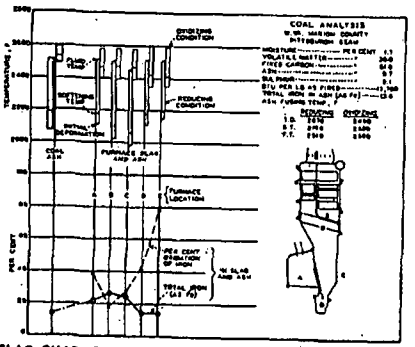

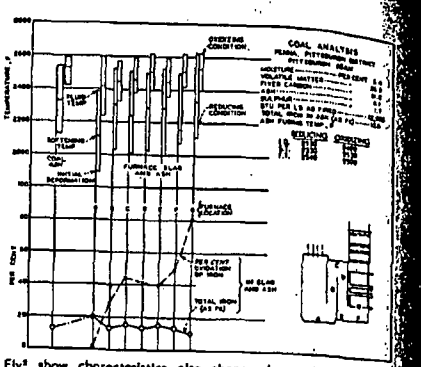

SLAG CHARACTERISTICS *differ with fuels and firing methods. Above charts as developed from studies by Bailey and Ely*[5] *show characteristics also change from place to place within boiler and differ again with changes in boiler design*

the fuel bed. Anywhere from 10 to 50% *is water soluble as contrasted to the almost insoluble fused deposits.*

Phosphatic deposits, the last of the group of high-temperature formations, result from the action of flyash on phosphorous compounds volatilized from burning fuels.

Preliminary stage of most bonded and phosphatic *deposits is usually a* white or light-colored scale that settles on tube surfaces. It is richer in alkali *salts than the later, outer layers and* has a lower melting point.

Cause of Bonding. Potassium and *sodium salts* act as binding agents in bonded deposits. They appear in British coals as (1) relatively nonvolatile silicates (2) easily volatilized chlorides. For this reason the Boiler Availability Committee, under whose direction these studies were made, decided to establish a relationship between chlorine content of coals *burned and severity of* trouble from bonded deposits.

Large-scale trials with a test boiler *firing coal of 0.04%* chlorine showed an accelerated deposit rate of the *bonded* type when chlorine content was increased to 0.25% by adding sodium chloride. When 86 British power stations were investigated they showed a further, interesting condition. Pulverized-coal fired boilers were relatively free from *this trouble.* A *possible* explanation is that the greater amount of flyash with pulverized coal is too much to be bonded by the limited amount of alkali salts in the available time.

Deposit Material. So much for the presence of potassium and sodium in binding agents. What about sulphates?

Most deposits on boiler and superheater tubes have a white, inner layer next to the metal. The character of this layer is important for it decides (1) how firmly deposit attaches to metal (2) how quickly it grows with *addition of flyash.*

Tests were run to determine influences on the character of this inner layer. A sample of a typical bonded deposit was powdered and introduced to the aerated flame of coal gas and its combustion products. A white alkali of sulphates formed on the metal. Wiping removed it.

Just adding sulphur dioxide to the coal gas changed the picture entirely. The white *deposit fused and stuck more* closely to the metal, probably because of alkali bisulphates.

The same experiment repeated in a nonaerated flame gave a white deposit. Presence of sulphur dioxide in the flame did not change the character of the deposit. Apparently the acid sulphates had not formed.

A further investigation indicated that *sodium* and potassium compounds are the *offending salts. Chlorides,* carbonates and sulphates of these elements gave the same results as the powdered *deposit* employed in the experiments. Oxides and sulphates of calcium, magnesium, iron and aluminum produced desposits that did not adhere strongly to the metal.

Effect of Temperature. The steel surface, which served for the deposit collection spot in the above experiments, was held at 400-500 C. At 550-600 C the adhesion of deposits containing alkali salts increased. They sintered and *developed a sticky outer surface.* Such conditions favor deposit growth by addition of flyash.

How do sulphates reach the metal surfaces? Most of the sulphur in flue gas is present as sulphur dioxide, but sulphur trioxide, free or combined with water as sulphuric acid, is the most important of the forms of sulphur as far as deposit formation is concerned. It raises dewpoint of gases considerably, *and this facilitates condensation* of acid.

H F Johnstone (Univ of Illinois *Bulletin 228,* 1931) believes that sulphur trioxide forms from the decomposition of sulphates in the fuel bed. The Boiler Availability Committee felt experiments to determine sulphur trioxide formation would prove illuminating and helpful.

The Experiments. Introduction of sulphur dioxide *to the atmosphere* of a flame made up of carbon monoxide and air produced small amounts of sulphur *trioxide.*

A second series of experiments probed catalytic action of ferric oxide on oxidation of sulphur dioxide to sulphur trioxide. The ferric oxide occurs as a film on steel tubing.

By passing flue gas over steel maintained at various temperatures, different amounts of *sulphur trioxide* were observed. At some times rusted steel served as the metal, at others steel *cleaned by sandblasting. When the* steel was heated a film of ferric oxide always formed quickly. Sulphur dioxide underwent conversion to sulphur trioxide, most actively at 600 C. (Economizer studies indicate iron sulphates figure in formation of sulphur trioxide and promote sulphatic deposits.)

Control of Sulphur Trioxide. Deposits increase with the presence of sulphur trioxide in flue gas. Control of deposits can come from (1) reducing sulphur trioxide in the gas (2) overcoming the influence trioxide has on dew-point.

A study of the combustion process revealed little deposit accumulation on metal until all the volatile content of the coal had been liberated. Rate of deposit growth increased considerably as coke burned to ash. Further, the *deposit adhered more strongly.*

Boiler trials with traveling grates showed fuel-bed conditions influence rate of deposit growth. With isolated areas of combustion continuing to the back end of the grate, deposits formed rapidly. A regulated combustion, with the fire ending evenly across the grate width and before the full travel of the grate, gave much less formation.

Further trials revealed that increasing the volatile content of fuel decreased troubles from deposits. For test conditions oil burners supplied liquid-fuel in addition to the normal coal supply of a traveling-grate furnace. Similar trials are reported under way with pulverized coal as auxiliary fuel.

Soot Removers. Next point of control — overcoming influences on dewpoint—resulted in a satisfactory experience with "smokes." These smokes introduced in flue gas lowered the dewpoint—at times to that of gas free from acid. Several substances supplied this "smoke," carbon, silica, magnesia and zinc oxide serving in this way. The lowering effect has been attributed partly to absorption of sulphur trioxide on the very large surface of the dispersed solid.

The next *constituent* of deposits to receive committee study was silica. In British coals this appears as aluminum silicates. Any of this substance carried mechanically from fuel bed to heating surface adds alumina as well as silica to the external deposits on heating surfaces. Some deposits showed no alumina at all. The inference, then, was that somehow silicon volatilizes in the fuel bed.

German engineers follow the theory advanced by R Lessnig[6] that silicon sulphides form in the boiler under the action of carbonaceous matter and iron sulphide on silicate. For this reason they exercise every care in limiting the amount of hydrocarbons in flue gas. They believe these substances act as reducing agents for forming silicon sulphides.

W Lange[4] has pointed out that silicon sulphides burn in air to form silica. Later developments show reduction of sulphides by hydrocarbons occur only on suspended particles containing both iron sulphide and silica. Sulphide in flyash amounts to little. Further, iron sulphide oxidizes in passing through the combustion chamber.

All these facts point up the findings of the Boiler Availability Committee and put the German practice of reducing hydrocarbons at variance with the evidence. The Committee believes increasing the hydrocarbons in flue gas decreases trouble from deposits. This was done in one case, cited above, by adding liquid fuel burners to a boiler that normally burned coal on a traveling grate.

Phosphatic Deposits. This class of deposit *forms* when phosphorous compounds volatilize. A special gas-fired furnace held at 1200 to 1700 C. served as the test medium for volatilization of phosphate. Reducing conditions accompanied by high temperatures produced this volatilization effect.

Phosphatic deposits have been found only in stoker-fired boilers employing coals of over 0.03% phosphorous. Pulverized-coal units carry out combustion under oxidizing furnace conditions so no phosphatic deposits occur. Traveling-grate stokers do volatilize phosphates but at a very slow rate.

Retort stokers develop reducing conditions, and phosphatic deposits seem prone to develop in this atmosphere. Waterwall cooling of the furnace however, may reduce furnace temperatures enough to make volatilization slow.

Suitable methods of cleaning represent the most important factor in operating boilers to peak availability. This rule of suitable cleaning applies to boilers both in and out of service. Deposits form slowly at first but once there, the rate of additional deposit growth increases rapidly.

Soot blowing and water lancing offer the best, practical cleaning methods for boilers under load.

The practice of hand-cleaning an out-of-service boiler leaves a skin of deposit. Once removed, this skin takes several hundred hours to reform. "Steamsoaking"—subjecting the heating surfaces to the action of saturated steam — removes this skin deposit. There are cases where better cleaning methods have lengthened boiler runs from under 1000 hr to 5000 hr.

Carrying a boiler on the line until deposit growth forces a shutdown is poor operation. Boiler-efficiency loss, while serious, represents only a fraction of the loss imposed by added *hours required to remove* the added deposit.

Where practicable reserve for pulverized firing any coals of over 1.8% sulphur, 0.03% chlorine, 0.03% phosphorous. Beyond this general rule no proved steps seem possible with stoker-fired units to alleviate deposit growth. A study of inorganic "smokes" is under way to determine the extent of help that can come from this source.

RATE OF AIR-HEATER DEPOSITS

Table I—Sulphur Coals on Stokers

Sulphur content	Acute trouble — No. of power stations	Acute trouble — Average run, hours	Minor trouble — No. of power stations	No trouble — No. of power stations
High-medium	9	1350-1810	0	0
High-medium-low	4	2030-2450	6	0
Medium-low	0	*	6	14
Low	0	*	0	6

Table II—Sulphur In Pulverized Coal

Sulphur content	Acute trouble — No. of power stations	Acute trouble — Average run, hours	Minor trouble — No. of power stations	No trouble — No. of power stations
High-medium	0	*	3	0
High-medium-low	0	*	0	0
Medium-low	0	*	1	6
Low	0	*	0	4

*Deposits did not cause shutdown

[5] "Significance of Coal-Ash Fusing Temperatures in the Light of Recent Furnace Studies," by E G Bailey and P O Ely, Babcock & Wilcox Co.

[6] Feuerungstech, 1940, 28, 143.
[4] Chemical, 1940, 14, 418.