the opportunity for boiler operators to compare urgency of removing the boiler from service. With chemical operating units unable to reduce steam demand safely at a moment’s notice, the forced-circulation boiler, in one case, was kept on the line at full rating in excess of 3 hr, despite a complete wall-tube rupture. This type of boiler, with its relatively smaller-diameter tubes and small control orifice in the water inlet, in addition to the fact that the generating tubes terminate above the water level in the drum, can suffer a complete tube rupture without the necessity of immediate removal from the line. This is an extremely vital factor in chemical processes where shutdowns must be made in an orderly and safe manner. In the two instances when rupture occurred in a wall tube or generating tube on the natural-circulation units, it was necessary to take the boiler off the line immediately, resulting in pressure upsets to chemical process. A natural-circulation boiler, upon loss of any tube, immediately becomes inoperable.

**CONCLUSION**

In summarizing and outlining the characteristics found in these two types of boiler units at the Koppers plant, it is not the intent to suggest advantages or disadvantages of any particular type of unit. That the forced- and natural-circulation principles are radically different would of necessity present different operating characteristics.

The forced-circulation unit has demonstrated particular operating assets as follows:

1. The ability to suffer loss of a tube and continue to operate until other apparatus is brought on the line to take its place, or until load can be sufficiently reduced so that boiler capacity is not required.
2. Water-level stability under conditions of rapid and large load changes.

The natural-circulation units have particular operating assets as follows:

1. Greater availability in comparison with forced-circulation type.
2. Less sensitivity to changes in feedwater conditions, rendering it more suitable for high make-up with high solids in the feedwater.
3. Lower susceptibility to scale formation under equivalent feedwater conditions.

The operating record of both of these types of steam generators reveals their ability to supply process-steam requirements under many adverse conditions. Chemical production of butadiene and styrene has been maintained at high rates throughout the operating period to date, and over-all operation should compare favorably with that of any other steam plant of its size and operating conditions.

**Discussion**

J. M. Harvey. The character of the water in the Ohio River and its tributaries is such that many problems must be met which do not exist where water of more stable quality, such as water from the Great Lakes, is utilized for boiler-feed purposes. Acid mine drainage and extensive use of these streams for disposal of industrial waste and sewage from the heavily populated surroundings make for extreme variation in the character of the river water.

Characteristic is the trend from a bicarbonate condition, with high dissolved solids and low suspended material during the heavy run-off in the spring and early summer to a highly acid condition, with high dissolved solids and low suspended material during the low flow in late Summer and Fall. Localized pollution and the presence of river pools may further influence the character of the river water at a particular plant intake.

Generally, the periodic variations in dissolved solids will follow a somewhat fixed pattern with minimum and maximum concentrations reaching about the same value each year, and with the average concentration varying not more than a few ppm over a period of several years. However, combination of conditions may produce considerable deviation from the normal pattern as shown by Fig. 5 in the paper, charting variations during a period when industrial activity was at an unprecedented high.

The wide flexibility of the water-conditioning facilities installed at Kobuta made it possible to cope with the variations imposed and maintain boiler-water conditions within closely defined limits. Even so, characteristics of the river water exert their influence and have been productive of adherent sludge deposits in the boilers. Specific measures were adopted several months ago which we believe, and which are proved in part, will solve this problem.

In January, 1945, silicate treatment was introduced to one of the natural-circulation boilers. At this time the routine water-testing program was expanded to include determination of the silica concentration in the boiler water and saturated steam. These tests soon established the fact that there was no significant difference between the silica present in the steam generated by the boiler receiving silica treatment and the boilers not receiving this treatment.

Since all the natural-circulation boilers had been mechanically cleaned just prior to the introduction of silicate treatment, inspection of these boilers in June, 1945, after a 6-months’ run, afforded the opportunity to compare the appearance of the internal surfaces of the boilers. The boiler subjected to silicate treatment was decidedly cleaner than the other natural-circulation boilers.

On the basis of these observed conditions, silicate treatment was extended to all the natural-circulation boilers as well as the forced-circulation boiler. Inspection of the forced-circulation boiler in October, 1945, after a run of approximately 60 days on silicate treatment, revealed accumulation of scale particles in the orifice headers to about the same extent as noted during previous inspections. However, finely divided sludge, which had been found intermingled with the scale particles on previous occasions, was almost entirely absent. The scale particles are identical in chemical composition to the finely divided sludge formerly found along with the scale particles. This is indicative possibly that the scale particles originate at some point in the circulating system where the finely divided sludge adhered and attained more coherent and compact form under conditions existing at that point. Thus we believe there is some possibility that the scale particles will be eliminated with continued operation on the silicate treatment.

In connection with the silicate treatment, it is also worthy of mention that inspection of the 35,000-kw back-pressure turbogenerator in October, 1945, showed the complete absence of any deposits. This inspection was made after approximately 2 years of operation, and silicate treatment was in effect during the last 9 months of operation.

H. J. Klotz. The authors of this paper are to be commended for the unprejudiced presentation of the comparison of the operating characteristics of forced- and natural-circulation boilers of the same capacity installed side by side in an industrial plant and performing under identical conditions as regards load and

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5 Chief Power Engineer, Stone & Webster Engineering Corporation, Boston, Mass. Mem. A.S.M.E.*
feedwater. The writer's connection, as consultant to the Office of Rubber Reserve, with the operation of the Koppers plant, has afforded an opportunity to observe that the plant-operating organization has been equally unprejudiced in its handling of the boilers. There has been not the slightest tendency to favor either type of boiler, but a conscientious effort has always been evident to meet any special requirements imposed by the two types of boilers. The fairness of their comparison has thus been assured.

It is, of course, too much to expect that a comparison in one plant only could form the basis to permit final and definite conclusions as to whether one or the other type of boiler should be installed. The principal offsetting features would appear to be the ability of the forced-circulation unit to continue in operation following the loss of a tube, an important item in many processes, compared with the greater availability of the natural-circulation boilers. Corrective measures adopted at the Koppers plant will probably obviate the importance of this comparison as it is believed the causes of the tube ruptures in the natural-circulation boilers have been greatly minimized, and the lower availability of the forced-circulation boiler should eventually be overcome by further progress in chemical treatment of the feedwater plus possible additional mechanical features to prevent sludge accumulation on the orifice strainers.

The extremely variable nature of the make-up water at this plant makes the latter an important consideration and one which, until it is overcome, points to the desirability of the natural-circulation boiler for comparable water conditions.

It is important to note that the pumps required for circulating water with the forced-circulation boiler have imposed no operating problem.

Experience at the Koppers plant indicates that the practicability of the forced-circulation boilers for industrial plants has been sufficiently proved to warrant additional installations, and that any plant considering the choice between the two types would be safe in basing its decision on the relative investments and space requirements after assuring itself that any possible feedwater limitations would be satisfactorily met.

W. S. Patterson.* The authors have refrained from comparing differences in design in the two boiler types unless these differences have, up to the present time, resulted in operating assets in favor of one type or the other. However, since forced circulation, applied to large steam generators, is new in this country, it will be of interest to point out some of the reasons for the difference which will be noted from a study of the paper, and some of the potential assets.

Small-diameter tubes are used in forced-circulation boilers because a high flow resistance and velocity in the tubes are desirable, and because a high fluid velocity in the tubes can be realized with a minimum quantity of circulating water handled by the pumps. Small-diameter tubes can have very thin walls, resulting in low hot face skin temperatures and low temperature stress in the tube metal even with very high rates of heat absorption. There is also a saving in weight of tube metal and weight of water in the tubes; but the advantages of small tube diameter are most apparent in high-pressure boilers as will be seen from Fig. 7 of this discussion.

Although bifurcated tubes have been used in natural-circulation-boiler furnaces, this is the first application of trifurcated furnace tubes. Such an arrangement decreases the number of header connections, orifices, and access openings. Before this boiler was placed in operation Pitot tubes were installed in each tube of several of the trifurcated furnace elements to check relative water distribution. The results are presented in Table 5 of this discussion.

### TABLE 5 DISTRIBUTION OF FLOW IN TRIFURCATED FURNACE CIRCUITS

<table>
<thead>
<tr>
<th>Trifurcate no.</th>
<th>Tube no.</th>
<th>Flow, per cent</th>
<th>Rear furnace wall</th>
<th>Side furnace wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>191</td>
<td>27.4</td>
<td>33.8</td>
<td>36.8</td>
</tr>
<tr>
<td>2</td>
<td>182</td>
<td>31.6</td>
<td>33.0</td>
<td>38.4</td>
</tr>
<tr>
<td>3</td>
<td>183</td>
<td>34.8</td>
<td>31.6</td>
<td>30.2</td>
</tr>
</tbody>
</table>

* Denotes tube in corner of furnace.

The convection boiler, called the "secondary generator," also employs 1/2-in.-OD tubes, but they are fitted with 1/3-in-high fins and disposed horizontally in a bank below the economizer. These tubes are bifurcated at the end adjacent to the control orifice so that each orifice serves two circuits which are intermeshed, with forged return bends and long-radius bends alternating through the length of each circuit. The tubes are arranged in staggered relationship with 21/4-in. horizontal and 31/4-in. vertical spacing, and because of their small diameter and transverse flow of the gases, a very high heat-transfer rate is obtained without the use of baffles and without resorting to a high gas velocity. The surface installed per cubic foot of space in the secondary generator is about twice that of a conventional boiler and each element is independently removable through a large door at one end.

The "water-cooled beams" mentioned in the paper, support the secondary generator and both economizer sections. They are shown at three elevations in Fig. 2 of the paper, and consist of two parallel sets of three headers each, with series flow through each set. The tubes supplying the outer end of the uppermost headers are shown coming off the main distributing header. The water passes through the uppermost headers, thence by external connections to the inner end of the lowest headers, through the latter to the outer end, and thence through external connections to the single secondary-generator inlet header containing the control orifices. The two intermeshed circuits of each secondary-generator element terminate in separate discharge headers which support the lower economizer section. From these headers the steam-water mixture is discharged to the boiler drum.

Since the steam drum is not required to support a bank of steam-generating tubes, it is located entirely outside the setting as shown in Fig. 2 of the paper, which is sometimes possible but

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rarely convenient in designing a natural-circulation boiler. In the case of thick drum shells exposed to hot gases, drum protection must be provided, which introduces a maintenance item for the operator; also, where a boiler baffle abuts the drum shell, a positive and tight seal must be maintained to prevent fly-ash erosion of the drum due to baffle leakage. These problems are absent when the drum is outside the setting and therefore represent potential operating assets. It will also be noted that all the drum-tube connections in Fig. 2 of the paper are in one quadrant of the shell, thus reducing to a minimum the amount of thick shell plate required.

The authors point out an operating disadvantage of a high-capacity boiler containing a very small quantity of water, when the rate of blowdown is high due to high make-up of water having high total solids. However, the low weight of water is also associated with low weight of tube metal and this combination results in a lower fuel requirement to place a forced-circulation boiler in service and less heat loss on cooling down. This would be a distinct asset in the case of a boiler subject to week-end shutdowns in many industrial plants. In combination with forced circulation, it also permits entry to the furnace for maintenance within 8 hr of the time the boiler is taken off the line, even in the case of a large high-pressure unit with a wet-bottom furnace. Also, with the increasing popularity of acid cleaning of boilers it is an operating asset to require only one quarter of the amount of acid, flushing water, and neutralizing solution, to say nothing of the time saved in filling draining, etc.; and 2 min operation of the pumps at hourly or half-hourly intervals will completely mix the solvent, re-establishing a uniform concentration and uniform temperature, both of which are important.

Fig. 2 of the paper shows that each pump is equipped with a shutoff valve at suction and discharge. It was originally intended that only one pump would be in operation and the other held as a spare with suction and discharge valves closed. With the method of operation used at this plant the spare pump idles at 400 rpm and with all suction and discharge valves open. The check valve located at each pump discharge has a bypass which permits operating the spare pump in this manner but limits re-circulation through the idle pump. The shutoff valves have never been used during operation because the availability of both pumps has been 100 per cent.

The authors give a figure of 10,000 lb per hr steam consumption for circulating-pump drives but the heat extracted in the turbine is only about 200 Btu per lb or 2,000,000 Btu per hr. The fuel equivalent of this is about 0.50 per cent of the fuel fired at maximum rated capacity and part of this energy is returned to the boiler water in passing through the pump.

The occurrence of scale chips in the orifice headers has not been uniform in all headers, and this was originally explained by the fact that the first supply tubes coming off the main distributing header go to the front or burner wall; the next group at each end go to the side-wall headers and the center group go to the rear-wall header. When the sludge and/or scale chips have been present in serious quantities, the front-wall header has generally contained the most and the rear-wall header the least. In fact, the strainers were not removed from the rear wall during one outage. Nevertheless, the availability of the forced-circulation boiler averaged close to 95 per cent from December 1, 1943, to April 1, 1945, and it would be of interest to learn how much greater availability was realized on each of the natural-circulation boilers to justify the conclusion drawn.

Our experience with water conditioning for the forced-circulation type of unit has also shown that feedwater of high quality is required to prevent deposits in the control-orifice strainers. Also, the relatively small volume of water contained in this type of boiler limits the concentration of constituents that may be tolerated in the feedwater.

The favorable comparison with regard to the operating characteristics of the forced- and natural-circulation boilers for the production of process steam is noted with interest.

It is our opinion that the operators of the plant are to be complimented upon maintaining continuous operation of the steam-generating facilities and related equipment under the rigorous conditions imposed throughout the 2-year war-production period.
Steam consumed by the circulating pumps means little unless translated into energy; the latter is obviously a charge against the efficiency of the forced-circulation unit. No discussion is offered of the greater space and building costs required for a natural-circulation design. At Kobuta, it appears that the building design was determined by the space required for the larger boiler and hence no appreciable savings accrued from the installation of a single forced-circulation unit. These savings might have been considerable, however, had the building been designed for four forced-circulation units.

It is unfortunate that Figs. 2 and 3 of the paper, showing cross sections of the two boilers, are not shown to the same scale. The tabulations, however, show that the natural-circulation boiler has 4500 cu ft greater furnace volume. For four boilers, this amounts to 18,000 cu ft which might have been saved had the building been designed for the forced-circulation type of boiler only. Weights are not given, but from the data on heating surface, tube sizes, and water volumes, it is clear that the weight of the natural-circulation boiler, filled with water for test, is more than twice the weight of the forced-circulation unit. As shown in the tables, the operating weight of water in the natural-circulation boiler is more than 4 times that in the other type. These factors materially affect the cost of building steel and foundations and should ultimately have an appreciable effect on the cost of equipment as well.

These are the reasons, of course, that manufacturers and operators are willing to spend time and money on such developments of the art. What we all want are better boilers at less cost than we now have. It is apparent from this paper that forced circulation is a constructive step in this direction.

Authors’ Closure

The silicate treatment as mentioned in Mr. Harvey’s discussion definitely showed promising results as to the elimination of sludge in the natural circulation boilers. Duplicate treatment in the forced-circulation boiler has not produced hoped for results and all inspections of this boiler unit since the treatment was initiated revealed scale at the orifice strainers in amounts equal or greater than on previous inspections. Sludge accumulations were, however, somewhat reduced. Operations at this boiler plant are now such that continued observation of this method of feedwater treatment is not possible as the forced circulation boiler has been out of service since early in November due to low steam demand to process. The elimination of the troublesome scale at the orifice strainers remains as an important factor in securing greater availability of the forced circulation unit, and the authors believe that feedwater consultants will overcome this difficulty by introduction of other suggested treatments, should the silicate not produce the desired results. The divergence in results of this duplicate treatment of the feedwater for both types of boilers further demonstrates that the natural circulation boilers are less susceptible to scale formation under equivalent feedwater conditions than the forced circulation unit.

Mr. Patterson’s discussion of certain design features and potential operating assets of the forced circulation boiler enhances the value of the paper for design engineers and operators of boiler plants. The authors, as operators, are naturally inclined to overlook design features unless they materially affect the boiler operation or are modified to improve the operation. The references to savings in weight, “secondary generator,” “water-cooled beams,” and drum location will no doubt be of great interest to all readers, and the authors concur in his discussion on certain minor advantages gained by low weight of water and lower requirements for acid cleaning. The further explanations of Mr. Patterson in regard to pump operation, soot blowers, and steam consumption of the pumps contributes much to enlighten the reader on points which the authors unintentionally might have slighted.

The conclusion that the natural circulation boiler has greater availability has been demonstrated by the operating records of the two types of units. While operating at near peak demands, the outage schedule required that each natural circulation boiler be taken off the line every six months with the outage time limited to three days. The outage schedule of the forced circulation unit required an outage each two months with outage time limited also to three days. The amount of maintenance work required on both types was relatively equal. Thus it can be seen that on a percentage of availability basis the natural circulation boilers would reach 98.36 per cent or 6 days outage per operating year while the forced circulation boiler would reach 95.08 per cent or 18 days outage per operating year. While the percentage availability difference does not seem too great, it is significant that the scheduled outage time required by the forced circulation unit amounts to three times that of the natural circulation boilers.

The authors appreciate the discussions of all these engineers and the favorable comments contained in these discussions. That the Kobuta Plant has had such an outstanding operating and performance record is partially due to the suggestions and recommendations of these outstanding men of the steam-generation field.

It is well to point out that since preparation of this paper all the 3 in. tubes between the pump discharge header and the orifice headers were mechanically turbinated. The amount of scale removed during this operation has led us to believe that these tubes are the source of scale particles, and their scheduled turbinating at times of boiler outages would do much to increase the operating time between outages of the forced circulation boiler.

It will be noted that the operating assets of the forced circulation unit are inherent for this type of boiler unit, while those of the natural circulation boiler are not limited by its type. It would thus seem that further developments to overcome any deficiency of operating assets for forced circulation will enable us to attain better boilers at less cost as asked by Mr. Ryan.