FOSSIL FUEL FIRED BOILER AIR AND GAS PATH

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Contents

Summary

Air is required when burning any fossil fuel. For coal, the ratio by weight of air to fuel is about 12. For a high heat release rate, therefore, a vast amount of air must be supplied and even more exhaust gas removed. Forced draught and induced draught fans drive the flows. These fans, located in the inlet and outlet ducts respectively, operate together to maintain balanced draught conditions in the furnace. This ensures that the furnace operates under a slight vacuum to prevent the egress of combustion products.

Air heaters in the system are arranged so that excess heat in the exhaust gas is transferred to the inlet air thus enhancing the thermal efficiency of the steam-generating unit. In coal-fired plants, some of the heated air is directed to the coal pulverizers, via primary air fans, to pick up the pulverized fuel and carry it into the furnace. Here the fuel-rich primary air is mixed with sufficient secondary air, coming directly from the air heater, to give the proper air–fuel ratio for good combustion.

Boilers must be protected from implosions arising from the sudden loss of ignition in the furnace and from explosions due to subsequent sudden ignition of clouds of suspended fuel particles. Proper operation of the fans can ensure protection during a flameout, and adequate purging of the gas ducts can prevent uncontrolled ignition of unburned fuel.

The furnace walls and convection passes are kept relatively clean and free from heavy ash deposits by frequent sootblowing. Sootblowers utilize a high-pressure jet of steam or air, and sometimes even water, to remove ash deposits from the gas path. This is essential in maintaining the proper balance between the heat absorbed by the furnace walls and in the convective passes.

In order to ensure that the exhaust gas is discharged in as clean a condition and as pollutant free as possible, provision is made to trap fly ash and to remove sulfur dioxide

and nitrogen oxides if necessary. Particulate matter may be removed very efficiently by means of electrostatic precipitators or fabric filters. The removal of sulfur dioxide, if produced, requires scrubbing in a desulphurization unit. Nitrogen oxides may be reduced during the combustion process but catalytic reducers can effect an additional reduction after leaving the furnace.

1. General Principles

1.1. Combustion Requirements

The burning of any hydrocarbon fuel requires oxygen from the atmosphere in sufficient quantity to ensure proper combustion. Since atmospheric air is a mixture of oxygen and nitrogen, a considerable amount of nitrogen must be handled to provide sufficient oxygen. Furthermore, excess air is usually provided to ensure complete combustion of the fuel under imperfect mixing conditions.

The net result is that, in large steam-generating units, vast amounts of combustion air must be provided to the furnace and even greater amounts of exhaust gases removed.

For coal, an air–fuel ratio of 11:1 to 12:1 is required. For oil this is somewhat higher. A typical coal-fired power plant with an electrical output of 500 MW requires about 50 kg s^{-1} of coal and about 550 kg s^{-1} of air to produce about 600 kg s^{-1} of exhaust gas. This, translated into volumetric air and gas volume flow rates at the inlet and outlet, gives about 500 $m^3 s^{-1}$ and 675 $m^3 s^{-1}$ respectively. To handle these flows very large ducts and fans are required and a considerable amount of energy is expended in maintaining these flows.

Air and fuel are supplied to the furnace and hot exhaust gases removed from it. The furnace itself must operate at a pressure very slightly below atmospheric pressure so that exhaust gases do not blow out through various inspection and access openings when they are not closed. However, it should not operate at too low a pressure otherwise excessive cold air will be sucked into the furnace.

In order to achieve this balanced condition, all large steam-generating units have separate fans supplying combustion air to the furnace and removing exhaust gases from it. The air and gas path of a typical coal-fired boiler plant is illustrated in Figure 1. The fans providing the air are “forced draught fans” and those removing the exhaust are “induced draught fans.” The flow through them is controlled by moving the control dampers or by varying the fan speed.

Between the forced draught and induced draft fans there is a progressive decrease in pressure through the system with the pressure in the furnace maintained at the desired slightly sub-atmospheric condition. The stack, which is downstream of the induced draught fan, provides some assistance to the flow because of the buoyancy effect of the hot exhaust gas over its height but this effect is relatively small compared with the driving effect of the fans.

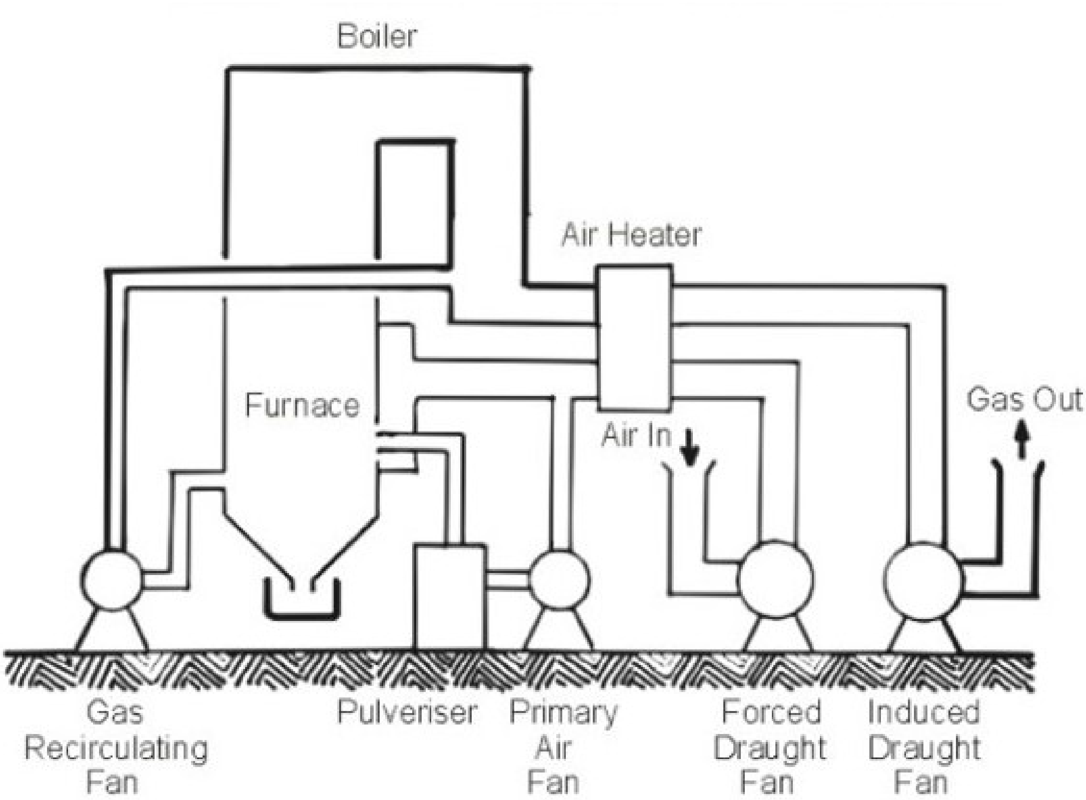

Figure 1. Air and gas path in a coal-fired boiler plant

1.2. Primary and Secondary Air

The combustion air supplied to the furnace is divided into separate primary and secondary air streams. This arrangement promotes rapid ignition of the fuel in a rich fuel–air primary stream and complete combustion in a plentiful supply of secondary air. Refinements to this arrangement allow for the reduction of flame temperatures and some control of nitrogen oxide emissions. In a coal-fired boiler, the primary air stream also serves to transport the pulverized fuel to the burners. This requires separate ducting and primary air fans to convey the primary air through the pulverizers. In oil and gas-fired boilers the primary air is only separated from the secondary air at the burners.

In coal-fired boilers the required air–coal ratio of the mixture leaving the pulverizers ranges from 1.2:1 to about 2.2:1 and is generally near 2:1 for vertical spindle mills. Thus the amount of primary air is relatively low compared with the amount of secondary air to give the required combustion air–fuel ratio of 11:1 to 12:1. The power requirements of primary air fans are, however, quite high because of the large friction pressure drops arising due to the high air velocities required to separate and transport the pulverized coal.

1.3. Air Ducting Arrangement

The air inlet for the steam-generating unit is nearly always near the top of the boiler where hot air accumulates inside the boiler house. Temperatures here are often 30 °C to 40 °C and higher, thus providing some initial air preheating derived from thermal loss through the boiler walls. The air is drawn in by a pair of forced draught fans that deliver the air to the air heaters for preheating. On leaving the air heaters, the hot air is directed to the air inlet plenum surrounding the burners on the sides or corners of the furnace. In the case of coal-fired boilers, primary air is separated from the secondary air just after the air heaters and directed to the pulverizers. This is tempered, if necessary to avoid too high a temperature in the pulverizer, by mixing with a small amount of cold air taken off the main stream just before the air heaters. There may also be an air bypass around the air heater to reduce the amount of heat absorbed by the air in order to maintain the exhaust gas temperatures. Alternatively, hot air recirculation from the heater outlet back to the forced draught fan inlet may be employed to maintain the exhaust gas temperatures. If the exhaust gas temperatures are too low, condensation may occur in the gas ducting thus leading to corrosion. Air ducting arrangements in a small 100 MW (electrical) coal-fired boiler plant are illustrated in Figure 2.

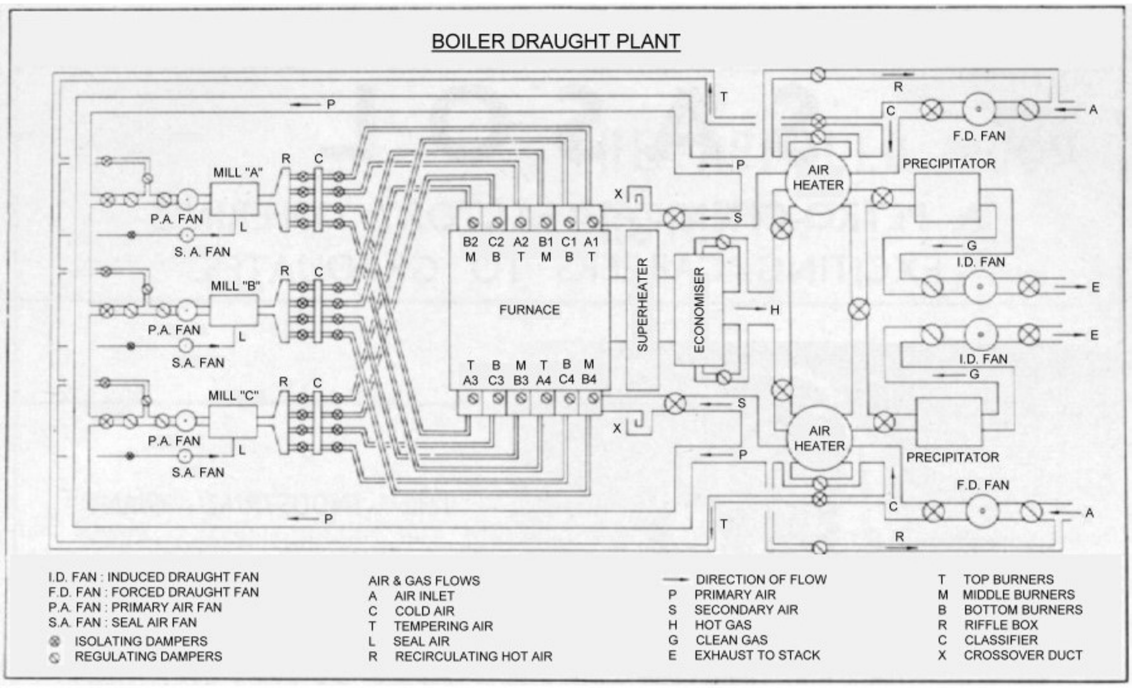

Figure 2. Air ducting arrangements in a coal-fired boiler plant

The hot exhaust gas is directed from the furnace through the convection pass where it passes over the tubes of the secondary superheater, reheaters, and primary superheater (usually, but not necessarily, in that order), and finally over the economizer. The arrangement of the furnace water walls and convection pass components are described in an earlier section. Gas recirculation is employed to balance the heat absorption between the furnace zone and convection pass, and gas tempering is used to balance the heat absorption between various components in the convection pass. Exhaust gas from after the economizer is extracted and recirculated by a gas-recirculating fan to the bottom of the furnace (recirculation) or to the top of the furnace (tempering). Although the temperature of the recirculated gas is quite high, it is still considerably lower than that of the furnace and is thus very effective in modifying the heat transfer characteristics. On leaving the economizer, the hot gas passes through the air heater where it transfers heat to the incoming cold air. The air heater is the last component that removes heat from the exhaust gas, so any heat remaining in the gas at its exit is lost to the atmosphere. For good thermal efficiency the temperature of the exhaust gas at this point should be as low as possible. Too low a temperature, however, can lead to condensation of water vapor and sulfur oxides, which ultimately form dilute sulfuric acid. Such a moist acidic environment leads to rapid corrosion of all steel components, especially the ducting and control dampers. To prevent this, the gas temperature must be maintained above the acid dew point throughout the remainder of the gas path where corrosion would be detrimental. The acid dew point increases with increasing sulfur content of the fuel and generally ranges from 135 °C to 160 °C. The arrangement of the main components of a typical large coal-fired boiler plant is illustrated in Figure 3.

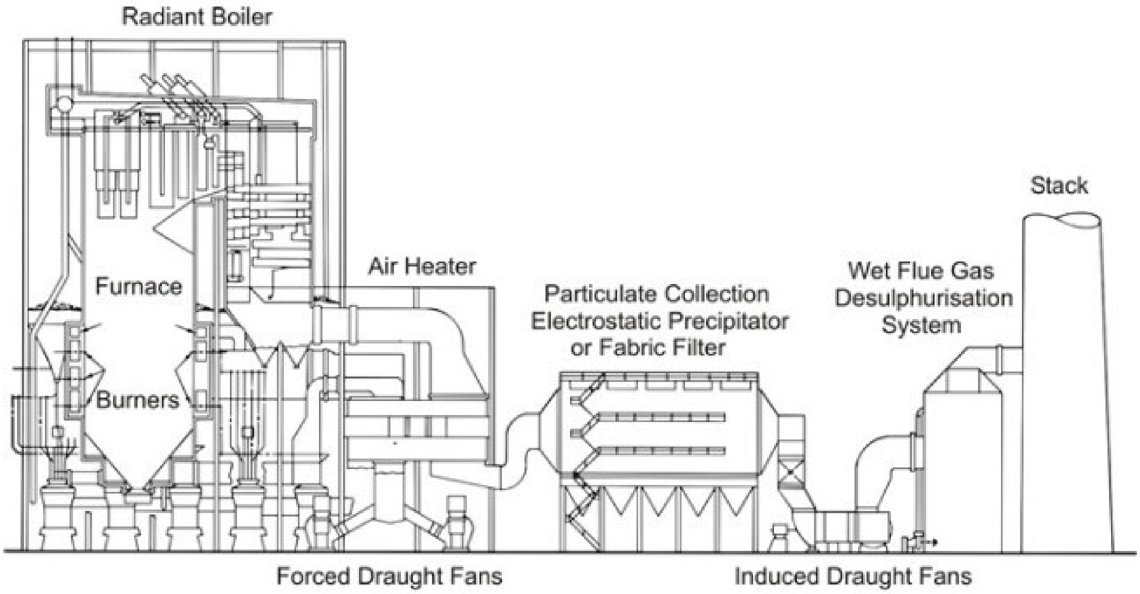

Figure 3. Gas path components in a coal-fired boiler plant (courtesy of Babcock and Wilcox)

On leaving the air heater the exhaust gas passes to the precipitator or baghouse where fly ash is removed. In coal-fired boilers approximately 80% of the ash is carried out as fly ash, so the quantity to be removed in the precipitator or baghouse is quite considerable even with coals of relatively low ash content. Modern precipitators and baghouses have a sufficiently high efficiency of particulate removal to produce a virtually clear exhaust plume.

After the precipitators there is a pair of induced draught fans to draw out the exhaust gas and to ensure balanced draught conditions in the furnace. These are usually the largest and most powerful fans in the plant as they handle the total mass of air and gaseous combustion products.

In the case of a plant burning fuel with high sulfur content, a flue gas desulphurization unit may be fitted to remove a major portion of the oxides of sulfur from the gas before discharge to the atmosphere. One successful method of doing this is by using wet scrubbers where the oxides of sulfur are reacted with a slurry containing limestone and removed from the system. In the process the hot exhaust gas becomes saturated with water and produces a dense plume of harmless condensed water vapor. The stack serves to disperse the exhaust gas at a sufficiently high elevation to avoid environmental impact on the immediate surroundings. Originally, tall stacks were employed to disperse and dilute particulate matter such as fly ash, but the advent of large steam-generating units producing vast amounts of ash made it imperative that flue gases be treated before dispersion.

2. Fan Characteristics

2.1. System Fans

2.1.1. Forced Draught Fans

The forced draught fans usually supply all the combustion air required by the furnace. They are usually of the medium-speed centrifugal type. They must be somewhat over-designed to allow for additional airflow arising from four possible sources. If the air heater has a hot air recirculating system back to the forced draft fan, it must be able to handle the extra flow at that temperature. Some leakage will inevitably occur from the inlet air path to the exhaust gas path through the seals of the air heater and additional air will be required to compensate for this loss. If the ambient air conditions are very humid, an increased capacity will be required to handle the volume of water vapor mixed with the air. Finally, additional capacity will be required to meet excess air requirements under all operating conditions.

2.1.2. Primary Air Fans

The primary air fans provide the air required for transporting pulverized fuel to the burners. Since higher pressures are required they are usually of the high-speed centrifugal type. They must be designed to operate in hot air conditions. When exhauster fans are used at the outlet of the pulverizers, instead of primary air fans at the inlet, they must be designed to operate in a coal–air mixture, which may be quite abrasive.

2.1.3. Induced Draught Fans

The induced draught fans are the largest in the plant since they have to handle the total gaseous products leaving the boiler. They may be of the medium-speed centrifugal type or the axial flow type. The axial flow type with variable pitch blades has a wider operating range with good efficiency making it more favorable for control purposes. It is usually the induced draught fan that provides the balanced draught conditions in the furnace and it must therefore continuously adjust the flow. Like the forced draught fan, the induced draught fan must be somewhat over-designed to allow for increased gas flow. Leakage from the inlet air path to the exhaust gas path through the seals of the air heater will increase the gas flow. Operating conditions with excess air and high ambient humidity will increase the mass flow rate, and any increase in gas temperature will of course increase the volume flow rate. Although the induced draught fans operate in the relatively clean gas downstream of the precipitators they are subject to hot conditions and possibly corrosive gases depending on the type of fuel used.

2.1.4. Gas Recirculating Fans

The gas recirculating fans operate under the most arduous conditions. They have to handle hot gas from upstream of the air heater on an intermittent and varying basis depending upon the boiler heat transfer requirements. This gas is also ash laden and abrasive so an additional dust collector is required if they are operated for a large percentage of the time. They are usually of the medium-speed centrifugal type with simple design to facilitate maintenance. During changes in load, or starting and stopping, they suffer thermal transients so it is desirable to provide them with a turning gear to maintain slow rotation when not in use to prevent thermal distortion.

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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.