Mechanism of Boiler And Steam Condensate Corrosion
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First and foremost, inspections should clearly understand process heating unit operations, which should tell the inspector if there is direct food contact of steam with either organic ingredients, packaging materials and/or finished products.

The following process heating operations are based on direct vs. indirect heating:

Indirect- Heat Exchanger
- Plate- eg. HTST Pasteurization
- Kettle- Double Wall
- Tube in Shell

Direct
- Sparging- Direct Steam Injection
- Capping- Lidding Operations
- Steam Blanching
- Steam Peeling
- Extrusion – Pre-Mix Operations

Now let’s review the chemical basis for using boiler additives.

Amine type of boiler additives are used to protect the integrity of steam lines and condensate systems. Steam condensate systems in food plants are generally treated to reduce or retard metal loss caused by oxygen and carbon dioxide corrosion according to the following equations:

\[
Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2
\]

\[
Fe(OH)_3 \rightarrow Fe^{+++} + 2OH^- \rightarrow Fe_2O_3 + 3H_2O
\]

\[
4Fe + 6H_2O + 3O_2 \rightarrow Fe(OH)_3
\]

Therefore iron (steel) can corrode forming ferric oxide (rust) in boiler systems and condensate lines. A further mechanism of corrosion of boiler systems is from dissolved carbon dioxide in the water to form carbonic acid. As carbon dioxide dissolves in the water, it causes the pH to be depressed by increasing the hydrogen ion concentration according to the reaction:

\[
CO_2 + H_2O \rightarrow H_2CO_3
\]

Therefore carbonic acid promotes the iron corrosion process by supplying a reactive hydrogen to form ferrous bicarbonate according to the following equation:

\[
2H_2CO_3 + Fe \rightarrow Fe(HCO_3)_2 + H_2
\]

Carbon dioxide enters the system either as a dissolved gas or combined in the bicarbonate
or carbonate (components of water hardness) alkalinity of the boiler feed water. Dissolved carbon dioxide will be removed from the feed water by a properly operated deaerating heater, but the combined carbon dioxide will remain in the feed water. The potential for carbon dioxide corrosion in a condensate system can be reduced by lowering the alkalinity of the boiler feed water by various external treatment methods such as water softening (ion exchange or reverse osmosis).

Additionally, oxygen can enter the boiler and condensate by direct absorption of air and by introduction with the feed water and subsequent flashing over with the steam. Depending on the plant and operations, either source could predominate. With proper mechanical deaerations and chemical oxygen scavenging all oxygen can be eliminated from boiler feed water. Good system design is required to minimize air contact with the condensate and subsequent oxygen absorption.

Possible Approaches to Reduce the Risk of Corrosion in the Absence of Volatile Boiler Chemical Treatments

It is apparent that the source of corrosion is due to the following:
- Corrosion of iron in water
- Oxygen (dissolved oxygen in water)
- Carbon dioxide corrosion

The rate of both boiler and condensate corrosion can be influenced by the following in-plant approaches:
- Mechanical deaeration of the feed water is an important first step in eliminating dissolved gases such as oxygen and other corrosive gases such as ammonia, carbon dioxide and hydrogen sulfide.

Application of a non-volatile chemical deaerator such as sodium sulfite which is low cost, ease of handling, relatively non-toxic according to the following equation:

$$2\text{Na}_2\text{SO}_3 + \text{O}_2 \rightarrow 2\text{Na}_2\text{SO}_4$$

(the sodium sulfate formed is non-scaling)

- Removal of carbonate and bicarbonate components of the water by ion exchange prior to entering the boiler system.

Utilization of deaeration (physical) in combination with chemical deaeration with sodium sulfite in addition to removal of alkalinity components such as carbonate and bicarbonate may offer a short-term alternative to the use of volatile amines.

Chemical Treatment of Condensate Systems
Condensate systems can be chemically treated to reduce metal loss caused by oxygen and carbon dioxide corrosion. The treatment chemicals consist of neutralizing amines, filming amines and in some cases ammonia.

**Neutralizing Amines:** Neutralizing amines will neutralize the acid (H\(^+\)) generated by the solution of carbon dioxide in the condensate according to the following equation:

\[
R-\text{NH}_2 + \text{H}_2\text{CO}_3 \rightarrow R-\text{NH}_3 + \text{HCO}_3
\]

Creating a condensate pH of 8.5 to 9.0

There are numerous amines that can be used for condensate pH neutralization and elevation. The selection of the appropriate amine is controlled by their stability and distribution ratio characteristics of the particular amine.

The distribution ratio of an amine is defined as

\[
\text{DR} = \frac{\text{amine in vapor phase}}{\text{amine in water phase (condensate)}}
\]

Amines with a distribution ratio greater than 1.0 have more amine in the vapor phase than in the water phase.

The distribution ratios at atmospheric pressure of FDA approved neutralizing amines are:

- Morpholine- 0.4
- Diethylamino ethanol- 1.7
- Cyclohexylamine- 4.0
- Ammonia- 10.0

**Filming Amines**

Another approach to preventing steam condensate line corrosion is the use of amines whose primary function is to create a film or coating when formulated with emulsifiers and dispersants. Filming amines provide protection from both carbon dioxide and oxygen. The major FDA approved amine for this purpose is octadecylamine.