

1 A major part of the corrosion in the system investigated occurs between the point of first condensation in the turbines and the condensate-pump discharge.

2 Corrosion of iron occurred in the portions of the system immediately following the first condensation of steam, even though sufficient ammonia was naturally present in the steam to maintain a pH of 8.5 at the condensate-pump discharge.

3 Feed of cyclohexylamine once a day provided better protection to both iron and copper alloys than was afforded by the ammonia naturally present in the system.

4 Continuous feed of cyclohexylamine along with sodium sulphite at the condensate-pump discharge still further reduced the iron and copper content of the condensate and of the boiler feedwater. Low levels of 0.02 ppm of Fe and 0.01 of Cu in the condensate have been attained in two plants.

5 No increase in ammonia content of the condensate has been observed as a result of the continuous feed of cyclohexylamine to a boiler producing steam at 900 F.

6 The substitution of morpholine for cyclohexylamine did not further reduce the iron content of the condensate; however, the copper content was increased slightly.

## Discussion

E. L. KISNER.<sup>3</sup> The authors are to be congratulated upon the excellence of their paper and their contribution to the art of combating corrosion in feedwater systems, which is currently a subject of considerable interest. The following discussion is an attempt to analyze the reactions resulting from the changes in treatment, especially at Long Beach plant 3, and account for the improvements noted from the data obtained.

In the beginning, the pH of the hot-well condensate, plant 3, did not deviate appreciably as the feeding of amines was reduced gradually and finally discontinued. It was then assumed that ammonia attributed to a new raw-water supply was responsible for the maintenance of a favorable pH of the feedwater. Furthermore, it was believed that a resumption of amine feeding might result in dangerously high alkalinities.

Since appreciable quantities of dissolved oxygen were reported, it is also quite likely that carbon dioxide entering the feedwater system with the evaporator vapor was not entirely deaerated. If the amounts of carbon dioxide and anhydrous ammonia remaining in the condensate were equivalent, a practically neutral solution of ammonium carbonate would result; an excess of carbon dioxide would render the solution acidic even though ammonia was present. It has been demonstrated that perfectly deaerated distilled water will attack iron at ordinary temperatures. Ferrous hydroxide is the product of corrosion and is soluble to the extent of about 4 ppm. The hydroxyl ions corresponding to the iron, reported in Tables 1 and 2 of the paper, could account for a pH of 8.7.

When the feeding of amines was discontinued, it was likely that the quantity of ammonia available both to neutralize the carbon dioxide and provide a suitable residual was insufficient to inhibit corrosion; therefore the condensate in the turbine exhaust was very aggressive but the rate of attack gradually diminished as the metal pickup progressed until a rather favorable pH of about 8.6 was obtained at the discharge of the hot well.

The dissolved oxygen became more active as the temperature of the water was elevated gradually soon after leaving the condensate pump. The iron gradually was converted to the ferric state; precipitation occurred owing to its extreme insolubility; the pH was lowered as a result of the corresponding diminution of hydroxyl ions and the corrosive attack was renewed.

Fortunately, the feed of cyclohexylamine was resumed. The pH of the hot-well condensate, however, did not change appreciably as would have been expected if the pH previously had been due to ammonia, but instead leveled off because the formation of iron hydroxide had been curtailed greatly. The iron at the condensate pumps was reduced about 50 per cent; the improvement in copper was not quite so remarkable. The authors concluded that the amine afforded better protection against corrosion than ammonia. The writer feels that if an adequate amount of ammonia had been available, perhaps the results would have been quite similar to those obtained with cyclohexylamine.

The continuous feeding of sulphite at the condensate pump, plant 3, had a twofold effect; a reduction in corrosion due to oxygen, as well as the deposition of iron oxide in the heaters. The continuous feeding of amines by assuring a more uniform concentration in the system was, in the writer's opinion, responsible for the remarkable reduction of metal pickup noted at the condensate pump.

It appears that the turbine exhaust is the most vulnerable area for corrosive attack. Condensation of steam and the volatile neutralizing agent should proceed simultaneously and proportionately in order to assure the optimum pH at all times. A study of these properties would provide a basis for preference between the various amines proposed and ammonia.

At the Redondo Steam Station, the application of amines broadened the area protected to include the metallic surfaces in contact with condensate before the point of caustic injection and the improvements are reflected in the data listed in Table 5 of the paper. There is some skepticism about the use of amines at the high temperature and pressure ranges approaching those obtained at Redondo, but this application has proved very successful.

J. D. RISTROPH.<sup>4</sup> The authors are to be congratulated on their presentation of data of definite value to the steam-generating industry.

The findings closely parallel the experiences of the Virginia Electric and Power Company in the usage of cyclohexylamine for control of pH and reduction of corrosion in the preboiler system.

The authors point out the value of continuous controlled feed of the amine in the reduction of corrosion. There is a definite possibility also of breakdown of the amine to ammonia when the slug-feed method of introduction of the amine is employed. This is due to momentary high concentration of the amine at the time of the introduction of the slug of chemical into the system. It has been our experience on a 1400-psig unit to encounter breakdown at any pH above 9.0. Reduction of the pH to 8.8 is followed quickly by a reduction of ammonia content from values ranging from 0.20 to 0.25 ppm ammonia to normal values of 0.05 ppm ammonia. The system normally is controlled at 8.6–8.7 pH by continuous feed of the amine. Sodium sulphite also is fed. Recent analyses show values of 0.02 ppm Fe and less than 0.01 ppm Cu.

The experience of Virginia Electric and Power Company relative to removal of old deposits from boiler-feed-pump casings and impellers by usage of the amine was given in a recent paper.<sup>5</sup> It is suggested that there may be some correlation between the increase in boiler-tube deposits in the period of 3-12-52 and 6-3-52 as shown in Table 3 of the paper because of the introduction of the amine in April, 1952, with subsequent removal of old deposition in the preboiler system.

<sup>4</sup> Virginia Electric and Power Company, Richmond, Va.

<sup>5</sup> "Contamination of Condensate by Heat-Exchanger-Tube Alloys," by J. D. Ristroph and E. B. Powell, *Trans. ASME*, vol. 75, 1953, pp. 729–745.

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