extraction-steam heating coils. The second inspection, made approximately 3 months after the first inspection, indicated the tubular air heater to be in first-class condition with only a thin coating of fine ash.

Station Heat Rates. The net station heat rates for unit No. 3, based on design calculations, are shown in Fig. 9. The actual operating results for the period from July 14, 1954, to March 31, 1955, are given in Table 1-A. During this period the average operating turbine load was 98,000 kw and the average over-all net heat rate was 9100 Btu per kwhr.

Table 1-A Potomac River Station Operating Report—No. 3 Unit
(From 1:00 p.m., July 14, 1954, to midnight, March 31, 1955)

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Turbine Load</td>
<td>98,000 kw</td>
</tr>
<tr>
<td>Station Service-% of Gross Generation</td>
<td>5.42%</td>
</tr>
<tr>
<td>Main Steam Pressure and Temperature</td>
<td>1876 psig, 1032 F</td>
</tr>
<tr>
<td>Hot Reheat Pressure and Temperature</td>
<td>384 psig, 928 F</td>
</tr>
<tr>
<td>Feedwater Temperature</td>
<td>455 F</td>
</tr>
<tr>
<td>Condenser Back Pressure</td>
<td>1.11 lb/in. Hg</td>
</tr>
<tr>
<td>Circulating Water Temperature</td>
<td>56 F</td>
</tr>
<tr>
<td>Make-Up-% of Boiler Feed</td>
<td>0.288%</td>
</tr>
<tr>
<td>Exit Flue Gas Temperature</td>
<td>256 F</td>
</tr>
<tr>
<td>Boiler Steaming Efficiency</td>
<td>91.2%</td>
</tr>
<tr>
<td>Boiler Use Factor</td>
<td>96.3%</td>
</tr>
<tr>
<td>Pounds of Coal per Kilowatt Hour Net</td>
<td>0.649 lb</td>
</tr>
<tr>
<td>BTU per Kilowatt Hour Gross</td>
<td>8,692 BTU</td>
</tr>
<tr>
<td>BTU per Kilowatt Hour Net</td>
<td>9,190 BTU</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>37.14%</td>
</tr>
</tbody>
</table>

The most efficient steam station reported by the Federal Power Commission for the year 1953 had a net heat rate of 9170 Btu per kwhr. The units in that station, however, are 175,000-kw cross-compound units with steam conditions of 2000 psig, 1050 F, which is inherently a more efficient design than our 100,000-kw tandem-compound unit designed for 1800 psig, 1050 F/1050 F.

Controlled-Circulation Boiler Performance. The controlled-circulation boiler unit is worthy of particular mention in that its design factors and performance have been almost exactly as predicted. The boiler steaming efficiency for the S/2-month period covered by Table 1-A was 91.2 per cent. The coal burned during this period had an average heat content of 14,162 Btu per lb as fired and an average sulphur content of 0.70 per cent. Steam temperatures have been controlled by burner tilt and an occasional use of steam soot blowers. No spray water, either for main-steam or reheat-steam temperature control, has been used except for the purpose of calibrating the spray water-control systems.

We wish to point out that all integrating watthour meters are carefully calibrated, automatic samplers are used for coal samples, all coal is weighed on accurate track scales, and weekly analysis of coal is performed in our own laboratory with a monthly verification by four other laboratories. Therefore we believe the performance reported for this unit to be true and representative.

Conclusions

Each advance in steam-cycle arrangement and in pressure and temperature entail design problems and present potential operating difficulties and the possibility of increased maintenance costs. It is appropriate, therefore, that, within the limits of realistic economic returns, maximum performance be exacted at each pressure classification. Particularly is this true in the range of pressures and temperatures common today, for there are diminishing returns as further advances are made in steam conditions. Furthermore, no matter how progressive and efficient the design may be, a generating unit is not earning any money when shut down for repairs or revisions.

The record of the unit under discussion is evidence of what can be done if careful attention is given to all details in selection of equipment, station design, and operation. The demonstrated performance, at steam conditions that are now generally accepted as somewhat conservative for utility stations, may be taken as an attainable datum for evaluating the advisability of assuming the costs and risks inherent in more advanced designs.

Discussion

W. W. Brown and R. M. Van Deuzer. The authors have presented an interesting paper showing how relatively high plant thermal efficiency can be gained "without assuming costs and risks inherent in more advanced designs." It seems possible, however, that higher-design throttle pressure using the same primary and reheat temperatures indicated in the paper would yield worthwhile thermal economy. Pressures up to 2350 psig have been used in several installations, without impairing reliability.

Since high boiler efficiency, 91.2 per cent, contributes largely to the excellent net heat rate for the unit, we should like further explanation on this subject. We know it is difficult to compare boiler efficiency in different areas of the country mainly because of solid fuel quality and its effect on efficiency assuming common stack temperatures. For example, we have now on order a large steam generator designed for 200 F stack temperature. With this temperature and using 80 F air ambient and lower-quality coal, we expect an efficiency of 90.2 per cent or 1 per cent lower than the boiler in question. We mention this to illustrate the important effect of coal quality and air ambient.

It might be helpful, therefore, if the authors would explain the factors contributing to the boiler manufacturer's efficiency guarantee, 91.2 per cent. One of these, of course, is the lower than average stack temperature of 230 F which will result in lower dry-gas loss and improved efficiency, but how about the others? In this case, was a higher ambient used than the 80 F generally accepted? In our most modern units we specify coal with 8 to 9 per cent moisture and 5 per cent hydrogen when requesting boiler-efficiency guarantees. How does this compare with the percentages used in the authors' case?

Chief Mechanical Engineer, Mechanical Engineering Division, The Detroit Edison Company, Detroit, Mich. Mem. ASME.

The author states that the boiler setting was specified for zero air infiltration. It is assumed that the unit is a balanced-draft unit. The high boiler efficiency guaranteed and attained in actual operation indicates that the infiltration is a negligible amount. One of the major economies claimed for pressurized furnaces is the savings attributed to low-infiltration losses. We have been convinced that this saving can be realized on a balanced-draft unit by careful attention to casing design. Results at the Potomac River Station substantiate this conviction.

We find considerable interest in the manpower figures stated in the paper. The men per kw compared very favorably with our St. Clair Station figures of 0.102 men per Mw. Four 150,000-kw units are now in operation, two units being operated from each of two control rooms. Considerations other than manpower, however, may lead to selection of centralized control, among these are improved operating conditions resulting from air-conditioned enclosed rooms, cleaner instruments with better accuracy and less maintenance. We feel, also, that better protection for operating in emergencies is important, particularly during a fire since the control-room air should be taken from outdoors and the room pressurized sufficiently to keep out smoke. It is our opinion that these things are worth the cost of the room enclosure. As a matter of interest the manpower ratio per Mw for our River Rouge Plant, now under construction, will be 0.080 based on three units totaling 820 Mw. This illustrates what size effect does to the ratio.

We believe, also, that conservative planning for units of 200 Mw and upward calls for additional manpower coverage for each unit as insurance against outage considering the large block of capacity involved.

We are most interested to learn that the omission of backing rings on the main steam, reheat, and boiler-feeding discharge lines, and the use of inert arc welding resulted in relatively clean piping systems so that a negligible amount of welding beads and fine welding chips was accumulated in the strainer. It would be helpful to know whether radiographic examination was used and, if so, at what stage or stages of completion of the welds.

N. R. Deming.\textsuperscript{16} It was pointed out that for a period of 8\textsuperscript{1/2} months the average over-all net heat rate was 9100 Btu/kwhr, a very desirable value. However, it would seem that when comparing the heat rate with those obtained in other steam stations, a correction should be made, at least for the 4.2 per cent excess throttle pressure over the design value. It is not always possible to control superheater and reheater temperatures to the desired values and, of course, any station heat rate is entitled to be benefited by the gain from having less than the design value of turbine-exhaust pressure.

Station heat rates are the result obtained from two kinds of measurements—fuel burned or heat added in the combustion process and net generation or station output. Obviously the accuracy of the heat-rate figure depends directly on the accuracy of each of these two measurements.

Without making specific reference to the Potomac River Station the writer wishes to question the reliability of load measurements taken from integrating watthour meters, even though they may be considered to be calibrated carefully. Irregular discrepancies between values from a calibrated watthour meter and the three-wattmeter method of load measurement of up to 1 per cent during acceptance economy tests of the writer's experience prompt this question. While it may be that discrepancies of this order of magnitude occur infrequently, it would be interesting to know what accuracy is expected by the electric utilities in heat rates computed from data collected over a long period of time.

E. H. Krieg\textsuperscript{11} and W. F. Ryan.\textsuperscript{12} The generating plants of Potomac Electric Power Company have a long tradition of sound engineering design and expert operation. This latest installation is in strict conformity with that tradition, and illustrates what gratifying results can be obtained with what the authors call a "conservative" design by meticulous attention to thermodynamic and mechanical details when combined with carefully planned and skillfully executed operating procedures. This plant also maintains the Pepco tradition for fine architecture, cleanliness, and quietness so essential in the nation's capitol, and also high output per operator. It is impossible to make direct or conclusive comparisons on operating personnel, but we doubt that any utility has been more efficient in respect to manpower, and the company's excellence in this respect dates from the earliest installation at Buzzard Point.

The plant is noteworthy for some features that are not in other plants or, if so, have not come to our attention. Unusual advantage has been taken of the potentialities of the low end of the heat cycle which has compensated to some extent for the "conservative" throttle condition. This has been a factor in achieving a performance of 9150 Btu per net kw output, in spite of a condenser back pressure of 1.36 in. Hg. This record was made possible by a 91.3 per cent boiler efficiency and a stack temperature of 256 F. The plant has enjoyed an unusually high availability with no outages chargeable to the cycle.

There is one particular in which Potomac River Station has occupied a unique position, in our experience, since the first unit went on the line, and that is its outstanding reputation for being "a good neighbor." Fig. 1 of the paper shows a group of apartment houses situated almost up to the plant property line. At the upper left-hand corner are the lights indicating the approach to the Washington airport. Another apartment house erected a short distance from that shown in the photograph, was built with white brick on the south side to help keep apartments cool in the summer, and after several years the white brick is still clean.

As the plant is close to the approach zone of the Washington Airport, the stacks had to be kept very low, about 160 ft above ground level. To make this possible, a combination of mechanical and electrical electrostatic dust collectors was used which, as the authors report, have attained the remarkable collection efficiency of 99 per cent. Those who have flown over the plant when going to Washington by plane can verify the statement that on such occasions it would seem that one could look to the bottom of the stack even when the plant is carrying full load.

In these days, when many utilities are having trouble with zoning boards, the Potomac River Station presents an outstanding example of the fact that a generating station, designed for its particular environment, can be a good neighbor and not a nuisance.

R. C. Roe\textsuperscript{13} and M. A. Matyers.\textsuperscript{14} The authors are to be congratulated on their description of the new addition to the Potomac River Generating Station. It is especially noteworthy that the performance of the plant, for its first 8\textsuperscript{1/2} months of operation, is so close to the anticipated performance shown in Fig. 9 of the paper. This fact emphasizes the ability of design

\begin{flushleft}
\textsuperscript{11} Consulting Engineer, Stone & Webster Engineering Corporation, Boston, Mass. Fellow ASME.
\textsuperscript{12} Senior Consulting Engineer, Stone & Webster Engineering Corporation, Honorary Mem. ASME.
\textsuperscript{13} President, Burns & Roe, Inc., New York, N. Y. Fellow ASME.
\textsuperscript{14} Chief Mechanical Engineer, Burns & Roe, Inc. Mem. ASME.
\end{flushleft}
engineers and equipment manufacturers to accomplish the objectives of their predicted design in the American power industry. This, in turn, permits power companies to design with assurance for the thermal economy appropriate to the state of development of their operating systems and thus to assure themselves of a maximum dollar return on their investment.

A noteworthy feature of the heat balance shown in Fig. 3 of paper both by those who presented written discussion and others who offered comments or asked questions during the session. The practice approaches the economy inherent in the direct-contact heater system which the writers' company has used on many of its high-efficiency stations where heaters are of the direct-contact type for all stages below the boiler-feed-pump suction. The three pumps operating on the condensate cycle would seem to have some disadvantages compared with the two pumps in the standard system of the writers' company. With the inherent present-day high reliability and availability of properly designed multisection condensate-heater pumps it would seem that full advantage could be taken of a full direct-contact heater system if it were desired.

Having gone so far, it would be of interest if the authors would explain why they did not use open heaters at the 21st and 22nd stage extraction points. We wonder also, in view of the seven stages of feedwater heating, why the temperature of the feedwater heater was not taken above 450 °F. Our own analyses indicate that an additional 30 to 50 deg of feedwater heating probably would pay off in an area of high fuel cost.

The low boiler flue-gas-outlet temperature of 256 °F is evidently made possible by the high quality of coal used in this station. This permits going to an extraordinarily high efficiency which could probably be duplicated in few other plants. Are enamel tubes being used in the air preheater to help eliminate corrosion? It is interesting to note that no evidence of plugging or corrosion of the cold end of the air preheater was found after 3 months of operation. Can the authors give the result of any more recent observations?

As the authors indicate, the omission of a central control room is somewhat unusual in a new steam power plant. While the stated manpower figures indicate economical manning in spite of this omission, we wonder whether some difficulties may not have appeared during emergency or transient conditions of operation.

We wonder also whether the authors could quote, at this time, the cost per kilowatthour of name-plate capacity of this new addition. In view of the special conditions of cleanliness and quiet that this plant must meet it would be expected that the construction cost would be somewhat high. It would be of interest to see how much increase in cost is necessitated by these special requirements.

**Authors' Closure**

The authors appreciate the general interest shown in this paper both by those who presented written discussion and others who offered comments or asked questions during the session.

The boiler losses predicted in the boiler contract and indicated by two heat-balance tests in field are given in Table 2.

The boiler specification and contract were based on 100 F air from the boiler room entering the forced-draft fans. The ultimate analyses of the coal samples obtained during the heat-balance tests indicated average moisture and hydrogen contents of 4.46 per cent and 4.47 per cent, respectively.

Due to the advantageous location of the 21st and 22nd stage closed feedwater heaters in the steam-dome space of the condenser, we do not believe that direct-contact heaters with associated pumping equipment would have been economically feasible in this particular installation.

We considered final feedwater temperatures up to 500 F but concluded that 450 F represented the most economical installation, as feedwater temperatures in excess of 450 F resulted in higher boiler costs which we could not justify.

Carbon-steel tubing is used throughout the tubular air heater, and another inspection continues to indicate a very satisfactory condition. We believe this can be attributed to two things—good quality coal and 125 F air entering the tube banks.

We gave serious consideration to providing a central-control room for the two new reheat units in this station. However, we were not able to satisfy ourselves that this was the economical thing to do. Further, we believe there are advantages to all plant operators being out in the station where they can see and hear. It is our honest opinion that operators distributed as at the Potomac River Station are in a better position to handle emergency conditions than they would be if housed in an enclosure. We have been able to handle all emergencies quite satisfactorily with the operating arrangement described.

It may be that an enclosed and properly ventilated central-control room could have an advantage in event of a serious fire. On the other hand, the fire might be discovered and controlled sooner by operators located out in the station.

The cost of this addition, consisting of two 100,000-kw design-capability reheat units, including the switchyard, will be very close to $31,000,000, or $155 per kw.

Visual inspection by a borescope was made of the inside condition of the first bead applied in the pipe welding by the inert-gas-shielded process. Any defects located were repaired by remelting the areas from the outside. A second visual inspection was made following the second bead. The welds were completed by the arc-welding process and radiographs made of the completed welds.

Messrs. Roe and Mayers suggest the possibilities of using open heaters at the 21st and 22nd stage extraction points and 30 to 50 degree higher final-feedwater temperature. Adoption of these changes would have resulted in higher cost and less convenience in operation which we consider not warranted in our case for the expected higher efficiency. A drain cooler in the 22nd stage heater limits the gain available from open heaters and location of the closed heaters in the condenser simplifies station layout and costs less.

The 4.2 per cent excess throttle pressure mentioned by Mr. Deming actually was the pressure at the superheater outlet. A better comparison of design and operating throttle conditions would be the heat contents which are 1510.9 and 1499.0 Btu per lb, respectively, or approximately 0.8 of 1 per cent below design conditions.