Fluidized Bed Combustion

Learning Outcome

*When you complete this module you will be able to:*

Discuss the basic theory and design of a fluidized bed steam generator and describe the special operational and control aspects of fluidized bed combustion.

Learning Objectives

*Here is what you will be able to do when you complete each objective:*

1. Define "fluidized bed combustion". State its benefits and sketch a simple fluidized bed arrangement.

2. Explain the operation of atmospheric fluidized bed combustion.

3. Explain the operation and advantages of pressurized fluidized bed combustion and sketch a combined cycle arrangement.

4. State the advantages and disadvantages of fluidized bed combustion.

5. State two start-up strategies and explain bed expansion.

Introduction

This module will serve as a brief introduction to the process known as “fluidized bed combustion” or FBC. This is a relatively new technology in the steam industry, having been very thoroughly researched over the past few decades. Several large systems are now using FBC, and it shows every sign of becoming a conventional technology for a number of furnace and combustion processes in the power and petrochemical industries.
FLUIDIZED BED COMBUSTION

This term covers a range of systems - there is no unique system. In a utility steam generator, it is a method of burning crushed coal in a bed of limestone particles and ash. The combustion air blows up from the bottom, thus keeping the bed in “fluidized” motion. The force of the air velocity on the particles must be sufficient enough to counteract gravitational forces, but not so great as to transport the entire bed of particles along with the air stream.

The bed materials are kept suspended - fluidized - by the same air that is used for combustion, so the intimate mixing of the burning coal and heated limestone ensures that combinations of sulphur, lime, and oxygen become relatively inert compounds such as calcium sulphate.

Fig. 1 shows a typical FBC unit. The coal and limestone are fed to the furnace and suspended in an updraft of fluidizing air from the FD fan. Notice that watertubes are submerged in the limestone-coal bed. The flue gases exiting the furnace are passed through the dust collector (cyclone) and any carryover of limestone particles is returned to the bed.

---

**Figure 1**

*Fluidized Bed Furnace*
**Benefits of FBC**

FBC has the potential for significantly increasing power generation efficiency, while at the same time meeting the stringent sulphur oxide (SO\(_2\)) and nitrogen oxide (NO\(_x\)) emission regulations that apply in an increasing number of countries.

In the past, coal had always meant pollution. The sulphur and nitrogen emissions of coal-burning power and heating plants, such as SO\(_2\) and NO\(_2\), dissolved in the water vapour of the atmosphere and came back down as toxic particles and corrosive acid rain.

Conventional coal-fired power stations with NO\(_x\) reduction, dust separation, and desulphurization equipment are complex and expensive. One study estimated that this cost would increase to 47% of the total capital outlay. The vast majority of power stations in the world are equipped with electrostatic precipitators or fabric filters for effective removal of fine dust.

Flue gas desulphurization (FGD) plants deal with sulphur products in the flue gas, but they are also expensive to build, troublesome to operate and maintain, and can entail problems with disposal of wastewater and sludge products.

**History of FBC**

Fluidized bed combustion technology has evolved from the fluidized bed process used for years in classifying, chemical reactor, and drying applications. Some of the patents date from the mid-1920s. Nonexistent or less stringent environmental constraints, coupled with low gas/oil prices, ruled out any substantial market for FBC boilers until the 1970s. Broad interest in North America was ignited by the OPEC oil embargo of 1973.

Some articles of 1982 vintage refer to some 2000 FBC boilers operating in China. Oil refineries have used circulating fluidized bed reactors in their fluid catalytic cracker (FCC) processes for more than 40 years.

**Types of FBC**

The two main types are atmospheric fluidized bed combustion (AFBC) and pressurized fluidized bed combustion (PFBC).

1. **Atmospheric Fluidized Bed Combustion**

The AFBC technology has attained commercial application with large industrial units that produce up to 500,000 kg/h of steam. It is expected that soon the increase in unit size will make available capacities of 1,000,000 kg/h.
Within the AFBC types are two major subgroups known as bubbling bed and circulating bed; each of these in turn having various classes.

With the AFBC, the combustion air pressure is typically 25 cm of H₂O pressure at the FD fan, 16 cm at the base of the active bed, with atmospheric pressure at the top of the combustion mass. In this design, the “bubbling” mass is maintained at an approximate depth of 1 metre so particles carried over - especially when fuel is added above the bed - are captured with cyclone separators and then reinjected into the bed to further improve combustion efficiency and sulphur reduction. In FBC, the fuel content by mass of the turbulent inert material is usually less than two percent.

Velocities through the bed of the fluidizing air are in the range of 2-3 m/s. This makes for more even temperature distribution, thus enhancing high thermal efficiency. The heating surfaces - water pipes to produce steam - can be submerged directly into the swirling mass to optimize heat transfer.

One boiler was originally a spreader stoker watertube that was converted to an FBC design. The steam generating system remained as original, but with additional steam generating tubes immersed in the bed - these immersed tubes now produce about 60% of the total boiler output, with the remaining 40% being produced by the original convection superheater and economizer sections.

The combustion can be controlled at a furnace temperature of 850°C instead of 1600°C, because this heat transfer coefficient is so high. Since nitrogen oxides are produced at high furnace temperatures, this factor virtually eliminates them from the stack gases, thus reducing a major source of acid rain.

A further advantage is that the crushed or pulverized limestone is easily mixed with the crushed coal to act as a desulphuring agent. At 850°C, the limestone is converted to calcium oxide and combines with the sulphur dioxide that is released from coal to form calcium sulphate (gypsum). This gypsum becomes part of the residual ash and can be utilized as an aggregate for building materials, so that even the furnace waste can be put to good use.

In theory, the SO₂ emissions could be nearly totally eliminated by this process, but in fact this depends on how much limestone is added, the depth of the bed, time in the limestone flux, and so on. For practical purposes, about 10% limestone reduces SO₂ emissions by 80%. For a coal containing 5% sulphur, close to 1/2 tonne of limestone would be fed for each tonne of coal, which is still cheaper than building and operating a Flue Gas Desulphurization system.

The results of one specific test indicate that by adding three times the theoretical quantity of lime required for the reactions, it is possible to reduce emissions of sulphur oxides by 80 - 90%.
2. Pressurized Fluidized Bed Combustion

The efficiency of a combined cycle plant based on PFBC is potentially about 5% higher than a conventional pulverized coal plant.

One type of combined gas/steam cycle uses a supercharged boiler where about 1/3 of the electrical power is provided by the gas turbine and 2/3 by the steam turbine(s).

Fig. 2 shows a pressurized FBC of this type, which has the advantages of FBC and combined steam-gas turbine cycle operations. The coal and limestone (dolomite) are treated and fed to the furnace. The combustion (pressurizing) air is delivered by the gas turbine compressors. The hot, pressurized combustion gases, after transferring most of their heat to the boiler, are then passed through cyclones and a granulator bed filter, to drive the gas turbine and its generator. The steam produced in the boiler goes to the steam turbines and condenser in a conventional power plant cycle.

Figure 2
Supercharged Boiler Combined Cycle

The potential advantages of this type of combined cycle include:

1. Larger total electrical power output compared to a gas turbine alone.
2. Increase in overall efficiency of power generation.
Improved fluidization quality for a PFBC boiler occurs because the higher pressure brings about a reduction in bubble size that is especially important for beds composed of fine particles. With this design the hot gases must be expanded through a turbine, so the boiler can’t be evaluated by itself. Performance measurement includes the gas turbine operation.

Another approach for a PFBC design uses compressed air as the cooling medium for the combustion chamber, which is then mixed with the pressurized products of combustion (after they have been cleaned). The mix then expands through the turbine, and any leftover heat energy passes to a waste heat boiler. In this cycle, about 60% of the power is from the gas turbine and the remainder from the steam turbine.

Compared with the FBC systems that operate at atmospheric pressure, the PFBC furnace has drawbacks that must be weighed against its advantages when choosing between the two for a specific application:

1. Complexity.
2. Erosion and/or corrosion/fouling of gas turbine blades.
3. Low furnace temperatures limit the steam temperature over the period of heat supply.
4. Feeding of fuel and bed materials into the pressurized system.

Advantages of Fluidized Bed Combustion

1. Flexibility of Fuels

A wide range of fuels can be burned using just about anything that has sufficient heating value to sustain steady combustion. Faces are extremely tolerant of variations in fuel characteristics, so low grade fuels with high moisture, high ash content of up to 70% (which will not burn successfully in any existing furnace), wood, heavy oil tarsands, coal mine tailings, waste gas refuse, shredded scrap tires, can all be used.

2. Less Maintenance

Slag is eliminated. Due to the lower operating temperature in the furnace, large “clinkers” are not produced, and the dry combustion residue is easier to dispose of than the wet sludge produced by normal furnaces. Also, soot-blowers are not required, thus eliminating the soot blowing equipment along with its associated maintenance and power requirements.
3. **Smaller Plant Size**

The plant is smaller due to the high heat transfer rate in the furnace and the absence of wet exhaust gas scrubbing equipment. This means the steam generator can be reduced by up to 25% in overall size, a significant savings in material and construction costs.

4. **Fuel Preparation**

The system, as compared to pulverized coal firing, is simplified because there is no need for coal pulverizers.

5. **Fuel Feed**

Coal may be added by a spreader stoker which throws the fuel over the bed in a predetermined pattern, using either overbed nozzles or feedthrough tubes located in the furnace bottom.

6. **Pressurized Combustion Chamber**

A pressurized combustion chamber makes cost savings possible because of more compact equipment and the opportunity to use a variety of more efficient fuel-to-electricity processes.

**Disadvantages of Fluidized Bed Combustion**

1. **High Power Requirements for Combustion Air**

For a given boiler output, an FD fan on an FBC unit might require 225 kW versus 75 kW for a stoker fired system.

2. **Carryover**

Gradual loss of the fluidized bed, including the fuel (carbon) particles, resulting in lower efficiency and higher cost dust collectors.

3. **Poor Combustion Control at Low Operating Rates**

This cannot be avoided without adding expensive control equipment.
Operation

Before coal can be burned in an FBC, it is necessary to heat the inert bed material to about 600°C (the ignition point of coal) using an auxiliary heating system. Two common methods are (1) combustion of auxiliary fuel as a flame above the bed fluidized with air; (2) passing hot gas through the bed.

A typical time to heat the bed to fuel-ignition temperature is one hour.

One AFBC plant operating at a steam pressure of 17,000 kPa and 540°C has a windbox divided into nine independently controlled compartments to allow separate fluidization of the bed for startup and for load reduction with either underbed or overbed firing.

Generally, due to the specialized fuel handling system, furnace heat transfer rates, ash removal, and flue gas treating equipment of an FBC unit compared to a conventional steam generator, its control systems are quite different. For example, the operator must be aware of bed expansion. This is one of the variables that can be successfully manipulated. The expanded bed height is normally at such a level that any boiler furnace tubes are covered to get maximum heat exchange. During operation, the working bed height can be adjusted through changes in limestone feed rate and bed drain rate.

CONCLUSION

Simple FBC has been available for decades, but rising prices for premium fuel generated interest in low grade fuels such as high ash/sulphur coal, sawdust, garbage, and other industrial wastes; the ability of FBC to handle this wide variety of fuels will ensure its increased use in the future. Full sized commercial and electric utility plants are now being built based on pilot plant research.

Although it is a relatively new technology in the generation of large quantities of energy, FBC - with its many variations - seems firmly entrenched, and probably is the most important advance in furnace design since the development of combined cycle, gas turbine-boiler systems.