6. FBC BOILERS

Syllabus

FBC boilers: Introduction, Mechanism of fluidised bed combustion, Advantages, Types of FBC boilers, Operational features, Retrofitting FBC system to conventional boilers, Saving potential.

6.1 Introduction

The major portion of the coal available in India is of low quality, high ash content and low calorific value. The traditional grate fuel firing systems have got limitations and are techno-economically unviable to meet the challenges of future. Fluidised bed combustion has emerged as a viable alternative and has significant advantages over conventional firing system and offers multiple benefits – 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 wastes. The fluidized bed boilers have a wide capacity range- 0.5 T/hr to over 100 T/hr.

6.2 Mechanism of Fluidised Bed Combustion

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream – the bed is called “fluidised”.

With further increase in air velocity, there is bubble formation, vigorous turbulence, rapid mixing and formation of dense defined bed surface. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid – “bubbling fluidized bed”.

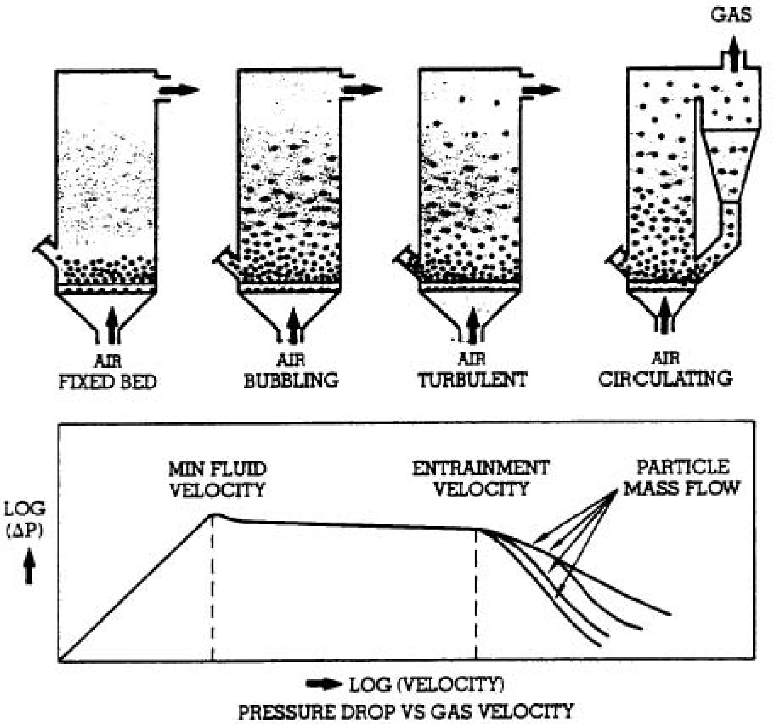
At higher velocities, bubbles disappear, and particles are blown out of the bed. Therefore, some amounts of particles have to be recirculated to maintain a stable system - "circulating fluidised bed".

This principle of fluidisation is illustrated in Figure 6.1.

Fluidization depends largely on the particle size and the air velocity. The mean solids velocity increases at a slower rate than does the gas velocity, as illustrated in Figure 6.2. The difference between the mean solid velocity and mean gas velocity is called as slip velocity. Maximum slip velocity between the solids and the gas is desirable for good heat transfer and intimate contact.

If sand particles in a fluidised state is heated to the ignition temperatures of coal, and coal is injected continuously into the bed, the coal will burn rapidly and bed attains a uniform temperature. The fluidised bed combustion (FBC) takes place at about 840°C to 950°C. Since this temperature is much below the ash fusion temperature, melting of ash and associated problems are avoided.

The lower combustion temperature is achieved because of high coefficient of heat transfer due to rapid mixing in the fluidised bed and effective extraction of heat from the bed through in-bed heat transfer tubes and walls of the bed. The gas velocity is maintained between minimum fluidisation velocity and particle entrainment velocity. This ensures stable operation of the



Fixing, bubbling and fast fluidized beds

As the velocity of a gas flowing through a bed of particles increases,
a value is reaches when the bed fluidises and bubbles form as in a boiling liquid. At higher velocities the bubbles disappear; and the solids are rapidly blown out of the bed and must be recycled to maintain a stable system.

Figure 6.1 Principle of Fluidisation

bed and avoids particle entrainment in the gas stream.

Combustion process requires the three "T"s that is Time, Temperature and Turbulence. In FBC, turbulence is promoted by fluidisation. Improved mixing generates evenly

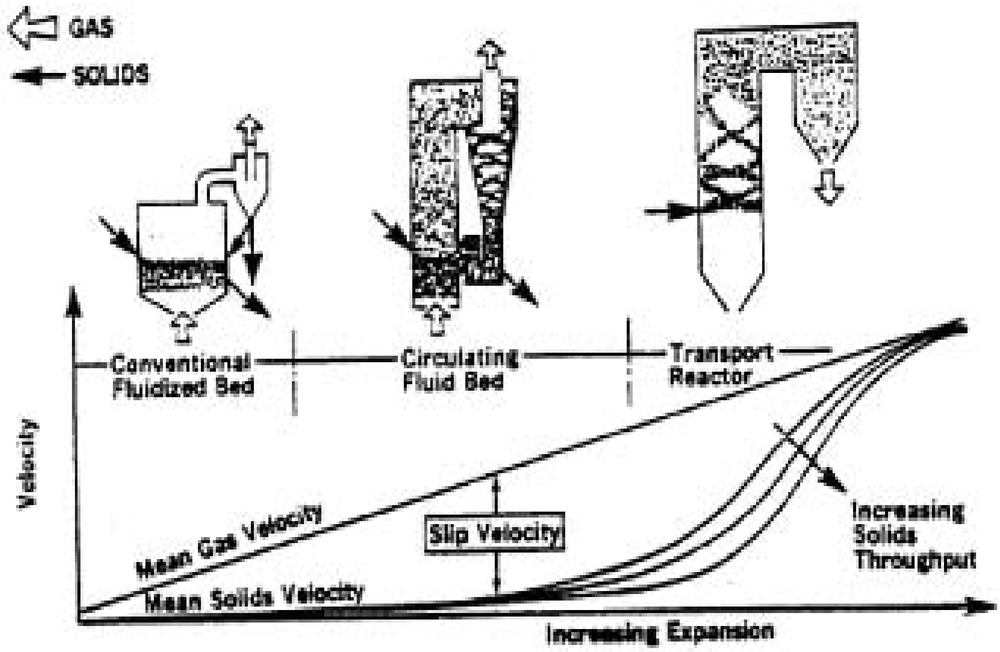


Figure 6.2 Relation between Gas Velocity and Solid Velocity

distributed heat at lower temperature. Residence time is many times greater than conventional grate firing. Thus an FBC system releases heat more efficiently at lower temperatures.

Since limestone is used as particle bed, control of sulfur dioxide and nitrogen oxide emissions in the combustion chamber is achieved without any additional control equipment. This is one of the major advantages over conventional boilers.

6.3 Types of Fluidised Bed Combustion Boilers

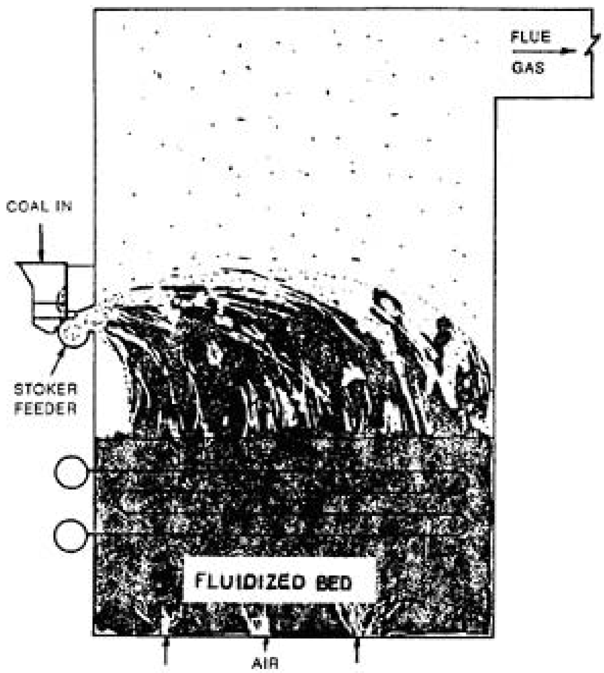
There are three basic types of fluidised bed combustion boilers:

1. Atmospheric classic Fluidised Bed Combustion System (AFBC)
2. Atmospheric circulating (fast) Fluidised Bed Combustion system(CFBC)
3. Pressurised Fluidised Bed Combustion System (PFBC).

6.3.1 AFBC / Bubbling Bed

In AFBC, coal is crushed to a size of 1 – 10 mm depending on the rank of coal, type of fuel feed and fed into the combustion chamber. The atmospheric air, which acts as both the fluidization 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 fluidising air is in the range of 1.2 to 3.7 m /sec. 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 deep 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



Features of bubbling bed boiler

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

- Distribution plate through which air is blown for fluidizing.
- 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.

Figure 6.3 Bubbling Bed Boiler-1

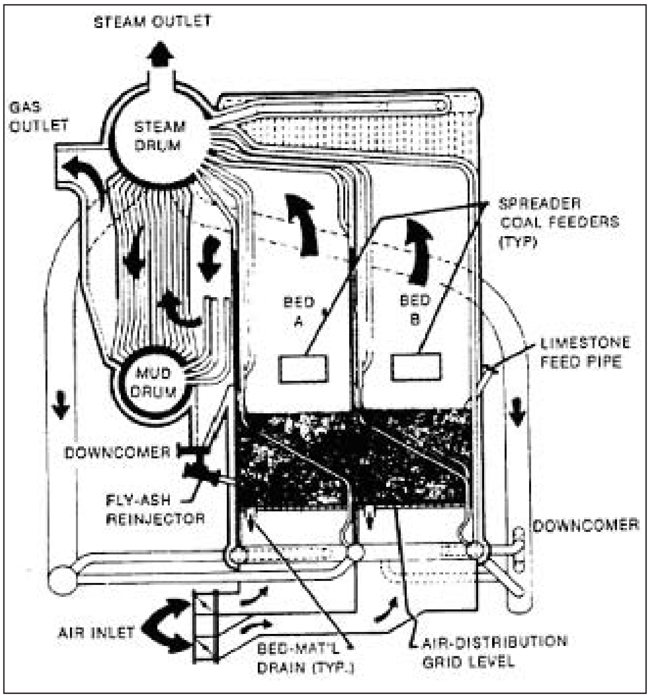


Figure 6.4 Bubbling Bed Boiler-2

ton of fuel burned. Typical fluidised bed combustors of this type are shown in Figures 6.3 and 6.4.

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

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

General Arrangements of AFBC Boiler

AFBC boilers comprise of following systems:

i) Fuel feeding system
ii) Air Distributor
iii) Bed & In-bed heat transfer surface
iv) Ash handling system.

Many of these are common to all types of FBC boilers.

1. Fuel Feeding System

For feeding fuel, sorbents like limestone or dolomite, usually two methods are followed: under bed pneumatic feeding and over-bed feeding.

Under Bed Pneumatic Feeding

If the fuel is coal, it is crushed to 1–6 mm size and pneumatically transported from feed hopper to the combustor through a feed pipe piercing the distributor. Based on the capacity of the boiler, the number of feed points is increased, as it is necessary to distribute the fuel into the bed uniformly.

Over-Bed Feeding

The crushed coal, 6–10 mm size is conveyed from coal bunker to a spreader by a screw conveyor. The spreader distributes the coal over the surface of the bed uniformly. This type of fuel feeding system accepts over size fuel also and eliminates transport lines, when compared to under-bed feeding system.

2. Air Distributor

The purpose of the distributor is to introduce the fluidizing air evenly through the bed cross section thereby keeping the solid particles in constant motion, and preventing the formation of defluidization zones within the bed. The distributor, which forms the furnace floor, is normally constructed from metal plate with a number of perforations in a definite geometric pattern. The perforations may be located in simple nozzles or nozzles with bubble caps, which serve to prevent solid particles from flowing back into the space below the distributor.

The distributor plate is protected from high temperature of the furnace by:

i) Refractory Lining
ii) A Static Layer of the Bed Material or
iii) Water Cooled Tubes.

3. Bed & In-Bed Heat Transfer Surface:

a) ***Bed***

The bed material can be sand, ash, crushed refractory or limestone, with an average size of about 1 mm. Depending on the bed height these are of two types: shallow bed and deep bed.

At the same fluidizing velocity, the two ends fluidise differently, thus affecting the heat transfer to an immersed heat transfer surfaces. A shallow bed offers a lower bed resistance and hence a lower pressure drop and lower fan power consumption. In the case of deep bed, the pressure drop is more and this increases the effective gas velocity and also the fan power.

b) ***In-Bed Heat Transfer Surface***

In a fluidised in-bed heat transfer process, it is necessary to transfer heat between the bed material and an immersed surface, which could be that of a tube bundle, or a coil. The heat exchanger orientation can be horizontal, vertical or inclined. From a pressure drop point of view, a horizontal bundle in a shallow bed is more attractive than a vertical bundle in a deep bed. Also, the heat transfer in the bed depends on number of parameters like (i) bed pressure (ii) bed temperature (iii) superficial gas velocity (iv) particle size (v) Heat exchanger design and (vi) gas distributor plate design.

4. Ash Handling System

a) ***Bottom Ash Removal***

In the FBC boilers, the bottom ash constitutes roughly 30 – 40 % of the total ash, the rest being the fly ash. The bed ash is removed by continuous over flow to maintain bed height and also by intermittent flow from the bottom to remove over size particles, avoid accumulation and consequent defluidization. While firing high ash coal such as washery rejects, the bed ash overflow drain quantity is considerable so special care has to be taken.

b) ***Fly Ash Removal***

The amount of fly ash to be handled in FBC boiler is relatively very high, when compared to conventional boilers. This is due to elutriation of particles at high velocities. Fly ash carried away by the flue gas is removed in number of stages; firstly in convection section, then from the bottom of air preheater/economizer and finally a major portion is removed in dust collectors.

The types of dust collectors used are cyclone, bagfilters, electrostatic precipitators (ESP's) or some combination of all of these. To increase the combustion efficiency, recycling of fly ash is practiced in some of the units.

6.3.2 Circulating Fluidised Bed Combustion (CFBC)

Circulating Fluidised 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 (see Figure 6.5).

This 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% of the total air), which enters the bottom of the furnace through air distribution nozzles. The fluidising velocity in circulating beds ranges from 3.7 to 9 m/sec. The balance of combustion air is admitted above the bottom of the furnace as secondary air. The combustion takes place at 840-900 °C, and the fine particles (<450 microns) are elutriated out of the furnace with flue gas velocity of 4–6 m/s. The particles are then collected by the solids 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 particles 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 CFB combustion process are temperature, residence time and turbulence.

For large units, the taller furnace characteristics of CFBC boiler offers better space utilisation, greater fuel particle and 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 vs. 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 application requiring more than 75 - 100 T/hr of steam.

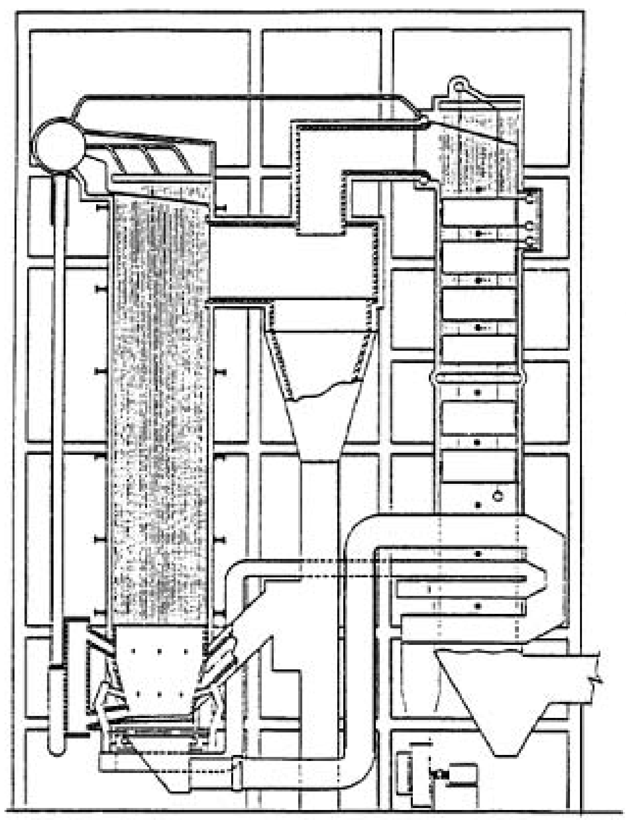
CFBC requires huge mechanical cyclones to capture and recycle the large amount of bed material, which requires a tall boiler.

A CFBC could be 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.

Major performance features of the circulating bed system are as follows:

a) It has a high processing capacity because of the high gas velocity through the system.
b) The temperature of about 870 °C is reasonably constant throughout the process because of the high turbulence and circulation of solids. The low combustion temperature also results in minimal NOx formation.
c) Sulphur present in the fuel is retained in the circulating solids in the form of calcium sulphate and removed in solid form. The use of limestone or dolomite sorbents allows a higher sulfur retention rate, and limestone requirements have been demonstrated to be substantially less than with bubbling bed combustor.
d) The combustion air is supplied at 1.5 to 2 psig rather than 3–5 psig as required by bubbling bed combustors.
e) It has high combustion efficiency.
f) It has a better turndown ratio than bubbling bed systems.
g) Erosion of the heat transfer surface in the combustion chamber is reduced, since the surface is parallel to the flow. In a bubbling bed system, the surface generally is perpendicular to the flow.



Circulating bed boiler

At high fluidizing gas velocities in which a fast recycling bed of fine material is superimposed on a bubbling bed of larger particles. The combustion temperature is controlled by 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 fluidized bed heat exchanger, where the heat is given up to the steam. The cooler fine material is then recycled to the dense bed.

Figure 6.5 Circulating Bed Boiler Design

6.3.3 Pressurised Fluid Bed Combustion

Pressurised Fluidised 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 upto 16 ata (16 kg/cm^2).

The off-gas from the fluidised bed combustor drives the gas turbine. The steam turbine is driven by steam raised in tubes immersed in the fluidised bed. The condensate from the steam turbine is pre-heated using waste heat from gas turbine exhaust and is then taken as feed water for steam 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 conventional system. The overall conversion efficiency is higher by 5% to 8%. .

(Refer Figure 6.6).

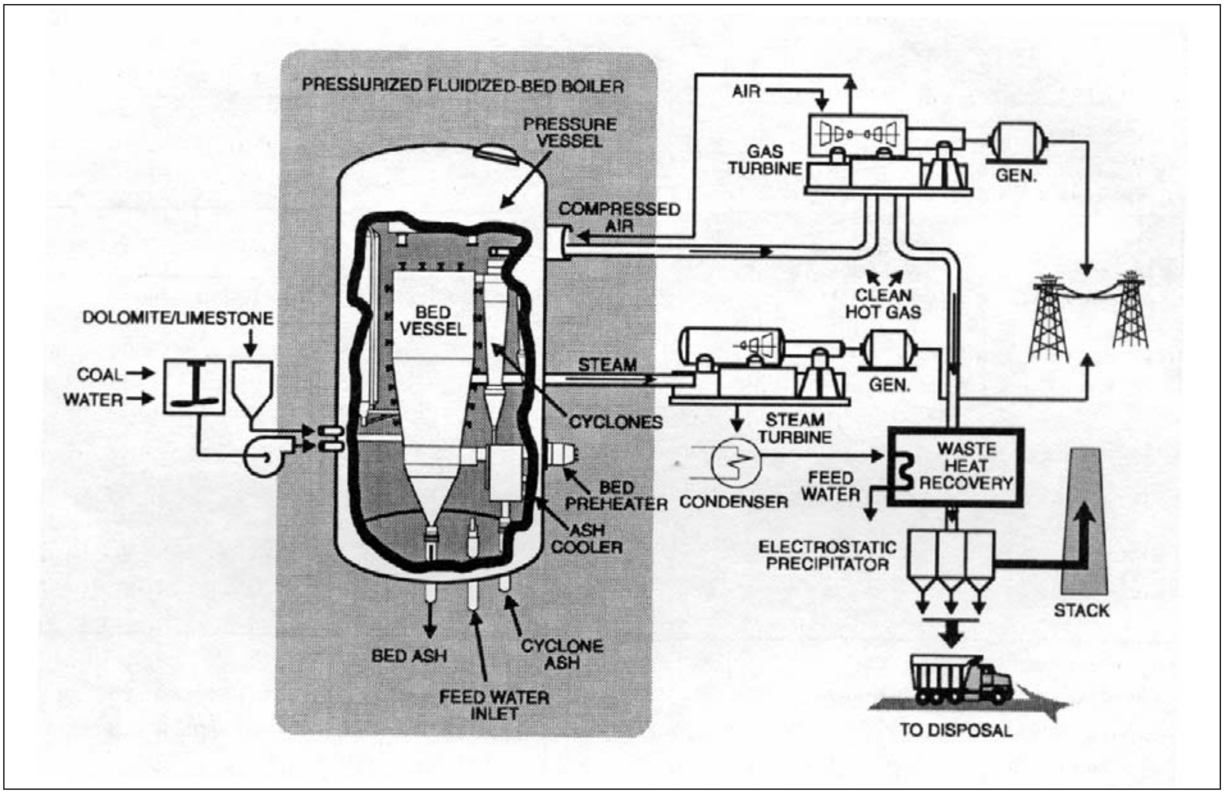


Figure 6.6 PFBC Boiler for Cogeneration

At elevated pressure, the potential reduction in boiler size is considerable due to increased amount of combustion in pressurized mode and high heat flux through in-bed tubes. A comparison of size of a typical 250 MW PFBC boiler versus conventional pulverized fuel-fired boiler is shown in the Figure 6.7.

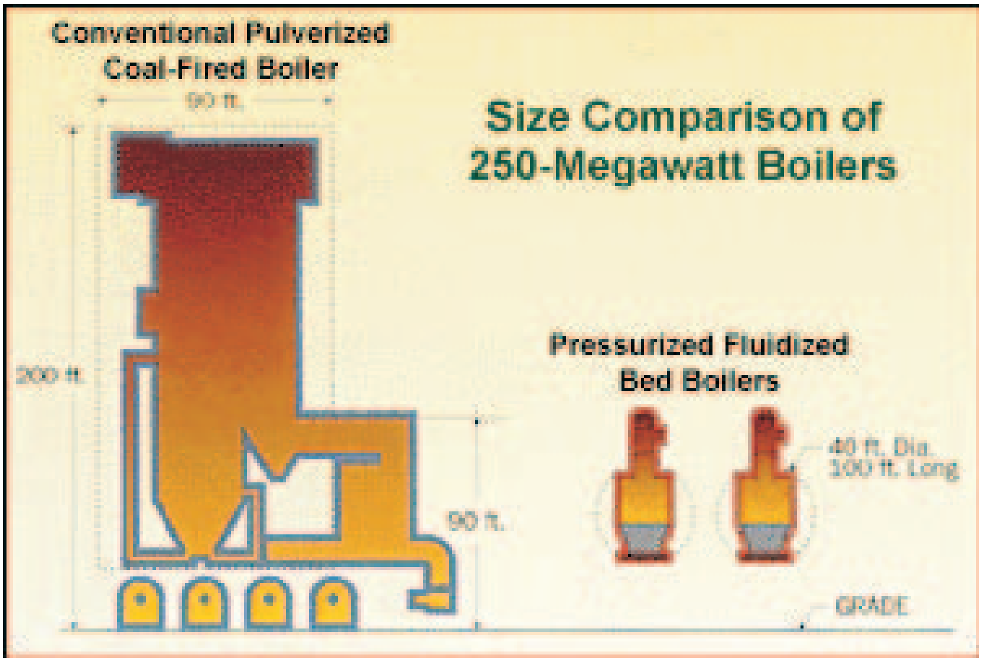


Figure 6.7 Comparison of PFBC Boiler Versus Pulverized Fuel Boiler

6.4 Retrofitting of FBC Systems to Conventional Boilers

Retrofitting fluidised bed coal fired combustion systems to conventional boilers has been carried out successfully both in India and abroad.

The important aspects to be considered in retrofit projects are:

a) Water/steam circulation design
b) Furnace bottom-grate clearance
c) Type of particulate control device
d) Fan capacity
e) Availability of space.

Retrofitting of a fluidised bed combustor to a conventional stoker fired water tube boiler may involve:

a) The replacement of grate by a distributor plate with short stand pipes for admitting air from the wind box located underneath.
b) Installations of stand pipes to remove ash from the bed.
c) Provision of horizontal hairpin tubes in the bed with a pump for forced circulation from the boiler drum.
d) Modification of crusher to size the coal/limestone mixture for pneumatic underbed injection of the mixture.

It may be emphasised that conversion of a conventional coal fired system to a fluidised bed combustion system can be accomplished without effecting major changes, after making a cost-benefit analysis. Oil fired boilers can also be converted to coal fired fluidised bed combustion systems. However it has to be examined on a case-to-case basis.

6.5 Advantages of Fluidised Bed Combustion Boilers

1. High Efficiency

FBC boilers can burn fuel with a combustion efficiency of over 95% irrespective of ash content. FBC boilers can operate with overall efficiency of 84% (plus or minus 2%).

2. Reduction in Boiler Size

High heat transfer rate over a small heat transfer area immersed in the bed result in overall size reduction of the boiler.

3. Fuel Flexibility

FBC boilers can be operated efficiently with a variety of fuels. Even fuels like flotation slimes, washer rejects, agro waste can be burnt efficiently. These can be fed either independently or in combination with coal into the same furnace.

4. Ability to Burn Low Grade Fuel

FBC boilers would give the rated output even with inferior quality fuel. The boilers can fire coals with ash content as high as 62% and having calorific value as low as 2,500 kCal/kg. Even carbon content of only 1% by weight can sustain the fluidised bed combustion.

5. Ability to Burn Fines

Coal containing fines below 6 mm can be burnt efficiently in FBC boiler, which is very difficult to achieve in conventional firing system.

6. Pollution Control

SO_2 formation can be greatly minimised by addition of limestone or dolomite for high sulphur coals. 3% limestone is required for every 1% sulphur in the coal feed. Low combustion temperature eliminates NO_x formation.

7. Low Corrosion and Erosion

The corrosion and erosion effects are less due to lower combustion temperature, softness of ash and low particle velocity (of the order of 1 m/sec).

8. Easier Ash Removal – No Clinker Formation

Since the temperature of the furnace is in the range of 750 – 900 °C in FBC boilers, even coal of low ash fusion temperature can be burnt without clinker formation. Ash removal is easier as the ash flows like liquid from the combustion chamber. Hence less manpower is required for ash handling.

9. Less Excess Air – Higher CO_2 in Flue Gas

The CO_2 in the flue gases will be of the order of 14 – 15% at full load. Hence, the FBC - boiler can operate at low excess air - only 20 - 25%.

10. Simple Operation, Quick Start-Up

High turbulence of the bed facilitates quick start up and shut down. Full automation of start up and operation using reliable equipment is possible.

11. Fast Response to Load Fluctuations

Inherent high thermal storage characteristics can easily absorb fluctuation in fuel feed rates. Response to changing load is comparable to that of oil fired boilers.

12. No Slagging in the Furnace–No Soot Blowing

In FBC boilers, volatilisation of alkali components in ash does not take place and the ash is non sticky. This means that there is no slagging or soot blowing.

13 Provisions of Automatic Coal and Ash Handling System

Automatic systems for coal and ash handling can be incorporated, making the plant easy to operate comparable to oil or gas fired installation.

14 Provision of Automatic Ignition System

Control systems using micro-processors and automatic ignition equipment give excellent control with minimum manual supervision.

15 High Reliability

The absence of moving parts in the combustion zone results in a high degree of reliability and low maintenance costs.

16 Reduced Maintenance

Routine overhauls are infrequent and high efficiency is maintained for long periods.

17 Quick Responses to Changing Demand

A fluidised bed combustor can respond to changing heat demands more easily than stoker fired systems. This makes it very suitable for applications such as thermal fluid heaters, which require rapid responses.

18 High Efficiency of Power Generation

By operating the fluidised bed at elevated pressure, it can be used to generate hot pressurized gases to power a gas turbine. This can be combined with a conventional steam turbine to improve the efficiency of electricity generation and give a potential fuel savings of at least 4%.

QUESTIONS	
1.	Explain the principle of operation of a FBC Boiler.
2.	The combustion temperatures in FBC Boiler is (a) 900°C (b) 1000°C (c) 550°C (d) 1400°C
3.	Explain how FBC Boiler operates the low combustion temperature
4.	In a AFBC Boiler the size of coal used is (a) 1–10 mm (b) 10–100 mm (c) less than 1 mm (d) 10–20 inches
5.	What is the function of an air distributor in a FBC Boiler?
6.	What are the various types of bed materials used in a FBC Boiler?
7.	In FBC Boilers, of the total ash bottom ash constituted (a) 30–40% (b) 80–90% (c) 50–55% (d) 100%
8.	How is the fly ash removed in the FBC Boiler?
9.	Explain the difference between CFBC and AFBC
10.	What are the advantages and benefits of CFBC Boilers?
11.	In a CFBC Boiler the capture and recycling of bed materials is accomplished by (a) settling chamber (b) cyclone (c) back filter (d) Scrubber
12.	The low combustion temperatures in FBC Boilers results in minimal formation of (a) SO_X (b) NO_X (c) CO_2 (d) CO
13.	The function of lime stone used as bed material is to remove (a) ash (b) carbon (c) unburnts (d) sulphur
14.	Explain the operating principle of PFBC Boiler.
15.	What are the aspects to be considered in retrofitting FBC to existing boilers?
16.	The efficiency of a typical boiler would be (a) 33% (b) 45% (c) 54% (d) 84%
17.	Enumerate the advantages of FBC Boilers.

REFERENCES

1. Energy Technology Handbook by *Douglas M.Considine*, McGraw Hill Inc, New York, 1977.
2. Pressurised FBC Technology by *W.F.Podolski*, Noyes Data Corporation, U.S, 1983.
3. Fluidised Bed Coal-Fired Boilers – Department of Coal Publications, Government of India Fluidised Combustion of Coal – A National Coal Board Report, London