HYD 231

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Hydraulic Laboratory
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Subject: Failure of heating elements in water heaters.

INTRODUCTION

The purchase of a number of electric water heaters for use at the Colorado-Big Thompson Project in Estes Park, Colorado, involved the expenditure of several thousand dollars. After approximately 2 months of operation, two of the heater element jackets were found to be corroded to such an extent that the heating elements failed to function. In accordance with a letter to Mr. P. E. Gearhart, Purchasing Agent, from John H. Keller, dated December 9, 1946, one of the faulty units was submitted to the Denver Laboratory for study and recommendations.

SUMMARY AND CONCLUSION

Measurements made on the electrical section of the heating element showed that they met the power requirements stamped thereon. Other tests made on the jacket showed that it was made of ferrous material. Failure of the element was due to corrosion of the jacket which had proceeded to an advanced degree, as shown in Figure 1. Figure 2 shows an enlarged section of Figure 1.

A study of the literature on corrosion of iron in natural waters, in conjunction with the analysis of a water sample taken from the Estes Park water system, indicated that corrosion of a jacket made of ferrous material is to be expected under conditions ordinarily found in water heaters. Rapid corrosion of the jackets indicates that the tanks might have a short life.

THE INVESTIGATION

The analysis of a water sample taken from the Estes Park water system is shown in Table 1. The analysis was made in the Denver Chemical Laboratory. According to a report taken from the *Journal of American Water Works Association*, Volume 26, No. 7, on "Corrosion of Natural Waters," water is considered neutral if its pH value is between 4.5, which is a weak acid, and 10, which is a weak base.

A pH value of 7 indicates truly neutral water. The pH of the water at the Estes Park Project is 7.4 which indicates a very slight alkaline state and would be considered by the Water Works Association to be neutral water.

Table 2 shows the chemical equations which apply to corrosive reactions. Equation (1) applies to any metal. For any metal above hydrogen in the electrochemical series, the metal goes into solution as cations. Since the jacket was of iron, iron cations are present in the water surrounding the jacket. The ionic hydrogen is supplied by the partial dissociation of water into hydrogen and hydroxyl ions. The atomic hydrogen may absorb energy from the solution and become a gas, or, if there is a source of dissolved oxygen, will combine with it to form water. In this particular problem considerable oxygen is present in the water. The atomic hydrogen is probably removed as fast as it is formed, and the action indicated by Equation (1) could proceed quite rapidly.

Equations 3 and 4 also apply to this problem and are shown in Table 2. The ionic iron from Equation 1 combines with the hydroxyl ions to form ferrous hydroxide and remains in solution. The ferrous hydroxide from Equation 3 combines with water and dissolved oxygen to form ferric hydroxide. The ferric hydroxide precipitates and forms a loose scale on the iron. The scale thus formed is quite porous and offers little, if any, protection against further corrosion. The temperature of the iron and water has marked effects on the rate of corrosion. For example, in a laboratory-controlled experiment on zinc, which exhibits similar reactions to iron, the oxidation rate was doubled by raising the temperature from 20° C to 55° C, but by raising the temperature to 100° C, the rate was increased by nearly 100 times the rate at 20°. The results are shown in detail in a report in the <u>Journal of American Water Works Association</u> of June 1946. Corrosion progressed at an accelerated rate in the water heaters, because of the high temperature of the heating element.

Examination of the water-heater jacket showed no tendency toward a scale deposit. Rather, it indicated that the water at Estes Park is a scale solvent, since the metal surface is deeply pitted with very little scale present. The formation of a protective scale therefore cannot be relied upon to prevent the corrosive reactions from taking place.

The cylinders containing the heating elements in the purchased heaters were found to be installed in a horizontal position approximately 10 inches above the bottom of the tank. The maximum corrosive activity took place on the upper side of the jacket. This would be expected since the flow of water in the immediate region of the jacket is upward due to the temperature gradient. The bubbles of dissolved air liberated from the water on the lower side of the jacket are carried away, while the bubbles on the upper side are protected, and since free air is composed of approximately 21 percent oxygen, the components for continued corrosion are present. As the corrosion progresses, small crevices hold the air liberated by heating, and the oxidation progresses at an accelerated rate.

A jacket made from suitable material would minimize the corrosive activity in this particular case. Copper or high-copper brass is recommended. Copper, being on the negative side of hydrogen in the electrochemical series, would be restrained from going into solution. The use of a copper jacket for the heater element, however, introduces galvanic cell action between the copper and the iron water tank. A slight amount of corrosion would result with the iron of the tank going into solution. The electrical current flow would be minimized in this case since the amount of mineral matter in the water is small. In addition, the area of the copper is small compared to the area of the iron and the galvanic couple should not greatly accelerate the present corrosion rate of the tank. To further eliminate the corrosion due to the galvanic couple, however, an electrical insulator could be used in mounting the heater unit in the tank.

The rapid failure of the heater jacket raises the pertinent question of the condition of the tank itself. Inasmuch as the water is not scale forming, it is anticipated that these tanks will have a short life. It is suggested that the project office check the length of service on these tanks, and notify the laboratories so that immediate steps can be taken to apply protective measures.

Table 1

ANALYSIS OF WATER SAMPLE FROM [illegible] TANK WATER SYSTEM

	PPM	Equiv. per liter
pH	7.4	
Total suspended solids	29	
Total dissolved solids	39	
Calcium	2.6	0.13
Magnesium	0.7	0.06
Sodium	2.5	0.11
Carbonate	6.0	0.20
Bicarbonate	15.3	0.25
Sulfate	2.4	0.05
Chloride	7.1	0.20
Nitrate	0.4	0.01

Table 2

PRIMARY REACTIONS OF CORROSION

Applies to any metal in pure water

1) Initial action
   $M(metal) + H^{+}(ionic) \rightarrow M^{+}(ionic) + H(atomic)$

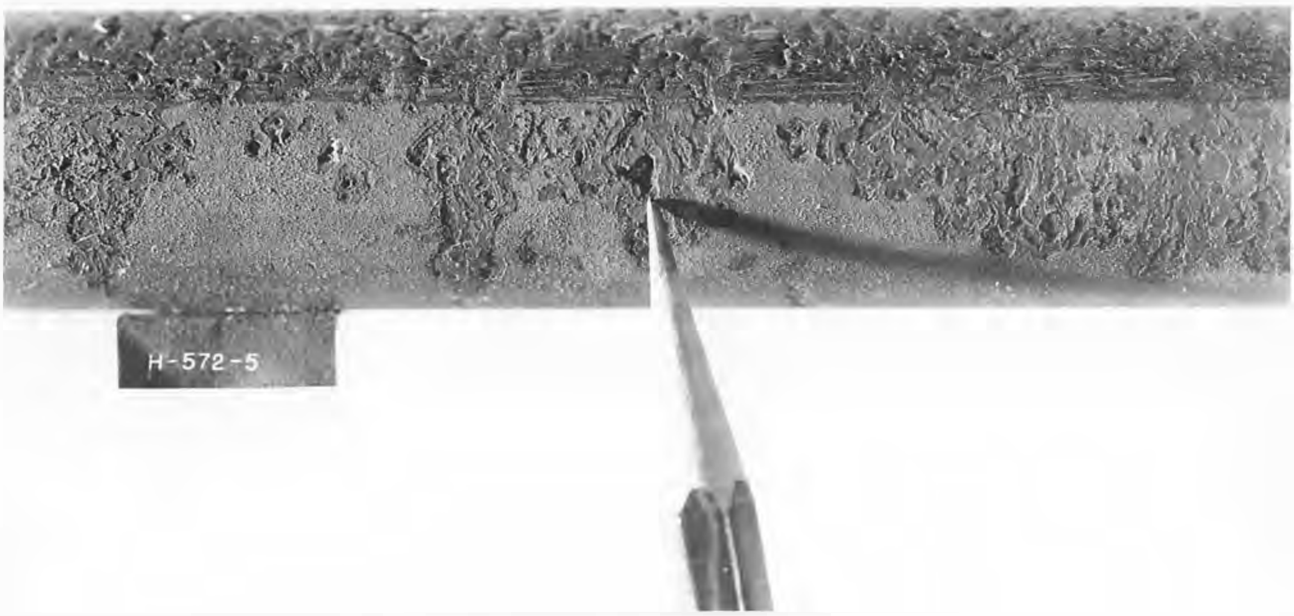
2) Controlling or rate-limiting reactions
   (a) $2H(atomic) + 1/2\ O_2(dissolved) \rightarrow H_2O(liquid)$
   (b) $2H(atomic) + energy \rightarrow H_2(gas)$

3) $Fe(metal) + 2H^{+}(ionic) \rightarrow Fe^{++}(ionic) + 2H(atomic)$
4) $Fe^{++}(ionic) + 2OH^{-}(ionic) \rightarrow Fe(OH)_2(molecular)$
5) $2Fe(OH)_2(molecular) + H_2O + 1/2\ O_2 \rightarrow 2\ Fe(OH)_3$ (molecular) rust

Figure 1

Corrosion of heating element jacket.

Figure 2



Enlarged view of pitted jacket surface.