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EFFECT OF EQUIPMENT MAINTENANCE AND AGE ON SULFURIC ACID PLANT EMISSIONS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Industrial Environmental Research Laboratory
Office of Research and Development
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SECTION I

SUMMARY AND CONCLUSIONS

The maintenance history for this report was collected from twenty sulfuric acid plants operated by six companies. Of the twenty plants three were of the dual absorption type. Age of the plants range from two years for a dual absorption plant to fifty years for the oldest single absorption plant. Information on service life of various pieces of critical equipment, type and frequency of maintenance required on this equipment, and the effect of equipment failure was tabulated and summarized for all plants studied. Neither statistical data on failures and maintenance performed nor sufficient data to make a statistical analysis of service life and maintenance were available. The information tabulated in the report is a summation of experience in the various plants with all plants given equal weight. The plants studied varied from poorly maintained to well maintained as indicated by the long service life of some of the plants. Quantitative measurement of the degree of maintenance for each of the plants was not possible, but the estimate of maintenance cost based upon plant cost was offered by several of the companies surveyed. A specific differentiation in maintenance cost between plants of different age was not available but maintenance cost ranged from a low of one percent to a high of seven percent of the plant cost per year. Sufficient records were obtained to permit a summarization of frequency and duration of shutdown by cause for the full range of plant ages covering twelve single absorption plants. These summations show the most frequent cause of shutdown was gas leaks, with mechanical equipment failures a close second. Gas leaks were fifth in the order of shutdown duration, preceded by the two semi-annual turnarounds, mechanical equipment failures, and acid leaks.

The following conclusions can be drawn from observation of the data collected.

1. Shutdown frequency and equipment malfunction are related to emissions and to preventive maintenance. An adequate preventive maintenance program will reduce the occurrence of emissions significantly. A quantitative measure of the reduction is not possible from the information obtained.

2. The optimum preventive maintenance program to minimize total plant operating cost including the control of emissions will cost approximately six percent of the plant investment annually. This cost will vary somewhat with the age of the plant, increasing to seven or eight percent for an older plant.

3. With inadequate maintenance, the service life of a sulfuric acid plant can be as short as ten years, while with adequate maintenance the service life will be of up to fifty years. Neglect of maintenance during the early years of plant life will require significantly greater

effort after the ten-year point to restore the plant to a reasonable level of maintenance.

SECTION II

RECOMMENDATIONS

The suggested format for organizing a preventive maintenance program included in this report is recommended to assist a company in establishing the optimum preventive maintenance program for any plant. The details and form of the program must be tailored to the specific plant needs and facilities.

The inspection technique is recommended for use by an inspector in determining the quality of plant maintenance and the effect on emissions. The recommended technique includes a check list for recording observations and data during the inspection. The maintenance policy will be evaluated by observing general plant conditions and checking the maintenance and production records for key items. The check list should be submitted with a report describing in more detail the conditions observed in the plant and in the plant records. The report should include recommendations for improved maintenance or improved preventive maintenance programs. The check list and report will serve as a reference to determine future status and improvements in plant maintenance.

To provide for long term data collection concerning maintenance and equipment failure without undue burden on the plant operator or EPA personnel, it is recommended that required upset emissions reports include information concerning the existence of a preventive maintenance program and a brief maintenance history of each piece of equipment that caused excessive emissions. The addition of these simple items to the emissions report will indicate trouble spots in the plant so that maintenance can be improved or equipment design changed to eliminate the source of emissions.

SECTION III

INTRODUCTION

Emissions from a well-designed sulfuric acid plant in excess of the design emission rate usually result from a failure to properly operate the plant, or from a failure of plant equipment. The frequency and severity of emissions resulting from equipment malfunction or failure are related to the schedule and extent of maintaining critical equipment in good working order and replacing equipment before it wears out. Thus, the quality of maintenance is an important factor in maintaining low emissions. This is particularly true in sulfuric acid production where low emissions depend not on one piece of control equipment but rather on the fine tuning of the process operation itself.

Although most emission standards do not usually apply during periods of process malfunction, reports of these upset conditions are usually required. Their frequency, duration, and severity are evaluated carefully to ensure that good operator care is being used; if the malfunctions are considered avoidable, then reasonable action will frequently be taken to correct these situations. A maintenance plan is occasionally required as a corrective measure for existing plants with excessive emissions. An enforcement agency may even require plant operators to submit maintenance plans for critical equipment before a construction permit is granted. It is also important to know the effect of age on the plant's capability to consistently meet a standard over its full operating life. As equipment gets older, malfunctions would be expected to occur more frequently, causing more frequent periods of abnormally high emissions.

The relationship between process operating parameters and emissions has been evaluated in a previous report "Sulfuric Acid Plant Emissions During Startup, Shutdown, and Malfunction".(1) The objective of the present study is to evaluate critical process equipment in both dual and single absorption sulfuric acid plants burning elemental sulfur and sludge acid and determine the effects of maintenance on the frequency and duration of malfunctions resulting in emissions in excess of the design emission rate. The effect of maintenance procedures on equipment reliability and emissions will be studied by using maintenance procedures recommended by equipment manufacturers and experience of sulfuric acid plant operators. By reviewing plants of different ages and with different amounts of preventive maintenance, the effect of age and maintenance quality on emissions can be determined. Plant experience will provide information on life cycles, frequency of breakdown, and the effectiveness of a preventive maintenance program in reducing breakdowns and the resulting emissions. The repair and replacement schedule for an average plant can also be determined.

The summation of this information can be used as a guide for establishing an effective preventive maintenance program incorporating the suggested Preventive Maintenance program format. Control reports for management feedback will also be included in the suggested program.

An inspection technique to be used by an enforcement agency inspector to evaluate the effectiveness of maintenance in the plant, including an inspection check list, will be provided. The approach used in the study and report should make the report useful for establishing an initial preventive maintenance program for a sulfuric acid plant, and for evaluating the effectiveness of existing preventive maintenance programs as well.

SECTION IV

CONTACT SULFURIC ACID PROCESS AND EQUIPMENT DESCRIPTION

CONTACT SULFURIC ACID PLANTS

For many years, the basic contact sulfuric acid plant has used the single absorption process. This process has been used to develop the basic technology and equipment applied in today's modern dual absorption process sulfuric acid plants. Both the single absorption and dual absorption units contain the same basic unit processes:

(1) Burning sulfur or sulfur bearing feed stocks to produce sulfur dioxide (SO_2)

(2) Cooling the resulting SO_2 containing gas

(3) Catalytic oxidation of the SO_2 to sulfur trioxide (SO_3)

(4) Cooling the resulting oxidized gas containing the SO_3

(5) Absorption of SO_3 in strong sulfuric acid

The primary difference between the single and dual absorption acid plants is a second absorber in the dual absorption plants for removing SO_3 from the process gas stream between the converter beds, in addition to the normal absorber which is located after the converter. Most of the sulfuric acid plant designs include variations in the arrangement of heat exchangers and converter beds and variations in the location of the primary absorber in the dual absorption plant. All sulfuric acid plants operate at temperatures up to 1750F and are exposed to highly corrosive materials. These process conditions place rigid requirements on the materials of construction, design factors and equipment. In this type of chemical plant, maintenance assumes a very important place in determining reliable operation of the plant.

Use of elemental sulfur as feedstock requires the simplest plant design. Other feedstocks such as spent acid or sludge acid containing moisture and organics are frequently used, but require revisions in the design of the SO_2 generating process and impose more difficult problems in emission abatement, operation and maintenance. Feedstock variations can also affect the sulfur conversion efficiencies in the catalytic converter, the volume of exhaust gases, and the character and volume of pollutants emitted. When a sulfuric acid plant uses sludge acid or reclaimed acid as feedstock, varying quantities of acid mist are generated in the furnace from combustion of organics in the feed. Oxides of nitrogen and carbon dioxide (CO_2) are also generated from this source. It is also possible to generate other solid particulate matter in the furnace by burning reclaimed acid. The generation of acid mist and other particulates in the furnace requires the addition of mist entrainment separators or electrostatic precipitators (ESP) before the recovery boiler and introduces additional corrosion problems in the ductwork and boiler areas.

SINGLE ABSORPTION PROCESS

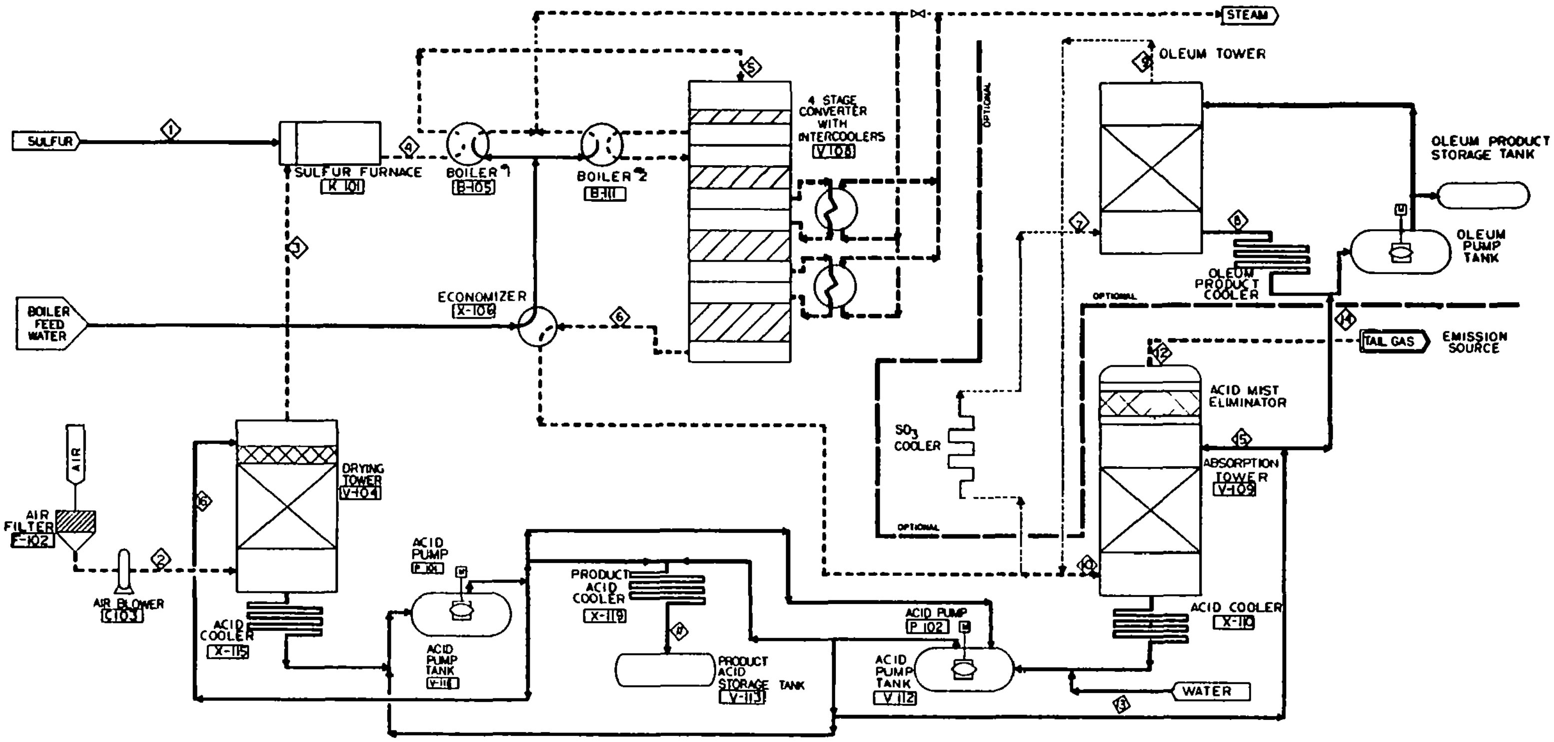
Process Description

A simplified process flow diagram for single absorption contact sulfuric acid plants burning elemental sulfur is presented in Figure 1.

In this process sulfur is burned with air to form a gas mixture containing approximately eight percent sulfur dioxide, 13 percent oxygen and 79 percent nitrogen. Combustion air is predryed by passing it through a packed tower circulating 93 to 98 percent sulfuric acid. This tower is constructed of steel and lined with acidproof brick to provide the necessary corrosion resistance. Predrying the air minimizes the acid mist formation and resulting corrosion throughout the system.

A plant burning sludge acid or reclaimed acid may be similar but will be equipped with electrostatic precipitators (ESP) or acid mist entrainment filters between the sulfur furnace and the recovery boiler to remove acid mist and solid particulates.

In addition to mist entrainment separators or ESP's installed in plants burning acid sludge, it is also common practice to install filters for removing organic matter before it is burned in the furnace and scrubbers to remove impurities from the gas generated. Use of sulfur containing organic impurities increases the frequency of plugging of the sulfur guns and other malfunctions in the sulfur handling system.



SINGLE ABSORPTION
SULFUR BURNING CONTACT
SULFURIC ACID PLANT
PROCESS FLOW DIAGRAM

FIGURE 1

KEY	
GASES	- - - - ►
LIQUIDS	———►

Filtration of the molten sulfur is often required. Additional problems are also encountered in cleaning the sulfur filter or plugging of the filter and subsequent loss of sulfur feed.

Combustion products from the sulfur furnace pass through a waste heat boiler to cool the gas and generate process steam. The duct work connecting the sulfur furnace to the boiler, as well as the sulfur furnace, is lined with fire brick to withstand the 1750F temperature generated by the combustion of the sulfur. The combustion products leaving the waste heat boiler contain sulfur dioxide (SO_2) and excess oxygen. Additional air is added to the gas stream following the waste heat boiler to provide the necessary oxygen for reaction with SO_2 in the converter. These gases then pass through a multiple bed converter containing vanadium pentoxide catalyst that promotes the combination of sulfur dioxide and oxygen to produce sulfur trioxide (SO_3). The catalytic oxidation of SO_2 to SO_3 increases the temperature of the gas mixture in the catalytic converter. The heat generated in the first stages of catalytic oxidation must be removed to control the temperature of succeeding stages of conversion. This heat is removed in additional waste heat boilers, economizers and superheaters to generate process steam. The design and operation of waste boilers is critical to ensure that condensation does not take place on cold surfaces in the boiler, causing excessive corrosion. Condensation can occur because of improper operation of the drying tower, use of dark sulfur or sludge acid, or improper operation of acid mist removal systems following the furnace.

The temperature of the gas entering the various catalyst beds is controlled by adjustment of gas bypass dampers around the waste heat boilers. Frequently, injection of cool air into the gas stream entering the converter is also used. This injection of cool air is called "air quenching". The temperature of gases leaving the converter is approximately 806F to 815F with approximately 98 percent of the SO_2 converted to SO_3. The exit gases are passed through an economizer to preheat the boiler feedwater being charged to waste heat boilers and to cool the exit gas to the proper temperature for the absorption operation.

Sulfuric acid is produced by passing the gases leaving the economizer through an absorption tower where SO_3 is absorbed in hot 98.5 to 99.0 percent sulfuric acid. The absorption tower is constructed of carbon steel lined with acid brick to prevent corrosion of the steel shell. In the absorption tower, sulfuric acid of desired strength is produced by controlling the acid concentration, water make-up and temperature of the feed acid. If fuming sulfuric acid or oleum is required, the gases containing SO_3 leaving the economizer are first passed through an oleum tower. Here SO_3 is dissolved in recirculating oleum with make-up 98.5 percent acid to produce oleum. The gas leaving the oleum tower is further stripped of SO_3 by passing through a normal acid absorber containing 98.5 to 98.8 percent sulfuric acid. The majority of single absorption acid plants is not equipped with an oleum tower, and can produce acid with a concentration of only 98 to 99 weight percent sulfuric acid.

Critical Equipment Description

Process Equipment

Process equipment critical to the control of excess pollutants from a single absorption acid plant is described in Table 1 (page 16). The equipment numbers in this table refer to the equipment shown on the single absorption acid plant flow diagram, Figure 1, in the previous section. Variations in design of acid plants by different companies will require some modification in this equipment list when applied to a specific type of plant. Also, different types of equipment are often substituted in the same service for those indicated on the equipment list.

One example of the variation in the type of equipment used in the same service is the waste heat boilers recovering heat from the process gas. Although fire tube boilers are most commonly applied in plants of smaller capacity, both fire tube and water tube boilers have been used in this service with water tube boilers preferred in larger plants. Fire tube boilers are normally preferred since they present less surface for corrosion and less brickwork subject to high temperatures and sulfur gases. Water tube boilers are desirable in larger sizes since the high pressure shell is not required.

The greatest variations in equipment are found in the number, location and type of heat exchangers used for acid cooling and gas heating and cooling. Heat exchanger design for

Table 1. CRITICAL EQUIPMENT DESCRIPTION FOR SINGLE AND DUAL ABSORPTION CONTACT SULFURIC ACID PLANTS

ITEM NO.	EQUIPMENT NAME	EQUIPMENT DESCRIPTION AND SIZES	DESIGNER'S/ MANUFACTURER'S NAME	MATERIALS OF CONSTRUCTION	OPERATING CONDITIONS		TYPE OF EMISSIONS AFFECTED		REMARKS
					TEMP. °F	PRESSURE PSIG	SO_2	ACID MIST	
C-103	MAIN AIR BLOWER								
(C-203)[a]	1. Blower	Single stage Centrifugal	A-C, Clark, Elliott and Roots	Cast iron case Cast steel impeller	Ambient	7	X		Insufficient air flow causes incomplete SO_2 oxidation resulting in SO_2 emissions.
	2. Turbine	Condensing or non-condensing, multi-stage	A-C, Coppus, Elliot and Terry	Standard materials	—	550			
	3. Air Filter	Oil bath wire mesh type	AAF	Carbon steel housing with oil impregnated steel with filter media	—	—			Protects drying system from plugging with dusts and dirt.
K-101	SULFUR FURNACE								
(K-201)	1. Furnace	Horizontal, refractory lined, approx. 14' diameter by 30' long	Chemico, CB&I, Davy-Powergas, Ingalls, Monsanto, Nooter, PD-M and TIW	Carbon steel shell insulated with firebrick	2000	7	X		Ash and tar from sludge acid coats firebrick and causes shell to overheat
	2. Burner System including sulfur pumps	Air or pressure atomizing spray or chequer type burners	Chemico, Davy-Powergas, Monsanto, Parsons and John Zink	Stainless steel	—	—	X		Plugging of burners or loss of sulfur feed causes loss of converter temperature control resulting in SO_2 emissions from upsets.
B-105	WASTE HEAT BOILERS								
(B-205 and B-211)		Horizontal firetube or vertical water tube type	B&W, CE, F-W, Erie City, and TIW			X	X	X	Steam is normally generated for turbine drives and export.
		Gas side		Brick lined Carbon steel	2000	600			Change in temperature of gas causes SO_2 emissions resulting from loss of converter temperature.
		Water/side		Carbon steel	500	7			Leaks in tubes causes acid mist emissions.
X-106	ECONOMIZER								
(X-206		Horizontal or vertical, single pass exchanger Shell side-gases	B&W, CE, Erie City and F-W	Carbon steel metallized with aluminum	850-400	1-3		X	Leaks in tubes causes acid mist emissions
		Tube side-BFW		Carbon steel	250-450	700			
(X-218)	SUPERHEATER								
		Horizontal shell and tube type heat exchanger Shell side-gas	B&W, Brown Fintube, CE, Erie City and Nooter	Carbon steel metallized with aluminum	800-950	2-4	X	X	Superheater is optional in single absorption plants. Loss of temperature control causes SO_2 emissions. Leaks in tubes causes acid mist emissions.
		Tube side-steam		Carbon steel	500-600	650			

Table 1 (Continued). CRITICAL EQUIPMENT DESCRIPTION FOR SINGLE AND DUAL ABSORPTION CONTACT SULFURIC ACID PLANTS

ITEM NO.	EQUIPMENT NAME	EQUIPMENT DESCRIPTION AND SIZES	DESIGNER'S/ MANUFACTURER'S NAME	MATERIALS OF CONSTRUCTION	OPERATING CONDITIONS		TYPE OF EMISSIONS AFFECTED		REMARKS
					TEMP. °F	PRESSURE PSIG	SO_2	ACID MIST	
X-110, X-115 and X-119 (X-210, X-214, X-215, X-219 and X-220)	ACID COOLERS	Cascade or shell and tube or Teflon bundle Cooling Water side Acid side	CIL, DuPont and Pentex	Cast iron, stainless steel or Teflon	 80-110 110-220	 40 40	X	X	Excessive loss of temperature control causes SO_2 from Primary Absorber and acid mist from Final Absorber. Water leaks cause acid dilution and upset absorption. Acid leaks cause rapid corrosion of equipment.
V-104 (V-204)	DRYING TOWER 1. Vessel	Vertical packed tower approx. 20' dia. by 45' high	Chemico, CB&I, Davy-Powergas, Ingalls, Monsanto, Hooter, Parsons, PD-M and TIW	Carbon steel shell with acid proof brick lining	120-170	7		X	Malfunction of entrainment separator and low flow rates, maldistribution, changes in concentration of acid causes acid mist emissions.
	2. Entrainment Separator	Knitted mesh pad	ACS, Brink and York	Teflon or Alloy 20 with Alloy 20 grid					
	3. Distributors and Piping	Troughs and pipe	Banner Iron Works	Gray cast iron					
	4. Packing	Extended surface packing-Intalox saddles	Knight, Norton	Chemical stoneware					Plugging and deterioration of packing causes drying inefficiencies.
V-108 (V-208)	CONVERTER 1. Vessel	Vertical, multi-state packed tower approx. 35' dia. by 45' high	Chemico, CB&I, Davy-Powergas, Ingalls, Monsanto, Hooter, Parsons, and PD-M.	Aluminized Carbon steel or firebrick lining	800-1200	3			
	2. Support Grids and Posts	Various types	Banner Iron Works	Mechanite cast iron					
	3. Catalyst	Cylindrical or spherical pellets	Allied Chemicals, Monsanto, and Stauffer	Vanadium pentoxide on clay support			X		Dirty or inactive catalyst causes high SO_2 emissions and high pressure drop. Excessive temperature causes loss of catalyst by evaporating the vanadium pentoxide. Moisture forms acid mist and causes formation of hard crusts, plugging and inactivating catalyst. Fluorine compounds attach carrier forming dust and plugging catalyst.

Table 1 (Continued). CRITICAL EQUIPMENT DESCRIPTION FOR SINGLE AND DUAL ABSORPTION CONTACT SULFURIC ACID PLANTS

ITEM NO.	EQUIPMENT NAME	EQUIPMENT DESCRIPTION AND SIZES	DESIGNER'S/ MANUFACTURER'S NAME	MATERIALS OF CONSTRUCTION	OPERATING CONDITIONS		TYPE OF EMISSIONS AFFECTED		REMARKS
					TEMP. °F	PRESSURE PSIG	SO_2	ACID MIST	
V-109 (V-209 and V-221)	ABSORPTION TOWERS 1. Vessel	Vertical packed tower approx. 20' dia. by 35' high	Chemico, CB&I, Davy-Powergas, Ingalls, Monsanto, Hooter, Parsons and PDM	Carbon steel with acid proof brick lining	450	4	X	X	Malfunction of mist eliminator and low flow rates, maldistribution, changes in concentration and temperature of acid causes acid mist emissions and SO_2 from Primary Absorber.
	2. Mist Eliminator	Knitted mesh pad	ACS, Brink, York	Alloy 20, Teflon or fiberglass pads with Alloy 20 support grids or Teflon rods					
	3. Distributors and Piping	Troughs and pipes	Banner Iron Works	Gray cast iron					
	4. Packing	Extended surface type - Intalox saddles	Knight, Norton and U. S. Stoneware	Gray cast iron Chemical stoneware					Plugging, deterioration and/or attrition of packing causes loss of absorption.
P-101 and P-102 (P-201 and P-202)	ACID CIRCULATING PUMPS	Vertical submerged centrifugal pumps mounted on a pump tank	Labour, Lewis, Tabor and Worthington	All wetted parts Alloy 20 or cast iron	160-220	35	X	X	Pump failure causes acid mist emissions and emergency plant shutdown.
(X-211 and X-217)	HEAT EXCHANGERS	Vertical shell and tube type	B&W, CE, F-W, Hooter, PDM and TIW						
		Shell-gas		Carbon steel	150-850	2-5			Loss of temperature control and tube leaks cause SO_2 emissions.
		Tube-gas		Aluminized carbon steel	150-700	2-5			

Table 1 Notes

a. Item numbers in parentheses are for dual absorption plants. Refer to Process Flow Diagrams Figure 1 and Figure 4.

b. Sizes are based on a typical 1500 TPD dual absorption plant.

c. Designer/Manufacturer abbreviations used:

AAF--American Air Filter Company Inc.
AC--Allis-Chalmers Corp.
ACS--ACS Industries, Inc.
Allied Chemical--Allied Chemical Corp.

Banner--Banner Iron Works
B&W--Babcock and Wilcox Company
Brink--Monsanto Enviro-Chem Systems Inc.

CB&I--Chicago Bridge and Iron Company
CCI--Catalyst and Chemicals, Inc.
CE--Combustion Engineering, Inc.
Chemico--Chemical Equipment Company
CIL--Canadian Industries Ltd.
Clark--Dresser Clark Division, Dresser Industries
Coppus--Coppus Engineering Corp.

Davy Powergas--Davy Powergas Inc. (Lurgi)
Duriron--Duriron Company Inc.

Elliott--Elliott Company - Carrier Corp.
Erie City--Erie City Iron Works

F-W--Foster Wheeler Corp.

Ingalls--Ingalls Iron Works Co.

Knight--Maurice A. Knight Co.

LaBour--LaBour Pump Co.
Lewis--Charles S. Lewis and Company Inc.

Monsanto--Monsanto Enviro-Chem Systems Inc.

Nooter--Nooter Corp.
Norton--Norton Company

Parsons--Ralph M. Parsons Company
PDM--Pittsburgh DeMoines Steel Co.
Pentex--Pentex Foundry Corp.

Roots--Roots-Connersville Division-Dresser Industries

Stauffer--Stauffer Chemical Co.

Taber--Taber Pump Company, Inc.
Terry--Terry Steam Turbine Company
TIW--Tower Iron Works Inc.

Worthington--Worthington Corp.

York--York Separators Inc.

John Zink--John Zink Company

acid cooling has evolved from open type, cast iron, cascade acid coolers used almost exclusively in older plants to the DuPont Teflon tube exchangers used in some modern plants. The cast iron cascade coolers still found in many of the older plants are relatively free from failures but are subject to corrosion if disruption of the water flow or distribution allows dry spots to form on the tubes. If the outside of the tubes are allowed to become dry because of poor water distribution, the dissolved solids in the water will precipitate and form a hard scale on the outer surface of the tubes reducing heat transfer. Poor water distribution is often caused by accumulation of algae or other suspended solids in the distribution trays. This type of cooler requires frequent cleaning to maintain an even water flow over the coils and an even heat transfer through the coil surface. Fouled heat exchanger tubes result in loss of temperature control on absorber tower acid and result in release of SO_2 or acid mist pollutants.

When shell and tube heat exchangers are used for acid cooling, scale resulting from dry tubes is not a serious problem, but the heat exchangers must be cleaned periodically to remove scale from the shell side of the tubes. This is normally done by acid cleaning and requires careful attention to prevent corrosion of the outside of the tubes by the cleaning acid. The frequency of cleaning depends upon the quality of cooling water used in the exchangers. Fouling on the water side of the shell and tube exchanger is also aggravated by operating the exchangers at high water temperatures.

Teflon tube exchangers consist of a bundle of very small diameter Teflon thermal plastic tubes immersed in the pump tanks. Cooling water flows through the inside of the tubes and the acid to be cooled flows through the pump tank. Since the tubes are very small in diameter they are subject to plugging from scale or suspended solids in the cooling water. To reduce the frequency of tube plugging, cooling water is filtered through sand filters to remove particles before flowing through the exchanger tubes. An air system is also installed to pulse air through the exchanger periodically to dislodge any accumulated debris from the tubes. With properly cleaned cooling water, maintenance requirements on the Teflon exchangers are low. The Teflon tube bundle is arranged so that when a single tube breaks it can be easily plugged to stop the flow of water into the concentrated acid stream. Since dilution water is added to the acid stream intentionally, a small amount of leakage in this manner is usually not detrimental to plant operation.

One of the most common causes of shutdown for maintenance is the occurrence of leaks in ducts, expansion joints, and transition pieces. These leaks can occur even in a new plant and usually result from faults in the welds of the original fabrication. Because this duct work is subject to high temperatures as well as corrosive gases, the combination of corrosion and mechanical stress causes frequent cracking of expansion joints and transition pieces. These cracks are a primary source of fugitive SO_2 and acid mist emission and require shutdown of the plant for repairs. The repair of such cracks by welding is difficult because sulfur will deposit in the cracks and will alloy with the steel, resulting in additional cracking after welding. Such repairs frequently require the parent metal around the crack to be removed to eliminate all accumulated sulfur before welding of a patch to close the opening. In this manner, the welding is performed on fresh metal not contaminated by absorption of sulfur.

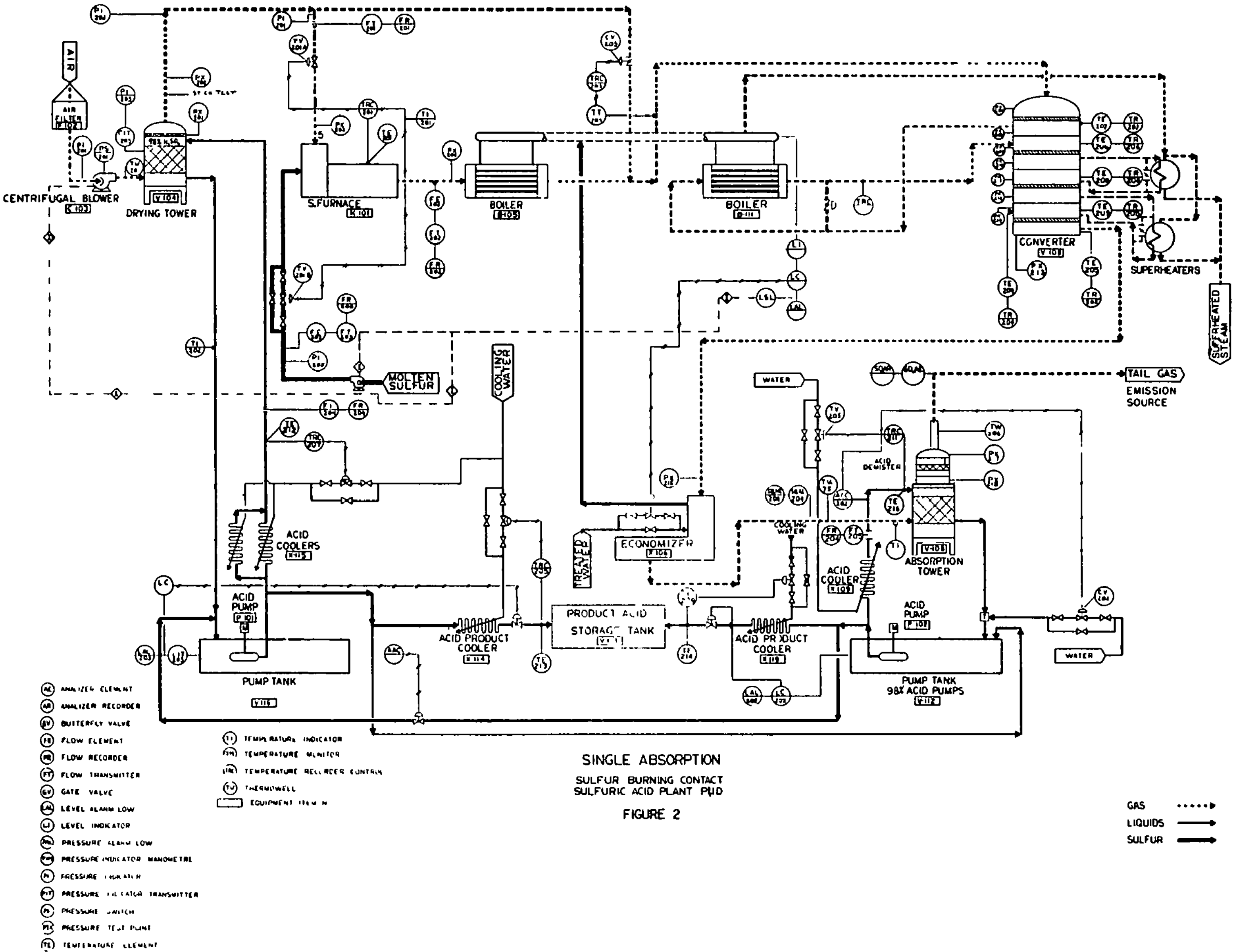
Instrumentation

The instrumentation for a contact sulfuric acid plant becomes more critical to pollution-free operation as the reliance on automatic controls increases. The close control required to meet the EPA standards requires precise calibration as well as reliable operation. Instrumentation is not only required to control the plant and maintain emission levels within limits but also provides a measurement of the product flow and analysis of the vent gases required for properly calculating the emission levels in compliance with federal regulations.

The most critical instrumentation in a sulfuric acid plant is that which controls the temperature of the gas entering the various sections of the catalytic converter. Other critical process parameters that must be controlled in a sulfuric acid plant are: sulfur and air flow to the sulfur furnace, acid temperature and concentration into the absorbers and drying tower, and feed water controls to the waste heat boilers. Typical instrumentation for a single absorption acid plant is shown in Figure 2. Instrumentation for a dual absorption acid plant is similar, consistent with the addition of the primary absorber and rearrangement of heat exchangers. Dual absorption plant instrumentation is shown in Figure 3.

The instrumentation system in a sulfuric acid plant can be either pneumatic or electronic depending upon the preference of the designer or operator of the plant. Thermocouples are almost invariably used for sensing temperature of the gas flows in and out of the catalyst beds. Therefore, electronic controllers and multi-point electronic temperatures recorders are most frequently used for temperature measurement. Both electronic and pneumatic instrumentation are reliable, given proper maintenance, although electronic instrumentation usually requires less maintenance for reliable operation.

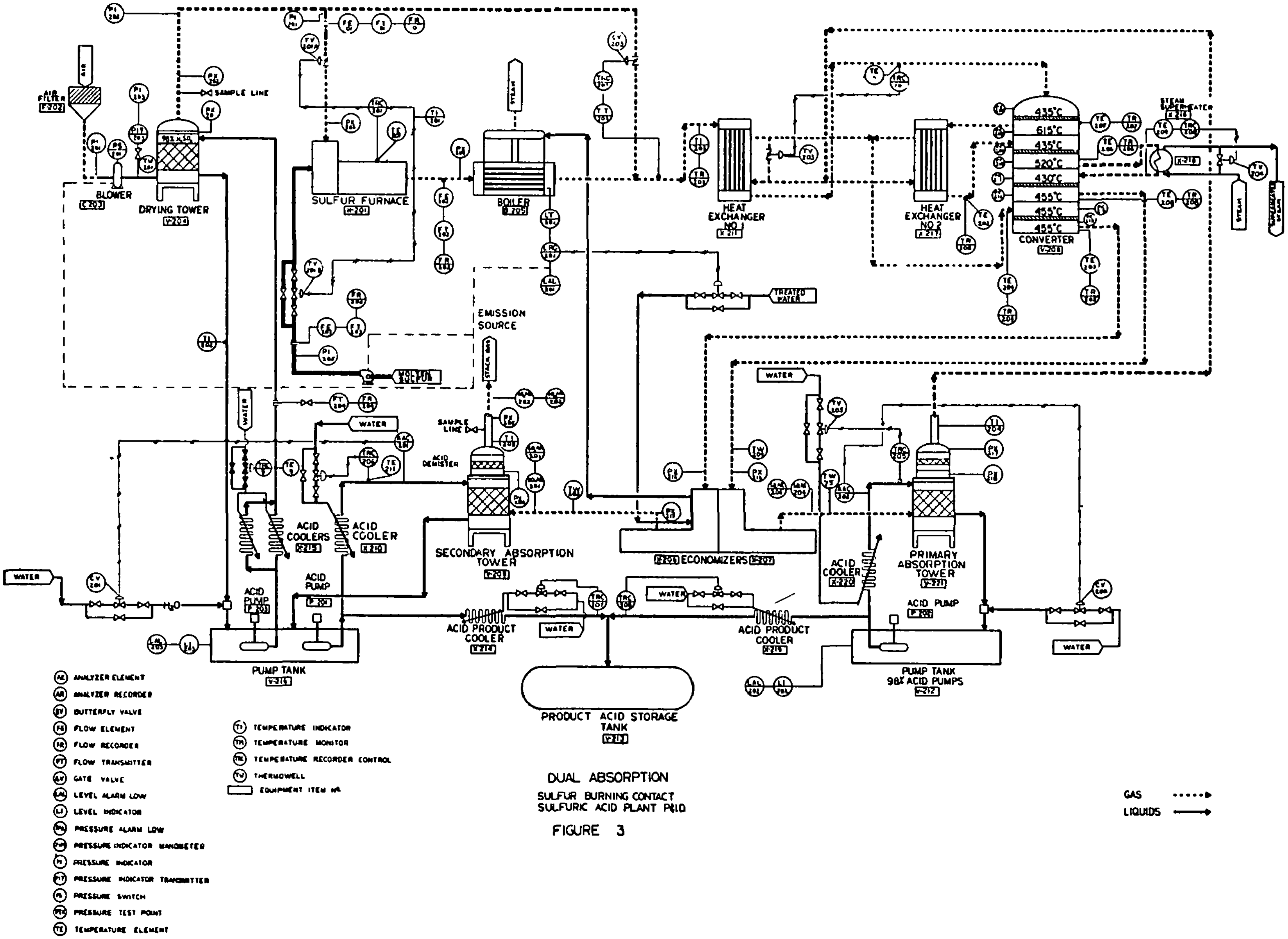
Acid flow meters may be installed in the plant for measuring the flow of acid to the absorbers and drying tower. However, the most common application of acid flow meters is in the measurement of product acid to storage. This flow reading is used to calculate emission levels from the plant. The most common type of meter for this application is the orifice meter with a differential pressure (D/P) cell transmitter.



SINGLE ABSORPTION

SULFUR BURNING CONTACT
SULFURIC ACID PLANT P&ID

FIGURE 2



DUAL ABSORPTION

SULFUR BURNING CONTACT SULFURIC ACID PLANT P&ID

FIGURE 3

Because of the corrosive nature of the hot sulfuric acid flowing through this meter, the orifice must be checked frequently to ensure the accuracy of the flow readings. D/P cells or pressure indicators connected to the process fluid will normally be equipped with chemical seals to prevent sulfuric acid from entering the instrument. Since the process seals are also subject to corrosion they must be checked frequently to prevent damage to the instrument from a ruptured seal. Some older plants are equipped with rotameters for acid flow measurement. These are normally of the armored type using a magnetically coupled indicator or transmitter. This type instrument should also be inspected frequently for corrosion to prevent inaccuracies in flow measurement.

Control of sulfur feed to the sulfur furnace is important for maintaining stable operation of a sulfuric acid plant. In older plants sulfur feed was controlled by the volumetric or gravimetric measurement of the sulfur feed in the dry form and constant inventory control of molten sulfur in the feed tank. This control was accomplished through weigh belts or batch weighers. This type of instrument may be found in modern plants to provide information for sulfur inventory control. A more satisfactory measurement of molten sulfur feed to the furnace however can be accomplished using a variety of standard type flow meters adapted for steam heating to maintain the sulfur in a molten condition. Typical flow meters that can be used in this service are positive displacement rotameters, orifice meters and variations on differential pressure type instruments. Where differential pressure instruments are used, seals must be provided to prevent molten sulfur from entering the instrument and causing corrosion or plugging of the instrument with solid sulfur. The most recent advancement in molten sulfur measurement is a turbine flow meter designed for use with high temperature, viscous, molten sulfur. The purity of the sulfur feed largely determines the type of instrument best suited for measuring molten sulfur flow. The presence of solid impurities in the molten sulfur can cause excessive wear or plugging of various types of instruments.

The thermocouples used for converter temperature measurement and control are relatively free from failure or maintenance requirements. These thermocouples must be installed, however, in thermowells to prevent corrosive process gases from contacting the thermocouples. Care must be exercised in sealing the thermowells to prevent corrosive vapors in the atmosphere from entering the thermowell. If scale or corrosion occurs on a thermocouple or in a thermowell, errors in temperature measurement will occur. Periodic inspection of thermowells should be conducted to permit replacement of the thermowell before corrosion penetrates into the thermocouple space.

If proper design is used in selecting and installing process transmitters and control instruments are located remotely in an air-conditioned area free from corrosive vapors, the primary maintenance consideration for instrumentation will be the protection of the field mounted instruments from corrosive atmosphere and liquids. This will require special enclosures, splash protection and corrosion proof coatings to prevent instrument cases from being corroded. It also may be necessary to apply air purge to electronic transmitters to prevent the corrosive atmosphere from entering the transmitter case. Pneumatic transmitters are naturally purged sufficiently to prevent corrosive gases from entering. Instrument air lines and electronic cables must be properly protected and maintained to reduce damage from the corrosive atmosphere and liquids. Where sulfuric acid leaks may occur, stainless steel or plastic instrument air lines are generally used to provide corrosion resistance. Instrument air tubing racks and cable trays are usually protected in these areas to reduce the possibility of direct contact with acid.

Proper maintenance of analytical instruments used for measuring the sulfur dixoide emissions from the vent stack is required by federal regulation. The instruments used most frequently for measuring SO_2 emissions are types using infra-red or ultra-violet light absorption or the coulometric titration of iodine. All instruments in this type of application must be calibrated on a proper schedule using standard gases of a known concentration. Daily inspection and preventive maintenance must be performed on these instruments to ensure reliable operation.

The portion of an analytical instrument system most difficult to maintain in proper operating order is the sampling system. Sampling systems are subject to corrosion, plugging with solids and flooding with accumulated condensate. Sampling systems must be cleaned and inspected regularly and blown down daily to maintain accurate readings from the analyzer.

The instrument and control system in most sulfuric acid plants includes only a few control valves in sulfuric acid service. A control valve in this service usually will have tungsten carbide internals and Teflon packing for maximum corrosion resistance. The exterior parts of the control valve must be protected to prevent atmospheric corrosion and acid leaks from destroying the diaphragm or piston housings. Control valves equipped with pneumatic positioners are particularly vulnerable to corrosion and must be carefully installed and maintained for reliable service. A control valve regulating the flow of sulfuric acid in a critical service should be inspected frequently during plant shutdowns to determine the condition of the valve internals before a major failure causes a plant shutdown.

Electrical

The electrical power system for a sulfuric acid plant is similar to the electrical system for any other type of chemical plant from the electrical design viewpoint. The area where sulfuric acid plants differ from many plants in the electrical power system is the requirement for special materials and special design to prevent corrosion resulting in failure from liquid acid and acid gases encountered in the service.

In most modern acid plants, the unit substation transformer is located outside a pressure-ventilated switchgear room with a secondary throat connection for buswork through the wall of the room and with a primary connection to an air-filled terminal box. This pressure-ventilated switchgear room may also house motor control centers, panelboards, and other electrical equipment in addition to the switchgear. The air supplied for this pressure-ventilated room must be clean air free of acid fumes. This installation method is used:

1. To protect electrical equipment from accumulation of dirt, dust and other foreign material.
2. To permit the use of less expensive and more easily maintained general purpose electrical equipment enclosures rather than costly corrosion-resistant enclosures.
3. To enable the substation to be positioned at the center of electrical load requirements, resulting in shorter runs of feeder cables.
4. To prevent access by unauthorized people.

All electrical equipment located in the production area and subjected to acid fumes must be housed in the proper type of enclosure to protect the equipment. NEMA type 4X water tight corrosion-resistant enclosures are used for control stations and must be coated with an appropriate acid proof paint to protect the metal. Aluminum conduit is frequently used to minimize corrosion of conduit runs. A substitute for aluminum conduit is PVC coated steel, although this type of conduit is subject to damage, leaving the bare metal exposed to acid corrosion. For this reason alumunum conduit is preferred. All electrical wire in an acid plant must have acid resistant insulation.

All electric motors in a sulfuric acid plant should be of a type suitable for chemical service. These motors are totally enclosed with alloy steel bolts and double sealed bearings. The outside of the motor housing is treated with an acid proof paint such as epoxy to protect the motor housing.

Careful inspection and planned preventive maintenance of the complete electrical system must be conducted frequently to find points of acid attack so repairs can be performed and the protective coatings replaced. All control devices such as motor starters and other contacting devices should be inspected frequently to detect corrosion of the electrical parts. Before opening, all enclosures should be cleaned to remove corrosive particles. If evidence of corrosive gas or liquid is found in the enclosure, the system should be inspected to locate the source of entry and gaskets or seals replaced to prevent further corrosion of electrical parts. All motor windings should be checked periodically with a megger to detect any deterioration of motor winding insulation. When maintenance is performed on any portion of the electrical system, care should be exercised to replace all covers and gaskets in proper condition to ensure continued seal of the system against entry of corrosive gases and liquids.

A sulfuric acid plant requires an extensive interlock system to prevent operation of the plant in an unsafe condition for personnel and equipment. Safety trips are connected to process services such as low water level in the boilers, high temperatures in the furnace, converter overtemperature, low combustion air flow and many others. The existence of these safety trips in electrical systems makes this type of plant control system susceptible to shutdown during electrical storms from voltage surges and momentary interruptions. Electrically held motor starters can also drop out and shut down the plant if voltage is interrupted for a very short period of time. To prevent unnecessary shutdowns from these surges and momentary voltage losses the safety trip system is equipped with time delays to prevent drop out on short interruption. Motor starters are frequently equipped with under voltage time delay relays to prevent drop out and plant shutdown on momentary interruptions. When equipped with these devices, maintained in good working order and correctly adjusted, the acid plant will experience fewer shutdowns from electrical service problems. If maximum security of operation is desired, an alternate electrical power service can be installed with automatic load transfer features. With this arrangement, the second source of power will be selected automatically if the primary source fails, reducing the chance of power loss. This service is expensive but may be justified for a large plant in areas of unreliable electrical service.

Piping, Ductwork, Insulation and Brickwork

Based on plants surveyed, in an average sulfuric acid plant approximately 34 percent of all of the forced shutdowns result from acid or gas leaks in the piping, coolers, ducts or vessels. Small leaks that occur are often patched temporarily while the plant is operating. The repair is then performed at a later time during a shutdown for other purposes. Many factors affecting the frequency of acid and gas leaks are dependent upon design of the plant equipment rather than maintenance. Many shutdowns however result from failures that could be prevented or postponed by proper preventive maintenance.

Sulfuric acid plants use both external and internal insulation to control heat losses and protect equipment from excess heat. Internal insulation is generally firebrick inside a carbon steel shell. Brick linings are also used in other vessels in sulfuric acid plants to protect the carbon steel shell against the effects of the hot sulfuric acid contained in the vessel. This brick is acid proof brick installed with acid proof mortar. External insulation is generally of foamed plastic, magnesia, or foam glass, depending upon the temperature level.

Piping acid leaks are caused primarily by corrosion of the carbon steel piping by the hot, concentrated sulfuric acid.

Carbon steel is used rather than alloy steel for these services to reduce cost. The accepted design practice is to include a corrosion allowance in determining the thickness of the pipe and allow for its replacement. Careful inspection of all plant piping is required to locate badly corroded pipe so it can be replaced before failure or a leak occurs. Special attention should be given to flanges and joints that are most subject to leaks. Use of proper gasket material is especially important in preventing leaks in flange joints.

Ductwork for transporting hot acid gases is subject to corrosion as well as stress cracking from thermal expansion of equipment. Corrosion of the ductwork and the production of corrosion products that foul the catalyst are reduced by flame coating the inside surfaces of carbon steel ductwork and vessels subject to corrosive gases with aluminum. This treatment reduces the corrosion rate of the carbon steel and decreases the frequency of gas leaks.

Major equipment in the plant is usually arranged to require the minimum length of duct to interconnect the furnace, boilers and converter. The short duct run reduces the cost of construction and corrosion possibilities but introduces other problems of stress from thermal expansion. These problems are accentuated with the high temperature ducts (up to 1700F) because of the need to install insulating fire brick linings with different coefficients of thermal expansion than the steel ducts.

The thermal expansion of ducts is controlled by installation of expansion joints and by the use of elbows to permit flexure of the duct. The furnace is often mounted on a movable base to permit it to move to compensate for expansion of the outlet duct. All of these measures decrease the stress applied to the ducts, but failures still occur in both brickwork and ducts at points of high stress. The expansion joints, duct elbows and flanges should be inspected regularly to detect cracking that will develop into a major leak. Expansion joints must be replaced on a regular schedule established by operating experience.

Thermal expansion of steel shells lined with brick causes frequent cracking of the brick lining. If the brick lining is not repaired regularly to maintain a strong mortar seal, the brick lining can fail completely and cause rapid destruction of the duct and force shutdown. Repointing the mortar in the acid proof and firebrick is normally done during the semi-annual shutdowns when equipment is open for inspection.

The absorber, drying tower and acid pump tanks are lined with acid proof brick to prevent hot concentrated sulfuric acid from contacting the carbon steel shell. If the integrity of the brick lining is maintained, the steel vessel will have a long service life. If the acid proof brick is permitted to deteriorate, early failure of the steel shell will occur resulting in leaks requiring shutdown and extensive repairs. An important factor in obtaining a long service life from acid proof brick linings is the workmanship used in installing the brick. Poor workmanship will result in gaps and cracks in the mortar causing leaks.

The insulation of the sulfuric acid plant is both internal and external. These types of insulation are illustrated by the external insulation on the absorber towers, pumps, tanks and acid piping; and internal insulating fire brick in the furnace, waste heat boiler, and converter. Additional insulation is applied to maintain the temperature in the gas ducts above the condensation point to prevent acid condensation in the ducts. If the ducts are allowed to cool below the dew point, the vapor carried in the gas stream will condense on the metal surfaces and cause extensive corrosion.

Fire brick linings in high temperature vessels must be maintained regularly to prevent massive failure of the carbon steel vessel shells resulting from high temperatures and corrosive gases. Careful maintenance of the external insulation will extend the life of equipment and permit high operating efficiency in terms of energy consumption.

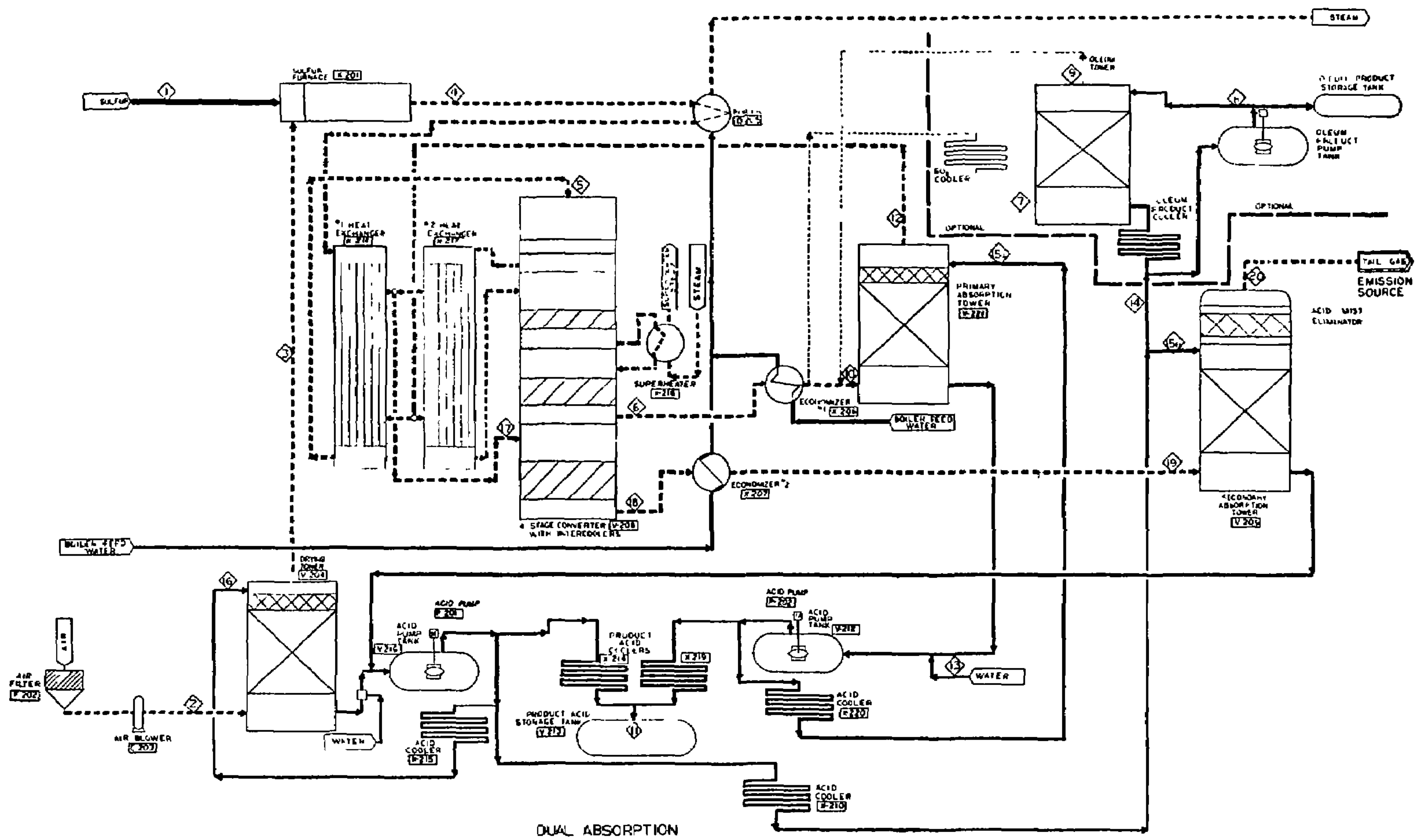
DUAL ABSORPTION PROCESS

Process Description

The average single absorption sulfuric acid plant will produce SO_2 emissions in the range of 1600 ppm to 2500 ppm when operating at normal efficiencies. Since this level of sulfur dioxide emissions is in excess of federal or state regulations, the need for lower sulfur dioxide emissions is accomplished by secondary absorption equipment. The need for more efficient sulfuric acid plants initiated the development of the dual absorption plant. The dual absorption process can convert 99.7 to 99.9 percent of the sulfur dioxide to sulfur trioxide for producing sulfuric acid. The increased complexity of the dual absorption acid plant also requires more reliable equipment and more effective control systems to maintain a low level of SO_2 emissions.

A typical modern dual absorption process burning elemental sulfur is shown in Figure 4. The primary difference between the single absorption and the dual absorption process is the addition of a primary SO_3 absorber for gas leaving the third catalyst bed. One process (Lurgi) uses the absorber after the second bed. Since the addition of an absorber between catalyst beds requires cooling and reheating the process gas, a change in the heat recovery system is also required.

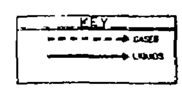
Comparison of Figures No. 1 and 4 will show that the sulfur combustion portions of the single and dual absorption plants



DUAL ABSORPTION

SULFUR BURNING CONTACT
SULFURIC ACID PLANT
PROCESS FLOW DIAGRAM

FIGURE 4



are similar. Air is compressed and dried in a drying tower with 93 to 98 percent sulfuric acid before it is used for combustion of sulfur in the sulfur furnace. The hot gases from a sulfur furnace then pass through the waste heat boiler to generate process steam. The waste heat boiler is designed to permit further cooling of the combustion products to approximately 795 to 820F in the No. 1 heat exchanger by reheating part of the gas from the primary absorber. The cool gases are then passed through the first bed of the catalytic converter where the gas temperature is increased by oxidation to SO_3 to approximately 1100 to 1130F. The high temperature gas exiting the first catalyst bed is cooled in the No. 2 heat exchanger to approximately 820F for reaction in the second catalyst bed. The heat is used to reheat the remainder of the gas from the primary absorber. Heat generated in the second catalyst bed is removed by a steam superheater in the process steam line from the waste heat boiler. Heat generated in the third catalyst bed is removed by an economizer in the boiler feedwater system before the gas is fed to the primary absorption tower. In the primary absorption tower the concentration of SO_3 in the gas is reduced to about 100 parts per million by contact with 98.5 percent sulfuric acid.

Cool gas leaving the primary absorption tower must be reheated before introduction to the fourth catalyst bed. This is accomplished by passing through No. 1 and No. 2 heat exchangers in parallel.

Variations in location of these heat exchangers is one of the major differences between plants from various designers. In a single absorption plant, the gas passing through the exchangers is not cooled below the condensation point at any time while passing through the catalytic converter. With proper design of heat exchangers and control of the process, condensation will not occur in the heat exchangers and not cause a corrosion problem. In a dual absorption plant, however, gases are cooled to 170F in the primary absorber. This low temperature results in more possibilities for condensation in the heat exchangers that follow the primary absorber. This high probability of condensation results in this being a major location of corrosion failure. These exchangers have received extensive attention in design to minimize or eliminate corrosion problems through variations in materials of construction, configuration and location. Although design improvements have increased the life of this exchanger, it still remains one of the major maintenance problems in many acid plant designs.

Approximately 97 percent of the SO_2 remaining in the gas stream is converted to SO_3 in the fourth catalyst bed. This gives a much higher overall conversion rate (99.7 to 99.9 percent) than is possible in the single absorption plant. The increased conversion efficiency results from the lower partial pressure of SO_3 in the gas, permitting the reaction to be driven more nearly to completion. The gases leaving the fourth catalyst bed are finally cooled in a second economizer that heats boiler feedwater before contacting 98.5 percent sulfuric acid in the secondary absorption tower. The gases leaving the secondary absorption tower will contain approximately 100 to 200 parts per million SO_2 under normal operating conditions and will meet the existing emission standards without further processing.

If oleum is required, an oleum tower is installed upstream of the primary absorber in a manner similar to the single absorption process.

With the exception of the location of the primary absorber and heat exchangers previously discussed, all major designers of dual absorption sulfuric plants use much the same basic equipment configuration. Important differences between these designs are found in the details of the converter, heat exchangers and absorbers. Air quench is also used in some dual absorption plants but is not frequently used because of waste in energy.

Critical Equipment Description

The major differences in critical equipment between the single absorption plant and the dual absorption plant is the addition of the primary absorber and substitution of gas-to-gas heat exchangers in place of the No. 2 waste heat boiler that is used in the single absorption plant. Additional critical equipment required for a dual absorption plant is shown in Table 1, page 16. Equipment numbers in this table refer to the process flow sheet for the dual absorption plant shown in Figure 3.

All dual absorption acid plants use gas-to-gas shell and tube heat exchangers to reheat the gas from the primary absorber. The location and arrangement of the gas heat exchangers will vary with different plant designers. The arrangement of the heat exchangers is important to the operation, maintenance and life expectancy of the exchangers.

The heat exchangers are normally constructed of carbon steel with all surfaces in contact with sulfur gases aluminized. These exchangers will not contribute to plant shutdowns or increased emissions if plant operation maintains the gas dry and free from acid mist. Efforts to minimize this problem are the primary reason for variations in heat exchanger arrangement between plant designers. Failure of temperature control equipment or malfunction of the plant that causes the temperatures to run abnormally low in the exchangers will accelerate corrosion and subsequent failure of exchangers. Since these variations are more prone to occur during start-up of the plant, malfunctions resulting in a shutdown and start-up will accentuate the corrosion problems.

The primary absorber used in the dual absorption units, with its associated pumps and acid coolers, is similar to that used in the single absorption plant and normally presents no additional maintenance or operational problems not encountered in the single absorption plant.

SECTION V

MANUFACTURER'S RECOMMENDED MAINTENANCE

Major maintenance functions recommended by the equipment manufacturers are presented in Table 2. This list covers only the critical equipment contributing to plant emissions and does not include many items of auxiliary equipment necessary for plant operations. The maintenance tasks listed are typical and will vary in kind and frequency of recommended maintenance between manufacturers. Since the tendency is for manufacturers to claim longer service life than can normally be obtained, the periods between major overhauls and estimated service life will probably be shorter in most applications. The final schedule for preventive maintenance and overhaul operations will be adjusted to reflect operating experience as shown in the sample preventive maintenance manual discussed in Section VII .

Table 2 shows most of the tasks scheduled to be performed annually. This period is influenced by the common practice of shutting down plants for annual overhaul. All maintenance possible is usually done during these annual shutdowns to reduce the number of forced shutdowns during the remainder of the year. Even when the service life on equipment is expected to be several years, it is normally inspected on an annual basis to provide assurance of reliable operation during the following year.

Table 2. MANUFACTURER'S RECOMMENDED MAINTENANCE OF CRITICAL EQUIPMENT FOR CONTACT SULFURIC ACID PLANTS

ITEM NO.	EQUIPMENT NAME	TYPE OF MAINTENANCE RECOMMENDED	FREQUENCY OF MAINTENANCE				ESTIMATED SERVICE LIFE (YEARS)	REMARKS
			PER SHIFT	DAILY	WEEKLY	AS INDICATED		
C-103 (C-203)	MAIN AIR BLOWER						15-20	
	1. Blower	Change oil in bearings				Annually		
		Check lubrication system		X				
		Complete overhaul				5 yrs.		
		Inspect for noise, vibration and hot bearings	X					
	2. Turbine	Change oil				Annually		
		Check oil filter pressure differential	X					
		Replace or clean oil filters				6 mo.		
		Check oil pressure and temperature	X					
		Complete overhaul				5 yrs.		
		Check for noise, vibration and hot bearings	X					
	3. Air Filter	Change oil bath						Frequency depends upon environmental conditions.
		Replace filter media				As req'd.		
		Check filter media drive and oil level			X			
K-101 (K-201)	SULFUR FURNACE						15-20	
	1. Shell	Repoint mortar				Annually		
		Replace refractory				As req'd.		
	2. Burner System	Relubricate sulfur pumps				3-6 mo.		
		Check pumps for noise and vibration						
		Replace sulfur spray nozzle	X			Annually		
B-105 and III (B-205)	WASTE HEAT BOILERS						20-25	
		Inspect tubes and clean				Annually		
		Test safety valves				Annually		
		Hydrostatic test				Annually		
X-106 (X-206 and 207)	ECONOMIZERS						20-25	
		Inspect tubes and clean				Annually		
		Hydrostatic test				Annually		
V-108 (V-208)	CONVERTER						20-25	
	1. Vessel	Inspect firebrick				Annually		
		Replace broken firebrick				As req'd.		
	2. Support grids and posts	Inspect for thermal distortion				Annually		
		Replace damaged items				As req'd.		
	3. Catalyst	Screen catalyst				6 mo.	15	Stock 10% of catalyst charge for replacement.
		Make-up lost catalyst				6 mo.		
V-109 (V-209 and 221)	ABSORPTION TOWERS						20-25	
	1. Vessel	Repoint mortar				Annually		
		Replace damaged acid proof brick				As req'd.		
	2. Mist Eliminator	Inspect and clean				Annually	3-5	
		Replace corroded parts				As req'd.		
	3. Distributors and Piping	Inspect				Annually	20-25	
		Replace corroded parts				As req'd.		
	4. Packing	Inspect for settling and clean				Annually	20-25	Wash sulfate deposits out as required. Stock 10% of packing charge for replacement.
		Add packing				As req'd.		
		Unpack and wash packing				3-5 yrs.		

Table 2 (Continued). MANUFACTURER'S RECOMMENDED MAINTENANCE OF CRITICAL EQUIPMENT FOR CONTACT SULFURIC ACID PLANTS

ITEM NO.	EQUIPMENT NAME	TYPE OF MAINTENANCE RECOMMENDED	FREQUENCY OF MAINTENANCE: PER SHIFT	DAILY	WEEKLY	AS INDICATED	ESTIMATED SERVICE LIFE (YEARS)	REMARKS
P-101 and 102	ACID CIRCULATING PUMPS						5-8	Spare pump normally installed to prevent shutdown of plant because of pump failure.
		Check bearing lubrication and temperature	X					
		Relubricate				3-6 mo.		
		Inspect for noise and vibration	X					
		Inspect and overhaul				Annually	7-10	
(P-201 and 202)		Inspect and clean pump tank				Annually	15	Check for accumulation of packing chips.
		Repoint mortar in pump tank				As req'd.		
(X-211 and 217)	HEAT EXCHANGERS	Inspect tubes and clean				Annually	2-5	
(X-218)	SUPERHEATER	Inspect tubes and clean				Annually	20-25	
X-110,115 and 119	ACID COOLERS						13-17	
	1. Cascade type	Clean tubes and troughs				As req'd.		
	2. Shell and tube	Inspect tubes and clean				3-12 mo.		Frequency of cleaning depends on water quality.
	3. Teflon bundle	Inspect tubes and tube sheets				6 mo.	Unknown	Requires filtered water.
V-104 (V-204)	DRYING TOWER						25-30	
	1. Vessel	Repoint mortar				Annually		
		Replace damaged acid proof brick				As req'd.		
	2. Entrainment Separator	Inspect and clean				Annually	3-5	
		Replace corroded parts				As req'd.		
	3. Distributors and Piping	Inspect				Annually	20-25	Stock 10% of packing charge for replacement.
		Replace corroded parts				As req'd.		
	4. Packing	Inspect for settling				Annually	20-25	
		Add packing to replace lost packing				As req'd.		
		Unpack and wash packing				3-5 yrs.		

SECTION VI

MAINTENANCE AND MALFUNCTION HISTORY

A summary of maintenance and malfunction history for the critical sulfuric acid plant equipment is given in Table 3. This history was compiled from maintenance data from several plants of various ages and types and with a variety of feedstock. The data shown represents typical or average experience. Another presentation of the frequency and duration of plant downtime is given in Figure 5 and Figure 6. These represent data from 12 plants with a wide variation in age and maintenance quality.

THE EFFECT OF MAINTENANCE QUALITY ON EQUIPMENT OPERABILITY

The effect of maintenance quality on plant operability is difficult to evaluate from plant maintenance data since the quality of maintenance performed in the plant cannot adequately be evaluated without firsthand experience. Plant operators seldom provide judgement on the quality of maintenance performed in their plants. Certain general relationships, however, can be stated on a qualitative basis as demonstrated by plant maintenance history.

The rotating equipment such as pumps and blowers will probably be the most affected by maintenance neglect. Failure to properly lubricate pump bearings as well as over lubrication of bearings can cause premature bearing failure. Failure to replace damaged bearings in pumps when needed can cause pumps to seize and shear shafts or damage casings beyond

Table 3. CRITICAL EQUIPMENT MALFUNCTIONS AND MAINTENANCE HISTORIES FOR CONTACT SULFURIC ACID PLANTS

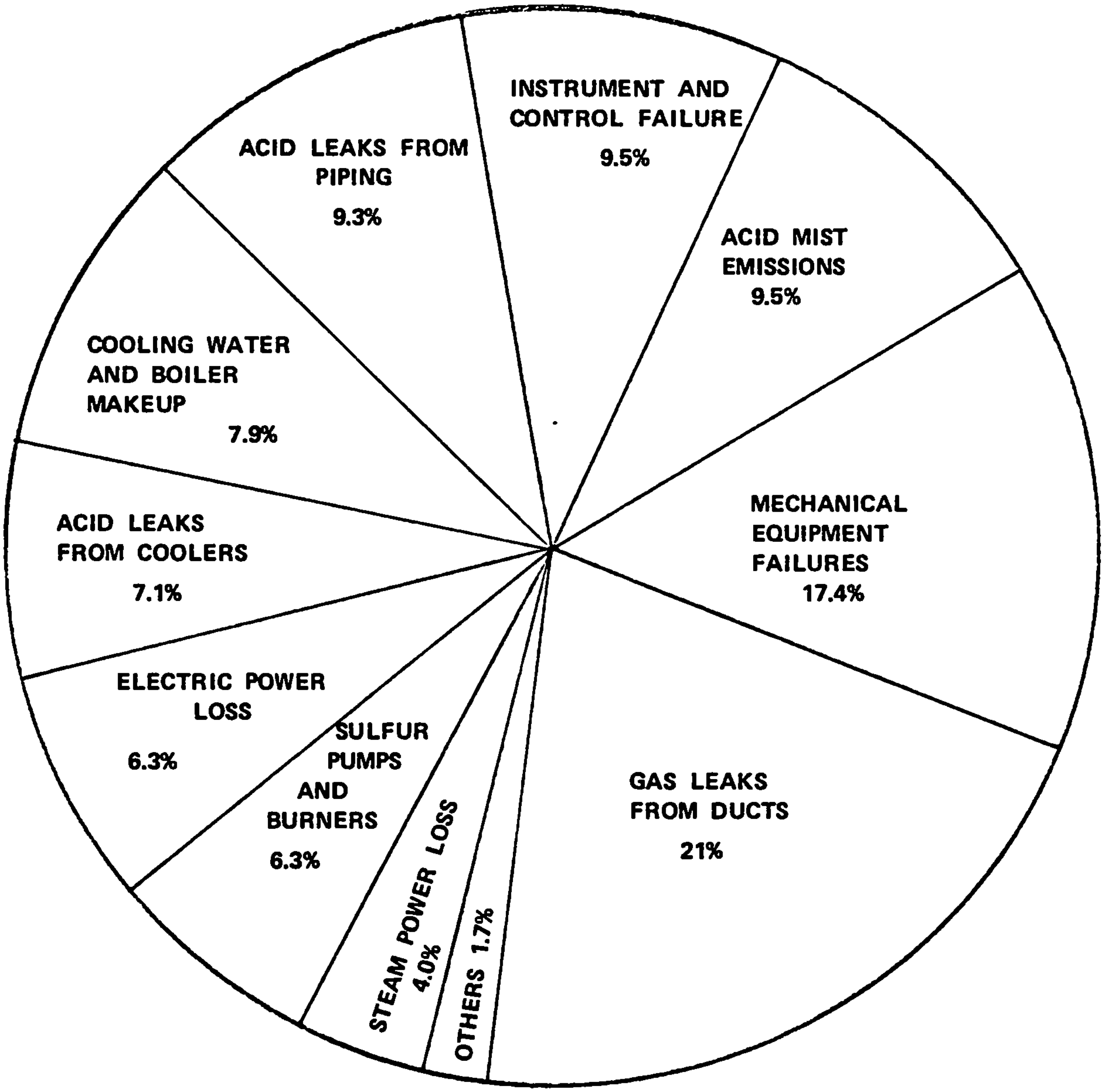
ITEM NO.	EQUIPMENT NAME	TYPE OF MALFUNCTION	CAUSE OF MALFUNCTION	MEAN TIME BETWEEN OCCURENCES	MAINTENANCE REQUIRED	MEAN TIME TO REPAIR	THEORETICAL EFFECT OF MAINTENANCE NEGLECT	AVOIDABLE BY PREVENTIVE MAINTENANCE
C-103 (C-203)	MAIN AIR BLOWER 1. Blower	Excessive vibration	Sulfate buildup on impeller	1-2 yrs.	Wash with water and caustic, drain and dry-out	1 day	Wear on bearings and mechanical failure	Yes
		Bearings overheating	Improper lubrication	Unknown	Lubricate	1 hour	Bearing failure-replace	Yes
	2. Turbine	Excessive vibration	Scale on rotor because of steam quality	Unknown	Wash rotor	1 day	Wear on bearings and mechanical failure	Yes
		Bearings overheating	Improper lubrication or or oil cooling	Unknown	Lubricate, clean oil filter, check oil pump, clean oil cooler or check cooling water supply	4 hour	Bearing failure-replace	Yes
	3. Air Filter	Insufficient air flow	Dirty filter	Unknown	Clean filter media, change oil bath, check drive	1 hour	SO_2 emissions and blower overheating	Yes
K-101 (K-201)	SULFUR FURNACE 1. Shell	Hot spot in shell	Deterioration of firebrick lining	1-2 yrs.	Repair firebrick and shell	1 wk.	Failure of furnace shell	No
		Generation of acid mist	Steam leaks from jacketing into sulfur	1/2-1 yr.	Replace burner or pipe	1-4 hrs.	Corrosion of plant equipment down stream and catalyst deterioration	No
	2. Burner System	No sulfur feed	Sulfur pump failure, plugged pipelines because of cold sulfur	1/2-1 yr.	Replace pump	2-4 hrs.	Loss of converter temperature control	No
					Unplug lines	1 day		Yes
B-105 and 111 (B-205)	WASTE HEAT BOILERS	Steam leak to gas stream	Corrosion of tubes	1 yr.	Replace tube	1 wk.	Internal corrosion of downstream equipment and catalyst deterioration	Yes
		Insufficient steam flow	Tube scaling because of water quality	Unknown	Clean tubes	2 days	Tube failure-replace	Yes
		No feedwater flow	Failure of feedwater system	1 yr.	Check and repair feedwater system	1 wk.	Tube failure-replace	Yes
X-106 (X-206 and 207)	ECONOMIZERS	Water leak to gas stream	Ruptured tube or seal leak	3-12 mo.	Plug tubes Replace tubes	4-6 hrs. 3 days	Internal corrosion of downstream equipment and catalyst deterioration	No
		Insufficient cooling	Plugged or coated tubes	6-12 mo.	Clean tubes	1 day	Ruptured tubes	Yes
(X-218)	SUPERHEATERS	Steam leak to gas stream	Ruptured tube or seal leak	1 yr.	Replace tube	1-2 days	Internal corrosion of downstream equipment and catalyst deterioration	No

Table 3 (Continued). CRITICAL EQUIPMENT MALFUNCTIONS AND MAINTENANCE HISTORIES FOR CONTACT SULFURIC ACID PLANTS

ITEM NO.	EQUIPMENT NAME	TYPE OF MALFUNCTION	CAUSE OF MALFUNCTION	MEAN TIME BETWEEN OCCURENCES	MAINTENANCE REQUIRED	MEAN TIME TO REPAIR	THEORETICAL EFFECT OF MAINTENANCE NEGLECT	AVOIDABLE BY PREVENTIVE MAINTENANCE
X-110 115, and 119 (X-210 215, 219 and 220)	ACID COOLERS 1. Cascade type	Insufficient and cooling	Scale on outside of tubes	Unknown	Water blast, scrap or wire brush	3-7 days	Acid mist emissions and opacity from stack	Yes
		Acid leak	Corrosion	3-6 mo.	Blankoff section Replace tube section	4 hrs. 2 days	Water pollution - acidic cooling water system	Yes
	2. Shell and tube	Insufficient acid cooling	Scaling of tubes	Unknown	Acid clean tubes	4-8 hrs.	Acid mist emissions and opacity from stack	Yes
		Acid leak	Corrosion	Unknown	Plug or replace tube	2 days	Water pollution - acidic cooling water system	No
	3. Teflon bundle	Insufficient cooling	Plugged tubes	Unknown	Back flush	1 hr.	Acid mist emissions and opacity from stack	Yes
		Water leak to acid	Leaking tubes	Unknown	Plug or replace tube	1 hr.	Excessive leakage causes acid mist emissions and stack opacity	Yes
V-109 (V-209 and 221)	ABSORPTION TOWERS 1. Vessel	Acid leaks	Corrosion	Unknown	Patch or weld	4-8 hrs.	Shell failure and water pollution Acid mist emission	No
	2. Mist Eliminator	Acid mist carry-over	By-passing or plugged pad	2-3 yrs.	Repair or replace	1 day	Internal corrosion of heat exchangers and catalyst deterioration from Primary Absorber. Acid mist emission and opacity from Final Absorber.	No
	3. Distributors and Piping	Low absorption efficiency	Maldistribution of acid	Unknown	Replace	2-5 days	High SO_2 from Primary Absorber and high SO_3 from Final Absorber	No
	4. Packing	Low absorption efficiency	Flooding, channelling, settling or disintegration of packing	1-2 yrs.	Wash and replace	1-2 days	High SO_2 from Primary Absorber. High SO_3 and opacity from Final Absorber	Yes
P-101 and 102	ACID CIRCULATING PUMPS	Low acid flow	Plugged suction Damaged impeller	Unknown 1-2 yrs	Clean pump and tank Replace	2-3 days 1 day	High SO_2 from Primary Absorber. Internal corrosion of downstream equipment from Drying Tower SO_3 and opacity from Final Absorber	No Yes
		No acid flow	Bearing seizure	Unknown	Rebuild pump	1-2 days	Plant shutdown	No

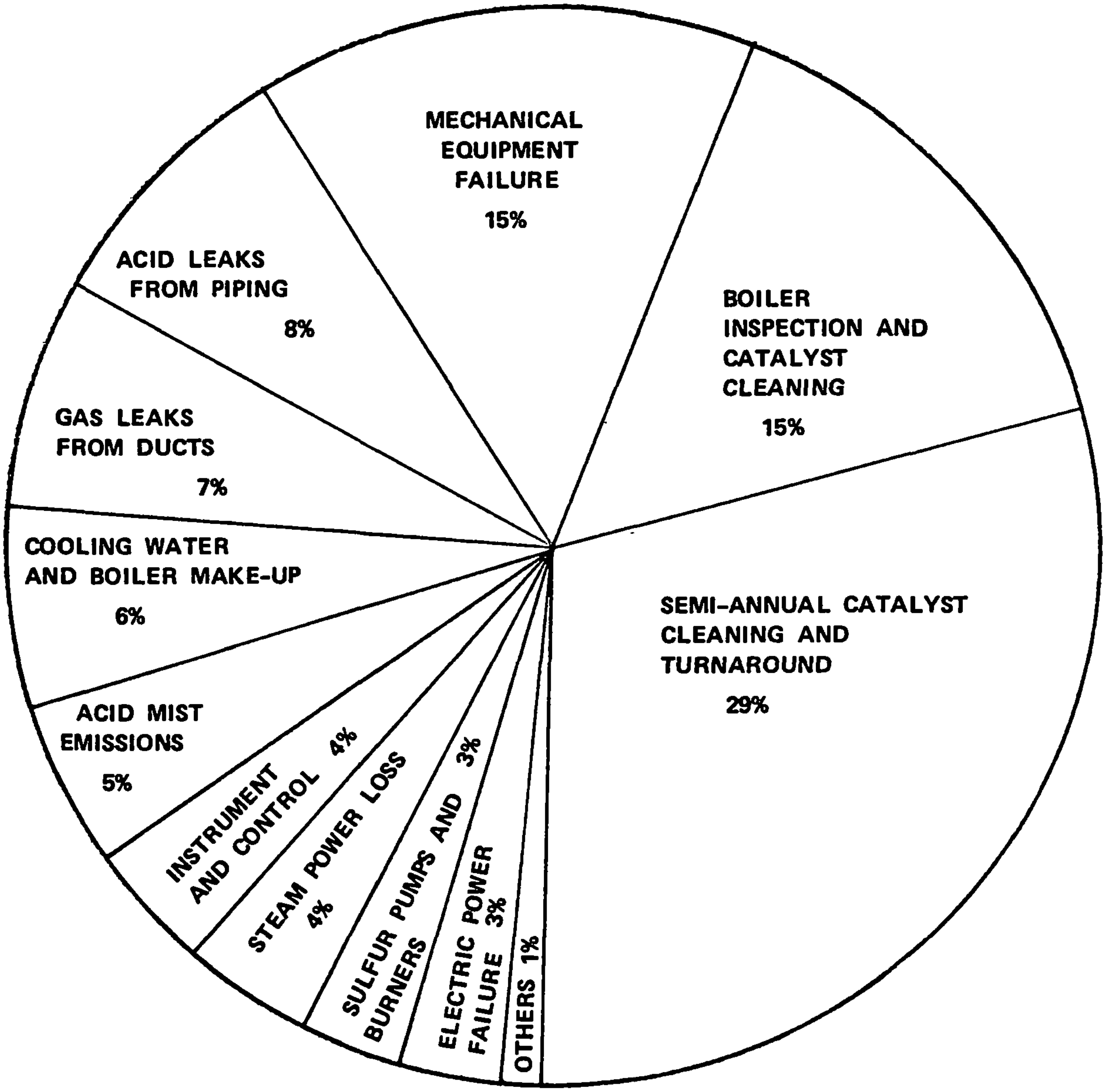
Table 3 (Continued). **CRITICAL EQUIPMENT MALFUNCTIONS AND MAINTENANCE HISTORIES FOR CONTACT SULFURIC ACID PLANTS**

ITEM NO.	EQUIPMENT NAME	TYPE OF MALFUNCTION	CAUSE OF MALFUNCTION	MEAN TIME BETWEEN OCCURENCES	MAINTENANCE REQUIRED	MEAN TIME TO REPAIR	THEORETICAL EFFECT OF MAINTENANCE NEGLECT	AVOIDABLE BY PREVENTIVE MAINTENANCE
V-104 (V-204)	DRYING TOWER							
	1. Vessel	Acid leak	Corrosion	Unknown	Patch	4-8 hrs.	Water pollution and shell failure	No
	2. Entrainment Separator	Acid mist carry-over	Corroded frame or pad by-passing and plugging	2-3 yrs.	Replace	1 day	Internal corrosion of downstream equipment catalyst deterioration and acid mist emission	No
	3. Distributors and Piping	Improper drying	Maldistribution of acid from corroded or plugged distributors	Unknown	Replace	2-5 days	Internal corrosion of downstream equipment, catalyst deterioration and acid mist emission	No
	4. Packing	Improper drying	Flooding or channelling from dirty or settled packing	1-2 yrs.	Wash and replace lost packing	1-2 wks.	Internal corrosion of downstream equipment, catalyst deterioration and acid mist emission	Yes
V-108 (V-208)	CONVERTER							
	1. Vessel	Buckling	Overheating	Unknown	Repair	3 days	High SO_2 emissions	No
	2. Support Grids and Posts	Collapse or buckling	Overheating	Unknown	Repair, replace or rebuild	2-4 wks.	Plugged converter High SO_2 emissions	No
	3. Catalyst	Low conversion efficiency	Dirty catalyst	6 mo.	Screen catalyst	5-7 days	High SO_2 emissions	Yes
			Damaged catalyts (over-heated)	Unknown	Replace catalyst		High SO_2 emissions	No
(X-211 and 217)	HEAT EXCHANGERS	Low heat transfer	Corrosion from acid carry-over	1-2 yrs.	Plug tubes Replace tubes	1 day 1 wk.	High SO_2 because of loss of temperature control	No
		Tube leaks	Corrosion from acid carry-over	1-2 yrs.	Plug tubes Replace tubes	1 day 1 wk.	Acid mist emissions	No



FREQUENCY OF UNSCHEDULED
SHUTDOWN BY CAUSE
SINGLE ABSORPTION PLANT

Figure 5



DURATION OF PLANT SHUTDOWN
BY CAUSE
SINGLE ABSORPTION PLANT

Figure 6

repair. Serious damage caused by neglect will always result in increased plant emissions. Obviously, the cost of plant operation also will be increased by such maintenance neglect.

One of the most significant indicators of the quality of plant maintenance is the frequency of unplanned shutdowns. Plants being forced to shut down often by a variety of failures invariably have poor maintenance programs and personnel usually do not detect and repair damaged equipment before a failure occurs.

Leaks in acidic gas and liquid lines represent one of the most frequent causes of shutdowns in any acid plant. A poorly maintained plant will experience more frequent leaks. One reason for failure of acid proof brick linings can be maintenance neglect. Improper or inadequate repair of leaks will result in reoccurrence of the leaks and cause more frequent shutdowns. A plant covered with temporary patches to stop leaks will also have a high emission rate at the start-up that follows forced shutdowns for repairs and will also have higher fugitive emissions.

The failure rates and resulting emissions from a poorly maintained plant are not corrected by a sudden change in maintenance philosophy from a minimum maintenance program to a more adequate maintenance program. Several years of high quality maintenance will be required to bring the plant up to the desired level of repair. The life of a well-maintained plant will be as long as twenty to fifty years while one receiving minimum maintenance will become almost inoperable in about ten years. This comparison is illustrated by data obtained from similar operating plants with different maintenance philosophies. Experience has shown that a single absorption plant will require a major overhaul on the average of every fourteen years. Sufficient operating history is not available to determine this period for dual absorption palnts.

PLANT AND EQUIPMENT LIFE CYCLE

The useful plant life reflects the life of all items of equipment installed in the plant. The normal life expectancy of critical equipment is shown in Table 2. The service life shown is in excess of twenty years for most of the major equipment. Some of the smaller pieces of equipment such as pumps have a shorter service life and must be replaced during the normal life expectancy of the plant. The life expectancy shown in Table 2, page 45, is based upon an optimum preventive maintenance program to obtain maximum economically, justifiable, useful life from the plant.

EFFECT OF AGE ON FORCED SHUTDOWN RATE

After the initial shake down period when the inherent weaknesses of a plant are detected and corrected, the failure rate in a plant is inversely proportional to the amount and quality of preventive maintenance. A slight rise in the rate will occur after the first few years, but this will be small if the preventive maintenance program is flexible and is updated frequently to compensate for the age of plant equipment.

This trend will continue until the amount of preventive maintenance required to achieve satisfactory on-stream time is no longer economically justifiable. At this point the plant will either require excessive maintenance expenditures or have a higher unit production cost for the product resulting from reduced on-stream time. Increased emissions will also occur as a result of the frequent shutdown and operational failures. The final result of maintenance neglect is shown in Table 3, Page 48, for the critical equipment considered.

SECTION VII

PREVENTIVE MAINTENANCE

DEFINITION OF PREVENTIVE MAINTENANCE

Eventually, all plant equipment must be repaired if it is to continue to fulfill a useful function. The need for these repairs can be prevented or deferred by proper servicing, or accomplished by replacement before failure, or replacement after failure occurs. The choice of the type of maintenance practiced in a plant is a management function.

Breakdown maintenance is always precipitated by the failure of some component in the plant to perform its necessary function. The breakdown maintenance philosophy makes no provisions for maintenance of equipment until failure occurs and is generally characterized by frequent plant shutdowns and long production outages.

The preventive maintenance philosophy, however, includes the first two functions illustrated above; i.e., servicing equipment to prevent or defer its failure and replacement and repair before failure occurs. Thus, with a preventive maintenance philosophy, equipment failure is less frequent, shutdown of plant operations occurs less frequently and forced shutdown periods are shorter. The preventive maintenance philosophy requires the establishment and implementation of a program tailored to accomplish management goals for a specific plant.

EFFECT OF PREVENTIVE MAINTENANCE PROGRAM

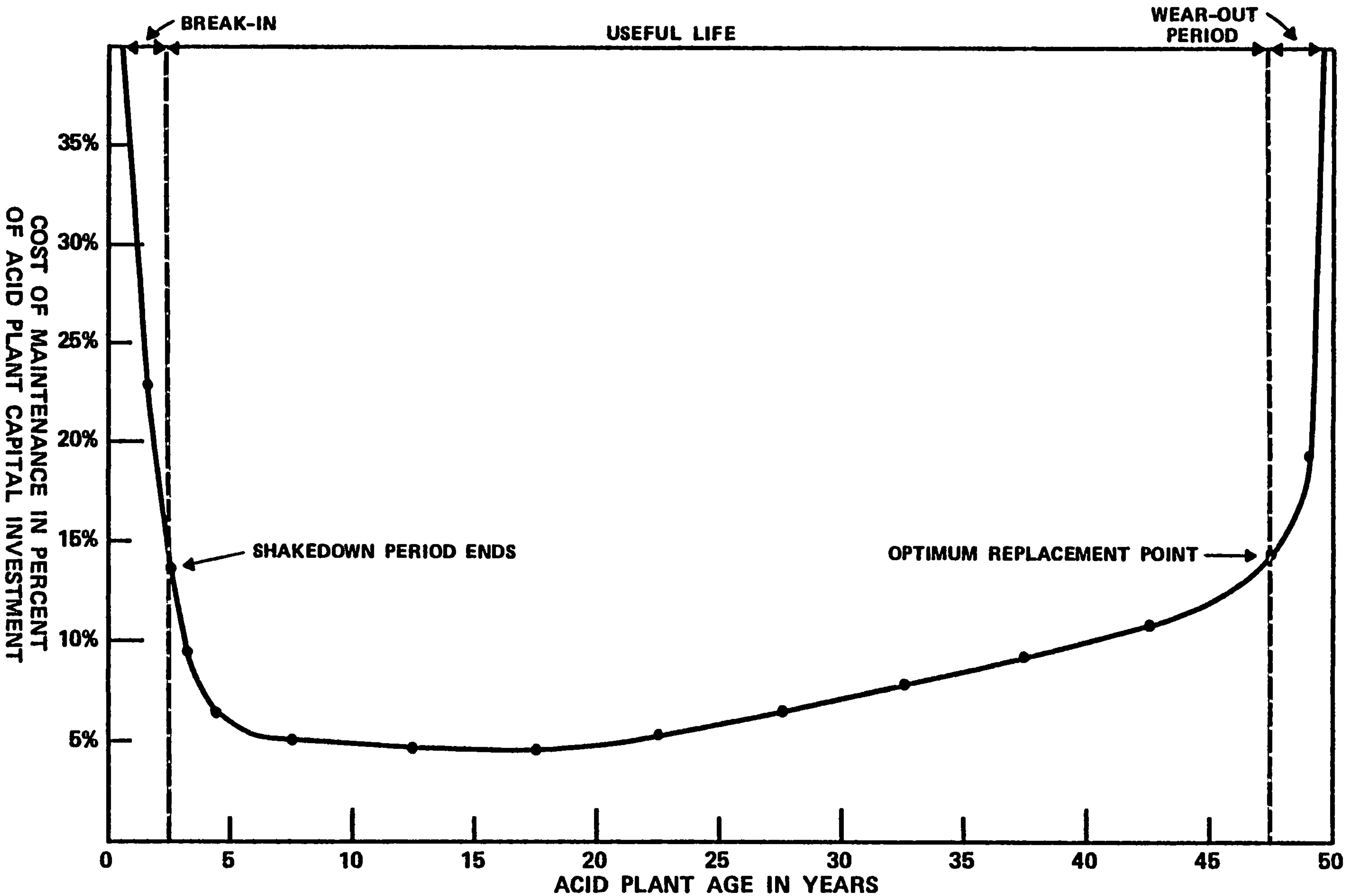
An effective preventive maintenance program affects several aspects of plant operation. The most significant effect is to reduce the total downtime and lost production resulting from equipment failure. Since lost production can be equated to money, the cost of lost production must be added to the cost of maintenance to determine the total cost of a maintenance program. As the amount of money spent on preventive maintenance is increased, the amount of money lost through production outage tends to decrease. Considering only production quantity and maintenance cost, the most desirable preventive maintenance program is one that produces the lowest overall production cost consistent with safe operation of the plant. Since preventive maintenance is a long range program, the long range overall cost of plant operation must be considered in optimizing a preventive maintenance program.

When market conditions demand maximum production, preventive maintenance can be tailored to provide a higher on-line time to maximize production volume. Frequently, optimization for production volume will require a preventive maintenance program similar to optimization for overall minimum cost. If the market advantage is temporary, however, emphasis on production may override maintenance considerations on the short term and cause maintenance to be deferred to a later time, although deferred maintenance may cost more over the long period. When market conditions are bad and the market for the product is not expected to improve within the life expectancy of the plant, a policy of minimum maintenance expenditure may be the wisest choice. With this type of program, plant life is shortened and any subsequent rebuilding of the plant will cost more than proper preventive maintenance during the period. However, if the plant is expected to be retired, operation with minimum maintenance can provide the most income for the plant during the final short period of the plant life.

Selecting a management policy for maintenance for maximizing the production rates, optimizing overall operating cost, or minimizing production cost in the short term is a management decision based on many factors. An additional factor that must be considered, however, in establishing a maintenance program is the legal requirement for maintaining plant emissions within established standards. In a sulfuric acid plant, this necessity may prevent the selection of the minimum cost route since equipment failure and malfunctions causing shutdowns and start-up of the plant will contribute to excessive emissions. When control of plant emissions is considered along with maximizing profit from the plant, a preventive maintenance program optimized on total cost and providing operation within emission standards must be established. The preventive maintenance program must be tailored for each specific plant based on operating and maintenance experience and judgement of plant management.

EFFECT OF EQUIPMENT AGE ON PREVENTIVE MAINTENANCE PROGRAM

A preventive maintenance program that is optimal for a new sulfuric acid plant, and produces the maximum return on the investment, and emissions within the standards, will be changed as the plant becomes older. During the first year of operation, most plants go through a shake-down period when weaknesses and faults in the design and equipment are located and corrected. After this shake-down period, the preventive maintenance program can be established at the optimum point. As the plant becomes older, the equipment failure rate will increase, and more replacement of equipment will be required rather than repair to keep the plant in proper operating condition. The general shape of a life cycle-repair curve is shown in Figure 7. The frequency of performing many preventive maintenance tasks will be increased as the plant becomes older. The required frequency of preventive maintenance tasks must be established based upon experience and modified as experience in the older plant dictates. A major rebuilding or reconditioning of the plant will also modify the preventive maintenance program and permit lengthening the period between preventive maintenance tasks to a point similar to that required for a new plant. A preventive maintenance program must be flexible to permit change with age of the plant if optimum maintenance is to be performed and emissions from the plant are to be maintained within the standard.

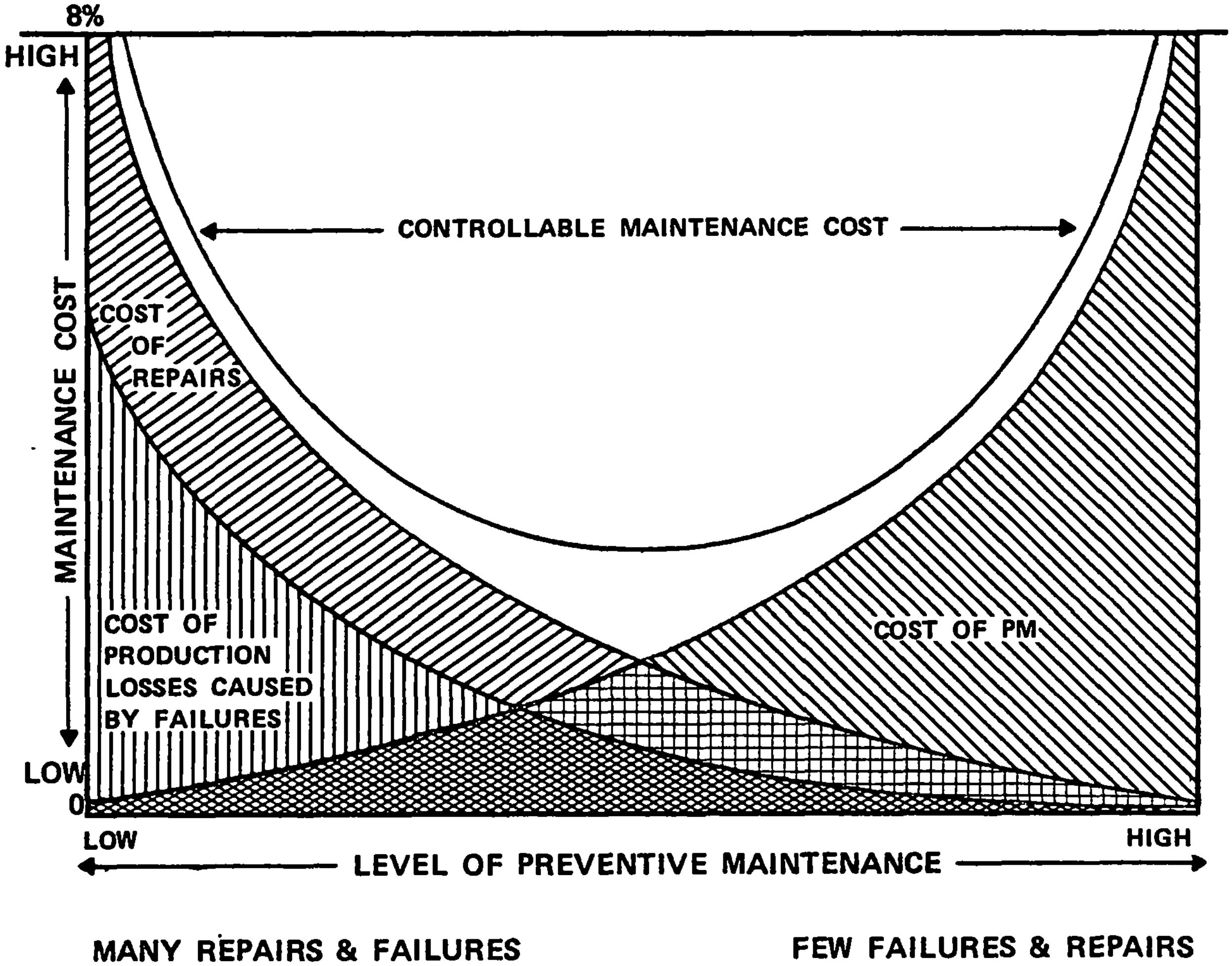


EFFECT OF EQUIPMENT AGE ON MAINTENANCE COST
Figure 7

COST OF PREVENTIVE MAINTENANCE PROGRAM

The cost of maintenance varies widely depending upon the type of plant, age and the philosophy of maintenance adopted by management. A philosophy of minimum maintenance may require an expenditure of as little as one percent of the capital investment for the plant per year. This low rate can be maintained for only a short period, however, before major renovation of the plant will be required. Most modern sulfuric acid plants that start with a good preventive maintenance program when the plant is new will spend about five percent of the plant capital investment per year for the maintenance program. This percentage will vary from three percent for the marginal program to a maximum of seven percent where great emphasis is placed upon maintenance. The higher figures represent expenditures by a company dedicated to good plant maintenance. Another company with a different philosophy of maintenance indicated an expenditure of less than one percent for a poorly maintained plant to a maximum of two percent for a preventive maintenance program considered to be excellent. Other companies indicated a maintenance cost between one and seven percent. The optimum expenditure is probably near five percent. A curve illustrating the relationship between the amount spent on preventive maintenance and the controllable maintenance cost is shown in Figure 8.

As a plant gets older, the expenditure required to maintain good operating conditions will increase to approximately seven percent when the plant is fifteen to twenty years of age. This expenditure level will maintain the



Controllable maintenance cost = cost of PM + cost of repairs + cost of production losses caused by failures.

COST OF PREVENTIVE MAINTENANCE

Figure 8

plant in approximately the same operating condition with failure rates similar to a new plant. The maintenance cost figures presented include the maintenance of emission control equipment. Installation of emission control equipment has increased the cost of maintenance of dual absorption acid plants by approximately 20 - 25 percent. This increase may be different for plants employing various types of tailgas cleaning systems.

SPECIAL MATERIALS TO REDUCE FAILURE

The use of special materials and alloys to reduce corrosion in the sulfuric acid plant is standard for some types of equipment. The submersible acid pumps supplying hot acid to the absorbers and drying towers are constructed of Alloy 20 to withstand the corrosion of hot sulfuric acid. These pumps would have very short lives if cast iron or a less resistant alloy was used. With proper maintenance, pumps made of Alloy 2 have a service life of five to eight years.

Acid coolers are most frequently made of cast iron or carbon steel with sufficient corrosion allowance to give a long service life. If the cooler tubes, however, are allowed to operate at a higher than normal temperature, very rapid corrosion and early failure will result. In modern sulfuric acid plants, there is an increasing use of coolers made of stainless steel and special tube bundles made of Teflon. Sufficient operating time is not available on the Teflon exchanger to evaluate economic justification, but service life should be indefinite as far as corrosion of tubes is concerned.

The most common maintenance problem that causes plant shutdown is leaks in the gas ducts, duct transition pieces and in expansion joints. These components are usually constructed of carbon steel with a flame sprayed coating of aluminum on the inside surfaces. This coating reduces corrosion and failure rate of the ducts and vessels and reduces the accumulation of corrosion products in the catalyst. The use of alloys for these massive sections is not economically justified. Additional studies, in view of the need to minimize the shutdown frequency and the resultant pollution, could show that special treatment is justified for transition pieces and expansion joints subject to the most severe conditions.

For many years, the carbon steel shell of the absorbers and drying towers has been protected from corrosion by installing a layer of asbestos, cemented with sodium silicate, between the acid proof brick liner and the shell. Frequently, an acid leak through a crack in the acid brick liner will penetrate the asbestos sheet and attack the carbon steel shell. In some recently built plants, a Teflon membrane is installed next to the steel shell in addition to the asbestos to provide additional corrosion protection. The result or economic justification of this modification is not known.

One of the most severe services in a sulfuric acid plant is removal of acid mist from the gases leaving the drying towers and absorbers. The mist eliminators are most frequently built with type 316 stainless steel frames and 316 stainless steel knitted wire mesh demister pads. The life of these units is usually short because of the effect of corrosion in the fine wire of the mesh pads. Longer service life can be obtained by using a knitted demister pads of Teflon in place of the type 316 stainless steel. Frequent failures occur in the type 316 stainless steel frame that supports the demister pad causing by-passing of acid mist. More corrosion resistant materials for the demister frame have not been used and probably could not be economically justified. The high efficiency mist eliminator, installed after the final absorption tower, usually incorporates a fiberglass pad. The fiberglass pad is not subject to corrosion deterioration but the 316 stainless steel frame and screen holding the pad is a likely point of corrosion failure.

With the increasing need for reliability and higher cost of replacement for the more complex dual absorption acid plants, the use of special materials to reduce corrosion and failure rates will probably increase. It is doubtful, however, that substitution of special materials for major pieces of equipment will be justified because the materials presently being used and the techniques of construction have been developed over a long period of time and have provided reasonable reliability in the severe service of a sulfuric acid plant.

SUGGESTED PREVENTIVE MAINTENANCE PROGRAM FOR SULFURIC ACID PLANTS

Organization of Preventive Maintenance Program

When a preventive maintenance program is organized, certain document systems and procedures must be established if the program is to effectively reduce the cost of maintenance, frequency and length of shutdown and emission of pollutants from the plant.

The first requirement of a preventive maintenance program is the development of a preventive maintenance manual that completely defines and describes the process equipment to be maintained, the maintenance task to be performed and the schedule for performing the maintenance.

Based upon the schedule for maintenance proposed by the manual, an overall maintenance schedule must be developed and maintenance plans formulated to integrate the maintenance within the operation of the plant. An evaluation of the effectiveness of the preventive maintenance program will require complete records of when and what maintenance is performed on each piece of equipment. A record of equipment failures and production downtime is also required in the recordkeeping system. The overall long range objective of the preventive maintenance program is minimizing the cost of plant operation and keeping plant emissions within standards. The emissions monitoring program required by law will evaluate the success of maintaining emissions within standards, but a cost accounting system must be established to determine the effectiveness of the overall maintenance program. As with any such plan and operating system, historical information must be used to modify and refine the program to achieve the goals set by the management when the program was established.

Preventive Maintenance Manual

The preventive maintenance manual provides a basis for establishing a preventive maintenance program. This manual must list all plant equipment subject to maintenance and describe the maintenance tasks required for each piece of equipment. Equipment manufacturer's recommendations should be used for establishing the type of maintenance required if extensive maintenance experience is not available on the equipment. The preventive maintenance manual should be refined as data on the frequency and techniques of maintenance are developed from analysis of maintenance records and from economic analysis of the cost accounting system. Revision of the manual should be perpetual using data feedback from these sources to compensate for aging of plant equipment.

A typical preventive maintenance manual listing the critical equipment for a typical single absorption and dual absorption acid plant is illustrated in Table 4. In an actual established program more pieces of equipment will be included depending upon variations in the design of the specific plant. The manual includes those maintenance tasks either recommended by the manufacturer or indicated by experience. Routine in-

Table 4

PREVENTIVE MAINTENANCE MANUAL

EQUIPMENT NUMBER	EQUIPMENT NAME	MAINTENANCE TASK DESCRIPTION	FREQUENCY				TYPE (1)	MANHOURS REQUIRED
			SHIFT	DAILY	WEEKLY	AS INDICATED		
C-103 (C-203)	Main Air Blower							
	1. Blower	Check Lubrication System		X			O	
		Check for Unusual Noise and Vibration	X				O	
		Check Bearing Temperature		X			O	
		Clean and Inspect Bearings and Lub System				12 Mo.	S	
		Wash and Inspect Rotor				12 Mo.	S	
	2. Turbine	Check Oil Pressure, Temperature and Level	X				O	
		Bleed Air from Lube Oil Filter			X		O	
		Wash and Inspect Rotor				12 Mo.	S	
		Clean and Inspect Bearings and Lube System				12 Mo.	S	
		Clean and Inspect Seals				12 Mo.	S	
		Test Governor and Trips				12 Mo.	S	
F-102 (F-202)	3. Filter	Check Filter Media Drive	X				O	
		Wash Filter Media and Change Oil in Bath				12 Mo.	S	
	Surface Furnace							
K-101 (K-201)	1. Furnace	Inspect Shell for Hot Spots	X				O	
		Inspect and Repair Fire Brick				12 Mo.	S	
	2. Burner System	Check Flame Pattern and Rod as Required	X				O	
		Check Pumps for Noise and Vibration	X				O	
		Check Pump and Motor Bearing Temperature		X			O	
		Check Steam Traps for Operation			X		O	
		Relubricate Sulfur Pump Bearings				3-6 Mo.	O	

(1) S = SHUTDOWN REQUIRED
O = MAINTENANCE PERFORMED WHILE OPERATING.

Table 4

PREVENTIVE MAINTENANCE MANUAL

EQUIPMENT NUMBER	EQUIPMENT NAME	MAINTENANCE TASK DESCRIPTION	FREQUENCY				TYPE (1)	MANHOURS REQUIRED
			SHIFT	DAILY	WEEKLY	AS IN-DICATED		
B-105	Boilers	Inspect Tubes and Fire-Brick				12 Mo.	S	
(B-205)		Clean Gas and Waterside of Tubes				12 Mo.	S	
		Repair Tube Leaks or Bulged Tubes				12 Mo.	S	
		Test Boiler and Safety Valves				12 Mo.	S	
		Clean, Lubricate & Check Alignment of Dampers				6 Mo.	S	
X-106	Economizers	Inspect Gas Side for Corrosion				12 Mo.	S	
(X-206)		Clean and Repair Tubes				12 Mo.	S	
(X-207)		Test Economizer and Safety Valves				12 Mo.	S	
		Clean, Lubricate & Check Alignment of Dampers				6 Mo.	S	
(X-218)	Superheater	Inspect Shell Side for Corrosion				12 Mo.	S	
		Test Superheater & Safety Valves				12 Mo.	S	
		Clean, Lubricate & Check Alignment of Dampers				6 Mo.	S	
X-110 X-115 X-119	Acid Cooler	Inspect for Leaks and Corrosion	X				O	
(X-210)		Clean Water Side of Tubes				As Needed	S	
(X-214) (X-215)		Clean Water Distributers on Cascade Coolers				As Needed	O	
(X-219) (X-220)								

(1) S = SHUTDOWN REQUIRED
O = MAINTENANCE PERFORMED WHILE OPERATING.

Table 4

PREVENTIVE MAINTENANCE MANUAL

EQUIPMENT NUMBER	EQUIPMENT NAME	MAINTENANCE TASK DESCRIPTION	FREQUENCY				TYPE (1)	MANHOURS REQUIRED
			SHIFT	DAILY	WEEKLY	AS IN-DICATED		
V-104 (V-204)	Drying Tower							
	1. Vessel	Clean and Acid Proof Brick and Shell for Corrosion and Leaks				12 Mo.	S	
	2. Entrain-ment Separator	Wash and Inspect for Cor-rosion and Bypassing				12 Mo.	S	
	3. Distribu-ters and Piping	Check for Corrosion				12 Mo.	S	
	4. Packing	Inspect for Attrition & Channeling--Clean and Replace as Required				12 Mo.	S	
V-108 (V-108)	Converter 1. Vessel	Clean and Inspect Fire Brick and Shell for Cor-rosion and Leaks				6 Mo.	S	
	2. Mist Eliminator	Check for Corrosion and Bypassing				12 Mo.	S	
	3. Support Grids and Posts	Check for Corrosion and Warping				12 Mo.	S	
	4. Packing	Inspect for Attrition and Channeling--Clean and Replace as Required				12 Mo.	S	

(1) S = SHUTDOWN REQUIRED
O = MAINTENANCE PERFORMED WHILE OPERATING.

Table 4

PREVENTIVE MAINTENANCE MANUAL

EQUIPMENT NUMBER	EQUIPMENT NAME	MAINTENANCE TASK DESCRIPTION	FREQUENCY SHIFT	DAILY	WEEKLY	AS INDICATED	TYPE (1)	MANHOURS REQUIRED
V-109 (V-209) (V-221)	Absorption Towers							
	1. Vessel	Clean and Inspect Acid Proofbrick and Shell for Leaks and Corrosion				12 Mo.	S	
	2. Mist Eliminator	Wash and Inspect for Corrosion and Bypassing				12 Mo.	S	
	3. Piping & Distributers	Check for Corrosion				12 Mo.	S	
	4. Packing	Inspect for Attribution and Channeling--Clean and Replace as Required				12 Mo.	S	

(1) S = SHUTDOWN REQUIRED
O = MAINTENANCE PERFORMED WHILE OPERATING.

Table 4

PREVENTIVE MAINTENANCE MANUAL

EQUIPMENT NUMBER	EQUIPMENT NAME	MAINTENANCE TASK DESCRIPTION	FREQUENCY				TYPE (1)	MANHOURS REQUIRED
			SHIFT	DAILY	WEEKLY	AS INDICATED		
P-101	Acid	Check for Noise and Vibration	X				O	
P-102 (P-201) (P-202)	Circulating Pumps	Place Spare Pump In Service			X		O	
		Check Pump and Motor Bearing Temperature		X			O	
		Check Bearings, Housing and Impeller for Wear and Corrosion				12 Mo.		
		Repack Seals				6 Mo.	S	
	Pump Tank	Clean Debris from Tank				6 Mo.	S	
(X-211) (X-217)	Waste Heat Exchanger	Clean and Inspect for Corrosion--Test for Tube Leaks				12 Mo.	S	

(1) S = SHUTDOWN REQUIRED
O = MAINTENANCE PERFORMED WHILE OPERATING.

spections, lubrications and checking by operating and maintenance personnel are not included in the sample manual but should be included in any established program. Emphasis is placed upon the completion of major maintenance during the annual plant turnaround to minimize breakdown maintenance.

Planning and Scheduling

As previously indicated, the schedule developed for a preventive maintenance program is based initially upon an equipment manufacturer's recommendation and previous experience of plant operations. As experience is gained, the frequency of maintenance tasks and the time required to perform these tasks will be refined to improve the efficiency of the maintenance program. The time required to complete a task is important when scheduling either on-line or shutdown maintenance to ensure all required tasks can be completed within the total scheduled downtime. Maintenance task plans for a specific shutdown must also be compatible with manpower availability.

Since the catalyst must be cleaned semi-annually in most plants, many of the annual tasks are scheduled during alternate semi-annual shutdowns. This minimizes the length of such shutdowns and provides the maximum opportunity for major maintenance or replacements during these periods. A well-organized and scheduled program will also have provisions for completing all task work that is due in the event of an unscheduled shutdown caused by equipment failure. Maintenance accomplished during these periods may prevent additional downtime resulting from equipment failure before maintenance can be performed during the next scheduled plant shutdown. These techniques for spreading work through the various planned shutdowns and taking advantage of opportunities for maintenance during unscheduled shutdowns will reduce the amount of work required during the semi-annual turnaround. Efficient planning of work to be performed during a shutdown will reduce the length of shutdown, and proper scheduling of maintenance will reduce unscheduled shutdowns resulting from equipment failure.

Recording Keeping Systems

A preventive maintenance program for a plant cannot be optimized without appropriate records of the maintenance history of that plant. Many forms of recordkeeping systems have been employed for preventive maintenance programs. These systems have been described at length in various books on the subject and will only be mentioned briefly in this report.

The most frequently used recordkeeping systems include single card, three card and punched edge card systems for manual sorting and retrieving of information. Also, various computer sorting and retrieval systems have been applied in larger installations. Regardless of the form of recordkeeping, certain basic information about the equipment and maintenance must be recorded for later analysis in order to evaluate and update the preventive maintenance program. The recordkeeping system must include, generally, a complete description of equipment, a record of what maintenance is performed, when the maintenance was performed and manpower requirements for completing the task. The equipment description part of the record will include the manufacturer's model, name, location within the plant and plant identification number. The maintenance tasks to be performed are detailed and special instructions concerning lubrication type, coatings and special parts or materials are included in the records.

The recommended maintenance frequency is also shown on the card. A record of maintenance performed is recorded by the maintenance mechanic or foreman after each maintenance task. The records of maintenance performed should include parts and materials used and time required to complete the task.

Cost Accounting Systems

Another part of the recordkeeping system necessary to evaluate the effect of the preventive maintenance program and establish the optimum schedule is the cost accounting system. This system must determine and record the cost of each maintenance task. These combined costs are the cost of the preventive maintenance program. The lowest overall cost results from the optimum amount of maintenance performed and should be the maintenance goal established by plant management.

Refining the System

Because of variations in plant design and operating conditions, there is no single optimum preventive maintenance program that can be applied to all plants. After the initial program schedule has been established, the process of refinement must begin. Each equipment failure should be analyzed to determine the cause of the failure and if the schedule or maintenance plan can be changed to prevent the failure from re-occurring and causing an unplanned shutdown. Careful revision of the system in this manner and proper analysis of cost provided by the cost accounting system will yield a preventive maintenance program that permits operation of the plant with a minimum number of unplanned shutdowns and therefore minimum emissions resulting from plant start-ups and operating malfunctions.

Reports

If a preventive maintenance program is to be effective, there must be feedback from the recordkeeping system to management to show status and effectiveness of the program. This feedback is provided by the monthly "Preventive Maintenance Performance Report" listing the maintenance tasks scheduled during the month and the number of tasks either performed on time, performed late or deferred. A percent compliance to the schedule for tasks requiring a shutdown and those performed while on line is a useful evaluating tool.

In addition to the Performance Report, a list of delinquent tasks should be provided with the original schedule, and a new schedule for their completion should be made. This report is often called the "P.M. Non-Compliance Report" and should include a statistical summary of the items appearing on the report.

A "Maintenance Operating Report" showing total downtime resulting from equipment failure and scheduled maintenance along with a list of shutdown causes, will assist in evaluating the established schedule and refining the P. M. Program. The report should include the last maintenance performed on the equipment causing the shutdowns and the date of the last and next scheduled maintenance.

SECTION VIII

INSPECTION TECHNIQUE

INSPECTION PROCEDURE

An inspector entering a sulfuric acid plant for the purpose of evaluating maintenance procedures usually will not have access to the internals of the plant equipment to determine the condition of the equipment and the expected Without direct access to the working parts of the machinery, the quality of maintenance must be inferred from the general plant appearance and a review of operating and maintenance records. In most instances, a plant that looks well cared for on the outside will be well maintained in the important areas. A plant that looks rundown will usually be in a bad state of repair and subject to frequent equipment failures and resulting emissions. A plant without a preventive maintenance program or one with an inadequate program will also be more subject to occurrences of high emissions from equipment failure and shutdown.

The most obvious indication that a sulfuric acid plant is not in compliance with the NSPS is high opacity of the plume from the stack. An inspector entering the plant will observe the stack and estimate the opacity of the plume. This observation will be preliminary to a general observation of plant conditions and will help form an opinion of the quality of plant maintenance.

A walk through the plant will provide an appraisal of the overall condition of the plant. Special attention should be given to liquid and gas leaks from the equipment and the presence of patches for temporary repair of plant leaks. The condition of external insulation should also be noted as an indication of the emphasis placed on maintenance.

The primary source of specific information concerning the status of maintenance of the plant is the maintenance record system. Satisfactory operation with a minimum of equipment failures and a minimum amount of emissions cannot be obtained without an effective preventive maintenance program. An effective program will have all of the elements, in some form, of the program suggested in Section VIII. A review should be made of the recordkeeping system, schedule and status reports to determine if the plant has established a suitable preventive maintenance program. Many variations in the form of the P.M. program are possible but the effectiveness of the program is the basis for determining its adequacy.

The effectiveness of the preventive maintenance program can be determined by reviewing the maintenance records for the past several months. The number of forced shutdowns resulting from equipment failures, normally reported in the operating log or maintenance reports, is a good indication of the adequacy of the preventive maintenance program and of the effectiveness of its application. The number of maintenance tasks scheduled but not completed should be shown in the monthly "Delinquent Maintenance" report. A large number of delinquent tasks and tasks that appear on several monthly reports in succession indicates the preventive maintenance program is not adequately followed. The total downtime for maintenance during previous months may indicate either excessive equipment failure or poor scheduling of maintenance tasks. This data must be weighed with factors such as delinquent maintenance tasks to determine the cause of high downtime.

Another significant source of information for evaluating maintenance quality is the quarterly report submitted by the plant operator to EPA explaining any occurrence of emissions in excess of the NSPS. Emissions resulting from equipment failure should be analyzed to determine if the failure resulted from a lack of preventive maintenance. Repetitive occurrences caused by the same plant equipment will almost always point to a deficiency in maintenance or design.

The net result of the review of records and reports will be a judgement on the adequacy of the preventive maintenance program and the application of the program by plant maintenance personnel. Shortcomings in the program should be noted and recommendations for improvement should be offered. It is doubtful that a single inspection can produce many conclusive evaluations. The accumulation of data from several inspections will establish the true picture of plant maintenance quality and its effect on emissions.

INSPECTION CHECK LIST

Figure 9 presents a check list that can be used to record data needed to evaluate a preventive maintenance program during a plant inspection. A maintenance inspection may be combined with an inspection of plant operations in which case the check lists for the two inspections can be combined and the first page will be common to the combined check list. The first page of the check list is for recording general plant identification information and description and data obtained from a spot check of stack emission opacity. The second page can be used to record the general appearance of the plant. Gas and liquid leaks should be recorded on this page with an indication of the severity of the leak. Since this part of the inspection is subjective, comments to qualify each observation will be helpful in the overall evaluation of plant maintenance quality.

The third page of the check list is used for recording a summary of data taken from the preventive maintenance records and operating and maintenance reports. Actual numbers should be entered in the form to provide a quantitative measure of the key points thereby indicating the effectiveness of the preventive maintenance program. The final summation of the form is a question calling for a judgement by the inspector on the adequacy of the preventive maintenance program. This judgement should be qualified by any pertinent comments and suggestions.

FIGURE 9

SULFURIC ACID
PLANT INSPECTION
CHECK LIST

Company Name ______________________________

Source Code Number ______________________________

Company Address ______________________________

Name of Plant Contact ______________________________

Unit Designation ______________________________

Plant Capacity ______________________________

Type of Feed Stock ______________________________

Inspection Date ______________________________

PRE-ENTRY OBSERVATIONS

Time: ______________

STACK PLUME:

EQUIVALENT OPACITY (Circle One)

0 10 20 30 40 50 75

OPACITY REGULATION
☐ In Compliance
☐ Not in Compliance

PLUME COLOR ______________________

WEATHER CONDITIONS:

Clouds: ______________________________
Wind: ______________________________
Humidity: ______________________________
Precipitation: ______________________________
Temperature: ______________________________

EQUIPMENT MAINTENANCE
PLANT INSPECTION

GENERAL HOUSEKEEPING

Below Average ☐ ☐ Average ☐ ☐ Above Average ☐

Comments: ____

____

____

____

____

EQUIPMENT APPEARANCE

Below Average ☐ ☐ Average ☐ ☐ Above Average ☐

Comments: ____

____

____

____

____

THERMAL INSULATION CONDITION

Below Average ☐ ☐ Average ☐ ☐ Above Average ☐

Comments: ____

____

____

____

____

ACID LEAKS OBSERVED: Number ______________ Severity ______________

GAS LEAKS OBSERVED: Number ______________ Severity ______________

EQUIPMENT MAINTENANCE RECORDS

Preventive Maintenance Program Established? Yes ☐ No ☐

Is P.M. Program being followed? Yes ☐ No ☐

Number of P.M. Tasks Not Completed Last Month ______________________

Previous Month ______________________

Number of Forced Shutdowns Last Month ______________________

Previous Month ______________________

Percent Down Time for Maintenance Last Month ______________________

Previous Month ______________________

Number of Occurrences of High Emissions Resulting from Equipment Malfunction Reported Last Quarter ______________________

Equipment Causing More Than One Occurrence

______________________ Number ____________

______________________ Number ____________

______________________ Number ____________

______________________ Number ____________

Is P.M. Program Adequate? Yes ☐ No ☐

Comments: ______________________

____

____

____

The recommended check list should be completed while the inspection of the plant and the records is made. It should be supplemented with additional facts or observations considered important to the task of evaluating the effect of maintenance on emissions.

INSPECTION REPORTS

The reports recommended for the preventive maintenance program in Section VII are primarily to assist the plant operator in managing the program. Although these reports should be available to the EPA inspector during a plant visit, routine submission of the reports to EPA would place an unneccessary burden on the operator and EPA. Some amount of routine evaluation of the maintenance program in the plant could be obtained by revising the format of the Quarterly Emissions Violation Report submitted by the operator to EPA. Data on the last date of overhaul and total service life of any piece of equipment responsible for emissions in excess of the NSPS could be included. Statements could also be required concerning the establishment of a preventive maintenance program and compliance with the program as indicated by the number of delinquent preventive maintenance tasks during the report period.

SECTION IX

REFERENCES

1. Calvin, E. L., F. D. Kodras. Evaluation of Emissions During Start-Up, Shutdown and Malfunction of Sulfuric Acid Plants. Industrial Environmental Research Laboratory, EPA by Catalytic, Inc., Charlotte, N. C. EPA-600/2-76-010. January 1976. 353 pages.

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16. ABSTRACT The report describes the effect of equipment maintenance and age on emissions from single- and dual-absorption sulfuric acid plants, using both elemental sulfur and recycled sulfur-containing acid sludge feedstock. A description is included of the critical equipment, manufacturer's recommended maintenance data, and malfunction history from 20 sulfuric acid plants. From this data, a recommended preventive maintenance program is provided for the critical equipment. A checklist is provided for an inspector to use in evaluating maintenance in an operating plant.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Preventive Maintenance	Stationary Sources	15E
Chemical Plants	Effects of Aging	07A
Sulfuric Acid		07B

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