How To Prevent Boiler Tube Corrosion

Proper operation and maintenance of low pressure heating boilers to prevent tube failures through corrosion cannot be overemphasized. By updating a widely used article prepared for HPAC almost 14 years ago (January 1955), the author tells how this can be accomplished.

By H. F. HINST
Plant Metallurgist
Tubular Products Div.
The Babcock & Wilcox Co.
Alliance, Ohio

CORROSION troubles in low pressure heating boilers—which usually operate at steam pressures below 15 psig or water pressures below 30 psig—often occur unnecessarily.

During the past 60 years, we have had many occasions to examine boiler tubes to determine the reasons for their failure. In very few cases have tube defects been the cause. In the vast majority of instances, the need for replacement has been traced to conditions of environment.

In power boilers, corrosion of the type common in heating boilers is rare. This is because operators of power boilers realize the importance of proper water and fire side conditions and take precautions to avoid such troubles. Many users of heating boilers, on the other hand, are not aware of the possibilities of corrosion. They often have little idea what causes it and lack the know-how and experience to combat it.

Fortunately, scale is not a major factor in low pressure boiler tube failures. A buildup of scale at tube ends, however, has in some cases resulted in failure through grooving next to the tube sheet.

Oxygen Attack on Water Side

Let us consider the various mechanisms that lead to pitting or water side corrosion since this is the most common type, accounting for 75 percent of the tube failures examined in our laboratory.

Steel does not corrode appreciably in dry air, only in the presence of moisture. Similarly, steel does not corrode in clean, alkaline, freshly boiled water if air is kept away.

This has been proved in the laboratory by placing samples of tubes in ordinary tap water in flasks and boiling the water, causing the steam to condense and run back into the flask. When the condensed drops of water were allowed to contact the air, corrosion of the tubes occurred. When the oxygen was removed from the air in the flask and condenser by running the air through pyrogallic acid, which is an oxygen absorbing acid, no corrosion of the tubes was evident.

This shows that the presence of oxygen is an important factor in corrosion problems. It was also found that if the heaters were shut down at night, the corrosion was much more rapid than if the water were kept boiling. In effect, some of the oxygen was excluded from the flask by the steam space over the boiling water. In low pressure heating boilers, the return water usually enters at the bottom, which does not afford the oxygen reduction that would be obtained if it dropped through the steam space.

Pitting is probably the most destructive form of corrosion that affects the water side of boiler tubes. Frequently only a few pits are present, and most of the surface is unattacked. In other cases, the pits cover most of the surface, and as an extreme, the pits run together, the corrosion taking the form of uniform attack. The concentration of pits is determined to a large extent by the degree of acidity or alkalinity of the water. Fig. 1 shows examples of water side corrosion of horizontal boiler tubes.

Acidity and alkalinity are expressed by chemists in terms of a scale of pH values, representing hydrogen ion concentration. A strong acid solution (strong muriatic or sulfuric acid) is rated as 1, and a strong alkaline (concentrated caustic soda) is rated as 14. A neutral water has a pH of 7.

If its pH is below 5, the water is actually sufficiently acid to dissolve the steel, and under these conditions no pits form. Instead, the corrosion is relatively uniform, and the steel gradually gets thinner until it is too weak to hold the pressure or a small hole develops.

If the pH is between 5 and 9.4, pitting takes place at a rate that depends on the concentration of oxygen in the water. Therefore, it is necessary that all air or as much air as possible be excluded from the boiler water.

In one experiment, a strip of steel hung in the middle of a fast moving stream did not rust while an identical piece hung in a stagnant pool at the edge of the same stream and connected to the first by a wire pitted badly. This shows that velocity and air content have an effect on the corrosion of steel. In most instances, pitting in horizontal fire tube boilers takes place along the top of the tubes on the outside, and it is believed that this is partly because of the difference in velocity of the rising water and steam bubbles, which creates an eddy effect along the top of the tubes and accelerates the corrosion, much as in the flowing stream experiment.

In any event, pitting would not occur in this type of boiler if no oxygen were present in the water.

Practically all ground surface supplies of water contain dissolved air, the quantity depending on the source, time of exposure, and temperature. Cold water retains more air than warm water, as can be seen by filling a clear bottle with cold water from a tap and allowing it to stand overnight. Small air bubbles will form on the sides, demonstrating that as the water warms up the gas is liberated.

This release of air in the form of bubbles creates a problem in a newly filled boiler. In a new boiler, or one that has been drained and refilled with cold water, air bubbles form on the tubes as the water warms up, and in a very short time pits develop under the bubbles because of the difference in oxygen concentration in the water surrounding the bubble. Penetration as great as 50 percent of the tube wall has been known to take place in water stagnant for two weeks duration. Once these pits form they propagate rapidly, even under operating conditions.

Sometimes a new set of tubes installed in a boiler has been found to last less than a year whereas the former tubes lasted five to 10 years. Obviously, something has changed. In many cases the tubes are blamed when actually there have been changes associated with the operation and maintenance of the boiler. A different method of starting up may have been used. Circumstances may have been such that the boiler was immediately fired when the old set of tubes was installed while the new set of tubes was exposed to the fresh water for some time. Air bubble pitting may have started, leading to the eventual failure of the tubes. The temperature of the fill water may have been different, with the result that more air was present in the new installation. The composition of the fill water may have changed; a thin scale may have been laid down at the beginning of the life of the old tubes, which served as a protection. Changes in electrical connections may have induced stray currents, leading to electrolytic corrosion. Small air or steam leaks around pipe joints and valves may have let air into the new setup. Air vents may have become plugged through jarring of the piping. In short, any number of things may have happened that caused the failure.

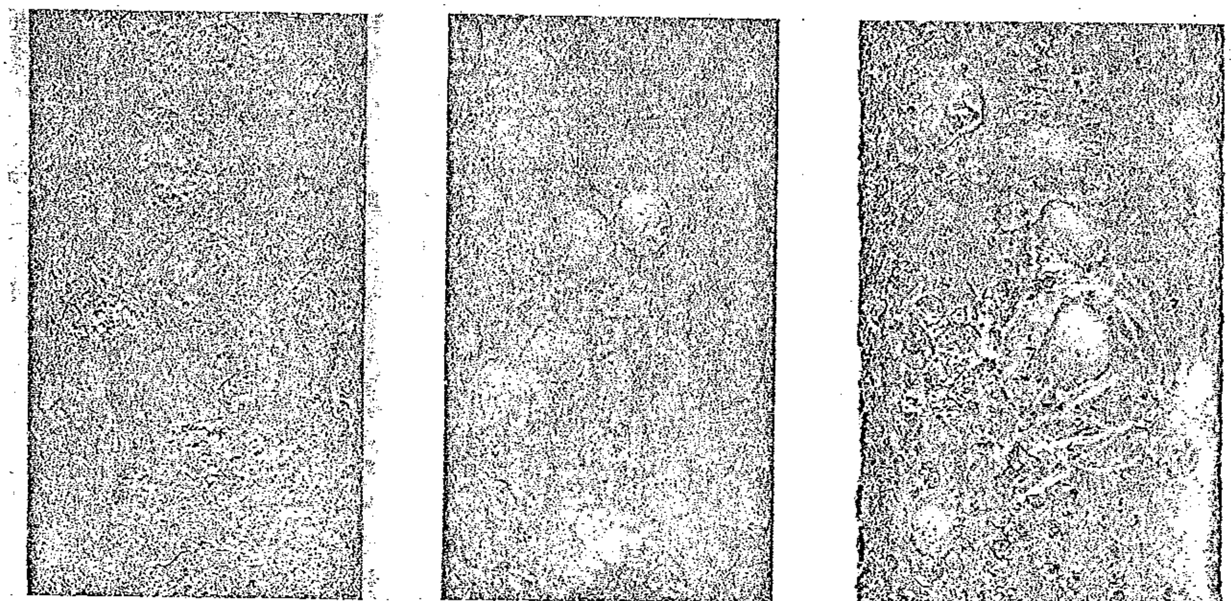
How To Remove Air

A large number of boiler tube failures take place in fall when the boiler is started up for winter operation. These result from the air bubble pitting described above as well as from oxygen being drawn into the system through packing and other sources.

To minimize chances of this occurring, a freshly filled boiler should be heated to bring the water to a good boil, and the steam so produced should be vented off to carry the released gases out of the boiler. Before this boil-out, water treating chemicals should be added so as to get good mixing. After the boil-out, the vents should be closed and the boiler used, or cooled down if not needed.

In hot water systems, production of steam is not desirable, so the water temperature should be raised to 180 to 200 F for a short time to allow most of the air to be driven off through vents.

In large boiler installations, air is removed from the feedwater by heating it up to the boiling point and venting off the dissolved gases. In small installations, this is hardly practical. In steam systems requiring large quantities of makeup water, however, it may be possible



1 PITTING is the most destructive form of water side corrosion of boiler tubes. These are examples of fire tubes attacked on the water side by corrosion resulting from excessive oxygen in the feedwater.

to fit the return condensate tank with a steam coil to preheat the water to near the boiling point. This tank would have to be vented to release the gases.

At any rate, air can be kept out of a boiler by heating the feedwater to release the air.

Another method suggested by F. N. Speller, a noted authority on corrosion, is to pass the feedwater through a deactivator, which is a tank containing steel scrap such as turnings or wires. The oxygen in the water attacks the steel in the tank so that corrosive properties are neutralized. The process is satisfactory if the tank is large enough to permit complete deactivation and if the scrap metal is renewed frequently. This practice is not often followed in steel heating boiler installations because other methods of control are usually more desirable.

In addition to the air carried into the boiler by makeup water, substantial quantities may be pulled in to the system during operation by the vacuum in the condensate line or by vacuum formed when the boiler is shut down or the fire allowed to die out. Warm days in spring and fall and even in winter often result in cooling down of small boilers and radiators. This causes a vacuum, which pulls air into the system through vents, valves, and packings. Proper maintenance of the entire heating system is a must.

Hot water systems should not suffer from air entering with makeup water because there should be no makeup. There are many cases, however, where makeup is required because personnel draw off hot water for custodial services or washing vehicles, circulating pumps leak, floats become water logged, or automatic feed systems stick.

Systems are sometimes designed to be pressurized with compressed air in such a way that a large area of water is exposed, allowing air to be dissolved. In one system, well water was pumped into a horizontal cylindrical tank pressurized across its entire surface. In another system, hot water from three boilers was pumped to an overhead horizontal tank of approximately 5000 gal capacity, which was pressurized with compressed air from a pump in another building. No one had any idea of how much air was being pumped into this system. Eighty pounds of sodium sulfite, an oxygen scavenger, added to this system every day could not keep up with the dissolved oxygen being pumped in.

Any pressurizing of this type should be in an offshoot of the system and not in the main stream. If it must be in the main stream, nitrogen gas should be used for pressurization.

With all these ways of air getting into a boiler, it appears that it is most difficult to keep it out. Fortunately, there are methods for rendering it inactive in boiler water.

Using Oxygen Scavengers

One method of removing oxygen from boiler water is to add an oxygen absorbing chemical such as sodium sulfite, as referred to above. This is practical if only small quantities are required for small quantities of oxygen. It is impractical, however, to try to handle large quantities of air by using this chemical in large quantities since constant additions will cause foaming.

Alkalinity of the water must be controlled in conjunction with the use of sodium sulfite. The pH should be 9.5 or higher.

Hydrazine is a chemical frequently used in large utility boilers to react with dissolved oxygen, but it is not recommended for heating boilers because it must be closely controlled. Seldom is such chemical control available in these installations.

Inhibitors are a class of chemicals that deposit a coating on the surface of the steel or react with it in some way to protect it against attack. The former Steel Boiler Institute compound, composed mainly of sodium chromate, was one of these. Similar compounds are available from most water treatment companies. When added to the water in recommended quantities, this chemical will protect boiler surfaces during operation or standby. Since it is harmful if taken internally and since it may stain other products, it should not be used if the steam is used for process work. It has the advantage of imparting a yellow color to the water, which the operator can see in the gauge glass and thus readily determine if more is needed.

Some trouble has been experienced in hot water systems from this material's formation of sodium chromate cyrstals in pump seals, resulting in leakage. Lower concentrations than the 2.2 lb per 100 gal recommended for steam boilers have therefore been suggested for hot water boilers.

The value of this treatment and of another inhibitor containing sodium nitrate and sodium nitrite was established in a series of tests reported in two HPAC articles titled *Pointers on the Care of Low Pressure Steam Steel Boilers*, published in February and April 1962. These tests proved that both the sodium chromate and the sodium nitrite-nitrate inhibitors were effective not only in preventing attack by dissolved oxygen but also in stopping further attack once it had started. There are some limitations on the amount of chlorides or sulfates that can be tolerated, but these are seldom a factor in waters used in heating boilers.

A few years ago, there was a flurry of gadget type water conditioning curealls being offered. One such device was tested in a supply line and proved ineffective in preventing or stopping corrosion of the tubes.

Don't Drain Needlessly

Many boiler owners completely drain their units once or twice a year in the mistaken belief that the water in the boiler is dirty. Actually, this practice, along with that of periodically draining small quantities of water from a boiler, should be discouraged because it causes loss of chemicals and requires makeup water, which brings in more oxygen. If additional chemicals are added each time to compensate for losses, however, little harm will be done. Insurance companies require periodic tests of the low water cutoff, and at such times protection should be insured by adding chemicals.

Instead of inhibitors, alkalizers such as caustic soda may be used. It is recommended that 2 oz of caustic soda per 100 gal of boiler water be added at the time of filling. This will insure a pH of 11 to 11.5, which will greatly reduce the pitting effect of dissolved oxygen. Some prefer a lower concentration, down to 1.3 oz per 100 gal, but outside of the possibility of foaming, the larger quantities can do little harm and can act as a safety factor should losses take place by draining. Alkalizers, however, will not stop pitting once it has started.

In new boilers, or in old boilers that have been retubed, a boiling out using cleaning compounds is recommended. This is necessary to remove oils and other coatings put on the tubes by the manufacturer prior to shipment or storage to prevent rust. These have no place in an operating boiler. Since they may shield portions of the tubes from direct contact with the water, pitting may be accelerated. A good boil-out is recommended, using a cleaning compound such as a detergent or a mixture of 2½ lb of caustic soda and 2½ lb of soda ash per 100 gal of water.

Dew Point Corrosion on Fire Side

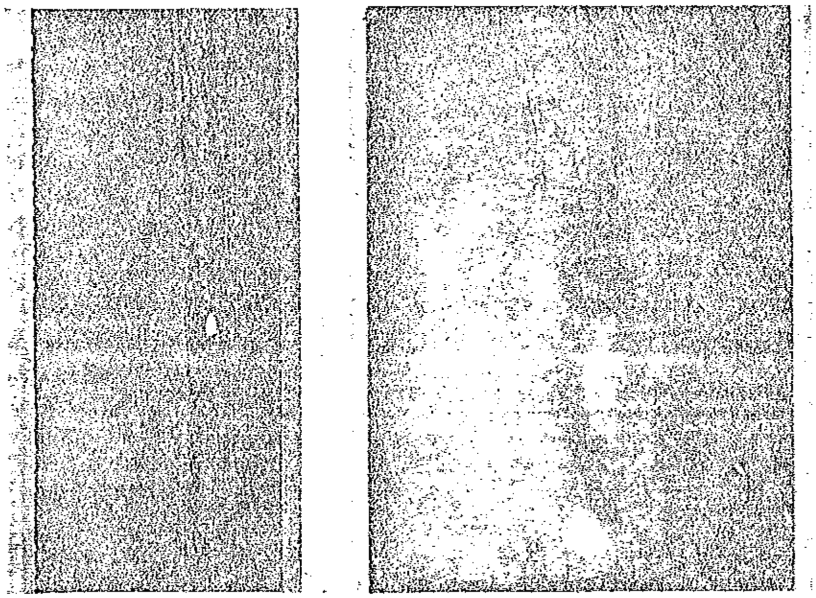
Approximately 15 percent of the tubes examined in our laboratory failed through fire side attack. Corrosion on the fire side of boiler tubes is caused by moisture condensing from the atmosphere during periods of shutdown or from flue gases during operation. This is called dew point corrosion (the dew point is the temperature at which a vapor first condenses).

Dew point corrosion is the localized penetration of tube walls, tube sheets, and other interior metal surfaces of a boiler by concentrated solutions of sulfurous and sulfuric acids. The corrodent always forms on the fire side of the surfaces. If formed in sufficient quantity, it can penetrate more than ½ in. of steel in a year. Since fire tubes or water tubes in a boiler are usually less than 0.200 in. thick, the rapidity of failure after onset of attack is not surprising. Fig. 2 shows examples of fire side corrosion of horizontal tubes.

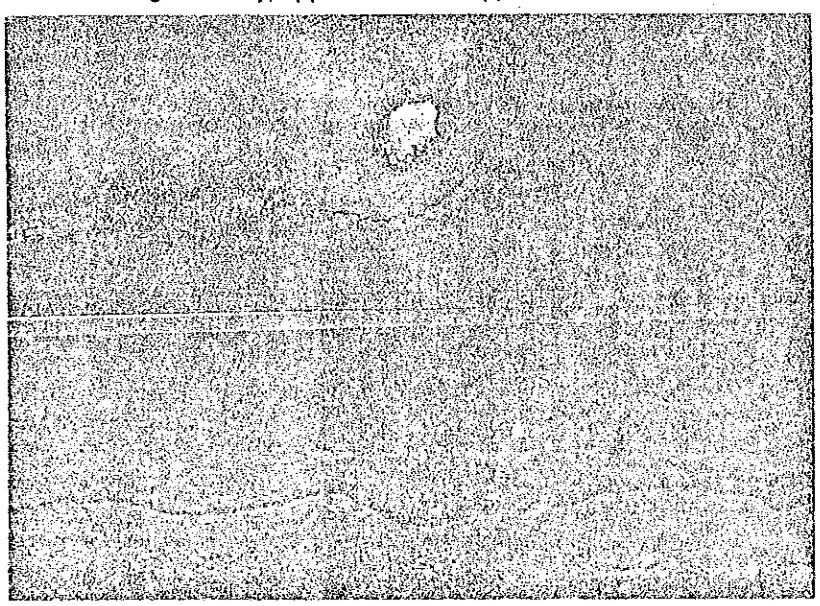
This type of corrosion is especially troublesome in areas with high humidity and is accelerated by the use of high sulfur fuels. Ash deposits accompany the combustion of any low grade fuel. These deposits collect on the fire side of all metal surfaces and contain, among other things, sulfur compounds such as sulfites and sulfates. In the absence of moisture, the deposits are of little concern. When the water vapor in the air condenses on the ash covered surfaces, however, the sulfur compounds readily dissolve to form acidic solutions.

Accumulations of soot on tubes should be periodically removed. Soot attracts moisture; and air, moisture, and steel together result in corrosion. Cleaning may be daily, weekly, or monthly depending on the fuel used and the method of firing.

Some hot water boilers—for example, those in greenhouses—operate at water temperatures of 140 to 150 F, and under such conditions the condensing gases from coal or oil firing form sulfurous



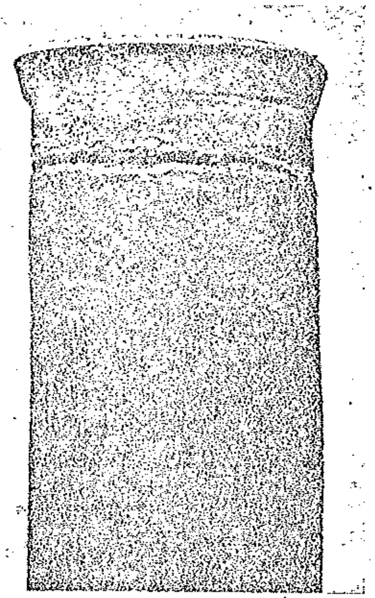
2 DEWPOINT corrosion attacks tubes on fire side. Tube at upper left is carbon steel fire tube. Boiler was fired with low grade fuel oil. Note lack of general corrosion. Tube at upper right is horizontal water tube; view is of underside. Below is shown a carbon steel horizontal fire tube sectioned longitudinallly, upper section at top, lower section at bottom.



and sulfuric acids, which attack the tubes and result in a more uniform type of corrosion. If the percentage of sulfur in the fuel is high, the situation is worse.

Even with gas firing of hot water boilers, serious fire side attack can occur. Some systems use outdoor-indoor controllers to reset system water temperatures up and down as outdoor temperature fluctuates. Low water temperatures can result in condensation of moisture from the flue gas, leading to serious corrosion of the tubes. High water temperatures reduce the probability of attack.

Regardless of the fuel used, dew point corrosion may occur during shutdown periods because of high humidity. When shutting down a boiler under such conditions, the fire side tube surfaces should be brushed and flushed to remove the winter's accumulation of soot and other products of combustion. This should be followed by blowing air through to dry the surfaces. Also, in extremely humid locations, the stack should be disconnected, or the damper at least closed, and a tray of unslaked lime placed in the ashpit to keep the fire side dry. The lime should be renewed whenever it becomes mushy to preserve its drying effectiveness. Oiling the



3 NECKING AND GROOVING is form of corrosion concentrated at ends because of strains.

tube surfaces with a good grade of oil is also recommended after cleaning them at the start of a shutdown period.

Many samples of scale removed from fire side surfaces have been found to be acid when mixed with water, and it is not surprising that the metal is eaten away to eventual failure. In some cases boilers are installed in damp cellars, sometimes with water on the floor constantly. It is obvious that humid air will have ready access to the fire side of boiler tubes if not kept out or guarded against.

Necking and Gooving

Some horizontal tube boilers suffer from a mechanism called necking and grooving. This shows up as a circumferential groove around the outside of a tube where the tube enters the tube sheet, as shown in Fig. 3. It usually occurs at the beginning of the first pass, which is the hottest end of the tubes. In all cases there is some corrosion in evidence in other areas, but it is concentrated at the ends because of strains from two sources. When tubes are rolled in, some unavoidable expansion takes place back of the tube sheet. Also, when a boiler heats up, the metal in the tubes expands, and with the ends fixed in the tube sheets, strains are set up at the ends. Sometimes the expansion is so severe that the tubes loosen in the sheets.

This end corrosion can be combated by more gradual firing, more gradual changes in temperature, and maintaining boiler water free of oxygen and under proper control. #

Follow These Rules

Out-of-Service Measures

- Boil out the boiler with an alkaline cleaner after installing new tubes to remove oil or other coatings from the tube surfaces. These protective coatings are commonly applied to new tubes to prevent rust during storage and transit; they will cause corrosion if left on the tubes during boiler operation.
- Bring a steam boiler to a good steam output as soon as it is filled after draining to deaerate the water. Heat the water in a hot water boiler to 180 to 200 F for the same reason. This will not remove all the air, but most of it will be driven off.
- Add sodium chromate or caustic soda to the water in recommended quantities.
- In damp locations, place a tray of unslaked lime in the ashpit to absorb moisture and close the boiler. Inspect lime occasionally and renew when it becomes mushy.

In-Service Measures

- Keep all boiler fittings air-tight.
- Add sodium chromate or caustic soda to the water in recommended quantities.
- Use a fuel with low sulfur content if possible to avoid corrosive action of sulfur gases.
- Brush, flush, and dry out the insides of fire tubes as often as possible to remove soot and other products combustion, and prevent the accumulation of moisture and condensed sulfur gases.
- Use sodium sulfite regularly in the boiler feedwater to remove the dissolved oxygen.
- Use a feedwater heater or deaerator to reduce the oxygen content.
- Prevent water leakage and avoid periodic draining of water from the system. This results in loss of treatment chemicals and requires makeup, which introduces air into the system.