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硫黄酸化物

sulfur oxides control in Japan

INTERAGENCY ENERGY / ENVIRONMENT RESEARCH AND DEVELOPMENT PROGRAM

overview: FGD in Japan

Because of major air and water pollution problems in Japan during the 1960's economic boom, the central government established the most stringent sulfur dioxide (SO_2) emission and ambient air standards in the world. Such controls were considered necessary because high levels of sulfur pollution can be potential health and environmental hazards. For example, inhaling sulfur dioxide can cause irritation of the respiratory tract, aggravating asthma and emphysema. Significant reduction in air visibility can result from sulfur pollution. Acid rain, another result of SO_2 emissions, has been shown to reduce agricultural and forest productivity, deplete soil nutrients, cause failure of fish spawning, and corrode building materials.

Sulfur oxides are generated from the burning of fossil fuels. In Japan the major source of SO_2 pollution is from the burning of heavy fuel oil by the electric power generating plants. The primary methods currently being practiced to control this pollution are flue gas desulfurization (FGD) and burning low sulfur fuels. During the past decade, significant progress has been made in installing FGD systems to control SO_2 pollution. The effectiveness in improving air quality in Japan and the reliability of these systems have been outstanding.

To evaluate these advances for their potential application in the U.S., the Honorable Henry M. Jackson, Chairman of the Senate Committee on Energy and Natural Resources requested the Environmental Protection Agency to organize an industry/government task force to visit Japan to obtain first hand information on their experience with FGD systems.

The task force members' observations during that trip, their prior knowledge, and information gathered from referenced sources comprise this report. The first section provides an overview of the:

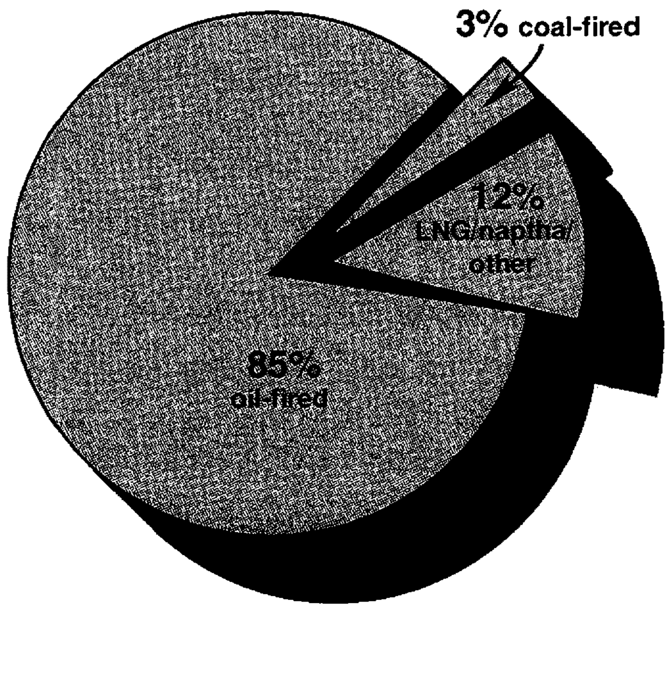
- Japanese energy status,
- SO_2 pollution emissions control regulations,
- The general status of FGD applications in the industrial and utility sectors,
- Comparison of Japanese and U.S. experience.

The second section provides detailed technical information on selected FGD installations visited including plant/FGD specifications, performance information and process flow diagrams. An appendix provides further information concerning members of the visiting task force, a listing of plants visited, and numbers and capacities of FGD systems in Japan.

energy status

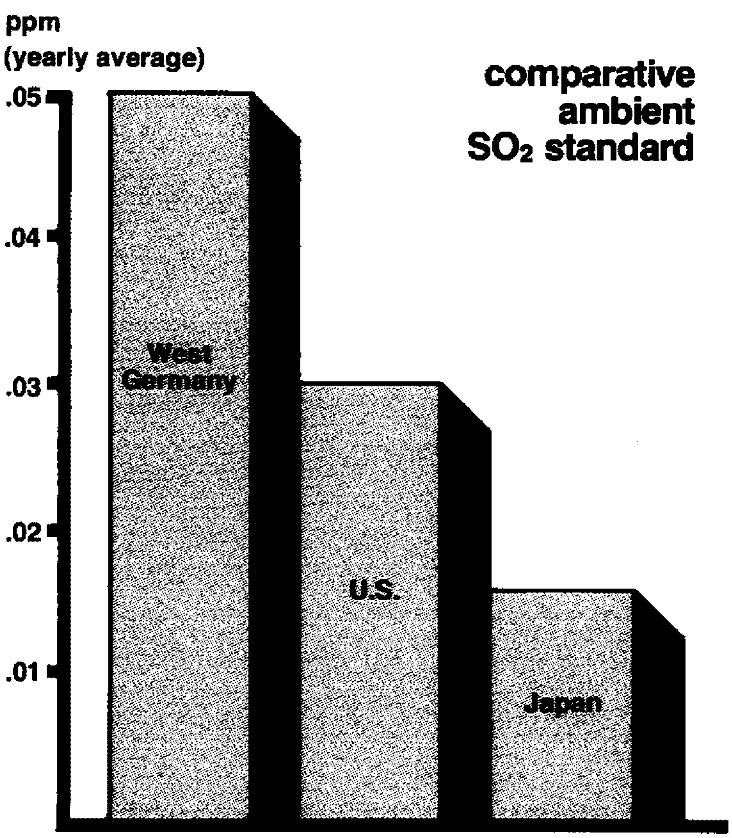
Approximately seventy-five percent of the utility power generated in Japan is fossil-fired steam-electric (87,475 MW including those plants under construction). Hydroelectric provides another 20 percent of the power, with nuclear steam-electric producing the remaining five percent.

total steam electric power fuels



Oil, most of it imported, fuels 85 percent of the country's total fossil-fired steam-electric power. A rapid increase in energy usage in recent years has meant a growing dependence on imported oil (presently over 70 percent of Japan's total energy supply). In an effort to reduce this dependence, the Japanese Government initiated, in 1974, the "Sunshine" Project promoting research and development on alternative energy technologies, including solar, geothermal, and coal liquefaction/gasification.

Low sulfur fuels, such as naptha and liquified natural gas (LNG), are also burned by some of the major power companies in heavily polluted sections of their service areas. These fuels account for 12 percent of the fossil fuels used for the production of steam-electric power, and imports also are rapidly increasing in this area.



Although, coal-fired utility capacity presently accounts for only about three percent of the total steam electric power produced, it is likely that this percentage will significantly increase in the years ahead as the price of oil continues to increase. Over 50 million tons of coal were mined yearly in Japan during the early 1960s. That dropped to around 20 million tons per year as oil imports increased. Though Japan currently imports over 60 million tons of coal annually, most of it is for coke production in the steel industry. As part of the "Sunshine" Project, the Ministry of International Trade and Industry (MITI) is promoting increased coal use by utilities. To this end EPDC, the government/industry funded Electric Power Development Company, has constructed and is operating a number of coal-fired power plants.

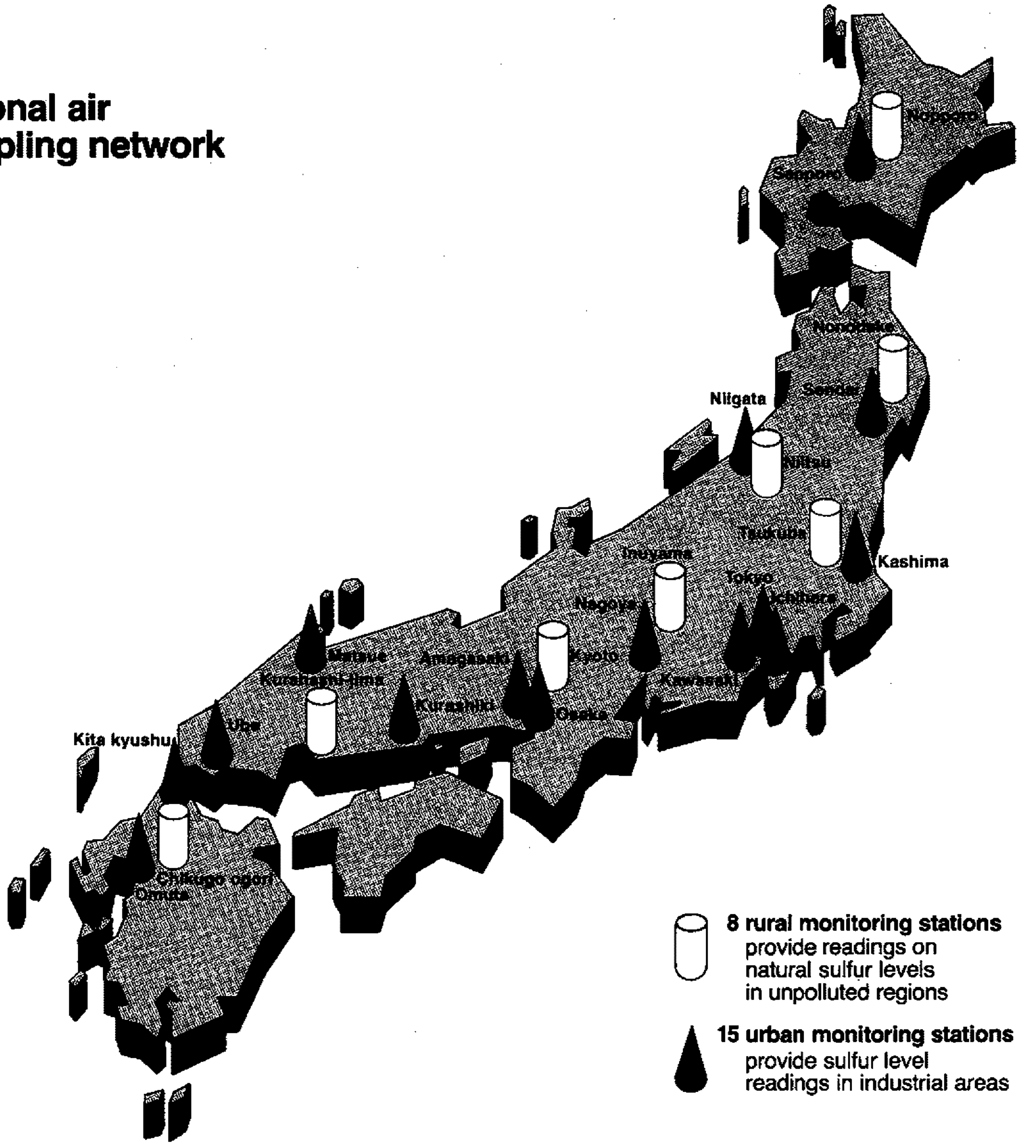
SO_2 pollution and regulation

Increasing use of coal by utilities means increasing potential for sulfur oxides pollution and the need for emission controls. Such pollution and emissions regulation are not new to Japan. Since 1967 environmental laws and standards have helped abate a serious sulfur dioxide (SO_2) pollution problem arising from industry's booming post-war recovery. This improvement reflects the effects of burning imported low sulfur oil, the widespread application of FGD systems, and hydrodesulfurization of residual oil.

Sulfur oxides emissions were reduced 50 percent between 1970 and 1975 as regulations became more restrictive. This occurred despite a 120 percent increase in energy consumption during that period. The ambient SO_2 standard was tightened from 0.05 parts per million (ppm) to 0.016 ppm (yearly average) in 1973 with a target achievement date of 1978. The daily average may not exceed 0.04 ppm, the hourly average 0.10 ppm. The standard is much more stringent than the standards in the U.S., 0.03 ppm (yearly average), or West Germany, 0.05 ppm.

The central government enforces the SO_2 emission standard through the "K value" system. Under this system, a specific allowable volume of SO_2 emission is calculated for each emitting source within 17 geographical areas. The allowable

national air sampling network

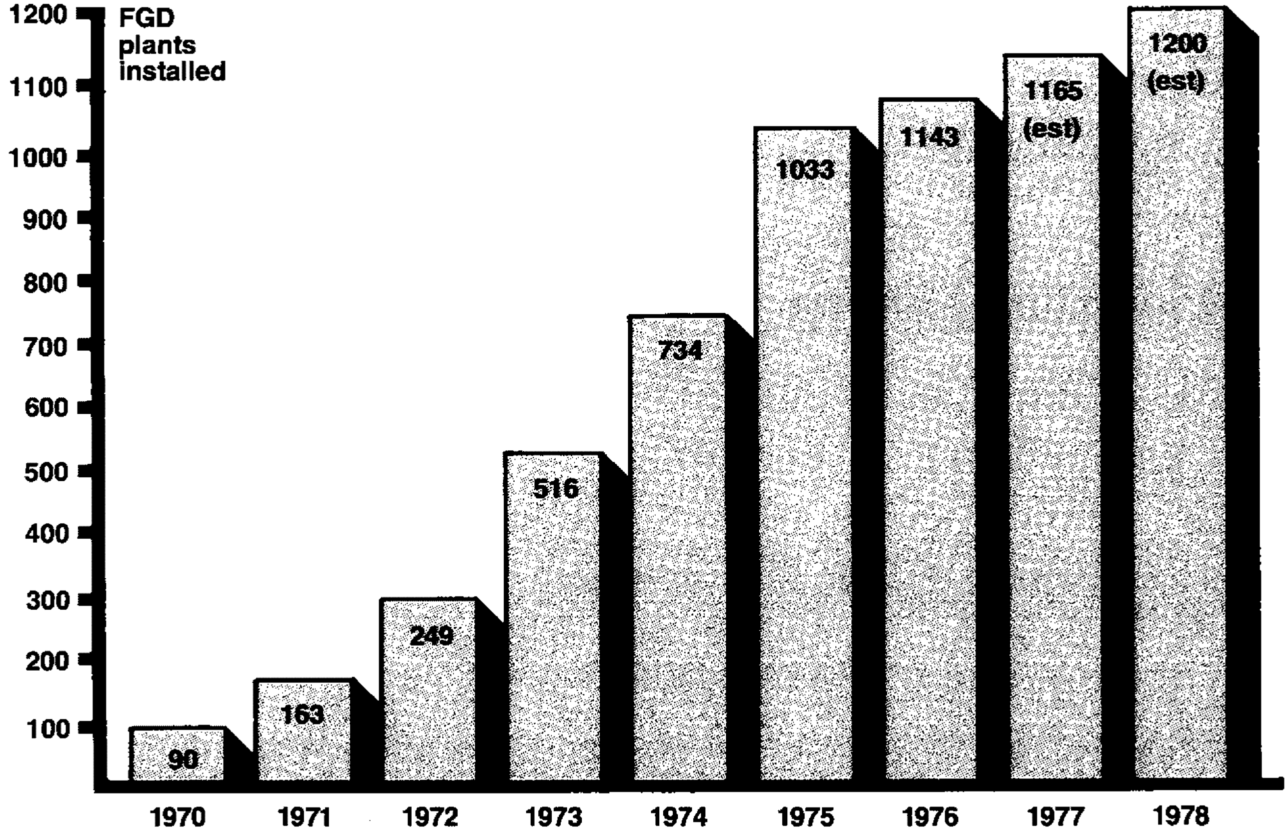


SO_2 is a function of stack height and a constant factor, K, specified for each geographical region. The K-factor value depends upon air quality and the number of emission sources within each region. The most heavily industrialized regions have the lowest K value. These K values have been revised downward almost yearly since 1974 to achieve the targeted 1978 ambient standard.

In large cities and heavily industrialized areas, however, this K-value emissions standard has proven unsatisfactory in keeping the ambient SO_2 concentrations below the 0.04 ppm daily average. Therefore, in late 1974 the central government issued a new regulation restricting the **total mass** of SO_2 emissions in each of the 11 most polluted regions. With its application to 13 more regions since then, a total of 34 percent of all of the sulfur oxides emission sources in Japan are now regulated by the mass standard. The new regulation has been instrumental in attaining the ambient standard in 98 percent of the regions.

Where total mass regulations are not in effect SO_2 emissions continue to be regulated by the K value system. Agreements between industry and prefectural or city authorities establish standards in these regions for larger, particularly new plants. These standards are sometimes more stringent than those of the central government. For example, many power plants in remote areas are required to use oil with a sulfur content less than 0.3 percent or to install FGD to attain the equivalent sulfur reduction.

growth of FGD plants in Japan



Fuel type is also subject to regulation. For example, plants smaller than 0.4 MW equivalent are required to use low sulfur oil. For large plants the prefectural governor has established specific allowable emission rates that can be met only by using ultra low sulfur oil or higher sulfur oil in combination with FGD. New plants in the most restrictive regions must attain a standard that is equivalent to burning oil of less than a 0.079 percent sulfur content. If more restrictive standards should be required for these regions, FGD may not provide adequate control.

The "Pollution-Related Health Damage Compensation Law," in effect since 1974, is another factor in SO_x emissions abatement. In certain designated polluted areas, inhabitants suffering from pollution-related illnesses receive medical care financed through special taxes. These taxes are assessed on total amount of SO_2 emitted by certain plants (those emitting more than 5,000 normal cubic meters per hour (Nm^3/hr) of flue gas, even though emission regulations are being met. This tax rate in the more heavily polluted areas has increased by a factor of 10 since 1975. Consequently, a number of companies presently meeting the regulations are considering installing FGD plants, as cost of FGD may be offset by the resulting decrease in the tax.

FGD control technology

Rapid progress was made in installation of FGD control systems between 1970 and 1975, when the number of plants grew from less than 100 to over 1,000. This growth stemmed largely from two factors: sizable cost savings in utilizing high sulfur fuels in combination with FGD as opposed to using low sulfur fuels and increasing confidence in the reliability of FGD system operation.

As of December 1978, over 500 major FGD plants, having a combined capacity of about 30,000 MW, were operating in Japan. There were also about 500 small systems installed in plants averaging 6 MW of equivalent capacity. Of the total FGD capacity, approximately one third or 10,076 MW is installed in utilities. Another 3,750 MW are under construction or planned. The remaining FGD capacity is in industrial boilers, sintering plants, smelters, and sulfuric acid plants.

The FGD capacity installed, under construction, and planned in the Japanese utility industry represents about 16 percent of its fossil-fired steam generating capacity. In the U.S., there is 15,773 MW of FGD capacity with an additional 54,327 MW under construction or planned. This 70,010 MW represents 26 percent of the total U.S. coal-fired generating capacity.

Growth in FGD capacity has begun to decline in Japan recently for several reasons. Ambient SO_2 concentrations in large cities and industrial districts dropped to the 0.02 ppm to 0.03 ppm range; this is close to achieving the ambient standard of 0.016 ppm. The recent downturn in the Japanese economy has affected FGD plant construction. Low sulfur fuels are being burned more extensively as low sulfur and high sulfur oil price differentials decrease and FGD by-products saturate their markets. And stringent nitrogen oxides (NO_x) emission standards have encouraged development of processes simultaneously removing NO_x and SO_x. Rather than install separate NO_x and SO_x control systems, industry is awaiting demonstration of the new technology. Present government policy mandating increased use of coal for power production, however, will likely reduce this decline in FGD growth rate.

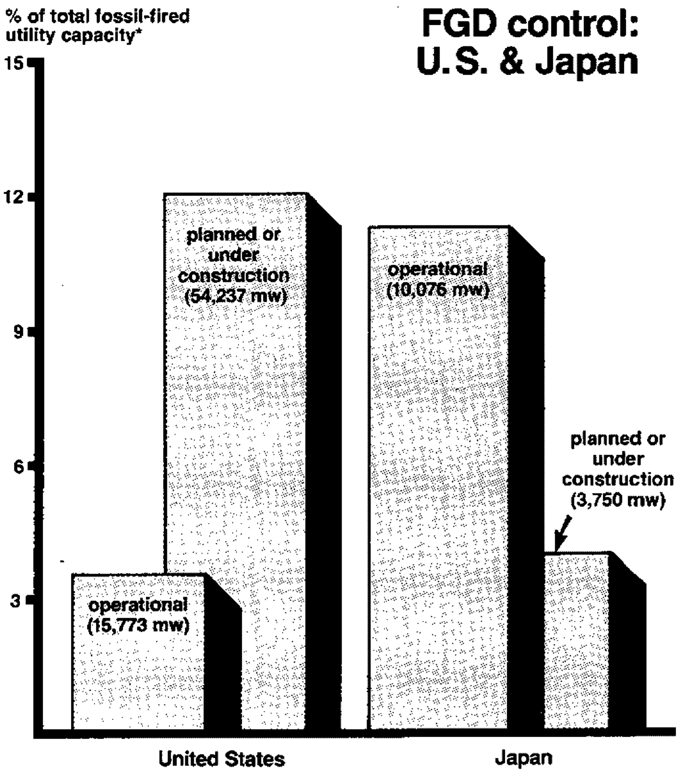
Among the FGD processes in use in Japan are the lime/limestone process producing usable gypsum (45 percent of total FGD plant capacity); the indirect lime/limestone process — double alkali type (15 percent); regenerable processes producing sulfuric acid; elemental sulfur, and ammonium sulfate as by-products (13 percent); and sodium scrubbing to by-produce sodium sulfite or sulfate (27 percent). The sodium sulfite is used by paper mills. Sodium sulfite is also oxidized to sulfate for use in the glass industry or discharged in treated wastewater.

The FGD processes in four Japanese plants are described in greater detail in Section II. These plants are included because of their similarity to U.S. utility scrubber applications. They are all coal-fired. Three are utility applications using the limestone process and producing gypsum. The fourth is an industrial boiler application that uses the lime throwaway process producing sludge.

significance

Japanese FGD technology is successful in both utility and industrial applications. Scrubber installations on coal fired plants routinely attain SO_2 removal efficiencies in excess of 90 percent and operational reliabilities of over 96 percent. Installations on oil fired and industrial units achieve similar efficiencies and reliabilities.

Although Japan and the U.S. have emerged as world leaders in developing and applying FGD technology, Japan has generally moved more rapidly than the U.S. because of its more serious air pollution problem. Technical, administrative, and governmental factors must be considered when comparing the U.S. with the Japanese experiences in FGD technologies.



*total U.S. capacity — 450,000mw (265,000mw coal-fired)
total Japanese capacity — 87,475mw (74,354mw oil-fired)

Technical factors — Three significant factors affect the performance of Japanese vs. U.S. FGD systems:

- Sulfur content of the fuels
- Closed vs. open loop operation
- Fuel and absorbent controls

Sulfur content of coal burned in Japanese utility and industrial boilers is significantly though not drastically lower than that used in U.S. power generating systems. Although this sulfur content ranges from 0.7 percent to 2.4 percent, a high ash content and intermediate heating values of Japanese coal give an SO_2 concentration in the flue gas equivalent to that produced from U.S. coals of somewhat higher sulfur content. For example, the 2.4 percent sulfur coal burned in a Japanese aluminum plant produces an inlet SO_2 concentration approximately equivalent to a 3.0 percent sulfur midwest or eastern U.S. coal.

Japanese FGD systems generally cleanse flue gases having SO_2 inlet concentrations of 400 to 2300 ppm — a range of inlet sulfur values not dissimilar to many of those in U.S. FGD systems on coal-fired utility boilers. Japan has no experience with the higher sulfur coal such as those used by many U.S. utilities. The higher SO_2 content flue gases associated with burning such coal are more difficult to scrub due to mass transfer limitations.

The successful operation of lime/limestone scrubbers in Japan has often been attributed to their generally open loop operation entailing purging large quantities of process liquids. In order to evaluate the Japanese FGD systems on a basis comparable to those in the U.S., however, it is necessary to relate the quantity of gypsum produced by an FGD system to the amount of process liquids purged, thus establishing an effective pond disposal solids concentration. When evaluated on this basis, the quantity of liquid purged in Japanese FGD systems is often quite similar to that removed in a typical closed loop U.S. scrubber system employing ponding.

Fuel and absorbent controls constitute the third technical factor affecting FGD systems performance. The suppliers and users of Japanese FGD systems consider the scrubber operation as essentially a chemical process. Raw materials flowing into the scrubbers are thus carefully controlled to minimize imbalances in the chemical reactions and to maximize efficiency. Predominant use of oil as fuel simplifies this control. When coal is used, blending prior to combustion ensures a relatively constant SO_2 loading into the scrubbing process. Utilization of only dry prepulverized limestone meeting strict size and composition specifications reduces variability in quality of the absorbent.

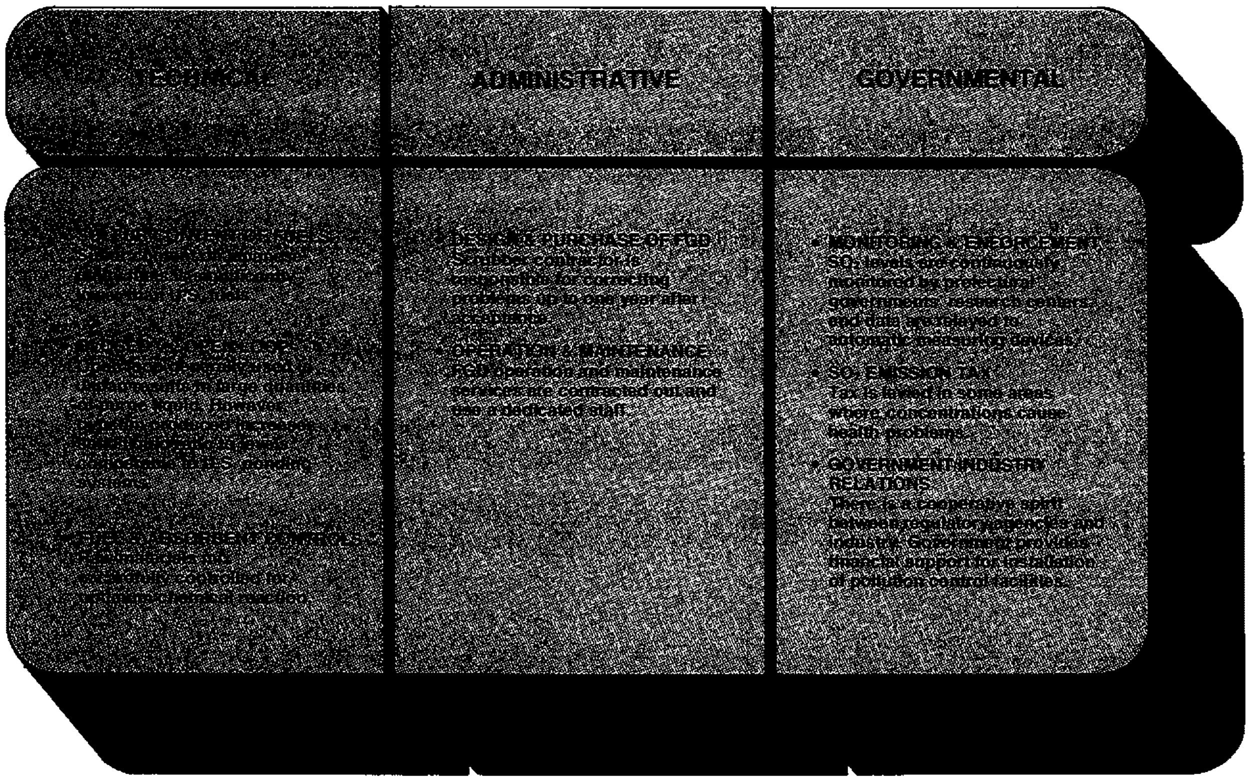
Administrative factors — Contractual arrangements for FGD systems in Japan and the U.S. differ somewhat in:

- Design and purchase
- Operation and maintenance

The Japanese prepare only general system specifications, and also demand that scrubber systems perform with a reliability compatible with that of the power generating plant. EPDC, for example, requires the system supplier to correct at his expense any process/equipment problems occurring within a year of EPDC's acceptance of the system. Japanese scrubber systems may initially be more expensive than U.S. systems, but they usually require less modification. The fact that one supplier (MHI) provides half the lime/limestone scrubbing systems in Japan undoubtedly enhances reliability.

Equally important, the Japanese recognize the need for specially trained personnel to operate and maintain FGD systems. Such personnel are concerned exclusively with the scrubbing systems and are not rotated into other power plant duties as is generally the case in the U.S. In some cases, contracts are negotiated specifically for such services.

key factors in Japanese FGD experience



Governmental factors — Within the context of Japanese governmental/industrial relations, the following have been significant in achieving FGD success:

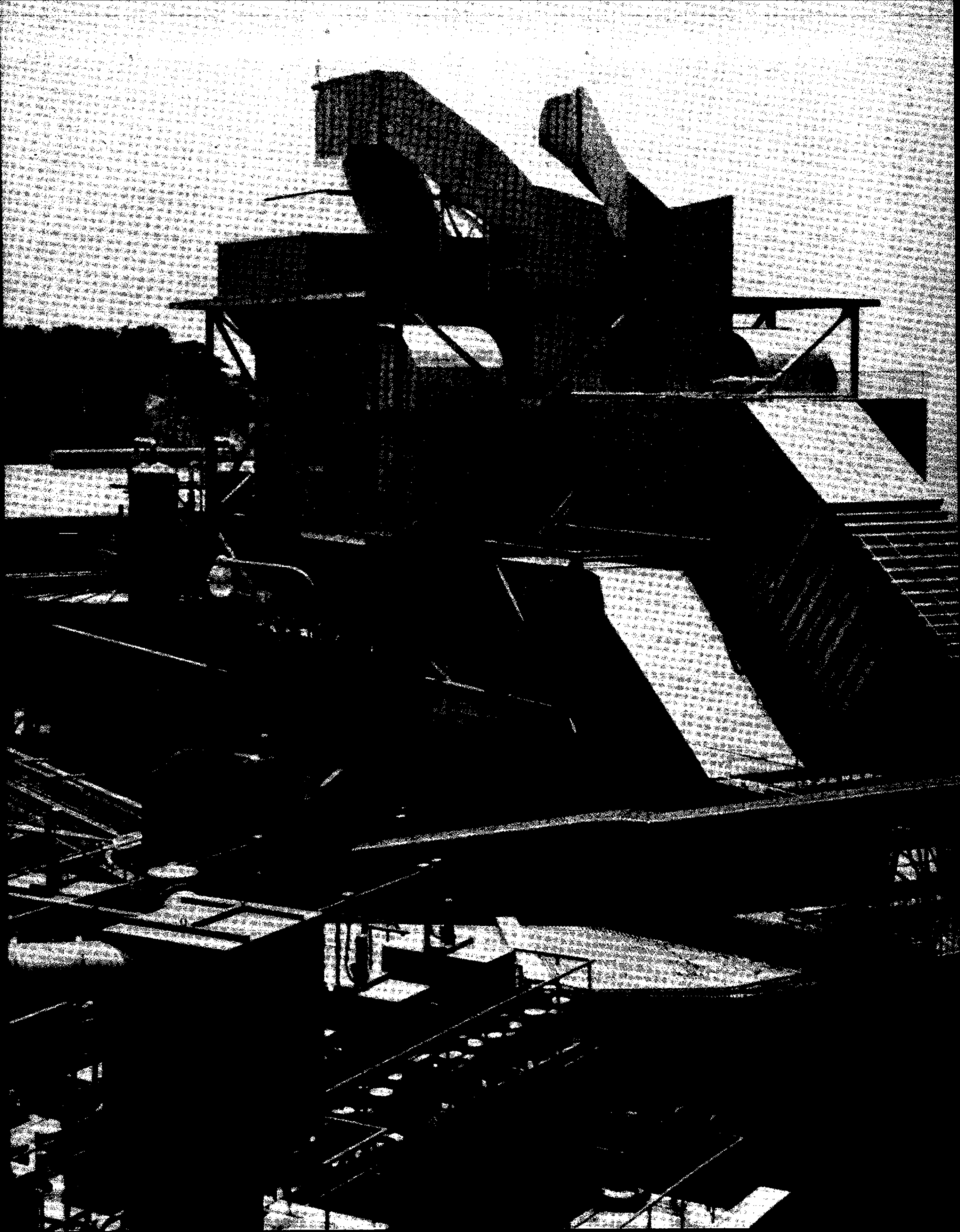
- Monitoring and enforcement
- SO_2 emission tax
- Government/industry cooperation

Japan employs a stringent, continuous monitoring and enforcement program. Many prefectural governments operate an environmental research center (subsidized by the central government), some of which are directly linked via telemetry systems to automatic monitoring stations located at major emission sources and key ambient sites. Emission sources must remain in constant compliance, or violations result in fines and/or forced shutdown of the source. Violations, consequently, rarely occur.

As outlined earlier, Japan taxes certain plants emitting more than 5000 Nm^3/hr of flue gas; tax proceeds are applied to medical care of those people suffering from pollution related illnesses. Taxes vary among the industrialized areas, one area having a rate of 345 yen/Nm^3 of SO_x emitted. In this area for a typical 150 MW plant emitting 100 Nm^3/hr of SO_x after 95 percent SO_2 control, the daily tax exceeds 828,000 yen ($4200). A number of companies are considering installing FGD systems despite present compliance with SO_x regulations, because the resulting reduction in tax obligation may well offset the cost of FGD.

A sincere cooperative spirit appears to exist between Japanese industry (users and suppliers) and the regulatory agencies. And the central government has assisted industry in many instances in constructing pollution control facilities by providing low interest loans and allowing seven-year depreciation of the facilities. MITI has had a major role in promoting cooperation.

The need for environmental controls for sulfur oxides was at a crisis level in Japan in the late 1960s. Japanese industry recognized the crisis and accepted the goal of a cleaner environment. Utilities and industry have made a sincere effort to acquire the best FGD systems available and to maintain good operability.



plants visited

During the first part of February 1978, a task force of representatives from the U. S. Environmental Protection Agency, Electric Power Research Institute, and the Tennessee Valley Authority visited 11 flue gas desulfurization plant sites in Japan. In addition, they conversed with employees of most of the major scrubber system suppliers, the Japan Environmental Agency, the Electric Power Development Corporation (EPDC), the Ministry of International Trade and Industry, and the Aichi Prefecture Environmental Research Center. The visits to the EPDC and Mitsui Aluminum plants were included because they operate coal-fired power plants.

The government-financed EPDC was created in 1952 to alleviate the serious power shortage in Japan during the post-war period of reconstruction. It undertakes the development of large scale or difficult power development schemes or multiple purpose projects incorporating integrated national land development plans. With power development schemes totaling some 800 billion yen ($3.36 billion/1978), the EPDC has completed 7000 MW of generating capacity at 50 sites. This includes coal-fired power plants constructed in accordance with the government's policy to cut dependence on imported oil. The EPDC assists in stabilizing electricity supply through sale of electricity to private utility companies, interchange of power between regions, and improved plant efficiency.

The scrubber systems of the three EPDC utilities and of the Mitsui Aluminum Company represent the successful application of FGD to coal-fired generating units. Technical information on these FGD installations follows. A comparison of the characteristics of each of these plants (as well as the others visited) is provided in Table 1 in the Appendix.

Control Boards and Generators, Chubu Electric Company (Courtesy of Japanese Embassy)

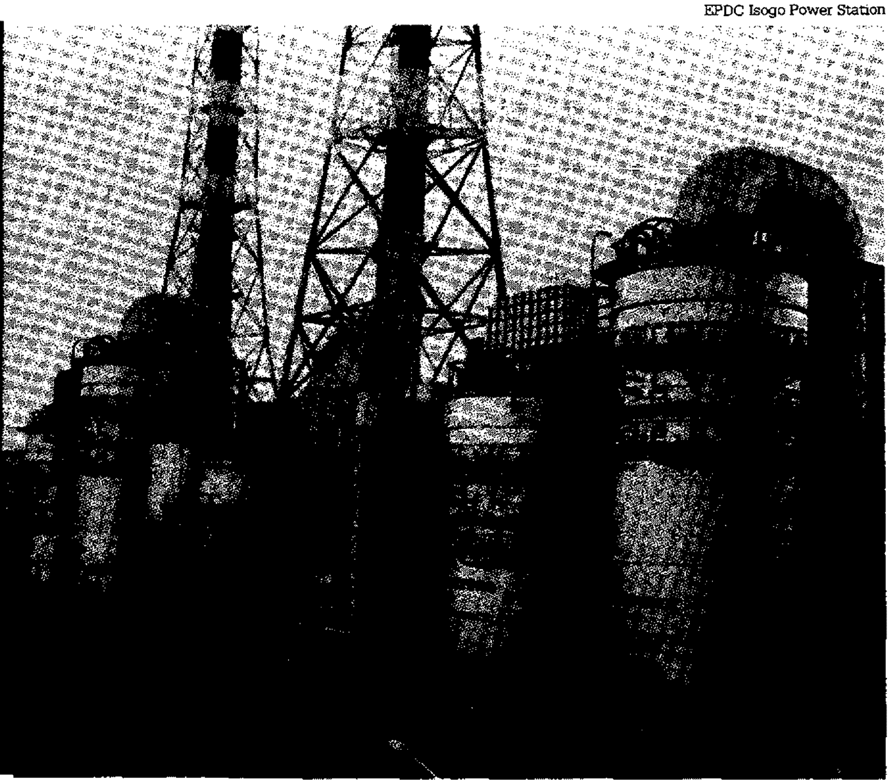
EPDC Isogo station

EPDC's Isogo Power Station is located in Yokohama, a heavily industrialized area near Tokyo. The environmental standards for the area are the most stringent in the country. SO_2 emission from the plant is limited to 48 Nm^3/day — equivalent to 60 ppm.

The plant consists of two 265 MW units. Boilers normally burn coal but can also be fired with low-sulfur oil. Occasionally a 50-50 coal and oil mixture is used depending on fuel availability and cost. Maximum sulfur content in coal used is 0.6 percent; it normally ranges from 0.3 to 0.5 percent.

The FGD system employed is the IHI Chemico process with limestone as the absorbent. Electrostatic precipitators are also used in conjunction with the two-stage venturi scrubber to reduce ash loading to 0.05g/Nm^3. Emission requirements have effectively been met by the FGD system. Reliability has been near 100 percent since startup in 1976.

EPDC Isogo Power Station



Process description — The Isogo FGD system has two equipment trains, each treating 900,000 Nm^3 of flue gas per hour. Previous existing induced draft fans supply gas to new booster fans to accommodate an FGD system pressure drop of 820 mm H_2O. The gas is cooled and cleaned in two-stages, fixed-throat venturi absorbers, with liquid-gas ratio in each stage of about 70 gal/1000 ft^3. The absorbers are of the Chemico type with pie-shaped chevron mist eliminator elements located around the circumference of the vessel at the scrubber outlet. Below the fixed throat venturi section, the superficial velocity is about 10 feet/sec.

About 70 percent of SO_2 removal takes place in the first stage, where pH is 5.4. The pH in the second stage is controlled at about 7. Facilities for sulfuric acid addition to adjust pH are provided, but have not been needed. Overall stoichiometry is about 1.05.

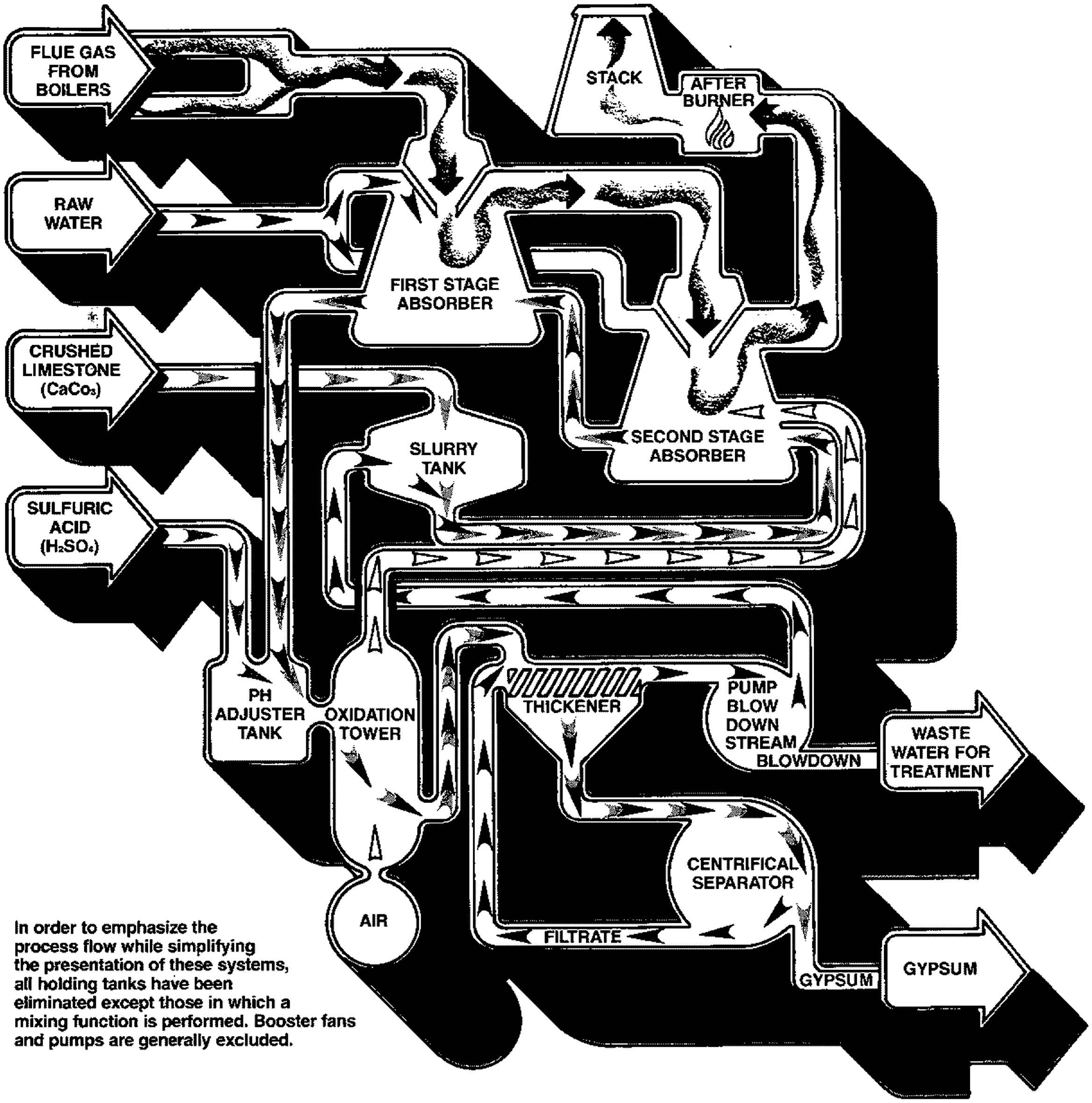
Pulverized limestone (100 percent through a 325 mesh) to slurried with fresh water to 15 percent solids. This slurry is then fed to the second-stage absorber, and the effluent is pumped to the first stage for maximum utilization of the limestone. Fresh water, used for a mist eliminator wash, dilutes the recirculated slurry to about 7 percent solids.

A bleed stream from the first stage absorber is treated in a forced oxidation system to produce gypsum. Gypsum is dewatered in thickeners and centrifuges; except for a blowdown stream, the clarified liquid is then returned to the absorber system. The blowdown is needed primarily to control chloride concentration below 5000 ppm. The liquid is discharged through a waste water treatment facility where the suspended solids, BOD, COD, and pH are controlled. Dissolved solids are not regulated.

The gypsum produced is low grade because of the high ash content (about 16 percent) and the relatively high moisture content (15 percent). However, it is suitable for use in cement and is sold for the cost of delivery.

The scrubber is constructed from mild steel and is flake lined (applied with a brush). Piping is rubber lined. Pumps have stainless steel housings and silicon carbide impellers.

ISOGO PLANT



Isogo — design/performance data

SO_2 control system	units nos. 1 & 2
flue gas rate (Nm^3/hr)	879,000 each
inlet SO_x (dry ppm)	—
inlet particulate (g/Nm^3)	—
inlet gas temperature (°C)	143
scrubber type	venturi
scrubber capacity (Nm^3)	900,000 each
absorbent	limestone
outlet SO_x at stack (dry ppm)	—
average SO_2 removal efficiency (%)	90
liquid purge rate (tons/hr)	—
utility consumption	
electric power (kw)	6,400 each
water (tons/hr)	—
limestone/lime (tons/day)	50 each
gypsum production (tons/day)	120 each
availability (%)	near 100

boiler	
power generation capacity (MW)	265 each
electrostatic precipitator efficiency (%)	96.7
coal	
heat value (kcal/kg)	6,200
sulfur content (%)	0.2-0.6
ash content (%)	16
load variation (%)	75-50

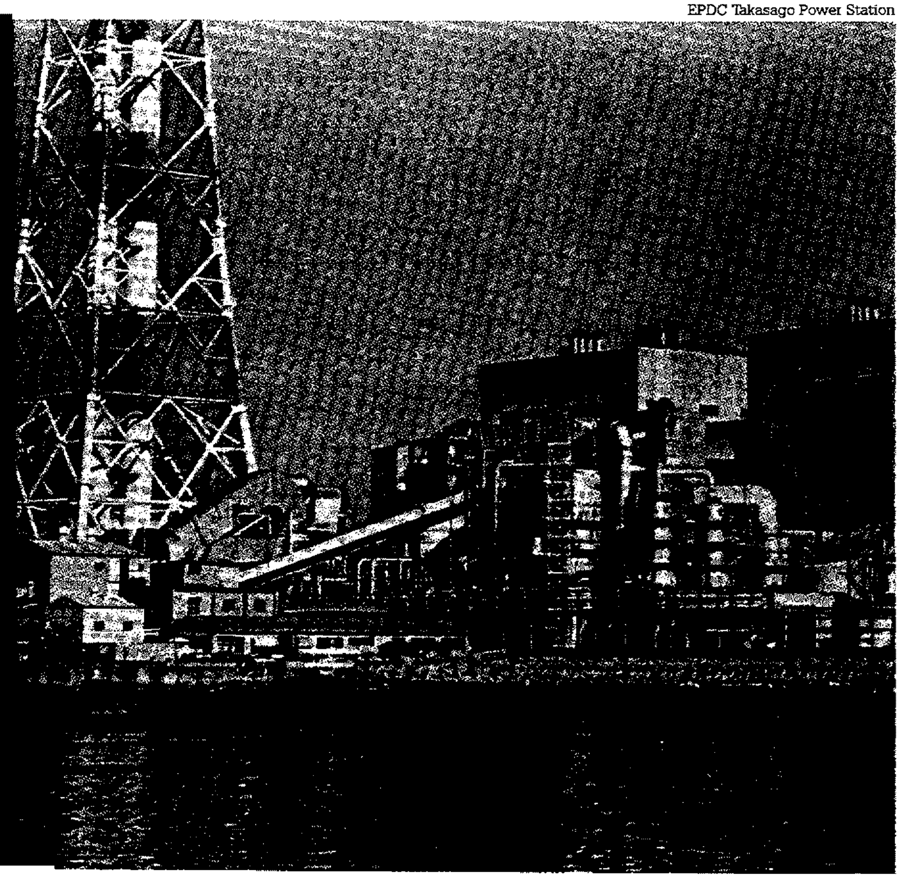
EPDC Takasago station

The Takasago power station is located near Himeji on the Seto Inland Sea. The station has two 250 MW coal-fired units that burn a blend of domestic coals averaging 2.0 percent in sulfur content.

SO_x emissions for the area were previously restricted to 400 Nm^3/hr. Under more stringent total mass emission regulations effective in April 1978, allowable emissions have been reduced to 243 Nm^3/hr (136 ppm) at full load.

The FGD systems, of the Mitsui-Chemico limestone-gypsum process, have consistently achieved average SO_2 removal efficiencies exceeding 93 percent while maintaining 99 percent operability. Systems maintain particulate outlet concentrations below 0.05 g/Nm^3.

EPDC Takasago Power Station



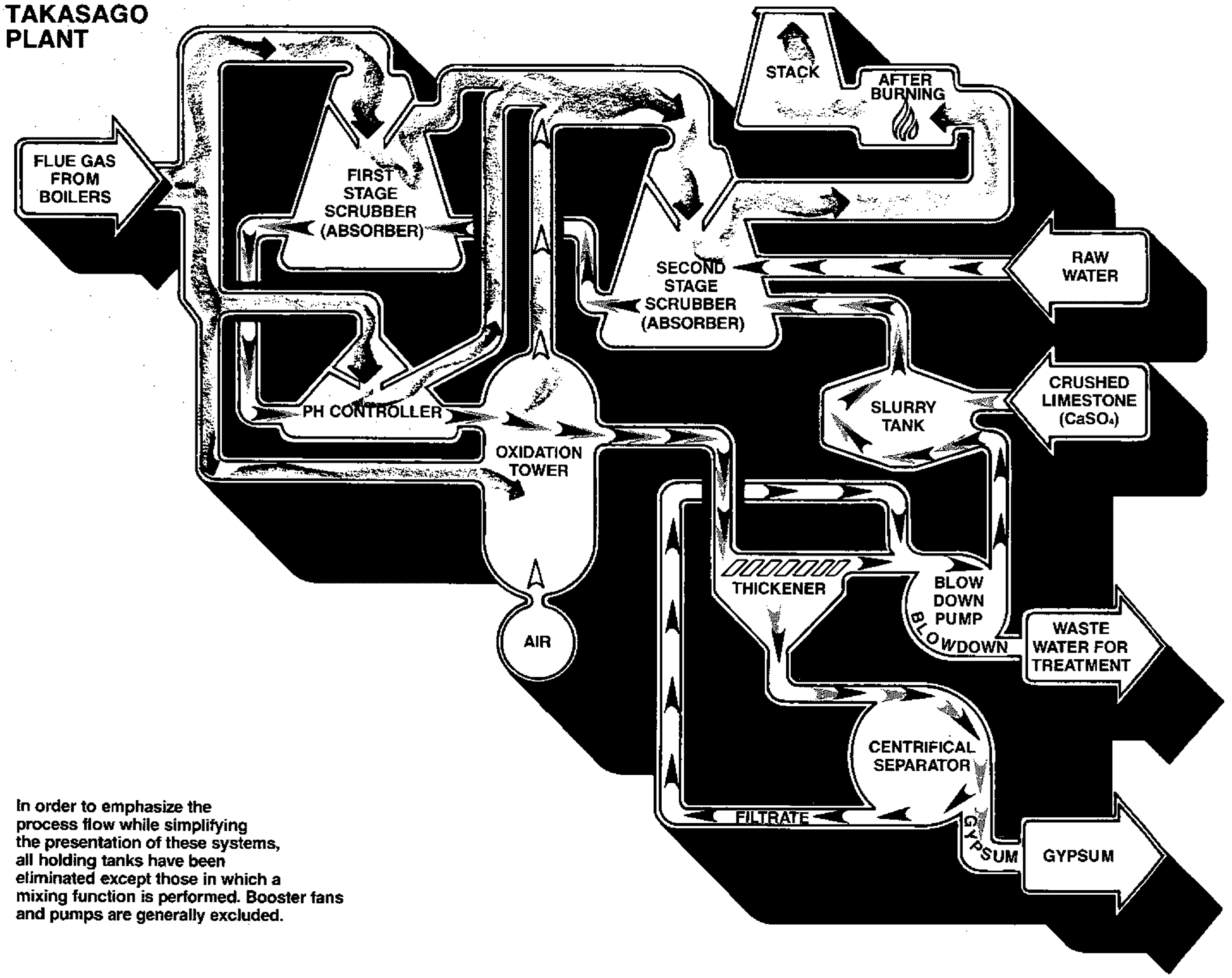
Process description — Flue gas from the Takasago boiler is split into three streams and sent to the first stage scrubber (75 percent), pH control tower (20 percent) and oxidation tower (5 percent). The flue gas exiting these vessels is then merged, passes through the second-stage scrubber and is reheated directly (using 0.3 percent sulfur oil) to 85°C prior to passing into the stack. The process is characterized by the pH control tower and oxidation reactor, which utilize SO_2 from the flue gas to lower the slurry pH to 5.8, thus increasing alkali utilization without using sulfuric acid.

Preground limestone (90 percent through a 325 mesh) is slurried on-site to 15 percent solids using centrate and thickener supernate and is fed to the second-stage scrubber at a stoichiometry of 1.0-1.05 based on the inlet SO_2. Process control is accomplished by measurement of flue gas volume and SO_2 concentration, which automatically determines the slurry make-up volume required.

Fine tuning of the make-up feed rate is maintained by pH control in the second-stage scrubber, which is operated at pH 6.2 and liquid/gas ratio of 6.5 liters/Nm^3. Recycle slurry from the second stage is fed to the first-stage scrubber, which operates at pH 6.0 and liquid/gas ratio of 6.5 liters/Nm^3. The recycle slurry is maintained at 5-6 percent solids. The gypsum slurry from the oxidizer is pumped to a thickener, concentrated to a 20 percent slurry and dewatered by centrifuge, producing gypsum containing approximately 10 percent moisture.

Thickener overflow and the centrate are returned to the process for limestone slurry make-up absorber liquid level adjustments and mist-eliminator washing. This supernate is also blown down (5 tons/hr for Unit No. 1, 10 tons/hr for Unit No. 2) to maintain chloride concentration below 8000 ppm.

Four-pass chevron-type mist eliminators are provided for the second stage scrubber, which is sequentially washed with process liquid and fresh water.



In order to emphasize the process flow while simplifying the presentation of these systems, all holding tanks have been eliminated except those in which a mixing function is performed. Booster fans and pumps are generally excluded.

Takasago — design/performance data

SO_2 control system	**units nos. 1 & 2**
flue gas rate (Nm^3/hr)	799,000
inlet SO_x (dry ppm)	1500-1700
inlet particulate (g/Nm^3)	0.1
inlet gas temperature (°C)	150
scrubber type	2-stage venturi
scrubber capacity (Nm^3)	842,000
absorbent	limestone
outlet particulate (g/Nm^3)	>0.05
outlet SO_x at stack (dry ppm)	>100
average SO_2 removal efficiency	93
liquid purge rate (tons/hr)	5
utility consumption	
electric power (kw)	6,500
water (tons/hr)	52
limestone/lime (tons/day)	125
gypsum production (tons/day)	230
availability (%)	98.8

boiler	
power generation capacity (MW)	250 each
coal	
heat value (kcal/kg)	6,000 (est.)
sulfur content (%)	2.0
load variation (%)	100-50

Located near Mihara on the Seto Inland Sea, the Takehara station consists of a 250 MW coal-fired unit and a 350 MW oil-fired unit. Since there are no large cities in the vicinity of the station, environmental regulations are relatively mild. The central government restricts emissions to 468 Nm^3/hr (600 ppm) and 503 Nm^3/hr (620 ppm) for Units No. 1 and 2, respectively. An agreement with the city and prefectural governments, however, limits Unit No. 1 SO_x emissions to 195 Nm^3/hr (240 ppm).

A Babcock-Hitachi limestone gypsum system operates on Unit No. 1. Coal burned in Unit No. 1 is domestic (Kyushu) blended on-site to achieve 2.0 percent sulfur. The Unit No. 1 FGD system achieves an operability in excess of 97 percent and an SO_2 removal efficiency exceeding 93 percent. Unit No. 2, burning 1.0 percent sulfur oil, has no FGD system at present.

Process description — At the Takehara Station, booster fans supply gas to the scrubber from 98% efficient electrostatic precipitators. The gas contains approximately 200 gm/Nm^3 of particulate matter and 1,730 Nm^3/hr of sulfur dioxide. The scrubber system consists of two identical scrubbing trains each designed to scrub about 400,000 Nm^3/hr. Upon entering the scrubbing system, the flue gas is split equally, each portion entering a prescrubber venturi section where the gas is quenched. The precooled flue gas then proceeds to a second-stage scrubber containing perforated plates that provide good gas-liquid contact. Gas flow through each scrubber train is controlled by separate fans.

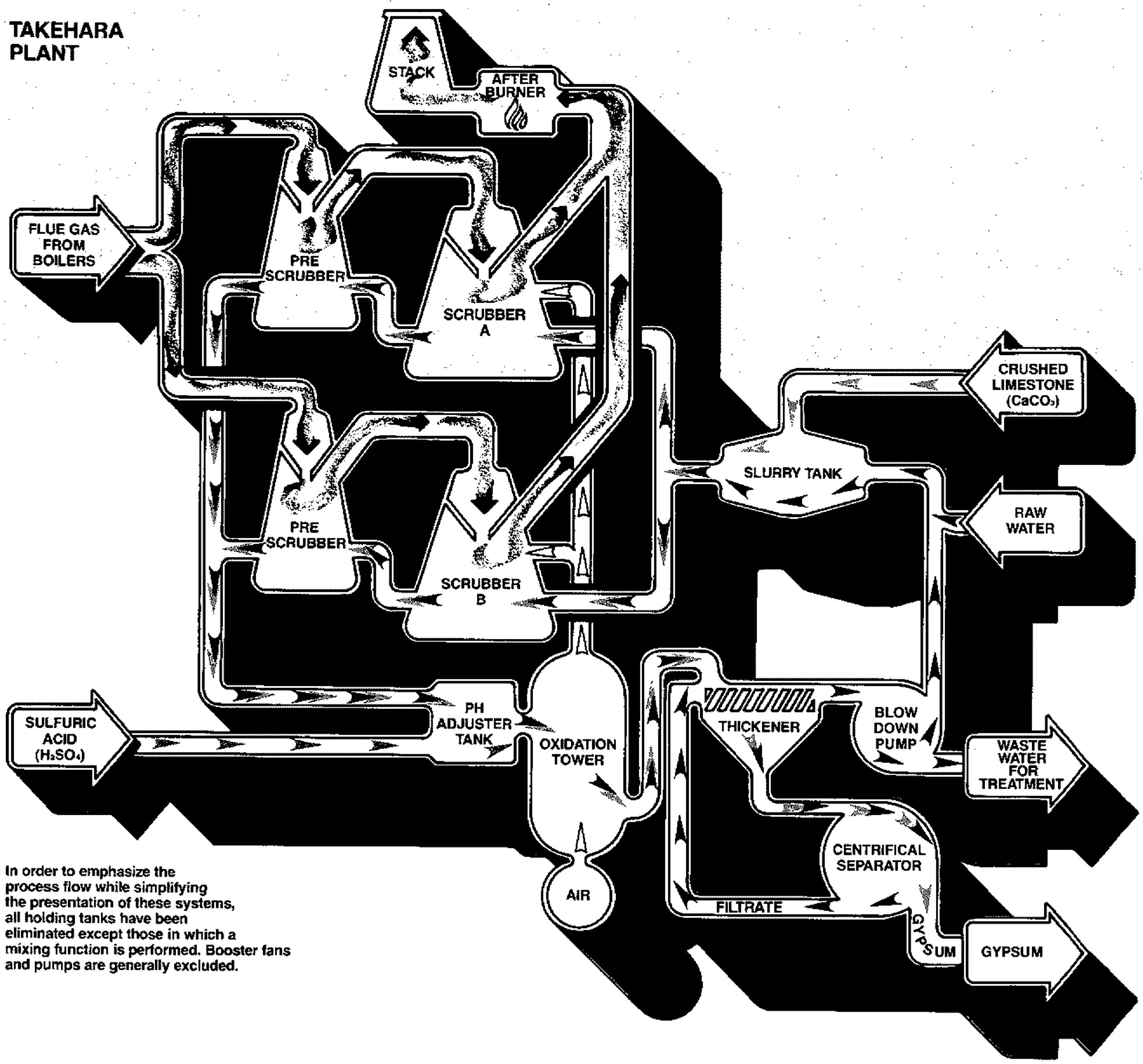
Prior to exiting the second stage, the flue gas passes vertically through a horizontal mist eliminator consisting of finned tube bundles. The cleaned gas is then reheated to 120°C by direct oil-fired reheaters before exiting through a 200-meter stack. Total pressure drop across the system is reported to be 650 mm H_2O (230 mm H_2O in the prescrubber and 385 mm H_2O in the scrubber). Fresh water is used to sequentially wash the mist eliminator sections. A complete wash cycle is about 2 hours and requires about 5-10 tons of fresh water per train.

The scrubbing system uses a limestone slurry of 10 percent solids. The slurry from the second-stage recycle tank, which has a liquid/gas ratio of about 2 liters/Nm^3, is bled to the first stage prescrubber and recycled at a liquid/gas ratio of about 2 liters/Nm^3. Slurry from this prescrubber recycle tank is continuously bled to a pH adjustment tank, where sulfuric acid is added to lower the pH before the slurry is pumped to an oxidation tower. After passing through the oxidation tower, the slurry is bled to a thickener. The supernatant liquid is returned to both recycle tanks and the underflow is then pumped to centrifuges, where final dewatering of the gypsum is accomplished by batch operation. The byproduct gypsum contains about 10 percent moisture and is sold for use in the cement and wallboard industries. Supernatant liquid from the centrifuges is pumped to the limestone preparation tank to slurry the limestone. This liquid contains substantial gypsum particles that act as seed crystals to control scale formation in the scrubber and to control size and type of gypsum crystals ultimately produced. In the second-stage recycle tank slurry, pH is controlled at 6.0; in the prescrubber recycle tank, pH is maintained at 5.0.

Process control is accomplished by measurement of flue gas volume and SO_2 concentration, which automatically determines volume of make-up slurry required. Liquor flow rate is kept constant during gas turn-down.

Energy requirements for the FGD system (excluding reheat) were reported as 3.1 percent of unit power generating capacity.

Plant operators routinely blend coal to maintain inlet flue gas sulfur dioxide concentrations of between 1550 and 1650 ppm. The plant has strict specifications for the pulverized limestone delivered dry to the plant site. Quality control of this limestone assures 95% through a 325 mesh screen, a minimum of 55.4 percent CaO, and impurities limited to 1.14 percent. Supernatant liquid is continuously blown down at a rate of 10-15 tons/hr to maintain a chloride level of 3500 ppm in the recirculated slurry.



In order to emphasize the process flow while simplifying the presentation of these systems, all holding tanks have been eliminated except those in which a mixing function is performed. Booster fans and pumps are generally excluded.

Takehara — design/performance data

SO_2 control system	**units nos. 1 & 2**
flue gas rate (Nm^3/hr)	809,000
inlet SO_x (dry ppm)	1500-1700
inlet particulate (g/Nm^3)	0.36
inlet gas temperature (°C)	140
prescrubber type	venturi
scrubber type	perforated plate
scrubber capacity (Nm^3)	852,000
absorbent	limestone
outlet particulate (g/Nm^3)	>0.03
outlet SO_x at stack (dry ppm)	>100
average SO_2 removal efficiency (%)	93
liquid purge rate (tons/hr)	10-15
utility consumption	
electric power (kw)	7800
water (tons/hr)	56
limestone/lime (tons/day)	130
gypsum production (tons/day)	225
availability (%)	97

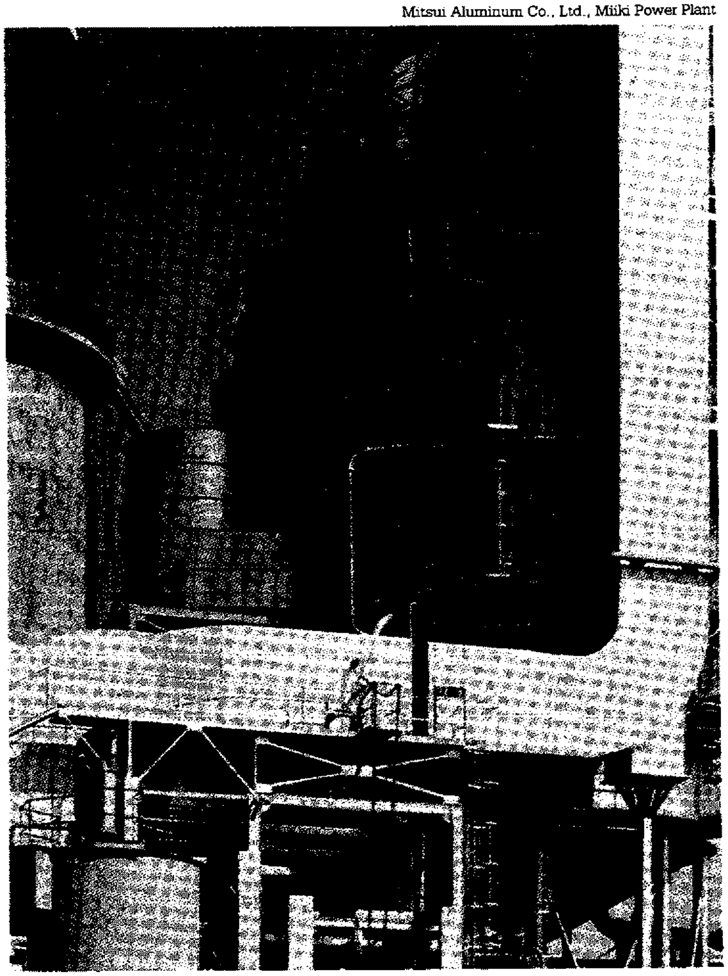
boiler	
power generation capacity (MW)	250
electrostatic precipitator efficiency (%)	98
coal	
heat value (kcal/kg)	6000
sulfur content (%)	2.0
ash content (%)	23
load variation (%)	100-40
annual load factor (%)	75

Mitsui Aluminum Company, Ltd.

The Miiki Power Plant in Omuta was built by the Mitsu Aluminum Company to provide an assured supply of electricity to its aluminum smelter. It is the largest privately-owned power station in Japan.

Unit No. 1 (156 MW) is equipped with a Mitsui-Chemico lime scrubbing system using carbide sludge waste from a nearby chemical plant. Unit No. 2 employs a Mitsui-Chemico limestone process by-producing gypsum that is sold for use in the wallboard and Portland cement industries. Both FGD units have achieved essentially 100 percent operability (except for one 10-day outage of Unit No. 2). Their SO_2 removal efficiencies have consistently been in excess of 90 percent.

Mitsui Aluminum Co., Ltd., Miiki Power Plant



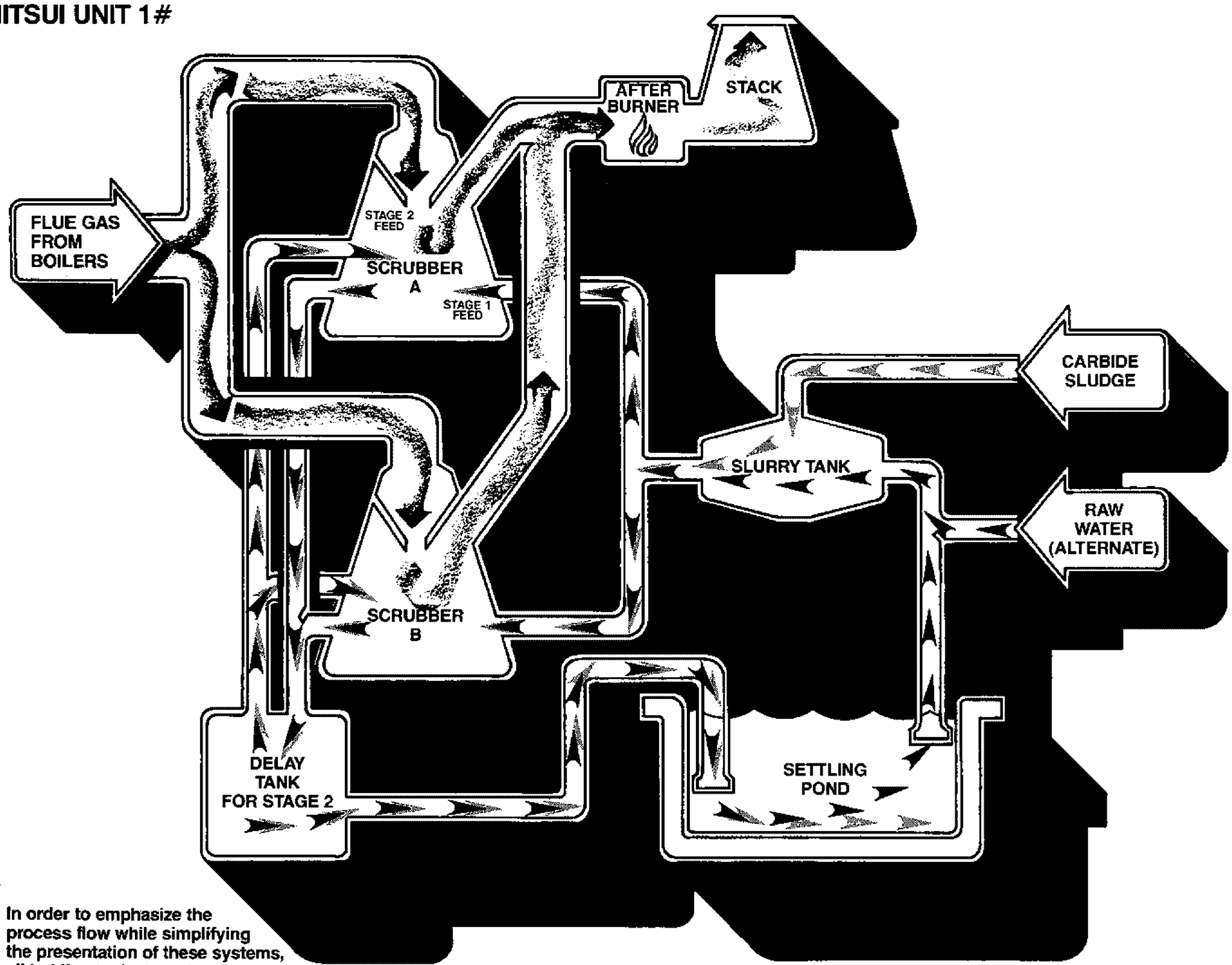
Process description — Unit 1 — Unit No. 1 of the Miiki Power Plant consists of two scrubber trains, each capable of handling 75 percent of total flue gas capacity (512,000 Nm^3/hr). Of additional interest is the 25-MW slip stream prototype subsequently added to study the limestone/gypsum process. Although this prototype is no longer in operation, reportedly it could be restarted to provide 100 percent flue gas treatment in conjunction with one train should the second train require shutdown.

Flue gas passes through a two-stage venturi scrubber (450 mm H_2O total pressure drop), where SO_2 and residual particulate are removed. The cleaned flue gas is reheated to 85°C prior to discharging through a 130-meter stack.

The system uses a mixture of wet (50-60 percent moisture) and dry (47 percent moisture) carbide lime, which is adjusted to a final slurry concentration of 15 percent. Make-up slurry feed rate is manually controlled by recycle slurry pH, which is maintained at 8 (although designed for 6.8). Suspended solids content of the recycle slurry is normally maintained at around 5-6 percent by weight. Liquid/gas ratio for each stage is around 40 gal/1000 standard cubic feet. Delay tank residence times for the first and second stages were reported as 20 and 4 minutes, respectively. A bleed stream from the first stage delay tank is transported to a settling pond, where the supernatant liquid is returned to the process for carbide lime make-up, absorber liquid level adjustments, and mist eliminator washing. Four-stage chevron-type mist eliminators are provided for both first and second stages and are intermittently washed with fresh water and recirculated pond liquor. Gas velocity through the mist eliminator is around 2.7 meters/sec.

Process description — Unit No. 2 — The process description for Unit 2 is not included here because it was the same limestone process as the Takasago plant, previously described.

MITSUI UNIT 1#



In order to emphasize the process flow while simplifying the presentation of these systems, all holding tanks have been eliminated except those in which a mixing function is performed. Booster fans and pumps are generally excluded.

Miiki unit 1 — design/performance data

SO_2 control system	**unit no. 1**	**unit no. 2**
flue gas rate (Nm³/hr)	512,000	552,000
inlet SO_x (dry ppm)	2100-2300	1900-2100
inlet particulate (g/Nm³)	0.6	0.6
inlet gas temperature (°C)	136	138
scrubber type	2-stage venturi	2-stage venturi
scrubber capacity (Nm³)	385,000 x 2	552,000 x 1
absorbent	carbide lime	limestone
outlet particulate (g/Nm³)	>0.06	>0.06
outlet SO_x at stack (dry ppm)	>200	>200
average SO_2 removal efficiency (%)	90+	90+
liquid purge rate (tons/hr)	90	20
utility consumption		
electric power (kw)	3650	4240
water (tons/hr)		36.5
bunker c oil (kl/day)	15	18
limestone/lime (tons/day)	110	110
catalyst (kg/hr)		20
gypsum production (tons/day)		180
availability (%)	100	99 (100 since 11/75)

boiler		
steam generation capacity (tons/hr)	490	550
power generation capacity (MW)	156	175
electrostatic precipitator efficiency (%)	98.6	98.6
coal		
heat value (kcal/kg)	5500-5800	5500-5800
sulfur content (%)	2.4	2.4
load variation (%)	100-50 (usually 100)	100-50 (usually 100)

appendix

task force members

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Professor, Chuo University
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plants visited

Plant Owner	Plant Site	Plant Type	FGD Process	Capacity (MW)	Absorbent	By-Product	Year Operational
EPDC	Takehara	C, U	Babcock-Hitachi	250	$CaCO_3$	Gypsum	1977
EPDC	Takasago	C, U	Chemico-Mitsui	250 (2 units)	$CaCO_3$	Gypsum	1975/76
EPDC	Isoga	C, U	Chemico-IHI	265 (2 units)	$CaCO_3$	Gypsum	1976
Mitsui Aluminum	Omuta	C, I	Mitsui-Chemico	175	$CaCO_3$	Gypsum	1975
Mitsui Aluminum	Omuta	C, I	Chemico-Mitsui	156	Carbide lime	Sludge	1972
Chuba Electric	Owase	O, U	MHI	375 (2 units)	$Ca(OH)_2$	Gypsum	1976
Chugoku Electric	Shimonoseki	O, U	MHI	400	$CaCO_3$	Gypsum	1977
Idemitsu Kosan	Chiba	O, I	Chemico-Mitsui	160	MgO	Sulfur	1975
Chuba Electric	Nishinagoya	O, U	Wellman-MKK	220	Na_2SO_3	H_2SO_4	1973
Naikai	Tamano	O, I	Dowa	30 (eq)	$Al_2(SO_4)_3-CaCO_3$	Gypsum	1976
Dowa Mining	Okayama	A	Dowa	50 (eq)	$Al_2(SO_4)_3-CaCO_3$	Gypsum	1974
Japan Exlan	Saidaiji	O, I	Kawasaki	80	$MgO - CaCO_3$	Gypsum	1976

C = coal, O = oil, U = utility boiler, I = industrial boiler, A = H_2SO_4 plant

number/capacities (1,000 Nm^3/hr) of FGD installations

Plant Constructor	Lime/Limestone[1]	Gypsum[2]	Indirect Lime/Limestone	Gypsum	Regenerable/ H_2SO_4, S $(NH_4)_2SO_4$		Once through Na_2SO_3 Na_2SO_4		Total	
Mitsubishi Heavy Industries (MHI)	33	(18,270)					3	(292)	36	(18,562)
Ishikawajima H. I. (IHI)	17	(4,445)					79	(4,351)	96	(8,796)
Hitachi, Ltd.	13	(6,940)			2	(590)	15	(603)	30	(8,133)
Mitsubishi Kakoki (MKK)	2	(256)			13	(6,478)	41	(913)	56	(7,643)
Kawasaki Heavy Industries	4	(756)	6	(5,450)			7	(256)	17	(6,380)
Tsukishima Kikai (TSK)	1		4	(398)	1	(88)	40	(4,042)	46	(4,528)
Chiyoda Chemical Engineering & Construction			14	(4,459)					14	(4,459)
Oji Koel							57	(4,280)	57	(4,280)
Fuji Kasui Engineering	7	(3,954)					6	(270)	13	(4,224)
Kurabo Engineering			5	(413)	1	(18)	106	(3,751)	112	(4,182)
Mitsui Miike-Chemico	4	(2,744)			1	(500)			5	(3,244)
Ebara Manufacturing			11	(1,914)			10	(1,167)	21	(3,081)
Nippon Kokan (NKK)	3	(245)	1	(150)	2	(1,990)	6	(62)	12	(2,447)
Kureha Chemical							8	(1,431)	8	(1,431)
Showa Denko							5	(1,372)	5	(1,372)
Cadlius							8	(1,291)	8	(1,291)
Sumitomo (SCEC)-Wellman					6	(1,288)			6	(1,288)
Mitsui Metal Enginnering	4	(1,006)			2	(130)			6	(1,136)
Kobe Steel	5	(1,125)							5	(1,125)
Japan Gasoline	1	(330)			1	(125)			2	(455)
Dowa Engineering			5	(453)					5	(500)
Niigata Iron Works			1	(185)					1	(185)
Mitsui Shipbuilding							1	(160)	1	(160)
Sumitomo Heavy Industries					1	(150)			1	(150)
Total	94	(40,171)	47	(13,422)	30	(11,357)	392	(24,241)	563	(89,138)

[1] Process type
[2] Byproduct

*500 add'l small FGD plants

steam power capacity vs. FGD capacity

Power Company	Total power capacity (MW) Existing	Under Construction	Total	FGD capacity (MW) Existing	Under Construction	Total	(%)
Hokkaido	1,270	1,225	2,495	0	525	525	21.0
Tohoku	3,925	1,200	5,125	550	350	900	17.6
Tokyo	19,167	4,400	23,567	283	0	0	1.2
Chubu	9,933	3,800	13,733	970	0	970	7.1
Hokuriku	1,412	1,000	2,412	600	500	1,100	45.6
Kansai	10,672	1,200	11,872	930	0	930	7.8
Chugoku	3,777	1,800	5,777	1,350	700	2,050	36.8
Shikoku	2,687	450	3,137	900	0	900	12.5
Kyushu	4,500	2,700	1,376	1,376	250	1,626	22.6
EPDC	1,430	1,000	2,430	1,280	1,000	2,280	93.8
Niigata	350	350	700	175	175	350	50.0
Showa	550	0	550	400	0	400	72.7
Toyama	750	0	750	250	0	250	33.3
Mizushima	462	0	462	156	0	156	33.8
Sumitomo	368	250	618	156	0	156	25.2
Sakata	0	700	700	700	0	700	100.0
Fukui	0	250	250	0	250	250	100.0
Others	5,512	375	5,887	0	0	0	0.0
TOTAL	66,775	20,700	87,475	10,076	3,750	13,826	15.8

FGD systems in Japan

Power company	Power station	Boiler No.	Boiler MW	FGD MW	Process developer	Absorbent, precipitant	By-product	Year of completion
Tohoku	Shinsendai	2	600	150	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1974
Tohoku	Hachinohe	4	250	125	Mitsubishi H. I.	CaO	Gypsum	1974
Tohoku	Niigata	4	250	125	Wellman-MKK	Na_2SO_3	H_2SO_4	1976
Tohoku	Niigata H.	1	600	150	Mitsubishi H. I.	$CaCO_3$	Gypsum	1976
Tohoku	Akita	3	350	350	Kureka-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1977
Tokyo	Kashima	3	600	150	Hitachi-Tokyo	Carbon, $CaCO_3$	Gypsum	1972
Tokyo	Yokosuka	1	265	133	Mitsubishi H. I.	$CaCO_3$	Gypsum	1974
Chubu	Nishinagoya	1	220	220	Wellman-MKK	Na_2SO_3	H_2SO_4	1973
Chubu	Owase	1	375	375	Mitsubishi H. I.	CaO	Gypsum	1976
Chubu	Owase	2	375	375	Mitsubishi H. I.	CaO	Gypsum	1976
Hokuriku	Toyama	1	500	250	Chiyoda	H_2SO_4, $CaCO_3$	Gypsum	1974
Hokuriku	Fukui	1	350	350	Chiyoda	H_2SO_4, $CaCO_3$	Gypsum	1975
Hokuriku	Nanao	1	500	500	Not decided	H_2SO_4, $CaCO_3$	Gypsum	1978
Kansai	Sakai	8	250	63	Sumitomo H. I.	Carbon	H_2SO_4	1972
Kansai	Amagasaki	1	156	35	Mitsubishi H. I.	CaO	Gypsum	1973
Kansai	Amagasaki	1	156	121	Mitsubishi H. I.	CaO	Gypsum	1975
Kansai	Amagasaki	1	156	156	Mitsubishi H. I.	CaO	Gypsum	1976
Kansai	Osaka	3	156	156	Babcock-Hitachi	$CaCO_3$	Gypsum	1975
Kansai	Osaka	2	156	156	Babcock-Hitachi	$CaCO_3$	Gypsum	1975
Kansai	Osaka	4	156	156	Babcock-Hitachi	$CaCO_3$	Gypsum	1976
Kansai	Kainan	4	600	150	Mitsubishi H. I.	CaO	Gypsum	1974
Chugoku	Mizushima	2	156	100	Babcock-Hitachi	$CaCO_3$	Gypsum	1974
Chugoku	Tamashima	3	500	500	Babcock-Hitachi	$CaCO_3$	Gypsum	1975
Chugoku	Tamashima	2	350	350	Babcock-Hitachi	$CaCO_3$	Gypsum	1976
Chugoku	Shimonoseki	2	400	400	Mitsubishi H. I.	$CaCO_3$	Gypsum	1976
Chugoku	Shimonoseki	1	175*	175	Mitsubishi H. I.	$CaCO_3$	Gypsum	1979
Hokkaido	Higashitomakomai	1	500	250	Not decided	$CaCO_3$	Gypsum	1981
Shikoku	Anna	3	450	450	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1975
Shikoku	Sakaide	3	450	450	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1975
Kyushu	Karita	2	375	188	Mitsubishi H. I.	CaO	Gypsum	1974
Kyushu	Karatsu	2	375	188	Mitsubishi H. I.	$CaCO_3$	Gypsum	1976
Kyushu	Karatsu	3	500	250	Mitsubishi H. I.	$CaCO_3$	Gypsum	1976
Kyushu	Ainoura	1	375	250	Mitsubishi H. I.	$CaCO_3$	Gypsum	1976
Kyushu	Ainoura	2	500	250	Mitsubishi H. I.	$CaCO_3$	Gypsum	1976
Kyushu	Buzen	1	500	250	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1977
Kyushu	Buzen	2	500	250	Kureha-Kawasaki	Na_2SO_3, $CaCO_3$	Gypsum	1978
EPDC	Takasago	1	250*	250	Mitsui-Chemico	$CaCO_3$	Gypsum	1975
EPDC	Takasago	2	250*	250	Mitsui-Chemico	$CaCO_3$	Gypsum	1976
EPDC	Isogo	1	265*	265	Chemico-IHI	$CaCO_3$	Gypsum	1976
EPDC	Takehara	1	250*	250	Babcock-Hitachi	$CaCO_3$	Gypsum	1977
EPDC	Matsushima	1	500*	500	Not decided	$CaCO_3$	Gypsum	1980
EPDC	Matsushima	2	500*	500	Not decided	$CaCO_3$	Gypsum	1980
Niigata	Niigata	1	350	175	MHI	$CaCO_3$	Gypsum	1975
Showa	Ichihara	1	150	150	Showa Denio	Na_2SO_3, $CaCO_3$	Gypsum	1973
Showa	Ichihara	5	250	250	Babcock-Hitachi	$CaCO_3$	Gypsum	1976
Toyama	Toyama	1	250	250	Chiyoda	H_2SO_4, $CaCO_3$	Gypsum	1975
Mizushima	Mizushima	5	156	156	Mitsubishi H. I.	CaO	Gypsum	1975
Sumitomo	Niihama	3	156	156	IHI	$CaCO_3$	Gypsum	1975
Sakata	Sakata	1	350	350	Mitsubishi H. I.	$CaCO_3$	Gypsum	1976
Sakata	Sakata	2	350	350	Mitsubishi H. I.	$CaCO_3$	Gypsum	1977
Fukui	Fukui	1	250	250	Not decided	$CaCO_3$	Gypsum	1977
		47						

*Coal-fired boilers. Others are for oil-fired boilers.

conversion factors

For convenience in comparing metric units with English system units and Japanese yen with dollars the following conversion factors may be useful.

1 m (meter)	=	3.3 feet
1 m^3	=	35.3 cubic feet
1 t (metric ton)	=	1.1 short tons
1 kg (kilogram)	=	2.2 pounds
1 liter	=	0.26 gallon
1 kl (kiloliter)	=	6.19 barrels

The capacity of flue gas desulfurization plants is expressed in Nm^3/hr (normal cubic meters per hour).

1 Nm^3/hr	=	0.59 standard cubic foot per minute

The L/G ratio (liquid/gas ratio) is expressed in liters/Nm^3.

1 liter/Nm^3	=	7.4 gallons/ thousand standard cubic feet

When using cost data in this report the following conversion should be used:

Yen/Dollar	=	238 (1978, first quarter)

for further reading

Elder, H. W. et al, **Sulfur Oxide Control Technology — Visits in Japan — August 1972** — Interagency Report, October 30, 1972.

Ando, J., **Recent Developments in Desulfurization of Fuel Oil and Waste Gas in Japan — 1973,** EPA-R2-73-229, May 1973.

Hollinden, G. A. and Princiotta, F. T., **Sulfur Oxides Control Technology — Visits in Japan — March 1974,** Interagency Report, October 15, 1974.

Ando, J. and Isaacs, G. A., **SO_2 Abatement for Stationary Sources in Japan,** EPA- 600/2-76-031a, January 1976.

Kawanishi, S., **Environmental Laws and Regulations in Japan,** Japan Environmental Agency Report, February 1976.

Ando, J. and Laseke, B. A., **SO_2 Abatement for Stationary Sources in Japan,** EPA-600/7-77-103a, September 1977.

Kagawa, T., **Quality of the Environment in Japan — 1977,** Japan Environmental Agency Report, November 1977.

Ando, J. "Status of SO_x and NO_x Removal Systems in Japan," in **Proceedings: Symposium on Flue Gas Desulfurization** — Hollywood, Florida, November 1977 (Volume 1) EPA-600/7-78-058a, March 1978.

Ando, J. et al, **SO_2 Abatement for Stationary Sources in Japan** — EPA-600/7-78-210, November 1978.

Laseke, B. A., ***EPA Utility FGD Survey:* December 1977-January 1978,** EPA-600/7-78-051a, March 1978.

Kagawa, T., **Quality of the Environment in Japan — 1978,** Japan Environmental Agency Report, December 1978.

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