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Stainless steels for flue gas cleaning

Dear Reader

Flue gas cleaning is inherently linked to expansion of industrial activity. As the cradle of the industrial revolution, the United Kingdom was the first country to address the problem some 150 years ago. During the past century, increased demand for power has gone hand in hand with the development of cleaning techniques to take care of the side effects. Thanks to these techniques, the atmosphere in Europe is much cleaner than it was twenty years ago.

Today, two regions are especially "hot" when it comes to flue gas cleaning systems: the US and China. China, since general expansion requires almost infinite addition of energy. In the US there are two factors driving the development: the US were early in installing scrubbers for today's power generating plants and many old installations are now up for replacement. In addition, the Clear Skies initiative prescribes a cut of SO_2 emissions from 11 million tonnes to a cap of 3 million tonnes in 2018. Meeting this goal will demand not only refurbishing of existing equipment but also construction of new scrubbers.

At present, there are essentially two concepts competing on the market: solid stainless steel or different types of coating techniques which include wall papering with corrosion resistant alloys or application of a polymer coating. The advantage of the stainless steel solution is the very long service life – if done properly the scrubber will outlast the power plant. As shown in this issue's paper, selecting a mix of grades meeting the corrosion demands in the different parts of the scrubber system can yield a solution with very low maintenance requirements. Such a reliable solution is particularly important for an industry where shutdown times should be kept to an absolute minimum.

Yours sincerely,
Claes Olsson, PhD
Acom editor

Stainless steels for flue gas cleaning

— laboratory trials, field tests and service experience

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Abstract

This paper describes different stainless steel grades suitable for construction of flue-gas desulfurization (FGD) systems. A collection of data from laboratory trials, field testing as well as practical service experience will be presented. The subject of materials selection for combustion and waste incineration plants is complicated, since the corrosivity of the gases may vary widely due to differences in fuel composition and also depending on where in the plant the detail will be situated. The intention is to present data that may assist in selecting the appropriate material for different parts of an FGD system. A table giving the general application areas for different grades is presented. Practical full-scale service experience from different locations is then presented supporting this table.

Keywords: stainless steel, desulfurization, FGD, flue gas cleaning, waste incineration, power plants, scrubbers, corrosion testing, field test, service experience

Introduction

Methods for removing sulfur oxides from flue gases have been studied for some 150 years. The first contry experiencing severe problems was the UK, where the effects of the industrial revolution first became evident in the mid 1800s. This resulted in a series of ideas for cleaning the gases resulting from carbon based power generation. The problems became evident with the introduction of large scale power plants in the 1920s. Early commercial systems were taken into operation in the UK of the 1930s. These plants were built with mild steels, sometimes with organic coatings. It was soon discovered that the corrosivity of the flue gases was much worse than expected. After a decline during the war, rising environmental concerns led to the re-introduction of commercial systems on the market in the 1970s, this time Japan and the US were market leaders. Today, flue gas cleaning is standard practice all over Europe.

The environments in flue gas cleaning (FGC) plants are often very complex and vary within wide ranges. No plant is like the other and material selection has to be done for each plant individually, based on the corrosive media, i.e. type of plant, location within the plant, operation conditions, plant design as well as the total economic aspect. The corrosivity is also varying within the plant. High alloy austenitic grades (e.g. S31254, S34565) are normally used in the scrubber itself, whereas lower alloy grades, e.g. type 316 stainless steel, can be used once the sulfur containing compounds have been removed.

These results have been presented previously at the NACE 2007 conference [1].

Corrosion

The main issues in an FGC plant are uniform corrosion, caused when condensates of acids are formed, and pitting and crevice corrosion, which are the greatest threats in washing water and washing solutions.

Uniform corrosion

When the temperature drops below the dew point, concentrated acids will precipitate and increase the risk for uniform corrosion. These acids are often contaminated with halides. If the condensate is formed at high temperatures with low pH and large

contamination levels, they will be so aggressive that no structural metallic materials will have sufficient corrosion resistance to withstand long-term exposure. At these temperatures, however, there will only be limited condensation. It is only when the steel temperature drops 20-30°C (68-86°F) below the dew point, that the amount of condensates will be sufficiently large to cause severe corrosion attack [2].

These problems can be avoided either by maintaining an operating temperature above the dew point or to lower it to a value where condensation is sufficient to keep the pH and halide levels on acceptable levels. It is also possible to spray the sensitive areas with water to further dilute the condensates.

The type of fuel used is also important. If sulfur containing oil is burnt, the main corrosive agent formed during condensation of flue gases is sulfuric acid, whereas in waste incineration plants, where frequently significant amounts of plastics are burnt, hydrochloric acid is the main acid formed.

Generally, the uniform corrosion resistance of a stainless steel is enhanced with increasing contents of chromium, nickel and molybdenum. The corrosion rate is often given in mm/year and can be presented in isocorrosion diagrams showing the combination of acid concentration and temperature giving a corrosion rate of 0.1 mm/y (3.9 mpy). Isocorrosion diagrams can be used for comparing the corrosion resistance between grades in different media but also as tools for material selection. Figures 1 and 2 show isocorro-

Fig. 1   Isocorrosion diagram (0.1 mm/y) in pure sulfuric acid.
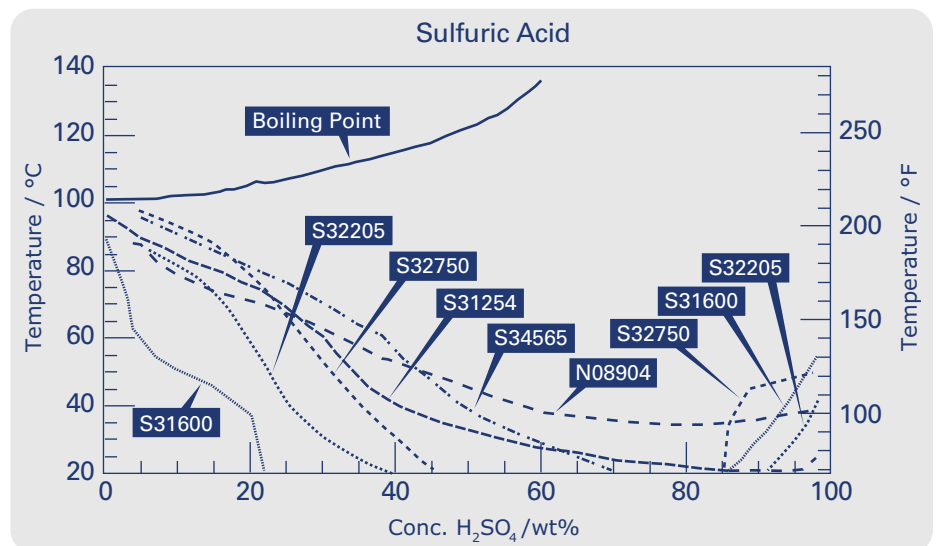

Fig. 2   Isocorrosion diagram (0.1 mm/y) in sulfuric acid with addition of 2 000 ppm chlorides.
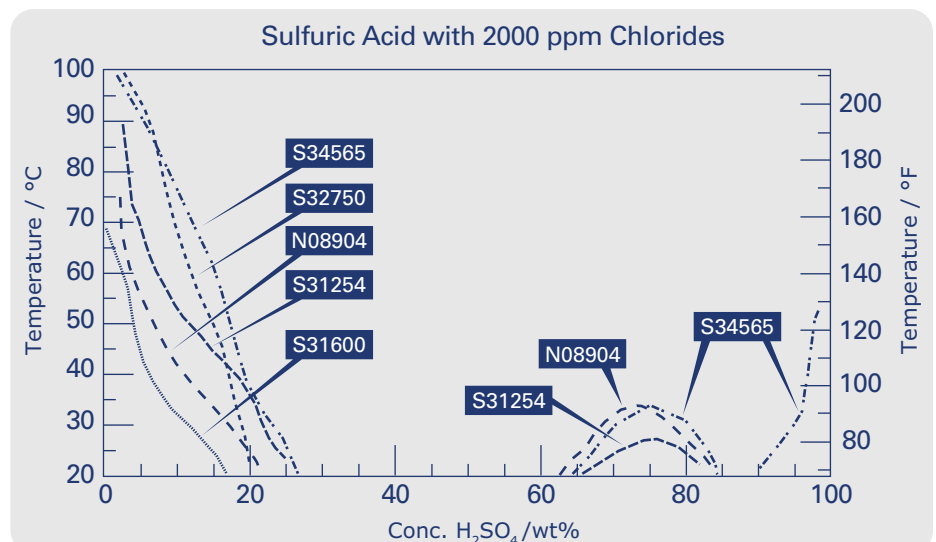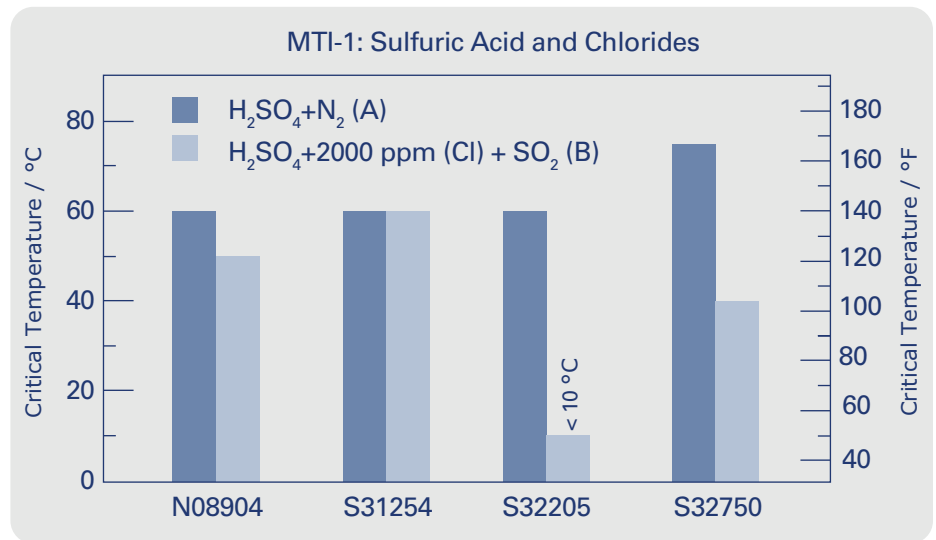
Fig. 3 Critical temperatures (MTI-1) in sulfuric acid solutions.

MTI-1: Sulfuric Acid and Chlorides

Legend:
- H_2SO_4+N_2 (A)
- H_2SO_4+2000 ppm (Cl) + SO_2 (B)

Left axis: Critical Temperature / °C (0, 20, 40, 60, 80)
Right axis: Critical Temperature / °F (40, 60, 80, 100, 120, 140, 160, 180)
X-axis categories: N08904, S31254, S32205, S32750

< 10 °C (label on S32205 bar B)

sion diagrams in pure sulfuric acid, and in sulfuric acid with addition of chlorides[3]. It should be noted that the presence of chlorides markedly increases the corrosion rates for all grades.

Figure 3 shows the critical temperature, i.e. the lowest temperature where the corrosion rate exceeds 0.127 mm/y (5 mpy) measured according to method MTI-1 [4] for different grades in two sulfuric acid solutions [5]. The data were taken from reference [5], with addition of new values for the grade S32750. In the pure dilute sulfuric acid (A) grades N08904, S31254 and S32205 have the same resistance whereas grade S32750 shows a higher resistance. In the simulated scrubber solution (B), the results are quite different despite the same sulfuric acid concentration. The presence of chlorides and sulfur dioxide does not influence the resistance of S31254 and only slightly N08904, whereas the corrosion resistance of the duplex grades S32205 and S32750 decreases dramatically.

Figure 4 shows a part from a 316-type pipe wall in a leaky draft valve, where sulfur trioxide, containing gas on the right side leaked through the valve and condensed, forming sulfuric acid on the other side (left), resulting in severe corrosion. The unattacked pipe wall to the right had a thickness of 6 mm (0.24"), while the pipe wall was partly perforated to the left. The steel grade of the draft valve was changed to N08904.

Fig. 4 A corroded 316-type pipe wall in a draft valve.
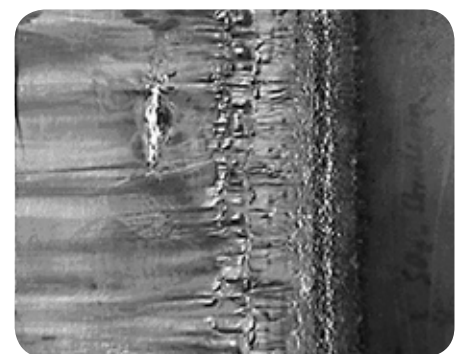
Pitting and Crevice Corrosion

Pitting and crevice corrosion are the most frequent corrosion types in FGC plants. They are most commonly observed on areas in contact with washing solutions and the risk increases with low pH values in combination with high halides concentrations.

The resistance to pitting and crevice corrosion increases with the alloying elements chromium, molybdenum and nitrogen. An empiric formula for estimating the localized corrosion resistance is given by the pitting resistance equivalent index (PRE). PRE is an empirically established index based on the levels of chromium, molybdenum and nitrogen: PRE = %Cr + 3.3·%Mo + x%N, where the value of x normally falls between 16 and 30 [6]. PRE values for steels commonly used in FGC are given in Table 1.

When comparing the corrosion resistance experimentally, common methods are to measure the lowest temperatures at which corrosion occurs. These temperatures are known as critical pitting temperatures (CPT) and critical crevice temperatures (CCT), cf. Figures 5 and 6. CPTs and CCTs may be determined either in standard laboratory electrolytes or in more complex solutions simulating real service environment.

These methods are useful in ranking materials for scrubber services, because the environments are typically acidic and high in chlorides. Crevice corrosion is especially important since it is difficult to avoid deposits in scrubber operation. It should be remembered that critical temperatures should only be used to rank different alloys, not for estimating performance in some real application. For example, neither the CPT nor the CCT give any information on propagation rates.

Fig. 5 Typical CPT values in 1M NaCl for some stainless steels tested in ground condition according to ASTM G150.
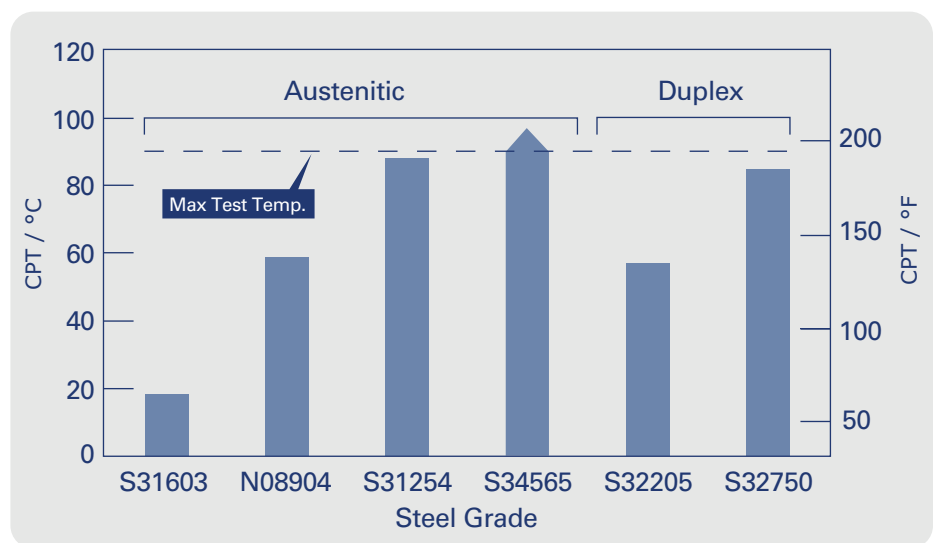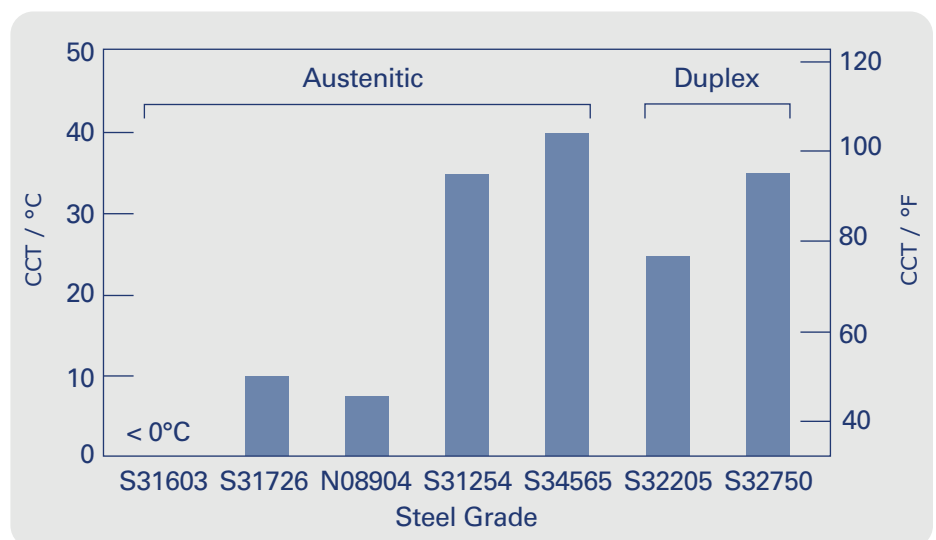

Fig. 6 Typical CCT values in 6% $FeCl_3$ + 1% HCl for some stainless steels tested in ground condition according to ASTM G48 Method F.

Stainless steels for FGD applications. Typical chemical composition, wt%. Table 1

UNS	EN		Cr	Ni	Mo	N	Others	PRE$_{16}$	PRE$_{30}$
S31603	1.4404	Austenite	17.2	10.2	2.1	—		24	24
S31603	1.4432	Austenite	16.9	10.7	2.6	—		25	25
S31703	1.4438	Austenite	18.2	13.7	3.1	—		28	28
S31726	1.4439	Austenite	17.8	12.7	4.1	0.14		34	36
N08904	1.4539	Austenite	20	25	4.3	—	1.5Cu	34	34
S31254	1.4547	Austenite	20	18	6.1	0.2	0.7Cu	43	46
S34565	1.4565	Austenite	24	17	4.5	0.45	5.5Mn	46	52
S32205	1.4462	Duplex	22	5.7	3.1	0.17		35	37
S32750	1.4410	Duplex	25	7	4	0.27		43	46

Stress Corrosion Cracking

Cases of stress corrosion cracking have not been frequent in FGC applications, with the exception of the re-heater where the temperature of the flue gas is raised before entering the stack. Evaporation of fluid droplets settling on the walls can rapidly produce enrichment in chlorides and cause stress corrosion cracking. Stress corrosion cracking has also been reported from flue gas inlets where the washing water has splashed in to the hot flue gas inlet, the wet-dry zone.

Stainless Steels

As mentioned earlier, an FGC plant can be divided into zones with different environments and consequently also different degrees of corrosivity. To find an optimal solution from performance and economical aspects, material selection has to be made for each zone individually. Some suggested grades are given in Table 1 together with the typical composition of these steels and their PRE values.

Below follows a short description of the characteristics of each grade:

316 type — Molybdenum alloyed austenitic stainless steel, e.g. S31603. To be used in mild environments, e.g. storage tanks.

317 type — Improved version of S31603, e.g. S31703 and S31726. Higher level of molybdenum but also alloyed with nitrogen to improve the corrosion resistance. Application examples include spray lances and the upper part of the absorber and demister.

904L — N08904, high alloyed austenitic grade. Developed to perform well in diluted sulfuric acid. Application examples include spray lances and the upper part of the absorber and demister.

254 SMO®(1) — S31254, high alloyed austenitic grade. Developed to perform well in solutions containing chlorides. Examples of applications are condensers, part of absorbers, stacks and gas ducts.

4565 — S34565, high alloyed austenitic grade. Frequently used in FGC applications with good results. Can be used for absorber vessels, spray lances, demisters, clean gas duct and the stack.

2205 — S32205, duplex grade with corrosion resistance similar to N08904 in many environments. High mechanical strength. Can e.g. be used for parts of absorbers and condensers.

SAF 2507® (2) — S32750, duplex grade with corrosion resistance comparable to S31254 but with higher mechanical strength. Typical applications include absorber and condenser parts.

(1)254 SMO is a trademark owned by Outokumpu Stainless
(2) SAF 2507 is a trademark owned by Sandvik

Corrosion Testing

For practical reasons, evaluation of the corrosion performance of different alloys are often performed in the laboratory, where the corrosive environment is simulated as close to the real application as possible. However, laboratory tests are confined to relatively short times. The practical upper time limit is of the order of one month. Normally, the environmental parameters (temperatures, concentrations) are kept constant to allow for a systematic evaluation. In practice, concentrations and tempertures within an FGC system can fluctuate within wide ranges over time. Field tests have the advantage of testing in the real application, but it can be more difficult to make systematic conclusions. In a typical field test, welded specimens of different grades are mounted on test racks, often with artificial crevice formers between each specimen. The test rack is welded in place on site where the test is performed and is often under exposure for at least half a year. By performing a field test, also the effect of process fluctuations is covered. One disadvantage of such coupon tests is that the heat transfer situation of real components may be difficult to simulate.

In the following, a laboratory test in simulated scrubber solutions and four field corrosion tests are described.
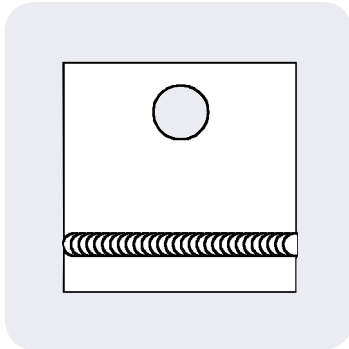
Fig. 7 Welded test specimen.

Fig. 8 Example of test rack.

Laboratory Tests in Artificial Scrubber Environments

Specimens according to Figure 7, in size 60x60 mm, were mounted on test racks similar to the one shown in Figure 8. On both sides of each specimen, multiple crevice formers of PTFE were mounted. The test racks were then assembled with a torque of 1.58 Nm (14 lb-in). All specimens were insulated from each other and from the test rack.

Corrosion tests were performed for 32 days in eight artificial scrubber environments prepared from sodium chloride and sodium fluoride. The pH was adjusted using sulfuric acid.

The steel grades tested, the composition of the artificial scrubber environments, pH and test temperatures, together with the test results are shown in Table 2.

None of the alloys suffered from uniform or pitting corrosion, and the maximum corrosion rate measured was 0.003 mm/y (0.12 mpy). Crevice attacks were found on some samples. Table 2 indicates the maximum crevice depth. Both alloys S34565 and S31254 were resistant even in solution A, which contained the highest amount of chloride and fluoride, at a temperature of 55°C (131°F). Both alloys also suffered crevice corrosion in the more diluted solution (C) at the higher temperature, 70°C (158°F). In solution A,

Test conditions and test results.   Table 2

	Test solutions							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Cl⁻ (ppm)	33 000	33 000	20 000	20 000	5 000	2 000	500	500
F⁻ (ppm)	1 000	1 000	200	200	200	200	50	50
ph	4.0	4.0	4.0	4.0	4.5	4.5	1.5	1.0
Temp, °C (°F)	55 (131)	50 (122)	70 (158)	55 (131)	50 (122)	50 (122)	50 (122)	50 (122)

Grade								
S31726				113	0	0	0	0
N08904				0	0	0	0	0
S31254	0	0	310	0				
S34565	0	0	210	0				
S32205				87		0	0	0
S32750	64	0		0		0	0	0

☐ Not tested   0 Resistant   X Not resistant, max attack depth in μm

grade S32750 was attacked by crevice corrosion, but was unattacked at 5°C (41°F) lower temperature, i.e. at 50°C (122°F) (solution B). Grade N08904 was slightly more resistant than grades S31726 and S32205. The results give the following ranking of the alloys with the least resistant alloys to the left:

S31726/S32205 < N08904 < S32750 < S34565/S31254

Field Corrosion Tests

For a simple evaluation, field corrosion tests are preferably performed with the same type of specimens and racks as used in the laboratory test described above. The racks are normally assembled in the laboratory and then welded in place on location.

Field Test 1: A field test was performed in an absorber at a high sulfur coal fired power plant in the US. Welded and creviced specimens were exposed for 1.5 to 3.5 years. Test conditions are shown in Table 3.

Two test racks were located in the absorber inlet duct; the results are shown in Table 4. The only grade suffering corrosion was S31600 after 3.5 years exposure.

The test result corresponded very well to the result obtained in the artificial scrubber solution "F" in the laboratory test. The laboratory test, performed at a lower pH and a lower temperature, indicated that grades S31726, N08904, S31254, S32205 and

Test conditions. Table 3

Cl⁻	pH	Temp °C (°F)
2 000	5.5	160 (320)

Test results, absorber. The figures given indicate uniform corrosion rate in mm/year. Table 4

Grade	Inlet duct, 2.5 years exposure				Inlet duct, 3.5 years exposure			
			Attack in				Attack in	
	Uniform	Crevice	Base metal	Weld	Uniform	Crevice	Base metal	Weld
S31603	0.01	0	0	0				
S31600					0.01	62	29	0
S31726	0.01	0	0	0	0.01	0	0	0
N08904	0.00	0	0	0	0.01	0	0	0
S31254	0.00	0	0	0	0.01	0	0	0
S32205	0.00	0	0	0	0.01	0	0	0
S32750	0.00	0	0	0	0.01	0	0	0

☐ Not tested   ▨ No attacks   ▨ Attacked

Test results, inlet duct lip. The figures given indicate uniform corrosion rate in mm/year. Table 5

Grade	Inlet duct, 2.5 years exposure			
			Attack in	
	Uniform	Crevice	Base metal	Weld
S31600	0.30	X	X	X
S31726	0.23	X	X	X
N08904	0.27	X	X	X
S31254	0.20	X	X	X
S32205	0.33	X	X	X
S32750	0.22	X	X	X

X Attacked

S32750 could pass the field corrosion test, as they also did. The lower alloyed grades S31603 and S31600 were not part of the laboratory test but could be expected to be less resistant than the others, and S31600 was also attacked in the field test.

At the lip of the inlet duct where the third test rack was exposed, the conditions were much more severe. See Table 5; the main reason being an accumulation of deposits. Underneath the deposits a corrosive environment was formed with very low pH and high concentrations of fluorides and chlorides. As seen in Table 5 none of the tested grades were resistant in this position. The corrosion rates varied between 0.2 mm/y (7.9 mpy) and 0.3 mm/y (11.8 mpy).

Field Test 2: A second field test was performed at three different locations in a peat fired power plant in Sweden. A schematic is shown in Figure 9.

The compositions, pH values and temperatures of the scrubber liquid at the different locations, are given in Table 6.

Welded and creviced specimens of grades N08904, S31254, S32205 and S32750 were tested for 4 months or two years. All grades were free from localized corrosion and the maximum uniform corrosion rate measured was 0.001 mm/y (0.04 mpy) in the scrubber, cf. table 7.

Fig. 9 The flue gas cleaning system of a Swedish peat fired power plant. The positioning of test racks is indicated by numbers 1, 2, and 3.
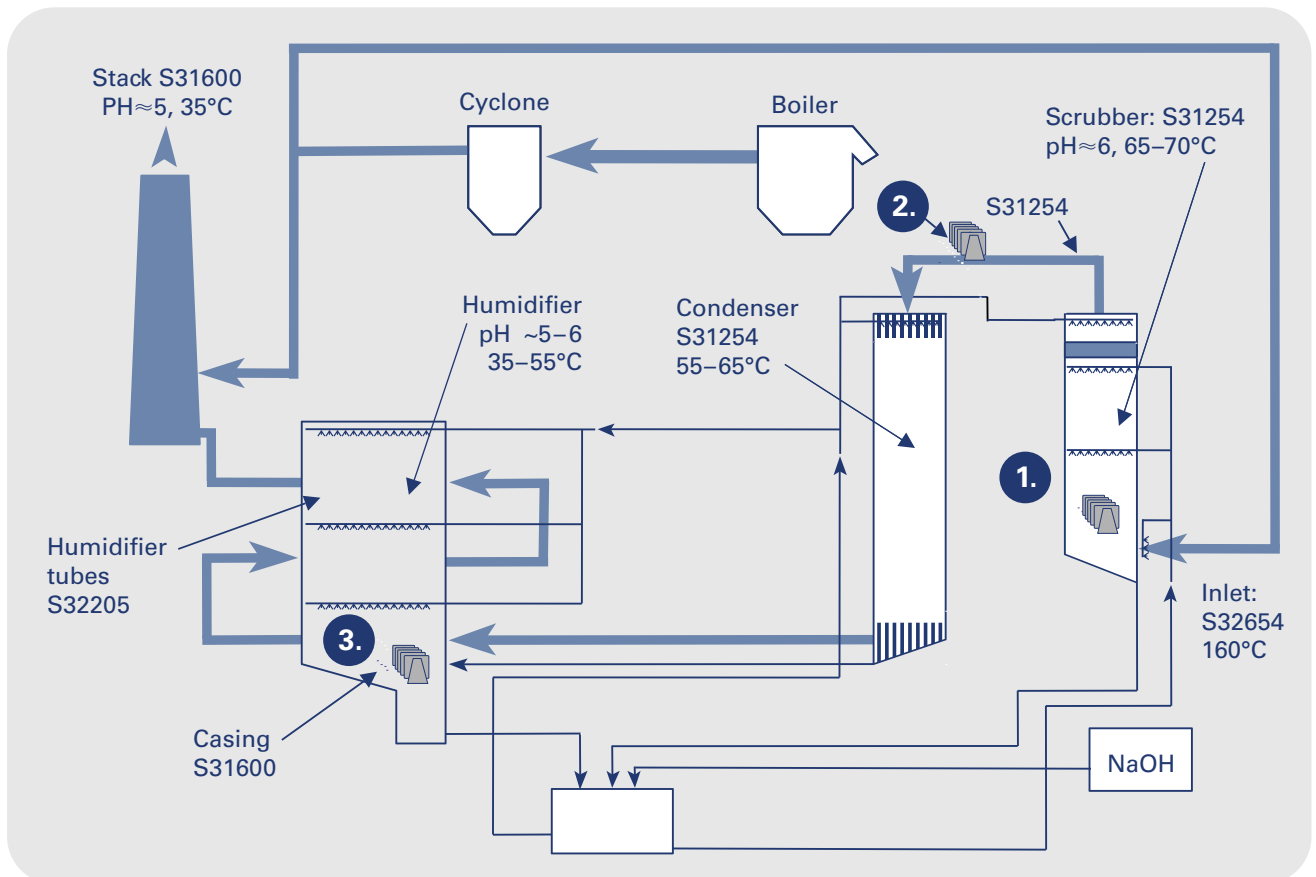
Test conditions.   Table 6

Test site	Cl⁻ (ppm)	F⁻ (ppm)	Br⁻ (ppm)	pH	Temp. (°C)	Temp. (°F)
1. Scrubber	5427	144	298	6	65 – 70	149 – 158
2. Scrubber/condenser	3597–5427	129 – 144	193 – 298	6	65 – 70	149 – 158
3. Humidifier	42– 86	0.8 – 1.3	4.2 – 6.6	5–6	35 – 55	95 – 131

Test results.   Table 7

Test site	Exp. time	N08904	S31254	S32205	S32750
1. Scrubber	4 months	0	0	0	0
2. Scrubber/condenser	2 years	0	0	0	0
3. Humidifier	2 years	0	0	0	0

0   Resistant

The results in the scrubber and scrubber/condenser can be compared to the laboratory test result in the artificial scrubber solution "E" in Table 2, where grade N08904 was resistant. Grades S32205, S31254 and S32750 were not tested but were supposed to be resistant under these conditions. Solution "E" had a lower pH and a lower temperature compared to the scrubber solution in the field test.

Field Test 3: A third field corrosion test was performed in an absorber tower at a high sulfur coal fired power station in the US. The FGD scrubber was of a counter flow 4-spray type, and the test rack was located between the lowest two spray zones in the path of one of the spray nozzles. The conditions in this zone are shown in Table 8.

Welded and creviced specimens were tested for eight months. The test result is shown in Table 9.

None of the specimens suffered uniform corrosion. The attacks observed in the base metal and in connection to the weld were crevice corrosion attacks under the deposits formed on the specimens.

The results obtained can be compared to the artificial scrubber solutions "A" and "B" used in the laboratory test described earlier. The laboratory test indicates that the grades S31600, S31726, N08904, S32205 and S32750 may not be resistant in the field test, but that grade S31254 may. However, although the temperature was higher in the field test, the higher pH made the environment less aggressive, and also grade S32750 passed the field test.

Test conditions.   Table 8

Location	Cl⁻ (ppm)	pH	Temp. (°C)	Temp. (°F)
Absorber inlet duct			160 – 170	320 – 340
Absorber outlet duct	35 000	5.5 – 6.2	80 – 105	180 – 220
Limestone slurry			60	140

Test result, absorber. The figure given, indicate the uniform corrosion rate in mm/y or max. attack depth in μm.   Table 9

Grade	Uniform	Crevice	Base metal	Weld
S31600	0.00	346	X1	0
S31726	0.00	73	X	X
N08904	0.00	42	X	0
S31254	0.00	0	0	0
S32205	0.00	119	X	0
S32750	0.00	0	0	0

0 No attack   X Attacked   X1 Attacks on cut edges

Fig. 10 Flue gas cleaning in a coal fired power plant.
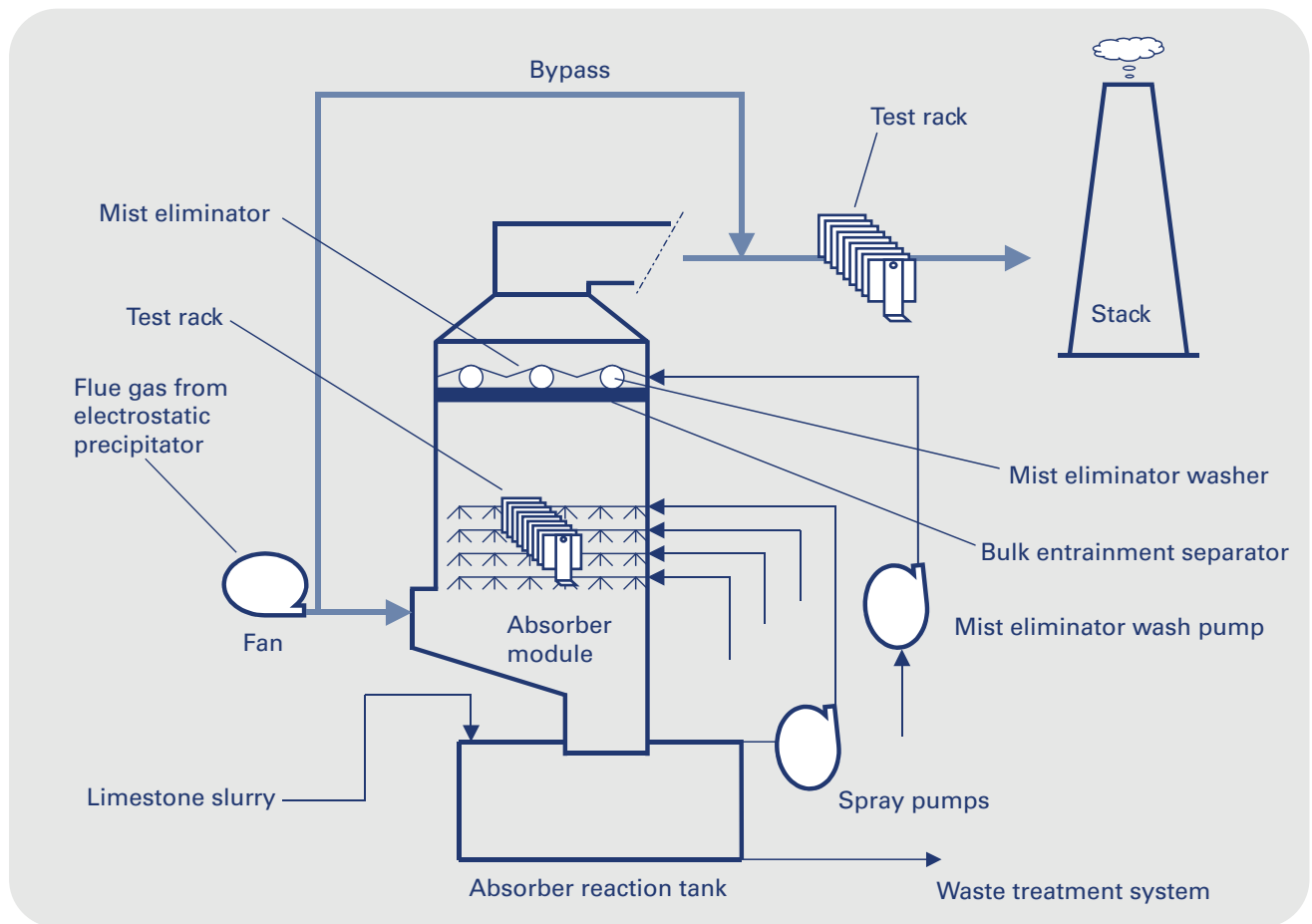
Field Test 4: A fourth field test was performed in a spray tower and in an outlet duct of a scrubber in a US coal fired power plant. See Figure 10.

In the spray tower, wet limestone and natural oxygen were used for desulfurization of the flue gas.

Welded and creviced specimens were tested for nine months in the spray tower and for eight months in the outlet duct. The conditions in the scrubber and the outlet duct are described in Table 10 and the test result in Table 11.

The conditions during this test were more severe, i.e. a higher chloride content, than in any of the tests in the artificial scrubber environments in Table 2 or in field test 3. Still, grades S31254 and S32750 performed rather well in the spray tower even if they suffered slight crevice corrosion. The reason for the relatively good performance was probably due to the higher pH in the field test. Grade S31600 suffered uniform corrosion with a corrosion rate of 0.163 mm/y (6.4 mpy).

In the outlet duct, most of the attack in the base metal and in connection to the weld was due to crevice corrosion under deposits. Grades S31726 and N08904 were the only grades showing pitting attack in the weld whereas S31254 and S32205 had crevice attack under deposits in connection to the weld. Grade S31600 suffered uniform corrosion, protecting it from local attack like pitting and crevice attacks and had a corrosion rate

Test conditions.   Table 10

Test site	Cl⁻ (ppm)	pH	Temp. (°C)	Temp. (°F)
Spray tower	60–80 000	5–5.5	~55	~130
Outlet duct	Some condensates formed, conc. of Cl⁻ and F⁻ unknown	2 in condensate	52–54	125–130

of 0.225 mm/y (8.9 mpy). The conditions in the outlet duct were slightly more severe compared to the spray tower, due to the formation of deposits and condensates.

Figures 11 to 16 show some of the specimens after testing in the spray tower.

Test result.   Table 11

Grade	Spray tower				Outlet duct			
			Pitting				**Attacks**	
	Uniform	**Crevice**	**Base metal**	**Weld**	**Uniform**	**Crevice**	**Base metal**	**Weld**
S31600	0.16	>1 000	214	X	0.23	0	0	0
S31726	0.01	373	335	X	0.01	117	X	X
N08904	0.00	119	220	X	0.00	182	X	X
S31254	0.00	83	0	0	0.00	100	X	X
S32205	0.02	215	58	X	0.00	116	X	X
S32750	0.00	87	X (1)	0	0.00	157	0	0

0 No attack   X Attacked, (1) attack in ID marking

The figures given, indicate the uniform corrosion rate in mm/y or max. attack depth in µm

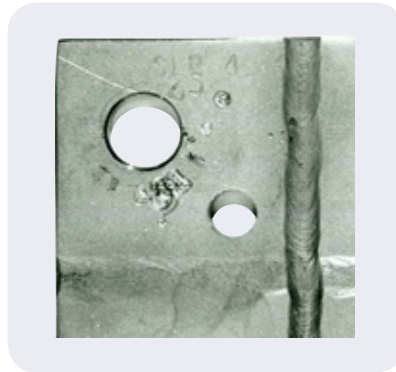**Fig. 11** Grade S31600

Fig. 12 Grade S31726

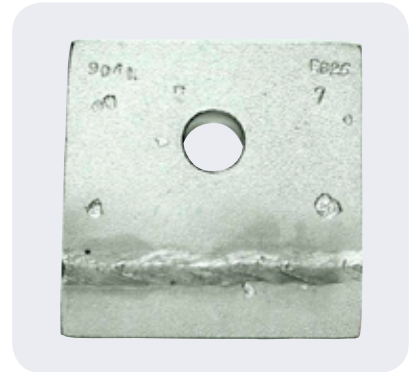**Fig. 13** Grade N08904

Fig. 14 Grade S31254
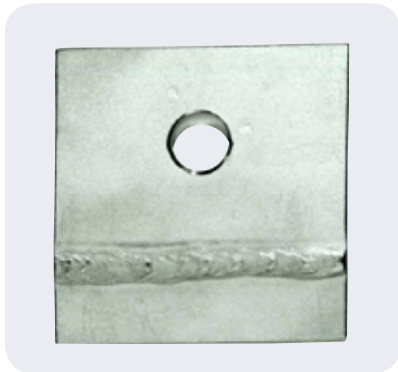

Fig. 15 Grade S32205

Fig. 16 Grade S32750

Service Experience

In the wet cleaning systems of plants mainly using wood or biomass as fuel, low corrosion rates are normally observed for stainless steels, indicating that standard austenitic materials e.g. 316-type can be used. The locations where corrosion might be observed are in the inlet of the condenser and inside the flue gas duct before the condenser. When serious corrosion damage occurs in waste incineration plants, it is usually due to unexpected changes in the fuel composition or other changes in service conditions. A possible scenario that might lead to severe increase in the corrosivity is occasional high contents of PVC plastics in the waste. This will lead to very high concentrations of HCl in the flue gas and its condensates.

In plants with biomass combustion only stainless steel of 316 type is common in the condenser inlet, the condenser, the flue gas ducts after the condenser and in stacks. Higher alloyed steels like S31254 and S32205 are occasionally used also in biomass combustion in e.g. condenser inlet and upper tube plate of tubular condensers. Also the nickel-base alloy N10276 can be found at the condenser inlet.

In plants with a mixture of biomass and assorted waste there is a trend that the use of higher alloyed steels increases with an increasing part of such waste in the fuel. The condenser inlets may be made of S31254, GRP (Glass-Reinforced Plastics) in scrubber condensers) or by lining with PTFE (PolyTetraFluoroEthylene). The upper tube plate in tubular condensers may be made of S31254. The separate plate heat exchanger in scrubber condensers has, in some cases, been made of titanium in plants for waste incineration. The latter is presumably valid for fuels, which do not contain substantial amounts of fluorine. Otherwise the corrosion resistance of titanium should be strongly questioned. Figure 17 shows three titanium specimens exposed in two waste incineration plants containing hydrogen fluoride in the flue gas. These specimens were attacked by severe uniform corrosion, and only the parts shielded by the crevice formers remained of the two specimens to the left [7].

In many US power stations, 317 type stainless steel (mainly S31726) has been applied for absorber construction. In modern flue gas desulfurization (FGD) units, this grade most probably will be replaced with the more cost-efficient duplex grade S32205.

In European FGD projects, there is a tendency to use higher alloy grades such as S31254 and S34565. Among the reasons, one finds high chloride levels, and demands for long-term guarantees from engineering companies, fabricators and material suppliers.

Service experience 1

A municipal waste incineration plant in Sweden is serving as a district heating plant. A schematic is given in Figure 18. The plant has two furnaces (1 and 3 in Figure 18) with an output of 6 MW and 25 MW respectively. The plant has license to burn 65 000 tons of waste per year. Both furnaces are equipped with a selective non-catalytic reduction (SNCR) system for nitrogen where a 35% urea solution is injected in the fireplace. The flue gas cleaning system is joint between the two furnaces. The flue gas passes an electrostatic precipitator (4) for dust separation. After this, the flue gas temperature is decreased to 150°C (302°F) in an economizer (6).

The gas then passes a reactor (7) where sodium sulfide, active carbon and burnt lime are injected to separate hydrochloric acid, sulfur oxides, heavy metals, dioxins etc. in the subsequent textile filter (8). After this dry cleaning, the flue gas enters the wet cleaning
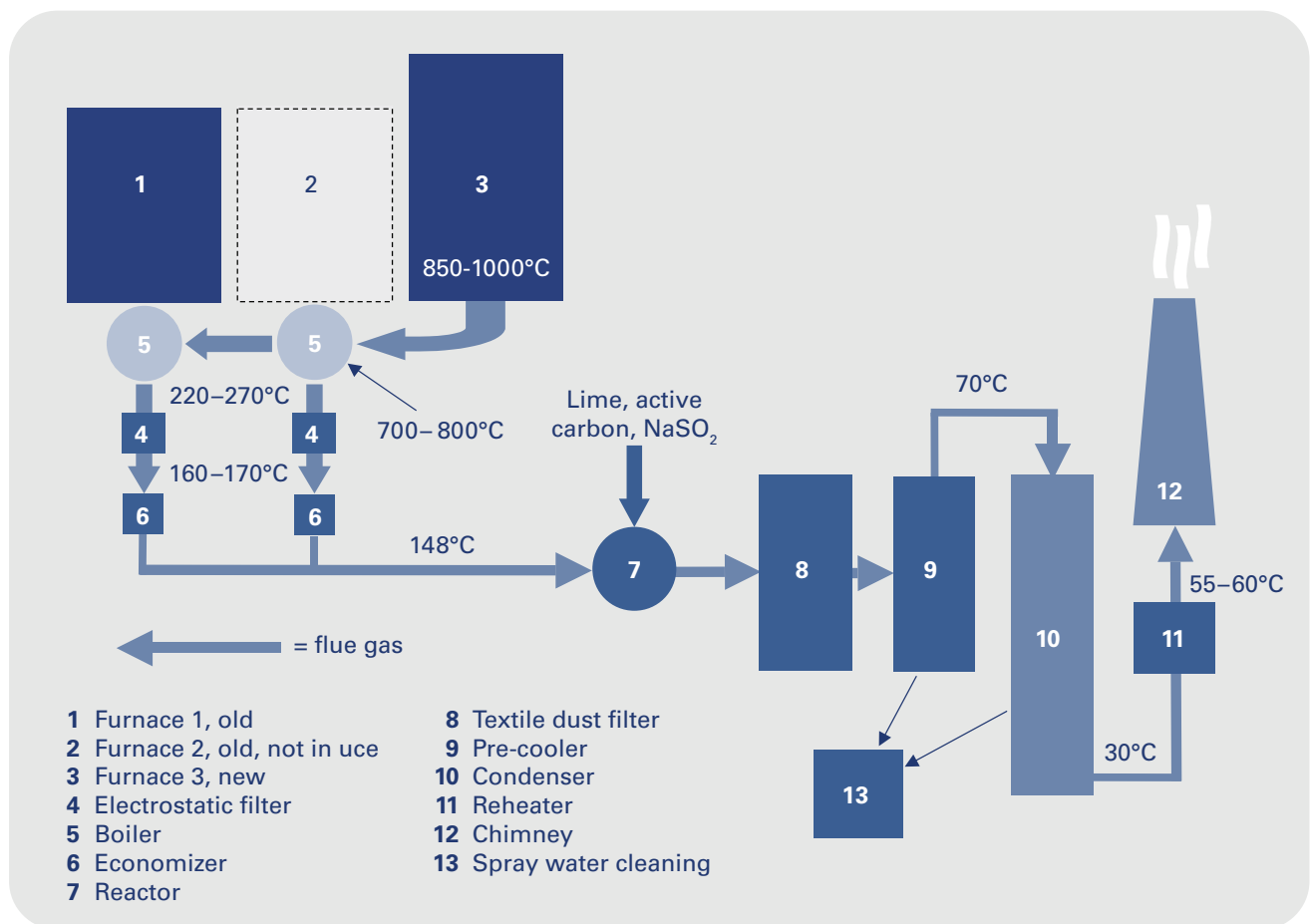
Fig. 17 Titanium specimens exposed in flue gas cleaning systems containing hydrogen fluoride.

Service conditions. Table 12

Temp °C (°F)	Scrubber 50 – 60 (122 –140)	Condenser 30 – 40 (86 –104)
pH	2	1
Cl⁻ mg/l	10 000 – 40 000	5 000
F⁻ mg/l	5	~0
SO₄²⁻ mg/l	500	100

stage with heat recovery. The gas is washed and cooled at the entrance to the scrubber (pre-cooler) (9) by injecting wash liquor in the flue gas. The approximate composition of the spray liquor is given in Table 12. The wash liquor used in the wet cleaning stage is re-circulated and pH adjusted condensate. The gas becomes water saturated. In the scrubber (pre-cooler), additional hydrochloric acid, heavy metals and dust are separated and the flue gas temperature is decreased to approximately 70°C (158°F). In the condenser (10) and the subsequent heat pump, the gas temperature is decreased to approximately 30°C (86°F). The condenser is made of S31254 and no corrosion problems are reported. This experience could be compared with the laboratory test solution "E".

Fig. 18 A municipal waste incineration plant in Sweden, serving as a district heating plant.

1 Furnace 1, old
2 Furnace 2, old, not in uce
3 Furnace 3, new
4 Electrostatic filter
5 Boiler
6 Economizer
7 Reactor
8 Textile dust filter
9 Pre-cooler
10 Condenser
11 Reheater
12 Chimney
13 Spray water cleaning

Service Experience 2

Figure 19 shows a schematic sketch of the double loop absorber installed in the La Spezia power plant of the Italian ENEL group. Apart from the raw gas entry where nickel-base alloy N10276 has been applied, the whole absorber tower including internals like distributing pipes, spraying systems, sieves, collection bowl, demister support are made out of stainless steel grade S34565. Downstream the demister, i.e. for the wall plates of the gas outlet, S31726 was selected.

La Spezia has been the first power station where ENEL specified grade S34565 for the bulk portion in a FGD system. Meanwhile this plant is in operation for more than five years without any corrosion problems. ENEL honored this positive experience and specified grade S34565 in the meantime for several other FGD projects – installation of new FGD plants as well as replacement of different components like spraying systems and exhaust draft fans in existing power plants where originally selected material suffered from crevice corrosion attack.

Fig. 19 Schematic of the double loop absorber installed in the la Spezia power plant of the Italian ENEL group.

La Spezia

Flue Gas Outlet:
S31726

Components for
Absorber Tower:
S34565

Flue Gas Entry:
N10276
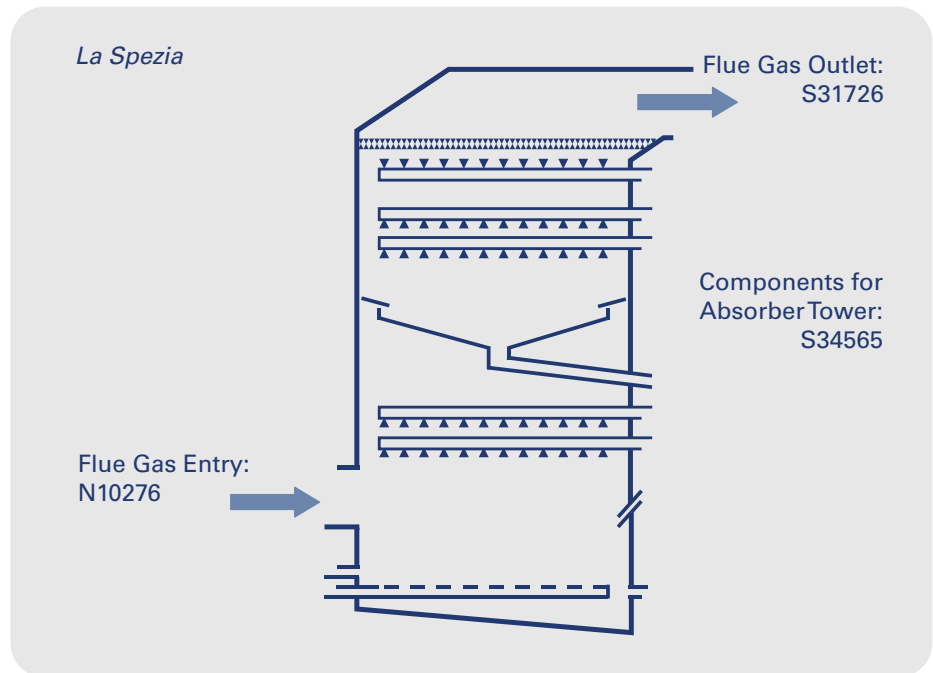
Conclusions

- The different environments in wet cleaning systems in FGC plants can be very corrosive.
- There are large variations in environments between different plants and material selection has to be done for each plant individually based on the corrosive media, i.e. type of plant, location within the plant, operating conditions, plant design and, not to be forgotten, the total economical aspect.
- The main corrosion risks for stainless steels are crevice corrosion and sometimes pitting.
- Laboratory corrosion tests in simulated scrubber environments, and especially field corrosion tests in already existing plants, are good tools to estimate the performance of different alloys in different flue gas cleaning applications.
- There are clear differences between the corrosion resistance of different stainless steels, and the following ranking is valid when crevice corrosion and pitting are the service limiting corrosion forms

S31603<S31726~N08904~S32205< S31254~S32750 ~S34565

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Outokumpu is an international stainless steel company. Our vision is to be the undisputed number one in stainless, with success based on operational excellence. Customers in a wide range of industries use our stainless steel and services worldwide. We are dedicated to helping our customers gain competitive advantage.

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