The corrosion and subsequent failure of dry kiln heating coils is an aggravating and costly problem for the kiln operator. This paper briefly reviews the causes and preventative measures pertaining to corrosion of a heating coil’s steam side and related piping.

**Corrosion Mechanisms**

The iron in steel piping is subject to corrosion in the presence of water, by the equation:

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Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2
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Iron + Water \(\rightarrow\) Ferrous Hydroxide + Hydrogen (condensate)

This reaction, in the absence of oxygen, tends to be self-limiting. The ferrous hydroxide raises the condensate’s pH, retarding the reaction rate. At elevated temperatures, the ferrous hydroxide can be converted to ferrous oxide (Fe₃O₄, magnetite), which acts as a passivating, protective layer on the steel’s surface.

The corrosion of the steel is significantly increased in the presence of oxygen, as the reaction forms ferric hydroxide, Fe(OH)₃. Neither it nor the ferric oxide (Fe₂O₃) that it eventually becomes has a retarding effect on the reaction, so the corrosion proceeds briskly, characterized by a pitting appearance.

In the presence of carbon dioxide, a solution of carbonic acid (H₂CO₃) forms in the condensate. Its reaction with iron yields ferrous bicarbonate (Fe(HCO₃)₂), which mildly retards subsequent corrosion by raising the pH slightly. This type of corrosion is characterized by a general thinning of the pipe where contacted by condensate.

**Other Complications from Coil Corrosion**

The impending failure of the coil and related piping is not the only impediment to kiln operation caused by corrosion. The corrosion byproducts can also have a dramatic impact. At some point after the steel corrodes, the dissolved iron may reappear as a deposit. The deposit may form within the coil, downstream of the corrosion, where it impedes heat transfer. Further downstream, it can plug steam traps and condensate lines, reducing flow rates. If the iron reaches the boiler, it can create severe deposits, leading to tube failures.

The discovery of iron deposits should, therefore, prompt an investigation of their source, as the deposits may appear before their corrosive origin is apparent. Conversely, the discovery of coil corrosion should cause the kiln/boiler operator to be wary of harmful iron deposits.
Sources of the Offending Gasses

Oxygen and, to a lesser extent, carbon dioxide are both present as dissolved gasses in a boiler's raw water makeup supply. The primary source of carbon dioxide is from the decomposition of certain minerals in the boiler. Carbonates (CO$_3^{2-}$) and bicarbonates (HCO$_3^-$) are commonly present in makeup water, and they will partially decompose in the boiler to form carbon dioxide.

There is an interesting aspect to this type of carbon dioxide evolution. Carbonates and bicarbonates are generally more plentiful in "hard" waters (those with high levels of calcium and magnesium) than "soft" waters. Therefore, it is reasonable to expect more carbon dioxide contamination where hard water is used for boiler makeup. Unfortunately, the installation of a water softener will not reduce the carbonate/bicarbonate content or its subsequent decomposition to carbon dioxide.

When oxygen and carbon dioxide are introduced and/or form in the boiler, they are readily purged from the boiler as non-condensable gasses, given their poor solubility in the hot boiler water. Traveling with the steam, they are then free to dissolve into the condensate as the steam condenses.

Oxygen and carbon dioxide can also be drawn directly into the coil through leaks of various kinds. This commonly occurs after the steam supply valve is closed and the residual steam condenses, drawing a slight vacuum. It should be noted that this method of intrusion also permits entry by another corrosive agent, namely the volatile organic acids that are driven from the lumber during the drying process.

Methods of Prevention

Mechanical Deaeration

The boiler feedwater should be preheated to drive off the majority of dissolved gasses that enter with the makeup water. This is the preferred method for reducing oxygen contamination of the steam.

Chemical Oxygen Scavenging

This involves the addition of a chemical to react with any oxygen that remains after deaeration. Ideally, the oxygen scavenger is fed to the storage section of the deaerator or feedwater tank. This affords it the maximum reaction time prior to entering the boiler. The most common scavenger is catalyzed sodium sulfite, fed at a rate that produces approximately 40 ppm residual sulfite in the boiler water.

Repair of Leaking Coils and Related Piping

This helps prevent the intrusion of corrosive gasses at the kiln itself, which are drawn into the system when a periodic vacuum is pulled. In addition, repairing leaks will also help reduce steam/condensate losses. This decreases the requirement for makeup water and its corrosive agents. Perhaps most importantly, eliminating steam leaks into the kiln also allows the operator to control the drying process more accurately.
Coil Venting

Deliberate venting from steam coils is a somewhat experimental process, meeting with mixed results. In theory, a small vent hole is made on the outlet side of the coil, through which non-condensable gasses are discharged. There are differing opinions as to how well this works, considering the risk of steam loss during coil operation, and air intrusion afterwards. A more elaborate scheme proposes the installation of thermostatic traps at the vent holes, although the success of such an arrangement is unknown.

Condensate Conservation

With the exception of steam used for conditioning/equalizing, all steam should be condensed and returned to the boiler for reuse. This requires the prompt repair of leaking coils and related piping, maintenance of steam traps, and ensuring that the condensate return system is in good operating order. These steps will reduce your requirement for raw makeup water and its corrosive agents.

Maximize Water Quality

Any boiler/kiln installation will require some makeup water. The operator can reduce the potential for corrosion by improving certain aspects of its mineral content. In some cases, more than one water source may be selected. In general, the source that exhibits the lowest alkalinity will produce less corrosion in the coils. Furthermore, this “softer” water may have a lower potential for producing mineral deposits, and require less treatment chemical to condition it properly.

Makeup water may also be “dealkalized” by suitable equipment. This will reduce its tendency to produce carbon dioxide in the boiler, and related corrosion.

Prevention of Waterlogging

Any discussion of waterlogging in a steam coil should be accompanied by a discussion of subcooling. As condensate backs up in a coil, its temperature drops below that at which it condensed; this is called subcooling. As its temperature drops, the condensate can more readily absorb oxygen and carbon dioxide from the steam space above it, resulting in a more corrosive condition.

Therefore, the prevention of waterlogging is crucial to corrosion reduction. The selection and maintenance of the steam traps and condensate piping design is critical. When these issues are overlooked, a frequent victim is the lower half of the booster coil in a double-track kiln, particularly when the condensate return tank is above-ground. At low steam flows, there is insufficient pressure to evacuate the coil. The steam/condensate interface becomes extremely corrosive as the temperature drops, and coil failure is predictable.

The Use of Volatile Amines

A group of chemicals known as volatile amines can be used to prevent corrosion within the coils and related piping. Ideally, amines are fed directly to the steam header, whereupon they flash to a vapor that travels with the steam.
Neutralizing amines will dissolve in the condensate to counteract the acidity associated with carbon dioxide contamination. Neutralizers are normally added in sufficient quantity to maintain condensate pH levels in a safely alkaline (greater than 7.0) range. A target pH of 8.0 - 8.5 is typical.

Upon reaching condensing temperatures, filming amines form a non-wettable barrier on the inside of the coils and related piping. This effectively prevents corrosion due to oxygen gas contamination as well as mildly acidic conditions.

Fed properly, the film is only a few molecules thick, so as to not interfere with heat transfer. Care must be taken to not overfeed filmers, as they can remove preexisting deposits of corrosion byproducts, forming large volumes of sludge and other debris in the condensate return system. Feed rates that produce a filmer residual of about 1 ppm in the condensate are typical.

"Intelligent" Sampling

When sampling kiln condensate to evaluate its chemical characteristics, it is absolutely essential to understand the basic principles that produce its chemistry. Important factors to remember include:

A. Condensate is relatively pure water; chemists call this "poorly buffered." As such, even slight contamination while sampling will produce erroneous test results. Additionally, some testing methods (such as electronic pH meters) do not perform well with poorly buffered solutions. Be prepared to use and compare several testing methods.

B. Be aware of the effects of subcooling on condensate pH. A coil that is idling at low steam flow may produce acidic condensate, when the adjacent kiln is producing "acceptable" condensate at high steam flows. Therefore, sampling of composite flows from a common point can produce misleading results.

C. Be aware of the piping configuration of the kiln, and how your condensate sample may become contaminated by other parts of the system. A common mistake involves drawing a sample from a condensate receiver tank that is contaminated by boiler water carryover. The sample will exhibit a "safely" alkaline pH, leading the operator to adjust amine dosages accordingly. Meanwhile, the kiln coils are slowly being dissolved by condensate that is actually acidic.

Summary

Condensate corrosion is a well-understood process that is preventable through a variety of mechanical and chemical means. The reader is encouraged to use the methods presented herein, with the assistance of an experienced consultant, to achieve this goal.