Clean Coal Technology Demonstration in Japan by Isogo Thermal Power Station

Coal is acknowledged as the dirtiest among all fuels. However, if appropriate technology is adopted, then the adverse impact on the environment can be contained. The Isogo Thermal Power Station, located only six kilometres from Yokohama, the second largest city in Japan demonstrates just the above. A team of technical persons from the energy Division of NITI Aayog visited the above plant in Jauary, 2017 and were convinced that India's power sector could depend on our coal reserves without hurting our air quality.

The Isogo power station originally consisted of two 1960s-vintage 265-MW subcritical units. During the late 1990s, Yokohama's environmental improvement plans aimed to enhance the stability of electric power supply while retiring older facilities. Electric Power Development Co., Ltd. (J-POWER), which owns and operates Isogo, entered into a pollution prevention agreement with the city. The new Ultra-supercritical (USC) Unit 1 (600 MW) was built while the original facility remained in operation, becoming operational itself in 2002. The two older units were then shut down and demolished. The new USC Unit 2 (also 600 MW) was constructed on the site of the old plant and started commercial operation in 2009. The continued operation while new units were erected improved the financials of the overhaul project.

Isogo Unit 2 operates at 25 MPa (3626 psi) and 600°C/620°C reheat achieving 45% efficiency, while Unit 1 operates at a slightly lower 600°C/610°C. Completion of both units more than doubled the power generated at the small peninsula site while lowering emissions levels to that of a natural gas-fired combined-cycle plant.

The plant was installed with a combination of environmental control systems, including a re-generable dry flue gas desulphurization (FGD) system, to achieve very low levels of emissions. The technology is also a multi-pollutant control system and can be used to take out NOx and mercury, in addition to SO2.

Main challenges in designing the plant

The new units were committed to emissions levels that were one third of the old units for SO_2, one eighth of the old units for NO_x, and one fifth of the old units for particulates. The advanced steam parameters, chosen to maximize efficiency to save fuel costs and reduce all emissions including CO_2, which necessitated the use of state of-the-art materials. The main and reheat steam conditions at the turbine of 25 MPa, 600°C and 620°C meant that even higher parameters needed to be withstood by the boiler pressure parts. There was a need to establish the new unit at a busy power station site in a densely populated urban area. This required keeping the old units operating throughout the period of construction. The new units, which generates more electricity than both of the two old units combined, was placed immediately adjacent to old units 1 and 2.

The limitation on space was the reason that it was decided to adopt a tower type boiler. Such boilers are taller than two-pass designs but the land area required is considerably less. This enabled sufficient space for lay-down and construction. The boiler-house height was reduced by adopting innovative design features in the boiler and by arranging for the boiler base level to be 5 m below ground level. The space constraint also led to the selection of the type of flue gas desulphurization unit. The activated coke re-generable system occupies less area than wet limestone scrubbers (and has lower water consumption and waste water outflow).

Overall configuration

Isogo new units have been designed to use international coals and Japanese coals. Primary NO_x emissions are kept low by the use of a combination of low-NO_x burners and over-fire secondary air. After the boiler, an SCR unit removes further NO_x, electrostatic precipitators remove dust, and a re-generable activated coke flue gas desulphurization system removes SO_2 from the flue gases before they reach the 200m stack, which is of an elliptical design to minimize skyline intrusion. The boiler converts water to superheated supercritical steam in a single pass. The steam is expanded in an ultra-supercritical turbine supplied by Fuji Electric (Siemens), reheated in the boiler, then expanded again, before being condensed and returned as water to the boiler. Steam parameters are 25.0 MPa/600°C/610°C. The condenser is cooled with sea water, which in this part of the world allows a condenser pressure of 5 kPa at the design conditions. The plant's own power consumption is about 5% of gross generated power, which is low partly because of the use of turbine driven feed pumps and partly from the use of innovative systems such as the dry FGD system.

Boiler combustion system

It is the first tower boiler to be used in Japan and this design was selected as space was restricted. It offered not only high efficiency from its high steam conditions, but also the usual advantages that we have come to recognize with once-through supercritical systems, such as flexibility, rapid start-up and stability. The boiler has an opposed wall firing system, with four levels of burners mounted in the front and rear walls of the furnace. The low-NOx burners are supplied with pulverized coal by the four vertical spindle mills. At plant maximum continuous rating (MCR), all four mills are normally operating, but the mills are sized to enable full output to be achieved with only three in use. It is possible to reduce burner output down to 35% MCR, accompanied by sliding steam pressure to maintain optimum efficiency.

Start up is on light fuel oil. Unlike HFO, this has little vanadium, and so is less harmful to the very high temperature heat transfer surfaces in the boiler. The boiler is also supplied with over-fire air above the upper burners. This, together with the low-NOx burners, gives effective primary NOx control and high burnout. Boiler thermal efficiency is 88.5% on an HHV basis, equivalent to about 92% on an LHV basis.

Emissions control equipment

In Isogo power plant, if carbon dioxide levels are not included, the plant is a nearzero emission plant. Emissions are exceedingly low, being only one tenth of the stringent design levels for SO_2 and dust, and one half of the NO_x design level.

NOx control

Combinations of combustion measures and flue gas treatment are used for NOx control. Low-NOx combustors and air staging in the boiler provide initial NOx minimization, and then a selective catalytic reduction system (SCR) removes 87.5% of the NOx leaving the boiler. The SCR unit is closely integrated with the boiler, being mounted just above the rotary air heater flue gas inlet. As it is also upstream of the electrostatic precipitators, it is known as a high-dust SCR system. In addition, the dry desulphurization system captures more NOx. The design value NOx for emissions at the stack is 20 ppm, but in practice 10 ppm is achieved (20 mg/m3, at 6% O2 , dry).

Particulates

Particulates are removed from the flue gas by the electrostatic precipitators, which are designed to allow no more than a very low 10 mg/m3 emission at the stack. However, in practice, performance is an order of magnitude better, and the concentration of particulates at the stack is extremely low at 1 mg/m3 (at 6% O2, dry). One of the reasons for this is that the downstream flue gas desulphurization system also catches a substantial proportion of the remaining particulates. Almost the entire production of ash is utilized in cement applications and for production of a potassium silicate based fertilizer for sale.

Flue gas desulphurization

The flue gas desulphurization system installed on Isogo New Units are a re-generable process which uses activated coke in a loop to capture the SO2 . It is required to remove 95% of the oxides of sulphur from the flue gas at Isogo, but the process performs much better than this, and residual levels of SO2 in the stack gas are at the exceedingly low level of 6 mg/m3 (at 6% O2 , dry). Sulphuric acid is produced as a by-product. J-POWER has acquired the rights to the technology from Mitsui Mining Co. and is marketing it under the name of ReACT (Regenerative Activated Coke Technology) as a multi-pollutant control system. This is because it can also simultaneously reduce NOx by catalyzing its reduction by ammonia to nitrogen (similar to the reaction in a SCR unit). It will also capture particulates, as well as heavy metals such as mercury in either elemental or ionic form. Some fine activated coke that cannot be recycled is suitable as a dioxin adsorption agent for incinerator off-gases.

Like active carbon, the activated coke is made by steam activation of coal, but it is more resistant to abrasion and crushing. The flue gases are drawn from the electrostatic precipitators by the induced draught fan, and then ammonia is added at the inlet to the desulphurization tower, which has two component modules. The flue gas, at 150°C, is admitted into the base of each adsorbed module, which contains a slowly down-flowing bed of the activated coke. The flue gas exits at the top at 125-150°C. SO2 and sulphur trioxide are adsorbed and converted on the surface of the activated coke to sulphuric acid and ammonium sulphate.

The used adsorbent leaving the base of the desulphurization tower is then conveyed to the regenerator. The latter also works as moving bed. The SO2 is regenerated by heat, which breaks down the adsorbed sulphuric acid and ammonium sulphate. Heat is supplied indirectly – heat exchanger tubing transfers heat from hot gases produced in a light oil burner. The issuing stream of SO2 -rich gas is sent to the by-product recovery stage for manufacture of sulphuric acid. The regenerator operates at a temperature of 450°C, so the regenerated coke is cooled in the lower part before exiting the regenerator. Regenerated activated coke, after fines removal, is returned to the adsorption reactor.

The system has a number of advantages over normal wet scrubbing systems for SO2 removal. It consumes far less water (only 10% as much), consumes 80% as much power and is regenerable. Although this equipment was installed at Isogo New Unit 1 specifically for desulphurisation, additional particulates and some additional NOx are captured, and, as discussed above, the process is capable of removing other species. Isogo New Unit 2, the ReACT process installed specifically as a multi-pollutant control system. The process is being marketed in the USA with focus on capturing heavy metals including mercury.

Steam turbine and water/steam system

The steam and water cycle of Isogo New Units is a single reheat condensing supercritical system of conventional configuration but using advanced steam parameters. The Fuji Electric (Siemens design) 600 MWe 3000 rpm steam turbine is a tandem compound machine with 3-D blading, sliding pressure capability and 45.3 inch (1150 mm) final stage rotor blades. There is a one single-ended high-pressure turbine, one double flow intermediate pressure turbine and one double flow low pressure turbine with a large exhaust area because of the long blade length to give maximum expansion at optimum installation cost.

The turbine is equipped for extraction of steam for eight stages of feed water heating. Main stream conditions are 25 MPa/600°C/610°C. The turbine is designed for sliding pressure operation to maintain efficiency as high as possible at reduced load, although the unit has been operating on base load each year to date. The low pressure turbine has a sea water cooled condenser mounted beneath it where the wet steam emerging from the turbine (at 5 kPa) is fully condensed to water. Steam flows over the tube bundles which carry the cooling sea water, pumped by the cooling water pumps. The system is designed to give no more than a 7°C rise in cooling water temperature to minimize environmental impact.

Outcomes

Combined, the two larger new units emit 50% less SO_x, 80% less NO_x, 70% less particulate, and 17% less CO_2 than the older subcritical units that were replaced. The reduction in criteria emissions has been accomplished using a multi-pollutant regenerative activated coke dry-type control technology (ReACT™) that captures SO_x, mercury, and NO_x while only using 1% of the water required by conventional wet Fuel Gas Desulfurization (FGD) systems. ReACT™ technology consists of a moving bed absorber with activated coke pellets downstream of the electrostatic precipitator. Mercury, SO_x, and NO_x are adsorbed onto the carbon pellets with ammonia injected to promote the nitrogen and sulphur reactions. In addition, the ReACT^{TM} system offers a secondary method of particulate control as the flue gas impinges on the coke pellets. Activated coke from the absorber is regenerated to reduce NO_x to N_2 and drive off SO_x.

In the process, the concentrated sulphur-rich gas stream created is used to produce sulphuric acid as a by-product for commercial sale. Isogo's Unit 2 has permit levels of 10 ppm and 13 ppm for SO_2 and NO_x, respectively, and usually achieves single-digit ppm concentration emissions. The system provides such exceptional pollution control that Isogo is ranked the cleanest coal-fired power plant in the world in terms of emissions intensity.

There are great learning's from the Isogo plant and similar projects implemented elsewhere. Even China has embarked on the path of clean coal. The story of coal has been resurrected by the new US Administration. India, too, needs to chalk out its own pathway, which includes renewable sources, abundantly available n the sub-continent.