UNS N08367 Alloy Superaustenitic Stainless Steel for Air Pollution Control Equipment

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ABSTRACT

Fossil fuel power plants are now faced with increasingly strict air quality control laws and EPA rules. New multi-pollutant legislation is controlling a wider range of emissions, while existing legislation is being enforced at more plants. These regulations will result in mandatory installation of pollution control equipment at a majority of coal fired plants within the US. In addition, the electrification of Asia and subsequent interest in reducing smog and acid rain has made pollution control a topic of international interest. The majority of flue gas desulphurization (FGD) units worldwide will employ wet scrubbing, which can reduce sulfur dioxide emissions by more than 90%. Wet scrubbing has also been found to be effective at removing mercury in many cases. Reduction of sub-micron particles, such as sulfuric acid aerosols particulates, may be efficiently removed through the use of a wet electrostatic precipitator (WESP). Due to the inherent contaminants generated by the combustion of coal, wet FGD and WESP's require the use of corrosion resistant materials in their construction.

A variety of metallic alloys are currently used in pollution control systems. This paper reviews the use of N08367 alloy, commercially referred to as AL-6XN®, in various FGD and WESP applications. Experimental data will be reviewed that supports the use of the alloy in the high chloride, low pH environments encountered for many components of the pollution control system. Examples of the application of N08367 in actual service will be presented.

N08367 alloy has proven to be a cost effective material of construction that fills the gap between the lower alloyed stainless steels, such as the 4% Mo austenitic and duplex grades, and the high Mo nickel based alloys. As N08367 alloy is an established material of construction, it is readily available in product forms necessary to complete an FGD or WESP system.

KEY WORDS

Superaustenitic, FGD, WESP, Flue Gas Desulfurization, Corrosion, Pollution Control

INTRODUCTION

Coal fired power plants currently generate more than half of the electric power in the United States. Due to supply concerns for other fuels, such as natural gas and oil, a multitude of new coal fired plants are being built to meet the rising electricity demands of modern society. Combustion of coal generates NOx, SO_2, particulates, and other pollutants that contaminate the environment. Pollution control legislation, such as the Clean Air Act, combined with EPA rules (e.g. CAIR), have mandated a significant reduction in emissions from these power plants. The "Cap and Trade" market approach that the government has taken to reduce emissions has caused a rise in the price of pollution credits, creating a financial incentive to reduce emissions as soon as possible. New legislation regarding mercury emissions has been imposed on the state government level, with federal legislation soon to follow. Thus, it is clear that pollution control will remain a major concern for the power generation industry for many years.

The most effective way to significantly reduce emissions of SO_2, and in some cases mercury, is through the use of flue gas desulfurization (FGD). There are several FGD methods available, examples include various dry scrubbing methods, sea water scrubbing, and wet scrubbing with lime or limestone. The majority of the scrubbers currently being installed use the wet limestone technology. This method is the best suited to scrubbing the high volume of flue gas emitted by large power plants. In addition, this method has the added advantage of allowing for the production of wallboard quality gypsum, which can be sold to partially offset the cost of scrubbing.

While FGD is very effective at removing SO2 from the flue gas, it does little to remove particles and aerosols with a diameter of less than approximately 2 microns. These particles, which may include sulfuric acid aerosols, increase the opacity of stack gas and can lead to an effect known as "blue plume". Sulfuric acid aerosols are a major contributor to acid rain. One effective way to collect sub-micron particulates is through the use of a wet electrostatic precipitator (WESP). These units are typically installed on top of or down stream of an FGD unit.

The corrosive conditions within an FGD and WESP are complex, with many factors contributing to the severity of the environment. The selection of an appropriate material will depend on the operating parameters of the system as well as the environment surrounding the specific components. The most important corrosive species generated during the combustion of coal are chlorides and fluorides along with sulfur bearing species. Contributing to the corrosive environment is the temperature, acid dew point, pH, crevice forming deposits, slurry additives, etc. Typically, several alloys are used in a system, which will be matched to the conditions under which a component is operating. Fortunately, extensive operating experience has been generated which can be used as guide to selecting appropriate materials of construction.

The purpose of this presentation is to review the properties and corrosion resistance of the 6% Mo alloy, AL-6XN® alloy (UNS N08367), in relation to pollution control systems. In addition, typical current applications of the N08367 alloy in the FGD and WESP systems are described.

BACKGROUND

A variety of alloys have been used in FGD and WESP systems. Some of these alloys are listed in Table 1. The appropriate alloy of construction will depend on the operating conditions and location within the equipment.

In the case of the absorber inlet, shown in Figure 1, the hot flue gas passes through the sulfuric acid dew point, leading to the condensation of hot, concentrated sulfuric acid. In this aggressive environment, a nickel alloy with a high content of molybdenum is necessary. The vast majority of absorber inlets in the United States and Asia are made of N10276 alloy.

The material of construction for the absorber tower is largely dependent on the chloride content of the slurry. Fluorides may also be present, which can be considered to be approximately the same as chlorides with regard to their effect on pitting of stainless steels. Since the fluoride content is usually very low, discussion of the effect of halides will be limited to chloride content. The chloride content of the slurry is largely determined by the chloride concentration of the coal being burned, and the rate at which fresh water is added to the slurry (blow down). In cases where a high blow down rate is not possible, e.g. where water treatment is inadequate, the slurry chloride content may become very concentrated.

Table 1
Nominal Composition (wt.%) of Stainless Steels
And Nickel –Base Alloys Used in FGD and WESP Systems

UNS Number	Alloy	Cr	Mo	Ni	Fe	Other
Duplex						
S32205	2205	22	3.25	5.5	Bal	0.16N
S32550	255	25	3.5	6	Bal	0.20N
Austenitic						
S31603	316L	18	2.5	12	Bal	
S31703	317L	19	3.2	13	Bal	
4Mo Austenitic						
S31725	317LM	19	4.5	15	Bal	
S31726	317LMN	19	4.5	15	Bal	0.15N
N08904	904L	21	4.5	25	Bal	1.5Cu
Superaustenitic						
N08367	AL-6XN	20	6.5	25	Bal	0.20N
Ni Based						
N06625	625	22	9	Bal	4.6	4.0(Cb+Ta)
N06022	22	22	13	Bal		3W
N10276	276	16	16	Bal	6.4	3.8W, 1.3Co

A useful way of ranking the resistance of a material to chlorides is through the Pitting Resistance Equivalent, PRE_N. Equation 1 gives a common formula for calculating the PRE_N for austenitic stainless steels. The elements Cr, Mo, and N provide resistance, especially when present together [1-3]. Nitrogen is particularly effective in the superaustenitic alloys with high Mo content [4-6].

$$PRE_N = Cr + 3.3Mo + 30N \quad (1)$$

The higher the PRE_N, the more resistant the alloy is to pitting and crevice corrosion in the presence of chlorides. Typical PRE_N values for various alloys are shown in Table 2. By listing the alloys by decreasing PRE_N, the 6% Mo alloys are positioned above (more resistant than) the conventional stainless steels and approaching the nickel alloys.

Table 2
Temperature for Initiation of Crevice Corrosion in 10% Ferric Chloride ($FeCl_3 \cdot 6H_2O$) Solution (1)
$PRE_N = Cr + 3.3Mo + 30N$

UNS Number	°F (°C)	PRE_N
S31603	27 (-3)	23
S31703	35 (2)	29
S31726	68 (20)	34
S31803	68 (20)	35
S32205	68 (20)	38
N08904	75 (24)	35
S32550	72 (22)	41
N08367	110 (43)	48
N06625	113 (45)	51
N10276	130 (55)	66

(1) per ASTM G 48 Practice B

The absorber outlet ducting will be exposed to some slurry carry over from the absorber as well as residual SO_3 from the flue gas. Since the temperature in the absorber outlet is typically well below the sulfuric acid dew point, low pH condensates containing chlorides are often present. Thus, a Ni-Cr-Mo alloy, such as N10276 or N06022, is often employed. However, the increased efficiency and improved design of modern scrubbers somewhat alleviates this issue, allowing for the application of stainless steels in some cases. A plot demonstrating the corrosion resistance of various alloys in sulfuric acid is given in Figure 2. The presence of chlorides in conjunction with sulfuric acid will generally increase the corrosion rate.

Since a WESP is typically located down-stream of the absorber tower, it will be exposed to similar conditions as the outlet ducting. However, the corrosive conditions within the WESP may vary by component. The continuous washing of the collector plates may mitigate corrosion by sulfuric acid, while other areas may be exposed to low pH solutions [7]. Thus, a combination of materials may be necessary in the construction of the WESP.

A general guide for alloy selection for FGD absorber towers is presented in Figure 3. This table applies to a temperature range of 50°C – 60°C (120°F – 150°F) and a fluoride content of less than 50 ppm. This table is based on the open literature on the subject and is intended to be used as a guide only. Factors such as deposit formation, fabrication procedures, contaminants, additives, etc., must also be taken into consideration when selecting the appropriate material.

N08637 SUPERAUSTENITIC ALLOY DEVELOPMENT

In the early 1970s UNS N08366 alloy, containing 6.3Mo, along with 20Cr and 24Ni, was introduced [8]. Used primarily as welded power plant condenser tube in seawater, this material performed well in the high chloride environment[9,10]. High Cr and Mo provided excellent resistance to pitting and crevice corrosion [1-3] but also promoted intermetallic phases. This limited the thickness at which the material could be produced to thin gages, such as that used for condenser tubing.

Nitrogen suppresses intermetallic phases [11-12] and 0.2 percent was shown to be beneficial to the 20Cr – 24Ni – 6.3Mo alloy [4]. Nitrogen also improves pitting resistance and increases strength. These benefits, incorporated into the N08367 alloy in the early 1980s, permitted a full range of product forms and much broader applicability. The N08367 alloy has found may uses in power plants [13,14], oil refineries, chemical and petrochemical plants [15], and pulp mills, as well as in a variety of seawater applications [16].

Not all alloys in the 6Mo family contain N, and some have a higher or lower nickel content than N08367 alloy. Some other 6Mo alloys also contain Cu which may cause intergranular attack in high chloride environments. All of these alloys have a low carbon content (“L” grades), and thus, are highly resistant to sensitization and intergranular corrosion.

At Allegheny Ludlum, the demand for higher PRE_N has led to the development of several versions of the N08367 alloy. A recent FGD project (to be described later in this paper) was constructed at the customer's demand entirely from N08367 alloy having 47.5 minimum PRE_N. Still greater customer requirements have led Allegheny Ludlum to create an enhanced version of N08367 alloy, designated AL-6XN PLUS™ alloy, which has 50.0 minimum PRE_N. Careful control of composition keeps it within the broad range assigned to N08367 alloy so that it can be used in all applications for which N08367 alloy has been approved.

FABRICATION CHARACTERISTICS

The N08367 alloy is readily welded to itself, other stainless steels, nickel based alloys, and carbon steel. Segregation occurs in as-cast matching-composition weld metal, leaving areas which are low in Cr and Mo, making them susceptible to pitting [17, 18]. For this reason a weld filler metal with -higher Mo content is needed for proper as welded corrosion resistance. Nickel alloy 625 (AWS ERNiCrMo-3) filler metal and 112 (AWS ENiCrMo-3) electrodes provide welds with corrosion resistance and mechanical properties generally comparable to the N08367 alloy base metal [10]. Other high-Mo, nickel-base filler metals, such as N01276 alloy are also suitable.

K. K. Baek, et al, (Hyundai Heavy Industries Co. Ltd.) [19] examined the influence of welding techniques on the corrosion resistance of S32550 and N08367 alloys. Pitting corrosion resistance of N08367 and S32550 alloys arc welded with various filler metals were evaluated using the "Green Death" solution (7 vol.% H2S04 +3 vol.% HCl +l wt.% FeCl3 +1wt.% CuCl2) to simulate FGD plant service. The Critical Pitting Temperature (CPT) of base metal was found to be 65 - 70°C, while Gas Tungsten Arc (GTA) and Gas Metal Arc (GMA) welds of N08367 made using ERNiCrMo-3 filler metal yielded CPT of 50°C. Welds made with ERNiCrMo-10 or ERNiCrMo-4 filler metals showed CPT of 60 - 65°C and 65 - 70°C, respectively. The authors concluded that proper pitting corrosion resistance of weldments of high-alloy stainless steels can be achieved by selecting filler metals having at least +10 higher Pitting Resistance Equivalent Number (PRE_N) value than the base metal regardless of the type of arc welding process. The over-alloyed filler metals would compensate for the segregation of Cr, Mo during weld solidification, which made the dendrite core more susceptible to pitting. Nitrogen addition to the GTA welds of N08367 made with ERNiCrMo-3 failed to improve pitting corrosion resistance, which was attributed to the precipitation of nitrogen in the weld metal in the form of Nb-nitride.

Maurer and Underkofler [20] described "Optimizing a 6% Mo Stainless Steel for FGD Service." Examined were composition effects, the response to varied thermal treatments, control of surface chromium depletion, stress levels, and fabrication. They showed that avoiding or minimizing microsegregation, chromium depletion at the surfaces, stresses and contamination during and after welding, machining or other fabrication operations is an important factor in optimizing a material for aggressive service. Such optimization becomes increasingly important as the cost of materials, maintenance, downtime and replacement escalate.

PAST LABORATORY WORK

Extensive testing has been performed comparing N08367 alloys to stainless steels and higher Ni-Mo alloys [21-24]. The testing includes standard ASTM corrosion testing as well as specialized testing intended to simulate FGD environments. Data from some of these tests are shown in the following tables.

An indication of the pitting resistance is given by the ferric chloride crevice corrosion data shown in Table 2, which is generated using test method ASTM G48-B. The capability of the N08367 alloy with 6.2Mo is seen to be close to that of nickel-base N06625 alloy (9Mo) and significantly better than N08904, S32205, and S31726 alloys. In the ferric chloride test without crevices, ASTM G48-A, the N08367 alloy withstands pitting at 62°C (145°F). There is a good correlation between the ferric chloride test results and the calculated value of the PRE_N for the various alloys.

Test data for N08367 alloy exposed to 24,000 ppm chloride water with temperature varied from 43°C (110°F) to 71°C (160°F) and pH varied from 4 to 0.5 with H_2SO_4 are presented in Table 3. No corrosion was observed at pH 4 or 2. With pH adjusted to 1.0, corrosion was not observed up to and including 66°C (150°F). However, at 71°C (160°F) crevice corrosion was observed. With pH 0.5, no corrosion was observed at 60°C (140°F) but crevice attack was observed at 66°C (150°F). The strong influence of the temperature on corrosion rate should be noted.

Table 3
24,000 PPM Chloride Water with pH and Temperature Varied (1)

Temperature	**Weight Loss, g/cm² (2)**			
°C (°F)	pH 0.5 (3)	pH 1	pH 2	pH 4
43 (110)	0.0000	0.0000	0.0000	0.0000
49 (120)	0.0000	0.0000	0.0000	0.0000
54 (130)	0.0000	0.0000	0.0000	0.0000
60 (140)	0.0000	0.0000	0.0000	0.0000
66 (150)	0.0186	0.0000	0.0000	0.0000
71 (160)	-	0.0234	0.0000	0.0000

(1) 30 day tests, procedures per ASTM G48-B
(2) Average of two tests
(3) pH adjusted with H_2SO_4

The effect of 1,000 ppm thiosulfate on corrosion in 10,000 ppm chloride is shown in Table 4. Corrosion is accelerated on the S31603 alloy at all pH levels by the thiosulfate addition. When pH was adjusted to 1.0 with H_2SO_4, all alloys including N08367 and N10276 materials were significantly affected. The addition of thiosulfate to control scaling in limestone FGD systems, thus, has potential for initiating or aggravating corrosion on stainless steels, and even N10276 alloy, under conditions of low pH or otherwise borderline passivity. These findings are in agreement with previous studies [25].

Crevice corrosion data for exposure to a severe acid-chloride solution, the "Green Death" solution, are given in Table 5. This test is commonly used to compare materials in reducing environments, such as that of the inlet duct of an absorber. Crevice corrosion is observed on S31603 and S31703 at room temperature. At 50°C (122°F) alloys with up to 4.4Mo are corroded. The N08367 (6.2Mo) alloy and higher Mo nickel-base materials resist attack. Further increase in temperature to 70°C (158°F) resulted in significant crevice corrosion on all alloys through the 9Mo N06625 alloy. The 16Mo N10276 alloy exhibited only superficial crevice corrosion.

The corrosion behavior of various alloys in a simulated FGD environment was evaluated by Agrawal, et. al. [11]. This study was later extended by Grubb, et. al., to include N08367 alloy [22]. The results of the study are shown in Tables 6 and 7. The initial study by Agrawal included an anonymous 6% Mo stainless steel, the results for which are included in the tables. The coupons were exposed in the presence of SO_2 to calcium chloride brines having chloride concentrations of 10,000, 20,000, 30,000, 50,000, and 100,000 ppm at temperatures of 55°C and 80°C. Most of the N08367 alloy coupons exhibited some staining but no significant etching or corrosion attack. The apparent corrosion rate was 0.1 mpy or less in coupons exposed at 55°C. At 80°C, a maximum apparent corrosion rate of 0.3 mpy was measured in the coupon that was exposed to 30,000 ppm chloride brine. Measured rates were 0.1 mpy or less in all of the other

N08367 coupons. Overall, the performance of the N08367 material was equivalent to that of the "generic" 6Mo alloy.

Table 4
Crevice Corrosion of Stainless Steel and Nickel Alloy(1) [22]
10,000 ppm Chloride and 1,000 ppm Thiosulfate 72 Hours at 66°C (150°F)

	Weight Loss, g/cm_2 [No. Crevice Sites Attacked] (2)			
Alloy	**pH 1 (3)**	**pH 2**	**pH 4.5**	**pH 6.5**
	10,000 ppm Chloride (as NaCl)			
S31603	0.0000[29]	0.0000[13]	0.0000[11]	0.0000[10]
S31725	0.0000**	0.0000[10]	0.0000[2]	0.0000[4]
S31726	0.0000**	0.0000[1]	0.0000[1]	0.0000[1]
N08367	0.0000[19]	0.0000[0]	0.0000[0]	0.0000[0]
N10276	0.0000[0]	0.0000[0]	0.0000[0]	0.0000[0]
	10,000 PPM Chloride (as NaCl), 1,000 ppm Thiosulfate (as $Na_2S_2O_3$)			
S31603	0.0142[40]	0.0002[40]	0.0000[27]	0.0003[17]
S31725	0.0070**	0.0000[3]	0.0000[1]	0.0000[0]
S31726	0.0009[39]	0.0000[1]	0.0000[0]	0.0000[0]
N08367	0.0013[40]	0.0000[0]	0.0000[0]	0.0000[0]
N10276	0.0011[40]	0.0000[0]	0.0000[0]	0.0000[0]

(1) Crevice generated using Delrin™ serrated spacers tightened to 55-60 in-lbs.
(2) Weight loss is average of duplicate specimens. Numbers in brackets are the maximum number of crevice contact sites (out of 40 total) evidencing corrosion.
(3) Sulfuric acid used to adjust pH
** General corrosion observed

Table 5
Crevice Corrosion Testing in Simulated Scrubber Environment (Green Death)

	Weight Loss g/cm^2 (2)		
Alloy	**25°C (75°F)**	**50°C (122°F)**	**70°C (158°F)**
S31603	0.0006	0.0343	0.0390
S31703	0.0007	0.0377	0.5000
S31725	0.0000	0.0319	0.0462
S31726	0.0000	0.0129	0.0462
N08904	0.0000	0.0221	0.0419
N08367	0.0000	0.0000	0.0266
N06625	0.0000	0.0000	0.0149
N10276	0.0000	0.0001	0.0004

(1) 7 Vol. % H_2SO_4, 3 Vol. % HCl, 1 Wt. % $CuCl_2$, 1 Wt. % $FeCl_3$
(2) Tests per ASTM G48-B procedures, 72 hour duration

Table 6
Results of Visual evaluation of the unwelded coupons after descaling.

	Attack Index – Front/Back				
Alloy	**1% °C**	**2% Cl⁻**	**3% Cl⁻**	**5% Cl⁻**	**10% Cl⁻**
	Temperature = 55°C				
S31603	3/3	3/3	3/3	3/3	3/3
S31726	1/ 2	0/2	1/1	0/1	3/3
S31803	0/0	0/1	0/1	0/1	0/1
6% Mo Alloy	0/0	0/1	0/1	0/1	0/1
N08367	0/1	0/1	0/1	0/1	1/ 2
N10276	1/1	1/1	1/1	1/1	1/1
	Temperature = 80°C				
S31603	3/3	3/3	3/3	3/3	3/3
S31726	3/3	2/3	2/3	1/ 2	1/ 2
S31803	2/2	2/2	2/2	1/1	1/ 2
6% Mo Alloy	0/0	0/1	0/1	0/1	0/2
N08367	0/1	0/1	1/ 2	0/1	0/2
N10276	1/1	1/1	1/1	1/1	1/1

Attack Index: no attack = 0, tarnish or light attack = 1
Moderate attack = 2, and severe attack = 3

Table 7
Apparent corrosion rate of unwelded alloys
in simulated SO_2 absorber environments.

	Appanrent Corrosion Rate, mpy				
Alloy	**1% Cl⁻**	**2% Cl⁻**	**3% Cl⁻**	**5% Cl⁻**	**10% Cl⁻**
	Temperature = 55°C				
S31603	4.1	3.9	5.4	7.3	5.3
S31726	0.2	0.1	0.1	0.1	1.3
S31803	0.2	0.2	0.1	0.0	0.1
6% Mo Alloy	0.0	0.0	0.0	0.0	0.0
N08367	0.0	0.0	0.0	0.0	0.1
N10276	0.1	0.2	0.1	0.1	0.1
	Temperature = 80°C				
S31603	5.8	4.2	2.7	3.2	3.8
S31726	1.7	1.0	0.5	0.4	0.2
S31803	2.1	1.3	1.1	1.3	0.4
6% Mo Alloy	0.0	0.1	0.0	0.0	1.1
N08367	0.1	0.0	0.3	0.0	0.0
N10276	0.4	0.6	0.4	0.5	0.3

Testing has also been performed under actual service conditions at various locations [21]. Field testing data was presented in 2000 [21] an excerpt of which is recapped in this presentation. Again, a "generic" 6 Mo sample was used in the testing. The testing above indicates that N08367 alloy is expected to perform similarly.

The most severe test conditions were found at the Orlando Utilities – Stanton Energy Plant. Various samples were exposed for 270 days. The slurry average chloride content was ~70,000 ppm, the pH was 5.6, and the temperature was ~130°F (54°C). Figure 4 shows the alloy samples after testing. Note the 6 Mo and N10276 displayed very good corrosion resistance. Crevice corrosion on a S31603 specimen was severe. Localized attack incurred by the S31726 stainless steel was considerably less than that suffered by S31603 stainless steel, but nevertheless still quite severe. One of the duplex stainless steel specimens exhibited under-scale type etching. The results demonstrate the superior resistance of the 6Mo stainless steels to the FGD environment compared to the lower alloyed stainless steels.

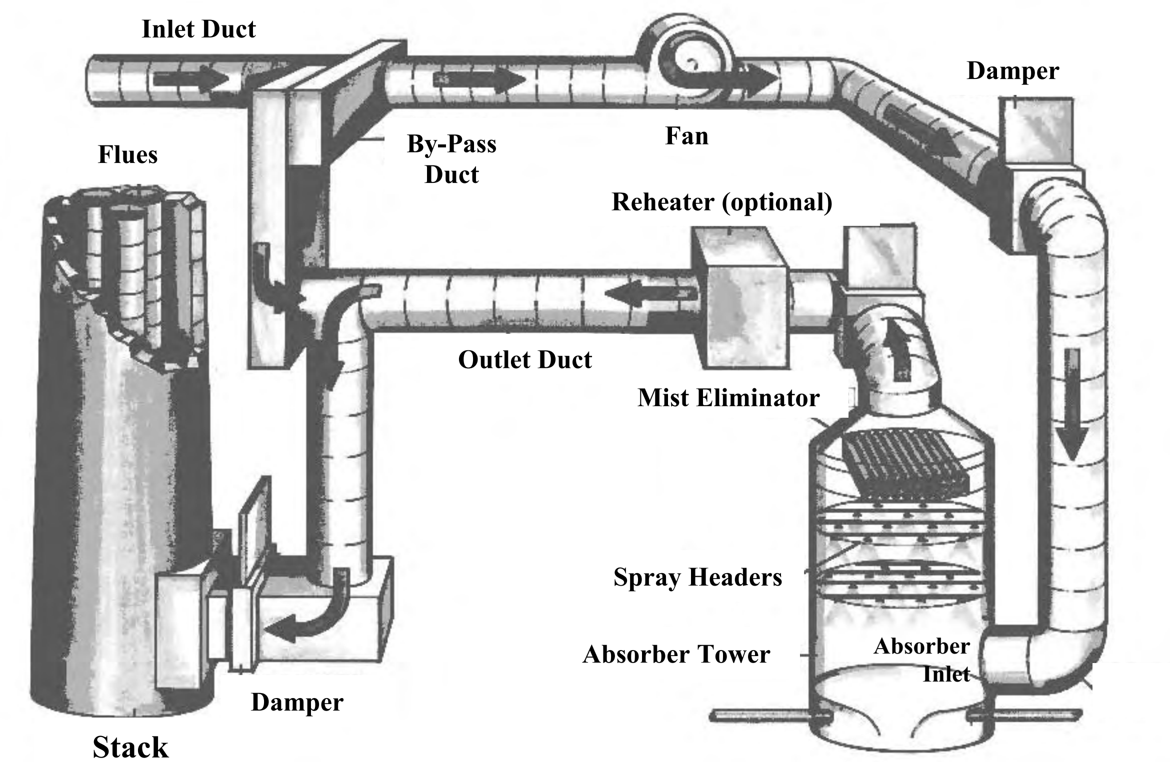


Figure 1: Schematic of an FGD system.

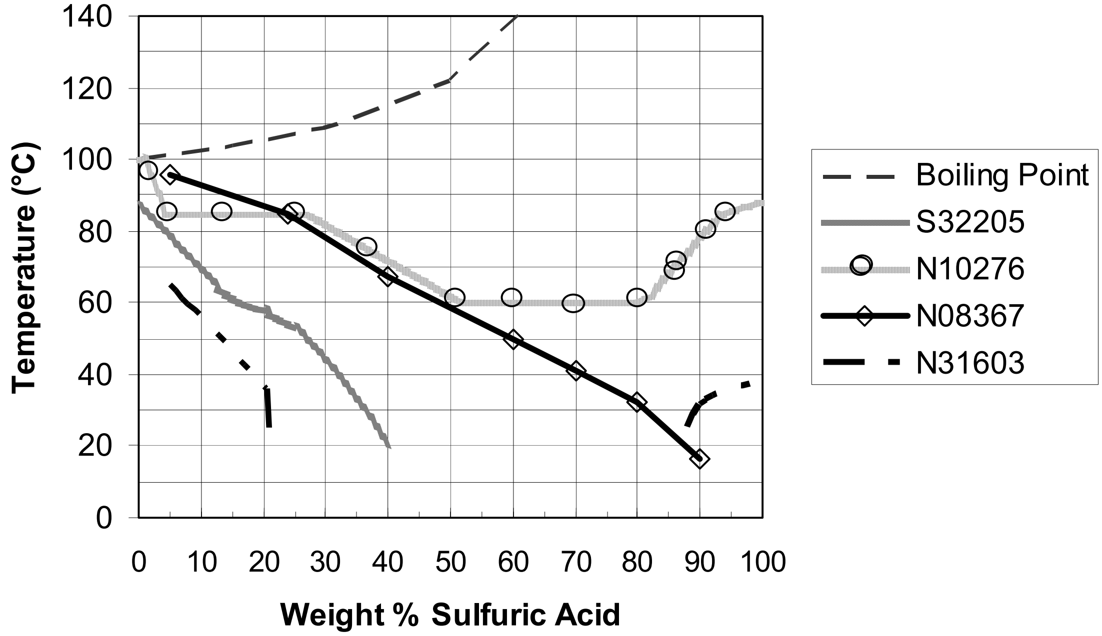


Figure 2: Corrosion of alloys in sulfuric acid. Lines indicate a corrosion rate of 0.1mm/yr (0.004 in/yr)

<table>
<tr><th></th><th></th><th>Mild</th><th colspan="2">Moderate</th><th colspan="2">Severe</th><th colspan="3">Very Severe</th></tr>
<tr><td></td><td>Cl - ppm</td><td>500</td><td>1,000</td><td>5,000</td><td>10,000</td><td>30,000</td><td>50,000</td><td>100,000</td><td>200,000</td></tr>
<tr><td>Mild</td><td>pH 6.5</td><td rowspan="2">S31603</td><td></td><td colspan="2">S31726
N08904</td><td rowspan="3">S32760
S32550</td><td rowspan="3">N08367</td><td colspan="2" rowspan="4">N10276</td></tr>
<tr><td>Moderate</td><td>pH 4.5</td><td></td><td></td><td></td></tr>
<tr><td>Severe</td><td>pH 2.0</td><td>S31726</td><td colspan="2">S32205</td><td></td></tr>
<tr><td>Very Severe</td><td>pH 1.0</td><td>S31726
N08904</td><td colspan="3">N08367</td><td></td><td></td></tr>
</table>

Figure 3: Alloy selection chart for FGD absorber towers.

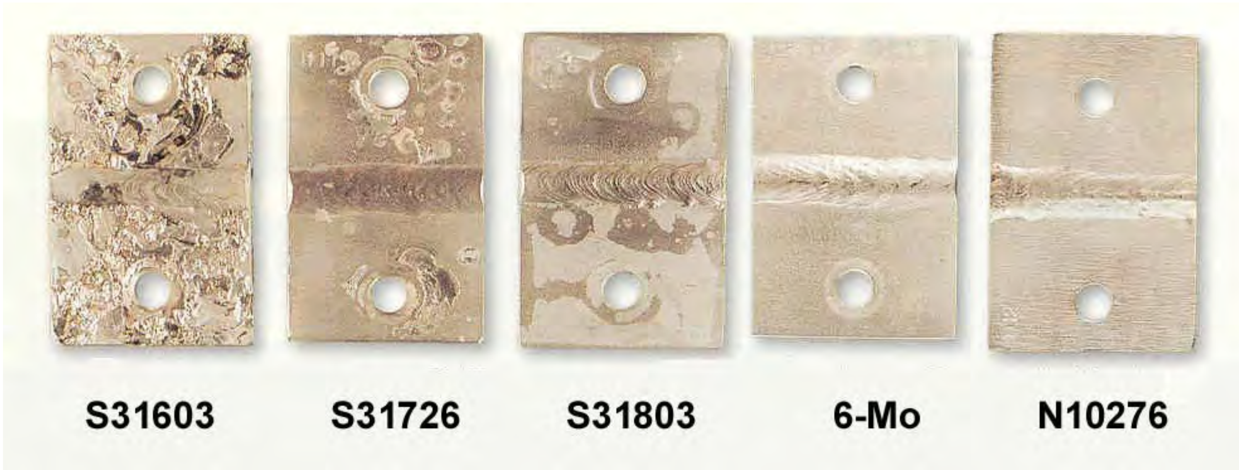


Figure 4: Results of exposure to ~70,000 ppm chlorides, at a pH of 5.6 and a temperature of ~130°F (54°C) for 270 days. Expose to slurry at Orlando Utilities' Stanton Energy Center in Florida.

N08367 ALLOY FGD SYSTEM & POWER PLANT APPLICATIONS

The following section gives several examples of the application of N08367 in actual pollution control applications.

Northern Indiana Public Service Company (NIPSCO) – Baily Generating Station Units #7 & 8. This station uses 2 to 4.5% sulfur bituminous coal. Pure Air on the Lake manages this FGD system. N08367 alloy has been used in several applications in this system. The successful performance of N08367 alloy in earlier applications has led to its utilization in other areas. Estimated conditions of the absorber are ~11,000 ppm chlorides, pH of 6, and 107°C (125°F).

- Original construction consisting of N08367 alloy recirculation piping, spray piping system, and rotary sparger unit (submerged in the limestone scrubber tank) have been in service for over 12 years. See Figures 5 & 6.
- In 1997, N08367 alloy was fabricated into top hats to protect flanged connections in rubber lined steel pipe for slurry pipe headers and the spray piping systems. Top hats were also installed in other areas in more recent times. See Figure 7.
- In 2003, N08367 alloy box beams replaced rubber coated carbon steel beams. These beams, located in the absorber tower, support a 28,000 piece grid packing system. See Figures 8 and 9.

Figure 5: N08367 Alloy Rotary Sparger

Figure 6: N08367 Alloy Spray Piping

Figure 7: N08367 Alloy Top Hats

Figures 8 and 9: N08367 Alloy Box Beams replaced rubber coated steel beams (right).

Louisville Gas & Electric (LG&E) – Cane Run Station Units #5 & 6
This station burns 3.5% sulfur coal. N08367 has been used in several applications in this system. The estimated chloride levels in the Unit #6 absorbers are ~5500 ppm. Unit #5 absorber is ~800ppm.

- In 1990, N08367 alloy replaced S31726 lining in two FGD downcomer ducts. See Figure 9. The S31726 liner failed in less than 3 years due to perforation from pitting. 14ga and 16ga sheet was used to wallpaper the duct. The N08367 alloy is still in service after 12 years.
- In 1999, N08367 alloy replaced a 16" coated carbon steel pipe for the pump suction system used to recirculate the scrubber liquor that quenches the flue gas in the absorber tower.
- The carbon steel supporting beams that support the absorber trays were wallpapered with N08367 alloy.
- In 2003, N08367 alloy was fabricated into liquid distribution rings in the absorber tower. These were installed to protect the absorber tower walls.

Figure 10: LG&E Cane Run #6 Absorber Tower and Downcomer

Korea Electric Power Company (KEPCO) – Taean Units 1-4, Hadong Units 1-6.
A total of 10 absorbers were installed for KEPCO, with start-up of eight units in 1998 and two in 1999. No problems have been reported since the installation. Each of the 10 wet limestone absorber towers was 16.8m (55 ft.) in diameter and serviced a 500MW boiler. N08367 alloy was used for absorber tower plates, internals including stiffeners and structurals, piping systems, and the absorber trays. Inlet SO_2 concentration was 645 ppm and chloride levels were ~20,000 ppm maximum. The N08367 alloy for this project was produced to a minimum PRE_N of 47.5 in order to meet the demanding requirements for corrosion resistance. One of the absorber towers may be seen in Figure 11.

Figure 11: Absorber tower at KEPCO Hadong power station.

Santee Cooper - Winyah Station
N08367 alloy plate was used for the absorber tower. Design chloride levels are 20,000 ppm with excursions to 30,000 ppm. Start-up will occur in 2007.

Figure 12: Absorber tower at Santee Cooper Winyah Station.

Indianapolis Power & Light (IP&L) – Petersburg Station
N08367 alloy was used for the wallpapering of a carbon steel duct connecting the electrostatic precipitator to the flue stack. Lower than expected temperatures led to condensation in the bottom of the 12 foot (3.7m) wide duct. The duct was approximately 150 feet (45.7m) long. 35,000 pounds (15,909 kg)of 14ga N08367 alloy sheet were supplied to wallpaper the bottom of the duct to protect against corrosion by the condensate which would include sulfurous acid and chlorides. Gas estimates through the duct were 33 lbs/hour of Cl^- and 29 lbs/hr of SO_2. The lining and duct are shown in Figure 13.

After 5 years in service the duct was removed from service with no reported problems. Reason for removal was the installation of the of a wet FGD system. Due to the success of N08367 in this application, it was selected for portions of the absorber tower contacted after the quench section.

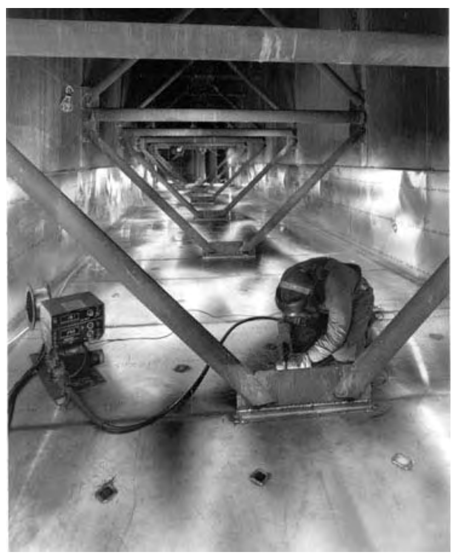


Figure 13: IP&L Flue Gas Duct with N08367 Alloy Lining

Central Illinois Public Service Company (CIPS) – Newton Power Station
N08367 alloy was fabricated into a turning vane for a flue gas stack. The turning vane was installed to address an undesirable cyclone effect at the base of the flue gas stack. Excellent resistance to pitting and crevice attack was demonstrated by the N08367 alloy, necessary for this plant which burns high sulfur coal. The N08367 alloy was chosen based on corrosion testing. The scrubber was decommissioned in 1994, but CIPS reported that the N08367 performed well in resisting corrosion over several years of service. The vane can be seen in Figure 14.

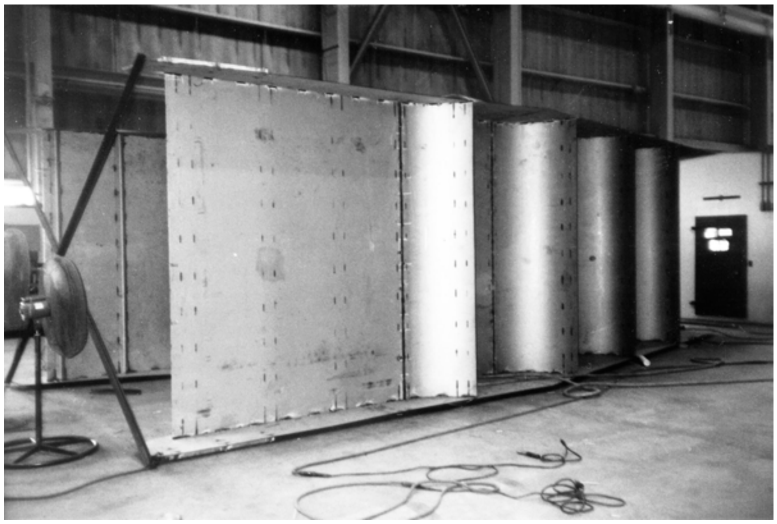


Figure 14: CIPS Turning Vane

Cinergy Corporation – Zimmer Station
N08367 alloy 14ga sheet was chosen to line six bypass ducts for each of the absorber modules. The carbon steel bypass ducts were corroding due to the condensation of acid. Installation was performed in early 2004. A photo of the duct may be seen below.

Figure 15

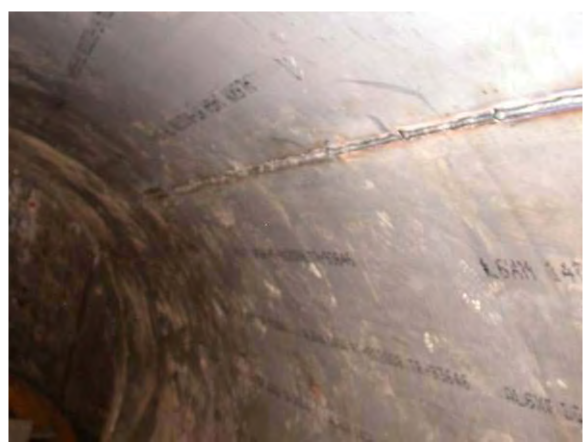


Figure 16

Electric Power Heat Exchangers & Condensers

Tubes and tubesheets of N08367 alloy are in use in direct flue gas reheaters. The N08367 U-tubes carry steam to reheat cold, wet scrubber flue gas before it reaches the exhaust stack. Three stacked heater bundles are shown in Figure 17. The frame and baffles for these modules are fabricated of the S31725 alloy. The N08367 tubes and tubesheet replaced N08825 alloy components which had previously been used and failed. Corrosion test data, which illustrated the N08367 alloy provides a substantial improvement in resistance to acid chloride environments, were used as an aid in selection. The N08367 alloy was a cost-effective alternative to the high-Mo nickel-based alloys.

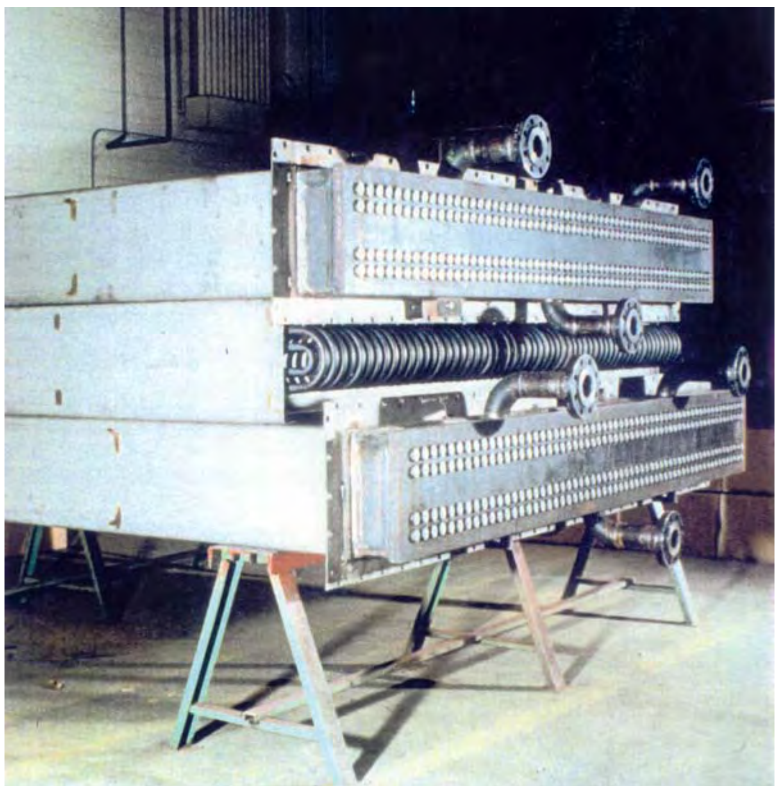
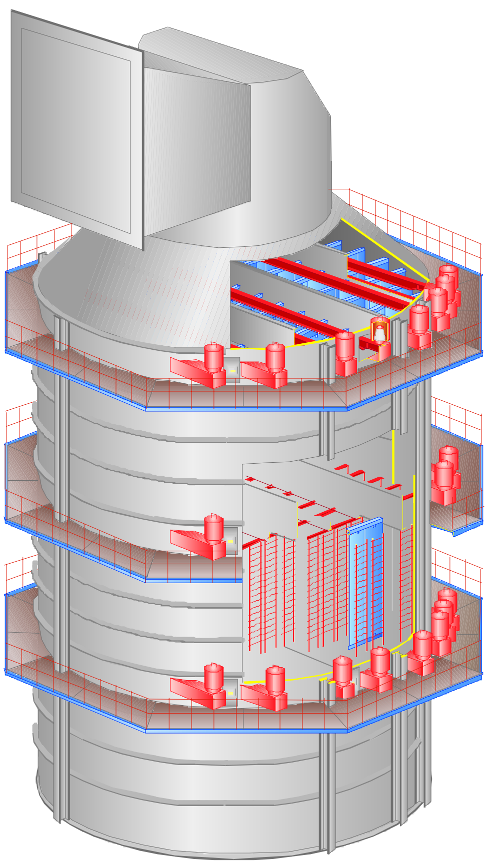
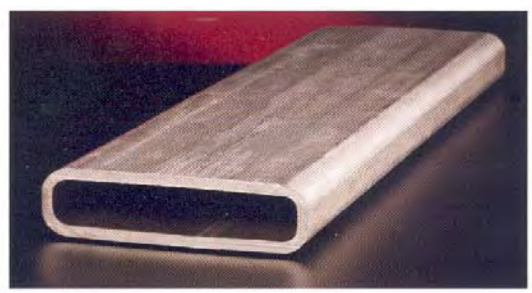


Figure 17: Stacked Heater Bundles

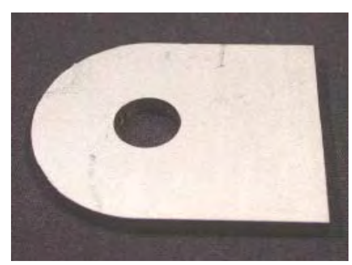
New Brunswick Power – Coleson Cove Power Plant

Over 14,000 feet (4267m) of N08367 box beams were furnished for use in a wet electrostatic precipitator (WESP). These beams were drawn to an overall size of 1.0" x 6.0" x 0.120" (25.4mm x 152mm x 3.2mm) average wall for the application. Over 300,000 lbs (136,364 kg) of N08367 alloy sheet was also supplied for use as collector plates, which were hung from the box beams. Over 42,000 lugs were also fabricated from plate. The box beams and lugs may be seen in the Figure below. The collector plates can be seen in the cut outs of Figure 18.





N08367 Box Beams



N08367 Lugs

Figure 18: Schematic of WESP at New Brunswick Power - Coleson Cove. Box beams and lugs may be seen on the right.

SBS Injection Lances
SBS Injection^{TM} is commercially proven technology to treat SO_3 aerosol emissions or "blue plume". When high-sulfur fuels are combusted, some of the sulfur is converted to SO_3 in the stack gases. Use of selective catalytic reduction (SCR) technology to reduce nitrogen oxide emissions at power plants causes additional sulfur to be converted to SO_3. Reaction of the gaseous SO_3 with water vapor from the flue gas, a wet scrubber, or the atmosphere, results in the generation of sulfuric acid mist, which contributes to the blue acid plume emitted from many power plants.

Sodium bisulfite, sodium sulfite, or sodium carbonate is injected via injection lances and atomizing nozzles into the flue duct to react with the SO_3 to form primarily sodium sulfate. N08367 has been used for elliptical shaped shrouds that both protect the injection lance spray piping and also provide a more aerodynamic profile to minimize the disruption of the flue gas flow. The most recent installation using N08367 shrouds was at Duke Energy Gibson Generating Station, but 10 plants currently have N08367 shrouds operating going back to the fall of 2003. The N08367 shrouds have held up well where the lances have been installed in ductwork after the SCR unit and prior to the air heater. Shrouds in installations made downstream of the air heater have in some instances experienced ash build up and the formation of concentrated of sulfuric acid. Under these severe conditions corrosion has occurred on some lances. Modifications to the lances have been made to reduce deposits and provide a more corrosion resistant material [26].

Figure 19: N80367 SBS Injection^{TM} Lances.

Northern Indiana Public Service Company (NIPSCO) – Schahfer Station
N08367 alloy ¼" (6.35mm) plate was chosen to replace type 317LM for internals such as liquid distribution rings, shown in Figure 20, beginning in the spring of 2003 in the four towers used to scrub the number 18 boiler. Operating conditions in the absorber are reported to be 1400-1500ppm chlorides, pH 5, 65°C – 71°C (150-160°F).

Figure 20: N80367 liquid distribution rings at NIPSCO Schahfer Station.

Hoosier Energy – Sullivan Plant
N08367 alloy 11ga sheet was chosen to line the top portion of the absorber module. N08367 alloy was chosen after coupon testing. The original tower was flake glass lined. The move to an alloy lining was based on the desire to decrease the amount of maintenance and repair on the unit. Operating conditions in the absorber are reported to be 5000 ppm chlorides, pH 5 to 6, 53°C (127°F). The first tower was relined in the spring of 2004. Since then a total of four towers have been relined with N08367 with two additional towers (2B and 2C) to be relined in the spring of 2007.

SUMMARY

N08367 alloy is currently being successfully used for many applications in FGD/WESP systems. These include absorber bodies, ducting, mixers, spargers, spray piping, turning vanes, dampers, wallpaper lining, reheaters, spray absorbers, collector plates, and structural supports. The alloy has been employed for over 20 years and has demonstrated excellent performance.

N08367 alloy is shown to be a cost effective material of construction to fill the gap between the 4Mo austenitic stainless steels and higher Mo nickel-based alloys. This material is available in a wide variety of product forms (plate, sheet, strip, bar, tube, pipe, fittings, flanges, etc.) needed to meet the requirements of all FGD and WESP system components.

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