The current and foreseeable global economy demands that material conservation becomes a matter of increasing importance (Lawrence and Li, 2002). Degradation of metals and alloys due to hot corrosion or erosion has been identified as a serious problem for many high temperature aggressive environment applications, such as boilers, internal combustion engines, gas turbines, fluidized bed combustion and industrial waste incinerators (Mahesh et al, 2008A; Seong et al, 2000 and Torrell et al, 2010). This ultimately necessitates an arduous and costly undertaking of replacing the affected components. It is therefore obvious that any means whereby the life of the component could be extended would be of great interest to all engineers, bringing about significant economic savings.

Corrosion is a ubiquitous problem that continues to be of great relevance in a wide range of industrial applications and products; it results in the degradation and eventual failure of components and systems both in the processing and manufacturing industries and in the service life of many components (Vardelle and Kuroda, 2007). Corrosion is both costly and dangerous. Besides indirect costs due to shut down and loss of efficiency, billions of dollars are spent annually for the replacement of corroded structures, machinery and equipment; and their premature failure can result in human injury or even loss of life (Sidhu et al, 2006H). The direct cost of corrosion in the U.S. and European Union has been estimated at 3-5% of the Gross Domestic Product of the member states (Vardelle and Kuroda, 2007).

Ferritic and austenitic steels are the most common boiler steels in use, and are also candidate materials for future coal combustion power plants. Ferritic steels are always a primary material choice, because of lower coefficients of thermal expansion and higher thermal conductivities compared to austenitic steels. However, many Ferritic steels have been shown to undergo high wastage rates under fluidized-bed conditions, due to erosion-corrosion (Huttunen et al, 2007).
Hot corrosion has been recognized as a serious problem in connection with the degradation of fireside boiler tubes in coal fired steam generating plants (Tao et al, 2009 and Xue-meit al, 2008). A case study was reported pertaining to a boiler tube failure of a power plant, where out of 89 failures occurring in one year duration, 50 failures were found to be due to hot corrosion and erosion by ash (Kumar et al, 2007, and Sidhu and Prakash, 2006E). Failure of heat exchanger tubes in coal-fired boilers due to high-temperature oxidation and erosion caused by the impact of fly ashes has become a key material issue in the design and operation of thermal power plants. It is recognized as one of the main causes of downtime in these installations (Hidalgo et al, 2001A and Shibli et al, 2007).

Coal is an attractive fuel owing to its low price linked to its worldwide availability and due to the future shortage of other fossil fuel reserves such as oil and gas. But combustion of coal generates very corrosive media particularly near the superheater tubes (Sidhu et al, 2006I). One of the most severe types of high temperature corrosion in coal-fired boilers is ash deposit corrosion (Seong et al, 2000). The impurities such as Na, V, K and S present in the fuel, form low melting point compounds on the surface of materials and induce corrosion. This is considered a root cause for the severe wastage of tube materials (Sidhu and Prakash, 2006D and Kamal et al, 2009A). In the combustion system, Na and S react with each other and form Na$_2$SO$_4$. Vanadium reacts with oxygen to form V$_2$O$_5$ and other complex vanadates. These compounds commonly known as ash, deposit on the surface of the materials and induce corrosion. The degradation of material occurs when these molten compounds destroy the protective oxide layers that naturally form on materials during boiler/gas turbine operation (Kamal et al, 2008). The complex environment (thermal, chemical and mechanical) in the industry makes it extremely difficult for one material to meet all the requirements (Dragos et al, 2005). Depending on the plant the conditions could be very severe, but in the last years the temperatures have been increased worldwide in order to produce more energy and the life-time of steel superheater tubes has been decreased (Torrell et al, 2010). Therefore, it is important to understand the nature of all types of environmental degradation of metals and alloys as vividly as possible so that preventive measures against metal loss and failures can be
economically devised to ensure safety and reliability in the use of metallic components (Sidhu et al, 2006J).

Attempts to decrease the maintenance costs of these components have increased the interest in shielding with protective coatings (Tao et al, 2010). Nowadays, there are several types of protective coatings being applied, and improvements at various levels have been reported (Cvijovic et al, 2008). Coatings can add value to the products up to 10 times the cost of the coating. Even if the material withstands high temperature without a coating, the coating enhances the life-time of the material. The compositions and structures of the coatings are determined in view of the role the coatings have to play in the various material systems and performance environments (Sidhu et al, 2006J). The materials used as coatings must ensure an effective protection against oxidation as well as have a high thermal conductivity (heat-exchangers) in order to provide good service behaviour and an effective and economical maintenance layout (Fernandez et al, 2005). The primary aim of the coating/surface treatment is the ability to produce a stable, slow-growing surface oxide scale providing a barrier between the coated alloy and the environment (Bala et al, 2007).

Nickel-chromium alloys attract the attention of metal scientists due to high temperature corrosion properties, which makes them widely used as thermally sprayed coatings in fossil fuel-fired boilers, waste incineration boilers, and electric furnaces (Saaedi et al, 2008 and Bala et al, 2009B). When nickel is alloyed with chromium, this element oxidizes to \( \text{Cr}_2\text{O}_3 \), which could make it suitable for use up to about 1200 °C. However, in practice its use is limited to temperatures below 800 °C (Hidalgo et al, 2001B).

\( \text{Cr}_3\text{C}_2 \)--NiCr coatings exhibit excellent wear and corrosion resistance properties (Matthews et al, 2003). The corrosion resistance is provided by NiCr matrix while the wear resistance is mainly due to the carbide ceramic phase (Kamal et al, 2008). The superior oxidation resistance has seen for a range of applications subject to combined erosion and high-temperature corrosion (Matthews et al, 2010). These coatings maintain high wear and corrosion resistance up to 900 °C and can be used to improve the performance life of components working at elevated temperatures (Guilemany et al, 2002B). In addition to these features, the coefficient of thermal expansion of \( \text{Cr}_3\text{C}_2 \)
(10.3×10^{-6} °C^{-1}) is nearly similar to that of iron (11.4×10^{-6} °C^{-1}) and nickel (12.8×10^{-6} °C^{-1}) that constitute the base of most high temperature alloys. This minimizes stress generation through thermal expansion mismatch during thermal cycles (Kamal et al, 2008).

Thermal spraying has been considered effective to apply the protective coatings, without affecting any other properties of the component material (Tillmann et al, 2010; Rico et al, 2009 and Roy et al, 2006). Thermal spraying is a common family of hardfacing techniques, which compared to other processes, is characterized by flexibility in coating material choice, low substrate thermal input and virtually no substrate dissolution (Bolelli et al, 2007). All thermally sprayed coatings consist of splats and splat boundaries. Coatings are prone to corrosive attack due to porosity present at splat boundaries (Uusitalo et al, 2004). With the advent of high velocity oxyfuel spray (HVOF) technique, thermally sprayed coatings, which previously had limited usefulness as corrosion protection coatings due to the presence of interconnected porosity in the structure, have now gained popularity and are being studied extensively for corrosion resistant properties (Sidhu et al, 2006Q). HVOF coatings give compact, low porosity, homogeneous, and hard structures with enough thickness to stop the advancing of electrolytes (Guilemany et al, 2008). The hypersonic velocity of the flame shortens the time of interaction between the powder and flame, while the low temperature of flame limits the grain growth and decomposition of coating (Bolelli et al, 2007). HVOF process has the advantage of being a continuous and most convenient process for applying coatings to industrial installations at site (Sidhu et al, 2006Q).

However, even using state of the art coating systems, it is not possible to achieve defect free thermal spray coatings (Stewart et al, 2005 and Dragos et al, 2005). The thermal sprayed coatings consist of voids originating from spraying process that are found at the splat boundaries, through which the coatings are mainly attacked in the corrosive environment (Kamal et al, 2009A). There are two kinds of pore geometry in thermal spray coatings, introduced by different mechanisms. One is lamellar porosity (elongated pores) at the lamellar or splat boundaries which is believed to arise from intermittent contact. The other types of pores are normally spherical in shape and arise from the expansion of trapped gases (Stewart et al, 2005). In hot corrosion studies of
plasma sprayed coatings, Sidhu and Prakash (2005A) reported diffusion and oxidation of iron from the substrates to the top layer of scale as well as the oxidation of the substrate steels, where it has been attributed to the porosity. Once the electrolyte reaches the substrate, it starts to corrode it and form the galvanic pair, which will decrease the bonding strength of the coating. Some infiltration of corrosive species is detected even in case of HVOF coatings (Uusitalo et al, 2004). This is the main reason for the density of the coatings by thermal treatments and sealers (Guilemany et al, 2002A and Zhang et al, 2010). Wang (2003) has reported improvement in elevated temperature erosion resistance of coatings by post heat-treating and sealing treatment. Heat treatment of thermal spray coatings have been reported to improve the corrosion resistance of thermal spray coatings by changing microstructure form lamellar to bulk-like (Sundararajan et al, 2009 and Bolelli et al, 2008).

In general high-temperature hot corrosion resistance of the coatings relies on the ability of the coating to produce and maintain a stable, continuous, slow-growing and adherent oxide scale such as Al$_2$O$_3$ and Cr$_2$O$_3$ on its surface, providing a barrier between the coated alloy and the environment (Mahesh et al, 2008; Dragos et al, 2005; Cvijovic et al, 2008; Saeidi et al, 2009 and Zhang et al, 2008A). However the formation of these protective scales depends on the coating composition and service conditions such as temperature and atmosphere (Tang et al, 2000).

The present research is aimed to evaluate the hot corrosion behaviour of ASME-SA213-T91 boiler steel in the laboratory as well as in the actual industrial environment. Subsequently, it is aimed to investigate hot corrosion behaviour of HVOF sprayed 75Cr$_3$C$_2$–25NiCr and Ni–20Cr feedstock alloys deposited on T91 boiler steel in order to control their high temperature degradation. In addition, influence of post treatment of the coatings on the hot corrosion behaviour has also been investigated.