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" FROM THE FIELD "

Magnetec Inspection, Inc.

Overheating & Cooling

Excellence in Eddy Current Inspection Technology & Failure Analysis

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Subject: Localized Over Heat & Associated Failures in Stainless Steel Pipe

Temperatures in excess of recommended limits will cause the steel to expand & creep unevenly & then shrink unevenly causing severe distortion (buckling), discoloration & scaling.

The Air Heater was located in a major mid-western food preparation company which process's raw food products to finished product. The Air Heater was inspected due to recent pipe failures which contaminated both equipment and bulk process lots. The pipe material failure occurred after a 10 year service cycle with numerous heat and cool down cycles. The Air heater operates as a 2 unit parallel feed heater with combustion gas to the outside of the pipes and filtered air to the pipe I.D. surfaces. The combustion gas generated from fuel oil burners enters the pipe matrix from a bottom duct inlet which feeds hot gases to one side of the heater which encompasses approximately 1/3 of the total pipe matrix. The heat is supplied across the bundle matrix with entry adjacent to the 21st row of pipes and flows through the pipe matrix and exiting via a stack. The air heater relies on radiance and convection heat transfer from the burners to the air supply pipe to heat the air with forced circulation to both systems. The hot gas flow then travels through 4 flow baffles as it passes through the pipe length. The filtered air enters through an inlet duct system to the bottom tubesheet and pass's once through the pipe length where it enters the plant hot air supply system. The hot combustion gas's enter the heater at 1600 degrees and impact the pipes which form the fist pass of directed gas flow through the heater. This section accounts for 40 pipes (approximately 10% of the total pipe matrix) and 1/5 of the pipe length which is in direct contact with the 1600 degree combustion gas. This firing condition to the heater makes this inlet section a high temperature area and would tend to overheat the piping at a much higher rate than other parts of the pipe matrix. The tubing consists of 400 straight tubes – 2" pipe O.D. X Schedule 5 wall X 304L X 20 Foot long and are currently 10 years old. Upon visual inspection there were numerous warped tubes with cracks and holes noted near/ adjacent to the inlet hot gas ducting which corresponds to the high heat area. The operating temperatures were in the upper range for this material and due to the age of piping would have experienced many years of temperatures near the sensitization zone for this material.

The materials of construction were specified as 304L stainless steel, which has excellent thermal properties within recommended operating limits. Thermal stresses induced from over-heating and cooling result in the localized buckling that can be seen on the piping. Temperatures in excess of recommended limits will cause the steel to expand and creep unevenly and then shrink unevenly causing further distortion. The 304L stainless steel with its chrome/nickel content is a highly heat resistant material and well suited to the application. The rate and amount of pipe distortion is also dependent on the number of heating and cooling cycles over the 10 years of service.

INSPECTION:

An inspection of the Air Heater piping showed severe distortion (buckling), discoloration & scaling. A pipe section was seen to have an extensive circumferential crack. The Air pipes were observed with light discoloration which indicative of an overheat condition.

The Eddy Current inspection detected inter-granular in the overheat locations adjacent to the heated air supply inlet with localized overheat affects diminishing as the flow passes across the pipe matrix & heat flux is dissipated by heat transfer to the pipes. There were numerous pipes which contained mechanical damages from buckling and crimping which correlates to the high heat flux zones and is consistent with material actions in overheat conditions. There were pipes with cracks which is also a secondary failure mode associated with the primary overheat condition. Overheat damage can be associated with low heat over long time frames, high heat over short time frames and high heat flux differentials which can occur with fast heat-up or cool down scenarios. The damage noted could have been from a single event or most likely a combination of the separate heat conditions.

View of Pipe Directly Adjacent to Inlet Hot Combustion Gases

Buckled Tube with Associated Failure

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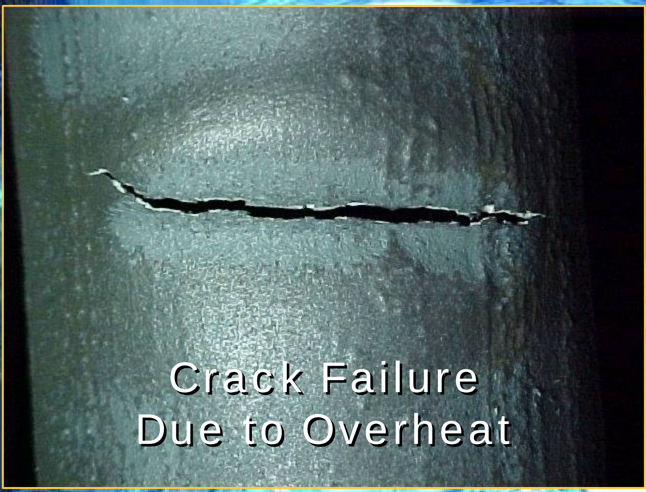

Crack Failure
Due to Overheat

Numerous Pipe Damages near Inlet
of Combustion Gas

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INTERGRANULAR CORROSION:

Exposure of the 18-8 austenitic stainless steels to temperatures in the 800°F to 1500°F (427°C to 816°C) range may cause precipitation of chromium carbides in grain boundaries. Such steels are "sensitized" & subject to intergranular corrosion when exposed to aggressive environments. The carbon content of Alloy 304 may allow sensitization to occur from thermal conditions experienced by autogenous welds and heat-affected zones of welds. For this reason, the low carbon Alloy 304L is preferred for applications in which the material is put into service in the as-welded condition. Low carbon content extends the time necessary to precipitate a harmful level of chromium car-bides but does not eliminate the precipitation reaction for material held for long times in the precipitation temperature range.

What happens is this: when chromium-nickel steel is heated to a temperature range of 800° to 1590°F, the carbon in the steel combines with chromium to form chromium carbides. This transformation is called carbide precipitation and reduces the corrosion resistance of the steel. The chromium is reduced in this heat-affected area and makes the steel subject to what is known as intergranular corrosion. Some stainless steels are known as low carbon grades to minimize this carbide precipitation; others, such as 321, are special alloys that reduce carbide precipitation by combining and stabilizing the chromium at elevated temperatures.

CONCLUSION:
It would appear that the operating temperature of the stainless steel pipe had been in excess of the recommended limits which resulted in extensive distortion taking place and caused/accelerated grain boundary disruptions and distortions, which greatly reduces the life of the steel.
Temperature probes on the pipe during operation would ensure that the maximum acceptable temperature is not exceeded. This would have prevented the damage from the high heat flux differential that is now evident in the existing pipe.

Pipe samples were removed from the bundle to document the active failure mechanisms and allow for material to be sent out for metallurgical analysis. The inter-relationship of susceptible materials and high heat flux's tend to be a central initiating factor that encompasses the recent failures. Based on the age of the air heater piping, significant overheat damage and economic losses due to food and equipment contamination the heaters were re-piped.