To anticipate one question which may arise, let it be said that the original hearth lining of the Institute boiler, which was No. 1 firebrick, failed in approximately six weeks of service. It was subsequently replaced with Carborundum brick which failed in sixteen days of service and caused us to call in refractory experts who pointed out that the brick-maintenance problem in a structure such as this is similar to an open-hearth steel furnace wherein the major attack is chemical and not thermal. A synthetic mullite brick lining was recommended and installed on both boilers and at present seems to have a satisfactory life. The indicated cost of annual maintenance of the hearth is approximately $5000.

**General Details of Plant**

To round out the story of this job, a brief description and a few pictures of the over-all installation may be of interest. The unit and its auxiliaries are installed completely out-of-doors, the only enclosure being that space under the coal bunker in which are located the front burners, the coal feeders and pulverizers, and the control console (Figs. 2 and 3). Fig. 4 shows the complete plant. It is intended to erect a duplicate unit in the future.

The relative simplicity of auxiliary equipment should be noted. Two deaerating feedwater heaters are installed, one operating at 10 psig and one at 200 psig. Within the pressure shell of each deaerator is located a continuous blowdown compartment, one cascaded into the other; a heat exchanger (counterflow to incoming feedwater) serves to cool the effluent of the 10-lb blowdown compartment. Two 100 per cent capacity turbine-driven, high-speed chrome-alloy feed pumps are installed. These are of the re-entry type each having a first section taking suction from the 10-lb heater and delivering to the 200-lb heater through a level control device, and a second section receiving from the 200-lb heater and delivering to the boiler with water-level regulation in the boiler achieved by regulation of turbine speed.

The ash-handling system is visible in this view and consists of a "Jetpulsion" pump serving a deaerating tank which will hold approximately 4 days' run of slag and can be discharged equally well to either railroad cars or trucks. Antifreeze protection on important lines is electrical.

Drafting of the boiler is a little unusual. Forced draft is provided by four motor-driven 40-hp single-stage blowers—two in each side of a plenum chamber at the rear base of the air heater. Each blower is fitted with a balanced multileaf check damper which prevents back-flow when the blower is stopped; each blower also has a vane inlet control, all four of which are operated simultaneously by the combustion control through a jack shaft. Three blowers will handle the boiler well beyond rated capacity, leaving one in reserve. This system avoids heavy foundations and extensive duct work, and it provides very good fan efficiencies at all loads since blowers can be started or stopped from the panel board as load varies. The induced-draft fan is conventional but has no dampers. Draft control is achieved by varying fan speed with a hydraulic coupling. The two circular stacks are free-standing and equipped with discharge orifices to give a full-load exit velocity of 4500 fpm.

**Operation of Auxiliaries.** Operation of the auxiliary system serving this boiler has proved simple and reliable except that we underestimated the problem of placing the spare boiler feed pump in service on a job where deaerating heater pressures are not related to unit loading. A superb operating crew finally figured out a way of placing the 200-lb heater in service with the unit running, but it can be imagined that the procedure was a precarious one. A low-capacity by-pass was finally installed around the 200-lb heater to permit this operation to be handled more safely and expeditiously. To those who plan the installation of a re-entry pump and open feed-heater system such as this (and we certainly recommend it from a maintenance and first-cost standpoint) it should be pointed out that the stand-by feed pump will vapor-bind its low-pressure suction (due to normal pump leakage) if it is permitted to stand with communications open to both deaerators. We learned the hard way that the respite of trying to start the feed pump in this condition can produce the most terrifying water hammer it has ever been the author's experience to hear. The practice now is to leave the stand-by pump and its pipe lined up to by-pass the 200-lb heater, then to cut that heater into service after water flow is established through the pump.

**Fluidizer Petroleum Coke Tested.** It may be known to some that this boiler has been used successfully in burning test lots of the fluidized petroleum coke which is produced by the new Standard Oil process. The features which permit the successful combustion of this fuel perhaps are not related to the furnace performance which is the subject of this paper, but it is likely that complete reinjection of dust is required with this fuel in order to completely burn out its carbon content.

**Conclusion**

We hope most sincerely that the excellent performance of this boiler, which has been the product of so many people in both the manufacturing and operating branches of the steam-generating industry, can be proved not to be an isolated example and that we individually, and the Society collectively, will prove that our management's insistence on placing a stop to the fly-ash disposal problem will be able to benefit the entire industry.

**Discussion**

G. W. Bice. This is an unusually interesting paper on what certainly appears to be an unusual steam-generating unit.

Fly-ash refriring has been tried a number of times in furnaces of various design, but has seldom been found satisfactory, and has nearly always been abandoned because of the practical difficulties encountered. No mention was made of fly-ash refriring difficulties experienced during initial operation of this unit. Surely there were some. It might be enlightening if the author would discuss this subject briefly in his closure.

Also, no mention was made of the ability of this unit to handle low-quality coals, in addition to the relatively good coals normally available in the Charleston, W. Va., area. If such coals have been burned, even on an experimental basis, it would be of interest, and helpful in evaluating the possible versatility of this design of furnace and its fly-ash refriring equipment.

During the past summer, several members of the ASME Special Research Committee on Furnace Performance Factors visited the subject plant, where they were afforded the opportunity of seeing this boiler in operation, and of talking with members of the operating staff. While they were impressed with the ease with which fly ash was being refrired, they were even more impressed with the freedom from fouling of the unit, and especially the furnace above the burners. Their interest and their curiosity were apparently contagious, as they have succeeded in convincing the committee as a whole that it would be worth while to invest a portion of the funds remaining in the committee's treasury in a series of formal tests on this unit. Tentative agreements have been reached with the owner, the boiler manufacturer, and the Bureau of Mines for furnishing the necessary materials, installation labor, test facilities, and test personnel, either on a no-charge basis or at cost. Thus it is hoped that additional detailed performance data on this very interesting installation will be

Assistant Mechanical Engineer, American Gas & Electric Service Corporation, New York, N. Y. Mem. ASME.
obtained soon, and can be presented to the Society within the next year.

OLLASON CRAIG. The author points out that by this method of firing there is an unexpected result in that no slag accumulation is experienced on the walls of the furnace above the burners or in any of the gas passages. It might be said that this is due to the high ash-fusion temperature of this particular coal. However, there is also a boiler of the same design, with the same method of firing, in a paper mill in Maine which uses Minto coal from New Brunswick. This coal contains an average of over 20 per cent ash and an average of over 8 per cent sulphur. The sulphur is mostly in the form of pyrites. Ash-fusion temperatures vary from 1800 to 2000 F. There are no wall blowers, slag blowers, or soot blowers in this boiler and there has never been any requirement for any such blowers. Also, no hand painting is used. The furnace walls and the gas passages are just as clean as those mentioned in the paper.

The author develops the point that the temperature of the gases leaving the furnace is considerably less than would be the case with dry-bottom firing but with the same heat release per square foot of furnace envelope. This at first seems somewhat puzzling but, upon giving the matter some thought, it becomes quite evident why this was so.

The temperatures at the top, the bottom, and the sides of the furnace are represented by the points A1, A2, B1, B2, and C1, C2, C3, C4 respectively. The temperature at the side of the furnace could be represented by a line parallel to the line joining A1 and A2. The temperature at the top of the furnace could be represented by a line parallel to the line joining B1 and B2.

Assume, finally, that all the heat is released in a narrow vertical band at the extreme bottom of the furnace. This would be represented by the point D1. Since no further heat is released, the temperature of the gases rising in the furnace can only decrease from the furnace bottom to the furnace top. At the furnace top the temperature leaving the furnace would be represented by a point such as D2. It is obvious that temperature D2 will be less than that of B3 or C4. The curves C1, C2, C3, and C4 would come the nearest to representing the conditions that would be experienced when firing a dry-bottom furnace. Consequently, the difference between C4 and D2 would represent the drop in temperature at the top of the furnace because of the method of firing by which all the heat is released at the bottom of the furnace. If the point C4 is projected horizontally to the curve D1-D2 the point of intersection would indicate the point in the height of the furnace where the temperature would be the same as in the case of dry-bottom-furnace firing. In other words, this would indicate that by releasing the heat entirely in the bottom of the furnace a smaller furnace can be used and a higher heat release per square foot of furnace envelope can be used to obtain the same temperature leaving the top of the furnace as would be the case with dry-bottom firing.

This line of reasoning also would seem to indicate that the temperature of the gases leaving the furnace is affected, not only by the heat release per square foot of furnace envelope, but is also affected by the way in which heat is released in the furnace. It would seem, then, that making use of the factor of heat release per square foot of envelope only could be very much of a fallacy and very misleading.

When natural gas is fired into the bottom of one of these furnaces, through the same burners as are used for coal firing, a very luminous flame fills the furnace bottom. This flame has very much the same appearance as the flame with coal burning. It appears to have about the same degree of luminosity and the same ability to radiate heat. This fact led to the thought that possibly the temperature of products of combustion leaving the furnace when burning natural gas would be about the same as when burning coal. Temperatures of gases at the top of the furnace were measured when burning gas and it was found that at the same load being developed by the boiler these temperatures were almost identical with those obtained when firing coal. It is to be presumed that the same thing will be true when firing oil. For these reasons it has been found that this type of design with this method of firing is particularly desirable in the future which will burn natural gas but expect that at some time in the future to find it desirable to change to coal firing. When the time comes to fire coal it will be unnecessary to make any changes to the furnace or to the burners and, of course, there will be no outage of the boiler in order to make the change-over.

There is a new form of fuel appearing which is called fluid coke. This is a by-product from a new process of petroleum refining. Fluid coke, however, is quite different from the petroleum cokes which have been obtained in the past. Fluid coke is very dense, exposes a minimum of surface for oxidation, is extremely hard to ignite, extremely difficult to maintain in stable combustion, and contains only from 4 to 5 per cent volatile matter. It has been expected, of course, that it is necessary to burn some auxiliary fuel in the form of oil or gas in order to obtain stable ignition.
Fluid coke has been burned quite successfully at the Blaine Island Plant and with as little as 6 per cent auxiliary fuel in the form of natural gas. This method of firing lends itself particularly to the burning of a very difficult fuel, such as fluid coke, because of the high turbulence and the high temperature that are obtained in the bottom of the furnace. There is now being installed in Delaware, for the Delaware Power and Light Company, three boilers, each having a capacity of 500,000 lb of steam per hr, the basic fuel being fluid coke. Fluid coke will be fired in the same manner as described in the paper.

C. F. Hawley. The author makes the following statement: "It would seem essential to the progress of the fuel-burning art to learn more about this phenomenon in the hope that the good features of this design can be extended to other boilers."

One of the phenomena mentioned is the fact that the furnace-exit temperatures were much lower than predicted. Further investigation on the basis of measurements with high-velocity thermocouples while burning pulverized coal, and also while burning gas, resulted in the furnace-temperature-performance curves shown as Fig. 6 of this discussion. These curves show the furnace-exit temperature plotted against the net heat release per square foot of effective furnace surface. The upper two curves are those for conventional front-wall firing, while the lower two curves are the measurements taken at the author's installation. It will be noted that when burning pulverized coal the temperatures with this arrangement are about 100 to 125 deg F below the conventional design and that when burning gas the spread becomes even greater. The two bottom curves also show that the temperatures at the exit of the furnace when burning either pulverized coal or gas are approximately the same.

The beneficial result of the lower temperatures is immediately apparent by comparing the net heat release which produces the same furnace-exit temperature. If we assume a desired exit temperature of 1950 F the conventional front firing requires a heat release per square foot of furnace envelope of 85,000 Btu. The unit with the bottom firing produces the same exit temperature with 110,000 release and permits a 20 per cent reduction in required furnace surfaces.

The absence of furnace slag above the burner throat and the elimination of furnace blowers remove the most serious operating problems connected with pressure-furnace operation and allow full use of the operating economics of pressure firing.

The design of unit shown as Fig. 7, herewith, is based on this experience and is in line with the hope expressed by the author that the good features of this design can be extended to other boilers. The arrangement is such that natural gas, oil, coal, lignite, fluid coke, delayed coke, or a combination of these fuels can be utilized. The furnace is of the same general design as the arrangement described in the paper with the same type of burners placed at the bottom, but in this case a completely water-cooled furnace floor. The fact that all the fuels burn with a radiant flame allows superheater-tube platens spaced across the upper part of the furnace to obtain the required steam temperatures while still making full use of the low furnace-exit temperatures resulting from the bottom firing. Two units of this type are now on order, one for 850,000 lb of steam per hr at 1550 psig with steam and reheat temperatures of 1005 F, and one designed for 1,550,000 lb of steam per hr at 1925 psig, with steam and reheat.

---

4 Chief Mechanical Engineer, Riley Stoker Corporation, Worcester, Mass. Mem. ASME.
temperatures of 1005 F. These units are designed for pressure-furnace operation.

M. L. Jones. The author's paper on the problem of disposal of fly ash and the method and equipment being used is timely. It would appear that both the manufacturers and the users of coal-fired boilers must take stock of our situation and ask if we are going in the right direction. The installations as discussed in the paper may give some leads which should be investigated.

The slag-tap or wet-bottom furnace had a period of popularity some 25 years ago and many units were installed. However, this type of unit became less popular until the early 1950's when the cyclone furnace was developed.

In the intervening period, air pollution became a problem in all coal-burning installations along with the resulting disposal nuisance of fly ash resulting from the installation of dust collectors. During this period the author and manufacturers, continued to install dry-bottom boilers while knowing that the dust emission from this type of boiler is high. That the author's paper presents some interesting points of discussion. The opposed-flame arrangement would seem to be helpful in creating furnace turbulence which is recognized as a material aid to good combustion. It also should be helpful in creating a high heat zone which will maintain high molen pool temperatures as well as melt the reinjected fly ash and possibly gasify some of the components of the fly ash.

The bent wall tubes of the burner line also may play an important part in the performance of the unit. The heat absorption of these walls plus the shadowing and directing the gases to the center of the furnace may be some of the contributing factors toward the performance being realized.

It would be of interest to know at what minimum steaming output the unit can be operated with satisfactory tapping of slag. The arrangement of the forced-draft fans is an interesting and unique solution and is particularly attractive when motor drives are used. One of the disadvantages of this installation, however, is the high noise level in the surrounding area which may create a problem. As an alternative, consideration might be given to using other types of fans which have lower noise characteristics.

It would seem that this type of installation should be examined in detail to determine what factors of combustion and boiler geometry contribute to the performance. With such information available, a more rational design of boiler will be realized.

A. A. Orning. The author has presented a report of unusual interest in regard to slagging and fly-ash emission from a pulverized-coal-fired steam-boiler furnace. Further consideration and additional data are needed to predict whether the unexpectedly good results with the particular coal might be expected with similar installations and different coals.

The author has given no data on ash characteristics. The ash-fusion temperature may be considered only as a useful guide but would be of interest. Since fluidity may have little bearing upon cleanliness of upper sections of the boiler but would be of interest with regard to feasibility of using the design for other coals. Alkali metal content of the coal ash is possibly of greatest importance.

The unique shape factors are certainly important in reducing slagging on wall areas immediately above the burners. Low angles of incidence of radiation, from the hearth and the flame volume below the burners, account for much of the absence of slagging in these areas. Flame impingement is probably absent or at low angles in these areas. Information regarding contours of slag deposits on the side walls would aid interpretation of these effects.

Data are given on heat-release rates per unit volume but not per unit projected area of wall surface in the primary furnace. Indicated low exit-gas temperatures depend upon these rates. Exit-gas temperatures are not given. The absence of bonded deposits at the furnace exit and in the first passes of the superheater results from a combination of effects. An increase in dust loading due to recycling is indicated but no data are given. The long path from the flame zone to the furnace outlet favors selective absorption of offensive components by the fly ash. High dust loading would favor this effect. The long path and the outlet geometry also indicate a low solid angle for flame radiation into the outlet. With other coals, of high sulphur and high alkali-metal content, these effects together with even lower exit-gas temperatures might not be adequate to prevent bonded deposits in the slag screen and the first passes of the superheater.

The furnace design presented offers interesting possibilities for control of ash deposits and fly-ash emission. Careful consideration of ash loading and composition must be given any application to coals with ash characteristics differing widely from those in the present application.

O. D. Whiddon. A great deal of enthusiasm is justifiably exhibited by the author over the results that have been obtained by an attempted solution to the fly-ash-disposal problem. Evidently, by refriring fly ash in a specially designed boiler, the author feels that the problem of fly-ash disposal is eliminated. However, the writer feels that the problem has, to some extent, only been changed. After refriring the fly ash, it is still necessary to dispose of the slag which could be as great a problem as disposing of fly ash in some situations. Also, the attendant refractory problem is not to be minimized. At least the refriring operation would give some choice to the purchaser of a boiler for specifying the type of ash disposal he would desire to best meet his individual conditions.

The possibility of eliminating the need for soot-blowing equipment in the boiler should have almost universal appeal. Possibly an analysis of the reason for this particular characteristic could lead to a method of modifying other boilers where refriring of fly ash is not possible or desirable.

However, both the fly-ash-disposal problem and the soot-blowing problem are of such magnitude that any possibility of eliminating or minimizing them should certainly be of interest to everyone connected with boiler manufacture and use. This fact leads me to make a recommendation that further data be obtained and analysis made to better understand the reasons for the exceptional boiler performance for possible universal use. It would seem that the Society might well be justified in such an undertaking through appropriate committees.

The author is to be commended for publicizing his experiences which could be a major step in improving boiler design and operation.

AUTHOR'S CLOSURE

Mr. Bice asks for information on the difficulties with refriring. Briefly, they have been limited to excessive wear of the original pipe-fitting material. Fittings have been replaced with some designed for use in pneumatic fly-ash handling systems. The refriring of dust from the boiler hopper has been discontinued in view of the fact that the amount of dust so handled was so small.

---

1 Principal Power Engineer, E. I. du Pont de Nemours & Company, Inc., Wilmington, Del. Mem. ASME.
2 Member Staff, Coal Research Laboratory, Carnegie Institute of Technology, Pittsburgh, Pa. Mem. ASME.
as to not justify the presence and maintenance of the pipe involved.

Except for avoiding fuels with nominal ash fluid temperatures in excess of 2700 °F, no effort has been made to specify any special coal for this unit. It has handled everything the local mines make available as well as some more distant coals whose purchase was dictated by price and availability only.

The minimum load at which subject boiler can be tapped has never been determined. It would, of course, vary with the fluid temperature of the coal ash and with the excess air required for good combustion of the coal. With ash fluid temperatures around 2350 °F, it is likely that good tapping would prevail down to about three-quarters of maximum rating, but it is my contention that no slag-tapping installation should be made where continuous service at less than nominal full load is contemplated.

Mr. Jones will be interested to know that steps are currently being taken in conjunction with the fan manufacturer to apply low draft-loss sound-absorption devices to the forced-draft fans.

Mr. Orning asks about the contours of slag deposits on the side walls of the furnaces. The answer is that above the throat of the furnace there are none whatever and it therefore appears that the freedom from slagging of this furnace design is associated with factors other than its shape and dimensional relationships.