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Review of New Source Performance Standards for Sulfuric Acid Plants

NSPS

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Review of New Source Performance Standards for Sulfuric Acid Plants

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

March 1985

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1.0 EXECUTIVE SUMMARY

The objective of this report is to review the new source performance standards (NSPS) for sulfuric acid plants in terms of developments in control technology, economics and new issues that have evolved since the original standard was promulgated in 1971. The achievability of the standard and the potential for making the standard more restrictive are analyzed in the light of technical and cost considerations and compliance test data available for plants built since the promulgation of the NSPS. The NSPS review includes the SO_2 emission and acid mist emission standards. The opacity standard, while included in the sulfuric acid plant NSPS, is not reviewed separately since it is directly related to the acid mist emission standard. The following paragraphs summarize the results and conclusions of the analysis.

1.1 Best Demonstrated Control Technology

Sulfur dioxide and acid mist are present in the tail gas from all contact process sulfuric acid production units. In modern four-stage converter contact process plants burning sulfur with approximately 8 percent SO_2 in the converter feed and producing 98 percent acid, SO_2 and acid mist emissions are generated at the rate of 26 to 56 lb/ton of 100 percent acid and 0.4 to 4 lb/ton of 100 percent acid, respectively. The dual absorption process is the best demonstrated control technology* for SO_2 emissions from sulfuric acid

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*It should be noted that standards of performance for new sources established under Section 111 of the Clean Air Act reflect emission limits achievable with the best adequately demonstrated technological system of continuous emission reduction (taking into consideration the cost of achieving such emission reduction, as well as any nonair quality health and environmental impacts and energy requirements).

plants, while the high efficiency acid mist eliminator is the best demonstrated control technology for acid mist emissions. These two emission control systems have become the systems of choice for sulfuric acid plants built or modified since the promulgation of the NSPS. Forty of the 46 new or modified sulfuric acid production plants built since 1971 and subject to NSPS incorporate the dual absorption process, and all 46 plants use the high efficiency acid mist eliminator.

1.2 Current SO_2 NSPS levels Achievable With Best Demonstrated Control Technology

All sulfuric acid production units subject to NSPS have demonstrated compliance with the current SO_2 NSPS control level of 4 lb/ton. The compliance test results for dual absorption plants showed a considerable range from a low of 0.12 lb/ton to a high of 3.8 lb/ton. The average SO_2 emission level obtained in the NSPS compliance tests for dual absorption plants is about one order of magnitude lower than the SO_2 emission level obtained from uncontrolled single absorption plants. Information received on the performance of several sulfuric acid plants indicates that low SO_2 emission results achieved in NSPS compliance tests apparently do not reflect day-to-day SO_2 emission levels. These levels appear to rise toward the standard as the conversion catalyst ages and its activity drops. Based on these considerations, it is recommended that the level of SO_2 emissions as specified in the current NSPS not be changed at this time.

1.3 Current Acid Mist Levels (and Related Opacity Levels) Achievable With Best Demonstrated Control Technology

All 46 sulfuric acid production units subject to NSPS showed compliance with the current acid mist NSPS control level of 0.15 lb/ton of 100 percent acid. The NSPS compliance test data are all from plants with acid mist emission control provided by the high efficiency acid mist eliminator. The data show a wide range with a low of 0.004 lb/ton to a high of 0.15 lb/ton. Acid mist emission (and related opacity) levels are unaffected by factors affecting SO_2 emissions, e.g., conversion catalyst aging. Rather, acid mist emissions are primarily a function of moisture levels in the sulfur feedstock and air fed to the sulfur burner, and the efficiency of final absorber operation. The spread observed in NSPS compliance test values is probably a result of variation in these factors. Making the acid mist standard more stringent is not believed to be practicable at this time because of the need to provide a margin of safety due to in-plant operating fluctuations, which introduce variable quantities of moisture into the sulfuric acid production line.

1.4 Cost Considerations Affecting the SO_2 NSPS

The cost effectiveness of control was estimated for four types of SO_2 control systems: dual absorption, ammonia scrubbing, sodium sulfite scrubbing, and molecular sieve adsorption. The cost effectiveness ranged from $245 to $625 per ton of SO_2 removed for the large (1,500 TPD) model plant size and from $282 to $751 per ton for the small (750 TPD) model plant size. For both plant sizes, dual absorption was estimated to be the most cost effective control option.

The cost analysis for acid mist control showed essentially no difference in cost effectiveness ($47-50 per ton of acid mist removed) for the vertical tube (Brinks type) and the horizontal dual pad (York type) mist eliminators for the two model plant sizes.

2.0 THE SULFURIC ACID MANUFACTURING INDUSTRY

2.1 Industry Characterization

2.1.1 Georgraphic Distribution

In 1971 there were 167 contact process sulfuric acid and oleum plants in the United States. By 1977 the number of plants had decreased to 150 and 32 sulfuric acid units were subject to the NSPS.[1] In September of 1984 there were 46 plants subject to the NSPS[2] out of a total of 132 plants.[3] Table 2-1 provides a summary of the number of units subject to NSPS and their design tonnage.

Figure 2-1 shows the geographical distribution of contact process sulfuric acid units subject to the NSPS. The heaviest concentration of new units is in Region IV (Southeast). The high concentration of sulfuric acid units constructed in Florida since 1971 can be explained by the presence of rich phosphate rock deposits. More than 80 percent of the phosphate rock mined goes into the manufacture of phosphate fertilizers,[4,5] which is also the end use of two-thirds of the total U.S. sulfuric acid production.[6] Since most sulfuric acid is consumed near its point of manufacture, units with production dedicated for phosphate fertilizer manufacture will usually be located near phosphate rock deposits.

2.1.2 Production

U.S. production of sulfuric acid from July 1983 through June 1984 totalled approximately 37.7 million tons, representing an average yearly increase of 2.2 percent (722,000 tons) since 1971.[7,8] Figure 2-2 shows total annual production of sulfuric acid for 1971 to 1983, including production by the lead chamber process, which has been phased out of the industry.

TABLE 2-1. NSPS SULFURIC ACID PLANTS

Company	Location	Unit	Capacity (TPD)
Agrico Chemical Co.	S. Pierce, FL	10	2000
		11	2000
	Donaldsonville, LA	10	1800
		11	1800
Allied Corp.	Anacortes, WA	D	115
American Cyanamid	Westwego, LA	1	1600
	Savannah, GA	1	800
Badger Army Ammunition Plant	Baraboo, WI	1	350
Beker Ind. Inc.	Conda, ID	1	1200
	Taft, LA	2	800
CF Ind. Inc.	Bartow, FL	7	2000
	Plant City, FL	C	1500
	Plant City, FL	D	1500
CIL Chem. Inc.	Sayerville, NJ	C	1000
		F	1000
Conserv. Inc.	Nichols, FL	1	2000
Farmland Ind.	Bartow, FL	3	1600
		4	1600
Freeport Chem. Co.	Uncle Sam, LA	D	1250
Gardinier, Inc.	Tampa, FL	7	1750
		9	2600
W.R. Grace & Co.	Bartow, FL	4	1800
		5	1800
		6	1800

TABLE 2-1. NSPS SULFURIC ACID PLANTS (cont)

Company	Location	Unit	Capacity (TPD)
Industrial Chemicals	Penuelas, PR	1	60
International Minerals & Chemicals Corp.	New Wales, FL	1	2750
		2	2750
		3	2750
		4	2500
		5	2500
Mississippi Chem. Corp.	Pascagoula, MS	3	1500
Occidental Chem. Corp.	White Springs, FL	C	1800
		D	1800
		E	2000
		F	2000
PVS Chem. Inc.	Copley, OH	1	250
Rohm & Haas Corp.	Deer Park, TX	3	800
Shell Chem. Co.	Wood River, IL	1	360
J.R. Simplot Co.	Helm, CA	4	1800
	Pocatello, ID	1	500
		2	600
Texasgulf, Inc.	Aurora, NC	3	1525
		4	1525
		5	3100
USS Agri-Chemicals	Ft. Meade, FL	1	2200
		2	2200

FIGURE 2-1

CONTACT PROCESS SULFURIC ACID PLANTS COMPLETED IN U.S. SINCE 1971

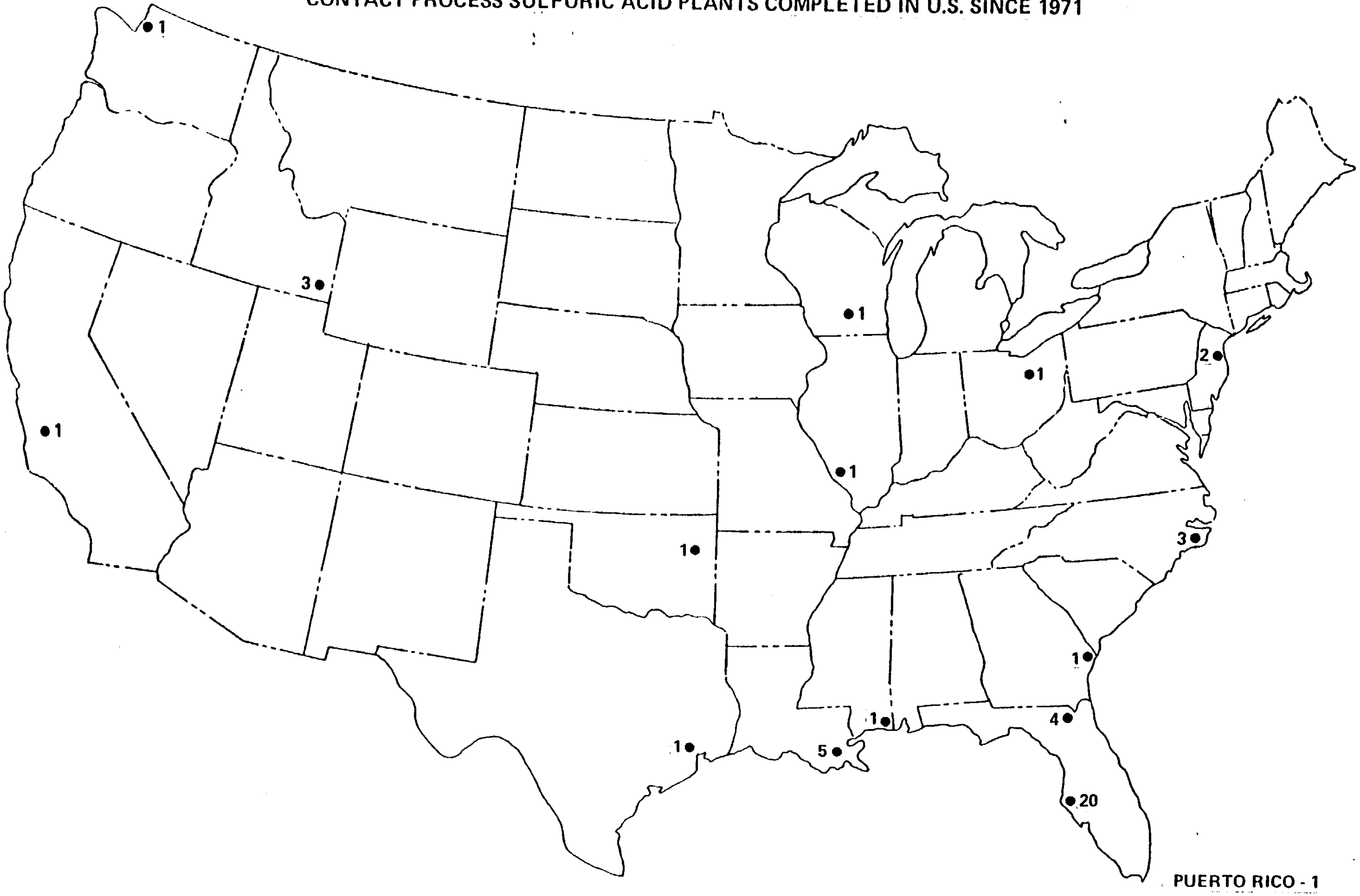
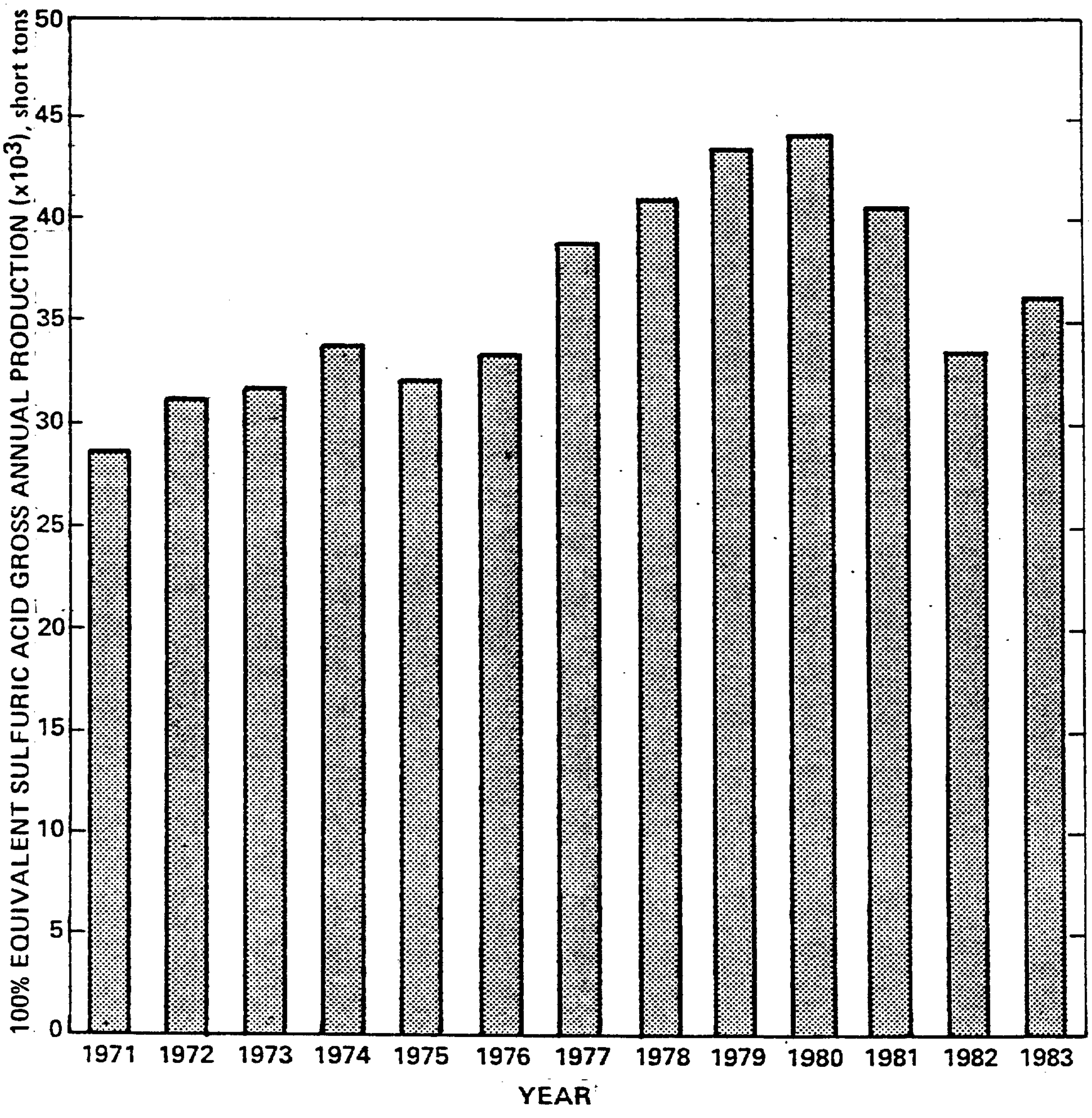


FIGURE 2-2

GROSS ANNUAL PRODUCTION OF SULFURIC ACID (NEW AND FORTIFIED), 1971 TO 1983



Production by the contact process represented 99.3 percent of total production in 1971, increased to 99.7 percent in 1975, and 100 percent in 1983. Table 2-2 shows the increase in sulfuric acid production by region from 1975 through 1983. Production in the South represented 70 percent of the U.S. Total in 1975 and 77 percent in 1983.[9]

TABLE 2-2. SULFURIC ACID PRODUCTION
(Thousand tons of 100% H_2SO_4)

Region	1975	1983	Change (%)	Total Production 1983 (%)
Northeast	1,903.7	1,440.1	-24	4
North Central	3,089.2	2,040.3	-34	6
West	4,528.2	4,736.3	+5	13
South	21,635.7	28,074.9	+30	77

The growth of the sulfuric acid industry since promulgation of the NSPS has been largely dominated by the growth in the phosphate fertilizer industry in the early and mid-seventies. Of the 46 contact process sulfuric acid units subject to NSPS, the output of at least 36 units is dedicated to the acidulation of phosphate rock as the first step in the manufacture of wet-process phosphoric acid and superphosphate fertilizers.

About 81 percent of the contact process sulfuric acid is produced from elemental sulfur, representing approximately 76 percent of the toal sulfur consumption in the U.S. The remaining acid is made from iron pyrites (3 percent); byproduct sulfuric acid from smelters (3 percent); and hydrogen sulfide, spent alkylation acid, and acid sludge from petroleum refineries (8 percent).[10]

Sulfuric acid is produced in various concentrations and in four grades: commercial, electrolyte or high purity, textile (having low organic content), and chemically pure (C.P.) or reagent grade. The various end uses of sulfuric acid are shown in Figure 2-3. In addition to the manufacturing of fertilizer, other major uses are petroleum refining (6 percent), inorganic chemicals (3 percent), synthetic rubber and plastics (3 percent), and inorganic chemicals (3 percent).[11] An increasing number of sulfuric acid consumers, specifically fertilizer manufacturers, produce their own sulfuric acid for captive use.

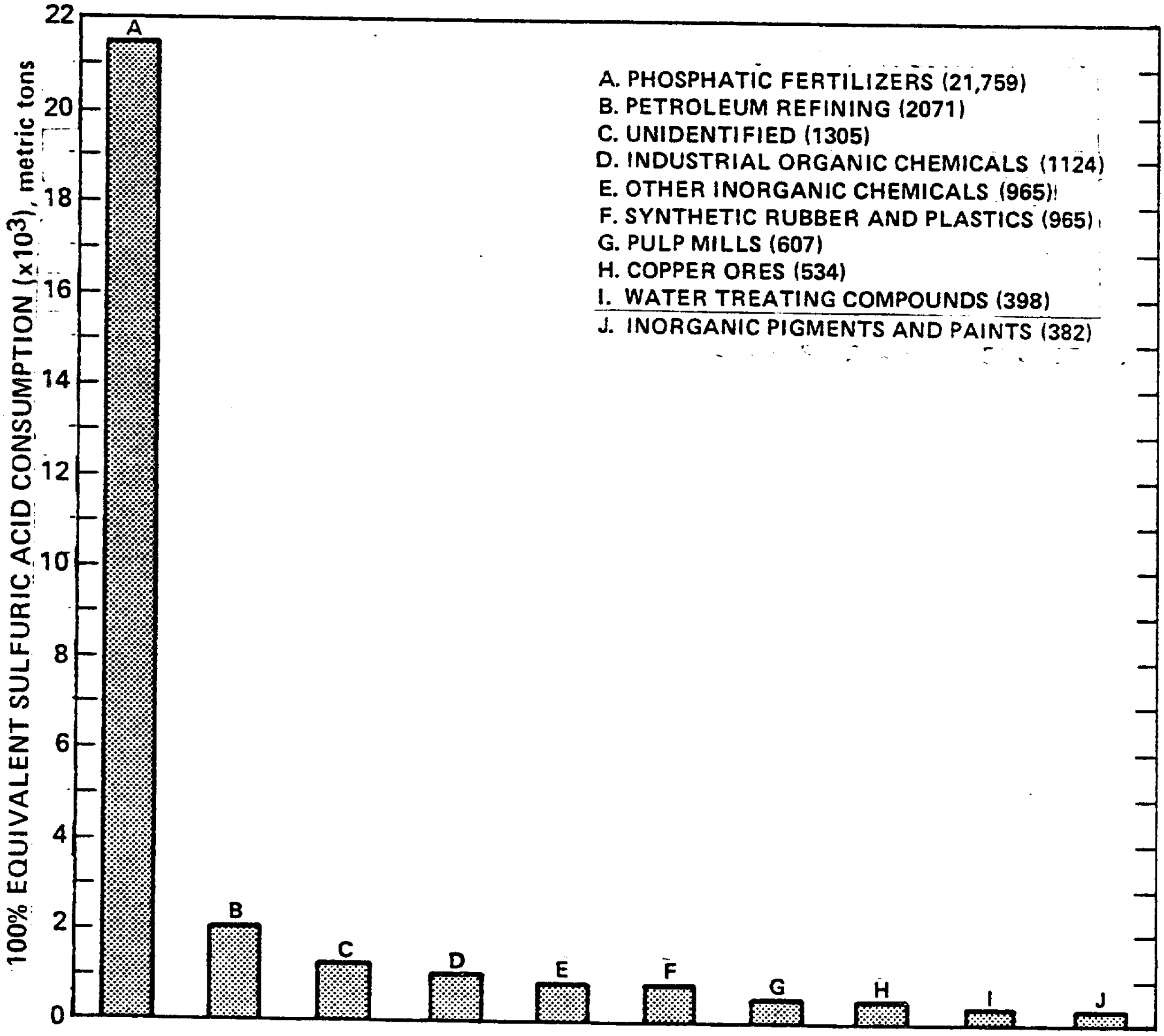
2.1.3 Industrial Trends

U.S. sulfuric acid production in 1971 was 29.0 million tons,[12] and approximately 36.6 million tons in 1983.[13] Production is expected to increase to 48.0 million tons by the year 1995.[14]

Tables 2-1, and 2-2, and Figure 2-1 show the strong trend towards siting sulfuric acid plants in the southern States. Over 77 percent of the sulfuric acid design capacity is located in EPA Regions IV and VI. In 1971, EPA projected two new units to be coming on-line each year for the next several years. On the average, three to four new units have actually been completed each year since 1971. Of the total of 46 new units, over half are located in Florida. Most of the sulfuric acid

FIGURE 2-3

SULFURIC ACID CONSUMED IN U.S. BY END USE, 1983



production units in the South are captive in nature with the output going into phosphate fertilizer production at the same plant complex. As stated earlier, 77 percent of the 1983 total national production of sulfuric acid was in the South. Therefore, based on the influence of high phosphate fertilizer production on the new construction in Region IV, and on the production trends of sulfuric acid most units projected to be coming on-line in the foreseeable future will probably be located in the South.

The location of sulfuric acid plants is not dependent on the location of sources of sulfur, but rather on the location of various industries associated with the use of sulfuric acid; i.e., the fertilizer and petroleum refining industries.

2.2 Contact Process for Sulfuric Acid Production[15]

All contact sulfuric acid manufacturing processes incorporate three basic operations: (1) burning of sulfur or sulfur-bearing feedstocks to form SO_2, (2) catalytic oxidation of SO_2 to SO_3, and (3) absorption of SO_3 in a strong acid stream. The several variations in the process are due principally to differences in feedstocks. The least complicated systems are those that burn elemental sulfur. Where there are appreciable organics and moisture as in spent acid and acid sludge, additional operations are required to remove moisture and particulates prior to catalysis and absorption. The compositiion of feedstock can affect the sulfur conversion ratio, the volume of exhaust gases, and the character and rate of pollutant releases.

2.2.1 Elemental Sulfur Burning Plants

Figure 2-4 is a schematic diagram of a contact sulfuric plant burning elemental sulfur. Sulfur is burned to form a gas mixture which is approximately 8 to 10 percent sulfur dioxide, 11 to 13 percent oxygen, and 79 percent nitrogen. Combustion air is predried by passing through a packed tower circulating 98 percent sulfuric acid which acts as a desiccant. Drying of the air minimizes acid mist formation and resultant corrosion throughout the system.

SO_2 is oxidized to SO_3 in the presence of a catalyst containing approximately 5 percent vanadium pentoxide. The temperature of the reacting gas mixture increases as the composition approaches equilibrium. Maximum conversion to SO_3 requires several conversion stages with intermediate gas cooling. The gas exiting the converter is cooled in an economizer to temperatures between 230° and 260°C, and SO_3 is absorbed in 98 percent sulfuric acid circulating in a packed tower. The acid content and temperature must be carefully controlled to prevent excessive SO_3 release.

If fuming sulfuric acid (oleum) is produced, the SO_3 containing gases are first passed through an oleum tower which is fed with acid from the 98 percent absorption system. The gas stream from the oleum tower is passed through the 98 percent acid absorber for recovery of residual sulfur trioxide.

2.2.2 Spent Acid and Other By-Product Plants

Where spent acid, sludge, and similar feedstocks are employed, the processes are more elaborate and expensive than sulfur-burning plants

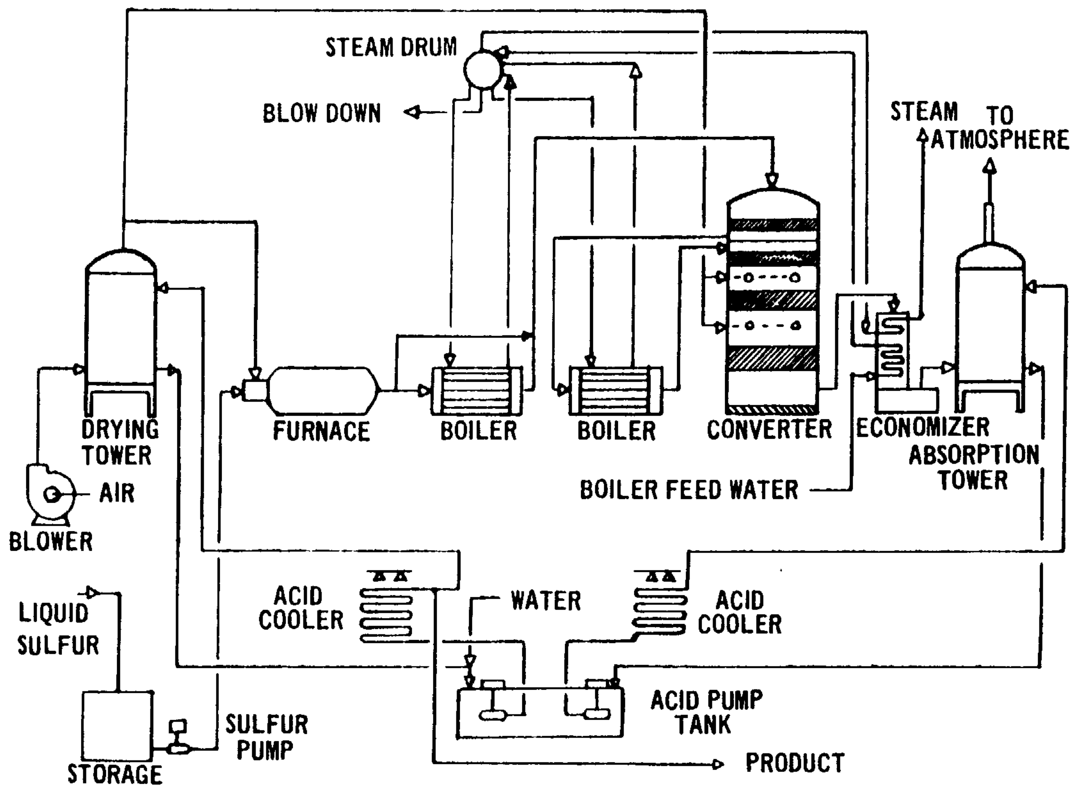


FIGURE 2-4
CONTACT-PROCESS SULFURIC ACID PLANT BURNING ELEMENTAL SULFUR

due to the fact that the sulfur dioxide containing gas stream is contaminated. Gases must be cleaned if high-quality acid is to be produced. This requires additional gas cleaning and cooling equipment to remove dust, acid mist, and gaseous impurities, along with excessive amounts of water vapor. Purification equipment consists of cyclones, electrostatic dust and mist precipitators, plus scrubbers and gas-cooling towers in various combinations. Figure 2-5 shows one configuration of a spent acid plant. The balance of the process following the drying tower is essentially the same as an elemental sulfur-burning plant.

A few plants burning only hydrogen sulfide or hydrogen sulfide plus elemental sulfur use a simplified version of the above process. Wet gases from the combustion chamber and waste heat boiler are charged directly to the converter with no intermediate treatment. Gases from the converter flow to the absorber, through which 70 to 93 percent sulfuric acid is circulating. In such a "wet gas" plant much of the sulfur trioxide from the converter is in the form of acid mist which is not absorbed in the absorption tower. High efficiency mist collectors are used both to recover product and to minimize air pollution.

2.3 Emissions from Contact Process Sulfuric Acid Plants[16]

2.3.1 Sulfur Dioxide

Mass SO_2 emissions vary inversely as a function of the sulfur conversion efficiency (i.e., fraction of SO_2 oxidized to SO_3). For sulfur burning plants, the inlet SO_2 concentration to the catalytic converters normally ranges between 7.5 and 8.5 percent, but can be as high as 10.5 percent. Conversion efficiency depends upon the number of stages in the catalytic converter and, to a lesser extent, on the amount of catalyst.

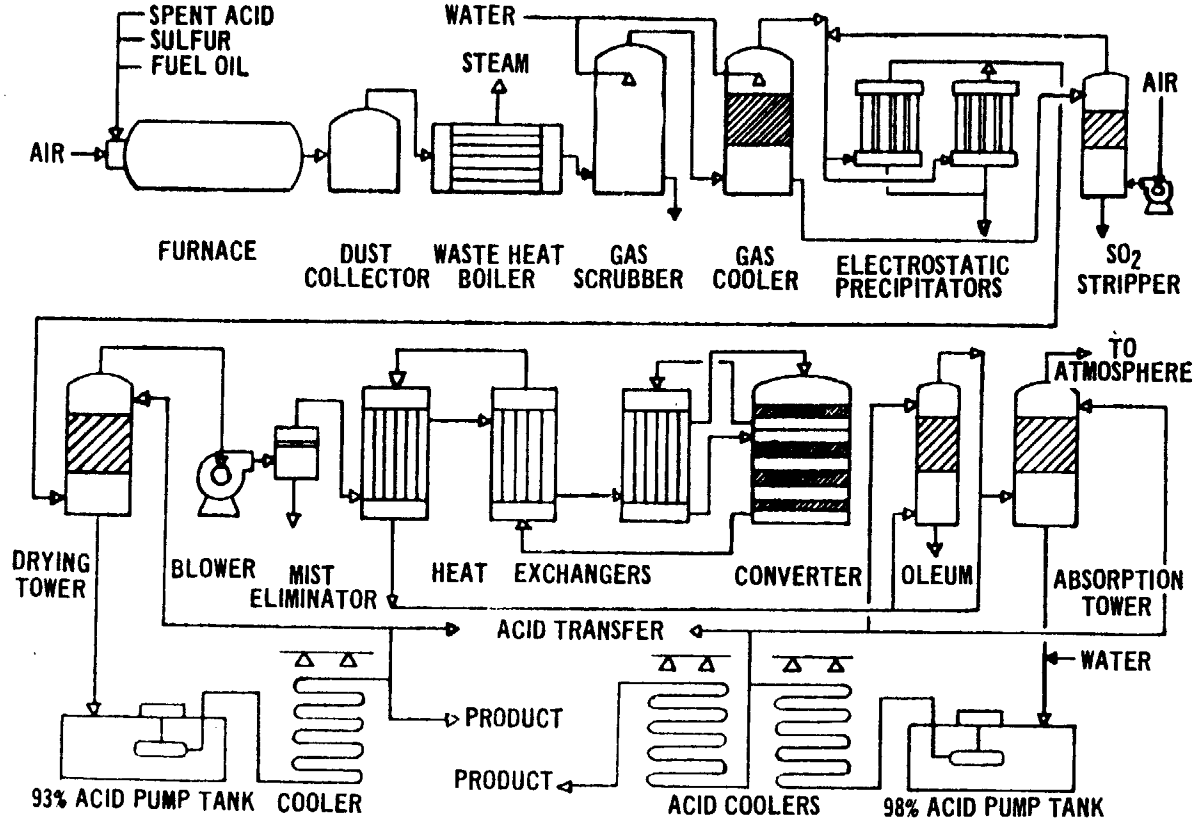


FIGURE 2-5
CONTACT-PROCESS SULFURIC ACID PLANT
BURNING SPENT ACID

Most plants built prior to 1960 had only three catalyst stages, and overall conversion efficiencies were approximately 95 to 96 percent. Sulfur burning plants built since 1960 generally have four or five stages and efficiencies normally range between 96 and 98 percent. For three-stage plants, SO_2 release ranges between 56 and 70 lb/ton and for four-stage plants, between 26 and 56 lb/ton.

Spent acid plants followed the same design trend. Most three-stage plants were built prior to 1960 and four-stage plants have usually been built after 1960. Typical SO_2 concentrations in the converter feed, conversion efficiencies, and resultant emissions for plants burning sulfur, H_2S or primarily acid sludge are given in Table 2-3.

TABLE 2-3. SULFUR DIOXIDE FEED AND EMISSIONS FOR FOUR-STAGE CONVERTERS

Feedstock	Sulfur	Hydrogen Sulfide (with some other sulfur compounds)	Acid Sludge
SO_2 in converter feed, % by volume	7.5 to 8.5	7	6 to 8
SO_2 emissions, lb/ton 100% acid	26 to 56	50 to 86	30 to 112
SO_2 emissions, ppm by volume	1500 to 4000	1500 to 4000	1500 to 4000

Exit SO_2 concentrations from contact plants vary as a function of the SO_2 content of dry gases fed to the converter. Where SO_2 strength is relatively low, there is a significantly greater volume of gases handled per ton of acid produced.

A plant with 4.0 percent SO_2 in the dry gases to the converter will exhaust over two and one-half times the gas volume of a plant operating on a 10.0 percent SO_2 stream, i.e., 147,500 ft^3/ton vs. 54,500 ft^3/ton.

The relationship between mass emission rate, sulfur conversion and SO_2 exit concentrations has been plotted in Figure 2-6 for plants of various SO_2 strengths. The curve can be used for uncontrolled single absorption plants and for those plants equipped with tail gas removal systems or with the dual absorption process. It can be seen that the NSPS of 4.0 lb per ton of acid requires 99.7 percent sulfur conversion (dual absorption) or an equivalent SO_2 exit gas concentration of 280 ppm. This conversion is achieved by the dual absorption technique. At 98 percent conversion, which is optimum for most single absorption contact plants, exit SO_2 concentrations can vary from 1,400 to 4,000 ppm as the inlet SO_2 content varies from 4.0 to 10.0 percent.

2.3.2 Acid Mist Formation

The sulfuric acid liquid loading in the tail gas from the absorber in a contact process plant is classified into two broad areas based on the acid particle size: (1) spray, which is defined as acid particles larger than 10 microns, and (2) mist, which is defined as acid particles smaller than 10 microns. The EPA method for measuring sulfuric acid mist (Method 8) reports SO_3 gas as well as particulate acid mist.

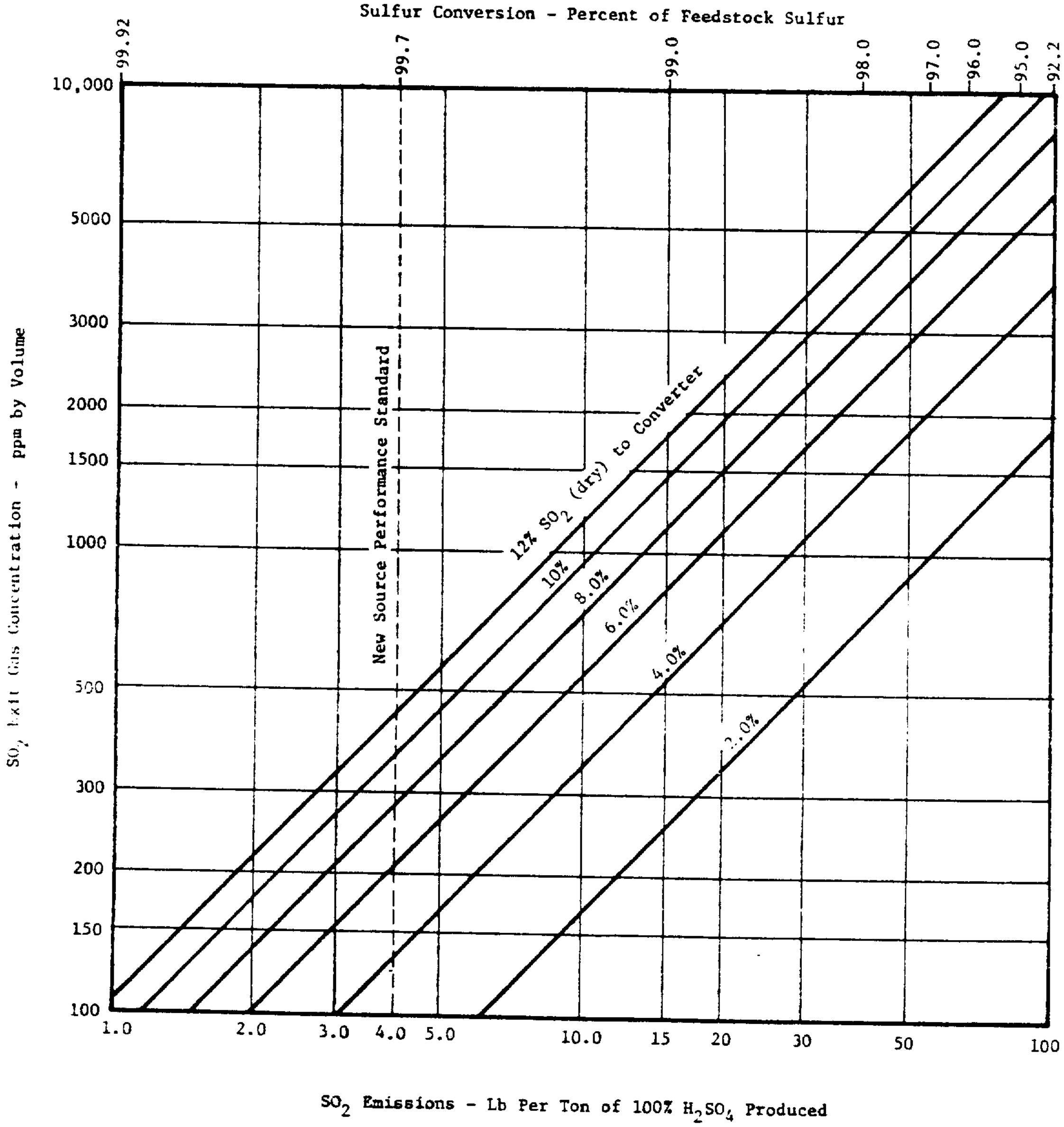


FIGURE 2-5
SULFURIC ACID PLANT FEEDSTOCK SULFUR CONVERSION VS. VOLUMETRIC AND MASS SO_2 EMISSIONS AT VARIOUS INLET SO_2 CONCENTRATIONS BY VOLUME

Spray is primarily formed by mechanical generation of particles that are formed when a gas and liquid are mixed together. Examples of spray formation are liquid droplets formed by nozzles and liquid entrainment leaving a packed tower. A typical tower design in a modern acid plant will have a spray loading of 0.08 to 0.15 grains per actual cubic foot (gr/ft^3) under normal operating conditions.

Acid mist formation is more complex to define than spray. There are two primary mechanisms of acid mist formation. The first mechanism is the reaction between two vapors forming a liquid or solid. This is best exemplified by the reaction of sulfur trioxide and water vapors to form submicronic sulfuric acid mist.

$$H_2O_{(\text{water vapor})} + SO_{3(\text{gas})} \longrightarrow H_2SO_{4(\text{liquid particulate})}$$

The second mechanism of mist formation is vapor condensation in the bulk gas phase by lowering the gas stream temperature beyond the liquid dew point. The dew point of a sulfuric acid under typical conditions is about 300° to 350°F. However, because of the uncertainties of non-ideal conditions and wall effects, the gas stream temperature is normally maintained between 375° and 425°F. This is done to insure that acid mist is not present to attack metal equipment.

The formation of sulfuric acid mist in an acid plant is due to a combination of these mechanisms. When a gas stream containing SO_3, H_2SO_4 and H_2O vapor is cooled below the liquid dew point, the H_2SO_4 vapor condenses and the SO_3 vapor and H_2O vapor combine to form H_2SO_4, which also condenses. Submicronic mist particles will be formed when the gas is cooled faster than the condensable vapor can be removed by mass transfer (i.e., "shock cooling"). The conditions for "shock cooling" are present in the absorbing towers of an acid plant.

The practical key to controlling mist formation is to keep the moisture content in a gas stream as low as possible. As an example of mist forming capability of extraneous water, 1 ounce of water vapor carried through the plant has the potential to produce 2.35 gr/ft^3 of submicronic acid mist. The water content of the gas stream will be increased if any of the following conditions are present:

1. High organic content of contaminated elemental sulfur (sulfur burning plants only).
2. Acid mist carryover from upstream equipment.
3. Inadequate drying of the process air stream.
4. Low absorbing tower acid strengths.

At acid strengths below 98.5 percent, the acid begins to exert a measurable water vapor pressure. The optimum absorbing tower acid has the minimum vapor pressure of both water (minimizing mist formation problems) and sulfur trioxide (minimizing SO_3 slippage).

In oleum producing plants, greater quantities and a much finer mist are produced. From 85 to 95 weight percent of the particles are less than 2 microns in diameter as compared with about 30 percent less than 2 microns for 98 percent acid production. Acid mist emissions prior to control equipment range between 0.4 to 4 lb/ton for sulfur burning contact plants producing no oleum to about 1 to 10 lb/ton for spent acid burning plants producing oleum, based on an 8 percent SO_2 feed to the converter.

Spent acid plants characteristically form acid mist in the early stages of the process. This requires mist removal prior to drying and oxidation as well as from the tail gas after absorption.

"Wet gas" plants burning hydrogen sulfide deliberately form acid mist by not drying the process gas. Much of this mist is recovered as product acid with gas cooling equipment and high efficiency mist eliminators or electrostatic precipitators.

For a given mass emission rate, acid mist concentrations vary as a function of the exhaust gas volume and the SO_2 concentration of the gases fed to the converter. Figure 2-7 shows a relationship between mass emission rates and concentrations over a range of SO_2 strengths. The curves can be used with any gas stream before or after mist eliminators, provided there is no dilution.

2.3.3 Visible Emissions (Opacity)

Acid mist in exhaust gases creates visible emissions ranging from white to blue depending on particle size, concentration and background. Where there is no control of mist, opacities generally range from 80 to 100 percent.

The effect of acid mist on opacity is very dependent on the size of the mist particle. The smaller particles scatter light more, producing a denser plume. Nevertheless, it has been demonstrated that opacity of the plume from an efficient SO_3 absorber is a function of acid mist concentration and that visible emissions can be eliminated by minimizing acid mist levels in the acid plant tail gas or through the use of a good mist eliminator. At the current NSPS acid mist control level, there are essentially no visible emissions (less than 10 percent opacity).

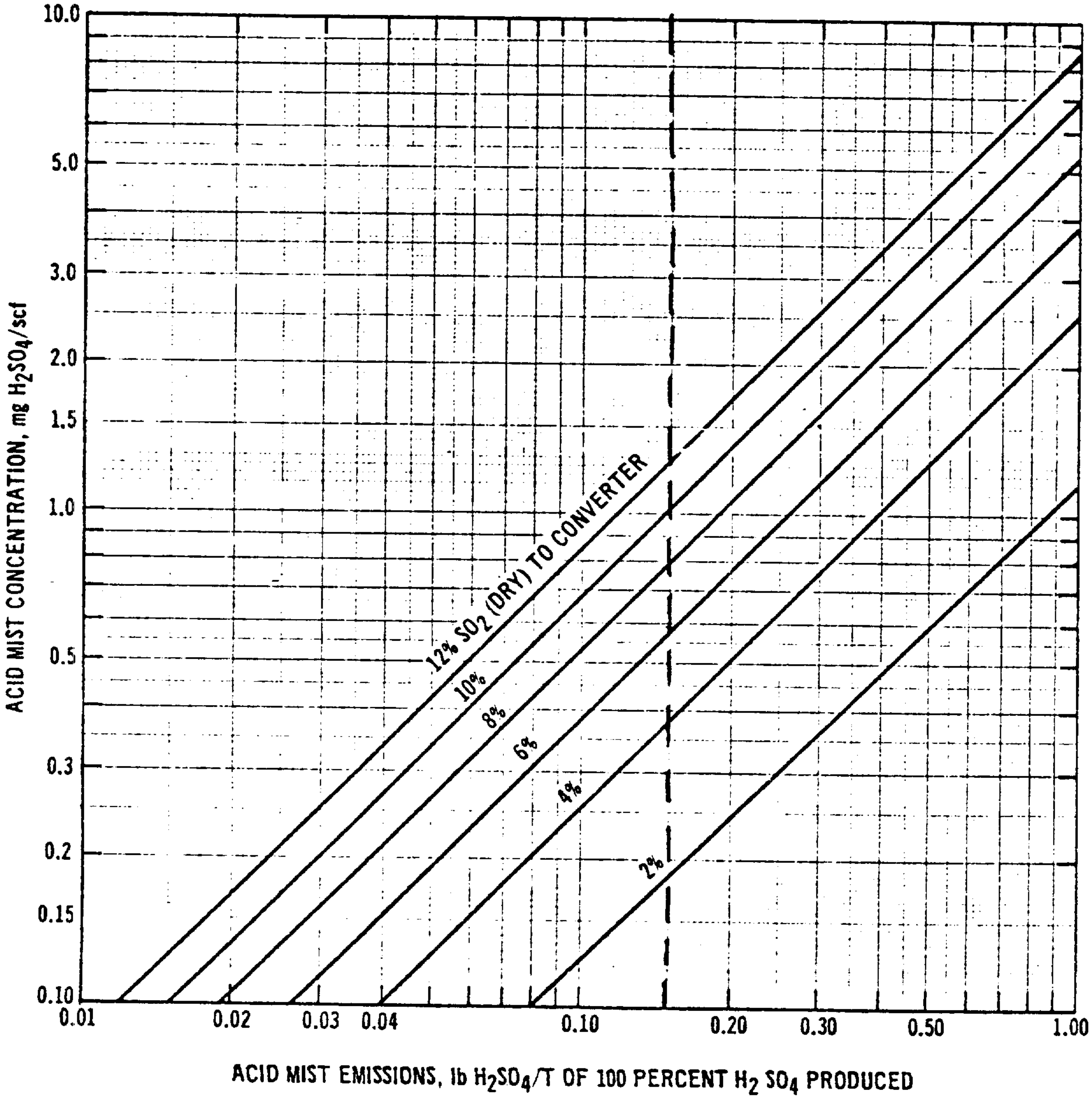


FIGURE 2-7
SULFURIC ACID PLANT CONCENTRATIONS OF MIST FOR MASS STACK EMISSIONS PER UNIT OF PRODUCTION AT INLET SO_2 VOLUME CONCENTRATIONS

2.3.4 Oxides of Nitrogen

Nitrogen oxides present in the converter gas also cause acid mist emissions, since they reduce the efficiency of the absorption tower. Nitrogen oxides may result from the fixation of atmospheric nitrogen in high temperature sulfur furnaces, or may be formed from nitrogen compounds in the feedstocks. Nitrogen oxides can be held to a reasonable minimum by using the same techniques which have been applied to steam generators. For instance, in the decomposition of spent acid containing nitrogen compounds, operation at furnace temperatures less than about 2000°F and a low oxygen content will generally keep nitrogen oxides concentrations below 100 ppm.

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f. Telephone Conversations initiated by Lee Beck, U.S. Environmental Protection Agency, to the following individuals:

Conversation Date	Person Contacted	Affiliation
February 13, 1984	Bruce Varner	EPA, Region V
February 16, 1984	Rick Watman	EPA, Region III
March 1, 1984	Mike Pucci	EPA, Region II
March 29, 1984	Mark Hooper	EPA, Region X
November 19, 1984	Ken Roberts	Florida Dept. of Environmental Regulation
November 19, 1984	John Cole	Florida Dept. of Environmental Regulation
November 19, 1984	Beverly Foster	EPA, Region IV
December 5, 1984	Steve Riva	EPA, Region II
December 5, 1984	Ed Chromanski	NJ Bureau of Air Pollution Control
December 5, 1984	Ann Zownier	NJ Bureau of Air Pollution Control
December 5, 1984	John Hollingsworth	CIL Chemicals, Inc.
January 23, 1985	Jerry Vetter	Beker Industries, Inc.
January 23, 1984	Pat McCoy	EPA, REgion V
January 25, 1985	Sammy Amerson	NC Division of Environmental Management
January 28, 1985	Johnnie Cole	Florida Dept. of Environmental Regulation
January 28, 1985	Fred Roe	GA Environmental Protection Division
February 4, 1985	Sammy Amerson	NC Division of Environmental Management
February 4, 1985	John Ledger	Idaho Division of Environmental Management

February 5, 1985	Ed Chromanski	NJ Bureau of Air Pollution Control
February 5, 1985	Byron Sullivan	NJ Bureau of Air Pollution Control
February 8, 1985	Ed Chromanski	NJ Bureau of Air Pollution Control
February 14, 1985	Craig Rushin	EPA, Region VI
February 22, 1985	Chris Roeder	Florida Dept. of Environmental Regulation
March 14, 1985	Lynn Malcolm	Ohio Environmental Protection Agency
March 27, 1985	Charles Meskal	Fresno County Air Pollution Control District

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3.0 CURRENT STANDARDS FOR SULFURIC ACID PLANTS

3.1 Background Information

Prior to the promulgation of the NSPS in 1971, almost all existing contact process sulfuric acid plants were of the single-absorption design and had no SO_2 emission controls. Emissions from these plants ranged from 1500 to 6000 ppm SO_2 by volume, or from 21.5 lb of SO_2/ton of 100 percent acid produced to 85 lb of SO_2/ton of 100 percent acid produced. Several State and local agencies limited SO_2 emissions to 500 ppm from new sulfuric acid plants, but few such facilities had been put into operation.[1]

Many sulfuric acid plants utilized some type of acid mist control prior to 1971, but several had no controls whatsoever. Uncontrolled acid mist emissions varied between 2 and 50 mg/scf, which is equivalent to about 0.4 to 9 lb of H_2SO_4/ton of 100 percent acid produced, the lower figure representing emissions from a plant burning high-purity sulfur. State and local regulatory agencies had only begun to limit acid mist emissions to more stringent levels. For example, some agencies had adopted limits of 1 and 2 mg/scf, respectively, for new and existing plants.

It is estimated that SO_2 emissions from sulfuric acid plants totalled 530,000 tons in 1971 and 180,000 tons in 1983.[2] This represents a 66 percent drop in SO_2 emissions from this industry during a time period when production increased by 26 percent. It is not known what portion of this drop in SO_2 emissions is due to NSPS-controlled plants or to existing plants covered by State Implementation Plans (SIP).

No corresponding data are available for the effect of the NSPS on acid mist emissions from the industry.

3.2 Facilities Affected

The NSPS regulates sulfuric acid plants that were planned or under construction or modification as of August 17, 1971. Each sulfuric acid production unit (or "train") is the affected facility. The standards of performance apply to contact-process sulfuric acid and oleum facilities that burn elemental sulfur, alkylation acid, hydrogen sulfide, metallic sulfides, organic sulfides, mercaptans, or acid sludge. The NSPS does not apply to metallurgical plants that use acid plants as control systems, or to chamber process plants or acid concentrators.

An existing sulfuric acid plant is subject to the promulgated NSPS if: (1) a physical or operational change in an existing facility causes an increase in the emission rate to the atmosphere of any pollutant to which the standard applies, or (2) if in the course of reconstruction of the facility, the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entire new facility that meets the NSPS.

3.3 Controlled Pollutants and Emission Levels

The pollutants to be controlled at sulfuric acid plants by the NSPS are defined by 40 CFR 60, Subpart H as follows:

1. Standard for sulfur dioxide

> (a) "On and after the date. . . no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from any affected facility any gases which contain sulfur dioxide in excess of 2 kg per metric ton of acid produced (4 lb per ton), the production being expressed as 100 percent H_2SO_4.

2. Standard for acid mist

> (a) "On and after the date. . . no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from any affected facility any gases which:
>
> > (1) Contain acid mist, expressed as H_2SO_4, in excess of 0.075 kg per metric ton of acid produced (0.15 lb per ton), the production being expressed as 100 percent H_2SO_4.
> >
> > (2) Exhibit 10 percent opacity or greater. Where the presence of uncombined water is the only reason for failure to meet the requirements of this paragraph, such failure will not be a violation of this section."[3]

The values of these standards were derived from the following data sources:

1. A literature search revealed that over 20 dual-absorption plants had been operating successfully in Europe for several years using both elemental sulfur and roaster gas as feed and that three of these plants produced maximum SO_2 emissions ranging from 91 to 260 ppm SO_2 by volume, or from 1.2 lb of SO_2 per ton of acid produced to 3.1 lb of SO_2 per ton of acid produced.
2. The two plants tested and evaluated by EPA engineers were a plant of typical dual-absorption design and a single-absorption spent-acid burning plant that used a sodium sulfite-bisulfite scrubbing process to recover SO_2 from tail gas.[4]

The dual-absorption sulfuric acid plant was the first of its kind in the U.S. and was used by EPA as part of the best demonstrated control technology rationale for the NSPS for SO_2 emissions. Since 1971, 40 dual-absorption plants have been built in the U.S. This process has become the best demonstrated technology in the industry for SO_2 control.

Emission tests from both the original dual-absorption sulfuric acid plant and the single absorption plant with sodium sulfite-sodium bisulfite scrubbing indicated that both operations were capable of maintaining SO_2 and acid mist emissions below 4 lb/ton and 0.15 lb/ton, respectively, at full load operations. Additionally, control of acid mist below 0.15 lb/ton at these plants resulted in stack emissions below 10 percent opacity. Continuous stack monitoring at these plants indicated that at full load, the plants could be consistently operated so that SO_2 emissions would be kept within the limits of the performance standard. In Section 5.0 of this report, NSPS emission test results for SO_2 and acid mist are presented for all sulfuric acid units completed since the promulgation of the standard.

3.4 Testing and Monitoring Requirements

3.4.1 Testing Requirements[5]

Performance tests to verify compliance with SO_2, acid mist, and opacity standards for sulfuric acid plants must be conducted within 60 days after the plant has reached its full capacity production rate, but not later than 180 days after the initial start-up of the facility. The EPA reference methods to be used in connection with sulfuric acid plant testing include:

1. Method 8 for the concentrations of SO_2 and acid mist
2. Method 1 for sample and velocity traverses
3. Method 2 for velocity and volumetric flow rates
4. Method 3 for gas analysis.

For Method 8, each performance test consists of three separate runs of at least 60 minutes duration each with a minimum sample volume of 40 dry standard cubic feet (dscf). The arithmetic mean of the three runs taken is the test result to which compliance with the standard applies.

The sulfuric acid production rate, expressed as tons/hr of 100 percent H_2SO_4, is to be determined during each testing period by suitable methods and confirmed by a material balance over the production system. Sulfur dioxide and acid mist emissions in lb/ton of 100 percent H_2SO_4 are determined by dividing the emission rate in tons/hr by the hourly 100 percent acid production rate.

3.4.2 Monitoring Requirements

SO_2 emissions in the tail gas from sulfuric acid plants are required to be continuously monitored. Continuous SO_2 monitoring instrumentation should be able to: (1) provide a record of performance, and (2) provide intelligence to plant operating personnel such that suitable corrections can be made when the system is shown to be out of adjustment. Plant operators are required to maintain the monitoring equipment in calibration and to furnish records of SO_2 excess emission values to the Administrator of EPA or to the responsible State agency.

Measurement principles used in the gas analysis instruments are:

1. Infrared absorption
2. Colorimetric titration of iodine
3. Selective permeation of SO_2 through a membrane
4. Flame photometric measurement

5. Chromatrographic measurement
6. Ultraviolet absorption.

The ultraviolet absorption system and the iodine titration method have received widespread application for SO_2 measurement in sulfuric acid plants subject to NSPS.

The continuous monitoring system is calibrated using a gas mixture of known SO_2 concentration as a calibration standard. Performance evaluation of the monitoring system is conducted using the SO_2 portion of EPA Method 8.

Excess SO_2 emissions are required to be reported to EPA (or appropriate State regulatory agencies) for all 3-hour periods of such emissions (or the arithmetic average of three consecutive 1-hour periods). Periods of excess emission are considered to occur when the integrated (or arithmetic average) plant stack SO_2 emission exceeds the standard of 4 lb/ton of 100 percent H_2SO_4 produced.

3.5 REFERENCES

1. Drabkin, M. and K.J. Brooks (Mitre Corporation). A Review of Standards of Performance for New Stationary Sources - Sulfuric Acid Plants. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-79-003. January 1979. p. 3-1.

2. Office of Air Quality Planning and Standards. National Air Pollutant Emission Estimates, 1940-1983. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/4-84-028. December 1984. p. 28.

3. U.S. Environmental Protection Agency. Code of Federal Regulations. Title 40, Subpart H, SC Part 60. Washington, D.C. Office of the Federal Register. December 23, 1971.

4. Office of Air Programs. Background Information for Proposed Standards. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. APTD-0711. August 1971. p. 43-48.

5. Reference 3.

4.0 STATUS OF CONTROL TECHNOLOGY

4.1 Control Technology Applicable to the NSPS Control of SO_2 Emissions from Contact Process Sulfuric Acid Plants

There are a few physical mechanisms and many chemical means of removing SO_2 from gas streams. Almost any soluble alkaline material will absorb a significant fraction of SO_2 even in a crude scrubber. For years, sulfur dioxide has been removed from many process gases where the SO_2 adversely affected the product. The problems of removing SO_2 from acid plant gases are principally that of finding the least expensive mechanism consistent with minimal formation of undesirable by-products. The control processes in use by the sulfuric acid industry in units installed since the promulgation of the NSPS are reviewed below.

4.1.1 Dual Absorption Process

The dual absorption process (used partially as the basis of the rationale for the SO_2 NSPS) has become the SO_2 control system chosen by the sulfuric acid industry since promulgation of the NSPS. This can be seen by examination of Table 4-1, which presents a tabulation of the new sulfuric acid units built since the promulgation of the NSPS together with their locations, design capacities, basic process design, and SO_2 and acid mist control technologies. As shown on Table 4-1, 40 of the 46 new units built since the promulgation of the NSPS have employed the dual absorption process for SO_2 control. This process offers the following advantages over other SO_2 control processes:

- As opposed to single absorption with scrubbing, a greater fraction of the sulfur in the feed is converted to sulfuric acid.
- There are no by-products

TABLE 4-1. CONTACT SULFURIC ACID PLANTS BUILT SINCE PROPOSAL OF THE NSPS[1]

Company	Location	Unit	Year Completed	Capacity (TPD)	Process Design	Emission Control System	
						SO_2	Acid Mist
Agrico Chemical Co.	S. Pierce, FL	10	1975	2000	DA	Process	York Demister
		11	1975	2000	DA	Process	York Demister
	Donaldsonville, LA	10	1974	1800	DA	Process	York Type "S"
		11	1975	1800	DA	Process	York Type "S"
Allied Corp.	Anacortes, WA	D	1975	115	DA	Process	Fiber Mist Elim.
American Cyanamid	Westwego, LA		1978	1600	DA	Process	Mist Eliminator
	Savannah, GA	1	1975	800	DA	Process	Brink Demister
Badger Army Ammunition Plant	Baraboo, WI	1	1981	350	SA	Sodium Sulfite	Mist Eliminator
Beker Ind. Inc.	Conda, ID	1	1973	1200	DA	Process	Brink Mist Elim.
	Taft, LA	2	1974	800	SA	Ammonia Scrubber	Brink Demister
CF Ind. Inc.	Bartow, FL	7	1975	2000	DA	Process	Brink HV Demister
	Plant City, FL	C	1975	1500	DA	Process	Brink Demister
	Plant City, FL	D	1975	1500	DA	Process	Brink Demister
CIL Chem. Inc.	Sayerville, NJ	C	1975	1000	DA	Process	Mist Eliminator
		F	1975	1000	DA	Process	Mist Eliminator
Conserv. Inc.	Nichols, FL	1	1982	2000	DA	Process	Monsanto CS-II
Farmland Ind.	Bartow, FL	3	1982	1600	DA	Process	Demisters
		4	1982	1600	DA	Process	Demisters
Freeport Chem. Co.	Uncle Sam, LA	D	1974	1250	DA	Process	Fiber Mist Elim.
Gardinier, Inc.	Tampa, FL	7	1980	1750	DA	Process	Fiber Mist Elim.
		9	1976	2600	DA	Process	Fiber Mist Elim.
W.R. Grace & Co.	Bartow, FL	4	1976	1800	DA	Process	Brink Demister
		5	1976	1800	DA	Process	Brink Demister
		6	1977	1800	DA	Process	Brink Demister
Industrial Chemicals	Penuelas, PR	1	1976	60	SA	Ammonia Scrubber	Glass Fiber Mist Eliminator

TABLE 4-1. CONTACT SULFURIC ACID PLANTS BUILT SINCE PROPOSAL OF THE NSPS (cont)

Company	Location	Unit	Year Completed	Capacity (TPD)	Process Design	Emission Control System	
						SO_2	Acid Mist
International Minerals & Chemicals Corp.	New Wales, FL	1	1975	2750	DA	Process	Brink Demister
		2	1975	2750	DA	Process	Brink Demister
		3	1975	2750	DA	Process	Brink Demister
		4	1981	2500	DA	Process	Brink Demister
		5	1981	2500	DA	Process	Brink Demister
Mississippi Chem. Corp.	Pascagoula, MS	3	1975	1500	DA	Process	Bayer/Lurgi Mist Eliminator
Occidental Chem. Corp.	White Springs, FL	C	1975	1800	DA	Process	Brinks Demister
		D	1975	1800	DA	Process	Brinks Demister
		E	1980	2000	DA	Process	Brinks Demister
		F	1980	2000	DA	Process	Brinks Demister
PVS Chem. Inc.	Copley, OH	1	1976	250	DA	Process	Monsanto Demister
Rohm & Haas Corp.	Deer Park, TX	3	1976	800	SA	Ammonia Scrubber	Fiber Mist Elim.
Shell Chem. Co.	Wood River, IL	1	1978	360	DA	Process	Fiber Mist Elim.
J.R. Simplot Co.	Helm, CA	4	1976	1800	DA	Process	Brinks Demister
	Pocatello, ID	1	1976	500	SA	Ammonia Scrubber	Brinks Demister
		2	1976	600	SA	Ammonia Scrubber	Brinks Demister
Texasgulf, Inc.	Aurora, NC	3	1976	1525	DA	Process	Brinks Demister
		4	1974	1525	DA	Process	Brinks Demister
		5	1981	3100	DA	Process	Brinks Demister
USS Agri-Chemicals	Ft. Meade, FL	1	1982	2200	DA	Process	Demisters
		2	1982	2200	DA	Process	Demisters

SA = Single Absorption
DA = Dual Absorption

- Contact acid plant operators are familiar with the operations involved.

Figure 4-1 is a process flowsheet of the dual absorption process. The SO_3 formed in the first three converter stages is removed in a primary absorption tower and the remainder of the gas is returned to the final conversion stage(s). Removal of a product of a reversible reaction

$$SO_2 + 1/2\ O_2 \rightarrow SO_3$$

drives the oxidation further toward completion approaching the reaction equilibrium expressed by:

$$K = \frac{SO_3}{(SO_2)\ (O_2)^{1/2}}$$

where K is the reaction equilibrium constant peculiar to the temperature of the reaction and the parenthetical entities are the molar quantities of the gases involved. The resulting SO_3 is absorbed in a secondary absorption tower which yields at least 99.7 percent overall conversion of the sulfur to sulfuric acid.[2]

The dual absorption process permits higher inlet SO_2 concentrations than normally used in single absorption plants since the second conversion step effectively handles the residual SO_2 from the first conversion step. Higher inlet SO_2 concentrations permit a reduction in equipment size which partially offsets the cost of the additional equipment required for a dual absorption plant. The dual absorption equipment occupies little more space than a conventional plant, even though an additional absorber is required.

Spent acid or H_2S may be used as feedstock in dual absorption processes with appropriate conventional process gas pretreatment, i.e., particulate

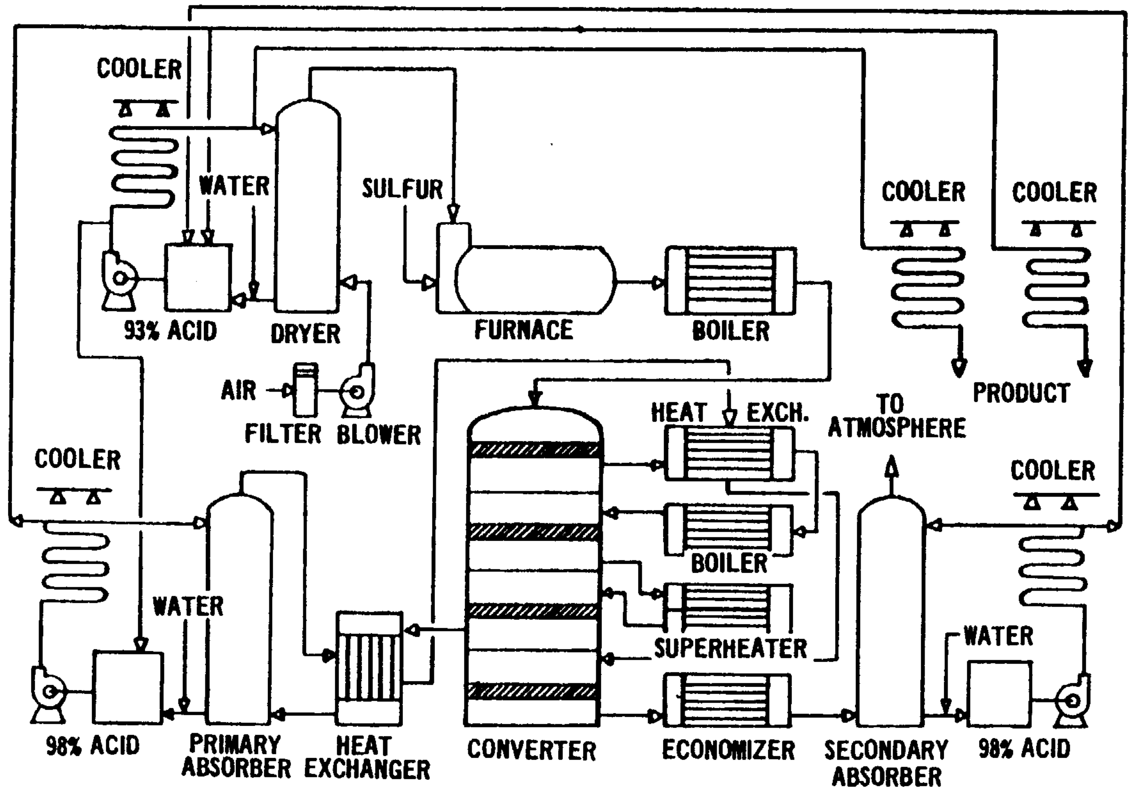


FIGURE 4-1
DUAL ABSORPTION SULFURIC ACID PLANT
FLOW DIAGRAM

removal. The dual absorption process requires the same types of equipment as the conventional single absorber design. Although additional equipment is required, the on-stream production factor and manpower requirement are the same.[3]

4.1.2 Sodium Sulfite - Bisulfite Scrubbing

Tail gas scrubbing systems are generally applicable to all classes of contact acid plants. They can provide control of SO_2 and to some extent SO_3 and acid mist.

In the Wellman-Power Gas process, the tail gases are first passed through a mist eliminator to reduce acid mist. Following mist removal, the SO_2 is absorbed in a three-stage absorber with a sodium sulfite solution. A sodium bisulfite solution results and is fed to a heated crystallizer where sodium sulfite crystals are formed and SO_2 gas and water vapor are released. The crystals are separated from the mother liquor and dissolved in the recovered condensate for recycle to the absorber. The recovered wet SO_2 is sent back to the acid plant.[4]

In all processes employing sulfite-bisulfite absorption even without regeneration, some portion of the sulfite is oxidized to sulfate, from which the sulfur dioxide cannot be regenerated in the heating sequence. This sulfate must be purged from the system. In the Wellman-Power Gas process, some thiosulfate is also formed. Apparently, the extent of oxidation is dependent on several factors such as the oxygen content of the gas stream, the temperature and residence time of the liquor in the recovery sections, and the presence of contaminants that may act as oxidation catalysts.[5]

Since promulgation of the NSPS, two plants have used the sodium sulfite-bisulfite control system. One of the plants was designed for dual absorption but later converted the second absorber to a sodium sulfite-bisufite system. The sodium sulfite-bisulfite system presented operational difficulties, however, and was subsequently converted to an ammonia scrubber, which is the control system the plant currently uses.[6] The other plant was designed to use sodium sulfite-bisulfite scrubbing from the outset. The plant is part of an Army ammunition production facility, however, and has not been used. Construction of the plant was completed in 1981 and the plant was operated only long enough to verify its operability. Emissions from the plant have not been measured.[7]

4.1.3 Ammonia Scrubbing

The ammonia scrubbing process uses anhydrous ammonia (NH_3) and water make-up in a two-stage scrubbing system to remove SO_2 from the acid plant tail gas. Excess ammonium sulfite-bisulfite solution is reacted with sulfuric acid in a stripper to evolve SO_2 gas and produce an ammonium sulfate by-product solution. The SO_2 is returned to the acid plant and the solution is treated for the production of fertilizer grade ammonium sulfate. The process is dependent on a suitable market for ammonium sulfate.[8]

Five NSPS sulfuric acid plants use an ammonia scrubbing system for tail gas SO_2 emissions control.

4.1.4 Molecular Sieves

This process utilizes a proprietary molecular sieve system in which SO_2 is adsorbed on synthetic zeolites. The adsorbed material is desorbed by purified hot tail gas from the operating system and sent back to the acid plant.

Since the promulgation of the sulfuric acid plant NSPS, one new unit was built with a molecular sieve system for SO_2 control. However, extensive operational difficulties with this system caused this plant to be retrofitted with a dual absorption system for SO_2 control. The dual absorption system was retrofited in January 1979 and has operated satisfactorily since that time.[9]

4.2 Control Technology Applicable to the NSPS for Acid Mist Emissions from Contact Process Sulfuric Acid Plants[10]

Effective control of stack gas acid mist emissions can be achieved by fiber mist eliminators and electrostatic precipitators (ESP's). Although ESP's are frequently used in the purification section of spent acid plants, there is no evidence that any have been installed to treat the stack gas of any new sulfuric acid plants. Even though ESP's have the advantage of operating with a lower pressure drop than fiber mist eliminators (normally less than 1 inch of water), lack of application of this equipment to new sulfuric acid units is probably due primarily to its relatively large size and resultant high installation cost compared to fiber mist eliminators. Maintenance costs (to keep the ESP's operating within proper tolerances for the acid environment which is corrosive to the mild steel equipment) are also high.

Mist eliminators are generally located downstream of the SO_2 absorbers to collect mist generated during the production process. An exception to this is when a sodium sulfite-bisulfite scrubber is used to control SO_2 emissions. With the sodium sulfite system, it is best to locate the mist eliminator <u>upstream</u> of the scrubber to minimize the formation of sulfates which must be purged from the system. The scrubber exit gas does not normally require mist removal.

Fiber mist eliminators utilize the mechanisms of impaction and interception to capture large to intermediate size mist particles and of Brownian movement to effectively collect micron to submicron size particles. Fibers used may be chemically resistant glass or fluorocarbon. Fiber mist eliminators are available in three different configurations covering a range of efficiencies required for for various plants having low to high acid mist loadings and coarse to fine mist particle sizes, respectively. The three fiber mist eliminator configurations are:

1. Verticle tube
2. Verticle panels
3. Horizontal dual pads.

4.2.1 Vertical Tube Mist Eliminators

Tubular mist eliminators consist of a number of vertically oriented tubular fiber elements installed in parallel in the top of the absorber on new acid plants and usually installed in a separate tank above or beside the absorber on existing plants. Each element consists of glass fibers packed between two concentric screens made of 316 stainless steel. In an absorber installation (see Figure 4-2) the bottom end cover of the element is equipped with a liquid seal pot to prevent gas bypassing. A pool of acid provides the seal in the separate tank design. Mist particles collected on the surface of the fibers become a part of the liquid film which wets the fibers. The liquid film is moved horizontally through the fiber beds by the gas drag and is moved downward by gravity. The liquid overflows the seal pot continuously, returning to the process.

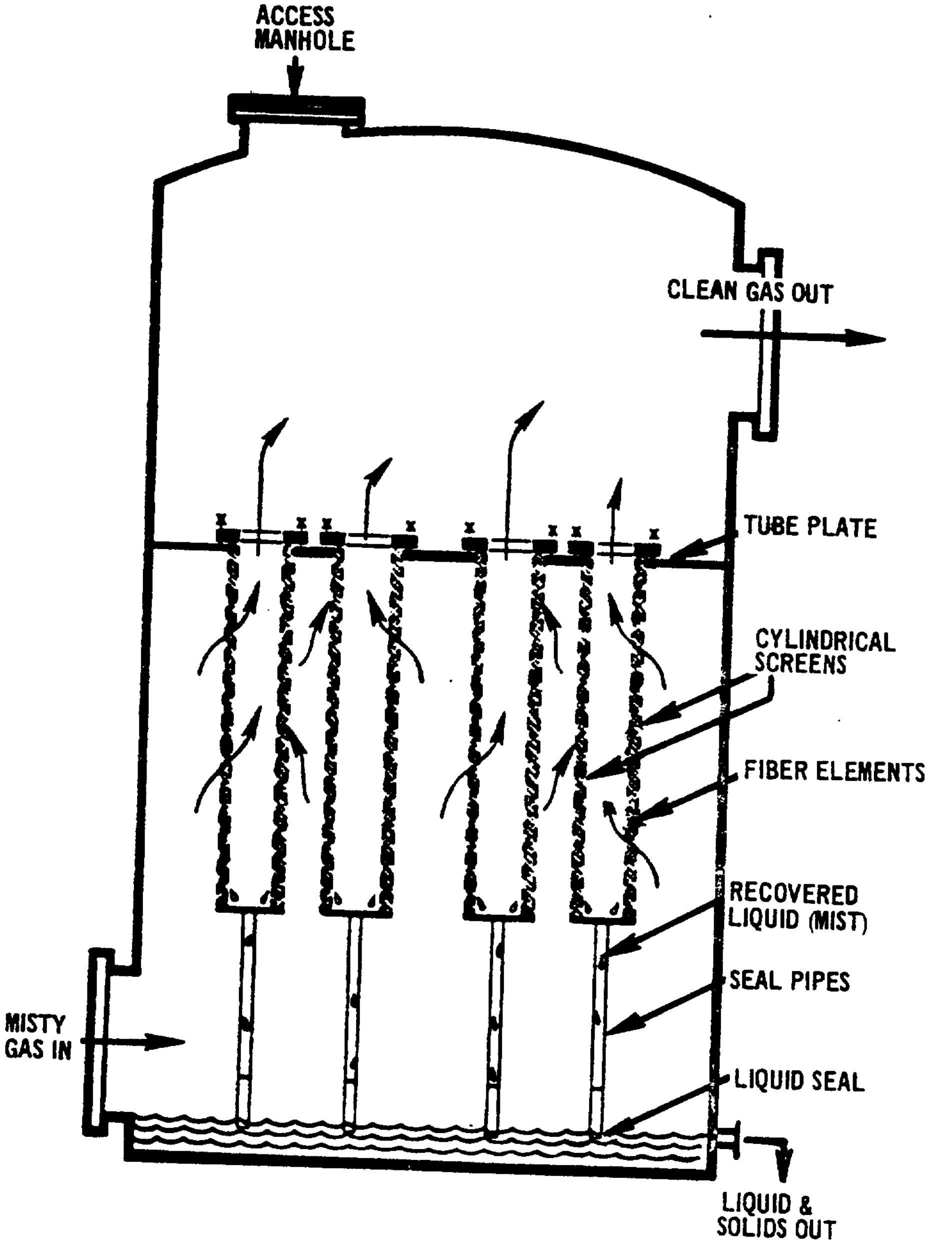


FIGURE 4-2
VERTICAL TUBE MIST ELIMINATOR INSTALLATION

Tubular mist eliminators use inertial impaction to collect larger particles (normally greater than 3 microns) and use direct interception and Brownian movement to collect smaller particles. The low superficial velocity of gas passing through the fiber bed (20 to 40 feet per second) provides sufficient residence time for nearly all of the small particles with random Brownian movement to contact the wet fibers, effecting removal from the gas stream. The probability that such a particle could pass through the bed following the resultant greatly lengthened travel path is very low.

Design volumetric flow rate through an element is about 1000 standard cubic feet per minute (scfm), and the number of elements required for a given plant size can be determined from the gas volume handled at capacity. Depending on the size of the sulfuric acid plant, anywhere from 10 to 100 elements may be used; each element is normally 2 feet in diameter and 10 feet high.

Pressure drop across the element varies from 5 to 15 inches of water with a higher pressure drop required for a higher removal efficiency on particles smaller than 3 microns. The manufacturer of these elements guarantees a mist removal efficiency of 100 percent on particles larger than 3 microns and 90 to 99.8 percent on particles smaller than 3 microns with 99.3 percent being most common. These efficiencies can be achieved on the stack gas of sulfuric acid plants burning elemental sulfur or bound-sulfur feedstocks (spent acid, wet gas, etc.) and producing acid or oleum.

Because the vertical tube mist eliminator does not depend only upon impaction for mist removal, it can be operated at a volumetric flow rate considerably below design with no loss in efficiency.

As can be seen on Table 4-1, the vertical tube mist eliminator (Brinks type) is used in the great majority of new sulfuric acid units for acid mist control.

4.2.2 Vertical Panel Mist Eliminators

Panel mist eliminators use fiber panel elements mounted in a polygon framework closed at the bottom by a slightly conical drain pan equipped with an acid seal pot to prevent gas bypassing. The polygon top is surmounted by a circular ring which is usually installed in the absorption tower and welded to the inside of the absorption tower head. Each panel element consists of glass fibers packed between two flat parallel 316 stainless steel screens. In large high velocity towers, recent designs have incorporated double polygons, one inside the other, to obtain more bed area in a given tower cross section. Pressure drop across the panel is usually about 8 inches of water.

As in the high efficiency tubular mist eliminator above, the gas flows horizontally through the bed, but at a much higher superficial velocity (400 to 500 ft/min) using the impaction mechanism for collection of the mist particles. Gas leaving the bed flows upward to the exit port, while the collected liquid drains downward across the pan and out through the seal pot back into the tower or to a separate drain system (see Figure 4-3).

The polygon may contain 10 to 48 vertical sides, each side normally consisting of an 18 1/2" x 53" panel. A smaller 18 1/2" x 26" panel is available for small plants, e.g., 35 tons per day.

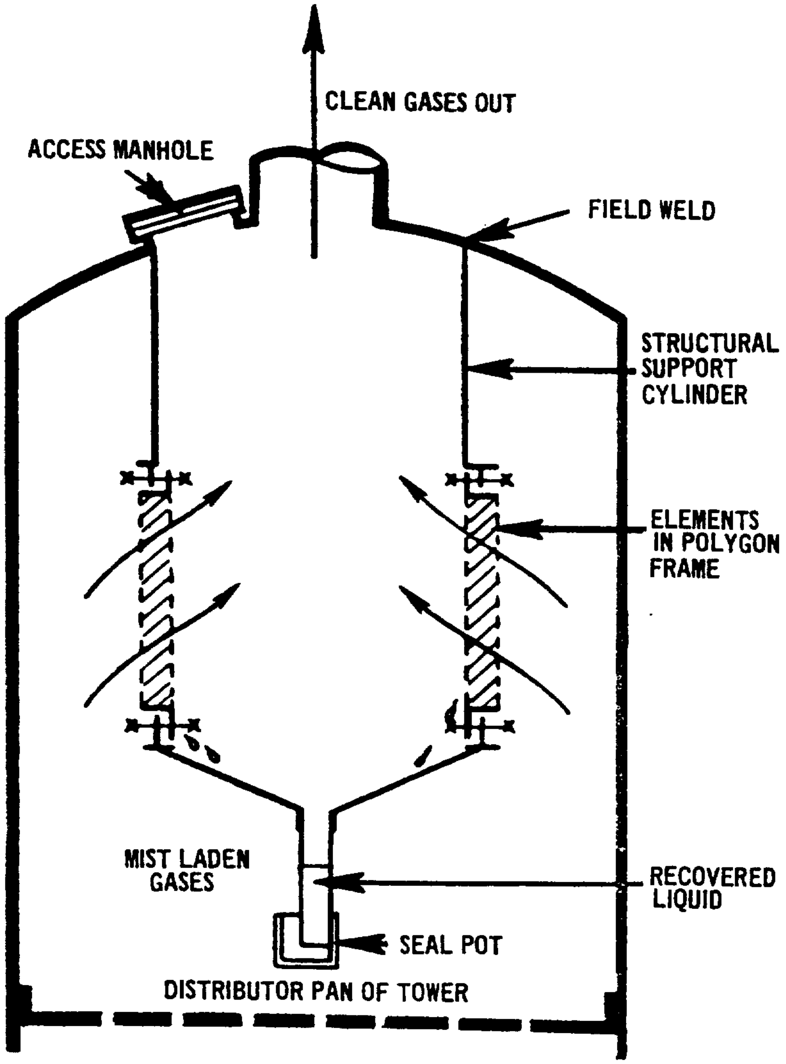


FIGURE 4-3
VERTICAL PANEL MIST ELIMINATOR INSTALLATION

Because of the large percentage of submicron mist present in the stack gas of a spent acid plant and of a plant producing oleum stronger than 20 percent, the vertical panel mist eliminator will usually give unsatisfactory performance for these plants when used for acid mist control in the tail gas. These units are generally used in dual absorption plants for removal of acid mist from the intermediate absorber to protect downstream equipment from corrosion.

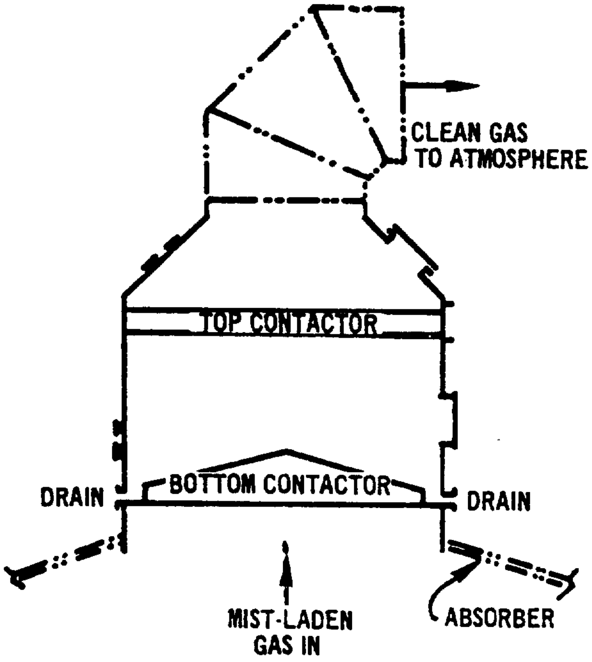
Vertical panel mist eliminators normally operate with a liquid level in the acid seal pot below the conical drain pan. Although the velocity through the panels could be increased at lower throughputs by raising the liquid level to cover the lower part of each panel, this would cause reentrainment of spray by the gas passing over the liquid level in the basket.

4.2.3 Horizontal Dual Pad Mist Eliminators

Two circular fluorocarbon fiber beds held by stainless steel screens are oriented horizontally in a vertical cylindrical vessel one above the other, so that the coarse fraction of the acid mist is removed by the first pad (bottom contactor) and the fine fraction by the other (top contactor), as shown in Figure 4-4. The bottom contactor consists of two plane segmented sections installed at an angle to the horizontal to facilitate drainage and give additional area for gas contact. The assembly may be located either adjacent to or on top of the absorption tower.

This unit uses the high velocity impacting mist collection mechanism, as does the panel mist eliminator; however, the collected acid drains downward through the pads countercurrent to the gas flow producing a scrubbing action as well. Collected acid may be drained from external connections or returned directly to the absorber through liquid seal traps.

Total pressure drop across both pads is usually about 9 inches of water. The superficial velocity through the unit is 9 to 10 feet per second. Hence, the diameter of the cylindrical shell and the pads is determined from the volume of gas handled. Height requirements for the unit depend upon whether it is located adjacent to or positioned on the absorber, but are roughly 1.5 to 2 times the diameter of the unit.



(COURTESY OF YORK SEPARATORS, INC.)

FIGURE 4-4
HORIZONTAL DUAL PAD MIST ELIMINATOR

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1. Information generated from the following sources:

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b. Tennessee Valley Authority. World Fertilizer Capacity - Sulfuric Acid. Printout dated August 16, 1984. 12 p.

c. SRI international. 1984 Directory of Chemical Producers. Menlo Park, California. 1984.

d. Letter and attachments from Thomas, W.C., State of Florida Department of Environmental Regulation, to Beck, L.L., EPA. May 21, 1984.

e. Massoglia, M.F., D.D. McFadden and L.L. Piper (Research Triangle Institute). The NSPS Triennial Review: Final Report. Prepared for U.S. Environmental Protection Agency, Washington, D.C. RTI Publication No. RTI/2747/01-18F, December 20, 1984.

f. Telephone Conversations initiated by Lee Beck, U.S. Environmental Protection Agency, with the following individuals:

Conversation Date	Person Contacted	Affiliation
February 13, 1984	Bruce Varner	EPA, Region V
February 16, 1984	Rick Watman	EPA, Region III
March 29, 1984	Mark Hooper	EPA, Region X
November 19, 1984	Ken Roberts	Florida Dept. of Environmental Regulation
December 5, 1984	Steve Riva	EPA, Region II
December 5, 1984	Ed Chromanski	NJ Bureau of Air Pollution Control
December 5, 1984	Ann Zownier	NJ Bureau of Air Pollution Control
December 5, 1984	John Hollingsworth	CIL Chemicals, Inc.
January 23, 1985	Jerry Vetter	Beker Industries, Inc.
January 25, 1985	Sammy Amerson	NC Division of Environmental Management
January 28, 1985	Johnnie Cole	Florida Dept. of Environmental Regulation
January 28, 1985	Fred Roe	GA Environmental Protection Division
February 4, 1985	Sammy Amerson	NC Division of Environmental Management
February 4, 1985	John Ledger	Idaho Division of Environmental Management
February 5, 1985	Ed Chromanski	NJ Bureau of Air Pollution Control
February 5, 1985	Byron Sullivan	NJ Bureau of Air Pollution Control
February 8, 1985	Ed Chromanski	NJ Bureau of Air Pollution Control

February 14, 1985	Craig Rushin	EPA, Region VI
February 22, 1985	Chris Roeder	Florida Dept. of Environmental Regulation
February 25, 1985	Pat McCoy	EPA, Region V
March 14, 1985	Lynn Malcolm	Ohio Environmental Protection Agency
March 27, 1985	Charles Meskal	Fresno County Air Pollution Control District

2. Drabkin, M. and K. J. Brooks (Mitre Corporation). A Review of Standards of Performance for New Stationary Sources - Sulfuric Acid Plants. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-79-003. January 1979. p. 4-1.

3. Reference 2, p. 4-26 and 4-28.

4. Reference 2, p. 4-28 and 2-29.

5. Reference 2, p. 4-29.

6. Telecon. Beck, Lee, EPA, OAQPS, with Riva, Steve, EPA, Region II. December 5, 1984. NSPS Sulfuric Acid Plants in EPA Region II.

7. Telecon. Beck, Lee, EPA, OAQPS, with McCoy, Pat, EPA, Region V. February 25, 1985. NSPS Sulfuric Acid Plants in EPA Region V.

8. Reference 2, p. 4-29.

9. Reference 7.

10. Office of Air Quality Planning and Standards. Final Guideline Document: Control of Sulfuric Acid Mist Emissions from Existing Sulfuric Acid Production Units. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/2-77-019. September 1977. pp. 6-1 through 6-23.

5.0 COMPLIANCE TEST RESULTS

Several resources were accessed to determine the NSPS compliance status of sulfuric acid plants operating in the United States, including:

- EPA Regional Offices
- State environmental control offices
- Local environmental control offices
- A printout of EPA's Compliance Data System
- A study performed for EPA's Office of Planning and Policy Evaluation by the Research Triangle Institute

The results of this survey show that there are 46 NSPS plants currently operating in the United States, and all appear to be in compliance with the NSPS.

5.1 Analysis of NSPS Compliance Test Results

The NSPS limits emissions of SO_2 to 4 pounds per ton of acid produced. As shown in Table 5-1, results of compliance tests (Method 8) on the 46 sulfuric acid units indicate that all have achieved the NSPS for SO_2. However, most of the plants operate with SO_2 emissions between 2 and 4 pounds per ton, and about half of these are in excess of 3 pounds per ton. The available information is insufficient to determine whether the plants with highest emissions could achieve lower emissions through changes in maintenance or operation.

Performance test results indicate that all plants have also complied with the NSPS for acid mist, and no violation of the opacity regulation was measured at 30 plants. Similar to the SO_2 emissions, many plants were found to be operating close to the NSPS limit for acid mist and opacity. Opacity data are not available for the remaining 16 plants.

TABLE 5-1. NSPS COMPLIANCE TEST RESULTS FOR SULFURIC ACID PLANTS[1]

Company	Location	Unit	Capacity (TPD)	Emission Test Results		
				SO_2	Acid Mist	Opacity
Agrico Chemical Co.	S. Pierce, FL	10	2000	3.72	0.11	0
		11	2000	3.43	0.12	0
	Donaldsonville, LA	10	1800	2.2	NA	NA
		11	1800	1.1	0.08	NA
Allied Corp.	Anacortes, WA	D	115	1.07	0.004	NA
American Cyanamid	Westwego, LA	1	1600	3.20	0.02	NA
	Savannah, GA	1	800	2.21	0.09	0
Badger Army Ammunition Plant	Baraboo, WI	1	350	Down/Never Tested		
Beker Ind. Inc.	Conda, ID	1	1200	3.7	0.12	NA
	Taft, LA	2	800	0.84	0.01	NA
CF Ind. Inc.	Bartow, FL	7	2000	0.12	0.02	NA
	Plant City, FL	C	1500	2.76	0.05	0
	Plant City, FL	D	1500	1.81	0.05	2.7
CIL Chem. Inc.	Sayerville, NJ	C	1000	1.12	0.04	0
		F	1000	3.7	0.12	0
Conserv. Inc.	Nichols, FL	1	2000	2.2	0.12	0
Farmland Ind.	Bartow, FL	3	1600	1.2	0.07	0
		4	1600	1.3	0.08	5
Freeport Chem. Co.	Uncle Sam, LA	D	1250	1.96	0.11	NA
Gardinier, Inc.	Tampa, FL	7	1750	1.37	0.05	0
		9	2600	1.98	0.06	0
W.R. Grace & Co.	Bartow, FL	4	1800	1.8	0.06	5.2
		5	1800	0.9	0.13	5.0
		6	1800	2.5	0.09	5.8

TABLE 5-1. NSPS COMPLIANCE TEST RESULTS FOR SULFURIC ACID PLANTS (cont)

Company	Location	Unit	Capacity (TPD)	Emission Test Results		
				SO_2	Acid Mist	Opacity
Industrial Chemicals	Penuelas, PR	1	60	0.15	0.02	NA
International Minerals & Chemicals Corp.	New Wales, FL	1	2750	2.64	0.04	0
		2	2750	2.29	0.03	0
		3	2750	3.17	0.06	NA
		4	2500	2.10	0.02	0
		5	2500	3.79	0.05	0
Mississippi Chem. Corp.	Pascagoula, MS	3	1500	0.95	0.13	NA
Occidental Chem. Corp.	White Springs, FL	C	1800	3.47	0.10	0
		D	1800	3.71	0.04	0
		E	2000	2.61	0.05	0
		F	2000	3.32	0.04	0
PVS Chem. Inc.	Copley, OH	1	250	2.53	0.09	NA
Rohm & Haas Corp.	Deer Park, TX	3	800	2.32	0.08	9.2
Shell Chem. Co.	Wood River, IL	1	360	3.24	0.01	NA
J.R. Simplot Co.	Helm, CA	4	1800	2.30	0.04	NA
	Pocatello, ID	1	500	3.6	0.15	NA
		2	600	3.6	0.15	NA
Texasgulf, Inc.	Aurora, NC	3	1525	1.7	0.05	0
		4	1525	1.8	0.07	0
		5	3100	2.52	0.13	0
USS Agri-Chemicals	Ft. Meade, FL	1	2200	2.0	0.05	6.6
		2	2200	1.2	0.04	6.6

5.2 Comparison of NSPS Compliance Test Data with Day-to-Day Emission Control Performance[2]

Literature indicates that dual absorption plants can be expected to operate after an initial startup period with fresh catalyst with SO_2 emissions in the range of 2 to 3 lb/ton. To determine whether emission control performance deteriorates with time, a number of inquiries were made of sulfuric acid plants that were subject to NSPS.

Data obtained from an 1,800 ton/day dual absorption sulfuric acid plant (two production units) indicated an apparent deterioration of emission performance following initial startup. The NSPS compliance test for this plant (Method 8) showed emissions to average 0.93 lb SO_2 per ton of acid produced. About a year later, emissions recorded by the continuous emissions monitor (CEM) had increased to 2.59 lb/ton. Nineteen months after the performance test, the emission recorded by the CEM had increased to 2.95 lb/ton, and the CEM data recorded 30 months after the performance test indicated a SO_2 emission rate of 3.2 lb/ton.

Another plant had an NSPS test result of 0.95 lb SO_2/ton after fresh catalyst was added to the absorption towers, but reported a day-to-day operating level of 1 to 2 lb SO_2/ton.

From these data, it can be seen that the SO_2 emission values obtained during the initial compliance test do not necessarily reflect day-to-day plant operating levels. These levels appear to realistically lie in the 2 to 3 lb/ton range for dual absorption units. There is a definite trend towards increased SO_2 emission values as the conversion catalyst ages and its activity correspondingly decreases. Thus, even though a large percentage of the compliance test results are significantly less than the NSPS of 4 lb/ton, it appears that SO_2 emissions tend to rise towards the control limit as the plant and catalyst age.

Acid mist emission (and related opacity) levels are unaffected by conversion catalyst aging. These emissions are primarily a function of moisture levels in the sulfur feedstock and air fed to the sulfur burner, and the efficiency of final absorber operation.

5.3 Analysis of SO_2 Excess Emissions Reports

Periods of excess emissions were compiled for each NSPS sulfuric acid plant operating in the United States during the period of April 1983 through March 1984.[3] During that 12-month period, 13 plants reported exceedances, with the number of individual exceedances at the 13 plants ranging in number from 1 to 49.

Analysis of these reports indicates considerable variation among respondents in the interpretation of the excess emission report (EER) requirements. The general provisions of the regulations define the content of EERs as it pertains to exceedances as:

> The magnitude of excess emissions computed in accordance with §60.13(h), any conversion factor(s) used, and the date and time of commencement and completion of each time period of excess emissions. [§60.7(c)(1)]

Subpart H defines exceedances as:

> Periods of excess emissions shall be all three-hour periods (or the arithmetic average of three consecutive one-hour periods) during which the integrated average sulfur dioxide emissions exceed the applicable standards in §60.82. [§60.84(e)]

Of the 13 reports showing exceedances, only five of these correctly defined exceedances as a 3-hour period during which the average emissions exceeded the standard. The remaining eight reported all periods of time during which the standard was exceeded. These periods ranged from 2 minutes to 20 hours. Many of the shorter periods of reported exceedances (2 hours or less) probably would not show up as exceedances if integrated over the 3-hour period in which they occurred. Conversely, exceedances lasting over 3 hours are reported as one exceedance, when as many as seven could be involved if converted to 3-hour integrated periods.

The effect of the apparent oversight of the 3-hour duration reporting requirements can be further illustrated by considering the 12 months of EER data reported by one plant. The plant reported 39 incidences of excess emissions for the year with the following durations:

° Less than 1 hour	18
° 1 to 2 hours	5
° 2 to 4 hours	6
° 4 to 6 hours	7
° Over 6 hours	3

Only about half of the reported exceedances would be considered excess emissions for which reporting would be required.

5.4 REFERENCES

1. Information generated from the following sources:

a. Stationary Source Compliance Division, U.S. Environmental Protection Agency. Compliance Data System Source Data Report. Printouts dated February 3, 1984, and January 25, 1985. 92 p.

b. Tennessee Valley Authority. World Fertilizer Capacity - Sulfuric Acid. Printout dated August 16, 1984. 12 p.

c. SRI international. 1984 Directory of Chemical Producers. Menlo Park, California. 1984.

d. Letter and attachments from Thomas, W.C., State of Florida Department of Environmental Regulation, to Beck, L.L., EPA. May 21, 1984.

e. Massoglia, M.F., D.D. McFadden and L.L. Piper (Research Triangle Institute). The NSPS Triennial Review: Final Report. Prepared for U.S. Environmental Protection Agency, Washington, D.C. RTI Publication No. RTI/2747/01-18F, December 20, 1984.

f. Telephone Conversations initiated by Lee Beck, U.S. Environmental Protection Agency, with the following individuals:

Conversation Date	Person Contacted	Affiliation
February 13, 1984	Bruce Varner	EPA, Region V
February 16, 1984	Rick Watman	EPA, Region III
March 29, 1984	Mark Hooper	EPA, Region X
November 19, 1984	Ken Roberts	Florida Dept. of Environmental Regulation
December 5, 1984	Steve Riva	EPA, Region II
December 5, 1984	Ed Chromanski	NJ Bureau of Air Pollution Control
December 5, 1984	Ann Zownier	NJ Bureau of Air Pollution Control
December 5, 1984	John Hollingsworth	CIL Chemicals, Inc.
January 23, 1985	Jerry Vetter	Beker Industries, Inc.
January 25, 1985	Sammy Amerson	NC Division of Environmental Management
January 28, 1985	Johnnie Cole	Florida Dept. of Environmental Regulation
January 28, 1985	Fred Roe	GA Environmental Protection Division
February 4, 1985	Sammy Amerson	NC Division of Environmental Management
February 4, 1985	John Ledger	Idaho Division of Environmental Management
February 5, 1985	Ed Chromanski	NJ Bureau of Air Pollution Control
February 5, 1985	Byron Sullivan	NJ Bureau of Air Pollution Control
February 8, 1985	Ed Chromanski	NJ Bureau of Air Pollution Control
February 14, 1985	Craig Rushin	EPA, Region VI
February 22, 1985	Chris Roeder	Florida Dept. of Environmental Regulation
February 25, 1985	Pat McCoy	EPA, Region V
March 14, 1985	Lynn Malcolm	Ohio Environmental Protection Agency
March 27, 1985	Charles Meskal	Fresno County Air Pollution Control District

2. Drabkin, M. and K. J. Brooks (Mitre Corporation). A Review of Standards of Performance for New Stationary Sources - Sulfuric Acid Plants. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-79-003. January 1979. pp. 5-9 through 5-11.

3. Massoglia, M.F., D.D. McFadden and L.L. Piper (Research Triangle Institute). The NSPS Triennial Review: Final Report. Prepared for U.S. Environmental Protection Agency, Washington, D.C. RTI Publication No. RTI/2747/01-18F, December 20, 1984.

6. COST ANALYSIS

This chapter presents current (June 1984) costs of control systems necessary to meet the sulfur dioxide and sulfuric acid mist emission provisions of the current NSPS for sulfuric acid plants. Four systems are analyzed for sulfur dioxide control: the dual absorption sulfuric acid process; the molecular sieve; the sodium sulfite-bisulfite scrubbing process; and the ammonia scrubbing process. For control of sulfuric acid mist, two types of mist eliminators are analyzed: the vertical tube ("candle" or "Brink") type and the horizontal dual pad (York "S") type. Capital and annualized costs are estimated for the following model plant sizes, all given on a 100 percent acid basis: 681 Mg per day (750 tons per day) and 1,361 Mg per day (1,500 tons per day).

The costs presented are based primarily on information provided by vendors and developed from literature sources. (See Appendix A for copies of letters sent to vendors.) Capital costs are on a turnkey basis and thus include the purchase cost of equipment and auxiliaries, taxes, freight, and all necessary installation costs, as well as indirect costs such as engineering and supervision, construction and field expense, contractor fee, and contingency. Annualized costs include direct operating costs such as operating labor, maintenance labor, utilities, and materials, as well as indirect costs such as capital charges, overhead, property taxes, insurance, and administration. Net annualized cost is also presented, representing total annualized cost less the credit for recovered sulfuric acid product. Since the capital costs were obtained from turnkey cost correlations, they are, by definition, "order-of-magnitude" (i.e., greater than ±30 percent in accuracy). Because many of the annualized costs were calculated directly, the accuracy of the annualized cost estimates is expected to approach that of a study estimate (±30 percent). Finally, cost effectiveness is given for both sulfur dioxide control and control of sulfuric acid mist.

6.1 DUAL ABSORPTION PROCESS

6.1.1 Capital Costs

The capital costs for dual absorption are estimated for the two model plants and represent the incremental costs of achieving the NSPS compared to an uncontrolled, i.e. single absorption, plant. The control system is comprised of all the equipment necessary for providing the second absorption: an absorption tower, pumps, heat exchangers, and piping and instrumentation.

The dual absorption process has essentially become the state of the art for producing sulfuric acid. Therefore, plant vendors are the best source of cost information concerning the second absorption portion of the plant. Accordingly, contact with vendors provided total turnkey costs (References 1, 2, and 3) from which were factored out the individual direct and indirect cost components by use of appropriate factors based on data from Reference 8. All costs were updated to June 1984 dollars by employment of the Chemical Engineering (CE) Plant Cost Index. Tables 6-1 and 6-2 present the capital costs for dual absorption for the model plants.

As an example of the factoring procedure mentioned above, consider the 681 Mg per day plant for which the incremental total direct cost for dual absorption is $1,118,000. The cost of the absorber itself is calculated to be 50 percent of the total direct cost ($558,000). Similarly the costs for the auxiliary equipment are as follows: $112,000 for pumps (10 percent of total direct cost); $168,000 for piping (15 percent); and $280,000 for heat exchangers (25 percent).

6.1.2 Annualized Costs

The annualized costs associated with owning and operating the second absorption system are estimated for each of the model plants. Direct operating cost includes operation, maintenance, utilities and catalyst replacement. Utilities include an "energy penalty" or loss of steam credit for reheating of the gas prior to reentering the converter. The cost of catalyst replacement includes the disposal cost for the spent catalyst. Assumed values for consumption and unit costs associated with these items are shown in Table 6-3.

Most indirect costs were factored from capital costs or direct operating costs using appropriate factors from References 4 and 8. Capital recovery was calculated from the total capital cost with a 10 percent rate of return and a 10-year equipment life (References 4 and 8).

The annualized cost development includes an estimation of the credit for sulfuric acid recovered as a result of the second absorption. The amount

Table 6-1

CAPITAL COST SUMMARY
INCREMENTAL COST FOR DUAL ABSORPTION
681 MG PER DAY (750 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Cost[a]	
Absorber	558
Pumps	112
Piping	168
Heat exchangers	280
Total Direct Cost[b]	1,118
Indirect Cost[c]	
Engineering and supervision (10 percent of direct)	112
Construction and field expense (8 percent of direct)	89
Contractor fee (6 percent of direct)	67
Contingency (12 percent of direct)	134
Total Indirect Cost	402
Total Capital Cost	1,520

[a] Direct cost for each item of equipment includes cost of auxiliary equipment, instruments and controls, taxes, freight, foundations, handling and erection, and any other required installation costs.

[b] Cost developed from information from References 1, 2, 3 and 8.

[c] Per Reference 8.

Table 6-2

CAPITAL COST SUMMARY
INCREMENTAL COST FOR DUAL ABSORPTION
1361 MG PER DAY (1500 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Cost[a]	
Absorber	791
Pumps	158
Piping	237
Heat exchangers	395
Total Direct Cost[b]	1,581
Indirect Cost[c]	
Engineering and supervision (10 percent of direct)	158
Construction and field expense (8 percent of direct)	126
Contractor fee (6 percent of direct)	95
Contingency (12 percent of direct)	190
Total Indirect Cost	569
Total Capital Cost	2,150

[a] Direct cost for each item of equipment includes cost of auxiliary equipment, instruments and controls, taxes, freight, foundations, handling and erection, and any other required installation costs.

[b] Cost developed from information from References 1, 2, 3 and 8.

[c] Per Reference 8.

Table 6-3

CONSUMPTION AND UNIT COST ESTIMATES FOR ANNUAL INCREMENTAL OPERATING COST OF DUAL ABSORPTION

(Based on 350 Stream Days Per Year)

Operating Cost Item	Consumption (Production)	Unit Cost (Credit)
Operating labor	525 hours per year[a]	\$10.89/hour[b]
Maintenance labor	525 hours per year[a]	\$11.98/hour[c]
Plant water	$3.91 m^3$ per 1,000 Mg[d]	\$0.20/m^3[e]
Electricity (pumps, fan)	47.5 Gj per 1,000 Mg[f]	\$15.28/Gj[g]
Loss of stream credit	335 Gj per 1,000 Mg[f]	\$7.30/Gj[g]
Catalyst replacement (including disposal)	$0.01 m^3$ per 1,000 Mg[h]	\$4,240/m^3[i]
Sulfuric acid credit	17 Mg per 1,000 Mg[j]	\$71.66/Mg[k]

[a] Reference 4.

[b] Reference 5.

[c] Ten percent premium over operating labor (per Reference 4).

[d] Calculated on basis of water required for absorption.

[e] Reference 6.

[f] Reference 7.

[g] Cost updated from Reference 13.

[h] Reference 9.

[i] Reference 4 and Reference 9 (updated).

[j] Calculated from incremental efficiency of dual versus single absorption.

[k] Reference 10.

of sulfuric acid recovered for each model plant was calculated from the difference in sulfur conversion efficiency between single and dual absorption (98 and 99.7 percent, respectively, Reference 9). Credits for this recovered product were then calculated using a price of $65 per ton ($71.66 per Mg) as quoted in the Chemical Marketing Reporter. This price is based on a Gulf Coast location and has remained quite stable during the period January to June, 1984. The annualized costs for dual absorption are shown in Tables 6-4 and 6-5.

Table 6-4

ANNUALIZED COST SUMMARY
INCREMENTAL COST FOR DUAL ABSORPTION
681 MG PER DAY (750 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Operating Cost	
Operation	
Operating labor	6
Supervision labor[a]	1
Maintenance	
Labor	6
Material (100 percent of maintenance labor)[b]	6
Utilities	
Plant water[c]	-
Electricity	173
Loss of steam credit	583
Catalyst replacement	10
Indirect Operating Cost	
Overhead[d]	
Plant (50 percent of operating labor, supervision and maintenance)	7
Payroll (20 percent of operating labor, supervision and maintenance labor)	3
Capital recovery (10 percent rate of return, 10 years equipment life)	247
Insurance, taxes, and administration (four percent of total capital cost)	61
Total Annualized Cost Without Credit	1,103
Credit For Recovered Acid	(290)
Net Annualized Cost	813

[a] 15 percent of operating labor (Reference 4)
[b] Reference 4

[c] Rounded to zero

[d] Factors from Reference 8

Table 6-5

ANNUALIZED COST SUMMARY
INCREMENTAL COST FOR DUAL ABSORPTION
1361 MG PER DAY (1500 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Operating Cost	
Operation	
Operating labor	6
Supervision labor[a]	1
Maintenance	
Labor	6
Material (100 percent of maintenance labor)[b]	6
Utilities	
Plant water[c]	-
Electricity	346
Loss of steam credit	1,165
Catalyst replacement	20
Indirect Operating Cost	
Overhead[d]	
Plant (50 percent of operating labor, supervision and maintenance)	7
Payroll (20 percent of operating, supervision, and maintenance labor)	3
Capital recovery (10 percent rate of return, 10 years equipment life)	350
Insurance, taxes, and administration (four percent of total capital cost)	86
Total Annualized Cost Without Credit	1,996
Credit For Recovered Acid	(580)
Net Annualized Cost	1,416

[a] 15 percent of operating labor (Reference 4)
[b] Reference 4
[c] Rounded to zero
[d] Factors from Reference 8

6.2 MOLECULAR SIEVE PROCESS

6.2.1 Capital Costs

There are no known applications of the molecular sieve process to control SO_2 emissions from a single absorption sulfuric acid plant. Reference 9 identified one such plant but indicated that the owner planned to convert the plant to double absorption. Furthermore, the major supplier of this technology for sulfuric acid plants no longer offers the process, presumably because the technology has not proven successful for this application.

Nevertheless, a modest amount of cost data for the molecular sieve process is available (Reference 11) and has been updated and presented in Table 6-6. The reader is cautioned that: (a) the original costs are old; (b) the original costs may have been high due to necessary developmental costs; and (c) the costs presented in Table 6-6 are representative of a process that may not be adequate for continuous compliance with the sulfur dioxide emission limitation.

6.2.2 Annualized Costs

The annualized costs for the molecular sieve process are updated from Reference 11 and also presented in Table 6-6. The total annualized costs on a per ton acid basis were updated from data in the reference by the use of the CE index and are assumed to hold for all model plant sizes.

6.3 SODIUM SULFITE-BISULFITE SCRUBBING

6.3.1 Capital Costs

Reference 9 indicated no applications for sodium sulfite-bisulfite scrubbing for sulfur dioxide NSPS compliance from the time of NSPS promulgation through 1978. Furthermore, because of the wide acceptance of dual absorption technology, it is not likely that many single absorption plants

Table 6-6

CAPITAL AND ANNUALIZED COST SUMMARY
MOLECULAR SIEVE PROCESS
(June 1984 Dollars)

CAPITAL COST

	Cost in Thousands of Dollars	
	681 Mg PD	1,361 Mg PD
Total Capital Cost Cost[a]	3,363	5,105

ANNUALIZED COST

	Cost in Thousands of Dollars	
	681 Mg PD	1,361 Mg PD
Total Annualized Cost[b]	1,119	2,237

[a] Includes all direct and indirect costs for applying the process to a new sulfur-burning sulfuric acid plant (Reference 11).

[b] Includes all direct and indirect annual costs (operating and maintenance, utilities, overhead, depreciation, insurance, taxes, and administration).

with sodium sulfite-bisulfite scrubbing have been or will be built. Nevertheless, sodium-based scrubbing appears to be a viable technology for meeting the NSPS and thus costs for this technology have been estimated.

The capital costs for the two model plants were developed from vendor information, scaling the cost for the model plants by use of a 0.6 exponent. The control system in each case consists of all necessary equipment to absorb sulfur dioxide from the weak exhaust stream and regenerate a strong sulfur dioxide stream suitable for conversion to elemental sulfur or liquid sulfur dioxide or for recycle to the sulfuric acid plant itself. The capital cost excludes the cost for this conversion or recycle and therefore the annualized cost does not include a credit for recovered acid, sulfur, or liquid sulfur dioxide. Total turnkey costs were supplied (Reference 14), which were then factored to show direct cost and the various items of indirect costs. Tables 6-7 and 6-8 present these capital costs for the two model plants.

6.3.2 Annualized Costs

The annualized costs associated with owning and operating the sodium sulfite-bisulfite scrubbing systems are estimated for each model plant. Direct costs include operating labor, maintenance, and steam. The operating labor and maintenance requirements were taken from Reference 15 and the steam requirement from Reference 14. Unit costs for these items were taken from Table 6-3. The cost to treat a bleed stream of sodium salts and the cost of making caustic soda were calculated but not included as they are negligible compared to other operating costs.

Indirect costs were factored from capital or direct operating costs using the appropriate factors from References 4 and 8. Capital recovery was calculated on the basis of a 10 percent interest rate and a 10 year assumed equipment life (References 4 and 8). The annualized costs for the model plants are shown in Tables 6-9 and 6-10.

6.4 AMMONIA SCRUBBING

6.4.1 Capital Costs

Only two ammonia scrubbing applications were identified in the earlier

Table 6-7

CAPITAL COST SUMMARY
SODIUM SULFITE-BISULFITE SCRUBBING
681 MG PER DAY (750 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Total Direct Cost[a]	3,280
Indirect Cost	
Engineering and supervision (10 percent of direct)	328
Construction and field expense (8 percent of direct)	262
Contractor fee (6 percent of direct)	197
Contingency (12 percent of direct)	393
Total Indirect Cost	1,180
Total Capital Cost	4,460

[a] Direct cost of equipment includes cost of auxiliary equipment, instruments and controls, taxes, freight, foundations, handling and erection, and any other required installation costs. Costs developed from Reference 14.

Table 6-8

CAPITAL COST SUMMARY
SODIUM SULFITE-BISULFITE SCRUBBING
1361 MG PER DAY (1500 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Total Direct Cost[a]	4,970
Indirect Cost	
Engineering and supervision (10 percent of direct)	497
Construction and field expense (8 percent of direct)	398
Contractor fee (6 percent of direct)	298
Contingency (12 percent of direct)	597
Total Indirect Cost	1,790
Total Capital Cost	6,760

[a] Direct cost of equipment includes cost of auxiliary equipment, instruments and controls, taxes, freight, foundations, handling and erection, and any other required installation costs. Costs developed from Reference 14.

Table 6-9

ANNUALIZED COST SUMMARY
SODIUM SULFITE-BISULFITE SCRUBBING
681 MG PER DAY (750 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Operating Cost	
Operation	
Operating labor[a]	274
Supervision labor[b]	41
Maintenance (4 percent of total capital cost)[c]	178
Utilities	
Electricity	125
Steam	633
Indirect Operating Cost	
Overhead[d]	
Plant (50 percent of operating labor, supervision and maintenance)	202
Payroll (20 percent of operating, supervision, and maintenance labor)	81
Capital recovery (10 percent rate of return, 10 years equipment life)	726
Insurance, taxes, and administration (four percent of total capital cost)	178
Total Annualized Cost	2,438

[a] Labor requirements from Reference 15.
[b] 15 percent of operating labor (Reference 14).
[c] Reference 15.
[d] Factors from Reference 8. Assumes that 50 percent of maintenance cost is maintenance labor.

Table 6-10

ANNUALIZED COST SUMMARY
SODIUM SULFITE-BISULFITE SCRUBBING
1361 MG PER DAY (1500 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Operating Cost	
Operation	
Operating labor[a]	412
Supervision labor[b]	62
Maintenance (4 percent of total capital cost)[c]	270
Utilities	
Electricity	251
Steam	1,266
Indirect Operating Cost	
Overhead[d]	
Plant (50 percent of operating labor, supervision and maintenance)	305
Payroll (20 percent of operating, supervision, and maintenance labor)	122
Capital recovery (10 percent rate of return, 10 years equipment life)	1,100
Insurance, taxes, and administration (four percent of total capital cost)	270
Total Annualized Cost	4,058

[a] Labor requirements from Reference 15.
[b] 15 percent of operating labor (Reference 14).
[c] Reference 15.
[d] Factors from Reference 8. Assumes that 50 percent of maintenance cost is maintenance labor.

NSPS review (Reference 9). Because of the production of ammonium sulfate as a by-product, this scrubbing process could possibly be desirable for sulfuric acid plants that are part of a fertilizer complex. Therefore, costs for this technology have been estimated, although the technology would probably only be employed in preference to dual absorption in highly-specific applications.

The capital costs for the two model plants were developed from information supplied by a vendor of this technology and using an approach similar to that for sodium-based scrubbing. As with the sodium sulfite-bisulfite scrubbing system, this system includes all necessary equipment to absorb sulfur dioxide and regenerate a strong sulfur dioxide stream for further processing. The cost of a plant to recover elemental sulfur or produce liquid sulfur dioxide is not included. The acid plant is assumed to be part of a fertilizer complex and thus facilities for granulating the ammonium sulfate by-product will be available. The direct and indirect costs were factored from the total turnkey costs (Reference 14) by employing appropriate factors from References 4 and 8. Tables 6-11 and 6-12 present the capital costs.

6.4.2 Annualized Costs

The annualized costs for ammonia scrubbing are estimated for each model plant. The direct costs include operating labor, maintenance, electricity, and the cost of ammonia, which can be noted to be the major annualized cost item. The operating labor and maintenance requirements were taken from Reference 15 while the steam and ammonia requirements were taken from Reference 14. The unit costs for these were from Table 6-3 and from Chemical Marketing Reporter for the unit cost of ammonia.

Indirect operating costs were factored from the capital or direct operating costs with factors from References 4 and 8. Capital recovery is based on a 10 percent interest rate and an assumed useful life of 10 years for the equipment. The annualized costs for the model plants are presented in Tables 6-13 and 6-14.

Table 6-11

CAPITAL COST SUMMARY
AMMONIA SCRUBBING
681 MG PER DAY (750 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Total Direct Cost[a]	1,544
Indirect Cost	
Engineering and supervision (10 percent of direct)	154
Construction and field expense (8 percent of direct)	124
Contractor fee (6 percent of direct)	93
Contingency (12 percent of direct)	185
Total Indirect Cost	556
Total Capital Cost	2,100

[a] Direct cost of equipment includes cost of auxiliary equipment, instruments and controls, taxes, freight, foundations, handling and erection, and any other required installation costs. Costs developed from Reference 14.

Table 6-12

CAPITAL COST SUMMARY
AMMONIA SCRUBBING
1361 MG PER DAY (1500 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Total Direct Cost[a]	2,344
Indirect Cost	
Engineering and supervision (10 percent of direct)	235
Construction and field expense (8 percent of direct)	188
Contractor fee (6 percent of direct)	141
Contingency (12 percent of direct)	282
Total Indirect Cost	846
Total Capital Cost	3,190

[a] Direct cost of equipment includes cost of auxiliary equipment, instruments and controls, taxes, freight, foundations, handling and erection, and any other required installation costs. Costs developed from Reference 14.

Table 6-13

ANNUALIZED COST SUMMARY
AMMONIA SCRUBBING
681 MG PER DAY (750 TPD) PLANT
(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Operating Cost	
Operation	
Operating labor[a]	274
Supervision labor[b]	41
Maintenance (4 percent of total capital cost)[c]	84
Utilities	
Electricity	78
Chemicals (ammonia)	662
Indirect Operating Cost	
Overhead[d]	
Plant (50 percent of operating labor, supervision and maintenance)	179
Payroll (20 percent of operating, supervision, and maintenance labor)	71
Capital recovery (10 percent rate of return, 10 years equipment life)	342
Insurance, taxes, and administration (four percent of total capital cost)	84
Total Annualized Cost	1,815

[a] Labor requirements from Reference 15.
[b] 15 percent of operating labor (Reference 14).
[c] Reference 15.
[d] Factors from Reference 8. Assumes that 50 percent of maintenance cost is maintenance labor.

Table 6-14

ANNUALIZED COST SUMMARY
AMMONIA SCRUBBING
1361 MG PER DAY (1500 TPD) PLANT

(June 1984 Dollars)

	Cost in Thousands of Dollars
Direct Operating Cost	
Operation	
Operating labor	366
Supervision labor[a]	55
Maintenance (4 percent of total capital cost)[b]	128
Utilities	
Electricity --	155
Chemicals (ammonia)	1,323
Indirect Operating Cost	
Overhead[c]	
Plant (50 percent of operating labor, supervision and maintenance)	243
Payroll (20 percent of operating, supervision, and maintenance labor)	97
Capital recovery (10 percent rate of return, 10 years equipment life)	519
Insurance, taxes, and administration (four percent of total capital cost)	128
Total Annualized Cost	3,014

[a] Labor requirements from Reference 15.
[b] 15 percent of operating labor (Reference 14).
[c] Reference 15.
[d] Factors from Reference 8. Assumes that 50 percent of maintenance cost is maintenance labor.

6.5 MIST ELIMINATORS

6.5.1 Capital Costs

The capital costs of mist eliminators for the model plants are estimated on the basis of contact with equipment vendors. Note that in accordance with the model plant parameters the 681 megagrams per day (750 TPD) plant employs a "Brinks" type mist eliminator, while the 1,381 Mg per day (1500 TPD) plant employs a York "Type S" mist eliminator. Each mist eliminator has an approximate efficiency of 97 percent. No data was found on a third type -- the vertical panel mist eliminator -- which was discussed in the earlier NSPS review (Reference 9). Discussion with vendors and mention in the literature (Reference 12) has indicated that this type of mist eliminator would not be efficient enough for this application, presumably because of its marginal effectiveness in removing submicron particles and possible re-entrainment problems when operating at high gas velocities. The mist eliminator capital costs are presented in Table 6-15.

6.5.2 Annualized Costs

Because mist eliminators have no moving parts and require little attention, the only significant direct operating cost is for moving gas through the unit. This electricity cost has been calculated on the basis of gas flowrate, pressure drop, and the unit cost of electricity previously presented in Table 6-3. The maintenance requirements for the demisters would be negligible (Reference 1) consisting of cleanout and minor repair as necessary during scheduled annual shutdowns. Indirect costs include capital recovery and insurance, taxes, and administration. There is also a substantial credit for recovered sulfuric acid. The annualized costs are also summarized in Table 6-15.

6.6 SULFUR DIOXIDE MONITORS

6.6.1 Capital Cost

The capital cost of an in-stack continuous monitor for sulfur dioxide

Table 6-15

CAPITAL AND ANNUALIZED COST SUMMARY

MIST ELIMINATORS

(June 1984 Dollars)

CAPITAL COST

Total Capital Cost in Thousands of Dollars	
681 Mg Per Day (750 TPD) Vertical Tube (Brinks)[a]	1361 Mg Per Day (1500 TPD) Horizontal Dual Pad (York)[b]
68	112

ANNUALIZED COST

	Annualized Costs in Thousands of Dollars	
	681 Mg Per Day (750 TPD) Vertical Tube (Brinks)	1381 Mg Per Day (1500 TPD) Horizontal Dual Pad (York)
Direct Operating Cost		
Utilities		
Electricity[c]	48	107
Indirect Operating Cost		
Capital recovery (10 percent rate of return, 10 years equipment life)	11	18
Insurance, taxes, and administration (four percent of total capial cost)	3	4
Total Annualized Cost Without Credit	62	129
Credit for Recovered Acid	(36)	(73)
Net Annualized Cost	26	56

[a] Includes all direct and indirect costs for the purchase and installation of the unit in the top portion of the final absorber in a new sulfur-burning dual absorption sulfuric acid plant. (Calculated from cost data from Reference 1.)

[b] Includes all direct and indirect costs for the purchase and installation of a mist eliminator vessel above the final absorber in a new sulfur-burning dual absorption sulfuric acid plant. (Calculated from cost data from Reference 18.)

[c] Pressure drops: 681 Mg per day -- 8 in. W.C.; 1381 Mg per day -- 9 in. W.C.

is estimated based on data supplied by vendors (References 16 and 17). The cost of the monitor is independent of acid plant size. Each monitor is a single-point extractive analyzer that employs a photoelectric (UV) principle. Continuous samples are aspirated from the stack to the analyzer and results are transmitted by a 4-20 milliampere electronic signal to the readout in the control room in the range of 0-500 ppm. A three-tube bundle connects the probe and the analyzer: one tube carries sample gas; the second is for calibration gas; and the third is for high-pressure blowback air to periodically clean the probe. The analyzer is automatically calibrated once every 24 hours. It is assumed that the distance between the probe and the analyzer is approximately 100 feet. The capital cost for continuous sulfur dioxide monitoring is shown in Table 6-16.

6.6.2 Annualized Cost

The only direct annualized cost item for the continunous monitor that is not negligible is for replacement of calibration gas (Reference 16). Indirect costs include capital recovery and insurance, taxes, and administration. The annualized cost for continuous sulfur dioxide monitoring is also shown in Table 6-16.

6.7 COST EFFECTIVENESS

6.7.1 Sulfur Dioxide Control

Cost effectiveness for the types of sulfur dioxide control is shown in Table 6-17. For the small model plant, cost effectiveness ranges from $311 per Mg of SO_2 removed to $827, and for the large model plant the cost effectiveness ranges from $270 to $687 per Mg of SO_2 removed. For both model plants, dual absorption is the least costly at $311 per Mg for the small plant and $270 per Mg for the large plant. Recalling the caveat from Section 6.2 concerning the costs of the molecular sieve process, it can be seen from Table 6-17 that dual absorption is significantly more cost-effective than other applicable control technologies. Indeed, dual absorption has accounted for over 87 percent of the sulfuric acid plants built in the period

Table 6-16

CAPITAL AND ANNUALIZED COST SUMMARY[a]
CONTINUOUS SULFUR DIOXIDE MONITORS
(June 1984 Dollars)

CAPITAL COST

Purchased cost of analyzer	40,800
Flexible tubing from probe to analyzer	2,950
Installation	6,000
Total Capital Cost	49,750

ANNUALIZED COST

Direct Operating Cost	
Maintenance (calibration gas)	700
Indirect Operating Cost	
Capital recovery (10 percent rate of return, 10 years equipment life)	8,100
Insurance, taxes, and administration (four percent of total capital cost)	1,990
Total Annualized Cost	10,800

[a] Costs apply to either model plant. Costs developed from References 16 and 17.

1973 to 1977 (Reference 9) and undoubtedly accounts for an even greater percentage for the period 1978 to the present. Dual absorption has become the state of the art for producing acid, partly because it is the most cost-effective technology for control of sulfur dioxide emissions.

6.7.2 Sulfuric Acid Mist Control

The cost-effectiveness for control of sulfuric acid mist is presented in Table 6-18. There is essentially no difference in the cost-effectiveness of $52 and $55 per Mg of acid removed, especially when it is considered that the costs were developed on a slightly different basis (see footnotes for Table 6-15). Both units are capable of performing at efficiencies higher than the 97 percent level required for other model plants to be in compliance (Reference 12). The horizontal dual pad mist eliminator is slightly less cost-effective because it is defined in the model plant analysis to have a slightly higher pressure drop (9 vs. 8 in. W.C.).

Table 6-17

COST EFFECTIVENESS
SULFUR DIOXIDE CONTROL
(June 1984 Dollars)

Control Method	Plant Size Mg/day (TPD)	Annualized Cost ($$10^3$/yr)[a]	SO_2 Removed Mg/yr (tons/yr)[b]	C/E $/Mg ($/ton)
Dual absorption	681 (750)	824	2650 (2920)	311 (282)
	1361 (1500)	1427	5290 (5820)	270 (245)
Molecular sieve	681 (750)	1130	2960 (3260)	382 (347)
	1361 (1500)	2248	5920 (6510)	380 (345)
Ammonia scrubbing	681 (750)	1826	2960 (3260)	617 (560)
	1361 (1500)	3025	5920 (6510)	511 (465)
Sodium sulfite-bisulfite scrubbing	681 (750)	2449	2960 (3260)	827 (751)
	1361 (1500)	4069	5920 (6510)	687 (625)

[a] Includes the cost of continuous sulfur dioxide monitoring.

[b] For dual absorption, calculated from the incremental amount of sulfuric acid recovered vs. single absorption; for other controls, calculated using a removal efficiency of 95 percent and assuming a 98 percent conversion of SO_2 to sulfuric acid in the single absorption process (Reference 9).

Table 6-18

COST EFFECTIVENESS
SULFUR ACID MIST CONTROL
(June 1984 Dollars)

Control Method	Plant Size Mg/day (TPD)	Annualized Cost ($$10^3$/yr)	Acid Removed Mg/yr (tons/yr)[a]	C/E $/Mg ($/ton)
Vertical tube (Brinks type)	681 (750)	26	504 (554)	52 (47)
Horizontal dual pad (York type)	1381 (1500)	56	1020 (1120)	55 (50)

[a] Calculated from acid recovery due to mist eliminator.

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This report reviews the current New Source Performance Standards for Sulfuric Acid Plants. It includes a summary of the current standards, the status of current applicable control technology, and the ability of plants to meet the current standards.

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