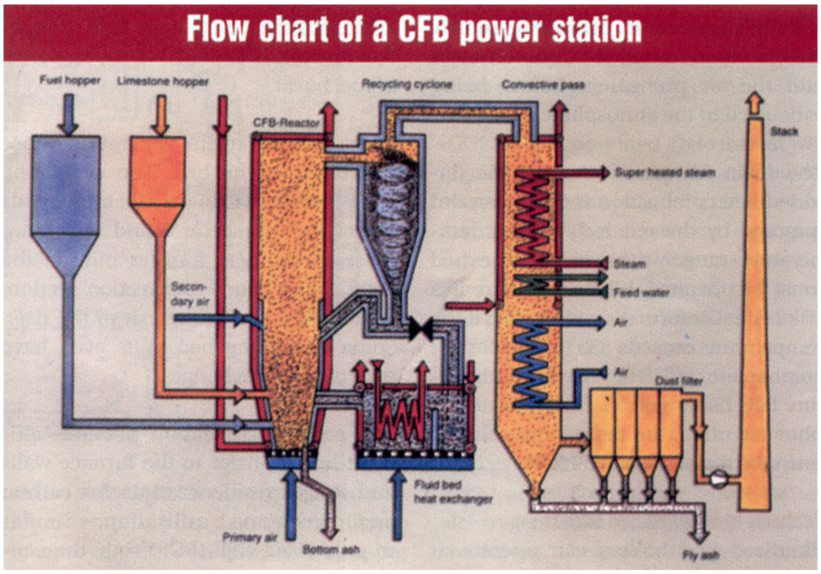
Boiler Technologies

Existing and emerging trends

Boiler technology the world over has evolved vastly over the years. From the conventional pulverized coal boilers to fluidised bed combustion technology and multi-fuel firing boilers, the industry has indeed come a long way.

This write-up describes the available and emerging technology options, their benefits and limitations.



CURRENT TECHNOLOGIES

Pulverised fuel boiler

Pulverised fuel boiler is the most commonly used method in thermal power plants, and is based on many decades of experience. Units operate at close to atmospheric pressure, simplifying the passage of materials through the plant.

Most coal-fired power station boilers use pulverised coal, and many of the larger industrial watertube boilers also use this fuel. This technology is well developed, and there are thousands of units around the world, accounting for well over 90 per cent of coal-fired capacity.

The coal is ground (pulverized) to a fine powder so that less than 2 per cent is +300 micro metre (μm) and 70-75 per cent is below 75 microns, for bituminous coal. The pulverized coal is blown with part of the combustion air into the boiler plant through a series of burner nozzles. Secondary and tertiary air may also be added. Combustion takes place at temperatures from 1,300 to 1,700 ^{o}C, depending largely on coal grade. Particle residence time in the boiler is typically two to five seconds, and the particles must be small enough for complete combustion to have taken place during this time.

This system has many advantages such as the ability to fire varying qualities of coal, quick responses to changes in load, use of high preheat air temperatures, etc. Pulverised coal boilers have been built to match steam turbines, which have outputs of between 50 and 1,300 Mwe. In order to take advantage of the economies of scale, most new units are rated at over 300 Mwe, but there are relatively few really large ones with outputs from a single boiler-turbine combination of over 700 Mwe. This is because of the substantial effects such units have on the distribution system if they should “trip out” for any reason, or be unexpectedly shut down.

Fluidised bed combustion

Fluidized bed combustion has emerged as a viable alternative and has significant advantages over the conventional firing system and offers multiple benefits. Some of the benefits are compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as SO_x and NO_x. The fuels burnt in these boilers include coal, washery rejects, rice husk, bagasse and other agricultural waste. Fluidised bed boilers have a wide capacity range – from 0.5 T per hour to over 100 T per hour.

There are three basic types of fluidized be combustion boilers:

- Atmospheric classic fluidized bed combustion system (AFBC).
- Atmospheric circulating (fast) fluidized bed combustion system (CFBC)
- Pressurised fluidized bed combustion system (PFBC).

AFBC/ Bubbling bed

In AFBC, coal is crushed to a size of 1-10 mm depending on the rank of coal, and type of fuel fed into the combustion chamber. The atmospheric air, which acts as both the fluidisation air and combustion air, is delivered at a pressure and flows through the bed after being preheated by the exhaust flue gases. The velocity of fluidizing air is in the range of 1.2 to 3.7 m per second. The rate at which air is blown through the bed determines the amount of fuel that can be reacted.

Almost all AFBC/ bubbling bed boilers use in-bed evaporator tubes in the bed of limestone, sand and fuel for extracting the heat from the bed to maintain the bed temperature. The bed depth is usually 0.9 m to 1.5 m and the pressure drop averages about 1 inch of water per inch of bed depth. Very little material leaves the bubbling bed-only about 2 to 4 kg of solids are recycled per kg of fuel burnt.

The combustion gases pass over the superheater sections of the boiler, flow past the economiser, the dust collectors and the air preheaters before being exhausted to the atmosphere.

The main feature of atmospheric fluidized bed combustion is the constraint imposed by the relatively narrow temperature range within which the bed must be operated. With coal, there is a risk of clinker formation in the bed if the temperature exceeds 950 ^{o}C and loss of combustion efficiency if the temperature falls below 800 ^{o}C. For efficient sulphur retention, the temperature should be in the range of 800 – 850 ^{o}C.

Features of bubbling bed boilers

Fluidised bed boilers can operate at near-atmospheric or elevated pressure and have these essential features:

- Distribution plate through which air is blown for fluidising,
- Immersed steam-raising or water heating tubes which extract heat directly from the bed,
- Tubes above the bed, which extract heat from hot combustion gas before it enters the flue duct.

Circulating fluidized bed combustion

CFBC technology has evolved from conventional bubbling bed combustion as a means to overcome some of the drawbacks associated with conventional bubbling bed combustion.

CFBC technology utilizes the fluidised bed principle in which crushed (6-12 mm size) fuel and limestone are injected into the furnace or combustor. The particles are suspended in a stream of upwardly flowing air (60-70 per cent of the total air), which enters the bottom of the furnace through air distribution nozzles. The fluidizing velocity in circulating beds ranges from 3.7 to 9 m per second. The balance of the combustion air is admitted above the bottom of the furnace as secondary air. The combustion takes place at 840-900 ^{o}C, and the fine particles (<450 microns) are elutriated out of the furnace with flue gas velocity of 4-6 m per second. The particles are then collected by the solid separators and circulated back into the furnace. Solid recycle is about 50 to 100 kg per kg of fuel burnt.

There are no steam generation tubes immersed in the bed. The circulating bed is designed to move a lot more solids out of the furnace area and to achieve most of the heat transfer outside the combustion zone – convection section, water walls, and at the exit of the riser. Some circulating bed units even have external heat exchanges.

The particle circulation provides efficient heat transfer to the furnace walls and longer residence time for carbon and limestone utilisation. Similar to pulverized coal (PC) firing, the controlling parameters in the CFBC process are temperature, residence time and turbulence.

For large units, the taller furnace characteristics of CFBC boilers offer better space sorbent residence time for efficient combustion and SO_2 capture, and easier application of staged combustion techniques for NO_x control than AFBC generators. CFBC boilers are said to achieve better calcium to sulphur utilisation 1.5 to 1 versus 3.2 to 1 for the AFBC boilers, although the furnace temperatures are almost the same.

CFBC boilers are generally claimed to be more economical than AFBC boilers for industrial applications requiring more than 75-100 T per hour of steam. CFBC requires huge mechanical cyclones to capture and recycle the large amount of bed material, which required a tall boiler.

At right fluidizing gas velocities, a fast recycling bed of fine material is superim posed on a bubbling bed of larger particles. The combustion temperature is controlled by the rate of recycling of fine material. Hot fine material is separated from the flue gas by a cyclone and is partially cooled in a separate low velocity fludised bed heat exchanger, where the heat is given up to the steam. The cooler fine material is then recycled to the dense bed.

At elevated pressure, the potential reduction in boiler size is considerable due to the increased amount of combustion in pressurised mode and high heat flux through in-bed tubes.

A CFBC boiler could be a good choice if the following conditions are met:

- Capacity of boiler is large to medium,
- Sulphur emission and NO_x control is important,
- The boiler is required to fire low-grade fuel or fuel with highly fluctuating fuel quality.

Pressurised fluid bed combustion

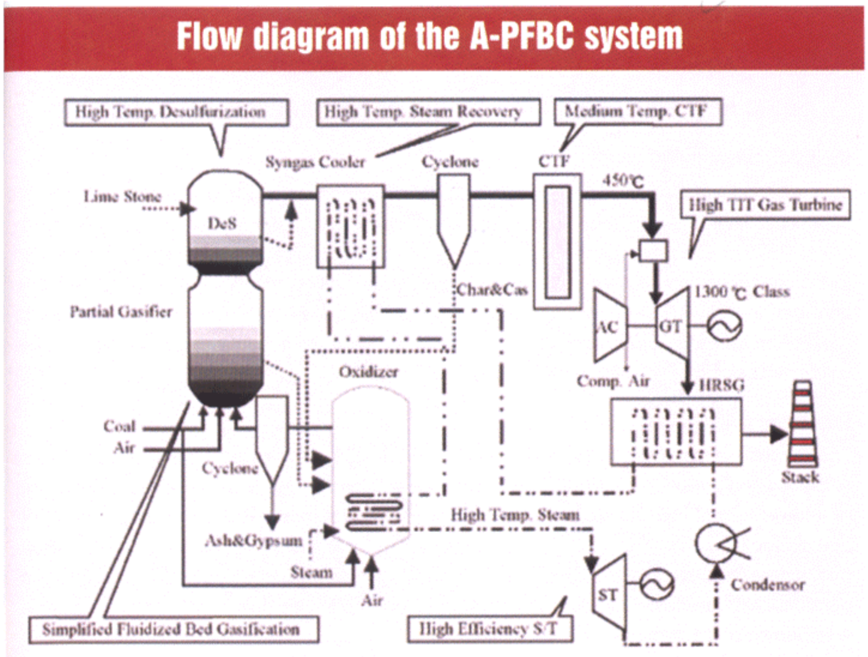
PFBC is a variation of fluid bed technology that is meant for large-scale coal burning applications. In PFBC, the bed vessel is operated at pressure up to 16 ata (16 kg per cm^2).

The off-gas from the fluidized bed combustor drives the gas turbine. The steam turbine is driven by steam raised in tubes immersed in the fluidized bed. The condensate from the steam turbine is preheated using waste heat from gas turbine exhaust and is then taken as feedwater for stem generation.

The PFBC system can be used for cogeneration or combined cycle power generation. By combining the gas and steam turbines in this way, electricity is generated more efficiently than in the conventional system. The overall conversion efficiency is higher by 5 to 8 per cent.

EMERGING BOILER TECHNOLOGY

Up till the 1970s, certain high-grade fuels like oil and better quality coals were utilised in boilers for power generation purposes. But with growing awareness of sustainable use of energy, extensive utilisation of better quality fuels has become a cause for concern.



To conserve fossil sources for purposes other than burning and steam generation, boilers with better fuel utilisation technology are required in addition to adopting boilers with multi-fuel burning capability. In this regard, there has been increased interest in areas like supercritical boiler technology, intergrated coal gasification combined cycle and advance PFBC technology, to name a few. Boilers now also burn a variety of waste fuels such as biomass and bagasse for cogeneration purposes.

Advanced-PFBC (A-PFBC) system

The A-PFBC (series type) technology, developed in Japan, makes use of the advantageous conditions of the raised GT temperatures and improved steam conditions while mitigating developmental loads (there is no need to develop a topping combustor).

In the A-PFBC system, the gas produced in the partial gasifier (syngas) is fed to a high temperature dry desulphuriser where syngas is desupphurised by using limestone, and then is cooled by a syngas cooler (SGC). The desulphurisation of the gas prior to cooling makes SGC atmosphere slow corrosive and enables more sensible heat of the gas to be recovered as high temperature steam. The cooled gas (450^{o}C) is subjected to strict dust removal with a cyclone, ceramic filter and is then fed to the combustor of the gas turbine to generate power.

The oxidiser plays a role not only in the combustion of unburnt carbon (char) transferred from the partial gasifier but also in oxidizing CaS formed in the desulphuriser into gypsum ($CaSO_4$). The high temperature flue gas from the oxidizer is introduced into the partial gasifier; thus the heat energy (sensible heat) of the flue gas is effectively used as a heat source for the partial gasifier.

Integrated coal gasification combined cycle

Integrated coal gasification combined cycle (IGCC) is a new coal-utilised power generation technology that achieves higher thermal efficiency and better environmental performance for the next generation.

In Japan, the development of original air-blown IGCC technology has been pushed forward as a national project.

Like PFBC, the technology is relatively new in connection with power generation. It was only in the late 1990s that coal-based IGCC plants for power generation started gaining acceptance.

IGCC uses a combined cycle format with a gas turbine driven by the combusted syngas, while the exhaust gases are heat exchanged with water/ steam to generate superheated steam to drive a steam turbine. Using IGCC, more of the power comes from the gas turbine. Typically 60 – 70 per cent of the power comes from the gas turbine with IGCC, compared with about 20 per cent using PFBC.

Coal gasification takes place in the presence of a controlled "shortage' of air/oxygen, thus maintaining reducing conditions. The process is carried out in an enclosed pressurised reactor, and the product is a mixture of CO and H_2 (called synthesis gas, syngas or fuel gas). The product gas is cleaned and then burnt with either oxygen or air, generating combustion products at high temperature and pressure. The sulphur present mainly forms H_2S but there is also a little COS. The H_2S can be more readily removed than SO_2. Although no NO_x is formed during gasification, some is formed when the fuel gas or syngas is subsequently burnt.

The IGCC demonstration plants use different flow sheets, and therefore test the practicalities and economics of different degrees of integration. As with PFBC, the driving force behind the development is to achieve high thermal efficiencies together with low levels of emissions.

Supercritical boiler

The earliest supercritical boilers were built in the US in the late 1950s and early 1960s. Designed to operate above steam's critical pressure of 3208 psi, these early units developed a reputation for high thermodynamic efficiency (around 35 per cent, based on lower heating value-LHV) but low reliability.

The materials of that era, plant owners came to realise, were simply not up to the temperature and pressure challenges, and the North American industry put supercritical technology "on the backburner". The ascent of gas-fired combined cycles continued to suppress interest in the technology in this region.

In Europe and Asia, however, supercritical technology continued to be pursued, and by the 1990s it had come to dominate new capacity projects. The capital cost of supercritical technology is slightly higher than subcritical, but fuel savings and environmental advantages can tip the scale.

Compared to the 1950s designs, steam pressures in most of these units have increased well into the supercritical range – up to 4,500 psig- although steam temperatures were maintained around the same 1,000 ^{o}F limit. The result was a thermal efficiency of approximately 40 per cent (LHV).

More advanced designs introduced in the late 1990s have raised steam temperature as high as 1,150 ^{o}F, achieving efficiencies of 44 per cent. And main steam conditions above 1,200 ^{o}F are foreseen, which should yield an efficiency approaching 50 per cent. The increase in efficiency not only reduced fuels cost, but also specific (per MW) emissions of NO_x and SO_2, as well overall emission of CO_2, compared to sub critical coal-fired boilers.

All supercritical boilers are of a once through arrangement, meaning that water and steam flow through the boiler circuitry only once. Contrast this with drum boilers, in which water and steam recirculate through the furnace enclosure. The major difference between the various once-through boiler technologies in the market is the configuration of the furnace enclosure circuits and in the system used to circulate the water through those circuits during start-up and at lower loads.

Reference Book:
Power Line
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