressure drop is large. By exchanging the dust collection type, we can improve plant efficiency.

4.2 Gas desulfurization type

When we use a commercialized wet type desulfurization system, the hot gas must be cooled down to an even room temperature. Because the chemical adsorption solvent commonly works efficiently in lower temperature. During the synthesis gas cooling, almost all involved steam is condensed and removed from itself. We could gain some extent heat by heating cold purified gas or boiler water for steam cycle. It isn't possible to decrease enough the both of gas enthalpy loss and gas volume loss. To avoid such losses, we can propose dry gas desulfurization system. As previously said, it can remove sulfur compound at more than 400°C. The result of the case 3 shows that net plant efficiency become one point higher than the case 2.

Table 2 Properties of design coals

Items		Bituminous Coal (Basic Design Coal)	Sub-bituminous Coal
High Heating Value (as received base)	kcal/kg	7230	5114
Total Moisture	wt%	9.0	25.2
Proximate Analysis			
Inherent Moistur	wt%	3.5	8.4
Fixed Carbon	wt%	56.6	48.6
Volatile Matter	wt%	30.4	37.7
Ash	wt%	9.5	5.4
Ultimate Analysis			
C	wt%	76.7	71.3
H	wt%	5.1	5.0
O	wt%	6.4	16.4
N	wt%	1.6	1.1
S	wt%	0.4	0.3

Table 3 Results of system improvement

	Dust Removal	Desulfur	ASU/GT Integration	GT Class	Net Plant Efficiency (HHV base)
Case 1	scrubber	wet type	no	1300°C	40.6%
Case 2	filter	wet type	yes	1300°C	43.1%
Case 3	filter	dry type	yes	1300°C	44.1%
Case 4	filter	dry type	yes	1500°C	46.7%

4.3 Air/Nitrogen integration

In IGCC system much power is necessary for compressors that are shown with small square mark (□) in Fig. 2. Especially the air compressor needs most huge power. To decrease these compression power means increase of net plant efficiency. As IGCC is operated with a high pressure (approximately 3 MPa), so pressurized oxygen to gasifier is needed. We supply it as separated oxygen from ASU. To make oxygen the compressed air (at least 0.6 MPa) must be supplied to ASU for adiabatic exploration. On the other hand, the GT integration with ASU can decrease the stand alone air compressor power. We have found that by proper setting of a flow rate of GT extraction air (1.2 - 1.4 MPa) for ASU resulted to maintain IGCC net output power and improve IGCC net plant efficiency. And the ASU can be operated with higher pressure to correspond with the provided extraction air pressure. The oxygen obtained from ASU has relatively higher pressure than no integration case. We can cut down an oxygen compression power because of lower pressure ratio. The nitrogen is also obtained from ASU with higher pressure

simultaneously. The nitrogen can be injected into GT by lower pressure ratio compression.

4.4 Next generation GT

If the GT inlet temperature is getting higher, we can improve the IGCC plant efficiency directly. The current commercialized GT with highest efficiency is 1300°C class. Toshiba continues to develop the 1500°C class GT technologies.

For the case 4 we only change the GT class from 1300°C to 1500°C in the case 3. The IGCC net plant efficiency is raised about 3 points from the case 3. Furthermore we have an expectation that IGCC efficiency will be jumped up about 2–3 points from the case 4 by use of other type 1500°C class GT which adopts a steam cooled blades system.

5. Parameter Survey

By means of the case 4 system that we are aiming at for the future, we carry out parameter survey about low quality coal and liquid fuel to clear the influence of fuel properties on design specification and plant net efficiency.

5.1 Coal fuel

We carry out trial design for low quality sub-bituminous coal shown in Table 2. This coal case needs following additional design consideration compared with the bituminous coal case.

- (1) High temperature synthesis gas cooler needs more 20% steam generation capability.
- (2) Coal mill needs more 30% capability.
- (3) Coal slurry supply pump capacity needs more 40% capability.

Other design change doesn't exist.

Result of trial design of sub-bituminous coal case shows that the net plant efficiency is 1.4% lower than the bituminous coal case.

5.2 Liquid fuel

We consider heavy oil C shown in Table 4 as standard liquid fuel and carry out fuel parameter survey for the supposed low quality liquid fuel. The characteristic of heavy oil C is that sulfur content is high compared with coal, and oxygen content is low, and ash content is few. There are following specification changes.

- (1) Steam injection to gasifier is needed.
- (2) The sulfur load of desulfurization unit is high.
- (3) The load of ash treating unit is very small.

We have carried out trial design for heavy oil C IGCC first of all. The net plant efficiency reached 47%. This results that heavy oil C is rather qualitative fuel than coal and has high heat value. We also have done trial design for Orimulsion™ fuel shown in Table 4. The net plant efficiency went down to 45%.

To analyze the efficiency difference such as

Table 4 Properties of liquid fuels

Items		C Heavy OIL (Basic Liquid Fuel)	Orimulsion™
High Heating Value	kcal/kg	10270	7180
Viscosity	cSt	40(at75°C)	135(at100°C)
Moisture	wt%	–	29.05
Ash	wt%	0.02	0.25
Ultimate Analysis			
C	wt%	85.4	60.0
H	wt%	11.4	7.5
O	wt%	2.0	0.2
N	wt%	0.2	0.5
S	wt%	1.0	2.7
Metal Content			
V	PPM	61	300
Na	PPM	13	70

Fig. 3 Result of fuel parameter survey

between heavy oil C and Orimulsion™, we carry out parameter survey focused on fuel properties. The heavy oil C is chosen as base liquid fuel. We survey the feature of properties with variety of sulfur content range as 1–6%, viscosity range as 20–30 000 cSt and metal V/Na content range as 60/10~300 PPM/100 PPM. The properties of Orimulsion™ are included between these variations. Furthermore the both largest sulfur content of 6% and largest viscosity of 30 000cSt come from asphalt properties.

5.2.1 Sulfur parameter survey The following design considerations are necessary to correspond high sulfur content fuel.

- (1) The stage number of fluidized bed desulfurizer should be incremented from 2 to 3 over 3% sulfur content.
- (2) The desulfur sorbent circulation flow rate between desulfurizer and regenerator should be increased.
- (3) Corrosion allowance of gas treating equipment should be reinforced.
- (4) Some equipment of sulfur recovery should be scaled up.

The result is shown in Fig. 3. As sulfur increased, the net plant efficiency failed. Figure 4 shows the difference of energy flow balance between $S=1\%$ and $S=6\%$. In these cases the GT output is almost equal,

Fig. 4 Difference of energy flow between $S=1\%$ and $S=6\%$

but the $S=6\%$ case needs more fuel feed. One reason is that the fuel content sulfur heat is taken into account total fuel heating value. But it can't work in GT, because the sulfur compounds are removed from synthesis gas to protect GT blades and keep environmental regulation. It works as heat source in sorbent regeneration reactor and consequently generates only valueless middle pressure steam. The other reason is that the increase of sulfur content needs more volumetric flow of both compressed air to regenerate sorbent and compressed nitrogen as diluent to control temperature in regenerator. These result to produce more auxiliary power consumption.

5.2.2 Viscosity parameter survey When fuel viscosity is higher than we expect, in order to maintain easy transportable state, following design considerations are necessary.

(1) More steam is required to raise and maintain fuel temperature, as viscosity of heavy oil drops together with rise of temperature. Furthermore the steam temperature should be higher than that of fuel to reduce viscosity sufficiently lower level.

(2) A design temperature of fuel supply system should be increased.

There was almost no fall of plant net efficiency. Otherwise fuel temperature is set at 250°C to decrease the viscosity from 20 000 cSt to 20 cSt, after all it means that heat is supplied to a gasifier and made advantageous condition for gasification reaction. It is supposed to offset the consumption of steam to heat up fuel and the effective degree of gasification reaction progress each other.

5.2.3 Metal V/Na content parameter survey When the metal quantities become increase, following

design considerations are necessary.

(1) The material of synthesis gas heat recovery equipment should be graded up corresponding to increase of suspended dust quantity and corrosive characteristics. These attention should be concerned with other equipment and pipes and instruments.

(2) The specification of ceramic filter should correspond to increase of dust load and maintain collection efficiency especially for sub-micron particles to keep metal concentration within the regulation of GT inlet.

Even though we took above mentioned design considerations, there was no efficiency fall.

6. Conclusion

Through the improvement activities described before, we obtained following results.

(1) We can propose high efficiency IGCC plant has more than 44% net plant efficiency by means of commercialized $1\,300^{\circ}\text{C}$ class GT.

(2) We will commercialize the IGCC system has more than 46% net plant efficiency by means of $1\,500^{\circ}\text{C}$ class GT in the near future.

(3) We ensure that, nevertheless some design considerations are necessary for low quality fuels, our IGCC system can use all these fuels to generate electricity efficiently without any change of main process.

(4) The result of parameter survey on fuel properties cleared that the sulfur content influenced on the plant net efficiency very much.

References

- (1) Cool Water Coal Gasification Program: Fifth Progress Report, EPRI AP-5931(1988).