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An Overview of the Effect of Hot Corrosion in Waste-to-Energy (WTE) Plant Environment

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Abstract - **The present study aims to study the hot corrosion behavior of the various alloys used in boiler tubes in the waste-to-energy plants. This study found that in the aggressive environment of waste to energy plants, there is failure of the boiler tubes due to hot corrosion and these plants are running at very less efficiency as compared to fossil fuel based power plants. It is also found that degradation problem in medical waste based plants is even more severe. The aggressive environment of these plants is mainly due to the presence of chlorine elements in the waste, used as fuel. In this study, a brief review of the performance of different alloys has been made in the environment of waste to energy plants.**

Keywords : **Corrosion, Incineration, WTE, Hot Corrosion, Boiler Tubes**

I. INTRODUCTION

The corrosion problems in waste-to-energy industry are usually rather severe, due to the heterogeneous nature of its fuel containing alkali metals such as sodium (Na) and potassium (K), heavy metals such as lead (Pb), tin (Sn) and zinc (Zn) and various chlorine-containing compounds, all of which can form potential corrosive agents and the waste which is used as a fuel could not be selected for composition and consistency [1-2].

Metals and alloys sometimes experience accelerated oxidation when their surfaces are covered by a thin film of fused salt in an oxidizing atmosphere at elevated temperatures. This mode of attack is called hot corrosion, where a porous non protective oxide scale is formed at the surface. Hot corrosion has been observed in boilers of WTE plants, industrial waste incinerators, internal combustion engines, gas turbines and fluidized bed combustion since the 1940s. [4-8].

The efficiency of waste to energy plants is of considerable interest and the efforts are being made to maximize the energy output from the plants [9], to fully utilize the potential of energy generation of these plants. Since the emergence of first WTE plant in the mid 1960's [3], the WTE plants operating worldwide are still running at low efficiency of around 25 % (steam temperature usually kept below 420^{o}C) as compared to coal-fired power plants with efficiency of around 47% (steam temperature of 580^{o}C) The main hurdle in increasing the operating temperature and hence increasing the efficiency of WTE plants is the high temperature corrosion of the boiler tubes[3,10-13]. One of the results of the survey[10] in USA, on several WTE facilities showed that the non-scheduled downtime due to the corrosion ranged from 0 to 20 days per year. Result showed that the maintenance cost due to corrosion, per boiler unit ranged from \$18,000 to \$1,200,000 per year and it ranged from \$0.23 to \$8.17 per ton of waste combusted. The typical cost is in the range of \$4 per short ton of waste combusted. The maintenance cost account for around 15% of the yearly cost of a WTE facility and the corrosion problems will cost WTE plant approximately 5% of its yearly total cost. If the revenue loss due to shutdowns is taken into account then the actual cost because of corrosion will be even higher.

This paper includes brief review of the performance of base materials, with the aim to understand their hot corrosion resistant properties, in the corrosive environment of waste to energy plant.

II. HOT CORROSION IN WASTE-TO-ENERGY PLANTS

Since no alloy is immune to hot corrosion attack indefinitely, although there are some alloy compositions that require a long initiation time at which the hot corrosion process moves from the initiation stage to the propagation stage[14].

The alloys used for boiler tubes in high temperature performance in corrosive environment are, in general, optimized with regard to their mechanical properties and resistance against hot corrosion. The iron and nickel base superalloys are commonly used for high temperature applications involving aggressive environment such as boilers and gas turbines for energy generation systems, marine applications, aircraft etc. However, the presence of combustion gases constitutes an extreme environment and the hot corrosion is inevitable when these alloys are used at high-temperatures for longer periods of time [15,16].

III. DEGRADATION OF BASE MATERIAL

The 304 stainless steel boiler tube used in a medical waste based plant failed for less than a year, as reported by Zhang[17]. The burning of waste produce chlorides and sulfides in the flue gases, which react with the boiler tubes at elevated temperature and cracking appeared in the tubes due to corrosion of the tubes, in this aggressive environment.

The working stress and residual stress also plays dominant role in the cracking of boiler tube called stress corrosion cracking in this chloride and sulfide environment. Krause[18] also reported that the corrosion rates of carbon and low alloy steels increases with both metal temperature and gas temperature, but for stainless steels initially it decreases as the metal temperature increases and are less sensitive to gas temperature. Spiegel[19] also reported that the steels and nickel based alloys corrode rapidly in the atmosphere of WTE plants. The laboratory tests conducted by Spiegel study the effect of heavy metal sulfates and chlorides in the corrosion of metallic materials used in waste-to-energy plants, beneath $CaSO_4$-K_2SO_4-Na_2SO_4-$ZnSO_4$-$PbSO_4$ salt mixture at 600^oC, the heavy metal chlorides $PbCl_2$, $ZnCl_2$ and also beneath a $ZnCl_2$-KCl mixture at 300-600^oC. Lu[3] also conducted the laboratory corrosion tests in the environment similar to the waste to energy plants, on five commercial Fe–Cr steels (CS20, 2.25CrMo, NF616, 12CrMoV, SS304), beneath $ZnCl_2$–KCl deposits having melting temperature of 523 K in the reducing atmosphere of 0.5H_2-0.5HCl-balance CO_2 gas mixture, and at the temperature of 673K and 773K. The study found that the accelerated corrosion takes place for all tested materials due to the porosity and spallation of the scales. This increased corrosion rates of all steels under the $ZnCl_2$–KCl deposits at 673–773 K were significantly high with respect to those measured in the same reducing atmosphere in the absence of chloride deposits. This is due to the penetration of the initially formed chlorine containing species through the scale down to the metal matrix, as the chorine rich species were detected close to the alloy/scale interface. It was also found in this study that the high-Cr steel SS304 having about 19wt.% Cr, did not exhibit an acceptable corrosion resistance against $ZnCl_2$–KCl deposit, against the general perception that the corrosion resistance increases with increasing Cr content.

The corrosion behaviour of Alloy 625 material, the material used in superheaters of high efficiency plants, is studied by Perez[11], in the presence of $ZnCl_2$-KCl molten mixture at 650^oC, typically WTE plant environment. It was found that the alloy developed a protective Cr_2O_3 scale in early stages, but this protective layer turned into porous spinel oxide scale after 100 hrs of exposure. Perez reported that the major components found in the deposits of these plants are heavy metals like tin, lead, zinc and the corrosion of the material is very severe in the incineration environment, due to complex reactions between the combustion gases containing HCl/Cl_2 or SO_2 and salt deposits (KCl, $ZnCl_2$, NaCl, Na_2SO_4 etc.). Also the metal tubes corrode more severely, when the temperature in incinerator exceeds the melting point of the depositing ash. Otero[20] found the high corrosion rates of ferritic 12 Cr MoV(low Cr) when this material was in contact with low melting point eutectic mixture (52-48)mol % of $PbCl_2$-KCl (melting point 684 K) at various temperatures (723 K, 773 K and 823 K).It is reported in this study that the corrosive problem in the waste incinerators is a major problem and this problem is due to complex nature of waste and the presence of greater number of corrosive impurities in the waste than those of regular fuels such as coal and oil.

Hanne[21] study the deposition and corrosion in a 10 MW wheat straw fired stoker boiler used for combined power and heat production. It was found that at the steam temperature of 450^oC the corrosion was found to be negligible. The corrosion rate increased moderately in the steam temperature interval 490–520^oC and it increases markedly at temperatures above 520^oC. The plant experienced enhanced corrosion for steam temperature above 490^oC due to selective corrosion takes place, where chromium is removed from the alloy leaving a degraded metal phase enriched in nickel. The corrosion in the plant was found due to the deposits on the heat transfer surfaces. The deposits found on the surfaces were rich in potassium and chlorine which are around 40–80 wt.% of the deposits because of their high content in straw and also silicon, calcium, and sulfur are present in small quantity. It was found that at 550^oC a dense and molten layer consisted of almost pure KCl is formed next to the metal oxide layer. But at 460^oC the inner layer was thinner, not as dense as at 550^oC and consisted of individual angular particles. The difference in the layer of the deposit may play the determining role in the corrosion of superheater tubes at temperature above 550^oC. Also the gaseous chlorine formed at the interface between deposit and scale, due to sulfation of KCl or formation of K_2 CrO_4, enhances the corrosion of surfaces. To avoid the accelerated corrosion, the plant is made to run at low steam temperature, but it decreases its efficiency. So for successful running of Bio-mass fired power plants, in future, the potential problem of corrosion has to be sort out. Hanne suggests one way of achieving this is to find the way of preventing the presence of potassium chloride in the deposit.

Marek[22] study the influence of biomass co-combustion on the fouling of boiler convection surfaces. In this study the biomass considered was: straw, wood and dried sewage sludge and the upper silesian coal with medium fouling inclination as a basic fuel. It was found that all kinds of biomass analyzed are characterized by higher fouling tendency than coal, resulting in the deterioration of boiler efficiency. The fouling tendency of sludge is always stronger than that of coal. During co-firing of 20% of sewage sludge more than 2% points of deterioration was found. Also the co-combustion of straw has the lowest influence on the heat transfer in boilers, but it can cause serious chloride corrosion of superheater tubes. The ash of the wood has very high amount of calcium and also higher than in coal, the amount of potassium in the absence of sulfur. The melting temperature of ash of this kind is high and on the boiler surfaces the deposits due to this kind of ash is found to be loose. But during co-firing of wood with coal having sulfur content, the fouling and sintering tendency will be higher. The ash of the Straw has mainly silica and potassium and the amounts of calcium and phosphorus are lower than in the wood, but higher than coal. The chlorine content in the straw and hence in the ash, depends on soil conditions. The chlorine compounds have strong fouling tendency. In the superheater area, the deposits found are strongly corrosive. The co-firing of straw with sulfur containing fuels can decrease the corrosion, due to the formation of protective layer of K_2SO_4 on the tube.

IV. SUMMARY

Degradation problems in the waste to energy plants require technological solutions. The corrosion resistance of superalloys can be improved by adding fair amounts of Al and Cr. However, these elements can be added only up to a limited extent as their higher concentrations adversely affect the mechanical properties of the alloys[14]. So, these alloys may not be able to meet both the high temperature strength requirements and high temperature corrosion resistance simultaneously for longer life. So, protective coatings are used to counter the latter. Also due to continuously rising cost of the materials as well as increased material requirements, the coating techniques have been given more importance in recent times. The necessity to preserve good mechanical properties of alloys at elevated temperature under the highly oxidizing and corrosive conditions led to the development of coating materials. The composition and structure of the coatings are determined by the role that they play in various material systems and performance environments and may vary from one system to another according to the requirements. It has been learnt from the published literature that the role of the coating is to provide a metal surface composition which will react with the environment to produce the most protective scale possible combining corrosion resistance with long term stability and resistance to cracking or spallation. The coatings are designed to serve as a reservoir for the elements forming or contributing to form the surface oxides [4,5,14].

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