Pulverized-Fuel Combustion in Trouble

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Pulverized-fuel (PF) firing is the combustion technique used in all of our great power-generating stations based upon coal. Until recently, an aura of "inevitability" surrounded this technique and tended to protect it from competitive ideas. Now, almost overnight, a sharp increase in concern over environmental quality has placed the future of PF firing in doubt. A number of groups, some represented at this Symposium, are exploring alternative procedures which, first, promise to reduce the cost of coal-fired power, and, second, offer opportunities for reduced cost of control of both ash and sulfur oxides emissions.

At least two concrete commercial developments are in the offing which should go far to dispel PF combustion's aura of inevitability:

- the installation of an Ignifluid boiler in the anthracite district of Northeastern Pennsylvania;
- Lurgi's installation of a combined gas- and steam-turbine power unit incorporating pressure gasification of coal.

Experimental and design studies now in progress also point toward new paths for coal development:

- work on the fluidized-bed boiler;
- interest shown by firms catering to the power industry in studies of combined-cycle arrangements generating power from gas produced from coal;
- continued interest in possibilities for use of coal in fuel cells and magnetohydrodynamic (MHD) devices;
- work directed toward development of a "Coalplex" yielding pipeline gas or liquid fuel or chemicals and low-sulfur coke for power use.

Viewed altogether, these commercial and experimental activities lead to the inescapable impression that a revolution in coal-power practice may be at hand.

The National Air Pollution Control Administration (NAPCA) has recognized the opportunity to steer this revolution into paths leading to better ways to control ash and sulfur emissions.

NAPCA has engaged Westinghouse Electric Co. to direct the development of a non-polluting fluidized-bed boiler, and United Aircraft to study schemes for generating power from clean gas made from coal.

A technique as mature as PF firing is hard to displace, and its advocates can be expected to work hard to keep it viable. It may be useful to review briefly the problems which they will face in an historical context.

The concerns of students of combustion may be listed roughly in the order in which they have arisen:

- to burn coal with an acceptably small loss of carbon to smoke and ashes;
- to provide clean combustion gases suitable for heating materials liable to be spoiled by ashes;
- to provide combustion gases for discharge to a stack which were sufficiently free of grit as not to constitute a neighborhood nuisance;
- to burn coal at the large throughputs needed to generate electricity after about 1925;
- to provide stack gases to meet increasingly higher standards for content of fly ash;
- to provide stack gases low in sulfur oxides.

Until about 1895, all devices for burning solid fuel handled the fuel in a bed at rest. In some, the bed gravitated downward in a shaft. In others, the bed rested or moved horizontally on a grate. Steam power engineers developed ingenious devices, the first patented by Watt himself in 1785, to feed coal continuously to a bed on a grate and to discharge ashes. Grit emissions from some of the grate devices were small, although their designers were at first more concerned with limiting losses of carbon.

The advantages of dealing with the coal in several steps were appreciated early. From 1735 onward, ironmakers in England used coke from beehive coke ovens. After 1800 an industry arose to supply illuminating gas, marketing coke as a byproduct. In 1836 gas producers were introduced to derive from coke a dust-free fuel gas suitable for burning where cleanliness was desired.

Often, a major incentive to technical change has been growth of demand for a commodity, making obsolete a technique whose scale-up to large size is difficult or uncertain. By the 1890's, cement manufacturers felt need for equipment of larger capacity than the shaft kilns used hitherto. An attempt to operate a rotary kiln for cement-making with producer gas was a failure. A kiln was operated satisfactorily with petroleum, but this fuel was then too expensive. The experience suggested that a suitable flame might be sustained by injecting pulverized coal into a rotary kiln via an air blast from a nozzle. Shortly, the cement industry developed techniques for pulverizing coal and burning the coal powder. Edison participated in this work, attesting its importance to late 19th-century technology.

By about 1915, steam power engineers realized that electricity demands would soon require steam flows larger than could be conveniently provided by a grate-firing technique. They felt an acute need for a new combustion procedure easier to scale upward in size than the existing grate-combustion devices. The experience of the cement industry was at hand: coal pulverizers, coal-conveying systems, and PF firing nozzles were available on the market. Engineers found it relatively inexpensive to undertake experiments on PF firing for raising steam. The work led to the Lakeside Station in Milwaukee. After the commissioning of two 20,000-Kw turbines in this station in 1922, PF firing soon became the choice for nearly all new power-station construction.

Engineers of the day regarded the PF boiler to be an advance from standpoint of dust emission. Herington (1) wrote in 1920:

> "It is quite true that perhaps 60 per cent of the ash goes up through the stack. This ash is of such light flocculent nature that it is dissipated over a wide area before precipitation occurs and no trouble can be expected from this source, although the amount of tonnage put out through the stack per day seems great. This is proved by the 'Lopulco' installation [at Oneida Street Plant of Milwaukee Electric Railway & Light Co.] where, after a period of two years' operation, although the plant is located in the heart of the business district of Milwaukee, no complaint has been heard from this source and no evidence of any ash or dust can be found on the roofs of any of the buildings in the vicinity. It is quite possible that this dust is of such fineness and such a nature that it is not precipitated until it encounters moisture."

It would appear that the engineer of 1920 was more concerned for his immediate neighbors than for a city or a region. He soon heard about it if a nearby housewife found "soot" on her wash, but voices were not yet raised concerning insults to lung tissue by fine matter. Would PF firing have seemed attractive for development if engineers had felt something like today's concern about fly ash?

A dry-bottom furnace, having steeply sloping walls, allows about 80% of the ash to leave with the gases, while the remainder drops out of the bottom in solid form. A wet-bottom furnace has a relatively flatter bottom and retains ash for a much longer time, so that about one-half leaves as molten slag. A cyclone furnace uses a coarser grind of coal and burns the coal in an intense combustion zone in which coal and gases whirl in cyclonic fashion. The effect is to separate about 70 to 90% of the coal's ash as a slag which can be tapped from the bottom. The changing attitude toward dust emissions is illustrated by the claim advanced in the 1930's, when the cyclone furnace was introduced, that it substantially solved the emission problem.

Figure 1, after Ramsdell and Soutar (2), illustrates the growth in concern over dust emissions. For more than 10 years, Consolidated Edison Co. of New York has recognized that the metropolitan settings of its stations imposes the necessity to provide equipment collecting fly ash at an efficiency greater than 99%. This necessity has led to electrostatic precipitators of great size, such as the one at the 1000-Mw unit of Con Edison's Ravenswood Station. This is shown schematically together with the boiler in Figure 2. There are two banks of precipitators, each 58 x 230 feet in plan and 75 feet in height. The enclosed volume is more than three times greater than the two combustion chambers of the Ravenswood unit, each 34 x 64 feet in plan and 138 feet in height. The Ravenswood precipitator cost $10,000,000 -- i.e., $10 per kilowatt. It has provided a collection efficiency of 99.5% in tests.

The Ravenswood precipitator operates at 700°F, while earlier precipitators in Con Edison's system generally operated at around 300°F. A reason for the higher temperature, which needs a larger precipitator to achieve comparable performance, was the introduction of coals of below 1.0% sulfur into Con Edison's system. Because ash from low-sulfur coal displays a high electrical resistivity at 300°F, a precipitator for this coal and this temperature would have to be much larger than a precipitator for a high-sulfur coal in any case, as Figure 3 shows (2). Figure 4 illustrates the rising cost of dust collection over the years, paralleling the increase in dust-collection efficiency (2).

Few existing coal-fired stations are equipped with precipitators of such high efficiency as those in Con Edison's system. In future PF stations, the power industry may find it hard to escape a cost on the order of that incurred at Ravenswood for fly ash control. A trend may be in the making, exemplified by the projected Four Corners Station in Arizona, toward scrubbing for fly ash recovery, in the hope that the costs of fly ash and sulfur oxides control may be shared.

A major drawback of PF firing for the future lies in the fact that a simple, one-step combustion places the coal's sulfur promptly into a form difficult to collect and recover. For typical coals, the combustion gases contain about 0.2 to 0.3% SO_2 by volume. The Ravenswood precipitator handles 4.3 x 10^6 cubic feet of gas per minute. The chemical treatment of such a vast throughput for removal of a constituent present in such small amount is almost certain to be costly.

Since the 1930's, research and development teams have worked upon many ingenious ideas for capturing SO_2 in stack gases from PF boilers. The history of many of these efforts is depressing: initial enthusiasm followed by abandonment when the economic facts became clear. At the moment, some half-dozen or so schemes are "alive", but none has passed the hurdle of commercial operation at the several-hundred-Mw scale of power generation common in the United States.

Recently, some argument, primarily semantic, has arisen concerning the "commercial availability" of systems for SO_2 control. Normal business prudence would argue against putting in a large number of several-hundred-Mw installations, simultaneously, for any of the now-available systems. An over-enthusiastic heralding of these systems could lead to pressure for such installations from environmentalists not overly concerned with either business or technological considerations. If the pressure succeeds, so much money and hope would be committed to the installations that funding for development work on more advanced schemes for sulfur oxides control would be difficult to obtain.

The history of classic disasters of engineering -- post-War Fischer-Tropsch synthesis, fluid hydroforming, nuclear-powered flight, numerous advanced-design aircraft, and more recently, Oyster Creek and high-speed rail equipment -- should teach prudence in the application of new processes on a giant scale. Many such disasters are a result of too-rapid application to meet an urgently felt need.

If trouble should develop almost simultaneously in a number of stack-gas cleaning installations, the news would reinforce the already general belief that pollutants from coal combustion are "impossible" to control, and might contribute toward another round of nuclear plant construction. The danger would be especially great if development of alternatives were not already well advanced.

Schemes to control sulfur from PF combustion have a make-shift, tacked-on aspect. The time is at hand to rethink the problem of burning coal with air pollution as an early consideration.

We have already remarked that PF combustion might not have seemed so attractive to the engineer of 1920 if he had been as much concerned with fly ash as with grit. Instead, he might well have concentrated upon ways to increase the burning capacity of his familiar grate devices.

An idea was at hand. Winkler filed his historic patent for a fluidized-bed coal gasification apparatus in 1922, and its commercial use began in 1926. It does not detract from the simple beauty of the idea to fluidize a bed of coal on a travelling grate to wonder why no one came forward with this idea before Albert Godel thought of it in the late 1940's. The "inevitability" of the PF technique was too inhibiting. Godel has stated that he himself did not at first conceive that his Ignifluid system might go into large utility boilers, and he believes he lost many years for lack of this concept.

Figures 5 and 6 give cross-sectional views through the lower portion of Godel's Ignifluid boiler (3). Godel has found that the ash of substantially all coals is self-adhering at a temperature in the vicinity of 2,000°F, no matter how much higher the ASTM ash-softening temperature may be. Coal is supplied in sizes up to 3/4 inch. As a coal particle burns, ash is released. Ash sticks to ash and not to coal, and ash agglomerates form. They sink to the grate, which carries them to the ash pit. Godel's bed operates adiabatically, except for radiation from the upper surface. The bed is rich in carbon, and combustion is incomplete within the bed. Secondary air, admitted over the bed, completes the combustion.

As a result of the high fluidizing-gas velocity (about 10 feet per second) and low air-to-fuel ratio, the coal-treating capacity of Godel's travelling grate is roughly 10 times greater than that of previous grate-combustion devices.

Recently, Babcock-Atlantique has promoted use of the Ignifluid boiler in large stations (4). A 60-Mw unit is in operation at Casablanca, and negotiations are well advanced for a 275-Mw unit to burn and remove accumulations of anthracite waste in Northeastern Pennsylvania. The waste has a high ash content, and Godel's system is uniquely capable of dealing with it.

For nearly 30 years, various groups have attempted, without much success, to burn pulverized fuel at high pressure to furnish hot gases to drive a gas turbine. The work to be reported here by BCURA and Lurgi point to paths of development whereby coal may take advantage of the substantial cost reductions which combined-cycle operation can afford.

As United Aircraft will report, the inevitable advance in gas temperatures for gas-turbine operation will bring an incentive to increase the power output from the gas turbine of a combined-cycle operation to levels of 50% and beyond (5). These developments will create an incentive to find techniques for gasifying coal in systems of high capacity and efficiency. For the American power industry, a gasifier handling the coal for 1,000-Mw in a single unit, or at most a few units, represents a reasonable target of development.

Fluidization at high velocity, perhaps with use of Lurgi's "circulating fluid bed" technique (6), comes immediately into mind.

There may be a way to combine this technique with ash agglomeration, for example, as practiced by Jéquier and collaborators at CERCHAR (7, 8).

Suppression of sulfur oxides from a two-step combustion of coal at high pressure should be far easier than from PF combustion. Sulfur would be available as H_2S, present in a far smaller volume flow of gas.

Finally, I call attention to the arrangements which have been made to bring liquefied natural gas from abroad, at prices which bring sharply into view the alternative of converting volatile matter in coal into synthetic gas. This development lends urgency to studies of schemes like the "Coalplex" depicted broadly in Figure 7. Much work sponsored in recent years by the U.S. Office of Coal Research has been directed toward development of such a Coalplex, especially work by Consolidation Coal Co. and FMC Corp.

The appearance of Coalplexes will result in availability of large supplies of low-sulfur coke, for which PF combustion is poorly suited. This fact is a powerful incentive to ready a better technique for combustion of carbon.

Figure 8 depicts broadly a logical precursor to the Coalplex of Figure 7 (9). This scheme would generate baseload power from the combustion of volatile matter, and would ship low-sulfur coke to power stations at a distance.

We see a natural evolution:

- The first Coalplex would be justified simply for its economy in dealing with sulfur.

- Later, modifications would "cream off" limited amounts of pipeline gas or liquid from volatile matter. Simplicities in the processing of volatile matter to products of higher value would result from opportunity to throw off high-level waste heat to steam for power.

- As time passed, further modifications would expand production of gas or liquid.

Ultimately, the recovery of sulfur from coal would be viewed as a mere incidental.

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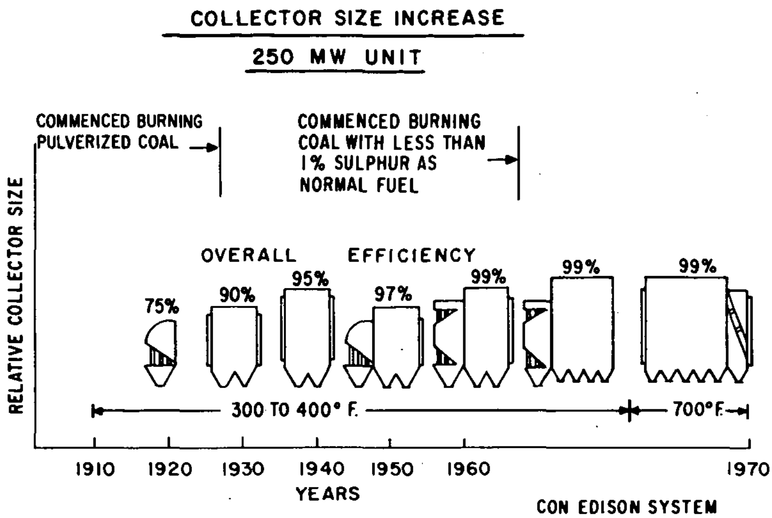

Fig. 1. Increase in size of dust collection equipment in Con Edison system, after Ramsdell and Soutar (2).

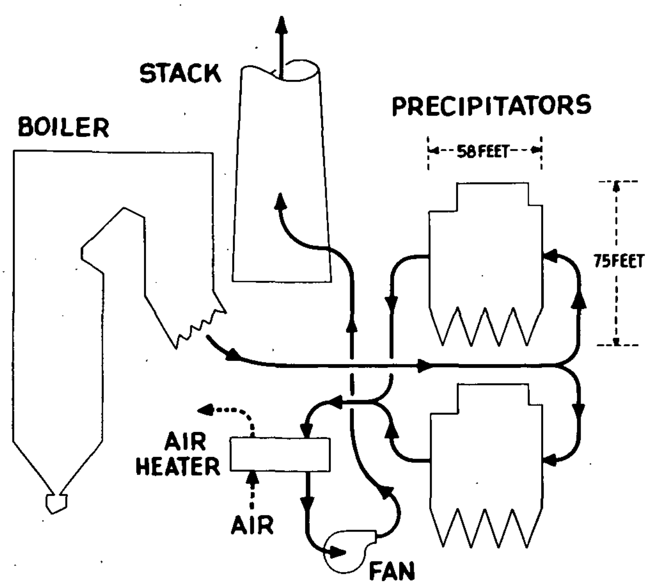

Fig. 2. Schematic view of boiler and electrostatic precipitators of 1000-Mw unit at Con Edison's Ravenswood Station.

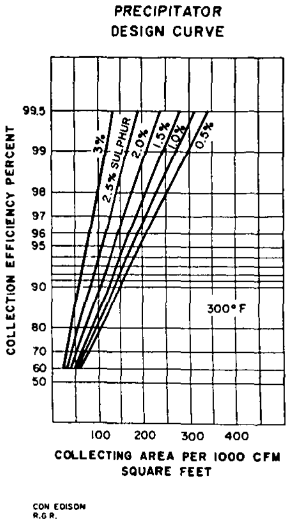

Fig. 3.

Relationship between collecting area and collection efficiency, as function of sulfur content of coal, for operation at 300°F, after Ramsdell and Soutar (2).

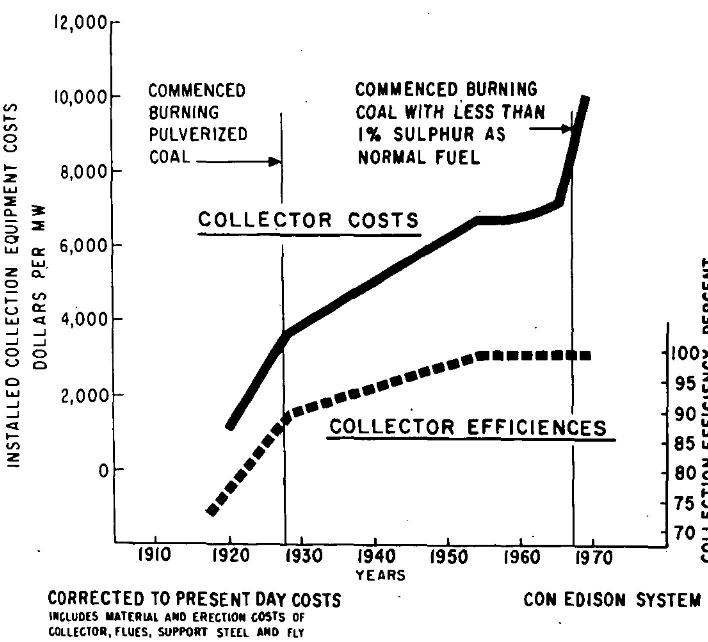

Fig. 4. Increase in cost of dust collecting equipment in Con Edison system, after Ramsdell and Soutar (2).

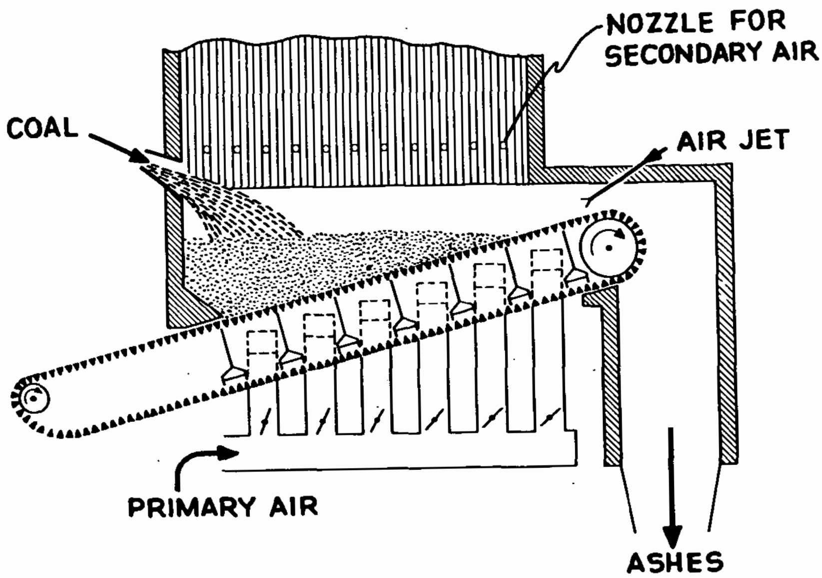

Fig. 5. Cross-sectional view of lower part of Ignifluid boiler, developed by Albert Godel and Babcock-Atlantique.

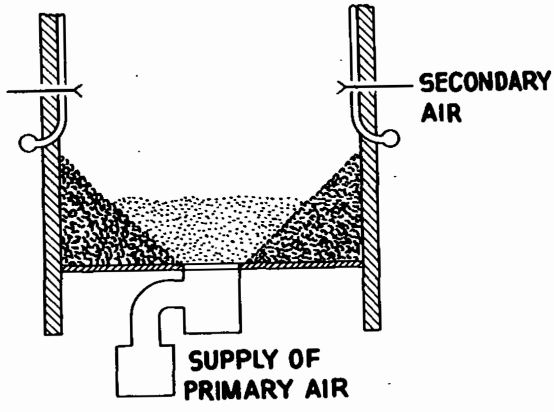

Fig. 6. Sectional view of Ignifluid boiler across the travelling grate, showing the fluidized combustion bed between two banks of static coal.

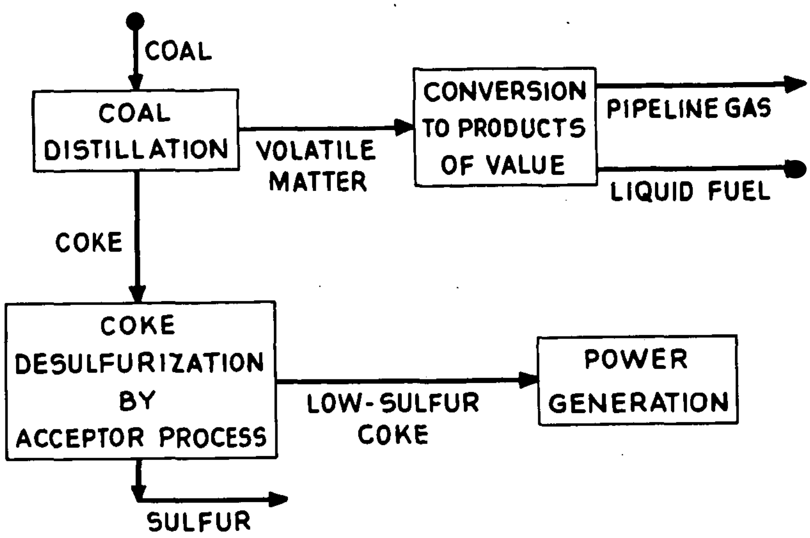

Fig. 7. A "Coalplex".

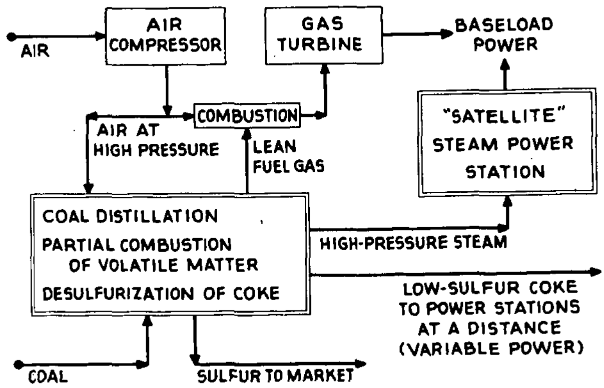

Fig. 8. Concept for a pioneering Coalplex directed toward recovery of sulfur and generation of coal power.