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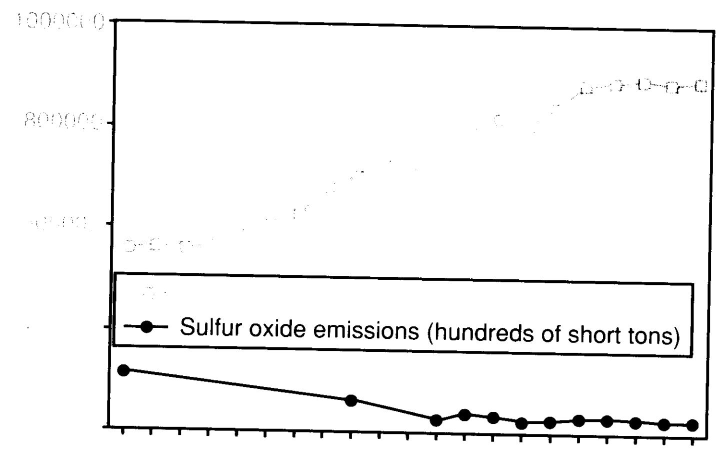
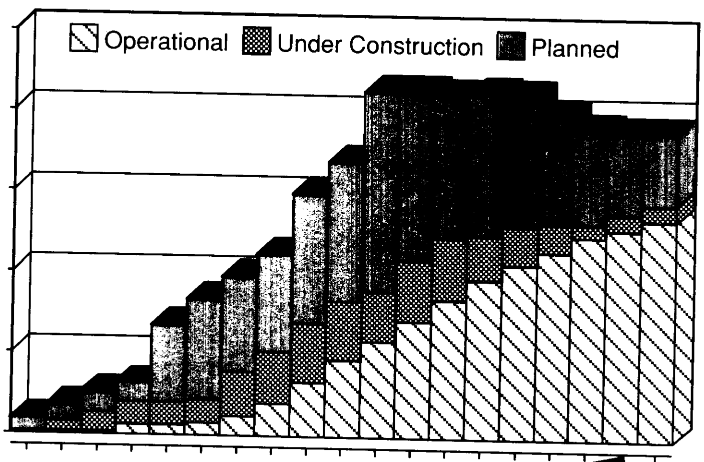
EPA

Flue Gas Desulfurization Technologies for Control of Sulfur Oxides

Research, Development, and Demonstration





Improved Technology for Environmental Protection

Improved Technology for Environmental Protection

Flue gas desulfurization (FGD) technologies have been applied in the United States during the past two decades to help reduce emissions of sulfur dioxide (SO_2) and, consequently, improve ambient air quality in response to clean air legislation. While the burning of coal, a primary source of SO_2 emissions in this country, has increased during this period, SO_2 emissions have been reduced by about 8 million tons, annually. The workhorses of these control technologies, wet lime and limestone systems, better known as "scrubbers," have been, to a great extent, pioneered, developed, and demonstrated by EPA's Air Pollution Prevention and Control Division (APPCD) [formerly known as the Air and Energy Engineering Research Laboratory (AEERL)].

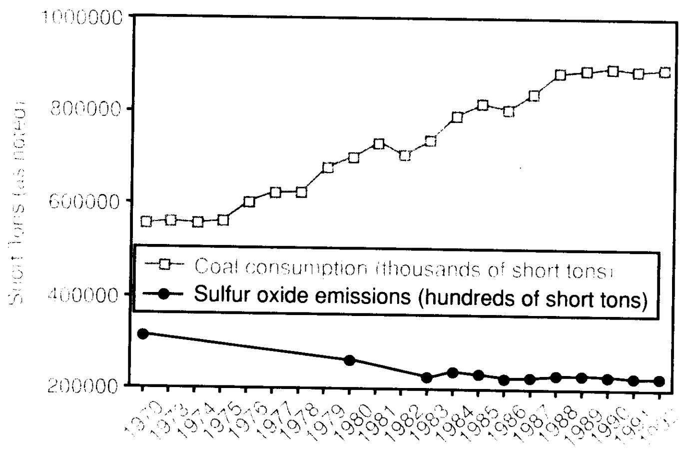


Figure 1. U.S. annual sulfur oxide emissions and coal consumption.

BACKGROUND

SO_2 in the atmosphere has been recognized as a major air pollution problem in the U.S. since the inception of clean air legislation. The Air Quality Act of 1967 required that states develop ambient air quality standards for SO_2. The Clean Air Act (CAA) of 1970 mandated performance standards for new and significantly modified sources of SO_2. In 1971, the Environmental Protection Agency (EPA) issued the first such standards for fossil-fuel-fired boilers greater than 25 MWe.[1] The new source performance standard (NSPS) limiting allowable emissions to 1.2 lb of SO_2 per million Btu of heat input to the boiler, promulgated by EPA in 1971, essentially limited operators of these boilers to two choices: use low-sulfur coal, or apply FGD technology.

In 1979 the NSPS were revised for power plants, requiring a percentage reduction of SO_2.[2] This mandate was intended to be technology forcing, essentially requiring all new power plants to add SO_2 removal equipment to the base design.

In the 1980s Congress began debating the need for additional SO_2 control as a means of reducing damage from acid rain, culminating in the Clean Air Act Amendments of 1990. Under Title IV of the Act, three distinct phases of SO_2 control are mandated:

- Phase I targets specific large sources to reduce SO_2 emissions 5 million tons by January 1, 1995.
- Phase II reduces all power plants to a nationwide emission level of 1.2 lb $SO_2/10^6$ Btu by January 1, 2000.
- Phase III requires that SO_2 emissions be capped beyond the year 2000.

As shown in Figure 1, U.S. SO_2 emissions have decreased from about 31 million tons in 1970 to about 23 million tons in 1992, in spite of the increase in coal consumption from about 560 million tons to about 890 million tons over the same period.[3,4]

At the end of the decade of the 80s, the U.S. utility industry was controlling about 68,000 MWe of electric generating capacity with FGD at an estimated installed cost of $10 billion. At that time, another 29,000 MWe of electric generating capacity had FGD systems under construction or in the planning stages. If the Clean Air Act Amendment goals are met, an additional 10 million tons of SO_2 emissions, annually, will be eliminated by the year 2000, such that future SO_2 levels will be stabilized at less than half the level of the early 1970s.[5] (Figure 2)

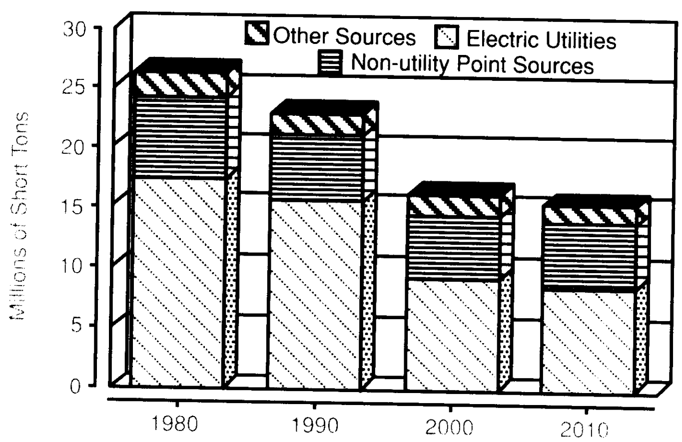


Figure 2. Past and projected trend in sulfur oxide emissions 1980 to 2010.

EPA's research program has played an important role in limiting SO_2 emissions growth in the U.S. The international community followed EPA's lead as evidenced by the aggressive SO_2 controls mandated in Japan and Europe.

EPA'S SULFUR OXIDES RESEARCH PROGRAM

In the early 1970s, the viability of wet lime and limestone scrubbing was controversial. EPA argued for acceptance and application of this FGD technology, while utility companies argued that the technology was not adequately demonstrated. At that time, predecessors of EPA's APPCD forged an interagency agreement with the Tennessee Valley Authority (TVA) to cooperatively evaluate and improve wet lime and limestone FGD technology at TVA's Shawnee Station in Paducah, KY, on three parallel 10 MWe prototype scrubbers. To support the Shawnee program, APPCD constructed a 0.1 MWe wet scrubbing pilot plant at the EPA facility in Research Triangle Park (RTP), NC, to solve some of the problems being experienced by the few commercial attempts at FGD. These problems included severe corrosion of scrubber components, plugging of the scrubber by solids, and poor SO_2 removal.[6]
Through the early 1980s this cooperative effort demonstrated a number of FGD improvements which are in commercial practice today. Important work was also conducted on evaluating scrubber waste disposal options.

By the mid 1980s, wet FGD had become commercially established and accepted by the U.S. utility industry--a complete turnaround from the perception just one decade earlier. At that time, APPCD focused SO_2 research on lower cost retrofit technologies such as dry scrubbing (spray dryer absorption), limestone injection with multistage burners (LIMB), calcium silicate injection (ADVACATE), and combined spray dryer/electrostatic precipitation (E-SO_x), in anticipation of a major U.S. acid rain retrofit program being considered by Congress.

RESEARCH ACTIVITIES

Lime and Limestone FGD

In the early 1970s when FGD was in its infancy, wet lime or limestone slurry scrubbing was the system of choice. A typical, no frills FGD system is shown in Figure 3. These systems were fraught with operating problems. The efforts of APPCD to bring wet FGD to commercial acceptance resulted in the following innovations researched and developed at the RTP pilot plant:

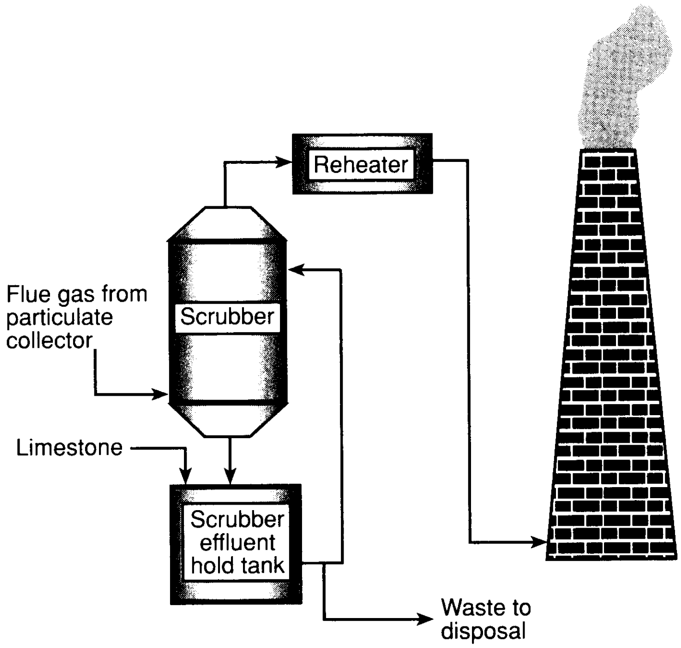


Figure 3. Wet FGD technology for SO_2 control.

- Use of high liquid-to-gas ratios (enhanced scrubber internal recirculation) to prevent scaling.
- Use of forced oxidation to avoid scaling and improve disposal/salability of solids.
- Use of thiosulfate-forming additives to inhibit scaling.
- Use of organic acid buffers to increase SO_2 removal and improve sorbent utilization.

Power Plant and FGD Waste Disposal

As a natural outgrowth of the research and development of FGD technologies, the predecessors of APPCD conducted a research and development program to deal with disposal of wastes from coal-fired power plants, including fly ash, bottom ash, and wet and dry FGD wastes, in environmentally acceptable ways. In this program, FGD and ash wastes were chemically and physically characterized. Methods of physically stabilizing wet FGD wastes and minimizing their permeability and leachability were investigated, and tested in both the laboratory and the field. The use of forced oxidation in wet FGD lime and limestone scrubbers also improved the stability of these wet FGD wastes. Procedures to determine the toxicity of trace metals leached from fly ash at disposal sites were investigated in support of Resource Conservation and Recovery Act (RCRA) regulation development.

Emerging Technologies

During more recent efforts to develop lower-cost alternatives to the standard wet FGD, more suited to retrofit of existing facilities, APPCD has fostered the development of:

- Spray dryer absorption.
- Furnace injection of calcium sorbent (LIMB).
- Calcium silicate injection (ADVACATE).
- Combined spray drying and electrostatic precipitator (E-SO_x).
- Use of organic acid buffers.
- Dual alkali technology from concept to full-scale application.

Technology Transfer

Over a 20-year period, APPCD has established FGD as a commercially accepted technology, through dissemination of program results at regularly sponsored symposia, sponsoring a number of commercial-scale demonstrations, publishing numerous journal articles, and holding industry seminars at the conclusion of successful demonstrations to ensure that vendors are able to offer FGD innovations, commercially. Also, the regulatory development has been greatly assisted by the APPCD program results, most notably in the 1979 NSPS for utility boilers, which was based largely upon FGD process improvements developed or sponsored by APPCD.

During this period, APPCD has co-sponsored SO_2 control symposia at intervals of about 1-1/2 years which have grown from about 100 attendees in the early 1970s to nearly 800 in the 1990s. The international audience for these symposia has gradually grown to where nearly one-fourth of the papers and attendees are from outside the United States, despite their being held in the U.S.

ACCOMPLISHMENTS

To foster the development and implementation of cost-effective SO_2 control technology, APPCD has:

- Conducted 15+ years of pilot wet lime and limestone FGD tests at RTP and TVA to improve the technology to a universal acceptance.
- Sponsored a number of commercial demonstrations to show high reliability, 90 percent SO_2 control wet FGD operation.
- Sponsored laboratory and field evaluation studies of power plant and FGD waste disposal.
- Sponsored SO_2 control technology symposia on a regular basis since 1971; conducted industry briefings to transfer successful technology demonstrations to the private sector.
- Published over 100 reports and hundreds of journal articles on FGD performance and economics.
- Published an economic model for evaluation of alternative SO_2, NO_x, and PM control technologies.
- Received 11 patents on SO_2 control technology with several more pending.
- During the 1970s and early 1980s, provided leadership through international forums such as NATO - Critical Challenges to Modern Society (NATO-CCMS) to transfer FGD technology to Europe.

Role of Other Non-EPA Research Organizations

The application of FGD control technology has burgeoned over the past two decades. In addition to the role played by EPA, FGD commercialization has been strongly influenced by the efforts of other federal agencies, including the Department of Energy, research organizations such as the Electric Power Research Institute, and a host of progressive-thinking, environmentally conscious innovators, private sector companies, FGD vendors, and the electric utility industry. These organizations have been instrumental in pushing FGD technology to its current level of high removal efficiency and high reliability. This successful implementation, and continuing improvement of FGD systems, attests to the accomplishments that can be made through worldwide collaboration and cooperation between regulators, research, and private industry. Figure 4 shows the number of U.S. operational, under construction, and planned utility FGD systems as a function of time.[6] Note that the effect of the 1990 Clean Air Act Amendments (Acid Rain) is not depicted here, but is expected to add many more applications of FGD technology in the post-2000 time frame.

IMPACTS

The major impacts of APPCD's SO_2 Control Technology research program are:

- Development of wet FGD technology which is reflected in the worldwide application of FGD by commercial vendors.
- Support of the landmark 1979 NSPS which required 70 to 90 percent reduction of SO_2 on a continuous basis.
- Development of several new SO_2 control technologies to enable cost-effective retrofit of existing power plants.

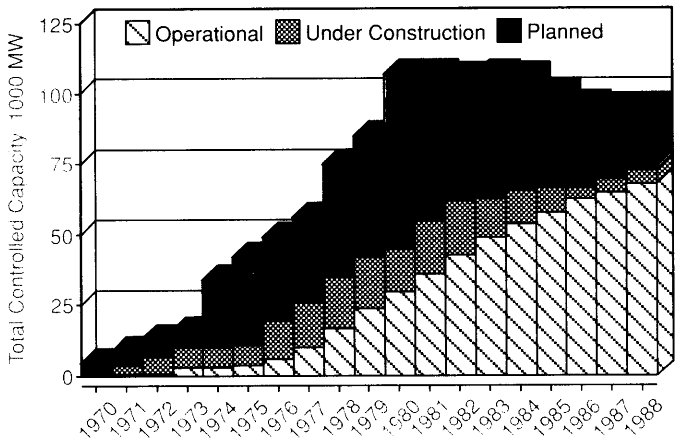


Figure 4. History of utility FGD status, December 1970 through December 1988.

- Development of process and economic models which enable the private sector to predict performance and costs of FGD technology.

Influencing FGD Technology Abroad

Of the 347 FGD units installed outside the USA, nearly 65 percent (223) are lime/limestone FGD units using technology first piloted and field tested under APPCD sponsorship in the 1970s.[7] In Japan 46 of 47 FGD units are wet lime/limestone units designed by five major Japanese vendors. During the 1970s these vendors attended FGD symposia in the U.S. cosponsored by APPCD and visited the FGD pilot facilities at RTP and TVA's Shawnee unit. Information on FGD design and operation was also exchanged freely during a number of visits made under a Japan/U.S. environmental agreement.

In Germany a similar situation to Japan exists in that 136 of the 205 FGD units are lime/limestone wet scrubbers, the majority designed by six German vendors. Most German scrubbers were installed in the mid-1980s as part of a massive acid rain mitigation program and had the benefit of the complete EPA/TVA pilot experience that ended in the early 1980s. The German vendors, too, were attendees at EPA-sponsored conferences on FGD, and the German government acquired additional information through NATO-CCMS activities chaired by the APPCD Director.

In summary, worldwide FGD use, most notably in Germany and Japan, is dominated by the lime/limestone wet scrubber where basic design evolved from the EPA-TVA pilot FGD evaluations.

Early participation by Japanese vendors, and later German vendors, in EPA-sponsored information exchanges, visits, and symposia promoted the rapid diffusion of FGD technology worldwide.

RECENT RESEARCH

DEVELOPMENT OF NEXT GENERATION SO_2 RETROFIT CONTROL TECHNOLOGIES

In the 1980s international focus on acid rain and the perceived need for low capital cost retrofit SO_2 technology altered APPCD's focus from wet FGD improvements toward development of lower cost dry SO_2 technologies. APPCD initially fostered the development of spray dryer FGD technology which quickly achieved commercial acceptance. During the latter half of this decade, APPCD developed three related technologies--lime/limestone injection with multistage burners (LIMB), advanced calcium silicate injection (ADVACATE), and electrostatic precipitator sulfur oxides removal (E-SO_x).

LIMB

LIMB technology (shown in Figure 5) was demonstrated at 50 to 60 percent SO_2 removal in two demonstrations sponsored by APPCD. A wall-fired demonstration at Ohio Edison's Edgewater Station was completed in 1989.[8] This was followed by a tangentially fired LIMB demonstration at Virginia Power's Yorktown Station.[9]

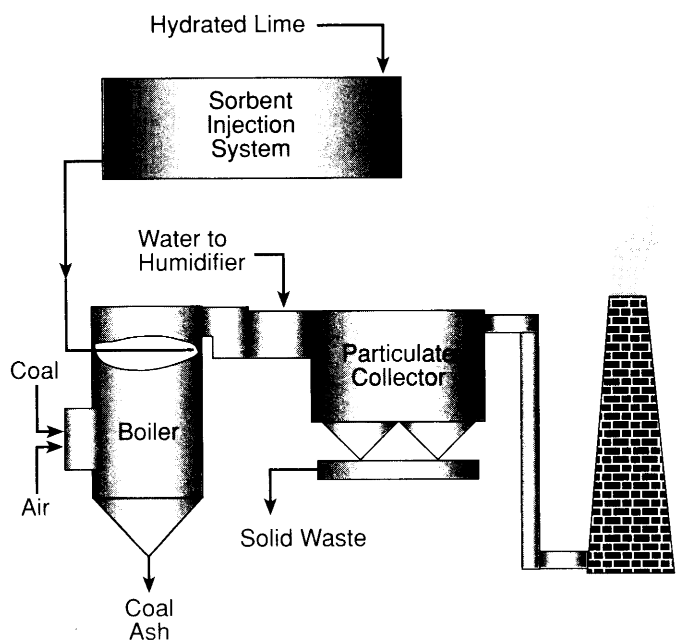


Figure 5. LIMB technology for SO_2 control.

Based on these two demonstrations, LIMB technology appears to be cost-effective for lower SO_2 control requirements compared to conventional wet FGD with decreasing coal sulfur, boiler size, and plant life expectancy. Figures 6 and 7 show the capital and annualized costs of a 300 MWe LIMB retrofit system firing 1.7 percent sulfur coal contrasted with the cost of some competing technologies.[10]

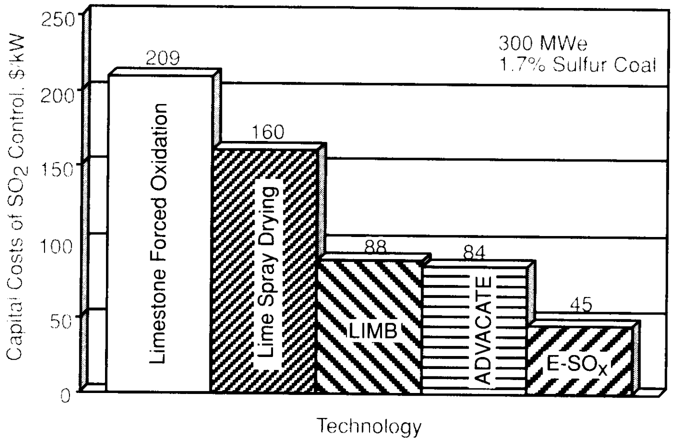


Figure 6. Capital cost of SO_2 control.

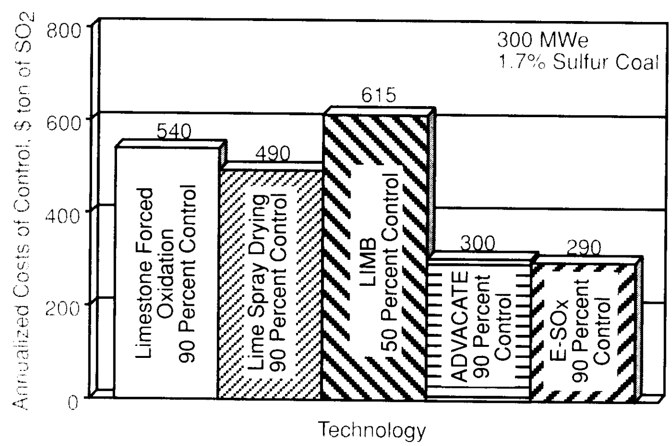


Figure 7. Annualized costs of SO_2 control technology.

ADVACATE

The ADVACATE technology (Figure 8) is perhaps the most competitive with conventional technology, offering comparable (90+ percent) SO_2 control at lower capital and annualized costs, also shown in Figures 6 and 7. To date, ADVACATE has been evaluated on a 10 MWe prototype, and demonstrations on a commercial scale are planned in the U.S. and overseas. The ADVACATE process was co-developed by APPCD with the University of Texas and is currently licensed for worldwide use.[11,12]

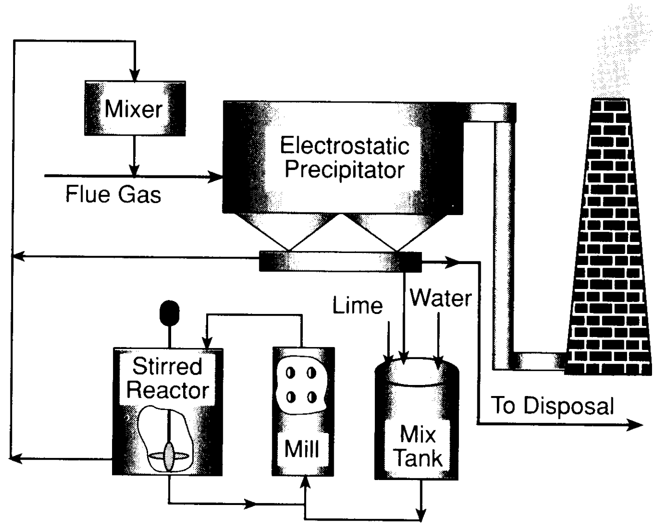


Figure 8. ADVACATE process for SO_2 control.

E-SO_x

The E-SO_x technology (Figure 9) combines improved electrostatic precipitation technology with conventional spray drying FGD techniques to provide SO_2 and dust capture in one unit. E-SO_x has been field evaluated on a

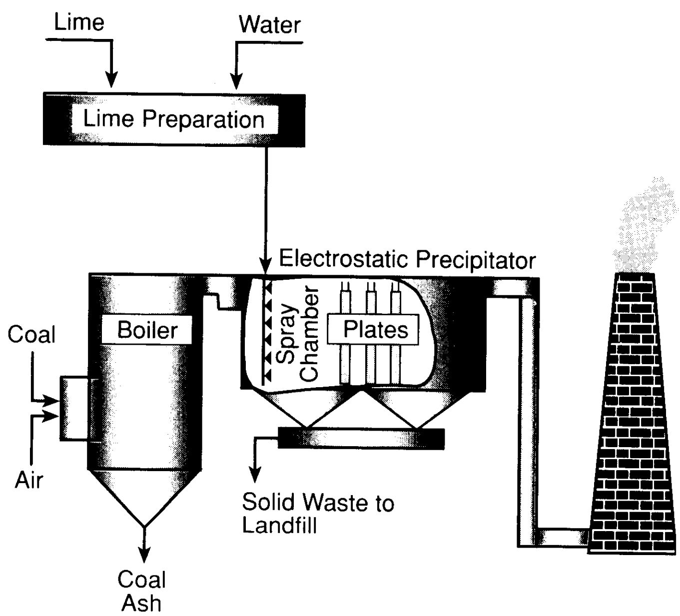


Figure 9. E-SO_x technology for SO_2 control.

5 MWe basis and is currently scheduled for installation on two commercial-scale power plants in Russia in 1994-97.[13] Figures 6 and 7 illustrate the low capital and annualized costs of E-SO_x. While capable of 50-60 percent SO_2 control on U.S. precipitators, the larger space available in eastern European electrostatic precipitators affords the chance for 70 percent and greater SO_2 removal using E-SO_x.

FUTURE PLANS

With the decreased emphasis of SO_2 control and more emphasis on control of toxic pollutants, acid gases, and nitrogen oxides, APPCD is focusing the experience, facilities, and resources acquired through two decades of SO_2 control research toward multipollutant control technologies. As a cooperative effort, the Gas Cleaning Technology and Combustion Research Branches of APPCD are jointly pursuing a number of interrelated control technology research activities including:

- Polychlorinated dibenzo-dioxin and -furan (PCDD/PCDF) control by sorbent injection.
- Mercury control by sorbent injection.
- NO_x absorption mechanisms.
- Metals control in combustion and post-combustion flue gases.
- Hybrid SO_x/NO_x control system development.
- Fine particle control.

These activities are being pursued through a combination of Federal, State, and private funding with the goal of reducing the overall cost of emission control for major combustion sources by customizing sorbent materials used for gas absorption and optimizing the absorption process such that the majority of pollutant gases, vapors, and particles are removed in integrated processes.

Several demonstrations of low cost retrofit SO_2 control concepts are still to be performed in the 1990s--most notably E-SO_x and ADVACATE in Third World countries--through the sponsorship of agencies such as The World Bank and U.S. Agency for International Development and new EPA programs such as the Environmental Technology Initiative.

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METRIC EQUIVALENTS

For the reader's convenience, two nonmetric units are used in this document, short tons and pounds, per million British thermal units.

To convert to the metric system, readers more familiar with that system should use:

lb/mm Btu x 0.43 = kg/GJ, and
short ton x 0.907 = metric ton.