

## FOSSIL FUEL COMBUSTION SYSTEMS

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## Summary

Solid fuels such as coal may be burned in different ways. The most common method in large steam-generating units is to grind it to a fine powder and inject it into the furnace with a stream of air. For certain coals, particularly those with a low ash-melting temperature, combustion in a cyclone furnace is more appropriate. Here the coal is crushed and injected into swirling air in a cyclone. The liquefied ash collects on the walls of the cyclone and is drained away. For small steam-generating units, stokers provide a slower, more stable combustion process. Lumps of coal are spread on a grate and burn in a flow of air passing through the grate.

Burners for coal, oil, or gas are similar in that fuel is injected into the furnace through the center of the burner while air for combustion is supplied through an annulus. The fuel ignites in a fuel-rich center zone and combustion is completed in an outer zone where the remaining air is mixed in. To minimize the production of nitrogen oxides, staged air admission is arranged by having an additional air annulus. This reduces the concentration of oxygen at temperatures at which nitrogen oxides are formed.

Fluidized beds are an alternative to traditional combustion. Here a bed of crushed coal and inert particles is maintained in a suspended or fluidized state by a stream of combustion air. Once ignited, combustion is slow and occurs at lower temperatures. This reduces the formation of nitrogen oxides. The formation of sulfur dioxide can also be reduced by the addition of limestone to the bed.

Coal gasification offers promise in that relatively pure gaseous fuel can be produced, thereby greatly reducing emissions that would otherwise occur if the coal were burned in the normal manner.

Although the manner in which fuel is burned has a marked impact on the combustion products, particularly pollutants, a somewhat broader view is necessary in that the procurement of the fuel and the disposal of its waste also have an impact on the environment. There also needs to be an economic balance between the use of clean-burning fuels with little need for gas cleanup and use of potentially polluting fuels with sophisticated boiler back-end facilities. This is particularly important when clean-burning fuels are required for and suited to small-scale or specialized use.

## 1. Pulverized Coal Burners

### 1.1. Pulverized Coal Supply

Pulverized coal from the coal pulverizers is conveyed in a stream of hot primary air from the mills to the burners where it is injected into the furnace space to be burned. Generally, the air–fuel ratio of the fuel mixture leaving the pulverizers is about 2:1 for vertical spindle mills and somewhat less for tube mills, and is at a temperature of about

65 °C for bituminous coals but may be up to about 95 °C for low volatile coals. The fuel mixture is conveyed in pipes to the burners, with each mill serving several burners. The velocity in these fuel pipes is typically about  $25 \text{ m s}^{-1}$  with a minimum of  $15\text{--}20 \text{ m s}^{-1}$ , depending upon the design, to avoid settlement or segregation of the pulverized coal. Too high a velocity leads to excessive erosion of the fuel pipes, particularly at the bends. Velocity limitations for both the pulverizers and the pipes mean that the primary air flow can only be reduced to about 60% to 80% of the full load value, so that if the coal feed is reduced to about 40% (which is about the lowest load that can be sustained on a single pulverizer) the air–fuel ratio leaving the pulverizer may be in the range of 3:1 to 4:1, which is much higher than the full load value of 2:1. These ratios are of course different for different types of coals but do have an impact on the combustion at the burner.

In order to ensure uniform distribution of the fuel mixture to the burners supplied by any pulverizer, all fuel pipes from any particular pulverizer usually have the same length and same number of bends so as to give the same head loss between the mill and the individual burners. Division of the flow into separate pipes is either at the mill exit or at riffle boxes along the pipe. Riffle boxes divide the flow across the pipe into multiple streams and then combine alternate streams into two separate flows so that any stratification of the initial flow is divided between the two emerging flows.

There is usually one more pulverizer than is required to meet full load conditions on the boiler, so there is at least one set of burners out of operation at any time. Under part-load conditions, more pulverizers and their corresponding burners will be out of operation. The boiler can operate at a load so low that only one mill and one set of burners is in operation, but under these conditions it may not be possible to reduce load on that pulverizer because of changing air–fuel ratios and the risk of unstable combustion. To operate below this point separate oil-fired burners are employed to maintain flame stability. Oil burners have to be used on start-up, particularly when the boiler is cold, to create suitable ignition conditions for the stable combustion of pulverized coal.

## **1.2. Burner Arrangement**

Burners may be arranged in the furnace in different ways that give different flame characteristics. There are three distinct methods: “downshot” where the fuel mixture is injected downwards, “horizontal” where the fuel mixture is injected horizontally, and “tangential” where the fuel mixture is injected tangentially towards a single combustion zone.

### **1.2.1. Downshot Firing**

In downshot-fired furnaces, the pulverized coal is injected downwards into a refractory lined lower furnace space where it ignites and burns out while rising into the water wall lined upper furnace space. This arrangement (as shown in Figure 1) provides for a long flame path for fuels that do not ignite easily or burn rapidly. It is suitable for the firing of low volatile coals such as anthracite. The hot refractory lining promotes ignition and the relatively larger carbon char particles produced from low volatile coals have a

longer residence time in the furnace zone to complete their combustion. Over the years, as furnaces have become larger, other systems of firing have been able to provide longer flame paths, and this method is no longer so common.

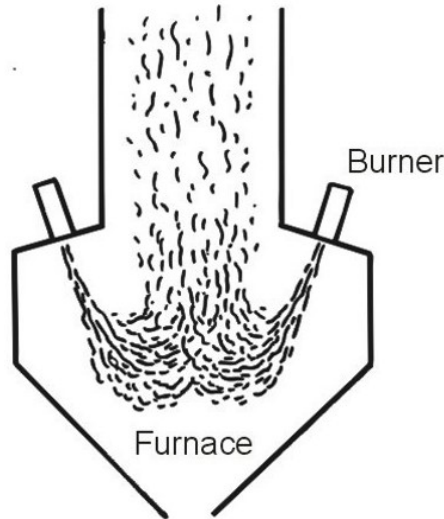


Figure 1. Downshot pulverized coal firing

### 1.2.2. Horizontal Firing

With horizontal firing, the burners are arranged in a pattern on the front or back or both front and back walls of the furnace (as shown in Figure 2). The pulverized fuel is injected horizontally into the furnace with a high degree of turbulent swirl to promote rapid combustion. Like downshot firing, each burner produces an individual and independent flame zone. This means that the correct amount of secondary air must be supplied to each burner to ensure proper combustion in each flame zone.

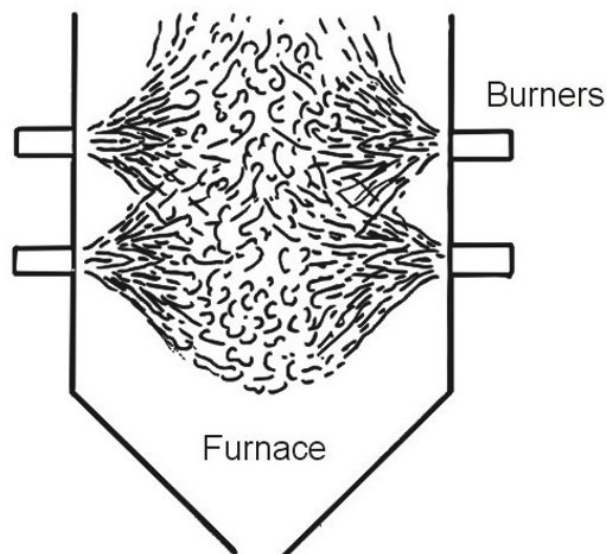


Figure 2. Horizontal pulverized coal firing

### 1.2.3. Tangential Firing

With tangential firing, the burners are arranged vertically in the four corners of the furnace (as shown in Figure 3). The pulverized fuel from each burner is injected horizontally and at a tangent to an imaginary horizontal circle in the center of the furnace space. This creates a cylindrical combustion zone with a strong swirl in the center of the furnace. Unlike horizontal firing, the flow leaving the burners is relatively straight and smooth, with turbulence to promote combustion occurring instead in the center of the furnace in a single large flame zone. This allows for less precise distribution of secondary air to the individual burners as any variations are averaged in the combustion zone.

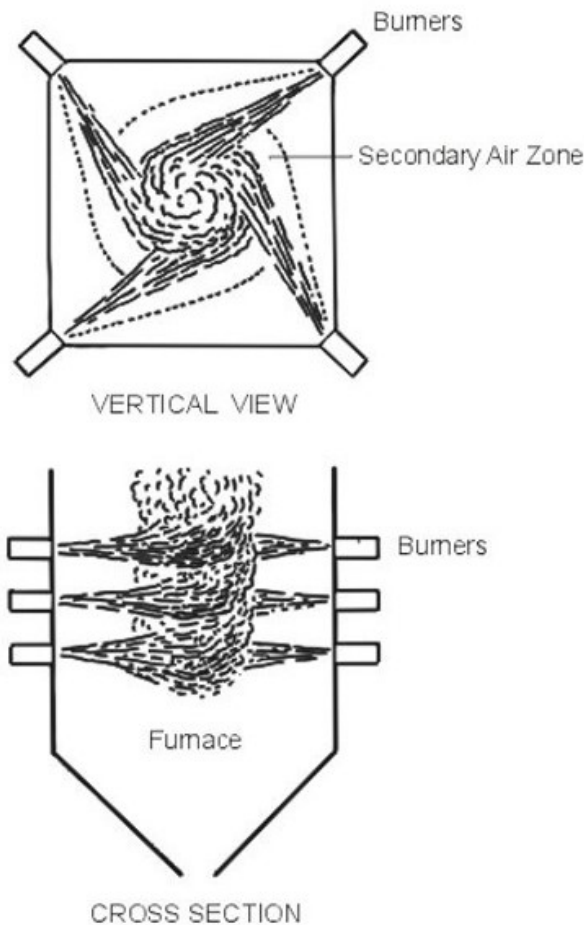


Figure 3. Tangential pulverized coal firing

### 1.3. Burner Types

To accommodate the different requirements of the firing systems discussed above, burners for them have to have different design configurations to ensure proper mixing and turbulence where needed. Furthermore, by controlling the mixing processes the amount of nitrogen oxides formed can be reduced.

### 1.3.1. Wall Burners

Wall burners are used in “horizontal firing” that requires a high degree of turbulence at the burner throat (as seen in Figure 2). To achieve this, the primary air carrying the pulverized coal may enter the burner nozzle tangentially or the burner nozzle may have internal spiral vanes or nozzle exit vanes. These features create increased tangential and axial velocities and generally more turbulence. The burner itself (as illustrated in Figure 4) is situated between the water walls of the furnace and the outer casing of the boiler in a plenum known as the “windbox.” The coal nozzle and any burner adjusting or control devices penetrate the boiler casing on the outside. On the inside, the water wall tubes are bent back and around to form a large enough opening for the burner. Secondary air is supplied to the windbox at temperatures of between 250 °C and 300 °C and completely surrounds the burner. It enters an annulus surrounding the burner nozzle either tangentially through movable controlling vanes near the throat or semi-radially through a sliding damper upstream of the throat. If the latter, then adjustable spin vanes are fitted near the throat. Both designs allow for the control of the amount of secondary air and the creation of a high degree of swirl immediately upstream of the throat. On leaving the throat at a velocity of about 36 m s<sup>-1</sup>, the secondary air completely surrounds the jet of primary air and pulverized coal. With such a high velocity in a partly axial and partly tangential direction, the flow spreads radially and creates a local lower pressure which induces rapid mixing with the primary air and complete burning of the coal following ignition of the volatiles.

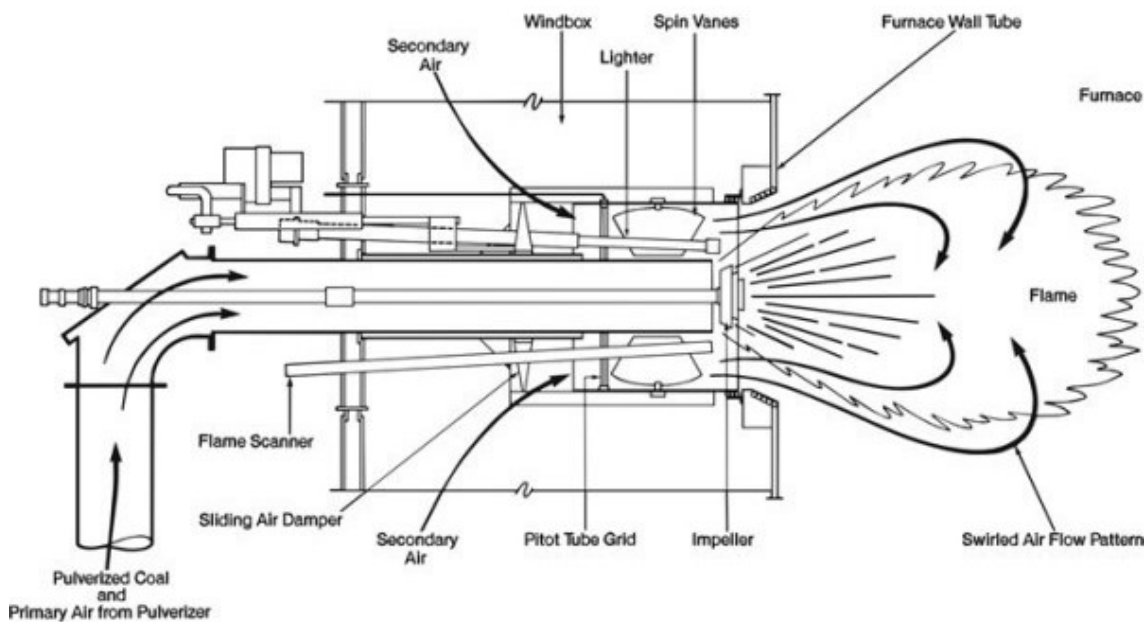


Figure 4. B & W S-type wall burner (courtesy of Babcock and Wilcox)

### 1.3.2. Corner Burners

Corner burners are used in tangential firing, which requires good projection of the fuel towards the center of the furnace (as seen in Figure 3). No turbulence needs to be created within the burner so the burner nozzles are slightly converging, with straight

vanes to direct the flow in the required direction. To accommodate multiple sets of burners, the individual burners are stacked vertically in the corner of the furnace between secondary air nozzles of similar design. The secondary air nozzles are supplied with air via controlling air dampers from windboxes outside the water walls at the corners of the boiler. The simpler nozzle design allows them to be movable and they can be directed slightly upwards or downwards to raise or lower the flame zone in the furnace. Such movement of the flame zone affects the pattern of heat absorption in the boiler. When the burners are tilted downwards, more of the furnace is exposed to hot gases and the water walls absorb more heat. When the burners are tilted upwards, less of the furnace is exposed to hot gases and the furnace exit temperature is increased, resulting in more heat being absorbed in the convective pass. This is useful in compensating for fouling of parts of the furnace walls or convective banks and for controlling superheat and reheat temperatures.

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### Biographical Sketch

**Robin Chaplin** obtained a B.Sc. and M.Sc. in mechanical engineering from the University of Cape Town. Between these two periods of study he spent two years gaining experience in the operation and maintenance of coal fired power plants in South Africa. He subsequently spent a further year gaining experience on research and prototype nuclear reactors in South Africa and the United Kingdom, and obtained an M.Sc. in nuclear engineering from Imperial College, London University. On returning and taking up a position in the head office of Eskom he spent some twelve years there, initially in project management and then as head of steam turbine specialists. During this period he was involved with the construction of the Ruacana Hydro Power Station in Namibia and Koeberg Nuclear Power Station in South Africa, being responsible for the underground mechanical equipment and civil structures and for the mechanical balance-of-plant equipment at the respective plants. Continuing his interests in power plant modeling and simulation, he obtained a Ph.D. in mechanical engineering from Queen's University

in Canada. He was subsequently appointed as Chair in Power Plant Engineering at the University of New Brunswick, where he teaches thermodynamics and fluid mechanics and specialized courses in nuclear and power plant engineering in the Department of Chemical Engineering. An important function is involvement in the plant operator and shift supervisor training programs at Point Lepreau Nuclear Generating Station. This includes the development of material and teaching of courses in both nuclear and non-nuclear aspects of the program.

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