SOME CASE HISTORIES OF FAILURE OF REHEATER TUBES

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Introduction

Failure of reheater tubes in some coal-fired boilers are encountered very frequently. This is in spite of the fact that the operating pressure in reheater is far less than that of superheater. In reheater the pressure is about 30 kg/cm^2 whereas in superheater it is 150 kg/cm^2. A dominant factor causing premature failure is the overheating and consequently creep or hot corrosion failure. The reheaters begin to receive steam only when the turbine is started up i.e., they are not cooled at all for appreciably long time during boiler start up. The same is true in an emergency shut-down of the boiler. In order to avoid overheating, reheaters are usually of convective type and less frequently of platen type. They are arranged in the zone of moderate heating where the flue gas temperature is around 750°C. In some places reheaters are cooled at a start up and shut down by fresh steam supplied through an attEmperature.

Some case histories of the failures of reheater tubes are being described below. Attention is also drawn to the failure of uncooled components : cleats, pins and lugs etc.

Example 1

Figure 1 shows a failed reheater tube from a boiler of 500 MW turbine. The reheater tube was of pendent type placed in the convective zone. The operating pressurre was 25 kg/cm^2 and steam outlet temperature 535°C. Flue gas temperature in the zone was 700-720°C (design). The tube material was 1.25Cr-0.5Mo (T11 grade).

The tube had suffered extensive damage on the outer surface in the form of pits. The dimension of the pits at some places were as big as 40 mm x 10 mm with a max. depth of 2 mm. For example see location 'a' in Fig. 1. The pitted surface bore brownish colour which was in sharp contrast, to the damage free surfaces of the tube. The latter bore usual black oxide. The failure had ocurred only in one coil after about 24,000 hour of service life.

The investigation carried out in NML showed the tube possessed the typical microstructure (ferrite plus bainite) and the mechanical properties also found to be normal. Also, no appreciable diAmetrical expansion was obersved.

Since the tube showed extensive pitted surfaces, x-ray microanalysis was carried out on the pitted surfaces

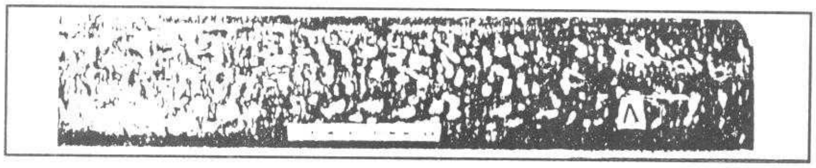

Fig. 1 : Photograph of As-received reheater tubes; pitted surface may be noted

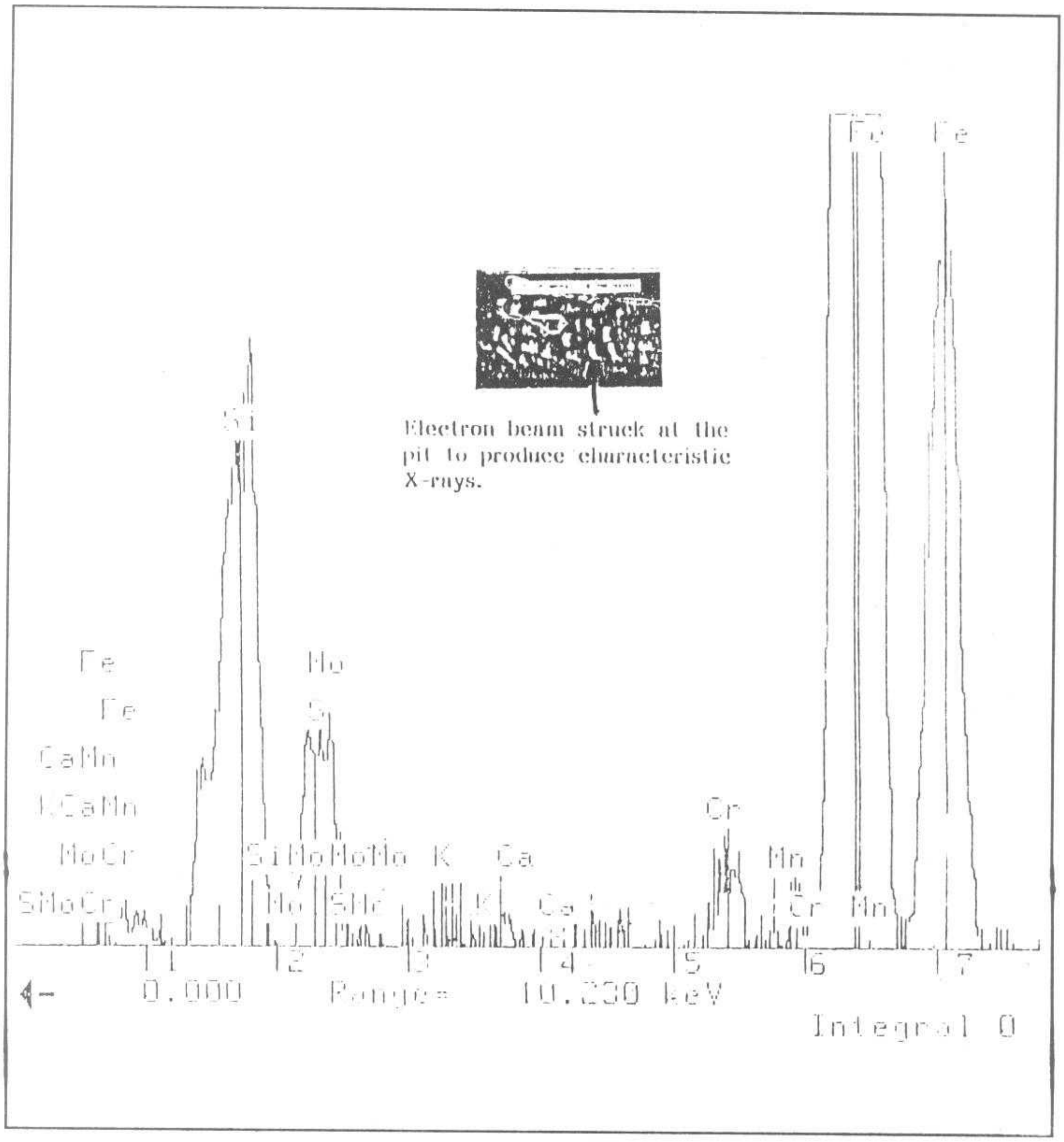

Fig. 2 : Analysis of elements present in the pit formed at the outer surface of tube No. 13/coil No. 3. Peaks of the elements K, Cl, Ca, Si and S may be noted (inset shows the fouled surface).

to ascertain the presence of corrosive elements. It may be noted that this facility is available with NML's scanning electron microscope. The results of the analysis are given in Fig. 2. The presence of highly corrosive elements like K and C1 were observed. The other elements which were observed and present in the pitted surface as can be seen from Fig. 2 were Ca, Si and S. The presence of these elements suggested that the attack was caused by the fusion of ash particles. Such attack usually occurs due to :

- o volatisation and condensation of volatile ash constituents Na_2SO_4 or $CaSO_4$ expressed as Na_2O to represent the fouling index as given in Table - 1. and/or mechanical adherent of fly ash particles

and/or

- o occasional temperature excursion giving rise to higher tube wall temperature about 650°C particularly during the starting period when no steam flows through the reheater tubes.

Ash particles of low fusion point can fuse and stick on the surfaces at such temperatures. Table - 2 shows the fusion temperature of some common chemical compounds which are likely to form on the tube surfaces. It may be noted that alkali metals along with S and Fe can form ash with fusion temperature as low as 620°C. The fuel oil used for the support can also cause this problem if the oil contains corrosive elements like V and S.

Example 2

Figure 3 shows another failure of a reheater tube. Here the failure had taken place from the welded cleats. Figure 4a schematically shows the cleats and pin arrangements and Figure 4b the failed pin/cleat. FRA and FRB as marked on Figure 3 are position where the cleats were welded. Figure 3 also shows the cross section of the failed tube. It may be seen that the tube had suffered external wastage of metal from one side (see the right hand side of the cross section).

Some other information available was :

- o Tube material specification : 2.25Cr-1Mo; cleat/pin material specification not available. However cleat was ferro-magnetic and the pin non-magnetic;

- o steam parameter : 535°C/35 cm^2.

The investigation showed that the failure was essentially on account of high temperature environmental attack. This was borne out by the microstrucures of the failed tube and the cleat given Figure 5. The Intergranular attack in case of both the tube and the cleat is obvious. This type of attack could be possible only if low fusion point ash formed as discussed in case of the previous failure.

From the Figure 4 showing the failed pin, it is evident that some low fusion temperature ashes had accumulated upon the cleats and pin

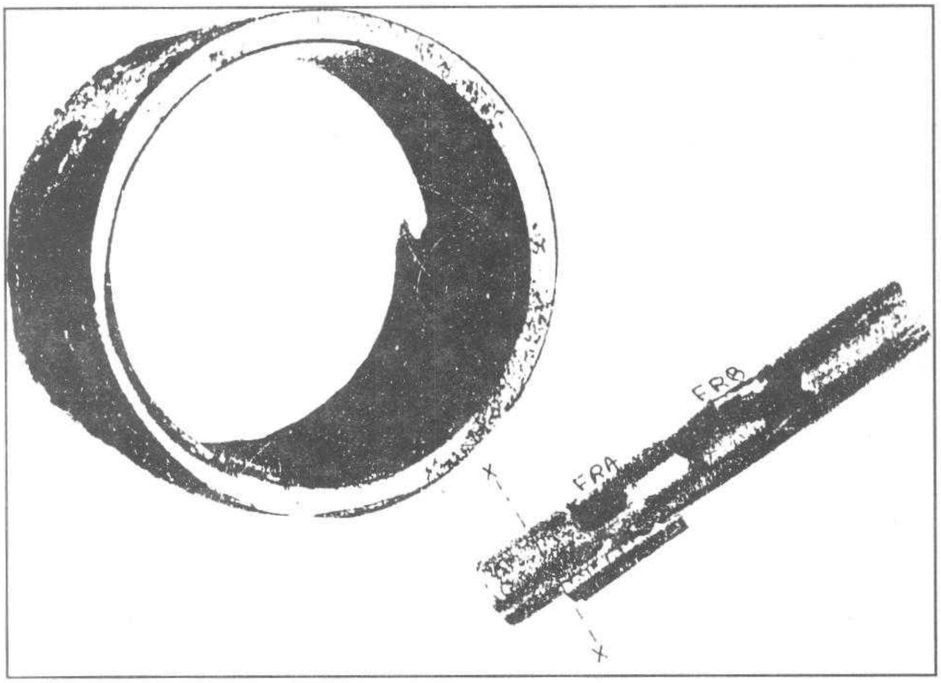

Fig. 3 : Photograph of the failed reheater tube. The bottom photograph shows cross section at X-Y

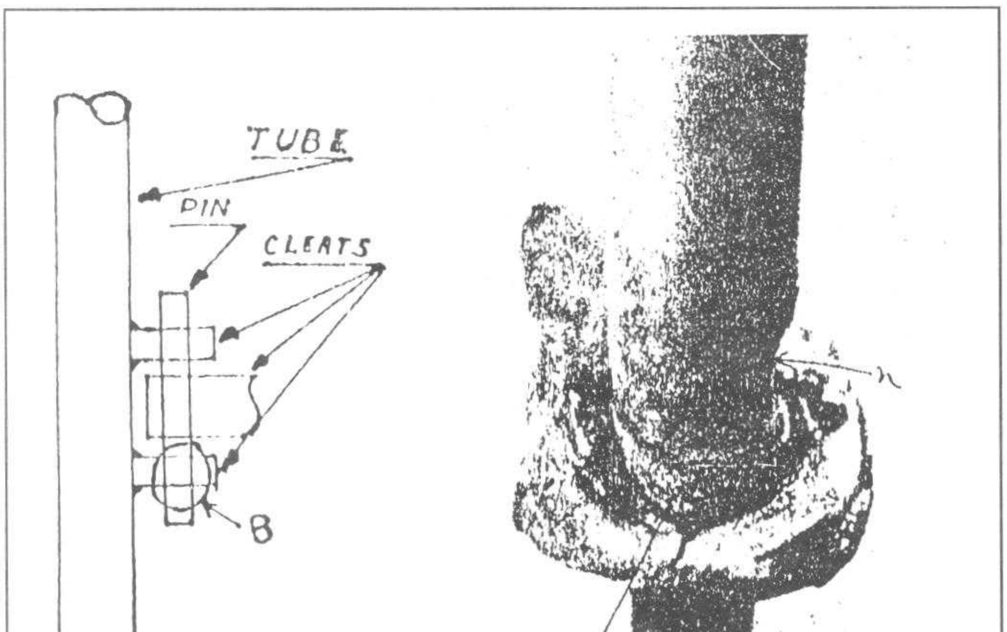

Fig. 4(a-b) : a : Schematic view of the reheater tube with cleats, and
b : Photograph of the pin with cleat in region marked B in 'a' above severe oxidation attack at 'm' and 'n' may be noted.

joints and eaten into them. As far as cleat and pin temperature is concerned, they certainly experience very high temperature because they are not cooled directly by the steam. Usually they operate at a temperature approaching that of flue gas which may lead to severe loss of creep strength and corrosion and, in worst case, melting. Failure of these support leads to misalignment of tube which may increase their exposure to the aggressive flue gases.

Example 3

Figure 6 shows another type of reheater tube. This had occurred in the same boiler as discussed under example 1 earlier. At least three failures were encountered in the same coil in a quick succession. These failure were reported to have occurred in the same tube at different heights and not in the portions which were replaced. Here the tube showed punctures at several places marked as A, B, C on the figure. The tube showed extensive diametrical expansion and as a result of which the outer surface developed longitudinal crack in the oxide scale as can be seen from Fig. 6(b). The dimetrical expansion observed was rather unusual because the operating pressure in reheater tubes are rather low and it was limited to the affected tube. This fact cast doubt if the material of proper specification was used. Tube material was analysed and found to be of plain carbon steel. That is, a tube of wrong specification got mixed up with the tubes during fabrication. If the analysis of tube were carried out when the first failure had occurred, the subsequent outages could have been avoided.

This failure was also analysed using Larson and Miller Parameter (LMP) plot given in Fig. 7. The value of LMP was calculated using the following equations:

$$LMP = T\,(20 + \log t_r) \times 10^3$$

In this case t_r was 24,000 hour and LMP corresponding to a stress level of 2 kg/mm^2 = 21. Using these data, operating temperature was found to be 588°C which is close to the service temperature which was measured and found to be 610°C. Hence, the failure was mainly on account of creep.

Example 4

Figure 6 shows yet another example of failure of reheater tubes. Here a longitudinal crack of about 35 mm length and a transverse opening of about 2 mm had occurred. The tube also showed some circumferential bulging near the rupture - 170 against 157 mm original circumference. Thick, hard, black and redish oxide layer was present on the outer surface. About 500 mm length of oxide layer in the rupture zone had completely peeled off from the outer surface. Adherent black oxide was present on inner surface which had cracked in both longitudinal and circumferential direction as a result the surface bore the appearance of a mesh (Fig. 8b). The failure had occured after about 50,000 hour of service life.

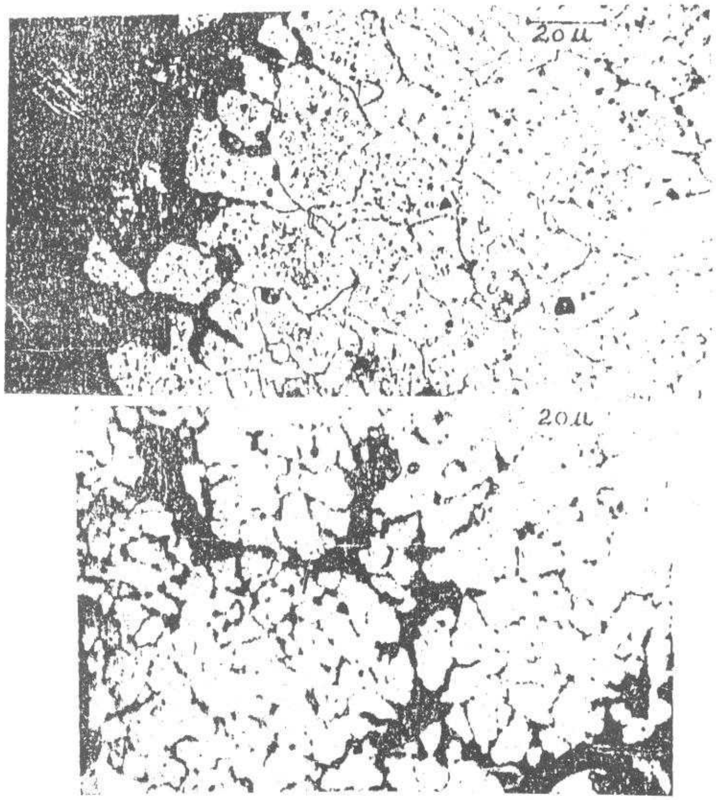

Fig. 5 : Microstructures showing integranular attack
a(top): Fire side of the reheater tube in the zone of failure
b(bottom) : Outer surface of the failed cleat

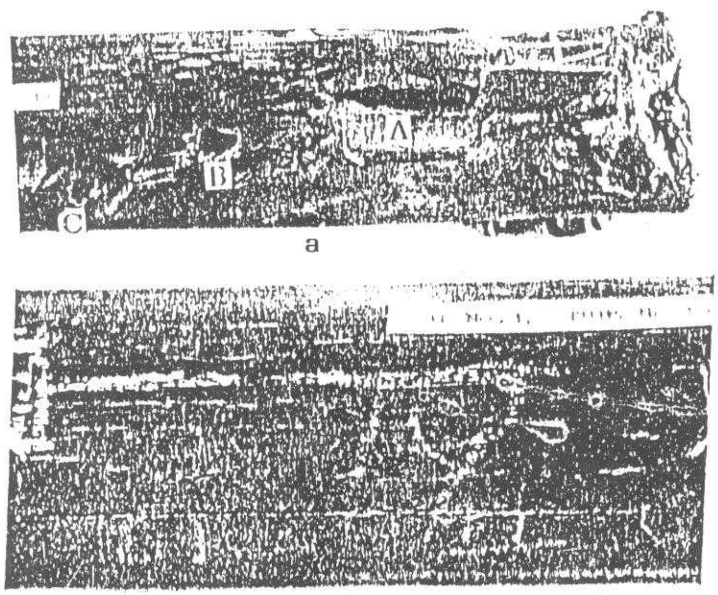

Fig. 6 : As-received reheater tube punctures and three places and (a) and longitudinal cracking of oxide on outer surface (b) may be noted

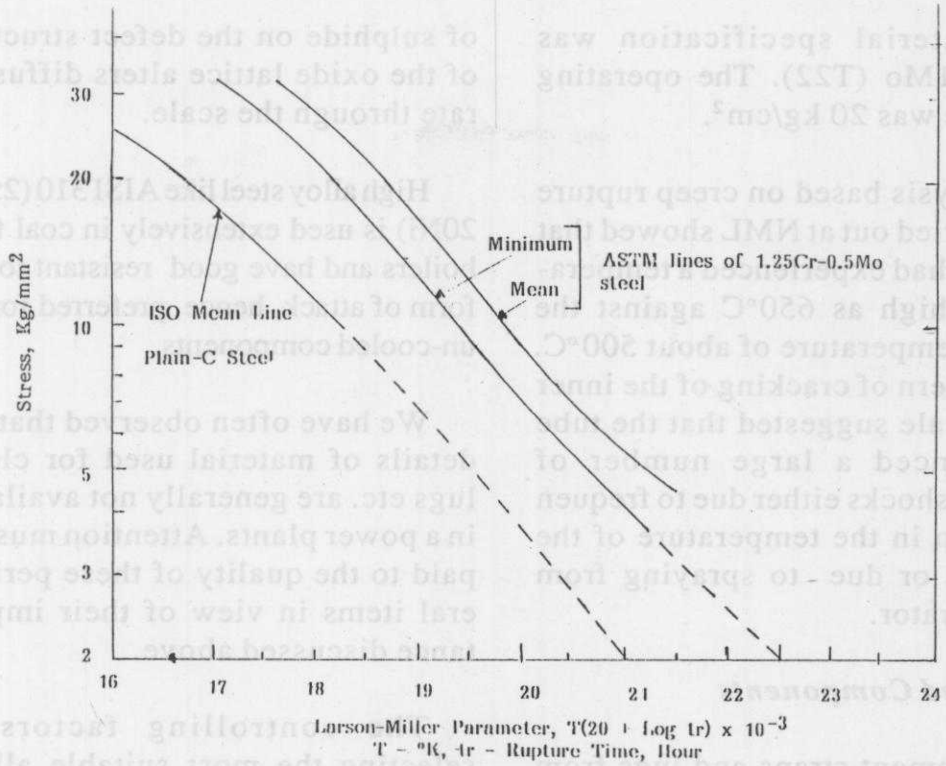

Fig. 7 : Stress versus Larson Miller Parameter plot for 1.25Cr-0.5Mo steel (ASTM-T11 Grade) and plain carbon steel (ISO data), dotted linc line represents extrapolation of the data to low stress levesls.

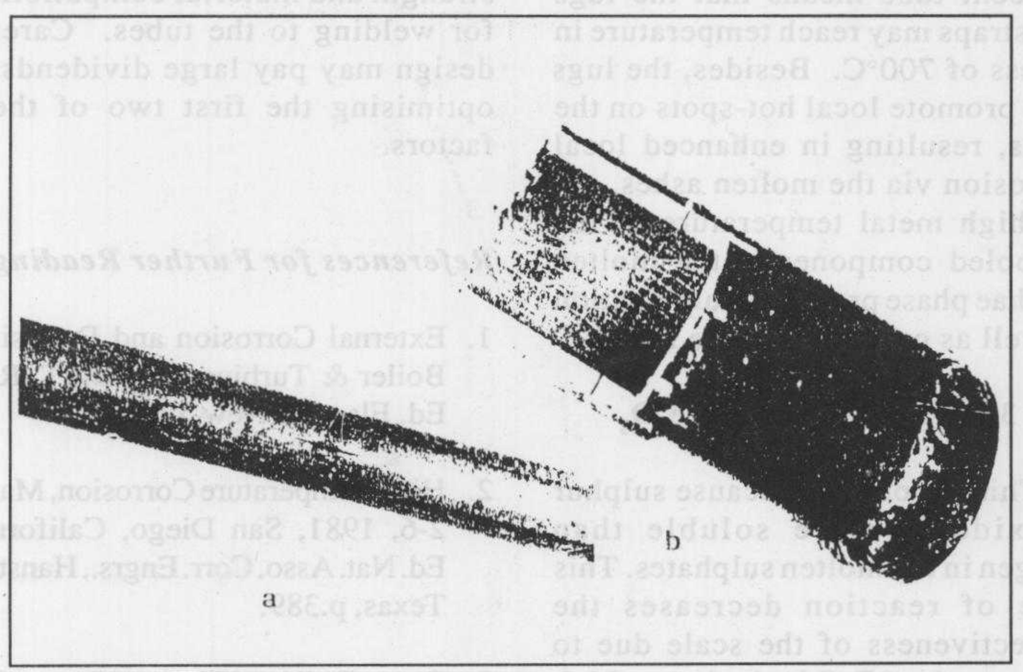

Fig. 8 : As-received failed tube, a narrow longitudinal crack (a) and oxide cracking on inner surface (b) may be noted.

The material specification was 2.25Cr-1Mo (T22). The operating pressure was 20 kg/cm^2.

Analysis based on creep rupture data carried out at NML showed that the tube had experienced a temperature as high as 650°C against the design temperature of about 500°C. The pattern of cracking of the inner oxide scale suggested that the tube experienced a large number of thermal shocks either due to frequen variation in the temperature of the flue gas or due to spraying from attemperator.

Uncooled Components

Alignment straps and lugs from the tube wall project into the gas steam and hence these are liable to allow the build up of ash deposit. Restricted heat transfer to the adjacent tube means that the lugs and straps may reach temperature in excess of 700°C. Besides, the lugs may promote local hot-spots on the tubes, resulting in enhanced local corrosion via the molten ashes. At the high metal temperature of the uncooled components, the molten sulphae phase promotes sulphidation as well as oxidation of the metal:

$$3Fe + SO_3 \rightarrow FeS + Fe_2O_3$$

This is possible because sulphur trioxide is more soluble than oxygen in the molten sulphates. This type of reaction decreases the protectiveness of the scale due to the growth of FeS inclusions which induces a stress in the scale leading to mechanical damage. The influence of sulphide on the defect structure of the oxide lattice alters diffusion rate through the scale.

High alloy steel like AISI 310 (25Cr-20Ni) is used extensively in coal fired boilers and have good resistant to this form of attack, hence, preferred for the un-cooled components.

We have often observed that the details of material used for cleats lugs etc. are generally not available in a power plants. Attention must be paid to the quality of these peripheral items in view of their importance discussed above.

The controlling factors in selecting the most suitable alloys for un-cooled an partially cooled components are the degree of cooling, the operating temperature range, chemical corrosion resistance, creep strength and material compatibility for welding to the tubes. Careful design may pay large dividends in optimising the first two of these factors.

References for Further Readings

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2. High Temperature Corrosion, March 2-6, 1981, San Diego, California, Ed. Nat. Asso. Corr. Engrs., Hanston, Texas, p.389.
3. Steam Boiler of Thermal Power Stations. M.I. Reznikov, Yu M. Lipov, Ed. Mir Pub., Moscow.

Table - 1
Ash Classification (Slagging/Fouling Indices)

Classification Criteria	Classification Index	Severity	Range
a. Ash Chemical Analysis	Slagging Index as Eqn. (1)	Low Slagging	$Rs < 0.6$
		Med. Slagging	$0.6<Rs<2.0$
		High Slagging	$2.0<Rs<2.6$
		Severe Slagging	$Rs>2.6$
	Fouling Index as Eqn. (2)	Low Slagging	$R_f < 0.2$
		Med. Slagging	$0.2<R_f<0.5$
		High Slagging	$0.5<R_f<1.0$
		Severe Slagging	$R_f>0$
	Fouling Index Expressed as a Function of Na_2O in Ash	Low to Med.	$Na_2O<0.3$
		High	$3<Na_2O<6$
		Severe	$Na_2O>6$
b. Ash Fusion Temperature	Slagging Index $Rs^* = \frac{MHT + 4(IDT)\ Min}{5}$	Med. Slagging	Rs*1340-1230
		High Slagging	Rs*1230-1150
		Severe Slagging	Rs*1150

$$Rs. = \frac{B}{A} \times S = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_3} X\ S \qquad (1)$$

$$R_f = \frac{B}{A} \times Na_2O = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_3} X\ Na_2O \qquad (2)$$

MHT - Max. Hemispherical Deformation Temp., IDT = Initial Deformation Temperature, B = basicity, A = Acidity

Table - 2
Probable Ashes with Fusion Temperature

Chemical Compund	Ash Fusion Temp. °C
Vanadium Pentoxide V_2C_5	690
Sodium Sulphate Na_2SO_4	888
Nickel Sulphate $NiSO_4$	841
Sodium Meta Vandate $Na_2OV_2O_5$	629
Sodium Pyro Vandate 2 $Na_2OV_2O_5$	654
Sodium Ortho Vandate 3 $Na_2OV_2O_5$	866
Nickel Ortho Vandate 3 $NiOV_2O_5$	899
Sodium Vanodyl Vandate $Na_2OV_25V_2O_5$	624
Sodium Iron Trisulphate $2Na_3Fe(SO_4)_3$	621