FOSSIL FUEL PLANT MATERIALS AND CHEMISTRY

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Contents

Summary

A pulverized-coal-fired boiler of the recirculating drum type is described as typifying commercial fossil plants. Other major types are fired by oil or gas. The predominant material of construction of the circuits is steel. The furnace water walls are carbon steel with low-alloy material in the hotter furnace regions of some plants. Higher alloys are required in the superheater and reheater: Cr-Mo steel at the superheater inlet but stainless steel at the outlet.

At the low temperature exit from the boiler, carbon steel is generally adequate for the economizer and air heater, though if the temperature falls below the acid dew point large corrosion allowances must be provided or protective coatings applied. In the flue gas treatment system, acid condensation may have to be counteracted in the baghouse, where particles are removed.

If there is a flue gas desulphurizer, the corrosion and abrasion caused by alkaline slurries and acid solutions are counteracted with coatings or materials such as stainless steel or nickel alloy. The steam turbine components are high-strength, low-alloy steels to withstand creep, fatigue, erosion, and stress corrosion cracking; titanium may be employed for rotors in the LP section. The condenser has a carbon steel shell but the cooling water source determines the tubing: brass, cupronickel, stainless steel, or titanium.

Chemistry on the combustion gas side is concerned with slagging and corrosion at the top of the furnace and ash fouling beyond. Oil-fired units may add a neutralizer such as

magnesia to counteract superheater and reheater corrosion by vanadium-based melts. Adjusting furnace air feed minimizes emissions of nitrogen oxides. Boiler water chemistry maintains de-oxygenated and alkaline conditions, using caustic control for small units, phosphates for large units, and volatile amines for high-performance plants. To ensure good quality feedwater and to guard against condenser leaks, ion-exchange condensate polishers may be installed.

1. Introduction: A Typical Plant

Various types of fossil-fuelled boiler and their operation are described in detail in preceding articles in this theme. As illustrative of a typical system and its materials, a coal-fired boiler (as shown in Figure 1.) is described briefly here.

The fire/combustion side of the boiler (as opposed to the steam/water side) essentially comprises two sequential parts, namely, “the furnace” and “the convection pass.” The furnace is the large, vertical enclosed space designed to combust the fuel. In the design of Figure 1, dried and pulverized coal is mixed with hot primary air supplied by the forced draft fan and the primary air fan via the air heater.

The hot air temperature is controlled partly by the addition of cool tempering air taken directly from the supply of the forced draft fan. The fuel mixture is conveyed pneumatically to the windbox where it is mixed with hot secondary air and injected into the furnace through the burners at a temperature up to 315 °C. The mixture burns rapidly and the hot flue gases transfer heat to the furnace walls primarily by radiation as they flow upwards towards the furnace exit and the convection pass and cool from about 2000 °C to about 1000 °C.

The gases then progressively lose heat by convection as they traverse the secondary superheater, reheat superheater, primary superheater, and economizer before leaving the steam generator enclosure and then the entire unit via the air heater at about 200 °C. Any pollution control measure is added as the final step before exhaustion to the atmosphere via the induced draft fan and the stack.

On the steam/water side of the boiler, feedwater, heated from 250 °C to 260 °C in the feedwater heaters on its return from the condenser, passes through the economizer. It is fed into the steam drum at or just below saturation temperature (about 365 °C) where it is directed towards the downcomers and furnace waterwalls. The steam drum separates the two-phase, steam/water mixture that is produced in the vertical tubes forming the furnace walls. Steam is led off and passes to the primary superheater, while the separated water descends through the downcomer system to headers at the bottom of the furnace, from where it boils as it recirculates back to the drum via the waterwalls.

In the scheme shown in Figure 1, the saturated steam from the drum undergoes two stages of superheat before being directed to the high-pressure turbine. In the primary superheater its temperature is raised to about 480 °C before the final superheat to about 540 °C in the secondary superheater. To avoid excessive temperatures in the final stage relatively cool attemperating water at about 150 °C can be sprayed into the steam flow directly after its exit from the primary superheater.

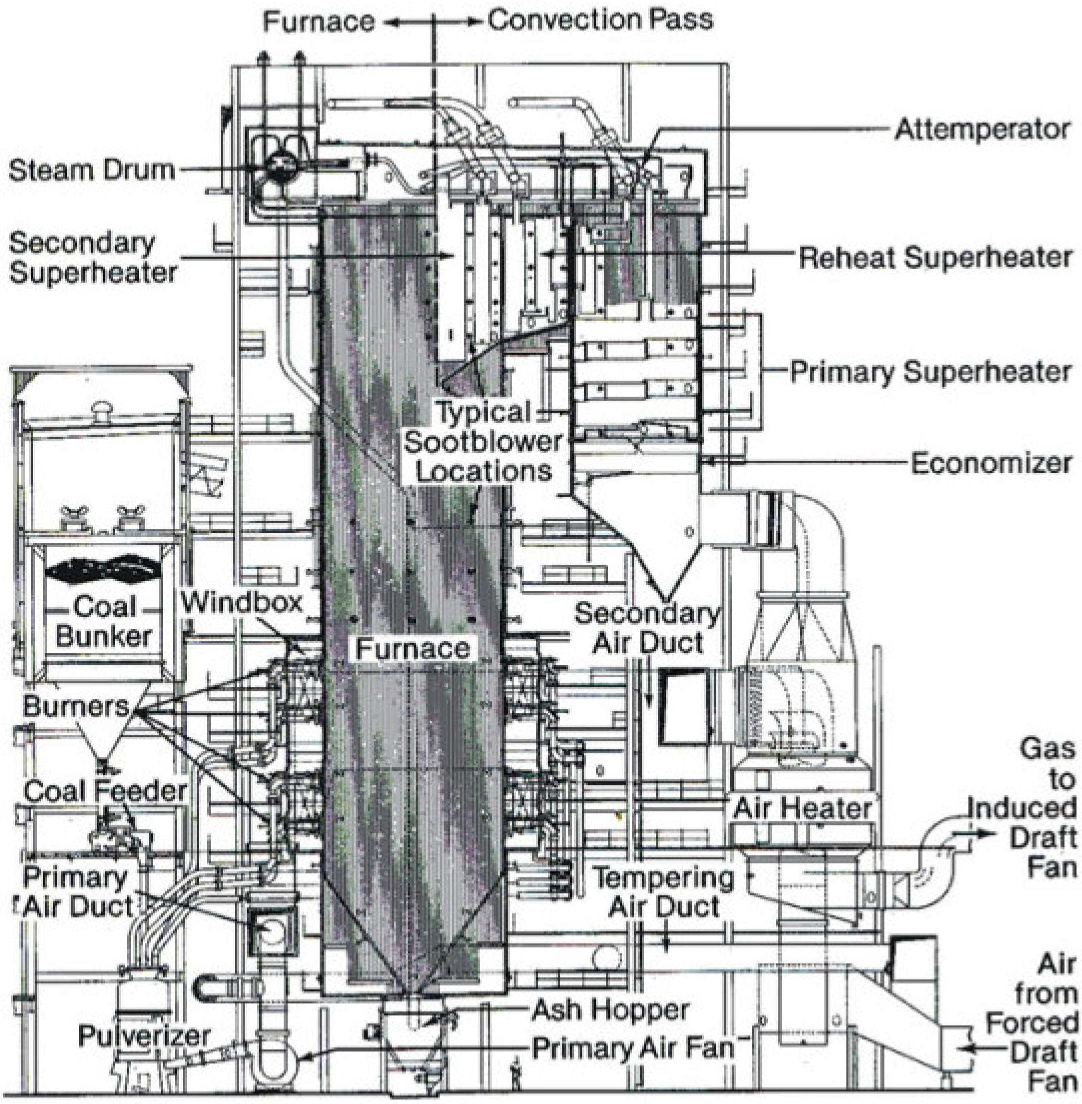

Figure 1. Coal-fired boiler (courtesy of Babcock and Wilcox)

The reheat superheater is a separate heat exchanger positioned in the convective pass between the primary and secondary superheaters. Its function is to increase the efficiency of the cycle by reheating steam leaving the high-pressure turbine and thereby increasing the temperature of the intermediate-stage turbine. It should be noted that although the reheated steam may be at about the same temperature as the steam to the high-pressure turbine, its pressure is considerably lower.

While a common final condition of steam in modern fossil units is superheated to about 540 °C at a subcritical pressure of about 16 MPa, there are boilers that provide steam at a supercritical pressure of about 24 MPa and about the same temperature. Since this condition is attained without a change of phase of the water, the system is once through, with no drum and no recirculation through the waterwalls. The design and material selection of the heat transfer surfaces must then take account of the high pressure (greater than the critical pressure of water at 22 MPa). There are also fossil boilers designed to operate at even higher temperatures: up to 650 °C and pressures in the region of 26 MPa.

A schematic diagram of typical gas and water/steam circuits of a subcritical coal-fired boiler is presented in Figure 2. The treatment of flue gas to remove particulates (fly ash) and sulfur dioxide is shown, although the reheater and details such as the lines to feed the feedwater heaters with steam bled from the high-pressure and low-pressure turbines are omitted.

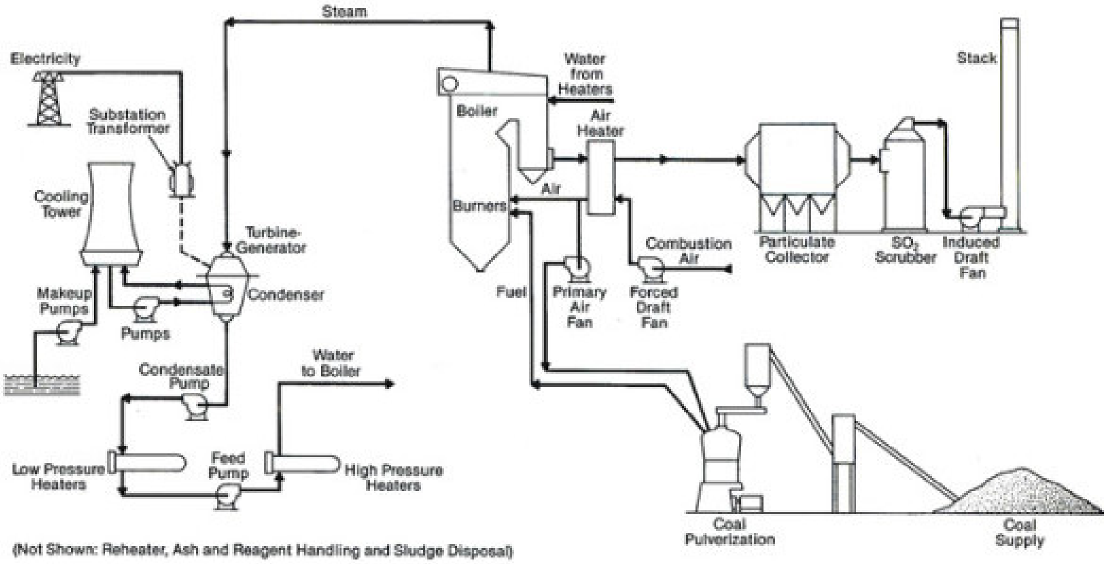

Figure 2. Schematic layout of a coal-fired boiler system (courtesy of Babcock and Wilcox)

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British Electricity International, London. (1992). *Modern Power Station Practice: Incorporating Modern Power System Practice. Volume E–Chemistry and Metallurgy,* 3rd edition, 576pp. Oxford, Pergamon. [This edition comprises 12 volumes dealing with all aspects of the electricity generation and transmission capability of the (former) UK Central Electricity Generating Board. The volumes cover subjects ranging from station planning and design to operation of the distribution system. *Volume E-Chemistry and Metallurgy* treats practices in fossil-fired boilers, from the points of view of system monitoring and operation to inspection and cleaning. The metallurgy of the important metals (including non-ferrous metals and alloys) is outlined and the characteristics and uses of non-metals (including ceramics and polymers) are presented. Techniques of chemistry control, environmental monitoring, analytical methods, and so on, are described in detail. The treatment of the subject matter is extensive and thorough and provides an excellent reference text. It should be of value to anyone with a technical background.]

Biographical Sketch

Derek Lister, B.Sc. Tech., M.Sc. Tech., Ph.D., M.I.Chem.E., C.Eng., F.C.I.C., was born in Nelson, Lancashire, England in 1939. He was educated at the local secondary technical school, the University of Manchester, and the University of Leicester, obtaining his bachelor’s and master’s degrees in chemical engineering and his Ph.D. in physical chemistry. He spent three years with the Atomic Power Division of English Electric Co., developing Magnox and AGR nuclear fuel, and four years as a Research Fellow at Leicester University, studying crystal growth and electron spin resonance, before joining Atomic Energy of Canada Ltd. at the Chalk River Nuclear Laboratories in 1969.

After a short period in CANDU nuclear fuel development he became involved in research into reactor chemistry. This was concerned mainly with chemistry control and corrosion in CANDU reactors, though contract research was done for the US nuclear industry as well. He became Senior Scientist and, in 1992, when Manager of the System Chemistry and Corrosion Branch, he was awarded the NB Power/AECL/NSERC Industrial Research Chair in Nuclear Engineering at the University of New Brunswick and moved to Fredericton.

At UNB, he contributes to the option in Nuclear and Power Plant Engineering in the Chemical Engineering Department and to other undergraduate courses. He has designed and constructed a research laboratory containing high-pressure, high-temperature equipment for studying reactor and power plant chemistry and corrosion and carries out research for the Canadian and overseas nuclear industries. He has published extensively in the fields of reactor chemistry and corrosion and heat exchanger fouling. He is now Chair of the Chemical Engineering Department as well as holder of the research chair and holds technical advisory positions on several national and international bodies. He enjoys skiing, tennis, drawing and painting, and French and English literature.