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Review article

Impact of increased power plant cycling on the oxidation and corrosion of coal-fired superheater materials

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ABSTRACT

As power generation from variable renewable energy sources such as wind and solar power continues to increase in the future, fewer baseload power plants will be needed. As a result, high operational flexibility is becoming a vital requirement for conventional power plants to allow for the smooth integration of the variable renewable energy sources (v-RES) into the grid. To understand the impact of high operational flexibility (increased cycling) for coal-fired power plant materials, five commercial coal boiler superheater and reheater materials were investigated under isothermal and cyclic conditions for 1000 h each. The candidate alloys investigated were: T91, VM12-SHC, TP347-HFG, DMV304 HCu and DMV310 N. The results (weight change kinetics and metallographic analysis) after exposure at a metal surface temperature of 650 °C clearly showed the impact of increased flexibility on the corrosion and oxidation of the materials. Oxide growth (weight gain), metal loss, oxide spallation, and grain boundary attack were found to be more severe under cyclic conditions than under isothermal conditions.

1. Introduction

The German "*Energiewende*" (energy transition) aims to reduce carbon emissions particularly from fossil fuel power plants such as coal-fired power plants to provide affordable and environmentally sound energy from renewable energy sources like wind and solar for the future [1,2]. Despite being very promising for the future, there are some challenges associated with accomplishing these goals. On the one hand, renewable energy sources like wind and solar power are variable in nature i.e. they fluctuate and their generation highly depends on the weather conditions – wind generation during windy periods and solar power on days with high sun intensity. This makes it difficult to reliably feed in power from these sources into the grid. On the other hand, dispatchable (or reliable) energy sources such as coal-based power plants are required to increase flexibility in order to allow for the smooth integration of variable renewable energy sources into the power grid. High operational flexibility is becoming a vital requirement for conventional baseload power plants such as coal power plants [3].

High operational flexibility for coal power plants basically means that the plants operate in different cycling modes which include among others ramping up and down, frequent starts and stops, load following operations, reducing minimum load as well as longer plant layups [4]. Since baseload power plants were designed for constant operation throughout the year with only a few shutdowns for maintenance and repairs, increased cycling will force these plants to operate beyond their nominal design limits. This means huge thermal transients on plant components particularly from cold starts which increase the damage on the materials – as can be depicted from Fig. 1. The impact of increased flexibility could therefore be detrimental to vital plant components such as boiler tubes, superheaters and reheaters [5–7]. It is therefore important to understand and evaluate the impact of increased cycling on plant materials of conventional baseload power plant.

High temperature oxidation and corrosion constitute the major causes of components failure in the high temperature sections of coal-fired boilers. As already mentioned above, the materials used in conventional coal boiler units are designed to provide good corrosion and oxidation resistance when operating within their design limits (normal 'isothermal' operation) but can wear quickly under increased cycling modes. Cycling causes inevitable large thermal and pressure transients which can lead to long-term structural damage of critical plant components such as superheaters and reheaters [8]. It is the goal of the current study to evaluate the oxidation and corrosion behavior of these components under increased cycling conditions to obtain useful information on the performance of the materials as well as mode of degradation involved.

In the present study, five commercial coal boiler superheater/

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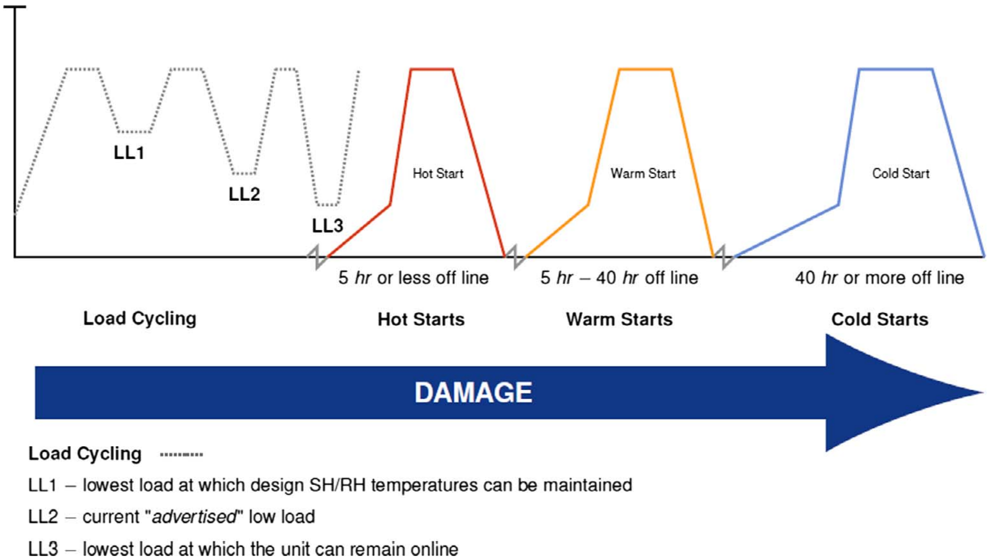

Fig. 1. Damage caused by the cycling from plant starts [6].

Table 1
Chemical composition of selected alloys.

Alloy	Fe	Cr	Ni	C	Mo	Mn	Si	Others
TPP91	Bal	8.75	0.4	0.105	0.95	0.45	0.35	V0.22
VM12-SHC	Bal	12	0.4	0.14	0.4	0.45	0.6	Cu 0.25; W 1.7; V 0.30; Co 1.8
TP347HFG	Bal	18	10	0.08	–	1.6	0.6	Nb 0.8
DMV304HCu	Bal	18.4	9.1	0.087	0.26	0.79	0.23	Cu 3.1; Nb 0.44; N 0.11
DMV310N	Bal	25.33	21.05	0.058	–	1.2	0.39	Nb 0.445; N 0.255

Table 2
Composition of fly ash.

Species	Concentration [wt%]	Normalized [wt%]
Na_2O	0.32	0.34
MgO	3.53	3.71
Al_2O_3	12.16	12.77
SiO_2	43.69	45.90
K_2O	1.44	1.51
CaO	17.01	17.87
Fe_2O_3	17.04	17.90
Sum	**95.19**	**100.00**

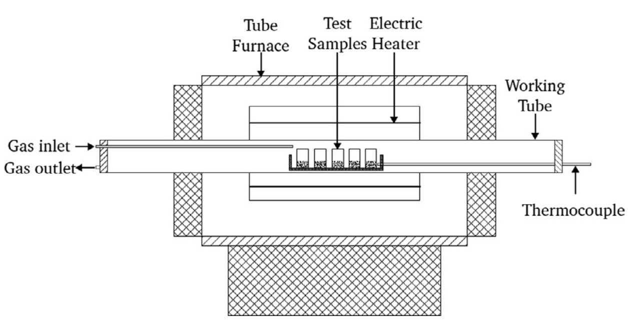

Fig. 2. Experimental set-up showing samples in tube furnace.

Fig. 3. Material sample showing bare metal and ash covered sections.

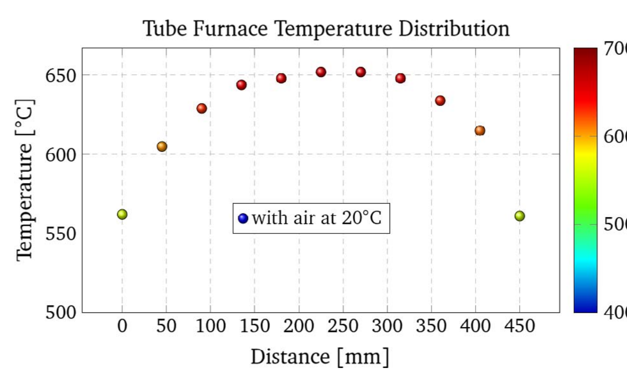

Fig. 4. Temperature distribution profile in the furnace.

reheater materials were selected for investigation namely: TP91, VM12-SHC, TP347-HFG, DMV304HCu and DMV310N. The materials were exposed each for a total of 1000 h under *discontinuous* isothermal test conditions and thermal cyclic conditions at a metal surface temperature of 650 °C. The samples were weighed at regular intervals to obtain information on the oxidation kinetics (oxide growth rate) of the materials. The corrosive medium used for the experiments was a synthetic gas mixture consisting of CO_2, O_2, N_2, SO_2 and H_2O. The materials were partly covered in fly ash to simulate the conditions in a coal boiler as well as to study the effect of ash on oxidation and corrosion. After exposure the materials were analyzed by means of light optical microscopy (LOM) and scanning electron microscopy (SEM) combined with energy dispersed X-ray spectroscopy (EDS).