Advances in NOx removal in smelter acid plants

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Increasing NOx levels in smelter gases have become a serious issue for acid plant operators leading to problems with both stack emissions and product acid quality. A further complication which results from high NOx levels is the difficulty of safely carrying out maintenance work on plant equipment containing NOx rich acid residues.

This paper discusses the chemistry of NOx formation and its subsequent distribution through the acid plant. This is followed by a review of the methods which have historically been applied to combat the impact of NOx on acid plant operation and a new approach which targets gas phase NOx destruction within the acid plant in order to eliminate all the problems associated with high NOx levels.

This technology, which involves the selective catalytic reduction of NOx prior to the acid plant converter, is described and 2 years of successful operation of this system at a European plant are reviewed.
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Introduction

This paper amalgamates the parts of the 1998 paper Effluents, Emissions and Product Quality (1) and the 2000 paper Budel Zink Sets a New Standard for NOx Reduction in an Acid Plant (2) which deal with the general aspects of NOx formation and treatment as related to an acid plant. Additional information is included as it relates to further projects and experience in the time since the original papers were presented.

NOx is the generic term used to refer to oxides of nitrogen. The common oxides of nitrogen present at the temperatures, pressures and concentrations encountered in an acid plant are NO and NO₂. The oxides of nitrogen are pollutants, and local jurisdictions regulate allowable NOx emissions levels in stack gases.

NO₂ in particular can cause a visible brown colour in stack gases if the concentration is high enough. As a useful rule of thumb, the brown colour will be visible in a stack if the NO₂ concentration in ppm is greater than 2400 divided by the stack diameter in inches (3). Therefore, for example, 25 ppm of NO₂ will just be visible in an 8-foot diameter stack (corresponding to 50 ppm NOx at a 1:1 ratio of NO:NO₂). A point of concern is that as the volumetric capacity of acid plants increase, the visible limit of NOx in the stack gas will decrease. The 8-foot stack diameter is equivalent to an acid tonnage of 1600 mtpd with a 50 ppm visibility limit while a 12 ft diameter stack relating to an acid capacity of 3500 mtpd has a visibility limit of only 32 ppm.

The maximum permitted concentration of NOx in the product acid is being reduced through marketing pressures. While concentrations of up to 30 ppm have been acceptable in the past, more recent specifications levels have been for not more than 5 ppm of NOx expressed as NO₃.

Another concern for NOx emissions is the acid sulphate sludge which is formed throughout the acid plant as a by-product of the reaction between acid mist and carbon steel. This sludge is manually cleaned from equipment during the scheduled maintenance shutdown. Unfortunately this acid sludge also absorbs NOx which is then emitted as brown fumes when the sludge comes in contact with humid atmospheric air. The TLC requirement for NO₂ is less than 3 ppm in many jurisdictions which requires complete personnel protection, self contained breathing apparatus, and mobile NOx scrubbers.
NOx formation

The NOx that occurs in an acid plant can be formed through a number of mechanisms in the upstream operations such as:

- Furnace Temperature - Thermal NOx,
- Oxygen Usage - Thermal NOx,
- Fuel Type and Usage - Fuel Bound NOx,
- Feed Type - Feed Bound NOx,

Furnace Temperature - Thermal NOx: The formation of thermal NOx occurs through the reaction of nitrogen and oxygen according to the reaction [1] below at temperatures above 1000o C.

\[
2\text{N} + \text{O}_2 = 2\text{NO} \quad \text{[1]}
\]

The rate of NOx generation is a function of temperature and oxygen concentration; consequently metallurgical plants potentially may receive more NOx in the feed gas as the primary smelting units generally operate at higher temperatures than Sulphur Furnaces.

Oxygen Usage - Thermal NOx: The increased use of oxygen enrichment in smelters and acid regeneration plants tends to increase the quantity of NOx formed due to the effect of higher temperatures and higher oxygen concentration (4). Using oxygen enrichment the NOx content peaks in the 35% to 50% (vol.) oxygen range. Beyond this level, the quantity of nitrogen present and available to form thermal NOx decreases.

Fuel Type and Usage - Fuel Bound NOx: Organic bound nitrogen present in some fuels, particularly coal and heavy fuel oils, is readily converted to NOx in the combustion process. This conversion is difficult to prevent when using coal or heavy fuel oil.

Feed Type - Feed Bound NOx: Some feeds to furnaces and smelters contain organic nitrogen compounds. For instance Methyl Methacrylate Spent Acid consists of almost 35% of ammonium sulphate and some concentrates, particularly Zinc concentrates, contain significant quantities of organic nitrogen compounds. While the operating conditions in an Acid Regeneration Furnace can be adjusted to minimise the production of NOx, the operation of the Smelter/Roaster is controlled more by metallurgical considerations. However the formation of NOx in the off-gas is ensured in either case.

NOx is formed by reactions of oxygen with nitrogen from any of the above sources in two equilibrium steps:

\[
2\text{N} + \text{O}_2 = 2\text{NO} \quad \text{[1]}
\]
\[
2\text{NO} + \text{O}_2 = 2\text{NO}_2 \quad \text{[2]}
\]
Temperatures above about 1000 ºC, such as in a smelter or a furnace, result in the formation of NO only by reaction [1]. The quantity of NO formed increases with increasing temperature. NO is a Henry's law gas with a very low boiling point and it cannot be captured in the gas cleaning system of an acid plant. As gas containing NO is cooled, NO₂ begins to form by reaction [2]. However, the NO oxidation equilibrium reaction is slow at gas cleaning system pressure, temperature and oxygen concentration, and relatively little NO₂ will be formed before the gas enters the contact section. It has previously been reported (5) that a small amount of NO₂ in the gas used to produce liquid SO₂ from a metallurgical acid plant caused high acidity in the final SO₂ product, due to a catalytic reaction with moisture to form H₂SO₄.

**NOx distribution in the acid plant contact section**

Although the NOx is present mainly as NO when the gas enters the contact section, the converter is loaded with V₂O₅ oxidation catalyst, so the NO is oxidised to approach the equilibrium level of NO₂. At the converter exit temperature, approximately 50% of the NOx will be present as NO₂. Data from NOx surveys in acid plants indicates that between 30 and 85% of the total NOx contained in the gas leaves the plant with the stack gas. The balance is absorbed into the acid in the Inter and Final candles or towers, and leaves the plant with the candle drips (if they are segregated), or with the product acid. It should be noted that the NOx distribution is not constant with inlet NOx concentration. At low levels of NOx, a lower proportion of the NOx reports to the product acid. Typical NOx distributions of plants with 10 and 150 ppm NOx in the inlet gas are given in Figure 1 and Figure 2, respectively.

Of the NOx absorbed by acid, typically less than 10% enters the large flow of acid circulating around the acid towers. Instead it concentrates in the much smaller quantity of acid mist formed at the inlet to the absorber towers. It has been suggested that the presence of NOx actually promotes the formation of quantities of acid mist (6), perhaps by reactions between NOx and SO₃ that form particles that act as nucleation sites for the acid mist. There are several reactions involved, but the net result can be summarised as:

\[
\text{NO}_2 + \text{NO} + 2 \text{H}_2\text{SO}_4 = 2 \text{HNOSO}_4 + \text{H}_2\text{O} \quad [3]
\]

Although the nitrogen acid compound physically present in concentrated sulphuric acid is actually nitrosylsulfuric acid (HNOSO₄), the analytical procedure for NOx in acid often reports NOx present as equivalent nitrous acid (HNO₂) or nitrate (NO₃⁻).

The result is a concentrated nitrosylsulfuric acid solution, which is collected in the absorber tower candles. The concentration of nitrosylsulfuric acid in the candles can be quite significant.
HNOSO₄ concentrations in the range 5% to 20% are common, and in extreme cases the HNOSO₄ concentration may reach 40%.

Figure 1: NOx distribution with low inlet NOx

Figure 2: NOx distribution with high inlet NOx (with candle segregation)
Note that reaction [3] is a reversible reaction. The HNOSO$_4$ will be hydrolysed on contact with water, for example when candle drips are diluted, to release NOx fumes that are noticeably brown due to the presence of NO$_2$. The hydrolysis is essentially complete when the H$_2$SO$_4$ / H$_2$O solution falls below about 60% (7). Below this strength little or no HNOSO$_4$ can exist in the acid. Great care must be taken in analysis of acid samples for NOx, because dilution of the sample with water will release the NOx.

Hydrolysis can also be a problem when the acid towers are opened during a shutdown and the acid in the candles comes into contact with moist air. A natural draft of ambient air via open manways through the candles can result in a visible brown plume that persists for days, even when the plant is shutdown! When the source of the NOx is a regeneration furnace, it may be possible to reduce the NOx content of the candles prior to a planned shutdown by reducing the furnace operating temperature for a few days.

There are many qualitative reports that high levels of NOx are associated with visible acid mist plumes from stacks, from both regeneration and metallurgical acid plants. Reports are common from single absorption plants, and less common from double absorption plants. In single absorption plants, persistent plumes occur at relatively low NOx levels, while in double absorption cases, the stack plumes seem to occur at significantly higher NOx levels.

In reaction [3], H$_2$O is produced along with HNOSO$_4$. It would be expected that if only this reaction occurred, there would be water present in the candle drips. However, a second reaction has been reported in other systems, such as the lead chamber process that was historically used to manufacture sulphuric acid (8):

$$\text{SO}_2 + 2 \text{HNOSO}_4 + 2 \text{H}_2\text{O} \rightarrow 3 \text{H}_2\text{SO}_4 + 2 \text{NO} \quad [4]$$

Reaction [4] consumes water and will effectively produce candle drips containing close to 100% H$_2$SO$_4$ with dissolved HNOSO$_4$. The reaction will stop as soon as the available water is consumed. Particularly in single absorption plants, there is a considerable stoichiometric excess of SO$_2$ present to consume the water that would be present in the candle drips.

The resulting highly concentrated acid in the candles will have a high partial pressure of SO$_3$ and therefore will be ineffective at removing mist from the gas. In this case, any unabsorbed vapour or mist leaving the packing of the tower and entering the candles will form the usual visible white acid mist plume. If the candles are standing, it may be possible to irrigate them from below with fresh acid from the absorber circuit to keep the SO$_3$ vapour pressure low and eliminate any plume.
Control of NOx in acid plants

A typical specification for NOx in commercial grade acid is 5 ppmw oxides of nitrogen as nitrates (equivalent to 10 ppm HNOSO$_4$). This, depending on the plant design, would limit the concentration of NOx in the feed gas to between 5 to 15 ppmv in order to produce a product acid that would require no additional treatment.

Primary NOx reduction

As previously noted, approximately only 10% of the NOx captured in the liquid is absorbed directly into the circulating acid. The remaining approximately 90% of the NOx reporting to the liquid is captured in the acid mist droplets formed at the inlet to the Absorption Towers. These mist droplets are subsequently captured in the mist eliminators located in the top of the towers and drained back to the bulk of the acid.

Absorption Towers that are fitted with candle type mist eliminators have an effective method for trapping and diverting these mist droplets containing the absorbed NOx.

Standing candles can be easily converted to segregate the drips by manifolding together the existing candle tube sheet drains and routing to outside the tower.

For hanging candles the individual drain legs must be manifolded together to collect the drips, and even then a significant portion of the acid can drain outside the candles and not be collected.

The candle drips that are segregated from the acid circuit are disposed of separately, to avoid contaminating the product acid.

Candle drip treatment

The simplest approach for treating the candle drips is to simply dilute and sewer or neutralise the candle drips. However this creates an acid yield loss and an additional effluent from the acid plant. Also care must be taken when diluting. The rapid hydrolysis and heat of dilution when the candle drips come into contact with water will result in the release of copious brown NOx fumes. In most cases it will be necessary to use a scrubber to avoid the release of NOx.
There are several techniques for treating the drips to remove the NOx content and return the sulphuric acid value into the acid circuit. One method (9) that has been used by Kvaerner Chemetics in two metallurgical acid plants takes advantage of the hydrolysis and heat of dilution to remove the NOx from the drips in a controlled fashion. The candle drips flow by gravity to a PTFE lined packed column, where they are mixed with water to dilute the acid below 60% H₂SO₄. The HNOSO₄ is completely hydrolysed, and the released NOx is vented from the top of the column. The nitrate free candle drips gravity drain into the acid pump tank. The overhead NOx fumes can be absorbed into water in a stainless steel packed absorber column to form a weak HNO₃ effluent solution. The process consumes no reagents or power since the acid flows by gravity. The equipment is simple, reliable, and small (a 12 packed column will treat the candle drips from a 2000 stpd acid plant).

Another method (10) involves the creation of a solution of SO₂ in weak sulphuric acid, by passing some of the process gas leaving the blower through a dilute sulphuric acid solution. The candle drips are then mixed with the SO₂ solution, and the NOx is reduced to nitrogen by reaction with the SO₂ in the liquid. The reduction reaction leaves no NOx or HNO₃ by-product for disposal.

**Product acid treatment**

Even if the candle drips can be segregated, unless the NOx content is below 15 ppmv, the acid plant product will not meet a NOx specification of less than 5 ppm. In this case the acid product must be chemically treated to reduce the NOx. Reduction can be accomplished by adding one of the reducing agents in the series (in order of decreasing cost and decreasing efficiency):

<table>
<thead>
<tr>
<th>Reducing Agent</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydracine</td>
<td>N₂H₂</td>
</tr>
<tr>
<td>Hydroxylamine</td>
<td>HONH₂</td>
</tr>
<tr>
<td>Hydroxylamine Sulphate</td>
<td>(HONH₂)₂·H₂SO₄</td>
</tr>
<tr>
<td>Sulphamic Acid</td>
<td>H₂N·SO₃H</td>
</tr>
<tr>
<td>Urea</td>
<td>H₂N·CO₂·NH₂</td>
</tr>
</tbody>
</table>

These reagents all have in common the amine group (-NH₂), and theoretically react to reduce NOx dissolved acid by a reaction such as:

\[
4 \text{HNOSO}_4 + 3 \text{N}_2\text{H}_4 = 5 \text{N}_2 + 4 \text{H}_2\text{SO}_4 + 4 \text{H}_2\text{O}\]  \[5\]

In practice, only hydrazine and to some extent hydroxylamine are effective at the conditions of temperature and residence time typically available in an acid plant. Pure sulphamic acid or urea...
will reduce the NOx only in weaker acid solutions, and by-product \((\text{NH}_3)_2\text{SO}_4\) may contaminate the treated product. The reducing agent must be added in excess to achieve adequate destruction of NOx, and post treatment with \(\text{H}_2\text{O}_2\) to destroy the excess reductant is then required. The cost of the reagent chemicals can be substantial. For instance if hydrazine is used as a reducer, and the NOx level in the acid is high, the cost may be as high as $2.00 per ton of product acid. Also the pure hydrazine is toxic, although the hydroxylamine or hydroxylamine sulphate are less toxic and easier to handle. Therefore, depending on local regulations, the cost of installing an engineered hydrazine storage and delivery system may be significant. In addition, when hydrazine is used it is extremely important to ensure that no excess hydrazine remains in the product acid. Often secondary hydrogen peroxide addition is employed to ensure destruction of any residual hydrazine. This further increases treatment costs.

**NOx destruction in the gas phase**

Many techniques are known for destroying NOx in gases. Most are inefficient and/or expensive, both in capital and operating cost. Only a few will be discussed here:

- Absorption in scrubbing solutions
- Selective non-catalytic reduction (SNCR)
- Selective catalytic reduction (SCR)

**Absorption in scrubbing solutions**

Acid plant tail gases are sometimes scrubbed to remove \(\text{SO}_2\) with alkaline solutions, such as in ammonia scrubbers or lime scrubbers. Alkaline scrubbing solutions are also known to absorb NOx in tail gases. However at the relatively low NOx levels present in typical acid plant stacks, the NOx is insoluble in the alkaline scrubbing solution and the NOx removal efficiency will be close to zero.

Hydrogen peroxide can also be used for tail gas scrubbing of \(\text{SO}_2\) and NOx with fairly high efficiency. However it will be most likely applicable in relatively concentrated NOx streams. The purchase cost of the \(\text{H}_2\text{O}_2\) will make this an expensive option. On an acid plant tail gas, the scrubber product would be a weak mixed \(\text{H}_2\text{SO}_4 / \text{HNO}_3\) solution, which would have to be disposed of or separated by steam stripping.

**Selective reduction**

The selective reduction reactions are performed using a reducing agent such as ammonia:
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6 NO + 4 NH₃ → 5 N₂ + 6 H₂O  \[6\]
6 NO₂ + 8 NH₃ → 7 N₂ + 12 H₂O  \[7\]

Any ammonia slip reacts with O₂:

4 NH₃ + 5 O₂ → 4 NO + 6 H₂O  \[8\]
4 NH₃ + 3 O₂ → 2 N₂ + 6 H₂O  \[9\]

Selective non-catalytic reduction

These reactions can occur at high temperature (above about 900 °C, i.e. at the conditions of the smelter or furnace outlet) without a catalyst (SNCR). SNCR is used to reduce NOx in power plant boiler gases. However in the typical hot smelter or furnace gas it is believed that the relatively high levels of dust and, of course, SO₂ will make the reaction largely ineffective.

Selective catalytic reduction

At more moderate temperatures (between 300 – 400 °C) a catalyst is used (SCR). Figure 3 shows a schematic diagram of the SCR DeNOx process. The process is generally the same whether applied to flue gases, exhaust gases, or to other off-gases. The main components of the SCR process consist of a reactor containing the catalyst and an ammonia storage and injection system. The ammonia can be in the form of liquid, water-free ammonia (under pressure), a 25% aqueous ammonia solution (at atmospheric pressure), or a urea solution.
The ammonia is evaporated in an electrically, steam, or hot water heated evaporator and is subsequently diluted with air before the mixture is injected into the process gas duct. The injection of the ammonia/air normally takes place through a system of nozzles in order to achieve a uniform mixing of the ammonia with the process gas. A static mixer may be placed in the gas duct to further improve mixing. This mixing is important so that the resulting gas-ammonia mixture has the uniform NH$_3$/NOx ratio required to ensure efficient removal of NOx and to minimise the NH$_3$ slip ("leakage") from the SCR reactor.

The normal operating temperature of the catalyst is between 300 °C and 425 °C but through the use of special catalysts the SCR process can be applied at temperatures down to 200 °C and up to 550 °C.

Based on reactions [8] and [9] above, any ammonia slip from the DeNOx operation results in reformation of NOx resulting in a reduction in DeNOx efficiency. Therefore, design of the ammonia injection system and catalyst bed is critical if high NOx reductions are required. SCRs have been successfully applied to treat gas streams in a number of industries including power and chemical plants. In fact, Selective Catalytic Reduction (SCR) of NOx by ammonia over vanadia/titania type catalyst is by far the most important commercial process today for removal of NOx. However, the process to date has had only limited application on a commercial scale in acid plants.
Application of SCR technology in a sulphuric acid plant

The application of SCR Technology in a Sulphuric Acid Plant requires in the first place a consideration for the location of the catalyst bed and the consequences of that location. Possible locations for the catalyst bed in order of ease of installation are:

- Before gas cleaning in the hot gas
- Before the stack
- After gas cleaning and before the dry tower
- In the dry gas section

Before gas cleaning in the hot gas

The gas at this point is hot and in the ideal temperature range for the operation of a SCR unit. Unfortunately, except in some special cases, the gas will contain significant quantities of dust and catalyst poisons such as arsenic, fluorides and chlorides that make this location unacceptable.

Before the stack

Another obvious location for the DeNOx catalyst is immediately prior to the acid plant stack, as the gas constituents at this location would be roughly similar to hundreds of other SCR applications. However, this location has some serious disadvantages:

- The NOx will be absorbed into the product acid in the acid plant, requiring an expensive chemical treatment, and potentially requiring the use of a hazardous reagent on site;
- NOx will build up in any residues throughout the plant as well as the acid plant candles, creating maintenance difficulties;
- If candle segregation is sufficient to maintain product acid quality (unlikely if high NOx is present), the candle draining must be disposed of safely, or treated by yet another system;
- The gas must be re-heated following the final absorption tower to a minimum of 200 °C, requiring auxiliary fuel firing in a double absorption plant, or several exchangers in a single absorption plant.

After gas cleaning and before the dry tower

This location avoids the first three disadvantages mentioned for the tail gas location above in so much as it occurs before the contact section. However the major disadvantage of having to heat the gas from near ambient temperature still exists. This heating requirement is further compounded by having to heat a wet SO$_2$ gas stream introducing extreme and probably insurmountable problems in materials of construction.
In the dry gas section

The location that eliminates these problems is in the dry gas section of the contact plant before the first catalyst bed. The benefits of this location are:

- The gas is hot and within the required temperature range.
- The NOx is destroyed before it encounters any acidic residues where it can be absorbed to create later problems during maintenance.
- The NOx is reduced to a level so that candle drip segregation is unlikely to be required and consequently eliminating the disposal or treatment problem.
- The NOx is reduced to a level so that product treatment is not required and eliminating the requirement to use potentially hazardous reagents.

Also, this location is virtually free of SO\(_3\), so there is minimal risk of a reaction of SO\(_3\) with ammonia resulting in the production of ammonia sulphate. This reaction would lead to fouling and equipment plugging as well as higher ammonia consumption. The DeNOx reaction results in a small increase in the moisture content of the gas stream. Any resultant dew point and mist considerations need to be, and are, addressed.

DeNOx catalyst

The SCR reactor usually consists of one or more layers of catalyst. The catalyst volume, and consequently the size of the reactor, depends on the NOx concentration, the desired degree of NOx reduction, the process gas pressure, the acceptable level of NH\(_3\) slip, and the dust content. One drawback of locating the DeNOx catalyst before the converter is the high level of SO\(_2\) in the gas stream. A major ingredient of the DeNOx catalyst is vanadium pentoxide, similar to conventional DeSOx catalyst. Therefore, the catalyst must be specially formulated to ensure that it has high activity for DeNOx operation.

SCR catalysts are normally based on a titanium dioxide (TiO\(_2\)) carrier, with combinations of oxides of vanadium, molybdenum, and tungsten, deposited on the carrier, as the active material.

The catalytic reaction is essentially a surface reaction. In order to maximise the activity the catalyst must provide a large external surface area and is therefore manufactured with a large number of parallel channels arranged in a honeycomb structure or in parallel plates. The size of the channels depends on the content of particulate matter (dust) in the gas and typically ranges from 3 mm (dust-free gas) up to 10 mm (dust contents of > 30 g/Nm\(^3\)). The catalysts are either available as extruded ceramic bodies, coated metal plates, or impregnated, corrugated ceramic fibres.
Topsøe DeNOx catalyst

Figure 4 shows the structure of Haldor Topsøe's DeNOx catalyst, which is based on a porous, fibre-reinforced titanium dioxide (TiO$_2$) carrier in a corrugated structure. The carrier is impregnated with metal oxides, most notably vanadium pentoxide (V$_2$O$_5$). The active material is homogeneously distributed across the surface.

![Figure 4 Topsøe's SCR DeNOx catalyst](image)

The catalyst is manufactured in monolithic blocks with 466mm × 466 mm cross section (18.3” × 18.3” ) and a height of 500 mm (19.7”), and is housed in a casing forming elements or cassettes. The elements are usually combined into modules, to facilitate handling and installation of the catalyst. The modules are tailored in size to varying design requirements. Due to the use of a fibre-reinforced type of carrier, the catalyst is very resistant to thermal shocks and erosion by particulate matter; however, the weight is considerably lower than traditional extruded or plate-type catalysts.

Incorporating the DeNOx bed in the acid plant

The DeNOx bed has been incorporated in two locations in the acid plant, after the cold exchanger and after the hot exchanger. With different operating temperatures, different DeNOx catalysts exhibiting different activities are employed in the different locations.

- Type 930 catalyst: This catalyst has the lowest operating temperature and the highest activity. It operates in the temperature range of 300 °C to 425 °C.
- Type 630 Catalyst: This catalyst operates in an intermediate temperature range and activity. The operating temperature range is 300 °C to 450 °C.
- Type 330 catalyst: This is the catalyst that can operate at the highest temperature and is most resistant to temperature excursions. It also exhibits the lowest activity. The operating temperature range is 400 °C to 500 °C.

The DeNOx catalyst, assembled into cassettes and modules, is installed in a separate vessel. The vessel design is more robust than the typical SCR container because of the requirement for the unit to operate at a higher pressure than occurs in a power plant flue gas installation. A diagram of a typical DeNOx catalyst vessel designed for use in a sulphuric acid plant is shown in Figure 5.

![Figure 5: DeNOx catalyst vessel](image)

It may be advantageous, at the same time as the DeNOx catalyst in installed, to expand or otherwise modify the existing sulphuric acid plant. One project incorporated the DeNOx catalyst within a new Bed 1 converter also containing catalyst for the conversion of SO2 to SO3. The unit also contained a new internal Hot Exchanger for additional maintenance benefits. A diagram of the combined DeNOx and DeSOx unit with the internal Hot Exchanger is shown in Figure 6.
A DeNOx removal requirement of 95% or greater is typically required for these systems. This can only be achieved if the criteria of even ammonia distribution within the gas and even distribution of the gas over the catalyst are obtained. The catalyst criteria is that flow deviations through the catalyst mass should be not greater than +/- 15%. This is achieved by performing extensive CFD analysis on the flow patterns in the catalyst vessel.

DeNOx performance

Typical performances required for the DeNOx systems are:

1. >95% based on an inlet NOx of 300 ppm giving less than 15 ppm in stack and less than 5 ppm in the acid product.
2. >97% based on an inlet NOx of 250 ppm giving less than 10 ppm in stack and less than 10 ppm in the acid product.

Experience has shown that this performance level has been achieved.

Conclusion

In summary it may be concluded that NOx levels in acid plants are tending to increase as smelting and acid regeneration technology changes. However, post treatment techniques are available by which NOx in the product acid and the stack gas can be controlled. In addition, technology is being applied with the objective of destroying the NOx in the gas before it enters the SO2 oxidation catalyst, which will elegantly eliminate the need for post treatment.
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This article was presented to the International Seminar "Review of the Agenda: New Initiatives in the Mining Sector", carried out on the 8-9 May, 2002, Santiago, Chile. This seminar was organized by the Chilean Copper Commission (COCHILCO), Chilean Mining Council and Universidad de Concepcion.