



Investigation on Heat Exchanger Pipe Failure

Papa Rao Mondli · D. Satish Kumar · Marutiram Kaza · Anil Bafna

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Abstract Convection heat exchangers are commonly used for heat transfer in high-temperature furnaces and processes. Pipes from U-bundles of a convection section of a MIDREX direct reduction ironmaking unit heater which carries reducing gas have been investigated for failure analysis. Repeated failures had occurred at a specific location. Samples of the failed pipe were subjected to microscopic and metallographic characterization. Inner diameter erosion and metal dust, carbides, oxides, and carbon were found at the failure location. Optical microscope revealed severe carburization on the inner surface that was in contact with heat exchanger gas. Coarse carbides at the grain boundaries accelerated the wear and corrosion by intergranular cracking. The reducing gas composition (with CO), dust composition (with carbides), and exposed temperatures (> 400 °C) confirmed that metal dusting is the cause of the failure. The high-temperature corrosion of steel is caused by hydrocarbon gases which form thermodynamically metastable carbides of the base metal. Such failures can be avoided by maintaining the pipe surface temperatures below 400 °C or using pipes manufactured from high-temperature-resistant steels.

Keywords Convection heat exchanger · Corrosion · Metal dusting

Background

JSW Steel has a 1.2 million ton per annum (Mtpa) direct reducing iron (DRI) plant based on the MIDREX process at its Vijayanagar, India works. It utilizes Corex gas to produce hot DRI for subsequent use in an electric arc furnace. Corex is a smelting reduction process which produces molten hot metal and generates high caloric export gas. In the DRI process, the Corex export gas and recirculated top gas from the MIDREX shaft furnace are mixed and compressed and subjected to a process to remove CO₂. The gas is then heated to the required process temperature in a convective heat exchanger. This heated gas is then used for the direct reduction of iron ore pellets in the MIDREX shaft furnace. The convective heat exchanger where the gas is heated is a cross-flow, unfinned tubular heat exchanger system where the reducing gas consisting primarily of CO and H₂ (54% CO, 30% H₂, 6% CO₂, 2% H₂O, and 1.5% CH₄) at 1.5 bar pressure is heated from 40 to 460 °C. The heat exchanger is a box-shaped chamber with a burner and combustion chamber at one side and an exhaust line on the other side. The heated air flows through four U-shaped tube bundles as shown in Fig. 1. The gas to these tube bundles is supplied by interconnected headers. Several grades of steel are used in different bundles based on its distance from the burner and combustion chamber and the exposed temperature. Puncturing and thinning of these heat exchanger tubes have been reported primarily in bundles 2 and 3. The failed steel tubes are of ASTM-A335-P11 grade having wt.% as 0.012% C, 0.45% Mn, 0.4% Si, 1.25% Cr, 0.5% Mo with the initial thickness of 4.4 mm. These pipes were designed for long life, and such premature failures are an unexpected phenomenon that has not been previously reported. Erosion problems on the outside of tubes resulting from impingement of wet, high-velocity gases such as

P. R. Mondli · D. Satish Kumar (✉) · M. Kaza · A. Bafna
JSW Steel Ltd, Bellary, India
e-mail: satishkumar.dabbiru@jsw.in

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