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A VIEW FROM THE PENTHOUSE: USEFUL INFORMATION FOR THE WORLD OF BOILERS

SUPERHEATER AND REHEATER TUBE MATERIALS

The materials of construction of a typical superheater or reheater in a high-pressure (>2000 psi) utility boiler vary from the inlet at the low-temperature end to the outlet at the high-temperature end. As the steam temperature rises from around 650°F to around 1005°F for a typical high-pressure drum-style boiler, material changes are made to accommodate both the rising temperature and the potential for increased fire-side corrosion. As the temperature increases, stronger alloys are required. For metal temperatures up to approximately 800°-850°F, carbon steels similar to SA178 and SA210 have been used. Older designs use SA209 T-1 carbon-½ molybdenum alloys to metal temperatures approaching 900°F. For metal temperatures to 1025°F, chromium-½ molybdenum alloys T-11 are preferred. Finally, for Metal temperatures below 1075°F, 2¼ chromium-½ molybdenum T-22 is the workhorse choice. For metal temperatures above 1075°F or more severe fire-side corrosion environments, the austenitic stainless steels of 304H, 321H, and 347H are the preferred grades. Table I gives the oxidation limits for the ferritic alloys commonly used.

TABLE I – OXIDATION LIMITS	
Carbon steel	850°F
SA209 grades	900°F
T-11	1025°F
T-22	1075°F
300-series stainless	1500°F

It should be pointed out that while the oxidation limits for carbon steel and the carbon + ½ molybdenum alloys may be 850° and 900°F and the ASME Boiler Code gives allowable stresses for these materials to 1000°F, the actual temperature limit should be 800°F and 850°F. Both of these alloy classes will graphitize during long-term service exposure. The carbide phase within the microstructure is unstable relative to the decomposition into ferrite and graphite. As graphite formation and growth proceeds, the strength decreases, especially when the graphite develops as a peculiar alignment called chain graphite. The SA209 alloys are more susceptible to this form of graphitization, but cases of carbon steel and chain graphite are known.

The substitution for T-22 of the austenitic stainless steels for applications where fire-side corrosion is a concern have centered on the 304H, 321H, and 347H grades. Table II gives the chemical analysis of these three alloys for chromium and nickel.

TABLE II – COMPOSITION		
	%Cr	%Ni
304H	18.0-20.0	8.0-11.0
321H	17.0-20.0	9.0-13.0
347H	17.0-20.0	9.0-13.0

The basic difference between 304H and the other two is the addition of titanium to 321H and columbium to 347H. For all practical purposes the chromium and nickel compositions are the same for all three. That is to say, if there is a fuel-ash corrosion problem with 304H, the use of either 321H or 347H will not provide a solution. The addition of titanium to 321H and columbium to 347H permits a stabilization heat-treatment that will prevent sensitization during high-temperature service.

Sensitization occurs at temperatures above about 1050°F when chromium carbides form preferentially along the austenite grain boundaries. The carbides deplete the austenite of chromium and the grain-boundary region becomes less corrosion resistant and therefore subject to intergranular corrosion. A stabilization heat-treatment performed at 1650°F forms either a titanium or columbium carbide. With the carbon removed as a high-temperature carbide, there is no free carbon available to form chromium carbide, and sensitization during service will not occur. However, no superheater element is given this stabilization anneal.

There are two principal reasons for not heat-treating superheater or reheater elements at 1650°F. The first is intergranular-corrosion failures in austenitic stainless steels seldom occur. The second is practical, the heat-treatment is expensive and correcting distortion that is likely is time-consuming.

Thus, there is no reason for the use of 321H and 347H, as the corrosion resistance of 304H will be essentially the same as 321H and 347H. The cost differential makes the choice of 304H desirable.

In older reheaters, a 9-chromium 1-molybdenum alloy (SA213 **T-9**) was occasionally used, but the allowable stresses are so low that the superior corrosion resistance of this 9-chromium alloy is not used in higher-stress applications of a superheater. Table III gives a truncated version of the allowable stress values for two 9-chromium alloys and 304H. The newer alloy, T-91 has a similar chromium-and-molybdenum content to T-9, but also includes alloying elements of columbium, nitrogen, and aluminum, which permits heat-treatment and thus has a much higher allowable stress. The values are better than 304H up to about 1100°F. However, the corrosion resistance of the T-91 is still not as good as the 304H material and therefore is not recommended for superheater-tube replacements.

TABLE III – ALLOWABLE STRESSES			
TEMP.	**T-9**	**T-91**	**304H**
°F		**KSI**	
800	12.8	18.7	15.2
900	11.4	16.7	14.7
1000	7.4	14.3	14.1
1100	3.3	10.3	9.8
1200	1.5	4.3	6.1

While the tubing grade of T-91 is not better than 304H for high-temperature applications, the substitution of the piping grade, P-91, does make sense for replacement of P-22 headers. At 1000°F, for example, the allowable stress for SA335 P-91 is 14,300 psi; for SA335 P-22 the value is only 8,000 psi. Thus, high-pressure headers and piping will be thinner, with less welding and may be less expensive to fabricate.

There are some welding concerns with this heat-treated ferritic material, the T-91 alloy. All welds need to be preheated <u>and</u> post-weld heat-treated per ASME Boiler and Pressure Vessel Code rules. There are no exceptions for any size or thickness!

When old superheaters and reheaters are replaced, it seems reasonable to select the low-alloy chromium molybdenum materials, T-11 and T-22 where possible, and use 304H for all other conditions. Substitution of the ½ chromium-½ molybdenum alloy, SA213 T-2, for carbon and carbon -½ molybdenum steels also makes sense.

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