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Japan 250 MW coal based IGCC demo plant set for 2007 start-up

By Harry Jaeger

Advanced two-stage air blown gasifier will be scaled up for a 650 MW commercialized plant powered by a G-class gas turbine for 48-50% IGCC plant efficiency.

Mitsubishi Heavy Industries is supplying a 250 MW coal-based integrated gasification combined cycle plant in Japan for mid-2007 startup.

It is being built at roughly one-half commercial scale as a demonstration unit to prove out new technologies for an advanced IGCC plant. Highlights:

☐ **Plant rating.** Net 220 MW output with 8125 Btu/kWh net plant heat rate (LHV) or 42% efficiency on 135 Btu/scf syngas fuel.

☐ **Power block.** Modified M701DA gas turbine with air extraction for the gasifier, HRSG, and oversized steam turbine.

☐ **Gasifier.** Two-stage dry feed air-blown entrained-flow gasifier, sized to process 1700 tpd coal feedstock, followed by cold gas cleanup.

☐ **Emissions.** Below 5 ppm NOx with selective catalytic reduction and below 8 ppm SOx after wet chemical absorption for sulfur removal.

Under contract with Clean Coal Power R&D Co., MHI is supplying equipment for the demo unit. Scope of supply includes the main components of the gasification system as well as the combined cycle power island.

Configuration

The demo plant is best described as a “partially integrated” coal-based IGCC design with a dry-feed air-blown entrained-flow gasifier.

The oxidant for gasification will come primarily from an extraction port installed in the modified gas turbine. Compressor air extracted from the gas turbine passes through a booster compressor on its way to the gasifier.

Gasifier pressure is high enough for product syngas to flow through downstream filters, heat exchangers, chemical cleaning systems, control valves and low-Btu gas fuel nozzles.

A relatively small air separation unit is also included in the gasification system to supply 1.25 million cu ft/hr of nitrogen which is used as an inert pressurized gas for coal transport.

This unit is only about 20-25% of the size that would typically be used for a similarly rated oxygen-blown gasifier where the ASU would consume about 10% of the gross plant power output and add upwards of 15% to plant cost.

Enriched air quality

The byproduct oxygen produced by the small ASU is added to the extraction air to supply an enriched air stream to the gasifier.

The enriched air flow makes gasifier operation more stable. Also, the “independent” ASU feature has the advantage of enabling the plant to change load more easily.

It operates at constant throughput regardless of plant load. It can also help make up for the drop in gasification system output as gas turbine compressor performance falls off at higher ambient temperatures.

Low-Btu syngas fuel delivered to the gas turbine will have a heating value typically in the range of 130-135 Btu/scf — slightly more than half that produced by the typical oxygen-blown gasifier.

The modified gas turbine, ISO rated at 142 MW in combined cycle operation, will exhaust into a bottoming cycle consisting of an HRSG and condensing steam turbine. Seawater will be used for plant cooling.

The steam turbine is rated at more than 110 MW to make use of additional steam generated by the gasifier; gas turbine will be configured as a dual-fuel turbine to burn kerosene for startup.

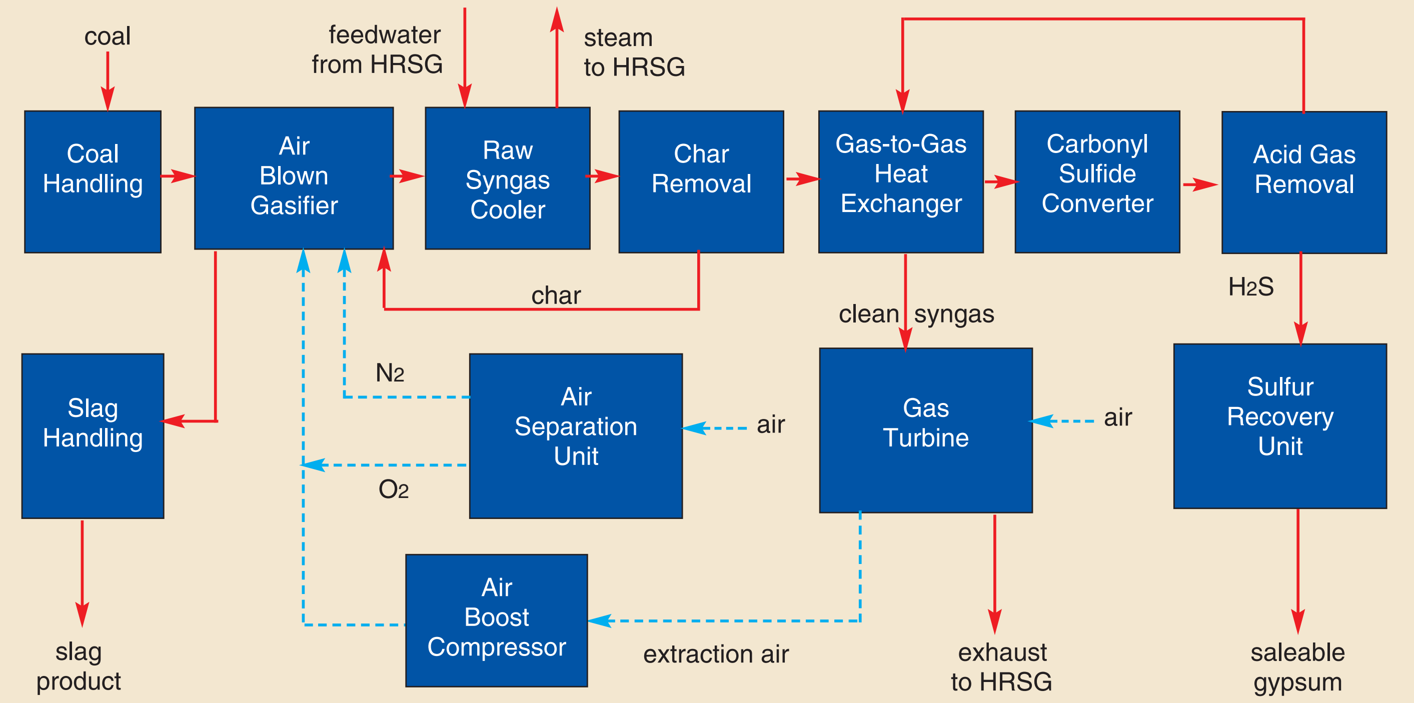
Clean Coal Power says the HRSG will be equipped with an SCR section to achieve exhaust NOx target level of 5 ppmvd (16% O_2 basis). This works out to be about a third of the NOx emissions produced by pulverized coal plants in Japan.

Project planners elected to go with a relatively modest D-class gas turbine technology (nominal 2200°F inlet temperature) and with inlet guide vane control available so as to stay within the desired scale of the demo unit.

42% net efficiency

Under this constraint, the plant is designed for a target gross power output of 250 MW. Resulting plant will deliver a net output of 220 MW and 42% net efficiency (8125 Btu/kWh heat rate on an LHV basis).

This achieves a project objective



Demo Plant Flow Diagram. Block diagram shows integrated air blown gasifier with cold gas clean-up system. ASU supplies nitrogen for coal transport and supplemental oxygen for enriching the gasifier air input. Steam generated by the raw hot gas cooler is sent to the HRSG for integration into the plant steam cycle. Char removal and recycling system contains cyclones and porous filters to trap particulates.

of matching the efficiency of the latest 700-1000 MW ultra-supercritical steam pulverized coal plants in Japan.

The demo plant is design rated at 48% gross efficiency, indicating that plant auxiliary loads and losses amount to some 12% of gross power rating, or 30 MW. Most of this goes to powering gasification equipment and the small ASU.

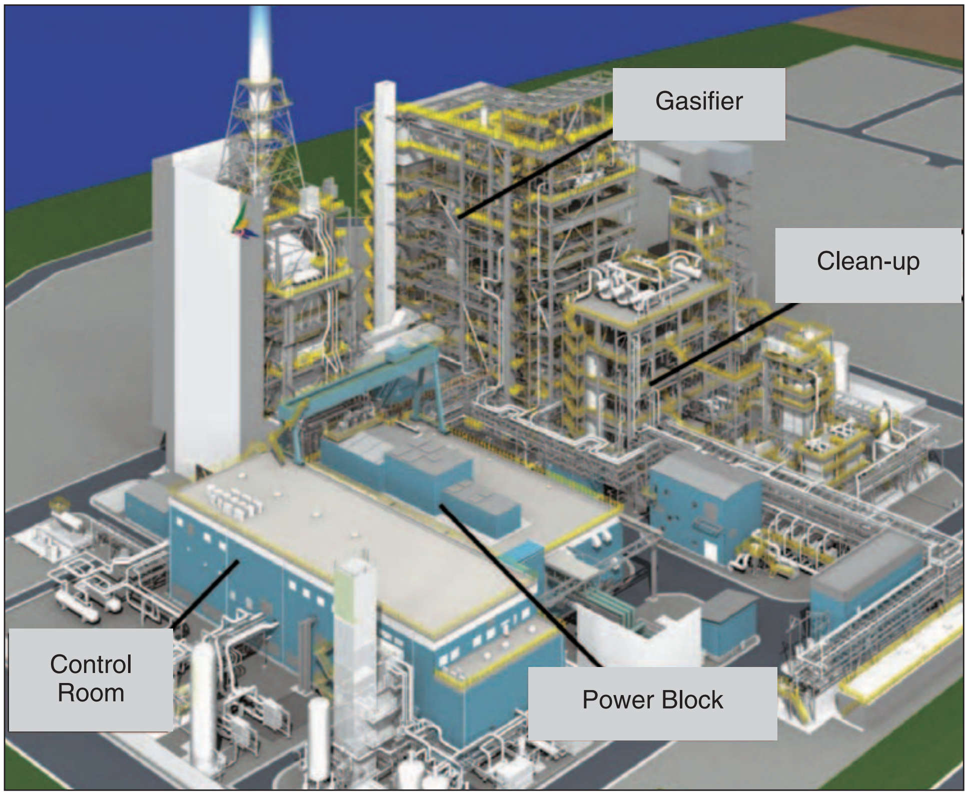
With F-class gas turbines such as the M701F, the same plant would be rated at 450 MW (50 Hz) and achieve an LHV efficiency in the range of 45-46%.

With G-class gas turbines as envisioned for fully commercialized 650 MW (50 Hz), plants, efficiencies in the range of 48-50% can be expected.

The efficiency spreads quoted reflect the difference in performance between going with a conventional cold gas clean-up system design as opposed to hot gas clean-up. Higher efficiencies reflect net gain of increasing fuel-gas temperature vs. reduced steam generation.

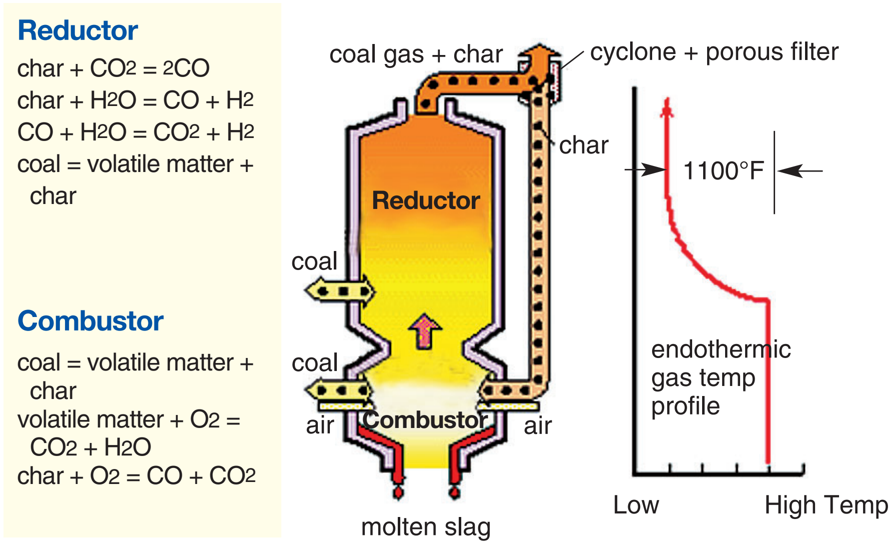
Although the earlier 200 tpd process pilot plant (see project history) included a developmental hot gas clean-up system, one of the decisions to come out of that test program was to go with cold clean-up for the 250 MW demonstration plant.

Sacrificing some efficiency was deemed necessary to meet more stringent emissions limits — as well as achieve the high reliability and avail-



250 MW demo plant project. Gasifier and combined cycle machinery should be ready to start IGCC operational testing in late 2007. Plant is sized to gasify 1700 tpd of powdered coal for a net output of 220 MW at 42% net efficiency (LHV).

Two-stage air blown gasifier. Coal and recycled char are fed into the first-stage combustor along with enriched air. Oxidation reactions generate a mixture of gases, primarily CO and CO_2, plus water vapor. In the second stage, more coal is fed into the upward flowing hot gas stream, but no more air added.


Reductor

$char + CO_2 = 2CO$

$char + H_2O = CO + H_2$

$CO + H_2O = CO_2 + H_2$

coal = volatile matter + char

Combustor

coal = volatile matter + char

$volatile\ matter + O_2 = CO_2 + H_2O$

$char + O_2 = CO + CO_2$

ability targets - within the time frame of the demonstration project.

Gasification and cleanup

The gasifier is sized to consume 1700 tpd of coal and will be capable of using a wide variety of feedstock from sources around the world.

At design point, it will supply 10.66 million scf/hr of approximate 135 Btu/scf syngas.

Raw hot gas (at about 2200°F) produced by the gasifier passes through an integral gas-cooler/steam generator and char removal/recycle system that includes cyclones and porous filters.

This arrangement enables the system to achieve extremely high carbon conversion (to syngas) rates – over 99.8% was measured in the 200 tpd pilot plant. High temperature filter system removes enough fine dust particles to meet allowable levels set by the gas turbine fuel specifications.

Steam generated by gas cooler is sent to the HRSG for superheating and integration into the main steam turbine supply. The gasifier has a “membrane water wall” that eliminates the need for a refractory lining and also supplies steam to the combined cycle system.

After char/dust removal and initial cooling, the product gas is further cooled in a gas-to-gas heat exchanger against clean syngas fuel on its way to the gas turbine.

Sulfur removal process

The fully cooled syngas then passes though a commercially available wet chemical absorption unit using MDEA (methyl-diethanol-amine) COS converter/acid gas removal system.

This unit essentially washes the syngas to remove sulfur and trace elements. It sends the sulfur, now in the form of H_2S, to the sulfur conversion/recovery unit where it is oxidized and absorbed in the high-performance limestone-gypsum unit.

This approach, resulting in the production of high-grade saleable gypsum, is favored over recovery as elemental sulfur, which is less easily recycled into a usable byproduct. Gypsum is a widely used building material in Japan.

The cooled, clean, and desulfurized fuel gas is then reheated in the gas-to-gas heat exchanger against the hot raw fuel gas, and delivered to the gas turbine fuel control valve and specially designed low-Btu gas fuel nozzles.

With this “cold gas clean-up system”, it is expected that the IGCC demonstration plant will achieve a SOx emissions limit of 8 ppmvd (16% O_2 basis).

On a per kWh basis, this works out to be about half the SOx emissions of a pulverized coal plant.

Air-blown gasifier

Dry feed design of the MHI gasifier avoids having to mix water with the pulverized coal feedstock as required by slurry transport designs.

The air-blown system also aims at reducing the auxiliary power consumed by a full-sized ASU associated with oxygen-blown gasifiers and high investment cost that goes with it.

Unique gasifier design features an up-flow two-stage configuration, namely a lower combustor chamber and upper reductor chamber.

A major feature of this configuration is that it enables continuous molten slag discharge at the bottom, and overall high carbon conversion to syngas, both in the same pressure vessel.

Stage one combustor

In the first stage, coal and recycled char are fed to the combustor chamber, along with the enriched air at relatively high air/fuel ratio.

Both full and partial oxidation reactions take place (see diagram) to generate a mixture of gases, primarily CO and CO_2. Water vapor needed for “water shift” gasification reactions in the second stage is also generated here.

Water vapor is formed as a product of combustion involving the hydrocarbons contained in the coal volatile matter which are liberated from the coal by intense heating.

This all takes place at very high temperatures which enable coal ash to separate from the gas stream in the form of fused molten slag.

The molten slag flows down to the bottom of the chamber, where it is quenched in water. It is recovered in the form of a glassy bead-like byproduct with less than 0.2 percent unburned carbon and virtually no troublesome leached trace elements to worry about.

It has a relatively high density, project engineers point out, so its volume is only about half that of the fly ash from a conventional coal plant. It also has possible commercial applications in road paving materials or as a fine aggregate for concrete.

The fact that the air fed to the combustor section is somewhat enriched with oxygen enhances this part of the process. It adds to the operating flexibility of the gasifier, also increases the heating value of the syngas ultimately delivered to the gas turbine combustor.

Stage two reductor

In the second stage, more coal is fed to the hot gas stream flowing upwards into the reductor, but no additional air is supplied.

Key process reactions that take place in this fuel-rich, low-oxygen environment include gasification of char to CO, reduction of CO_2 to CO, reduction of H_2O to H_2, additional pyrolysis of coal, and subsequent gasification of products of pyrolysis.

These reactions are generally endothermic in nature, resulting in a drop in gas mixture temperature by approximately 1100°F before the gas stream exits at the top of the gasifier.

At this reduced temperature, solid particles containing char or ash carryover are hardened so that sticking and fouling of downstream heat exchanger surfaces is minimal, and not a concern.

The raw syngas, a mixture mostly of CO, H_2, and N_2 (carried through from the air and coal transport medium) flows into a cyclone/porous filter arrangement designed to trap and recycle remaining char and dust back to the combustor stage.

Power block

Demo plant combined cycle unit has a single-shaft power train comprised of the modified M701DA gas turbine, steam turbine and generator.

Gas turbine's low-Btu combustors have a basic diffusion flame design as opposed to lean-premix design for dry low NOx combustion (cannot be used for low-Btu fuels).

The combustors have specially designed fuel nozzles capable of handling high volumes of syngas from the gasifier, where typical heating values are in the range of 120-140 Btu/scf. They also have dual-fuel capability to operate on syngas and to burn kerosene on startup.

MHI experience burning low-Btu fuels dates back to the 1950s. This includes first-of-a-kind applications in Japan with blast-furnace gas and modern gas turbines (M701DA) in 1987, with gas heating values below 100 Btu.

More recently, M701F gas turbines in single-shaft combined cycles have been operating on syngas diluted with nitrogen for NOx control and on low-Btu blends of blast furnace and coke-oven gases. ■

Nakoso 200 tpd pilot plant. Design included a 12.5 MW gas turbine (but no bottoming steam turbine) and a developmental hot gas clean-up system. Oxidizing air for the air blown gasifier was extracted from the turbine. Pilot plant testing ended in 1995.

Coal-based gasification R&D in Japan

Initial program started in the early 1980s with a 2 ton-per-day gasifier process development unit.

This was followed by a 200 tpd pilot plant that included a 12.5 MW gas turbine (but no bottoming steam turbine) and a developmental hot-gas clean-up system. Oxidizing air for the air-blown gasifier was extracted from the gas turbine.

Following some additional testing on a 24 tpd confirmation test unit at MHI, it was concluded that the integrated air-blown system was ready for the next step toward commercialization. Plans were set for the 250 MW "semi-commercial scale" demonstration project to confirm plant reliability, operability, maintainability, safety and economics.

The demonstration plant project started in the mid-1990s with a series of feasibility studies. That was followed by a preliminary design effort supported by additional testing. In 2001, under the direction of the newly formed Clean Coal Power Co., the final plant design was undertaken. CCP represents nine regional electric utilities, the Electric Power Development Corp., and CRIEPI.

Project schedule calls for completion of the gasifier installation (started May 2005) and combined cycle machinery by May 2007, start of gas and steam turbine runs by June, gasifier light-off and start of demonstration runs by September 2007, and completion of demonstration operation by March 2010.