

## Electromagnetic Filtering of Magnetite from Steam Boiler Condensate

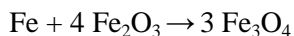
By Joel Meissner

Magnetite formation within a steam boiler system is costly to plant managers as a result of increased maintenance and lost production time. Does your steam plant have problems with Magnetite? Talking with pulp and paper mill managers has yielded surprising responses to that question. While some understand the complexities of water chemistry and the resulting formation of Magnetite along with the difficulties these particles present, others have stated “We don’t have a problem with Magnetite; in fact it helps our system.”

So is Magnetite a problem or not? It is true that a thin film of Magnetite along the water side of a steam boiler tube is beneficial as it passivates the tube surface and aids in the prevention of corrosion. Chemical additives are often added to the makeup water upon commissioning a new boiler to accelerate the formation of this protective layer. An additional benefit comes from the fact that the film acts to improve thermal transfer efficiency.

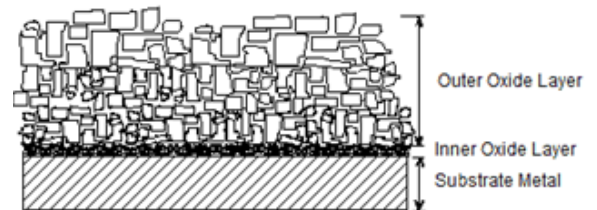
### Magnetite Formation

To fully understand the benefit of Magnetite let’s first look at how Magnetite is formed within a steam boiler system. Magnetite is a product of the iron oxide called Hematite. It is formed on the steam side of the boiler tubes under pressure and high temperature in the presence of water and can be expressed by the following equation.

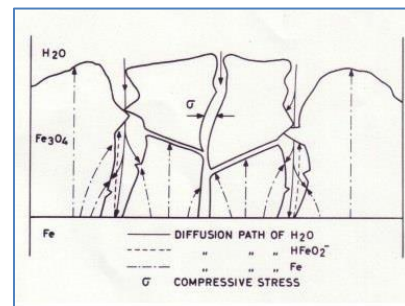


So if a Magnetite film protects the boiler tubes from corrosion and increases thermal transfer efficiency, why is Magnetite formation a problem? The Magnetite film is actually comprised of two layers. The inner layer, directly in contact with the boiler tubes, is dense, compact and continuous, providing excellent corrosion protection. The outer layer is less dense, porous, and loosely bound to the inner layer. Each of these layers will continue to increase in thickness due to water diffusion in the outer porous layer, and latticed diffusion in the inner layer. Quite simply, over time the

layer increases in thickness and a coarser porous scale begins to form on top of the thin layer (see illustration below).



If left undisturbed, the growth rate decreases. There are at least two mechanisms which cause the disruption of this coarser layer. The first is chemical in nature. The porous layer allows dissolved oxygen in the water to diffuse through the pores and creates conditions for superheated boiling below the surface of the scale. The pressure from the expansion of the bubbles in these areas will weaken and fracture the Magnetite film.



Courtesy of “The Protection Effectiveness of Magnetite Layers in Relation to Boiler Corrosion.” W.M.M. Huijbregts, A. Snel (1)

The second mechanism is mechanical in nature as the Magnetite and the steel tube have significantly different coefficients of expansion. When the boiler is shut down for maintenance or production downtime the tube walls cool and contract. The strain developed between the tube and the Magnetite layer will fracture the scale. In either case, the result is that the coarse scale breaks free from the surface and enters into the water condensate system. The surface of the boiler tube where the scale broke free is now subjected to accelerated corrosion. Once the protective layer of Magnetite is compromised, highly caustic ferric chloride within the

water system will enter into these microscopic pores and begin to corrode the steel tubing. (2)

### *Magnetite Scale Problems*

Within the boiler itself, the biggest problems caused by scale is overheating leading to the rupture of boiler tubes. While the thin dense film of Magnetite is thermally conductive, thicker porous layers create a more ceramic-like insulating layer which limits the thermal transfer. It is estimated that a scale thickness of 1/16" will increase fuel consumption by as much as 12.5%. This phenomenon leads to premature failure through softening, bulging and eventual rupturing of the boiler tubes. Even before a catastrophic rupture occurs, loss of heat transfer efficiency, reduced flow, and complete plugging of the tubes will lead to reduced performance and increased cost to maintain temperatures and flow.

In summary, Magnetite scale can cause

- thermal damage
- increased cost to maintain performance
- increased cost to clean and repair tubes
- unscheduled downtime
- reduced working life of a boiler

While excessive Magnetite scale not only damages heat transfer surfaces within the boiler, the shedding of this scale creates numerous downstream problems in the form of fouling. Fouling is the restriction of flow in piping and equipment. Process equipment, filters, sand beds, screens, needle valves, and steam traps are susceptible to reduced performance and in some cases complete blockage from Magnetite particles. This fouling directly affects both the equipment availability and cost of operations. Corrosion products and impurities can accumulate in the secondary side of steam generators, causing accelerated corrosion, steam flow disruption and heat transfer loss. Components are cleaned either mechanically, such as by scrubbing and grinding, or chemically through acid etching.

### *Magnetite Control*

One method of controlling excessive build-up of Magnetite particulates is the process of boiler blowdown. It is used to control boiler water parameters to minimize the accumulation of scale, corrosion, carryover and other problems. Suspended solids which

are introduced by feedwater, chemical treatment precipitates, and soluble salts, are removed through the regular use of blowdowns. In essence, the particulate loaded water is blown out of the system and replaced with cleaner make-up water.

Inefficient blowdown may lead to carryover of particulate laden boiler water into the steam system which leads to the formation of solid deposits. But excessive blowdown wastes energy, water, and expensive treatment chemicals. Blowdown rates typically will range from 4% to as high as 20% when makeup water contains high solids content.

An example would be a boiler operating at 50,000 lb/hr at a pressure of 125 psig with a blowdown heat content of 330 Btu/lb. If the continuous blowdown system is set at 5% of the maximum boiler rating, then the blowdown flow would be about 2500 lb/hr containing 825,000 Btu. If the boiler runs at a typical efficiency of around 80%, and the heat requires about 1050 cu-ft / hr of natural gas, then the loss of energy is approximately \$42,000 per year based on 8000 hours of operation at \$5 per 1000 cu-ft. (3)

Any reduction in blowdown contributes to water and fuel savings. When uniform concentrations are maintained at or near maximum permissible levels in the boiler water, savings result in several areas, including makeup water demand, cost of processing water, cost of blowdown water waste treatment, fuel consumption, and chemical treatment requirements. These savings are noticeably greater where makeup water quality is poor, where heat recovery equipment is nonexistent or inefficient, and where operating conditions are frequently changed.

Removal of Magnetite within the condensate system is therefore beneficial for numerous reasons.

- Reduced blowdown frequency
- Reduced reintroduction of Magnetite particles into the steam cycle
- Reduced fouling of screens, filters, heat exchangers,
- Improved heat transfer efficiency
- Improved efficiency of heating fuel
- Reduced dependence on chemical additives
- Reduced downtime
- Reduced maintenance

### *Filtering Alternatives*

There are several mechanical devices available to filter the condensate return and prevent Magnetite particles from reentering the steam boiler. Several considerations must be given when choosing a condensate filter including pressure, temperature, flow rate, and certainly the startup costs as well as on-going costs. The options include cartridge filters, ion exchange condensate polishers, mixed bed condensate polishers, sand filters, precoat filters, reverse osmosis, and electromagnetic filters.

The most common technology utilized within the paper industry is the ion exchange condensate polisher. The units are robust and if well maintained and under proper operating conditions provide low Magnetite concentrations at the outlet although they are limited to certain flow conditions. The mixed bed polishers are suitable for power generation stations but the condensate temperatures at paper mills are too great for available anion resin grades. These two types polishers are usually preceded by some other form of filtration to remove the larger solids to prevent fouling. Sand filters are another low-cost option although they quickly become fouled with particulates reducing the flow rate and requiring them to be rebuilt frequently.

Cartridge filters are frequently used since the implementation cost is relatively low and the filter media has improved over the years to handle the higher temperatures in the paper mill condensate lines. While this is a simple well understood technological solution, the cost of filter cartridges and regular maintenance offset the initial savings. Shortly after a boiler start-up operation, the particulates which shed from the boiler tubes will quickly cause fouling of the cartridges.

Reverse osmosis is an effective method of removing both particulates and dissolved solids. It works by passing the feedwater through a semipermeable membrane by pressurizing the inlet side sufficiently to overcome the osmotic pressure. The downside to these filters is that they cannot handle pressures greater than 1000 psig, electrical usage costs are very high, and significant amounts (20-30%) of energy laden condensate are dumped into the waste stream.

### **Electromagnetic Filtration**

Another solution is electromagnetic filtration or EMF as it is commonly known. Electromagnetic filtration is a simple, cost-effective way to remove suspended, magnetically susceptible material from process streams.

Originally, electromagnetic filters (EMFs) were intended to remove Magnetite ( $\text{Fe}_3\text{O}_4$ ), which is present in most boiler condensate and in nuclear power systems, but they have also been proven effective in removing weakly magnetic species such as Hematite ( $\text{Fe}_2\text{O}_3$ ) and copper. Other materials such as cobalt, nickel, and chromium, which form spinel crystals or ferrites, can also be efficiently removed.

Modern EMFs are extremely efficient. They can easily remove over 95% of the Magnetite present in a condensate stream, and depending on the conditions in a particular application, they can remove over 90% of total iron and well over 50% of the copper found in typical boiler condensates.

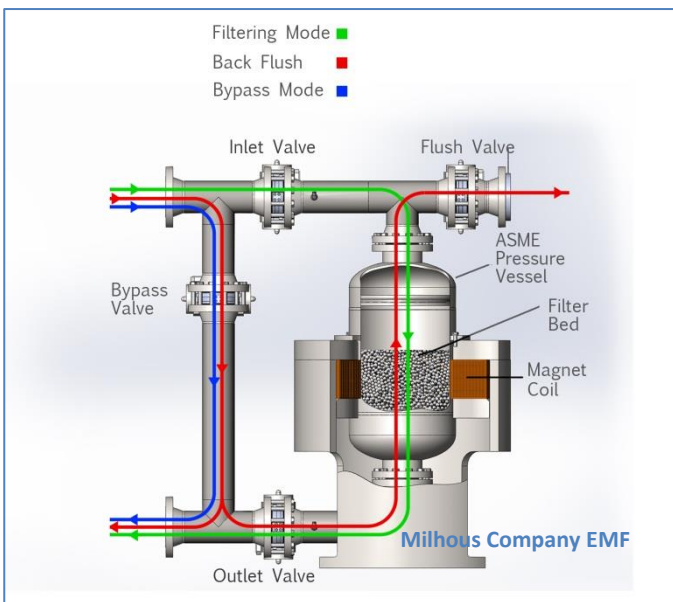


EMF units employ an electromagnetic solenoid wrapped around a vessel which is filled with a stainless steel matrix. When the magnet is energized, the matrix in the vessel will attract and hold the Magnetite particles without affecting the flow of the condensate lines. Once the pressure differential begins to increase, the filter controller automatically degausses the filter media and back-flushes itself much like a swimming pool filter. These filters will handle the flow rate and water temperatures of a paper mill condensate line without any further maintenance for up to 40 years of continuous operation. One huge advantage is that the units will extract particles down to submicron sizes without any fouling of the bed. Once the units are installed, they run and maintain themselves. There are two types of EMF units available, a ball matrix and a filamentary matrix.

The ball matrix filter available from the Milhous Company in the United States was originally developed in the 1960's by Siemens. Babcock & Wilcox purchased the technology from Siemens and spent considerable resources to reengineer it to maximize the efficiency of the filter. In 2009, Milhous Company then purchased the technology and today offers six different sizes for varying applications.

The matrix material is comprised of type 430 stainless steel balls and has a void volume of 40%. The efficiency of a ball matrix filter is not affected by the micron size of the material to be filtered. They can remove suspended material from 20 microns down to 0.08 microns in size and when used in a system where the suspended material is predominantly Magnetite, they are independent of the flow rate through the filter up to the maximum design flow rate.

A ball matrix filter is flushed by degaussing the magnet and the bed of balls and the flow is reversed to



upset the bed and tumble the balls which knock the corrosion products from their surfaces. This tumbling occurs within 15 seconds and is largely responsible for the tremendous bed-life of the matrix which will last for approximately 40 years.

The second type of electromagnetic filter available is the filamentary matrix filter produced by Sala of Sweden. The matrix is composed of either expanded metal, or wire mesh and compressed steel wool. The media within these filters will last for several years before requiring replacement unlike the 40 year lifespan of the ball matrix filters. As the steel wool begins to

deteriorate, small particles may actually be introduced into the condensate if they are not captured in the screens. Replacing the media requires breaking down the pressure vessel to access the screens whereas a ball matrix vessel never needs replacement of the media. Filamentary matrix EMF units require an additional air accumulator tank and high pressure air for flushing making it slightly more complex than the ball matrix filters.

Electromagnetic filters work by intensifying the magnetic force within the matrix to capture the magnetic particles. Several factors influence the ability of the matrix to attract and hold these particles. The greatest factor is the percentage of Magnetite or strongly magnetic species within the condensate stream. Secondly, the flowrate is another variable which greatly affects the performance of the filter as the magnetic force must overcome the dynamic force of the flowing liquid which tends to wash the particles out of the matrix. The greater the velocity, the greater the magnetic force must be in order to hold the weakly magnetic or paramagnetic particles such as Hematite.

Removing weakly magnetic or paramagnetic particles with an EMF may sound paradoxical but it does occur and is quite predictable. Weakly magnetic particles will agglomerate with strongly magnetic particles such as Magnetite and will be captured by the magnetic force of the filter media. Particles such as copper, chromium, and nickel on the other hand will combine chemically with Magnetite to form spinel crystals which are strongly magnetic and removed very efficiently as long as the Magnetite concentrations are significant enough. Elemental copper in some condensate streams will plate around the Magnetite particles making it relatively easy to remove it from the fluid. Data has shown that a ball matrix filter will remove over 60% of copper in the stream if over 50% of the iron present is in the form of Magnetite.

Tests have shown that the Milhous Company filter is the most effective overall. It operates at significantly lower power consumption, is more efficient in removing up to 95% of all magnetic particles, and removes as much as 50% of paramagnetic particles such as copper. The Milhous filter was originally developed for use within the nuclear power industry and met the rigorous requirements for continuous maintenance-free operation. It is the only design to offer a truly permanent matrix

and consistent efficiency for the life of the equipment. Because of the unique ability of this matrix to be thoroughly cleaned each time the filter is flushed, the matrix will never have to be replaced or chemically cleaned to restore filtration efficiency.

Since electric power is the only consumable associated with the filter, a great deal of effort was made to design a series of filters that demand a minimum of power. The result is that the Milhous units typically use a third of the power required of their competitor. Depending on which size unit is installed, the power supply to energize the magnet coil will draw between 14 to 19 Amperes of DC power. When power consumption is considered over the 40 year life-span of the filter, the Milhous company equipment has an overwhelming cost advantage over competing technologies.

The Milhous EMF unit consists of a carbon steel pressure vessel filled with small magnetizable stainless steel balls surrounded by a magnet coil and coil cooling circuit. An outer carbon steel jacket and support structure houses the filter, magnet coil, and cooling circuit. The outer carbon steel jacket provides magnetic shielding to eliminate stray magnetic fields for safety purposes. The power control module is fully programmable to allow for automatically degaussing and backflushing the filter on either a predetermined schedule or manually as needed.

During normal operation, the flow of process water is downward through the magnetized ball bed. The inlet and outlet valves are open and the flush and bypass valves are closed. High field gradients in the interstices between the balls attract the magnetic particles which collect on the balls. The pressure drop through the filter bed is low and does not increase significantly as the filter becomes loaded.

The automatic cleaning cycle consists of the following steps:

- Opening the bypass valve
- Closing the process inlet and outlet valves
- Degaussing the filter bed
- Opening the process outlet and flush outlet valves.

With the upward flow of flush water into the filter, the ball bed is fluidized and balls rise and fall in a tumbling action. This tumbling action scrubs and dislodges the collected particles which are flushed

through the outlet line. This action is schematically shown in the diagram above. The entire cleaning process is completed in approximately 2 minutes. The matrix balls are designed for the life of the filter and never need replacement.

*International Paper has made it a corporate policy to include an electromagnetic filter in all their pulp and paper mills.*

### **Long Term EMF Study Results**

After 4 years of continuous operation in a pulp and paper mill in the United States several observations were made by the mill operators about the Milhous EMF. During that time over 2 billion liters (550,000,000 gallons) of condensate had been filtered with almost 230 kilograms (500 pounds) of impurities having been removed from the steam generator feedwater. During one scheduled outage, the water sides of the steam generator were inspected and found to be “whistle clean”. The maintenance engineer determined that the previous requirement for chemically cleaning of the tubes every two years could safely be extended up to six years. They also noted that the deaerating tank and other components downstream of the EMF were almost devoid of iron oxides and related impurities normally deposited by the condensate. Analysis of water samples taken prior to the scheduled outage showed that the filter was removing an average of 96% of the magnetic iron oxides. The facility reported that:

- They experienced increased boiler availability
- There were fewer boiler cleanings required
- Softener maintenance had been reduced
- They had a reduction in feedwater makeup
- The unit had already paid for itself through reduced maintenance and greater boiler availability

Furthermore, they estimated that since the filter is using approximately 5 kilowatts of power with no other consumables or labor required, it was costing less than 5 cents to purify 3,785 liters (1,000 gallons) of condensate. (4)

Chemical and mechanical cleaning of boilers and heat exchangers to remove Magnetite is done on a frequent basis throughout the pulp and paper mill industry. Since EMF provides a more cost effective and

efficient method of performing this task, it appears that it is an underutilized solution. Ion exchange columns still cannot handle the high temperatures and cartridge filters cannot sufficiently handle the large flows required to efficiently filter out Magnetite from large condensate streams. Electromagnetic filters generate no waste products and can operate under much higher temperatures and flow rates than traditional filters. Minimal maintenance and low operating costs along with a 40 year lifespan make them an attractive alternative for steam plant operators. This proven technology has yet to be fully recognized for the economic advantages it provides.

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