

Measuring Internal Oxide Scale in Boiler Tubes



Background

The very high temperatures found inside steam boilers (in excess of 1500 °F (800 °C)) can cause the formation of a specific type of hard, brittle iron oxide called magnetite on the inside and outside surfaces of steel boiler tubing. At very high temperatures, water vapor will react with the iron in the steel to form magnetite and hydrogen according to the formula: $3 \text{ Fe} + 4 \text{ H}_2\text{O} = \text{Fe}_3\text{O}_4 + 4 \text{ H}_2$

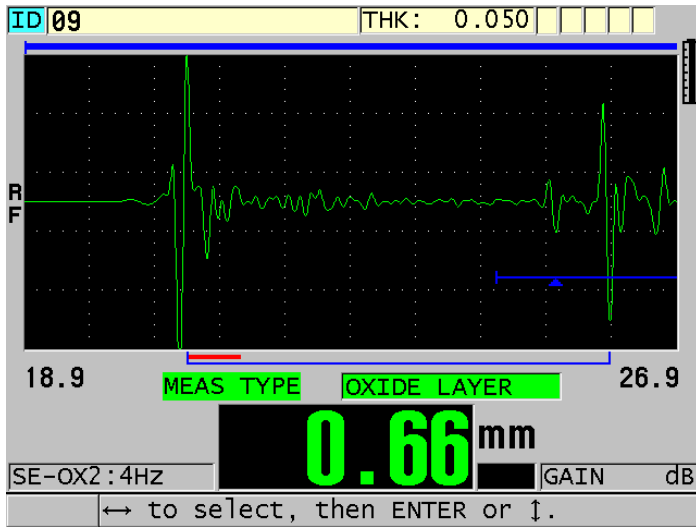
The speed of this reaction increases with temperature. Oxygen atoms will diffuse inward through the magnetite layer, and iron atoms will diffuse outward, so the scale continues to grow even after the tube surface is completely covered.

Magnetite scale acts as thermal insulation on the pipe, since the thermal conductivity of scale is only about 5% that of steel. When heat can no longer transfer efficiently from the flame through the tube into the steam inside, the tube wall will heat up to temperatures beyond the intended operating range. Long-term exposure to overly high temperatures, combined with the very high pressure inside the tube, leads to intergranular micro-cracking in the metal and to creep deformation (a slow swelling or bulging of the metal), which, in turn, eventually leads to tube failure by bursting.

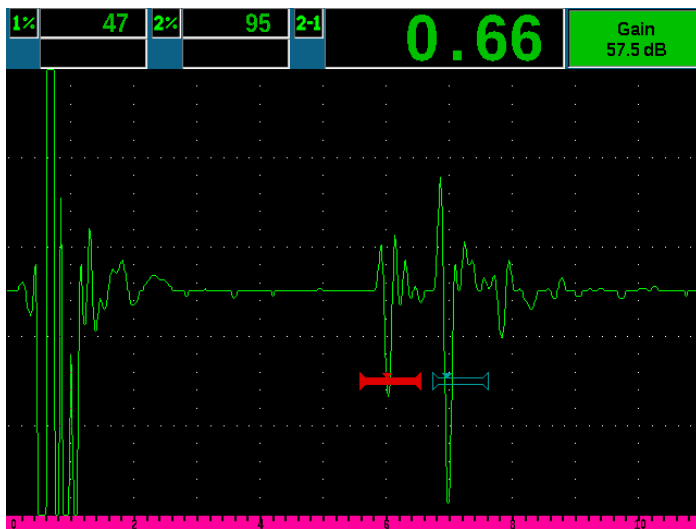
A secondary issue is oxide exfoliation, in which pieces of oxide scale break off (usually due to thermal stresses during boiler startup or shutdown). These hard pieces will be carried by the steam flow into the turbine, where, over time, they will cause erosion damage.

The growth of magnetite scale and the associated metal damage are primary limiting factors with respect to boiler tube service life. The process begins slowly and then accelerates; as the scale grows thicker, the tube wall becomes hotter and that, in turn, increases the rate of scale growth and metal damage. Studies in the power generation industry have indicated that the effect of scale is relatively insignificant up to thicknesses of approximately 0.012 in. or 0.3 mm, but that beyond that thickness the negative effects of scale increase rapidly. Periodic measurement of scale thickness enables a plant operator to estimate remaining tube service life and to identify and replace tubes that are approaching the failure point. Ultrasonic testing provides a quick and nondestructive method for measuring scale. Handheld, portable instruments, such as the 38DL PLUS® thickness gage or the EPOCH® series flaw detectors, can measure internal oxide layers down to a minimum thickness of approximately 0.2 mm or 0.008 in. using the commonly recommended M2017 transducer (20 MHz delay line). The specialized M2091 transducer, which is a 20 MHz shear

wave probe, can be used along with shear wave couplant to measure down to approximately 0.152 mm or 0.006 in. In all cases, the coupling surface must be smooth and, in some cases, surface preparation will be required.



Typical internal oxide measurement with a thickness gage and M2017 delay line transducer (zoomed)



Typical internal oxide measurement with a flaw detector and M2017 delay line transducer, showing delay line echo at left of screen

Further detailed information on the subject of oxide scale and its effects on boiler tubing may be found in the book *Metallurgical Failures in Fossil Fired Boilers* by David N. French (John Wiley Sons, 1983).

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Products used for this application



EPOCH® 6LT

The EPOCH 6LT portable ultrasonic flaw detector is optimized for one-handed operation and delivers excellent performance in rope access and high-portability applications. Lightweight with an ergonomic design, the instrument fits securely in a user's hand or can be strapped to the leg for rope access applications.



38DL PLUS®

The 38DL PLUS advanced ultrasonic thickness gage uses dual element transducers for internal corrosion applications and features THRU-COAT® technology and echo-to-echo. Single element transducers can be used for very precise thickness measurements of thin, very thick, or multilayer materials.



EPOCH 650

The EPOCH 650 conventional ultrasonic flaw detector offers excellent inspection performance and usability in a wide variety of applications. This intuitive, rugged instrument is a continuation of the popular EPOCH 600 flaw detector with additional capabilities.

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