Special Alloys for Flue Gas Desulfurization Systems

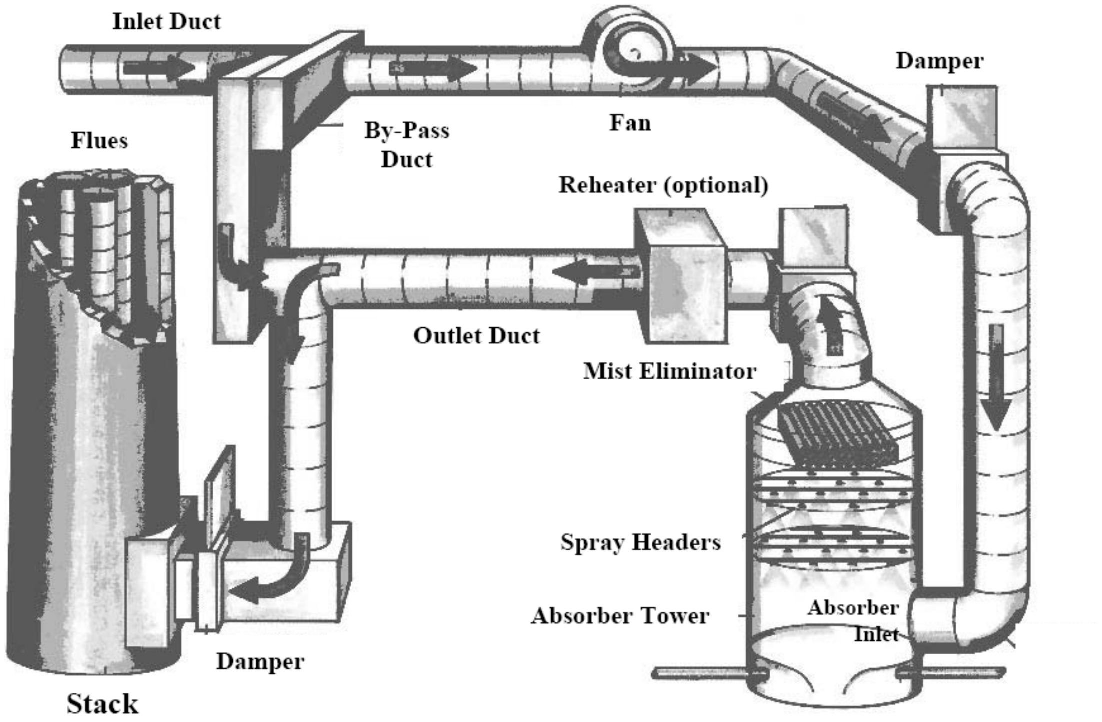


Figure 1-Flue Gas Desulfurization Sytem structure

Introduction

Flue gas desulfurization is a process of elimination of sulfur oxides from gas products that are developed by burning of fossil fuels. The traditional burning techniques result in the release of large amount of sulfur in the fuel in oxidized form and emitted into the flue gas that result in the creation of Acid Rain that refers to application of the precipitation of acids from the environment which are detrimental to nature and health. Acid rain has been a serious issue that is concerning the global governments.

Low Sulfur based fuel combustion instead concentrated sulfur fuels has a significant role in decreasing the pollution however sulfur oxide collection technique is still vital. Considering this, the present emphasis is on discarding the sulfur oxides subsequent to combustion by damped scrubbing with alkaline slurries for example lime, limestone in absence or presence of gypsum.

Heanjia Super-Metals has achieved extreme experience in the economical functionality of nickel based alloys in the FGD conditions.

<u>Emission standards</u>

The first development of emission standards was done on country basis in 1970 in Japan and secondly in United States. Becoming conscious of environmental issues increased in 1980s, the standards became more tight and extensively applicable. This procedure is followed throughout 1990 as the broad understanding is obtained about the damaging effects of atmospheric pollution and the awareness of technical and economical feasibility of control of gas releases.

The standards are generally applied to broad combustion units such as most of fossil fuel based boilers installed in the power production industries and other major industrial pollution sources. Various nations for example United States work on the smaller plant releases, with regular stringency of the laws becoming effective. The diverse regulation levels have been implemented in the several countries on the base of local conditions and apparent requirements. Difference in the laws has also occurred on the base of plant size, kind of fuel burned and specific time limits for fulfillment with present emission laws. Generally the new plants are needed to meet the tightest emission limits.

Background of FGD

Concepts of discovering methods of eliminating sulfur dioxide from boiler and furnace exhaust gases are around 1.5 centuries old. With the fast growth of industries in the 20th century, the issues related with the release of bulk amounts of SO2 from single location began to become a public concern. Initially it was assumed that FGD conditions would be normal and that carbon or low alloy steel would offer the suitable functionality. Although when the first FGD scrubbers started functioning, intense corrosion problems occurred. The FGD systems have been upgraded over the past 35 years from coated carbon steel to clad stainless steels and high nickel alloys. For the traditional FGD units the construction materials options were very little. Stainless steel 316 was often the common and alone corrosion resistant alloy for consideration. Understanding the corrosive conditions of damped limestone FGD many analyses were done and several new corrosion resistant alloys were developed and used for the FGD systems. Few of these alloys are – 2205 duplex stainless steel, Incoloy 725, Inconel 625, Hastelloy C276 and Hastelloy C22. Considering the absorber inlet, the hot flue gas travels through the sulfuric acid dew point, causing the condensation of warm and concentrated sulfuric acid. In the vigorous conditions, a nickel alloy with high molybdenum content is important. Major absorber inlets in America and Asia are constructed of Hastelloy C276 alloy.

The choice of construction material for absorber tower is widely based on the chloride % in the slurry. Fluorides may also be available that are almost same as of chloride corresponding to their influence on the pitting of stainless steels. As the fluoride concentration is often very small, the effect is generally limited to chloride %. The chloride concentration in the slurry is widely assessed by the chloride content of combustible coal and the rate of inclusion of fresh water to slurry. Due to scarcity of water or less concern of waste disposal or inadequate regulations, several FGD installations attained small or no discharge operation modes which vastly increased the content of soluble salts in the absorber slurry, offered chloride contents found several times larger than that observed in marine water. This deeply increased the corrosion sensitivity of FGD media. The result of the corrosion analyses ib 1980s was the discovery of recent traditional construction materials for FGD.

SS 316l, SS 317LM, SS 904l, alloy G3, alloy 625 ETC, alloy C276 ETC, super austenitic stainless steel and duplex stainless steel.

After the studies it was recommended that moderate modifications in FGD unit applications could enable using the more cost-effective standard duplex stainless steels instead of highly costly superaustenitic or super duplex steels. In 2000, another wave of FGD installations was made. Because of increased price of raw materials, particularly nickel and molybdenum, alternatives to nickel alloys and highly alloyed stainless steels were found. The duplex stainless steels comprise of less nickel content and in few cases molybdenum % is smaller than austenitic alloys while providing equivalent resistance to chloride induced pitting corrosion. In conditions where large blowdown rates are feasible, 2205 duplex stainless steel was chosen however the outcomes were not consistently successful. In this program 2205 steel got some sensitivity to corrosion in the concentrated chlorides that its prolong functionality was affected. It is essential to test few factors that may be included in this issue such as deposit production, fabrication methods, contaminants and additives should be considered while choosing the suitable material.

Crevice corrosion resistance of stainless steels

The corrosion resistance provided by grades of stainless steel is remarkably decreased with crevice or other constraints. The crevices may occur by accumulations on bolts, gaskets, washers, etc. in the FGD absorber and sumps parts. The slurry accumulations usually develop that can be the reason for pitting beginning. It is imperative that the effect of crevice development must be taken into account while deciding construction alloys particularly with absorber sump. The comparison of critical pitting temperature and critical crevice corrosion temperature is shown in the following table:

Critical crevice corrosion temperature (CCCT) and critical pitting temperature (CPT) in ASTM solutions

UNS series	CCCT(1) of, oC	CPT(2), oF, oC	ECPT(3), oF, oC	PREn
S31603	27, -3	59, 15	63, 17	23
S31703	35, 2	77, 25	93, 34	29
S31726	68, 20	100, 38	134, 56	34
S32205	68, 20	122, 50	122, 50	36
N08904	75, 24	109, 43	104, 40	35
S32550	72 , 22	131, 55	169, 76	41
S32760	104, 40	160, 71	170, 77	42
N 08367	1137, 45	172, 78	194, 90	47

The mechanism of crevice corrosion is:

1. The passive layer always causes metal loss at very slight rate
2. Tight crevices prevent the entrance of oxidizer and exit of corrosion materials
3. The charge balance factors absorb negative ions, commonly chlorides into the crevice
4. The metal ions in the crevice hydrolyze to produce metal hydroxide precipitates or gels and emit hydrogen ions
5. The acidification of crevice increases as long as the crevice regions depassivates and quick corrosions initiates
6. Reduction reactions, often oxygen reduction at the areas far from crevice consume electrons that allow quick oxidation of the metal in the crevice region.

Depassivation pH and critical pitting potentials are never same for the all metallic materials.

Mandatory Oxidation

To enhance the gypsum byproduct quality during the FGD procedure and hence its worth, mandatory oxidation was introduced to enhance oxidation of sulfite to sulfate in the sump. Without mandatory oxidation, the highest oxidizing potential in the absorber was restricted by small oxygen % of the flue gas generally 3 – 10%. The oxidation of sulfite to sulfate decreases the oxygen concentration more in the absorber slurry. The entry of air of oxygen through sump accelerates the local redox potential and improves the potential difference between less adherent and highly adherent crevice producing accumulations, hence increasing the crevice corrosion.

It should be observed that exposures in the spray area of the absorber vessel however not in sump, the sump portion didn't cause a problem. While it seems that in some units, air sparging was included into the absorber pump, it is unclear that how many units have used mandatory oxidation traditionally.

Manganese Accumulation

Bacteria take part in the bioconversion of metal oxides for example iron and manganese. The iron accumulation bacteria oxidize ferrous (Fe2+) and ferric (Fe3+). The bacterial also causes oxidation of manganous ions to manganic ions with associated accumulation of manganese dioxide. These bacteria have been observed to enhance the ennoblement of metals and pitting attack. It has been shown that the production of surface biolayer comprising of manganese accumulating bacterium, Leptothrix discophora caused the ennoblement of stainless steel grade 316l.

The corrosion related with the manganese accumulation is an old mechanism. Hydrated manganese oxides are commonly noticed to be comprising of water side accumulations on heat exchanger tubes. In a plant alongside Ohio River, a N08020 steel tube with manganese enriched deposit attacked by pitting in six months. Some permanganate in these accumulated found with moisturized manganese dioxide. It was observed that permanganate is produced while chlorination by oxidation of manganous ions to manganic and permanganate ions. More is found, stainless steel 316 pits within 1 day in a KMnO4 – NaCl solution at room temperature.

Manganese induced pitting corrosion resistance

Pitting corrosion sensitivity						
Alloy	KMnO4 + NaCl				FeCl3	
	20oC	50oC	75oC	90oC	20oC	50oC
S31603	Pitting occurred	-	-	-	Pitting occurred	-
N08020	Pitting occurred	-	-	-	Pitting occurred	-
N08367	No pitting	No pitting	No pitting	No pitting	No pitting	Pitting occurred
Inconel 600	No pitting	Pitting occurred	-	-	Pitting occurred	-
Alloy C276	No pitting	No pitting	No pitting	No pitting	No pitting	No pitting
S44400	Pitting occurred	-	-	-	Pitting occurred	-
S44627	No pitting	No pitting	Pitting occurred	-	Pitting occurred	-

It was found that stainless steels are resistant to bacterial action. The conditions causing pitting or crevice corrosion or both can be prevented by cleaning and using alloys that are extremely resistant to this corrosion procedure.

Damped scrubbing process

FGD is basically a simple procedure conducted in the milder environments as compare to other chemical procedures in the industry; several material troubles have been occurred.

The production of wallpaper sheet lining of carbon steel with thin nickel based materials such as stainless steels is useful in this regard. Earlier it was discovered that non-metallic coated carbon steel would be the cost-effective approach to use the materials in the FGD units. Although it was found to be unsuitable because the coatings are prone to mechanical deformation and need a specific set of operation environments that if not achieved will cause poor adhesion. Considering the life cycle costs and reduced revenues, the alloy manufacturing often gives a benefit over a coated steel units.

The damages have also been noticed in the metallic systems causing inadequate metal selection, bad welding and production and inappropriate knowledge or control on the operation environments. The alloy choice can now be done with trust depending on the experience and history of wide on-site and lab corrosion analysis.

The acid or chloride conditions in a FGD scrubber are widely intense. The influences of sulfuric acid corrosion over a large pH limit in availability of chlorides and fluorides received from the fuel and accumulated in the scrubbing media should be taken into account. This condition causes to beginning of crevice attack when sludge and scaling occur.

Suitable enhancement has been performed in the production and application of different FGD units.

The nickel alloys and stainless steel grades with suitable selection and operations, are able to offer the economical solutions to the common material issues occurring in the application of FGD system. Hence the maintenance costs with the large limits of system presence are insured for the plant operation life anticipated with the traditional electrical power production operations.

Wide experience has been achieved with damped lime to limestone scrubbing of flue gases with the help of nickel based materials to overcome the corrosion based issues. Above 40% of the entire damped limestone or gypsum absorber towers made globally utilized nickel containing materials. Moreover, it is expected that 70% of whole absorber towers will use stainless steel grades and nickel alloys in this century.

Corrosive factors

Sulfur oxides are developed while coal combustion with water to produce attacking acids with water. Normally the FGD units must be competent to function with a fuel sulfur concentration about 4% with least 95% elimination of sulfur oxides.

<u>Temperature</u>

In the standard service temperature limits in the FGD scrubber if not high, these can cause a significant effect on the corrosive conditions. The received flue gas is often at about 160oC or 320oF and is quenched to 50 to 65oC or 122 to 149oF while traveling through the scrubber units. The scrubber outlet temperature is crucially close to the condensation temperature for sulfurous or sulfuric acid. The condensation of acid occurs in the exiting ducts, dampers and stacks, need the installation of acid resistant materials, it is crucial to understand that complete bypass the conditions with unprocessed flue gas may occur and should be hold.

The estimated content of sulfuric acid expected in condensate will vary from 26 to 55% with the normal service, increasing to above 80% with the complete bypass.

<u>pH manage</u>

The operation conditions are analyzed closely to decrease the scaling in the scrubber unit. The calcium sulfite crystallization can be limited by maintaining the pH of slurring within the appropriate limit. Very small pH value causes to decrease the scrubber performance. Scrubbing slurries should normally be maintained in the mild acid condition of pH 4.5 to 5.5 using limestone. Moreover sulfur or thiosulfate inclusions are widely used to reduce scaling. The quenching of the flue gas to suitable reaction temperatures need water processed with neutralizing agents to prevent small pH values. Adequate temperatures vary as specified by the fuel utilized, such as they are larger if brown coals called Lignite are used. These are functional limits that should be taken into account while deciding the material for use.

Chloride %

Another troubling corrosive factor in the scrubber condition is the availability of chlorides from the scrubber water and also from the absorption of hydrogen chloride released by burning of chloride based coals. The chlorides can concentrate due to evaporation as well as redistribution of water in one cycle unit to levels above 100 x 10(3) ppm causing severely corrosive acid chloride solutions. It is imperative with the obligation of tight controls on the chloride ejection in waste water. The procedures like multi-stage flash distillation or blow down may be essential for chloride removal from process water removed from the FGD unit.

In a dual loop unit the large chloride condition can be controlled to the cooling area of the scrubber. The remaining scrubber areas with chloride magnitudes in some thousand ppm limit will be less severe and may not need to use extremely resistive nickel based alloys.

Fluoride %

About 3,000 ppm of fluorides may occur in coals that accumulate on the metals beneath the scale piles, worsening the acid chloride crevice attack of the stainless steels. The nickel based alloys with larger chromium and molybdenum magnitudes may be needed to prevent these corrosions caused by chloride and fluoride levels that may be 100,000 ppm or higher.

Corrosion resistant nickel materials

Stainless steel grades and nickel alloys achieve corrosion resistance by producing the thin, passive oxide layer containing chromium that is immediately produced when a material comes in contact of air. This layer producing feature is common in all metallic materials consisting of chromium above 12%. The chemistry of oxide layer definitely changes with the material’s chemistry. Although if the layer damages, it can still offer corrosion resistance in the several conditions. For each operation there is a metal that definitely offers suitable and economical application.

Types of Attack in FGD System

Stress corrosion cracking: SCC of stainless steels is not an issue at the standard service temperatures about 50 to 65oC or 122 to 149of however it becomes an issue at exceeding limits of 150 to 175oC or 302of to 347oF and above.

It is crucial to determine that in fact when pH and chlorides of the vast solution if are suitably controlled there is always the chance of accumulation of chlorides under the piles or on the heat transmitting surfaces that can cause conditions sensitive to stress corrosion cracking.

Pitting effect of chloride content and pH level

Broad study on the effect of chloride ion content, pH and temperature on the functionality of nickel based materials has been performed in the process industry operations and in seawater based applications. It is almost relevant to conditions occurred in FGD systems. There is a specific connection between localized corrosive attack and pH and chloride percentage. The accumulated solids can cause localized corrosion by accumulating chlorides and offering oxygen scarce crevice environments. The material choice should be considered by keeping these types of accumulation in mind while in service.

The analyses in the controlled conditions have enabled to describe the pH or chloride limits for several nickel alloys of use, this information is significant to describe the conditions in which the application of stainless steels and highly corrosion resistant nickel alloys are needed. The choice of suitable alloys to meet the conditions occurred in FGD systems can be available by considering the Pitting Resistance Equivalent Number (PREN) that can be utilized to evaluate materials. The larger value of PREN describes more resistive potential of alloy to pitting corrosion. Following is the formula to calculate the PREN for austenitic stainless steels. Chromium, molybdenum and nitrogen elements offer resistance when particularly are together.

PREn = %chromium + 3.3* % Molybdenum + 16* % nitrogen

The PREn offers a quick estimated comparison of the different alloys. It estimates the critical crevice temperature in the marine water or lab stand-in ferric chloride. The larger the value of PREn, more the alloy is resistant to pitting and crevice corrosion in the chlorides media. Following table shows the PREn values for different alloys:

Temperature for causing crevice corrosion in 10% Ferric chloride ($FeCl_3.6H_2O$) solution

Alloy grade	UNS series	Of	oC	PREn
SS 316l	S31603	27	-3	23
SS 317l	S31703	35	2	29
SS 317 LMN	S31726	68	20	33
2205 Duplex stainless steel	S31803	68	20	33
2205 Duplex stainless steel	S32205	68	20	35
SS 904l	N 08904	75	24	35
Alloy 255	N 08367	110	43	44
Inconel 625	N 06625	113	45	51
Hastelloy C276	N 10276	130	55	74

Temperature

Generally increasing temperature accelerates the corrosion rate or extent of sensitivity of alloy to get attacked. To achieve the higher temperature service in FGD system or to consider the feasibility of temperature excursions in service, high nickel alloys are capable of performing in the vigorous conditions.

Effect of Molybdenum

It is referred that molybdenum improves the resistance of austenitic stainless steels and nickel alloys to general corrosion and particularly resistant to chloride based solutions and sulfur dioxide vapors. For instance, the recognition of the value of increased magnitude of molybdenum led to the production of SS 317LM with molybdenum magnitudes of 4 to 4.5 %, molybdenum exceeding the specification for SS 317 for specific corrosive applications.

Nickel materials use in FGD systems

Most of the traditional FGD systems were designed using carbon steel with non-metallic finish and rubber lining because of insufficient knowledge of the conditions to be occurred. There was also scarcity of consistent information of stainless steels and nickel alloys. In addition of suitable progress with enhanced coating technique, issues occur that may only be resolved through the selection of a suitable grade of nickel based alloy.

The corrosion resistance feature is enhanced by increasing contents of chromium (Cr), Nickel (Ni), Molybdenum (Mo) and Nitrogen (N). Chromium offers passive secured surface layers and molybdenum and nitrogen enhance the resistance to pitting and crevice corrosion. Nickel supports in renovating the damaged secured layers and also enhances fabrication and weldability.

The material that consists of suitable combination of these alloying agents, it will offer enhanced resistance to corrosion in the FGD scrubber conditions at the low price.

Significance of stainless steel

The standard stainless steels are stated where applicable however, the steels consisting of larger contents of chromium, nickel and molybdenum are widely chosen for use in the vigorous conditions. Low carbon or titanium or niobium stabilized steel grades prevent the intergranular attack. The issues such as chloride induced SCC can be resolved by stating alloys consisting of 42% nickel or comprising of austenitic-ferric microstructure for example 22 and 25% chromium containing duplex steel grades.

Field testing and experience with nickel based alloys in FGD equipments

In around 1970s, over 160 field analyses have been performed on the various corrosion resistant alloys in the diverse FGD systems. Moreover, from 1980, around 57 utilities have configured Hastelloy alloys in the extremely corrosive conditions in the damped scrubbing units. Following are the results received from the field analyses and experiences received from the various installations. The economical thin sheet metallic lining is checked for the problems related with control and reliability. Moreover the future of corrosion and wear resistant alloys is also outlined with the worthy solutions to the erosion issues that occur in FGD systems.

Introduction

When in the situation of choosing security materials for corrosion resistant performance, it is essential to have an estimate of expected life of the system and to choose materials that have verified prolong functionality. A big % of the future FGD systems will use high efficiency wet limestone processing and high performance corrosion resistant alloys.

1. Among the all corrosion resistant materials, the high functional nickel based alloys have a popular role.
2. Experience with these high performance alloys has been verified by- field data and functionality.

Field test

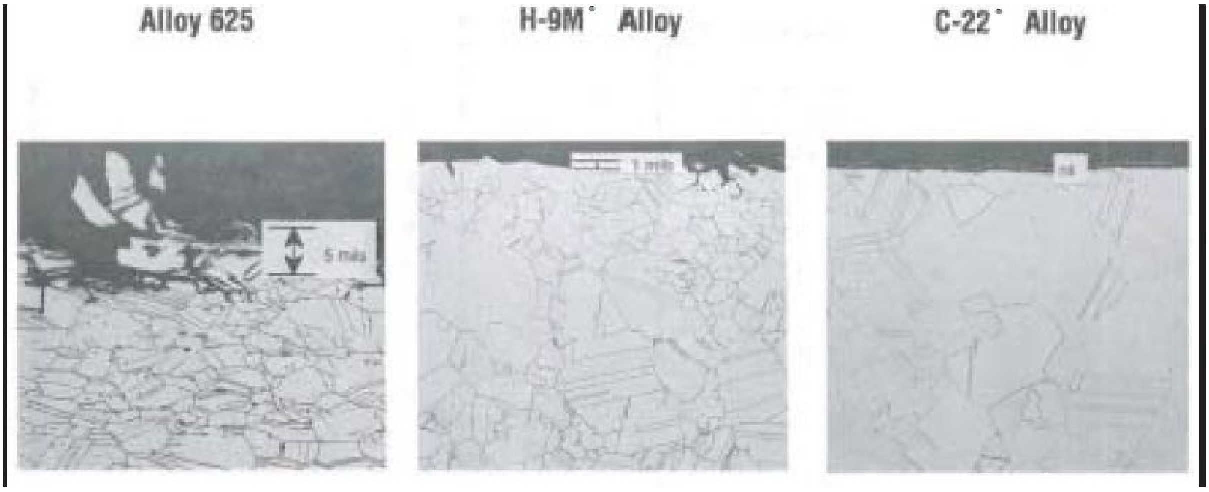
Two kinds of field testing have been conducted in the FGD. The coupon rack configurations are utilized to analyze the wide range of alloys and in other, alloy panels are utilized to analyze the eligible alloys, the wider areas of exposure to conditions in which every alloy is welded directly to the internal surface of the equipment. The coupon test racks assist in ranking a vast range of alloys for suitable functionality while the test panels provide in-situ functionality information for each eligible alloy in the real application conditions.

Every alloy sample is separated by ceramic spaces to secure from the galvanic corrosion among the unlike metals. The samples generally include the weld seam to inspect all materials in the as-welded form. It is essential because the FGD systems are also large that they cannot obtain annealing after fabrication. In the as-welded form, the weld regions possess a cast microstructure that normally attains slighter corrosion resistance as compare to wrought base metals. The alloys that are resistant to corrosion in the both weld and base metal conditions can be chosen for prolong reliable functionality.

Corrosion resistant alloys

Carbon steels, stainless steels and high performance nickel based alloys can be welded together to offer testing as panels. The convenience of welding alloy panels to internal surfaces, combined with the benefit of subjecting an alloy to practical environments, has encouraged many engineers to implement this method over the test rack design.

The alloy panels are checked at every downtime and when needed, testing of corrosion or damage is noted. In few special cases, the tiny parts are removed and stored for study. Mean thickness loss and pit per crevice depth are measured and recorded. If desired, the affected metallographic areas of alloys are tested and filed as shown in the following figure:



The entire data collected from field analyses is composed to prepare easy and quickly accessible information.

Functionality

The following cases of Hastelloy C alloy grades have offered consistent functionality in the power industry over several years.

RD.Morrow Sr. Power Plant- In this plant, double coal fired units of same capacity 200MW have been installed with limestone FGD system. Here 1.3% sulfur coal is combusted and at the complete load, 62% of flue gas is scrubbed, the remaining is bypassed for reheat purposes. The corrosion issues and their solutions in this unit got lot of popularity. It was discovered that the inlet duct door wet or dry region of the absorber section was an intensely corrosive region.

The sludge was evaluated for a specific time limit in the inlet region to determine the corrosive media. The specimens received at two different periods describe extensive difference in the fluoride and chloride content percentages. One sludge sample consisted of 80,000 ppm chlorides however other had 6,300 ppm chlorides and 87,000 ppm fluorides. The welded alloy G panels using **Hastelloy C-276 wire** were installed to assist in preventing the media. After performance of six months, alloy G panel damaged although alloy C276 welds functioned consistently. Therefore alloy C-276 was chosen for sheet line in the attacking regions.

In 1987, while the shutdown, 7 years after the configuration, a tiny part of alloy C276 noticed to have wide crevice corrosion. It was eliminated and replaced during the standard shutdown. By the way, **Hastelloy C-22** was analyzed in this complicated region to compare the alloys in the same regions. Slight etching was observed in alloy C22 in the adjacent region and no further corrosion was noticed.

Texas Units- The Sandow Power Plant inlet duct section was undergoing the corrosive attack, temperature variations from 180oF to 350oF or 82oC to 177oC in this region causes the wet-dry interface. The technical experts for Texas units visited the different power units to observe the functionality of high alloy sheet linings. On the base of regulars, a metallic linings of Hastelloy C-22 sheet was selected as the most trustworthy and economical solution to the inlet duct corrosive issues. Currently, around 1,200 square feet of alloy C-22 has been offering adequate performance since installed in 1988.

Alloy C-22 sheet was again chosen to line problem region in scrubber outlet duct and floor in T.U. electric in 1989. The maintenance checking in 1990, of this duct showed corrosion rates far from the expectation. Most of the corrosion was found in sluggish area where the deposition of acid materials took place. The repairs were done in the routine downtime and an everlasting solution is in progress to prevent the stagnant regions and enhance the bypass reheat combination, offered adequate performance since 1988 after installation.

Lower Colorado River Authority- The Fayette Power Project is a recent power plant of capacity 400MW. It was basically made for outlet duct region, although in an effort to decrease the future maintenance expenses and significant unplanned shutdown, the whole duct area was lined with alloy C-22. Till date no considerable corrosion based issues have been noticed in alloy C-22 lined parts of this FGD system.

National Power, UK- The Drax unit is one of the biggest wet FGD systems across the globe. The outlet duct unit has six 660MW power systems to a common group. Alloy C-22 was used in one million pounds of weight to secure the outlet duct, dampers and internals from attacking failure that was noticed on a sample rig which was treated as test panels to function in the required corrosive media. The maximum level of consistency of the construction alloys is a need for this unit as the Drax unit supplies power without a planned downtime for 39 months at a time. There are more examples of field installed metallic linings for Hastelloy C-276 and alloy C-22 that are listed in the tables at the end of this study.

Economical thin sheet metallic lining

The major reason of wide acceptance of high functional Hastelloy alloys is implementation of a fabrication method, welded-in liners, prolong used in the chemical processing units. This metallic lining method has been widely implemented in the utilities due to economics.

FGD life cycle economics state the requirement for the consistent construction materials. Configuration of FGD unit may include 10-20 % of the entire power plant cost. With increased system reliability, there is often a relatively larger initial cost. There are two apparently opposing attributes – reliability and economy, have been reconciled by using metallic lining method with Hastelloy alloy grades in FGD units.

Several techniques followed to estimate the lucrative benefits of alternative corrosion control techniques. Nace standard RP-Q2-72 offers a method of assessing the Annual Cost that is well accepted and has been extensively utilized in FGD sector. The outstanding functionality at the different power units over the past 10 years offers credibility to the economy of metallic ring technique using the high performance nickel base alloys. In severe environments, where lower grade materials do not perform adequately, expensive replacements were repeated before the installation of Hastelloy alloy.

Reliability and quality control

Depending on experience of nickel based alloys such as Inconel 625 alloy and Hastelloy G alloys and of enhanced Hastelloy C grades in the recent 10 years, a significant trust has been obtained with these alloys for providing consistent performance and low maintenance required for FGD system. To ensure this kind of greater functionality, quality control measures are becoming vital problems for design and procurement engineers. They prefer to be guaranteed that an alloy they are buying is of the same quality as that of alloy chosen based on past analysis offers accepted functionality.

Erosion corrosion

The issues of erosion corrosion in FGD units have not been completely fixed by the alloys offered. But nickel based alloys have provided suitable performance for many years of installation.

Fabrication factors

There have been several papers written on the factors of welding duplex stainless steels and various instructions on welding for FGD service or welding or duplex steels have been prepared. But these didn't give much stress on the problems related with the post weld cleaning.

Pickling of welds is a common post weld cleaning method. Since it is completely a chemical process, reaction time is essential. Adequate time should be given to dissolve heat tint or other contaminants occurred while welding. For weldments of duplex stainless steel 2205, pickling period and mechanical surface treatment had a vital influence on the pitting resistance. More is the pickling times, more increase in the pitting resistance strength. Duplex 2205 test welds had a significantly massive heat tint. Heat tints are porous and preferably absorb chloride ions. It may be that as welded, unpickeld surface didn't offer passive nature, however the as-welded surface gave better performance in pickling, to achieve the maximum pitting resistance, mechanical surface treatment is essential because of physical elimination of unwanted heat tint and contaminants that emerge while welding. However pickling enhances the as-welded surface, pitting potentials remain considerably smaller than for pickling of mechanically processed surface. The comparatively bad behavior of glass bead blasted surfaces to the pickling may be because of the surface morphology influence instead the traditional surface hardness influence. When tested using a scanning electron microscope, a glass beaded surface was observed to be smeared that caused the production of several tiny and tight crevice surfaces. However other mechanical treatments didn't introduce such kind of surface.

Pitting potential of Duplex stainless steel at 60oC

Surface treatment	Pitting potential (mV versus SCE)	Areas corroded
As welded	No passivity	
As welded, 60 minutes pickling	168	
As welded, 3 hours pickling	396	6 pits weld, 1 parent plate

Ground, 120 grit	342	1 pit weld
120 grit, 1 hour pickling	509	3 pits weld
120 grit, 3 hours pickling	740	3 pits weld, 1 HAZ, 1 parent plate
Ground, 600 grit	740	13 pits weld, 1 parent plate
600 grit, 1 hour pickling	716	2 pits weld
Grit blasted, 60 minutes pickling	638	1 pit parent plate
Glass beaded	295	1 pit weld, 6 parent plate
Glass beaded, 3 hours pickle	550	1 pit weld, 1 parent plate

Outline

1. Decisions on materials chosen for latest FGD wet scrubbing systems are recommending corrosion resistant nickel based alloys referred to their proven and reliable functionality over the several years.
2. The proven service of Hastelloy C-22 thin sheet lines in these units offer an economical idea to secure the vast regions that are subjected to the corrosive conditions.
3. Buying the high performance alloys in the standard quality control specifications ensures that trusted corrosion protection is obtained in the service

Technical Information

Outcomes from rack no. 515 reheat bypass duct 450 MW, 1.8% sulfur coal, one year service in wet limestone scrubbing unit in 1983

Alloy	Corrosion rate, mpy	Pitting corrosion		Crevice corrosion	Highest pit depth (mils)
		Base metal	Weld metal		
C Steel	31	Half dissolved		-	-
SS 316l	6	Extremely Intense	Extremely Intense	Extremely Intense	35
317l	4	Extremely Intense	Extremely Intense	Extremely Intense	35
317l	3	Intense	Extremely Intense	Intense	28
20CB-3 alloy	6	Extremely Intense	Intense	Intense	38
Incoloy 825	5	Extremely Intense	Extremely Intense	Intense	47
SS 904l	3	Extremely Intense	Intense	Intense	35
700	2	Intense	Extremely Intense	Intense	27
777	3	Extremely Intense	Extremely Intense	Intense	38
Ferralium alloy	4	Intense	Extremely Intense	Intense	24
Inconel 625	0.5	Intense	Medium	Nominal	28
Alloy G3	0.7	Intense	Intense	Medium	19
Hastelloy C-276	0.1	nominal	nominal	Very nominal	1

Outcomes from Rack No. 593 Bypass Duct 620 MW, 2.7 % sulfur coal, 1 year service in limestone scrubbing unit (1984)

Alloy	Corrosion rate, mpy	Pitting corrosion		Crevice corrosion	Highest pit depth (mils)
		Base metal	Weld metal		
Steel C	20	Half dissolved		-	-
SS 316l	2	Extremely Intense	Extremely Intense	Extremely Intense	57
SS 317l	2	Extremely Intense	Extremely Intense	Extremely Intense	37
317L +	1	Intense	Intense	Intense	17
20CB-3 alloy	2	Extremely Intense	Extremely Intense	Extremely Intense	77
Incoloy 825	2	Extremely Intense	Extremely Intense	Extremely Intense	66
SS 904l	0.7	Extremely Intense	Extremely Intense	Extremely Intense	125
254 SMO alloy	1	Medium	Extremely Intense	Medium	8
700	1	Medium	Medium	Medium	11
777	0.9	Intense	Intense	Extremely Intense	16
Ferralium alloy	2	Medium	Intense	Medium	15
Inconel 625	0.1	Medium	Intense	Intense	9
Alloy G3	0.1	Medium	Intense	Extremely Intense	7
Hastelloy G30	0.1	Medium	Medium	Intense	8
Hastelloy C276	0.1	No corrosion	No corrosion	No corrosion	0
Hastelloy C22	0.1	No corrosion	No corrosion	No corrosion	0
Titanium	0.1	No corrosion	No corrosion	No corrosion	0

ASTM quality control tests mean corrosion rates in MPy

Condition	Alloy 625	Alloy C-276	Alloy C-22
ASTM G-28A 50% H@SO4 plus 42 g/l Fe2(SO4)3 boiling	23	250	40
ASTM G-28B 23% H2SO4 plus 1% CuCl2 + 1.2% HCl boiling	2721	55	8

Chemistry of recommended alloys for use

Alloy C22	Ni	Cr	Mo	W	Fe	C
UNS N06022	Rem.	20 to 24	12 to 17	2 to 4	2 to 8	0.02
Hastelloy C-22	Rem.	21.3 to 22.1	13 to 13.8	13 to 13.8	3.6 to 4.5	Below 0.007

Corrosion of different welding methods

ASTM G-28A (50% sulfuric acid H2SO4 + 42 g/l Fe2(SO4)3 boiling for 24 hours

	Corrosion rates, mpy				
	Base metal	SMAW, 5.4 KJ/ cm, 12.7 mm	GMAW Sp.A.M. (12.6 Kj/cm, 19 mm	GMAW Sh.A.M. (7.8 Kj/cm, 9.5 mm)	GTAW, 7.9 KJ/cm, 3.2 mm
Hastelloy C276	250	235	246	344	207
Hastelloy C-22	40	69	56	53	44
ASTM G-28A (23% sulfuric acid H_2SO_4 + 1.2% HCl + 1% $FeCl_3$ +1% $CuCl_2$) at 85oC for 24 hours					
Alloy C-276	250	235	246	344	207
Alloy C-276	40	69	56	53	44

Influence of welding method, heat supply on resistance to corrosion for 24 hours, 11.5 % H_2SO_4 + 1.2% HCl + 1 % $FeCl_3$ + 15 $CuCl_2$

Welding method	Thickness, mm	Heat supply, Kj/cm	Hastelloy C22	Hastelloy C276	Inconel 625
GTAW automatic copper clamps	3.2	7.9	100	100	55
GMAW manual short arc mode	9.5	7.8	102	95	50
SMAW manual 3.2 mm dia.	12.7	5.4	100	100	50
GMAW manual spray arc mde	19	12.6	102	95	50
Standard unwelded base material	average		101	97.5	51.3
			120	110	75

Pitting corrosion resistance

11.5 % H_2SO_4 + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$

Alloy	Critical pitting temperature, oC
Hastelloy C22	120
Ultimet alloy	115
Hastelloy C276	110
Inconel 625	75
6B	45
20CB-3 alloy	30
SS 316l	25