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REVIEW PAPER ON HIGH TEMPERATURE CORROSION AND ITS CONTROL IN COAL FIRED BOILERS

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Abstract- Recent research and development on high temperature corrosion problems, with the techniques available to control this problem, is reviewed and discussed in this paper. Boiler is an essential element of power generation plants. With increasing fuel and energy costs, maintaining the reliability and consistent performance of a boiler while minimizing energy costs is challenging for any industrial plant. Since boiler systems are constructed primarily of carbon steel, the potential for corrosion is high which can result in a forced shutdown of the boiler and the industrial process. The fireside corrosion in coal fired utility boilers is one of the main problems. Superheaters and reheaters suffer from steam oxidation on their inner surfaces and hot corrosion on the fireside. Fireside corrosion cannot be eliminated completely but it can be controlled. There are several techniques to control the high temperature corrosion problems in boilers which are Fuel blending, use of additives, replacing tubes with more corrosion resistant materials, thermal spray coating, thicker tube walls, adjustment of firing rate, amount of excess air, air temperature and amount of recirculating flue gas can be very effective in controlling the amount and composition of ash deposit, and effective boiler design and construction can also help in controlling ash deposition etc.
Keywords: High Temperature Corrosion, Coal Fired Boiler, Thermal Spray Coatings.

1. INTRODUCTION

High temperature corrosion in coal fired boilers in thermal power plant is a serious problem in power generation equipments, gas turbines, aircrafts and chemical process systems, it causes shutdowns, damage to the components, unsafe operations, reduced efficiency and high maintenance cost [1]. In the recent study, the total annual estimated corrosion cost in the U.S. is a $276 billion approximately which is 3.1% of the Nation's Gross Domestic Product. This cost of corrosion problem is more than the annual cost of natural climate related disasters, which is averaging $17 billion on yearly basis. It is unlikely to control weather related disasters but corrosion cost can be controlled with suitable corrosion prevention management system. The report further revealed that the 25% to 30% of annual corrosion costs in U.S could be saved with corrosion prevention [2].

The understanding of these problems and thus to find solutions to protect the systems is essential. Development of materials which can operate under extreme conditions and at high temperature is gaining importance in these days. This can be achieved by either material modification or changing the environment or by creating the barrier in component surface and environment. The use of surface coating to protect the material from the surrounding environment is gaining importance in the field of surface engineering [1,2].

Corrosion is degradation of metals due to chemical reactions, when a gas or liquid chemically attacks an exposed metal surface. Corrosion converts a refined metal into a more chemically stable form, such as its oxide, hydroxide or sulfide [3,4]. It is the gradual destruction of materials and accelerated by high temperatures, acids and salts. Corrosion products e.g., rust stay on the surface and protect it. But by removing these deposits the surface will again expose and corrosion will continue. Power generation plants are one of the major sufferers from severe corrosion problems resulting in the substantial losses. High temperature corrosion can take place inside the tube known as steam side corrosion which is due to quality of steam, outside the tube that is called as fireside corrosion caused by corrosive elements present in the flue gas. High temperature corrosion occurs in superheater and reheater tubes of coal fired power plant boilers. The corrosive nature of the flue gases containing oxygen, sulfur, and carbon, may cause rapid material degradation which can lead to premature failure of components. High temperature corrosion in a boiler firing coal is mainly caused due to the presence of impurities like sulfur, alkali metals and chlorine. In fuel oil fired boilers, the main impurities are vanadium, sulfur, sodium and chlorine [5]. These elements combine to form various types of vapors and condensed phases during the consumption process. Combustion of coal generates very corrosive environment near the superheater tubes of the boilers. The boiler tubes suffering severe corrosion have sulphate salts concentrate at the deposit interface which become partially fused since these salts contain alkali metals of sodium and potassium. The chemistry of these reactions taking place during combustion is complex and is widely varying. However, all the reactions undergo certain changes that are simple to understand. The sulphur in the fuel combines with oxygen to form sulphur dioxide and trioxide, depending upon the availability and temperature [6,7].

2. HOT CORROSION AND OXIDATION DEGRADATION PROCESSES

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Depending on the temperature, degradation processes can be divided into three categories according to increase in temperature: type II hot corrosion also known as LTHC, type I hot corrosion also known as HTHC, and oxidation [8,9], as shown in figure 1.

2.1. Hot corrosion type II (LTHC):

This type of hot corrosion occurs in the temperature range of 600 and 850oC where a liquid salt phase is only formed because of significant dissolution of some corrosion products. This is the of process sulfate formation from the substrate at a certain pressure for sublimation of sulfur trioxide. Due to the reaction of sulfate with alkali metal, low melting point particles are formed that prevent forming a protective layer.

2.2. Hot corrosion type I (HTHC):

This type of hot corrosion occurs in the temperature range 750–950oC

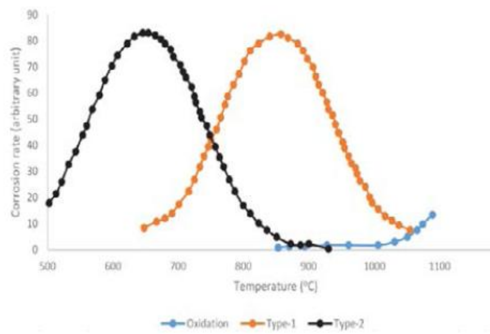

Figure 1. The temperature range for hot corrosion type II, hot corrosion type I, and oxidation [9].

where pure sodium sulfate is above its melting temperature. It includes the transportation of sulfur from a deposit like sulfate (Na_2SO_4) through oxide layer into metal substrate with formation of stable oxides. After reaction between a stable sulfide like Cr, and a moving sulfur through a scale, the base metal sulfides form a disastrous sequence at molten phase because this type of hot corrosion seems to occur at 750–950oC.

2.3. Oxidation

Oxidation is the reaction between a metal and air at high temperature in the absence of an aqueous phase also known as dry-corrosion. It occurs at 950oC and higher temperature. The rate of oxidation depends on the transportation of cations or anions through the oxide layer and grain boundary. When a metal is exposed to oxygen, reaction proceeds when the oxygen pressure is higher than the pressure needed to balance the metal-metal oxide [9,10]. The stability of oxide in a set of elements is determined by the dissociation pressure which is lowest for Al and Cr in comparison with Fe, Co and Ni. If the Cr content of NiCr alloy is more than 10%, a continuous and protective layer will form. For cobalt base superalloys to form a continuous oxide layer, Cr content should be at least 25% because of different diffusion behaviors of Cr in Co alloys. To increase the oxidation resistance of chromia at a temperature above 850oC (because it sublimates and becomes volatile oxide “CrO_3”) the addition of aluminum is preferred, especially for severe and critical conditions like gas turbine blades. An important feature is that the rate of oxidation declines with time because the oxide layer behaves like a barrier and prevents oxidation by separating the reactive gases. If the oxide layer is not protective, it cannot prevent the progress of oxidation [9-12].

3. METHODS TO CONTROL HIGH TEMPERATURE CORROSION

3.1. Surfacing Engineering

Surfacing Engineering is the most emerging field to improve the surface i.e. corrosion, oxidation and wear resistant depending upon the required service conditions in an economical way. This can be done by depositing a layer of superior material on the substrate of sufficient mechanical strength. Protective coatings used on structural alloys and energy conversion units, prevent surface degradation. Some of the factors that must be taken into account include substrate compatibility, adhesion and resistance to corrosion. The recent development of surface coatings and new methods of coating are available which can provide the desired properties that were previously unachievable [13-14].

3.1.1. Thermal Spray Coatings

Thermal Spray Processing is a very rapidly growing field in surface engineering. Thermal spraying processes fall in two categories: high and low energy processes. Thermal spray coating technique is used to protect components from erosion, high temperature oxidation and hot corrosion at high temperature in boilers [15]. The low energy processes, often referred to as metalizing, arc and flame spraying. The high energy processes include plasma, D-gun and high velocity combustion spraying

[16-18]. The coating material may be in the form of a powder, rod and wires which do not sublimate or decompose at temperatures close to their melting points, can be used as spraying materials [19]. Many thermal spray coating deposition techniques are available and choosing the best technique depends on functional requirements, adaptability of the coating material to the intended application technique, level of adhesion required (size, shape, and metallurgy of the substrate), availability and cost of the coating application equipment. Thermal spray processes such as High Velocity Oxy Fuel (HVOF) and Plasma

Spraying are often applied to deposit high-chromium, nickel coatings onto the outer surface of various parts of the boilers, e.g. tubes to prevent the penetration of hot gases, molten ashes and liquids to the carbon steel boilers tube [20].

Singh et al. mentioned that plasma spray process provides the possibility of developing coatings of NiCrAlY powder on the Ni-based superalloys Superni 75 and Superni 600. The plasma sprayed NiCrAlY coatings have shown fairly good adherence to the substrate superalloys and developed protective oxide scales to protect the substrate from oxidation. The main oxides formed were NiO, Cr_2O_3, Al_2O_3 alongwith a spinel $NiCr_2O_4$. The uncoated Superni 600 showed a comparatively less weight gain than NiCrAlY coated superni 75. The main phases analysed for the coated superalloys are oxides of nickel, chromium and aluminium and spinel of nickel and chromium, which were suggested to be responsible for developing oxidation resistance at high temperatures [26-28].

Overlay coatings include a family of corrosion resistant alloys specially designed for high temperature surface protection. They are often referred to as MCrAlY coatings, here M is the alloy base metal (typically nickel, cobalt, or combination of these two) and it can be used either as overlays or as a bond coat . Materials rich in oxides formers such as Cr and Al, are needed to resist in high temperature and corrosive environment and but processibility of such bulk alloys is very limited, and the alternative use of thermal sprayed coatings. Most of the nickel base alloys are corrosion resistant and those containing chromium have good resistance to oxidation at elevated temperatures. NiCrAlY coatings are used for resistance to high temperature oxidation and sulphidation [21-24].

Kaushal et al. compared the high temperature performance of HVOF-sprayed and detonation gun sprayed Ni–20Cr coating in laboratory and actual boiler environments deposited on boiler steel ASTM-SAE 213-T22. The specimens, with and without coating, were subjected to molten salt (Na_2SO_4–60%V_2O_5). Authors found that HVOF-sprayed coating was to be intact during exposure to both given environments; whereas the D-gun coating showed spallation of its oxide scale during exposure to the molten salt environments. An overall analysis of the results indicated that the HVOF-sprayed Ni–20Cr coating should be a better choice for the given boiler applications [32] .

Bala et al. investigated that a new emerging technique i.e. cold spray coating process was used to deposit Ni-20Cr and Ni-50Cr powder on SA 516 (grade 70) boiler steel. The uncoated steel showed considerable weight gain after exposure in the actual boiler environment, whereas for the coated steels there was initial weight loss followed by negligible weight change. Based upon thickness loss data the cold-sprayed Ni-50Cr coating was found to provide better E-C resistance than the Ni-20Cr coating [31] . In the studies made by Sidhu et al., it has been reported that with the application of coatings the resistance towards air oxidation as well as hot corrosion increases. Ni–20Cr coatings on boiler steels, namely Grade1, T11, T22 by plasma spray process was studied. The coatings were also tested in the actual boiler environment. After plasma coating all the steels showed much lesser overall weight gain as compared to uncoated specimens in the given molten salt environment [37]. The formation of phases like Cr_2O_3 and $NiCr_2O_4$ in the protective scale of the coatings was suggested to induce requisite resistance in the boiler steel.

In the literature, considerable work has been done on thermal spray coatings to examine the characterization and properties of the coating. The researchers also investigated the influence of spray parameters and powder morphologies on the resulting coatings. In demanding corrosion applications, it is not just sufficient to specify alloy name and coating technique but for reliable coatings the whole coating production envelope needs to be considered, including alloy selection, spray parameters, base metal properties, surface preparation, heat input etc.

3.2. Combustion Catalysts

Combustion catalysts can be used for all types of fuels. The function of combustion catalysts is to increase the rate of oxidation of the fuel. These are also helpful for those fuels which are difficult to burn within a given fixed furnace volume. Combustion catalysts also improve boiler efficiency by reducing the carbon loss in the flue gases.

3.3 Fuel Additives

Fuel additive plays an important role in complete combustion of fuel as well as control on corrosion deposits, slagging, reduction in air pollution emission, These additives are added on the coal before combustion, directly into the combustion chamber or the flue gas stream i.e. after combustion such that chemical reactions take place to oxidize, neutralize and convert residuals from combustion that can cause increase slagging, corrosion and air pollution. Thus the thermal efficiency of the boiler will increase. As Vanadium pentoxide (V_2O_5) having low melting point forms hard deposits in the super heaters [28]. These deposits lead to corrosion. Vanadium pentoxide converts sulfur dioxide to sulfur trioxide. Fuel additives oxidize unburnt carbon, reduce sulfates and convert vanadium pentoxide to vanadates with high melting point. Thus deposits will become dry/powdery and will lose their adhesion. Smutting, dust and NOx are non desirable elements in the emissions. The smutting is due to unburnt carbon with sulfuric acid [29]. The higher will be the combustion temperature, more will be the amount of NOx produced. The emissions of dust and NOx are subject to legislative control. The affect of these pollutants can be neutralized by fuel additives.

3.4 Burner Angle

The investigation conducted in this research is finding out the right tilt angle for the burners in the boiler that causes an efficient temperature distribution and combustion gas flow pattern in the boiler [41].

4. CONCLUSION

Hot corrosion is serious problems in coal fired power plants, so it should be controlled to increase overall efficiency and safe operation. The various factors in corrosion control include: use of high grade coal, fuel blending, super alloys, combustion catalysts, fuel additives, proper air distribution and proper burner angle. In addition to that it is very important to understand the behavior of metals at high temperatures, especially their corrosion behavior and providing corrosion resistant coating. Thermal spray coatings play an important role to overcome the problem of corrosion.

5. ACKNOWLEDGEMENTS

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