

Review Article

Corrosion Problems in Incinerators and Biomass-Fuel-Fired Boilers

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Incinerators are widely used to burn the municipal waste, biowaste, wood, straw, and biomedical waste. Combustion of these types of waste results in generation of chlorides of sodium and potassium which may attack the metallic part of the incinerator. In biofuel-fired boilers, similar type of highly corrosive environment is present. Attempt has been made to review the corrosion problems and their solutions as per the available literature.

1. Introduction

Incineration is a high temperature process that reduces the organic and combustible waste to inorganic, combustible matter and results in drastic reduction in volume and weight of waste [1–3]. Incinerators are widely used to dispose of industrial, hazardous, nonhazardous, commercial, municipal, some agriculture, and hospital wastes [4]. Normally, incinerators are operated at high temperature between 300°C and 1100°C based on volume and type of waste, incinerator, and fuel used [5]. In a recent literature it is opined that incineration is a dying technology for waste treatment, as it is unreliable and produces a secondary waste stream more dangerous than the original [6]. Establishment of the incinerator to dispose the hazardous waste was passed by US EPA in 1976 as “Resource Conservation and Recovery Act PL 94-580.” Postmanaging systems for flue gases are widely used in incinerators to reduce any harm which can be created by stream of flue gases. These systems consist of devices such as electrostatic precipitator, venturi scrubber, packed bed scrubber, plate tower, dry scrubber, semidry scrubber, bag filters or bag houses, wet electrostatic precipitator, and ionizing wet scrubber [7]. Hence, secondary stream can be cleaned so as to make it harmless by application of the abovementioned equipments.

As waste generation has increased considerably worldwide in the last few decades; the combustion of biomedical

waste, municipal solid wastes, and biomasses in fluidized-bed boiler facilities is an attractive solution for both energy production and conservation of land, otherwise wasted in landfills [8, 9]. Landfill disposal of waste may result in ground water pollution if the landfill site is inadequately designed or operated [1]. In locations where population densities are high, the use of landfills for waste disposal has become less feasible and waste incineration becomes a more attractive option [10]. Millions of tons of municipal solid waste (MSW) are produced every year which have been treated using incineration technique which reduces waste mass by 70% and volume by up to 90%, as well as providing energy to generate electricity [11]. Waste generated from biomedical activities reflects a real problem of living nature and human world [8]. Improper disposal of health care wastes, syringes, and needles that are scavenged and reused may lead to spreading of diseases such as hepatitis C and AIDS [12]. Hence, such waste is desired to be disposed properly. Incineration is a thermal process, which destroys most of the waste including microorganism [13]. Surveys show that most incinerators are operated at incorrect temperature and do not destroy the waste completely due to use of insufficient fuel [14]. It is necessary to adequately oxidize the principal organic hazardous waste to the 99.99% destruction. Near complete destruction of hazardous waste can be achieved only at temperature around 1000°C and above where intense reaction conditions can be provided with the help of increased turbulence in the combustion

zone to maximize the reaction and minimize residence time. Adequate pressure has to be provided for creating necessary scrubbing of halogens and particulate matter [14]. Use of very high temperature in incinerator will lead to degradation of construction material, thereby decreasing the service life of components facing higher temperature.

2. High Temperature Corrosion Problem in Incinerator

Corrosion damage is a major issue in waste incinerators which required constant repair thereby adding to running cost [15]. Fireside corrosion has been frequently encountered in incinerators [16]. During combustion of waste and some types of biomass, high levels of HCl, NaCl, and KCl are released. Both chlorides and sulphates containing melts may form on superheater tubes during waste incineration. Molten chlorides are more frequently encountered due to their lower melting points [17]. Miller and Krause [18] found that accumulation of elements such as sulphur, chlorine, zinc, aluminium, potassium, and occasionally lead and copper occurred at the metal/scale interface as a deposit in municipal incinerators. Ma and Rotter [19] reported that municipal solid waste maintains a large quantity of chlorine, as one of the free elements that causes high temperature corrosion after fine fly ash particles condense on heat exchanger surfaces. Yokoyama et al. [20] suggested that HCl gas, salts, and sulphates in the bed cause corrosion of the heat-exchanger tubes in a fluidized bed waste disposal incinerator, while abrasion is due to the vigorous movement of sand in the bed. Agarwal and Grossmann [21] found that high temperature corrosive attack in incinerators is caused by constituents such as oxygen, carbon, hydrogen, nitrogen, halides (Cl, F, and Br), sulfur, organophosphate compounds, and molten salts and/or liquid metal attack due to presence of low melting point metals such as lead, tin, antimony, bismuth, zinc, magnesium, and aluminium. Material wastage in the high temperature region of most waste incinerators mainly occurs by chlorination and chloride-induced corrosion, although attack by acid/basic fluxing caused by sulfate deposits, molten chlorides, and erosion may also play an important role [21].

Several studies have been reported regarding corrosion in incinerators environments. Ishitsuko and Nose [22] discuss the stability of protective oxide films in waste incineration environment such as NaCl-KCl and NaCl-KCl-Na₂SO₄-K₂SO₄ conducted in three different levels of basicity. In a waste incineration environment, a protective Cr₂O₃ film easily dissolves in molten chlorides as CrO₄²⁻ because pO₂²⁻ of the molten chlorides tends to have small value due to the effect of water vapour contained in the combustion gas. Li et al. [23] conducted a study on various Fe-based alloys with different Cr and Ni content and Fe, Cr, and Ni pure metals. The studies have been conducted in simulated waste incinerator environment at 450°C beneath ZnCl₂-KCl deposits in flowing pure oxygen. They concluded that adherence of corrosion products to the substrate was worse for higher Cr-containing materials, while the corrosion resistance to the environment could be improved significantly by increasing

the Ni content, whereas Zhang et al. [24] investigated the corrosion behaviour of Fe and four commercial steels with different Cr contents in an oxidizing atmosphere containing HCl at 500–600°C, which did simulate the environment to which materials are usually exposed in waste incinerator. All the specimens underwent an accelerated corrosion. They suggested that increasing Cr content in the alloy can improve their corrosion resistance. Sorell [25] found out that in municipal solid waste incinerator dominant corrosive species are chlorides, typically in combination with alkali metals [Na, K] and heavy metals [Pb, Zn]. A new probe design consisting of water-cooled support lance made from a nickel-base superalloy with an air-cooled probe head in which the samples were kept between the ceramic plates and the probe was introduced into the WTE plant [15]. From this study they concluded that corrosion is mainly due to high temperature chlorine attack, either through gaseous species like HCl or Cl₂ or by chloride particles, which are deposited on superheater tubes leading to strong damage by acceleration of oxide formation [15]. Effect of adding molybdenum and silicon in steels was also examined and it was found that in hot corrosion environment, molybdenum as well as up to about 1% silicon decreased the corrosion rate. Tests were conducted on T91 ferritic steel and AC66 austenitic steel under several atmospheres present in coal-fired plant and waste incinerator in several ash mixtures and at different temperature. Exposure time was generally 100 hours and sometimes 500 hours. In coal-fired plant, the actual degradation depended on the alkali sulphates and SO₂ contents and on temperature. The HCl presence had little impact. While in waste incinerator the degradation was more pronounced, the development of a thick, badly adherent corrosion layer occurred, with deep internal degradation of the alloys which was attributed to the active oxidation due to molten alkali chlorides [26]. Jegede et al. [27] also tested the Udimet alloy and the 310SS in simulated waste incineration flue gases at 750°C, isothermally for 72 h and 120 h, and also cyclically tested for 120 h. In both the conditions, the substrate showed initial weight gain followed by weight loss after some cycles. They reported that chlorine forms volatile species which may evolve through the cracked scale thereby leaving behind defective and porous scale. Oh et al. [28] discussed corrosion behavior of a series of commercial superalloys in flowing argon-20 pct oxygen-2 pct chlorine at 900°C. They reported that the decrease in mass of alloys may be due to formation of volatile chloride or oxychloride as corrosion products. Delay et al. [29] also confirmed that mobilisation of alkali and trace elements present in clinical waste can lead to accelerated deterioration of the plant components and may cause environmental damage. Covino et al. [30] further suggested that the waste incinerators have more severe thermal gradient influenced corrosion problems than most coal combustors because the ash deposited in waste-to-energy (WTE) plants typically contains low melting fused salts and eutectic mixture that can lead to accelerated corrosion [30]. Ni et al. [31] determined the fly ash composition and bottom ash composition of the medical waste incinerator (MWI) operated in China. They discussed that fly ash mainly consisted of Ca, Al, Si, Mg, Na, O, C, Cl, and S while the bottom ash consisted of CaCO₃,

SiO_2 , and $\text{Ca}[\text{OH}]_2$. They also reported that the chlorine content in fly ash from the MWI was higher than that in the fly ash generated by a municipal solid waste incinerator (MSWI).

3. Biofuel-Fired Boiler

Increasing fuel prices and efforts towards sustainable energy production have led to the exploration of new biofuels both in the energy sector for the production of heat and power in boilers and also in the transportation sector for the production of new high quality transportation fuels to be used directly in engines [32]. It was opined that biomass may be the only renewable energy source that can replace conventional fossil fuels directly [33]. Integration of biomass with combined cycle gas turbine (CCGT) power plants gives improvement in efficiency and possible cost reduction as compared to stand alone plants [34]. At present around 12% of the global energy requirement is generated by combustion of biomass fuels, which vary from wood and wood waste (e.g., from construction or demolition) to crops and black liquor [35]. Biomass is a kind of fuel having low density, is bulky, and releases the volatiles [36]. Biomass fuels are burned in three main types of boilers, namely, grate fired, bubbling bed, and circulating fluidized bed units. These boilers are normally operated solely to generate electricity but can also be operated to simultaneously generate a combination of heat and power [37]. It is found that there is a growing interest in the use of biofuels for energy purposes due to various reasons such as reduction in dependency on imported oil, generation of 20 times more employment, mitigation of greenhouse gases [38–40], and reduction of acid rain [41]. It is a thumb rule that co-combustion of mixtures of biomass waste-based fuel and coal with energy input of the biomass up to 10% causes slight decrease in N_2O emissions and may cause only mild or practically no operational problems [42]. Apart from these benefits some technical issues associated with cofiring include fuel supply, handling and storage challenges, potential increase in corrosion, decrease in overall efficiency, ash deposition issues, pollutant emissions, carbon burnout impacts on ash marketing, impacts on selective catalytic reduction (SCR) performance, and overall economics [43]. Problem of fuel supply occurs as biofuels tend to have high moisture content, which adds to weight and thereby increase the cost of transportation. It can add to cost as biomass has low energy densities compared to fossil fuels. A significantly larger volume of biomass fuel is required to generate the same energy as a smaller volume of fossil fuel and so it will add to cost. The low energy density means that the cost of the fuel collection and transportation can quickly outweigh the value of the fuel; hence, it should be transported from shorter distances [44]. It was also reported that many power plants burning fuels such as waste-derived fuels experience failures of the super heaters and/or increased water wall corrosion due to aggressive fuel components even at low temperatures [45]. One of the biggest challenges encountered in biomass-fired are the increased tendency for bed agglomeration and the increased fouling of convective

heat transfer surfaces, sometimes associated with increased corrosion. The most destructive property of biomass towards agglomeration, fouling, and corrosion appears to be due to their ash constituents such as sulphur, chlorine, and phosphorous [46]. Alkali chlorides are formed during biomass combustion and transported via aerosols or in the vapour phase within the combustion gas, subsequently depositing on the metallic surface or on the already formed oxide layer [47].

4. Corrosion and Environmental Effect in Biofuel Boiler

In recent years [48], in Sweden, there has been a move away from burning fossil fuels to biomass in order to reduce CO_2 emissions. Burning of 100% biomass causes severe corrosion problems. The chlorine contents of wood, peat, and coal are relatively similar, but there is considerably more sodium and potassium and less sulphur in wood fuels and it is suggested that the formation of complex alkali chlorides principally causes the corrosion problems. Experience from Swedish power stations fired with 100% wood-based biofuels has shown that conventional superheater steels (low chromium ferritic steels) have to be replaced after about 20,000 hours if the steam temperature is 470°C or higher [48]. Henderson et al. [49] have reported that most biomass fuels have high contents of alkali metals and chlorine, but they contain very little sulphur compared to fossil fuels. The alkali metal of major concern in wood is potassium. The majority of potassium is released into the gas phase during combustion and is mainly present as potassium chloride [KCl] and potassium hydroxide [KOH]. The alkali metals form compounds with low melting temperatures and can condense as chlorides causing widespread fouling of superheater tubes and other operational problems during combustion. Figure 1 shows the superheater tube corroded at a 100 MW facility fired with high chlorine (>1%) biomass with bituminous coal [50].

Chlorine may cause accelerated corrosion resulting in increased oxidation, metal wastage, internal attack, void formations, and loose nonadherent scales. The most severe corrosion problems in biomass-fired systems are expected to occur due to Cl-rich deposits formed on superheater tubes [51]. Viklund et al. [52] have conducted corrosion testing in waste-fired boiler for short-term exposure (3 h) to analyse composition of deposits and initial corrosion, as well as long-term exposures (1550 h) to investigate corrosion rates. These investigations were done with ferritic steels 13CrMo44 and HCM12A, the austenitic steels Super 304, 317L, Sanicro 28, and the nickel-base alloys Hastelloy C-2000 and Inconel 625. Analysis revealed a deposit dominated by CaSO_4 , KCl, and NaCl, but also appreciable amounts of low melting salt mixtures such as ZnCl_2 -KCl, PbCl_2 -KCl, FeCl_2 -KCl, and NaCl - NiCl_2 . Metal loss measurements showed unacceptably high corrosion rates for 13CrMo44, HCM12A, and Super 304. The corrosion attack for these alloys was manifested by the formation of mixed metal chloride/metal oxides scales. A different type of behaviour was seen for the higher alloyed austenitic steels and nickel-base alloys, which were able to



FIGURE 1: Corrosion with high chlorine biomass cofiring [50].

form a chromium rich oxide next to the metal. However, these alloys suffered from some localised pitting attack. The behaviour is explained by oxide dissolution in the molten salts that are present in the deposit [52]. Reidl et al. [53] have found that the main biomass fuels used in Austria are bark wood chips and saw dust. They reported severe corrosion in several wood chips and bark combustion plants equipped with hot water fire-tube boilers which lead to leakage from several heat exchangers tubes after less than 10,000 operating hours. Uusitalo et al. [54] reported that severe corrosion occurred in oxidizing conditions of simulated biofuel-fired boiler environment where samples were exposed to synthetic salt containing 40 wt% K_2SO_4 , 40 wt% Na_2SO_4 , 10 wt% KCl, and 10 wt% NaCl at 550°C in oxidizing and reducing atmosphere for 100 h. Corrosion tests were performed on low alloy ferritic steel and austenitic stainless steel, HVOF coating (Ni-50Cr, Ni-57Cr, Ni-21Cr-9Mo, and Fe_3Al), laser cladding (Ni-53Cr), and diffusion chromized steel. They also reported that oxides at splat boundaries were attacked by chlorine along which it penetrated [54]. Karlsson et al. [55] reported the influence of NaCl, KCl, and $CaCl_2$ on corrosion in biomass fuel boiler and suggested that $CaCl_2$ is less corrosive as compared to NaCl and KCl. They further suggested that the presence of KCl and NaCl strongly accelerated the high temperature corrosion of 304L stainless steel in 5% O_2 + 40% H_2O environment with nitrogen as carrier gas at 600°C. Corrosion is initiated by the formation of alkali chromate [VI] through the reaction of alkali with the protective oxide. Chromate formation is a sink for chromium in the oxide and leads to a loss of its protective properties. Pettersson et al. [56] had studied the effect of KCl on 304 austenitic stainless steel in presence of 5% O_2 and 5% O_2 + 40% H_2O environment at 400–600°C for exposure time of 1 week. Their studies showed that KCl is strongly corrosive species and maximum corrosion occurred at 600°C. Corrosion is initiated by the reaction of KCl with the chromia containing oxide that normally forms a protective layer on the alloy. This reaction produces potassium chromate particles, leaving chromia-depleted oxides on the alloy surface. Pettersson et al. [57] also reported the effect of KCl, K_2SO_4 , and K_2CO_3 and concluded that KCl and K_2CO_3 strongly accelerate the corrosion of 304L while K_2SO_4 has little influence on the corrosion rate. Sharp et al. [58] suggested that alkali metals and chlorine released in biofuel boilers cause accelerated corrosion and fouling at

high superheater steam temperature due to which they have to be operated at lower temperature much below than those of advanced fossil-fuel-fired boilers resulting in decreased efficiency. Hernas et al. [59] confirm that high temperature corrosion of rotary air preheaters during combustion of biomass and coal is due to the presence of alkali metal chlorides in the deposits. Karlsson et al. [60] studied the corrosion in biofuels boilers and concluded that corrosion is mainly due to alkali chlorides and hydrogen chloride. Studies [61] were conducted on two high temperature resistant steels, Sandvik 8LR30 [18Cr 10Ni Ti] and Sanicro 28 [27Cr 31Ni 4Mo], to determine the role of ash deposit in the refuse incinerator and straw/wood fired power plant. Ash for this study was collected from radiation chamber, superheater, and economiser sections in both waste incineration and straw-fired/wood chip fired power plants. They carried out these investigations in laboratory at flue gas temperature of 600°C and metal temperature of 800°C up to 300 hours exposed to HCl and SO_2 . They reported that both aggressive gases and ash deposits increase the corrosion rate synergistically, due to the reaction between potassium chloride with sulphur dioxide and oxygen which results in the formation of porous unprotective oxide [61]. The presence of elements such as chlorine and zinc, together with alkali metals from the biomass, has the potential to form sticky compounds that increase the deposit growth rate and rapidly increase corrosion rates [62]. The successful operation of combustion units depends on the ability to control and mitigate ash-related problems, which can reduce the efficiency, capacity, and availability of the facilities, thereby increasing the power cost. Such problems include fouling, slugging, corrosion of equipment, and pollutant emissions [63]. Soot blowing is the most common method of reducing the effects of deposits on the heat transfer tubes [62]. One way to mitigate corrosion on fireside is by changing environment by fuel additives such as sulphur. It was also found that ammonium sulphate reduced the deposit growth rate and halved the corrosion rate of ferritic/martensitic steels in a wood-fired boiler. With the addition of the sulphate, iron sulphides were formed within the oxide, which are believed to have hindered the corrosion process and iron chlorides were largely absent [64]. Viklund et al. [64] also found that addition of ammonium sulphate to biomass-fired boilers decreases corrosion tendencies. In situ exposures were carried out in a waste fired, 75 MW, CFB

boiler in Händelö, Sweden. The plant is burning 30–50% of household waste and 50–70% of industrial waste and deposit was found to be dominated by Na, K, Ca, Cl, S, and O. Low alloyed ferritic steel EN1.7380 [Fe-2.25Cr-1Mo] and the austenitic EN1.7380 [Fe-18Cr-9Ni] were exposed during 4 hours on air-cooled probes. Metallography shows a marked difference in corrosion attack between the two steels. It was suggested that addition of 300 ppm of SO₂ results in drastic reduction of corrosion rate as it leads to formation of K₂SO₄ which does not react with Cr₂O₃ and also suppress formation of alkali-chlorides rich deposits. Addition of sulphur or sulphur containing compounds to the fuel resulted in 50–70% decreases in corrosion rate of exposed sample. Karlsson et al. [65] reported that the addition of digestive sewage sludge to the 12-MWth CFB boiler at Chalmers University of Technology resulted in a decreased corrosion rate of 304L and Sanicro 28 at 600°C after 24 hours of exposure. Lee et al. [66] reported that addition of lime or MgO with the blast reduces the corrosion as magnesium combines with vanadium to form magnesium vanadate which is solid at the boiler temperature. Kaolin (Al₂O₃-SiO₂) addition can significantly reduce superheater deposits, corrosion, and slagging and thus enhance the operation of the biomass-fired boiler [67]. Kaolin, which is abundant in kaolinite (Al₂Si₂O₅(OH)₄), is employed to capture the alkali metal vapors eluding from the combustion region [68, 69].

5. Remedial Measures

Guilemany et al. reported possible solution for the oxidation of exchanger steel tubes through HVOF thermal spray coatings and concluded that wire and powder HVOF coatings show good properties to protect steel exchanger pipes against the erosion produced by the impact of the ashes in the flue gas [103]. Rezakhami [119] compared the effect of simulated oil-fired boiler environment (70% V₂O₅-20% Na₂SO₄-10% NaCl exposed to 550°C and 650°C for 6 cycles each of 48 hours) on various ferritic steels and austenitic steels as well as on some thermally sprayed coating. Austenitic steel suffers from uniform corrosion, while ferritic steel attacks by the grain boundary corrosion. Thermally sprayed FeCrAl, 50Ni-50Cr, Tafaloy 45LT, and Cr₃C₂NiCr coatings were also tested in the given condition and the result showed that all the coatings provide good resistance to corrosion and help in increasing the life of both the steels [119]. Singh et al. [120] investigated superficially applied Y₂O₃ as inhibitor which leads to reduction in high temperature corrosion of superalloys in presence of Na₂SO₄-60V₂O₅ at 900°C under cyclic condition. Goyal et al. [121] confirm that the addition of inhibitor such as ZrO₂ to boiler environment such as Na₂SO₄-60% V₂O₅ can help in decreasing the corrosion rate of superalloys at high temperature. Yamada et al. [106] tested the D-gun, HVOF, and plasma sprayed 50% Ni-50% Cr alloy coating on steel and Ni based superalloys in actual refuse incineration environment. Analysis revealed the presence of chlorine, which is the main cause of hot corrosion in the coated areas. D-gun sprayed coatings give maximum corrosion resistance in boiler of actual refuse incineration

plant working for 7 years without any problem and are expected to have longer life. Paul and Harvey [122] tested the corrosion resistance of four Ni alloy coating deposited by HVOF onto P91 substrate under simulated high temperature biomass combustion condition. It was observed that alloy 625, NiCrBSiFe, and alloy 718 coating performed better than alloy C-276.

6. Discussion

Demand of electricity production is increasing constantly with the increase in population. In India, the electricity demand has been growing up to 3.6% every year. Most of these energies are generated from fossil fuels like coal and so forth. Burning of coal leads to the emission of greenhouse gases such as carbon dioxide, which will cause global warming. These gases cause environmental pollution. Mining of coal also leads to environmental degradation. Hence, using the biofuels or organic and other waste for generating power can lead to two basic advantages. Two requirements are needed: firstly decreasing the use of fossil fuel and secondly saving the area waste in landfills. Incineration technique currently is being used to dispose municipal solid waste, biowaste, and medical waste. In case of medical waste higher incineration temperature is necessary to kill the microorganism to avoid the spread of diseases. The type of environment in the incinerator will depend on the type of fuel waste being burnt.

Burning of municipal waste produces compounds such as ZnCl₂, PbCl₂, KCl, and NaCl, whereas straw waste burning produces higher concentration of KCl and K₂SO₄. Burning of wood will produce higher amount of NaCl and Na₂SO₄ along with KCl and K₂SO₄, whereas coal as a fuel will lead to the production of salt species such as Na₂SO₄, K₂SO₄, and (NaK)₂(FeSO₄)₃. Production of all such types of species leads to corrosion which is breaking down essential properties of metals due to attack by corrosive compounds on the metal surface. The information regarding the behaviour of different alloy and coatings has been summarized in Table 1.

From table it can be seen that NaCl will lead to severe corrosion. Alloy steels and superalloys are resistant to sulphates environment but addition of chlorides increases the corrosion rate manifolds. Active oxidation is the main mechanism for the corrosion in chlorides environment leading to mass loss due to formation of volatile species, formation of porous scale, and internal oxidation.

It is also seen that Ni-based superalloys are more resistant to chloride containing environment but are susceptible to corrosion in sulphur containing environments. Cr₂O₃ forming alloys are prone to corrosion in alkaline flux which dissolves chromium-based species leading to enhanced corrosion. In case of wood, municipal waste, and biomedical waste the burning can be carried out at temperature around 500–1000°C, whereas in case of medical waste incinerator secondary burning is required where temperature may be around 1200°C. This required the use of superalloys and coatings to take care of the aggressive environment at high temperature.

TABLE I: A summary of corrosion studies on some alloys and coatings under chlorides and sulphates containing environment.

| S. number | Material | Environment | Brief detail |
|-----------|---|--|--|
| 1 | Vacuum induction melted cast nickel-base superalloy (wt.%) is C = 0.14, Cr = 9.0, Al = 5.8, Ti = 2.7, W = 10.5, MO = 2.1, Co = 10.1, Nb = 1.1, Ni = balance | 100% Na ₂ SO ₄ , 75% Na ₂ SO ₄ + 25% NaCl, and 60% Na ₂ SO ₄ + 30% NaVO ₃ , + 10% NaCl tested at 900°C, 925°C, 950°C, and 975°C | Parabolic growth, internal sulfidation; formation of volatile species causing voids and pits at grain boundaries was reported [70] |
| 2 | Ni-based superalloy bars, which contain mainly Ni with 6.3 wt.% Al, 6 wt.% Cr, and some Co, Ti, Mo, W, and Ta | Na ₂ SO ₄ and 75 wt.% Na ₂ SO ₄ -25 wt.% NaCl mixture studied in air at 900°C | Corrosion products were laminar, porous, and spallable. Internal sulfidation of the superalloy was seen [71] |
| 3 | Powder metallurgy (PM) Rene95 Ni-based superalloy | 25% NaCl + 75% Na ₂ SO ₄ salts at 650°C, 700°C, and 750°C | The corrosion kinetics followed a square power law at 650°C while following linear ones at 700°C and 750°C [72] |
| 4 | 310 stainless steel | NaCl/Na ₂ SO ₄ of varying ratio salts at 750°C | 75% NaCl mixtures give severe corrosion with uniform internal attack. Increase of Na ₂ SO ₄ content leads to intergranular attack [73] |
| 5 | Silicon and aluminium with and without cerium were simultaneously codeposited by diffusion into austenitic stainless steel (AISI 316L) | 50 wt.% NaCl + 50 wt.% Na ₂ SO ₄ deposits at 750°C for 120 h at 10 h cycle | Ceria addition improves the corrosion resistance of coating [74] |
| 6 | T-91 steel and T-22 steel | 75 wt.% Na ₂ SO ₄ + 25 wt.% NaCl at a temperature of 900°C in a cyclic manner | T-91 steel was found to be more corrosion resistant than T-22 steel [75] |
| 7 | HVOF sprayed WC-NiCrFeSiB coating deposited on Ni-based superalloy (Superni 75) and Fe-based superalloy (Superfer 800H) | 75 wt.% Na ₂ SO ₄ -25 wt.%; NaCl mixture was studied in air at 800°C | Oxidation resistance is improved by formation of oxides of Ni, Cr, and Co and their spinels on the surface scale and at the boundaries of Ni, W rich splats [76] |
| 8 | CM 247 LC | Pure Na ₂ SO ₄ as well as Na ₂ SO ₄ and NaCl mixtures of different concentrations at various temperatures | Severely corroded in just 4 h and completely consumed in 70 hr when tested in 90% Na ₂ SO ₄ + 10% NaCl at 900°C [77] |
| 9 | Co, Co-10Cr, and Co-10Cr-5Al alloys | Na ₂ SO ₄ -25% NaCl environment at 1173°C | The mass gain is in the following order: Co-10Cr-5Al < Co < Co-10Cr [78] |
| 10 | Ni + CrAlYSiN nanocrystalline composite coatings and NiCrAlYSi reference coatings, K438 alloy | 75 wt.% Na ₂ SO ₄ + 25 wt.% NaCl) environment at 900°C | Both coatings improved the hot corrosion resistance of K438. For the composite coating, the oxide scales were composed of -Al ₂ O ₃ , Cr ₂ O ₃ , and minor NiCr ₂ O ₄ [79] |
| 11 | Mar-M 509 | Na ₂ SO ₄ or Na ₂ SO ₄ + 1% NaCl, Na ₂ SO ₄ + 25 wt.% NaCl at 750°C | Na ₂ SO ₄ + 25% NaCl were very aggressive compared to that of either pure Na ₂ SO ₄ or Na ₂ SO ₄ + 1% NaCl. Sulfidation-oxidation mechanism has been proposed [80] |
| 12 | Ti-48Al-2Cr-2Nb alloy | 75% Na ₂ SO ₄ and 25% NaCl (mass fraction) at 800°C | Interphase selective corrosion of one phase causes pits at the laminar interphase during hot corrosion. The refinement of these laminations leads to mitigation of this problem [81] |
| 13 | Cobalt-base superalloy K40S with and without NiCrAlYSi coating | Na ₂ SO ₄ and Na ₂ SO ₄ containing 25 wt.% NaCl salt deposit | Bare alloy suffered from accelerated corrosion with nonprotective and nonadherent scale. NiCrAlYSi coating provides protection forming α-Al ₂ O ₃ scale [82] |
| 14 | Nickel-base superalloy GH37 | 75 wt.% Na ₂ SO ₄ -25 wt.% NaCl at temperature of 700 and 850°C under stresses of 471 and 196 MNm ⁻² | Creep rupture life is reduced in this environment at both the temperatures with reduced period of crack initiation and increases rate of creep propagation [83] |
| 15 | Ni-based superalloy (Superni 75) and Fe-based superalloy (Superfer 800H) | Air and molten salt (Na ₂ SO ₄ -25% NaCl) environment at 800°C under cyclic conditions | The formation of scale rich in Cr ₂ O ₃ , NiO, and spinel NiCr ₂ O ₄ has contributed to better oxidation and hot corrosion resistance of Superni 75 as compared to Superfer 800H [69] |

TABLE 1: Continued.

| S. number | Material | Environment | Brief detail |
|-----------|--|---|---|
| 16 | Ni ₃ Al containing small additions of Ti, Zr, and B | With and without Na ₂ SO ₄ -NaCl salt deposits at 600–800°C | Accelerates corrosion seen at 600 and 800°C under salt. At 600°C alumina scale is formed and at 800°C NiO-Al ₂ O ₃ with sulphur compounds [84] |
| 17 | Al-gradient NiCoCrAlYSiB coating on a Ni-base superalloy using arc ion plating (AIP) | Pure Na ₂ SO ₄ and Na ₂ SO ₄ /NaCl (75 : 25, wt./wt.) salts were performed at 900°C in static air | By partially sacrificing Al ₂ O ₃ (i.e., Al), the gradient NiCoCrAlYSiB coating specimen behaved excellently in the two kinds of salts [85] |
| 18 | Cr13Ni5Si2-based metal silicide alloy | Na ₂ SO ₄ -25 wt.% K ₂ SO ₄ at 900°C and Na ₂ SO ₄ -25 wt.% NaCl at 850°C | Metal silicide alloy exhibited high hot corrosion resistance in molten Na ₂ SO ₄ -25 wt.% K ₂ SO ₄ due to the very high Cr content. Addition of NaCl to Na ₂ SO ₄ accelerated the cracking and spalling of the Cr ₂ O ₃ oxide scales and promoted the formation of sulphides [86] |
| 19 | Fe-28Cr and Fe-28Cr-1Y | 0.1 to 1.0% HCl on the oxidation in argon-20% O ₂ at 600 and 700°C | Formation of FeCl ₂ , CrCl ₂ , and CrO ₂ Cl ₂ was observed with evaporation during corrosion. 1% Y resulted in marked improvement in corrosion protection by allowing formation of Cr ₂ O ₃ rich layer [87] |
| 20 | Ni-11Cr nanocomposite, Ni-10Cr, and Ni-20Cr alloys | 25NaCl + 75 (Na ₂ SO ₄ + 10K ₂ SO ₄) in air at 700°C | In case of nanocomposite, fast formation of continuous chromia scale provided the protection, whereas internal sulfidation was only observed in both the alloys [88] |
| 21 | Udimet alloy and 310SS | Simulated municipal waste incineration flue gas at 750°C, isothermally for 72 and 120 h, and also under thermal cycling for 120 h | In case of Udimet, the formation of volatile MoO ₂ Cl ₂ and WO ₂ Cl ₂ is likely to have caused weight loss and porous oxide. In contrast, the kinetics of 310SS under thermal cycling show linear rate of corrosion [27] |
| 22 | Fe, Cr, Ni, the ferritic alloys Fe ± 15Cr and Fe ± 35Cr, and the austenitic alloys: alloy 800, alloy 825, and alloy 600 | N ₂ ± 5 vol% O ₂ He ± 5 vol% O ₂ + 500–1500 vppm HCl at temperatures between 400 and 700°C using discontinuous exposures | Active oxidation is found to be the main mechanism of corrosion above 500°C [89] |
| 23 | Cast Fe-Cr-Ni alloy (Cr-25.5, Ni-13, Mn-0.5, C-0.3, Si-1.2, Ti-0.4, Al-0.05, S, and P each: <0.01%, and bal. Fe) | (K, Na) Sulfate + 21 wt.% chloride with the [K]/[Na] ratio on mole basis equal to 1.4 | Alkali sulphate deposit increases the corrosion rate by factor of 200 and alkali sulphate chloride mixture increases the rate by about 20000 times as compared to air oxidation [90] |
| 24 | Three Fe-30.1Mn-6.93Al-0.86C base alloys with different aluminium and chromium contents | NaCl deposit (2 mgcm ⁻²) 750 to 850°C in air | With 8% Al, air oxidation gives Al ₂ O ₃ . Addition of chromium gives best oxidation resistance at 750°C and 800°C. In hot corrosion with NaCl deposit the addition of chromium reduces the metal loss, but overall resistance was not improved [91] |
| 25 | Cr ₃ C ₂ -NiCr cermet coatings deposited on Superni 75, Superni 718, and Superfer 800H | 75 wt.% Na ₂ SO ₄ + 25 wt.% K ₂ SO ₄ film at 900°C for 100 cycles | Cr ₃ C ₂ -NiCr-coated superalloys showed better hot corrosion resistance than the uncoated superalloys [92] |
| 26 | Electroless nickel coating (EN), hot-dip aluminum with added silicon coating (HD), and pack aluminide coatings (PC), on low carbon steel | NaCl (2 mg/cm ²) oxidized at 850°C for 1–169 h isothermally | The aluminized coatings (HD and PC) had lower corrosion rates than that of EN coating. Preoxidation is helpful in case of pack cementation [93] |
| 27 | Fe-20% Cr alloy | KCl, NaCl, Na ₂ SO ₄ , and K ₂ SO ₄ pure salts and a mixture of these salts at 800°C | Alkali oxides under oxidizing condition have higher solubility for Fe and Cr containing species as compared to their solubility in alkali sulphates [94] |

TABLE 1: Continued.

| S. number | Material | Environment | Brief detail |
|-----------|--|--|--|
| 28 | K38G cast alloy by multiarc ion plating and LP-CVD (NiCoCrAlY and diffusion aluminide coating) | 75 wt.% Na ₂ SO ₄ + K ₂ SO ₄ and 75 wt.% Na ₂ SO ₄ + NaCl salt mixture at 900°C | Low oxidation rate observed in case of coatings, whereas presence of salts accelerated oxidation rate. NiCoCrAlY coating showed the better hot corrosion [95] |
| 29 | IN 788, IN 718C, IN 100, and Ni-30Al (NiAl) | Na ₂ SO ₄ , NaCl, and Na ₂ SO ₄ -NaCl mixtures with O ₂ and O ₂ + SO ₂ environments | Na ₂ SO ₄ with SO ₂ in the environment gives maximum corrosive rate at 750°C. All the binary and superalloys Al ₂ O ₃ Cr ₂ O ₃ forming showed less corrosion when either SO ₂ or NaCl was absent from the corroding media [96] |
| 30 | Low and high alloy steels | NaCl or a fly ash tested at temperature of 500°C and high alloy steels at 600 and 700°C | Formation of porous unprotective scale and active oxidation were noticed to be catalysed by chlorine [97] |
| 31 | Boiler tube steel (X20CRMV121 and AISI 347FG) | KCl and/or K ₂ SO ₄ and real deposits exposed to a synthetic flue gas (6 vol% O ₂ , 12 vol% CO ₂ , 400 ppmv HCl, 60 ppmv SO ₂ , balance N ₂) in 550°C from 1 week to 5 months were used | Both the alloys suffered minor internal attack with the KCl. Pitting was also observed [98] |
| 32 | CM 247 LC superalloy, NiCoCrAlY, NiCoCrAlY 1% Hf, NiCoCrAlY 1% Si, NiCrAlY, CoCrAlY coating | 95% Na ₂ SO ₄ 5% NaCl and 90% Na ₂ SO ₄ 5% NaCl 5% V ₂ O ₅ environments at 900°C | MCrAlY exhibits maximum life in both sodium chloride and vanadium containing environments. Presence of trace elements in the coating reduces coating life significantly [99] |
| 33 | IMI 834 | Na ₂ SO ₄ , 90% Na ₂ SO ₄ -10% NaCl, Na ₂ SO ₄ + 5% NaCl + 5% V ₂ O ₅ at 500, 600, and 700°C | Significant weight loss was observed with pitting-type corrosion in the presence of NaCl [100] |
| 34 | Nickel aluminide Ni ₃ Al containing up to 8 mass% Cr and up to 0.9 mass% Zr | The chlorination and sulfidation tests were carried out in both oxygen-deficient (HCl/H ₂ and H ₂ S/H ₂ , resp.) and oxygen-containing (Cl ₂ /O ₂ and SO ₂ /air, resp.) atmospheres. 750 to 1100°C | Undoped Ni ₃ Al shows excellent resistance in air, in carburizing gases, and in chlorinating/oxidizing atmospheres, whereas in oxygen-deficient chlorinating gas atmospheres and in sulphidising atmospheres its resistance is poor. Zirconium addition is beneficial in case of oxygen-deficient chlorinating environments but increases the oxidation rate in air and in chlorinating [101] |
| 35 | Mar-M247 superalloy, aluminized and boroaluminized by pack cementation | Na ₂ SO ₄ -NaCl molten salt, 1000°C | Hot corrosion resistance increased for the specimens containing NiAl. Post heat treatment increased the corrosion resistance of the aluminized layer for Mar-M247; boroaluminized Mar-M247 specimens decrease corrosion resistance due to blocking of outward diffusion of Cr by boron [102] |
| 36 | AISI C-1055 (UNS G10550), Inconel wire | In situ test, samples with 2 cm ² of surface were covered with an excess of eutectic salt mixture and tested for 360 h at 400°C. KCl : ZnCl ₂ salt mixture | Wire and powder HVOF coatings show good properties to protect steel heat exchanger pipes against the erosion produced by the impact of the ashes in the flue gas [103] |
| 37 | Fe, Ni, and some model Fe-Ni alloys | Atmospheres of varying chlorine (10 ⁻³ , 10 ⁻⁵ , and 10 ⁻⁷ Pa) and low oxygen potentials (10 ⁻¹¹ -10 ⁻¹⁵ Pa) at temperatures of 800 and 1000°C | At 800°C in all three atmospheres the reaction kinetics was linear and the corrosion product was identified as ferrous chloride. At 1000°C under conditions of 10 ⁻³ Pa, Ni was found to be inert. A limiting Ni content of 50% was found to confer excellent chlorination resistance to iron [104] |

TABLE I: Continued.

| S. number | Material | Environment | Brief detail |
|-----------|---|---|--|
| 38 | Binary Fe-Cr alloys (of compositions 2, 5, 9, 14, and 25 wt.% Cr) | Bioxidant oxygen-chlorine environment ($P_{O_2} = 10^{-11}$ Pa, $P_{Cl_2} = 10^{-3}$ Pa) at 1000°C and, for comparison, in oxygen of low fugacity ($P_{O_2} = 10^{-11}$ Pa) for periods up to 96 h | Increasing levels of chromium gradually suppressed corrosion such that the Fe25Cr alloy exhibited virtually no attack. The principal corrosion product was $FeCl_2$ vapour with small amounts of Cr_2O_3 scale. Attack of the metal occurred initially via the grain boundaries, leading in the later stages to severe corrosion [105] |
| 39 | 50% Ni-50% Cr alloy HVOF spray coated boiler tubes, SS400, SUS310S, INCOLOY 825, Inconel 625 | Actual refuse incineration plant | This plant had operated for about 7 years without any problems and the coated tubes are expected to have longer life [106] |
| 40 | CoNiCrAlYRe alloy | Molten Na_2SO_4 at 900°C | Advantages of proper preoxidation treatment were suggested, as keeping repairing for Al_2O_3 scale and inhibiting sulfur penetration [107] |
| 41 | Ti-6Al-4V (Ti-31) alloy | In air and 60% V_2O_5 - Na_2SO_4 and Na_2SO_4 -50% NaCl at 750°C | The degradation of Ti-31 occurs due to the chemical reactions between titania and chloride ions, sulphur, and vanadium present in the environments [108] |
| 42 | St35.8 steel, 13CrMo4-5 steel, St35.8 steel with chromium and aluminium diffusion coatings, HVOF (CrC-WCo Cr_3C_2 -NiCr, Ni-55Cr), plasma (TiC-NiCo) | The erosion tests with pure SiO_2 as erodent. In the E-C tests 0.1 wt.% KCl + SiO_2 , and KCl (7 g). Oxidising atmosphere 8% oxygen and gas temperature (850°C) and specimen temperature 550°C | The nickel-based HVOF coating with high chromium content showed good resistance against E-C at elevated temperature in presence of chlorine. Carbide containing HVOF coatings cannot resist elevated temperature and oxygen attack in presence of chlorine [109] |
| 43 | Ferritic and austenitic boiler steels, five high velocity oxy-fuel (HVOF) coatings, laser-melted HVOF coating, and diffusion chromized steel | Oxidizing atmosphere containing 500 vppm HCl, 20% H_2O , 3% O_2 , and Ar as a balance temp = 550°C for 1000 h | Homogeneous and dense coatings with high chromium content performed well and protected the substrate material. Corrosive species were able to penetrate through some of the HVOF coatings and attack the substrate via interconnected network of voids and oxides at splat boundaries [110] |
| 44 | Low alloy ferritic steel and austenitic stainless steel, five high velocity oxy-fuel (HVOF) coatings, a laser cladding, and a diffusion chromized steel | 40 wt.% K_2SO_4 , 40 wt.% Na_2SO_4 , 10 wt.% KCl, and 10 wt.% NaCl., oxidizing and in reducing atmospheres at 550°C for 100 h | Corrosion was extremely severe in oxidizing conditions because of active oxidation. In reducing atmosphere corrosion was retarded due to depletion of chlorine in the scales by evaporation of metal chlorides, and formation of a layer rich in chromium, sodium, sulfur, and oxygen adjacent to the metal surface. Chlorine was able to penetrate through the coatings along splat boundaries [54] |
| 45 | Ferritic boiler steel, one austenitic boiler steel, five high velocity oxy-fuel (HVOF) coatings, one laser-melted HVOF coating, and one diffusion chromized steel | 500 ppm HCl, 600 ppm H_2S , 20% H_2O , 5% CO, and Ar as a balance at 550°C for 1000 h | Homogeneous and dense coatings with high chromium content performed well and were able to protect the substrate. Some of the HVOF coatings were attacked by corrosive species through interconnected network of voids and oxides at splat boundaries [111] |
| 46 | Superni 718, Superni 600, and Superco 605 | 40% Na_2SO_4 + 10% NaCl + 40% K_2SO_4 + 10% KCl environment at 900°C | Both Ni-based superalloys showed good corrosion resistance while Superco 605 showed spallation throughout the 100 cycles [112] |
| 47 | Alloy 214 alloy 600 Inconel 601, Haynes 230, Hastelloy X, Haynes 556, Haynes 25, Haynes 188, alloy 800H, Hastelloy C276, 310 stainless | Argon—5.5% oxygen—0.96% HCl—0.86 SO_2 at 900~ under isothermal and thermal cycling conditions | All the alloys showed good resistance under isothermal conditions but degradation under thermal cycling conditions due to failure of the protective scales. Formation of volatile chlorine-containing compounds was observed [113] |

TABLE I: Continued.

| S. number | Material | Environment | Brief detail |
|-----------|--|--|---|
| 48 | NiCoCrAlYSi coating and gradient coating | Oxidation tests were conducted in static air at 1000 and 1100°C, respectively. For hot corrosion test: 75 wt.% Na ₂ SO ₄ + 25 wt.% NaCl at 900°C | The gradient coating has provided better protection against corrosion attack than the normal NiCoCrAlYSi coating due to its advantage of possessing Al rich reservoir. The favourable corrosion resistance should be attributed to the gradient distribution and enrichment of Al [114] |
| 49 | 316L stainless steel (SS), surface modified with intermetallic coatings. Three different types of intermetallic coating systems containing aluminum, titanium, and titanium/aluminum multilayers | NaCl salt-applied alloys kept in an air furnace at 800°C up to 250 h | Titanium-modified alloys show the best hot-salt oxidation resistance with the formation of an adherent, protective, thin, and continuous oxide layer [115] |
| 50 | Platinum-iridium films (Ir = 0; 32; 46; 83; 100 at%) were deposited on the nickel-base single crystal superalloy TMS-82+ through magnetron sputtering | 900°C with the Na ₂ SO ₄ + 10% NaCl salt coatings | The lowest mass gain was observed for the Pt-46Ir aluminide coating, which formed the dense and continuous protective Al ₂ O ₃ scale on the surface [116] |
| 51 | T92, HR3C, and 347HFG steels; nickel-based alloy 625 | 600, 650, and 700°C | Ferritic alloy (T92) proved to be the poorest performing alloy [117] |
| 52 | Superni-75 | Actual medical waste incinerator operated at 1100°C | With the growth of a thin Cr ₂ O ₃ interface layer along the scale/surface boundary, the performance of the alloy improved against the attack by the flue gases in the real service conditions [118] |

7. Conclusions

- (1) Incineration is a worldwide used technique to burn waste and to produce energy, but the corrosion problem encountered during the burning of waste is one of the reasons for the unforeseen shutdown of these incinerators.
- (2) Corrosion in incinerators and biomass-fuel-fired boilers may occur due to the presence of salts such as chlorides or sulphates.
- (3) Researchers showed that presence of chlorine in environment is mainly responsible for the damage of protective oxide.
- (4) Addition of sulphur or sulphur containing compounds to the fuel resulted in decreases in corrosion rate in incinerators and biofuel-fired boilers.
- (5) Coating can be sprayed using different thermal spray technique which can save the material from direct contact with the salt and hence enhance the life. Already, D-gun and HVOF sprayed coatings such as 50% Ni-50% Cr, alloy 625, NiCrBSiFe, and alloy 718 have been tried in simulated refuse incinerator and biomass-fuel-fired boiler environment and had shown good performance.
- (6) Superficial application of inhibitors to decrease the corrosion in the given environment can be done.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

- [1] "Treatment and disposal technologies for health-care waste," http://www.who.int/water_sanitation_health/medicalwaste/077to112.pdf.
- [2] C. Mbohwa and B. Zvigumbu, "Feasibility study for waste incinerator plant for the production of electricity in Harare, Zimbabwe," *Advanced Materials Research*, vol. 18-19, pp. 509–518, 2007.
- [3] M.-C. Hung, S.-K. Ning, and Y.-H. Chou, "Environmental impact evaluation for various incinerator patterns by life cycle perspective: a case study in Taiwan," in *Proceedings of the 2nd International Conference on Environment Science and Technology*, vol. 6, pp. 84–88, IPCBEE, 2011.
- [4] D. Crowley, A. Staines, C. Collins, J. Bracken, and M. Bruen, "Health and Environmental Effects of land filling and incineration of waste—A Literature Review," A Report of School of Food Science and Environmental Health, Dublin Institute of Technology, 2003.
- [5] S. W. Manyele and I. S. Kagonji, "Analysis of medical waste incinerator performance based on fuel consumption and cycle times," *Engineering*, vol. 4, pp. 625–635, 2012.
- [6] N. Tangri, "Waste incineration: a dying technology," in *2nd GAIA Global Day of Action on Waste and Incineration*, Quezon City, Philippines, 2003.
- [7] Refuse Incineration Plant, <http://turnkey.taiwantrade.com.tw/en/Content.aspx?ID=28>.
- [8] A. Rajor and Kunal, "Bio-medical waste incinerator ash: a review with special focus on its characterization, utilization and leachate analysis," *International Journal of Geology, Earth and Environment Sciences*, vol. 1, no. 1, pp. 48–58, 2011.
- [9] H. H. Krause, "High temperature corrosion problems in waste incineration systems," *Journal of Materials for Energy Systems*, vol. 7, no. 4, pp. 322–332, 1986.

- [10] B. A. Baker, G. D. Smith, and L. E. Shoemaker, NACE International, Corrosion 2001, Houston, Tex, USA, March 2001.
- [11] Y.-H. Chang, W. C. Chen, and N.-B. Chang, "Comparative evaluation of RDF and MSW incineration," *Journal of Hazardous Materials*, vol. 58, no. 1–3, pp. 33–45, 1998.
- [12] S. Batterman, "Assessment of small scale incinerators for health care waste," Environmental Health Sciences, University of Michigan, January 2004.
- [13] S. S. Kalsi, T. S. Sidhu, and H. Singh, "High temperature corrosion in bio medical waste incinerator," in *Proceedings of the National Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering*, Punjab, India, February 2010.
- [14] J. J. Santoleri, "Heat recovery—an economic benefit to hazardous waste incineration systems," *Journal of Heat Recovery Systems*, vol. 3, no. 2, pp. 145–155, 1983.
- [15] B. Waldman, D. Schrupp-Heidelberger, B. Stöcker, F. Haider, S. Horn, and R. Warnecke, "Corrosion monitoring in waste-to-energy plants," EUROCORR, European Federation of Corrosion, Edinburgh, UK, IOM3, London, UK, September 2008.
- [16] E. Otero, A. Pardo, M. C. Merino, M. V. Utrilla, M. D. López, and J. L. Del Peso, "Corrosion behavior of IN-800 superalloy in waste-incineration environments: hot corrosion by molten chlorides," *Oxidation of Metals*, vol. 51, no. 5, pp. 507–525, 1999.
- [17] P. Viklund, "High temperature corrosion during waste incineration," Thesis in Corrosion Science, KTH Royal Institute of Technology, Division of Surface and Corrosion Science, Stockholm, Sweden, 2011.
- [18] P. D. Miller and H. H. Krause, "Fireside metal wastage in Municipal Incinerators," in *Proceedings of the ASME Winter Annual Meeting*, vol. 29, pp. 217–229, New York, NY, USA, December 1970.
- [19] W. Ma and S. Rotter, "Overview on the chlorine origin of MSW and Cl-originated corrosion during MSW & RDF combustion process," in *Proceedings of the 2nd International Conference on Bioinformatics and Biomedical Engineering (iCBBE '08)*, pp. 4255–4258, May 2006.
- [20] T. Yokoyama, Y. Suzuki, H. Akiyama et al., "Improvements and recent technology for fluidized bed waste incinerators," *NKK Technical Review*, no. 85, pp. 38–43, 2001.
- [21] D. C. Agarwal and G. K. Grossmann, "Case Histories on the Use of Nickel Alloys in Municipal and Hazardous Waste Fueled Facilities," Corrosion 2001, NACE International, Houston, Tex, USA, March 2001.
- [22] T. Ishitsuko and K. Nose, "Stability of protective oxide films in waste incineration environment—solubility measurement of oxides in molten chlorides," *Corrosion Science*, vol. 44, pp. 247–263, 2002.
- [23] Y. S. Li, Y. Niu, and W. T. Wu, "Accelerated corrosion of pure Fe, Ni, Cr and several Fe-based alloys induced by $ZnCl_2$ –KCl at 450°C in oxidizing environment," *Materials Science and Engineering A*, vol. 345, pp. 64–71, 2003.
- [24] K. Zhang, Y. Niu, C. Zeng, and W. Wu, "Corrosion of iron and four commercial steels in a Cl-containing oxidizing atmosphere at 500–600°C," *Journal of Materials Science and Technology*, vol. 20, no. 2, pp. 213–216, 2004.
- [25] G. Sorell, "The role of chlorine in high temperature corrosion in waste-to-energy plants," *Materials at High Temperatures*, vol. 14, no. 3, pp. 137–150, 1997.
- [26] K. Weulersse-Mouturat, G. Moulin, P. Billard, and G. Pierotti, "High temperature corrosion of superheater tubes in waste incinerators and coal-fired plants," *Materials Science Forum*, vol. 461–464, pp. 973–980, 2004.
- [27] A. Jegede, V. Vasantasree, and M. G. Hocking, "Corrosion of Ultimet and 310SS in a simulated waste incineration environment 750°C," *Journal of Materials Science Letters*, vol. 14, no. 15, pp. 1089–1091, 1995.
- [28] J. M. Oh, M. J. MaNallan, G. Y. Lai, and M. F. Rothman, "High temperature corrosion of superalloys in an environment containing both oxygen and chlorine," *Metallurgical Transactions A*, vol. 17, pp. 1087–1094, 1986.
- [29] I. Delay, J. Swithenbank, and B. B. Argent, "Prediction of the distribution of alkali and trace elements between the condensed and gaseous phases generated during clinical waste incineration," *Journal of Alloys and Compounds*, vol. 320, no. 2, pp. 282–295, 2001.
- [30] B. S. Covino, G. R. Holcomb, S. D. Cramer, S. J. Bullard, and M. Ziomek-Moroz, "Corrosion in Temperature Gradient," http://www.netl.doe.gov/publications/proceedings/03/materials/manuscripts/Holcomb_m.pdf.
- [31] M. Ni, Y. Du, S. Lu et al., "Study of ashes from a medical waste incinerator in China: physical and chemical characteristics on fly ash, ash deposits and bottom ash," *Environmental Progress and Sustainable Energy*, vol. 27, no. 4, 2012.
- [32] A. Pettersson, *Characterisation of fuels and fly ashes from Co-combustion of biofuels and waste fuels in a fluidised bed boiler [Ph.D. thesis]*, University College of Borås, Borås, Sweden, 2008.
- [33] G. Trif-Tordai and I. Ionel, "Waste biomass as alternative bio-fuel-Co-Firing versus Direct Combustion," in *Alternative Fuel*, p. 304, InTech, 2011.
- [34] E. Pihl Erik, S. Heyne, H. Thunman, and F. Johnsson, "Highly efficient electricity generation from biomass by integration and hybridization with combined cycle gas turbine (CCGT) plants for natural gas," *Energy*, vol. 35, no. 10, pp. 4042–4052, 2010.
- [35] C. Mobbs, "Firing Installations for Wood and Other Biomass Fuels," Guidelines/guidance by source category: Part III of Annex C, Victoria, Australia, 2006.
- [36] X. Wang, X. Zhao, L. Ma, and Q. Zhao, "Deposition and corrosion problems of biomass fired boiler," in *Proceedings of the 3rd International Conference on Measuring Technology and Mechatronics Automation (ICMTMA '11)*, pp. 852–854, IEEE, January 2011.
- [37] W. B. A. Sharp, "Superheater corrosion in biomass boilers: Today's Science and Technology," Oak Ridge National Laboratory, p. 3, 2010.
- [38] S. Belosevic, "Modeling approaches to predict biomass co-firing with pulverized coal," *The Open Thermodynamics Journal*, vol. 4, pp. 50–70, 2010.
- [39] J. S. Tumuluru, S. Sokhansanj, C. T. Wright, R. D. Boardman, and N. A. Yancey, "A review on biomass classification and composition, co-firing issues and pretreatment methods," in *Proceedings of the American Society of Agricultural and Biological Engineers Annual International Meeting*, pp. 2053–2083, Louisville, Ky, USA, August 2011.
- [40] S. N. Naik, V. V. Goud, P. K. Rout, and A. K. Dalai, "Production of first and second generation biofuels: a comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 2, pp. 578–597, 2010.
- [41] I. Ionel, F. Popescu, N. Lontis, G. Trif Tordai, and W. Russ, "Co-combustion of fossil fuel with biofuel in small cogeneration systems, between necessity and achievements," in *Proceedings of the 11th WSEAS International Conference on Sustainability in Science Engineering*, pp. 27–29, Timisoara, Romania, 2009.

- [42] K. Svoboda, D. Baxter, and J. Martinec, "Nitrous oxide emissions from waste incineration," *Chemical Papers*, vol. 60, no. 1, pp. 78–90, 2006.
- [43] L. Baxter, "Biomass-coal co-combustion: opportunity for affordable renewable energy," *Fuel*, vol. 84, no. 10, pp. 1295–1302, 2005.
- [44] Yakima County Public Works, Solid waste division, *Review of Biomass Fuels and Technologies*, R.W. Beck, 2003.
- [45] D. Bankiewicz, *Corrosion behaviour of boiler tube materials during combustion of fuels containing Zn and Pb [Academic Dissertation]*, Laboratory of Inorganic Chemistry, Process Chemistry Centre, Department of Chemical Engineering, Abo Akademi University, Turku, Finland, 2012.
- [46] E. C. Zabetta, V. Barisic, K. Peltola, and A. Hotta, "Foster wheeler experience with biomass and waste in CFBs," in *Proceedings of the 33rd International Technical Conference on Coal Utilization and Fuel Systems*, Clearwater, Fla, USA, 2008.
- [47] S. C. Cha and M. Spiegel, "Fundamental studies on alkali chloride induced corrosion during combustion of biomass," *Materials Science Forum*, vol. 461-464, no. II, pp. 1055–1062, 2004.
- [48] P. J. Henderson, P. Ljung, P. Kallner, and J. Tollin, "Fireside corrosion of superheater materials in a wood-fired circulating fluidised bed boiler," in *Proceedings of the EuroCorr*, 2000.
- [49] P. Henderson, P. Szakalos, R. Pettersson, C. Andersson, and J. Hogberg, "Reducing superheater corrosion in wood-fired boilers," *Materials and Corrosion*, vol. 57, no. 2, pp. 128–134.
- [50] A. A. Khan, W. de Jong, P. J. Jansens, and H. Spliethoff, "Biomass combustion in fluidized bed boilers: potential problems and remedies," *Fuel Processing Technology*, vol. 90, no. 1, pp. 21–50, 2009.
- [51] H. P. Nielsen, F. J. Frandsen, K. Dam-Johansen, and L. L. Baxter, "Implications of chlorine-associated corrosion on the operation of biomass-fired boilers," *Progress in Energy and Combustion Science*, vol. 26, no. 3, pp. 283–298, 2000.
- [52] P. Viklund, A. Hjornhede, P. Henderson, A. Stalenheim, and R. Pettersson, "Superheater corrosion in a waste-to energy plant," in *Proceedings of the Impacts of Fuel Quality on Power Production & Environment*, 2010.
- [53] R. Reidl, J. Dhal, I. Obernberger, and M. Nardoslawsky, "Corrosion in the fire tube boilers of biomass combustion plants," in *Proceedings of the China International Corrosion Control Conference*, paper no. 90129, Beijing, China, October 1999.
- [54] M. A. Usitalo, P. M. J. Vuoristo, and T. A. Mäntylä, "High temperature corrosion of coatings and boiler steels below chlorine-containing salt deposits," *Corrosion Science*, vol. 46, no. 6, pp. 1311–1331, 2004.
- [55] S. Karlsson, J. Pettersson, L. G. Johansson, and J. E. Svensson, "Alkali induced high temperature corrosion of stainless steel: the influence of NaCl, KCl and CaCl₂," *Oxidation of Metals*, vol. 78, pp. 83–102, 2012.
- [56] J. Pettersson, J. E. Svensson, and L. G. Johansson, "KCl-induced corrosion of a 304-type austenitic stainless steel in O₂ and in O₂ + H₂O environment: the influence of temperature," *Oxidation of Metals*, vol. 72, pp. 159–177, 2009.
- [57] J. Pettersson, N. Folkesson, L.-G. Johansson, and J.-E. Svensson, "The effects of KCl, K₂SO₄ and K₂CO₃ on the high temperature corrosion of a 304-type austenitic stainless steel," *Oxidation of Metals*, vol. 76, no. 1-2, pp. 93–109, 2011.
- [58] W. B. A. Sharp, D. L. Singbeil, and J. R. Keiser, "Superheater Corrosion Produced By Biomass Fuels," Paper no. C2012-0001308, NACE International, Houston, Tex, USA, 2012.
- [59] A. Hernas, B. Chmiela, and B. Szezueka-Lasota, "Unotypical bromine corrosion in boilers co-firing biomass," *Journal of Achievements in Materials and Manufacturing Engineering*, vol. 54, no. 1, pp. 58–66, 2012.
- [60] S. Karlsson, J. Pettersson, J.-E. Svensson, and L.-G. Johansson, "KCl-Induced high temperature corrosion of the austenitic stainless steel 304L—the influence of SO₂," *Materials Science Forum*, vol. 696, pp. 224–229, 2011.
- [61] K. Gotthjaelp, P. Brondsted, P. Jansen, J. Markussen, M. Montgomery, and E. Maahn, "High temperature corrosion in biomass incineration plants," Final Report EFP 95, Project Number 1323/95-0008, 1997.
- [62] J. Sandberg, Malardalen University Press Dissertation Number 116, School of Sustainable Development of Society and Technology, Malardalen University, Västerås, Sweden, 2011.
- [63] D. Vamvuka and G. Bamdelis, "Evaluation of wood residues from Crete as alternative fuels," *International Journal of Energy and Environment*, vol. 1, no. 4, pp. 667–674, 2010.
- [64] P. Viklund, R. Pettersson, A. Hjörnheide, P. Henderson, and P. Sjövall, "Effect of sulphur containing additive on initial corrosion of superheater tubes in waste fired boiler," *Corrosion Engineering Science and Technology*, vol. 44, no. 3, pp. 234–240, 2009.
- [65] S. Karlsson, L.-E. Amand, and J. Pettersson, "Reducing high temperature corrosion when burning waste by adding digested sewage sludge," The Swedish and Finnish National Committees of the international flame research foundation-IFRE, 2012.
- [66] S.-H. Lee, N. J. Themelis, and M. J. Castaldi, "High-temperature corrosion in waste-to-energy boilers," *Journal of Thermal Spray Technology*, vol. 16, no. 1, pp. 104–110, 2007.
- [67] Y. Niu, H. Tan, L. Ma et al., "Slagging characteristics on the superheaters of a 12 MW biomass-fired boiler," *Energy and Fuels*, vol. 24, no. 9, pp. 5222–5227, 2010.
- [68] S. Konsomboon, S. Pipatmanomai, T. Madhiyanon, and S. Tia, "Effect of kaolin addition on ash characteristics of palm empty fruit bunch (EFB) upon combustion," *Applied Energy*, vol. 88, no. 1, pp. 298–305, 2011.
- [69] T. S. Sidhu, A. Malik, S. Prakash, and R. D. Agrawal, "Cyclic oxidation behavior of Ni- and Fe-based superalloys in air and Na₂SO₄₋₂₅%NaCl molten salt environment at 800°C," *International Journal of Physical Sciences*, vol. 1, no. 1, pp. 27–33, 2006.
- [70] D. Deb, S. Ramakrishna Iyer, and V. M. Radhakrishnan, "A comparative study of oxidation and hot corrosion of a cast nickel base superalloy in different corrosive environments," *Materials Letters*, vol. 29, no. 1-3, pp. 19–23, 1996.
- [71] M. Li, X. Sun, W. Hu, H. Guan, and S. Chen, "Hot corrosion of a single crystal Ni-base superalloy by Na-salts at 900°C," *Oxidation of Metals*, vol. 65, no. 1-2, pp. 137–150, 2006.
- [72] L. Zheng, Z. Maicang, and D. Jianxin, "Hot corrosion behavior of powder metallurgy Rene95 nickel-based superalloy in molten NaCl-Na₂SO₄ salts," *Materials and Design*, vol. 32, no. 4, pp. 1981–1989, 2011.
- [73] C.-C. Tsaur, J. C. Rock, C.-J. Wang, and Y.-H. Su, "The hot corrosion of 310 stainless steel with pre-coated NaCl/Na₂SO₄ mixtures at 750°C," *Materials Chemistry and Physics*, vol. 89, no. 2-3, pp. 445–453, 2005.
- [74] R. M. Hussein and A. A. M. Albadrany, "High temperature hot corrosion resistance of coated stainless steel at NaCl/Na₂SO₄ mixtures environments," *Anbar Journal For Engineering Sciences*, no. 1, pp. 12–24, 2012.

- [75] D. Gond, V. Chawla, D. Puri, and S. Prakash, "High temperature corrosion behaviour of T-91 and T-22 bare steel in 75wt.%Na₂SO₄+25wt.%NaCl molten salt environment at 900°C," *Journal of Minerals & Materials Characterization & Engineering*, vol. 9, no. 7, pp. 593–606, 2010.
- [76] T. S. Sidhu, A. Malik, S. Prakash, and R. D. Agarwal, *Thermal Spray 2007, Global Coating Solutions*, ASM International, Cleveland, Ohio, USA, 2007.
- [77] I. Gurrappa, "Hot corrosion behavior of CM 247 LC alloy in Na₂SO₄ and NaCl environments," *Oxidation of Metals*, vol. 51, no. 5, pp. 353–382, 1999.
- [78] G. Fu, X. Guo, Q. Liu, X. Zhao, and Y. Su, "Hot Corrosion of Co-based Alloys with 25%NaCl+75%Na₂SO₄ Coating at 1173 K," *High Temperature Materials and Processes*, vol. 323, pp. 317–321, 2013.
- [79] L. Zhu, S. Zhu, and F. Wang, "Hot corrosion behaviour of a Ni + CrAlYSiN composite coating in Na₂SO₄-25 wt.% NaCl melt," *Applied Surface Science*, vol. 268, no. 1, pp. 103–110, 2013.
- [80] S. P. Akbar Hussain, V. Pandurangadu, and S. S. Kumar Reddy, "Investigations on the effect of sodium chloride in low temperature hot corrosion of Mar-M 509 AT 750°C," *Research Inventy*, vol. 2, no. 7, pp. 31–34, 2013.
- [81] W.-Y. Zhao, B.-W. Xu, Y. Ma, and S.-K. Gong, "Inter-phase selective corrosion of γ -TiAl alloy in molten salt environment at high temperature," *Progress in Natural Science: Materials International*, vol. 21, no. 4, pp. 322–329, 2011.
- [82] K. Zhang, M. M. Liu, S. L. Liu, C. Sun, and F. H. Wang, "Hot corrosion behaviour of a cobalt-base super-alloy K40S with and without NiCrAlYSi coating," *Corrosion Science*, vol. 53, no. 5, pp. 1990–1998, 2011.
- [83] T. L. Lin, Y. H. Zhang, and H. W. Yang, "Influence of hot corrosion on the creep strength of the nickel-base superalloy GH37," *Materials Science and Engineering*, vol. 62, no. 1, pp. 17–24, 1984.
- [84] Y. Niu, F. Gesmundo, F. Viani, and W. Wu, "The corrosion of Ni₃Al in a combustion gas with and without Na₂SO₄-NaCl deposits at 600–800°C," *Oxidation of Metals*, vol. 42, no. 3-4, pp. 265–284, 1994.
- [85] Z. B. Bao, Q. M. Wang, W. Z. Li et al., "Preparation and hot corrosion behaviour of an Al-gradient NiCoCrAlYSiB coating on a Ni-base superalloy," *Corrosion Science*, vol. 51, no. 4, pp. 860–867, 2009.
- [86] L. Yuan and H. M. Wang, "Hot corrosion behaviors of a Cr₁₃Ni₅Si₂-based metal silicide alloy in Na₂SO₄ + 25 wt.% K₂SO₄ and Na₂SO₄ + 25 wt.% NaCl molten salts," *Intermetallics*, vol. 18, pp. 324–329, 2010.
- [87] F. H. Stott and C. Y. Shih, "High-temperature corrosion of iron-chromium alloys in oxidizing-chloridizing conditions," *Oxidation of Metals*, vol. 54, no. 5-6, pp. 425–443, 2000.
- [88] C. Zhang, X. Peng, J. Zhao, and F. Wang, "Hot corrosion of an electrodeposited Ni-11 wt % Cr nanocomposite under molten Na₂SO₄-K₂SO₄-NaCl," *Journal of the Electrochemical Society*, vol. 152, no. 9, pp. B321–B326, 2005.
- [89] A. Zahs, M. Spiegel, and H. J. Grabke, "Chloridation and oxidation of iron, chromium, nickel and their alloys in chloridizing and oxidizing atmospheres at 400–700°C," *Corrosion Science*, vol. 42, no. 6, pp. 1093–1122, 2000.
- [90] B. P. Mohanty and D. A. Shores, "Role of chlorides in hot corrosion of a cast Fe-Cr-Ni alloy. Part I: experimental studies," *Corrosion Science*, vol. 46, no. 12, pp. 2893–2907, 2004.
- [91] C.-J. Wang and Y.-C. Chang, "NaCl-induced hot corrosion of Fe-Mn-Al-C alloys," *Materials Chemistry and Physics*, vol. 76, no. 2, pp. 151–161, 2002.
- [92] S. Kamal, R. Jayaganthan, and S. Prakash, "Evaluation of cyclic hot corrosion behaviour of detonation gun sprayed Cr₃C₂-25%NiCr coatings on nickel- and iron-based superalloys," *Surface and Coatings Technology*, vol. 203, no. 8, pp. 1004–1013, 2009.
- [93] C.-J. Wang and C.-C. Li, "Corrosion behaviors of AISI 1025 steels with electroless nickel/aluminized coatings in NaCl-induced hot corrosion," *Surface and Coatings Technology*, vol. 177-178, pp. 37–43, 2004.
- [94] D. A. Shores and B. P. Mohanty, "Role of chlorides in hot corrosion of a cast Fe-Cr-Ni alloy. Part II: thermochemical model studies," *Corrosion Science*, vol. 46, no. 12, pp. 2909–2924, 2004.
- [95] D. Xie, S. Zhu, W. Dai, and F. Wang, "Influence of NiCoCrAlY and diffusion aluminide coating on oxidation and hot corrosion of a Ni-based superalloy," *Materials Science Forum*, vol. 546-549, no. 3, pp. 1739–1746, 2007.
- [96] D. W. McKee, D. A. Shores, and K. L. Luthra, "The effect of SO₂ and NaCl on high temperature hot corrosion," *The Electrochemical Society: Solid-State Science and Technology*, vol. 125, no. 3, pp. 411–419, 1978.
- [97] H. J. Grabke, E. Reese, and M. Spiegel, "The effects of chlorides, hydrogen chloride, and sulfur dioxide in the oxidation of steels below deposits," *Corrosion Science*, vol. 37, no. 7, pp. 1023–1043, 1995.
- [98] H. P. Nielsen, F. J. Frandsen, and K. Dam-Johansen, "Lab-scale investigations of high-temperature corrosion phenomena in straw-fired boilers," *Energy and Fuels*, vol. 13, no. 6, pp. 1114–1121, 1999.
- [99] I. Gurrappa, "Identification of hot corrosion resistant MCrAlY based bond coatings for gas turbine engine applications," *Surface and Coatings Technology*, vol. 139, no. 2-3, pp. 272–283, 2001.
- [100] I. Gurrappa, "Mechanism of degradation of titanium alloy IMI 834 and its protection under hot corrosion conditions," *Oxidation of Metals*, vol. 59, no. 3-4, pp. 321–332, 2003.
- [101] J. Klöwer, U. Brill, and U. Heubner, "High temperature corrosion behaviour of nickel aluminides: effects of chromium and zirconium," *Intermetallics*, vol. 7, no. 10, pp. 1183–1194, 1999.
- [102] J. H. Cho, T. W. Kim, K. S. Son et al., "Aluminizing and boroaluminizing treatments of Mar-M247 and their effect on hot corrosion resistance in Na₂SO₄-NaCl molten salt," *Metals and Materials International*, vol. 9, no. 3, pp. 303–310, 2003.
- [103] J. M. Guilemany, M. Torrell, and J. R. Miguel, "Study of the HVOF Ni-Based coatings' corrosion resistance applied on Municipal Solid-Waste Incinerators," *Journal of Thermal Spray Technology*, vol. 17, no. 2, pp. 254–262, 2008.
- [104] K. N. Strafford, P. K. Datta, and G. Forster, "The high temperature chloridation of iron, nickel and some iron-nickel model alloys," *Corrosion Science*, vol. 29, no. 6, pp. 703–716, 1989.
- [105] K. N. Strafford, P. K. Datta, and G. Forster, "High-temperature chloridation of binary FeCr alloys at 1000°C," *Materials Science and Engineering A*, vol. 120-121, no. 1, pp. 61–68, 1989.
- [106] K. Yamada, Y. Tomono, J. Morimoto, Y. Sasaki, and A. Ohmori, "Hot corrosion behavior of boiler tube materials in refuse incineration environment," *Vacuum*, vol. 65, no. 3-4, pp. 533–540, 2002.

- [107] L.-C. Chen, C. Zhang, and Z.-G. Yang, "Effect of pre-oxidation on the hot corrosion of CoNiCrAlYRe alloy," *Corrosion Science*, vol. 53, no. 1, pp. 374–380, 2011.
- [108] M. Anuwar, R. Jayaganthan, V. K. Tewari, and N. Arivazhagan, "A study on the hot corrosion behavior of Ti-6Al-4V alloy," *Materials Letters*, vol. 61, no. 7, pp. 1483–1488, 2007.
- [109] M. A. Uusitalo, P. M. J. Vuoristo, and T. A. Mäntylä, "Elevated temperature erosion–corrosion of thermal sprayed coatings in chlorine containing environments," *Wear*, vol. 252, pp. 586–594, 2002.
- [110] M. A. Uusitalo, P. M. J. Vuoristo, and T. A. Mäntylä, "High temperature corrosion of coatings and boiler steels in oxidizing chlorine-containing atmosphere," *Materials Science and Engineering A*, vol. 346, pp. 168–177, 2003.
- [111] M. A. Uusitalo, P. M. J. Vuoristo, and T. A. Mäntylä, "High temperature corrosion of coatings and boiler steels in reducing chlorine-containing atmosphere," *Surface and Coatings Technology*, vol. 161, no. 2-3, pp. 275–285, 2002.
- [112] D. Mudgal, S. Singh, and S. Prakash, "Hot corrosion behavior of some superalloys in a simulated incinerator environment at 900°C," *Journal of Materials Engineering and Performance*, vol. 23, no. 1, pp. 238–249, 2014.
- [113] R. Prescott, F. H. Stott, and P. Elliott, "Investigations of the degradation of high-temperature alloys in a potentially oxidizing-chloridizing gas mixture," *Oxidation of Metals*, vol. 31, no. 1-2, pp. 145–166, 1989.
- [114] S. M. Jiang, H. Q. Li, J. Ma, C. Z. Xu, J. Gong, and C. Sun, "High temperature corrosion behaviour of a gradient NiCoCrAlYSi coating II: oxidation and hot corrosion," *Corrosion Science*, vol. 52, no. 7, pp. 2316–2322, 2010.
- [115] U. Kamachi Mudali, N. Bhuvaneshwaran, P. Shankar, H. S. Khatak, and B. Raj, "Intermetallic diffusion coatings for enhanced hot-salt oxidation resistance of nitrogen-containing austenitic stainless steels," *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science*, vol. 35, no. 6, pp. 1799–1806, 2004.
- [116] Y.-N. Wu, A. Yamaguchi, H. Murakami, and S. Kuroda, "Role of iridium in hot corrosion resistance of Pt-Ir modified aluminide coatings with Na₂SO₄-NaCl salt at 1173 K," *Materials Transactions*, vol. 47, no. 8, pp. 1918–1921, 2006.
- [117] T. Hussain, A. U. Syed, and N. J. Simms, "Fireside corrosion of superheater materials in coal/biomass co-fired advanced power plants," *Oxidation of Metals*, vol. 80, pp. 529–540, 2013.
- [118] H. Singh and T. S. Sidhu, "High temperature corrosion behavior of Ni-based superalloy superni-75 in the real service environment of medical waste incinerator," *Oxidation of Metals*, vol. 80, pp. 651–668, 2013.
- [119] D. Rezakhami, "Corrosion behaviours of several thermal spray coatings used on boiler tubes at elevated temperatures," *Anti-Corrosion Methods and Materials*, vol. 54, no. 4, pp. 237–243, 2007.
- [120] H. Singh, G. Gitanjali, S. Singh, and S. Prakash, "High temperature corrosion behaviour of some Fe-, Co- and Ni-base superalloys in the presence of Y₂O₃ as inhibitor," *Applied Surface Science*, vol. 255, no. 15, pp. 7062–7069, 2009.
- [121] G. Goyal, H. Singh, and S. Prakash, "Effect of superficially applied ZrO₂ inhibitor on the high temperature corrosion performance of some Fe-, Co- and Ni-base superalloys," *Applied Surface Science*, vol. 254, no. 20, pp. 6653–6661, 2008.
- [122] S. Paul and M. D. F. Harvey, "Corrosion testing of HVOF coatings in high temperature environments for biomass applications," in *Proceedings of the International Thermal Spray Conference (ITSC '12)*, pp. 21–24, Houston, Tex, USA, May 2012, published in *Journal of Thermal Spray Technology*.



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