Electron beam processing of combustion flue gases

A report on the use of radiation to protect the environment

by Vitomir Markovic

Increasing use of coal in electric power plants and industry generates severe environmental problems due to the release of toxic gases, sulphur dioxide (SO_2) and nitrogen oxide (NO_x), into the atmosphere. The immediate and long-term impact in the form of "acid rain" creates an environmental problem on a wide geographical scale, resulting in international problems and disputes.

National standards and regulations for emission limits are becoming increasingly stringent because of greater concern for environmental protection and international pressure to reduce and eliminate the devastating effect of acid rain. Massive investments are being made in some countries in technologies which reduce air pollution by flue gases.

One new technology — electron beam (EB) processing — has proved its potential for:

- Improving air quality and eliminating acid rain problems by reducing emission of SO_2/NO_x in a single-stage process
- Converting toxic components in flue gases into a byproduct with commercial value as agricultural fertilizer or soil conditioner.

The radiation processing technology is reliable and simple to install, use, and control, and it is safe for operating personnel and the environment. *No radioactivity* is produced during operation and, when switched off, *no residual radiation* exists.

Conventional removal of SO_2 and NO_x

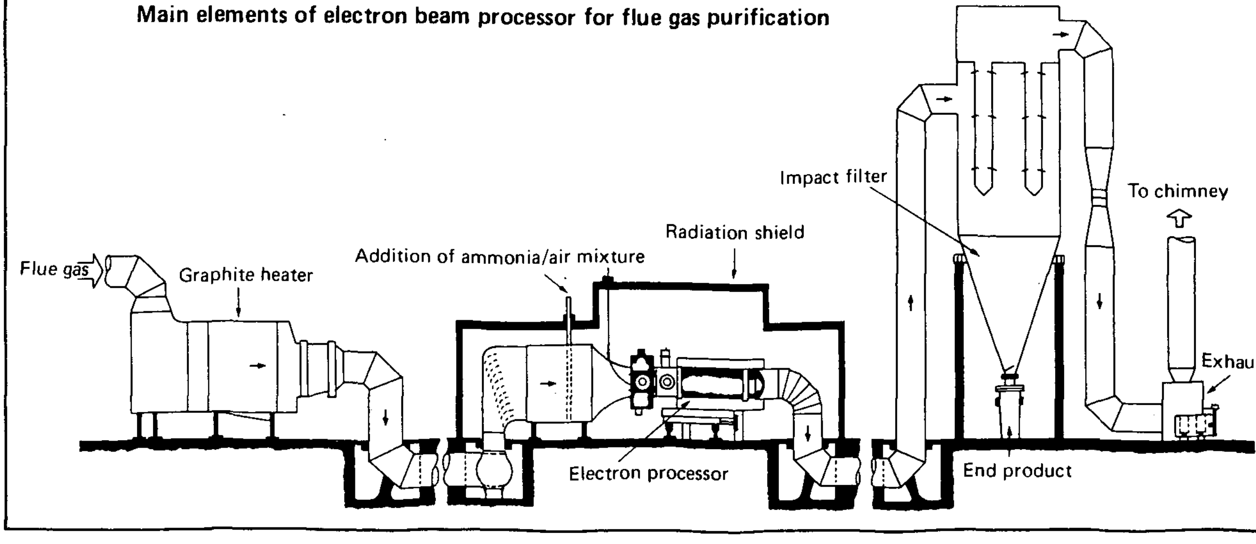
The conventional technique using equipment known as scrubbers efficiently removes SO_2 from flue gases. Yet SO_2 removal processes that are dry, semi-dry, or use lime produce byproducts of no commercial value that pose additional problems of waste disposal. The wet limestone process, with forced oxidation, produces gypsum as a byproduct. This does have a market value, although some uncertainty exists as to the potential market's size.

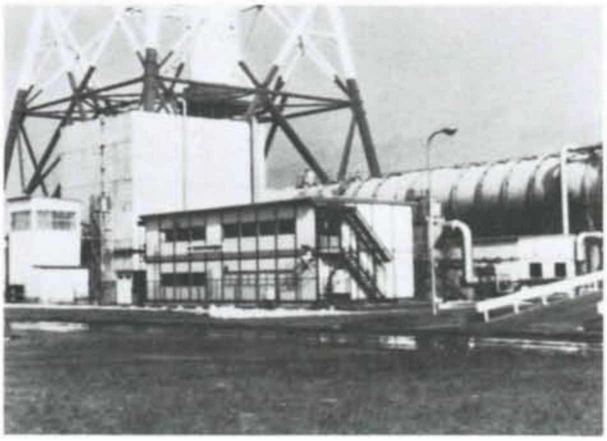
The removal of NO_x gases is performed by a separate process, selective catalytic reduction (SCR), which uses ammonia reagent to convert nitrogen oxides to atmospheric nitrogen.

No reliable chemical methods have yet been developed for simultaneous removal of both SO_2 and NO_x gases in one single-stage process.

Mr Markovic is a staff member in IAEA's Section on Industrial Applications and Chemistry, Division of Physical and Chemical Sciences. His review is largely based on information provided at the IAEA consultants' meeting, "Electron Beam Processing of Flue Gases", held in Karlsruhe, Federal Republic of Germany, 27-29 October 1986.

Main elements of electron beam processor for flue gas purification





This pilot-scale plant in Japan uses radiation to treat exhaust gas from a steel sintering furnace plant of the Research Association for Abatement and Removal of NO_x in the Steel Industry.

Radiation processing of flue gases

High-energy radiation ionizes and excites molecules and atoms leading to the formation of very reactive free radicals, ions, and molecules in excited states. These can react either between themselves, with oxygen and water present in the system, or with some chemical component added to the system intentionally, giving products that can be precipitated and collected by convenient means. These processes have been used as the basis for the electron beam gas scrubber first developed by the Ebara Manufacturing Corporation in Japan. The process was tested on a laboratory scale from 1970-74 and on a pilot scale during 1977-78, first in a batch mode and later in a continuous reactor. The pilot plant (with a capacity of 10 000 cubic metres of nitrogen per hour) was constructed and tested at the Nippon Steel Works in co-operation with Ebara and the Japan Atomic Energy Research Institute (JAERI), Takasaki Radiation Chemistry Research Establishment. *(See accompanying photo.)*

With the support of the US Department of Energy, Ebara has further developed an electron beam process for scrubbing flue gases. This so-called "Ebara process" is based on irradiation of flue gases from coal or hydrocarbon fuel boilers in the presence of ammonia. As a result, SO_2 and NO_x are simultaneously removed with high and easily controlled efficiency, which can reach 100% for SO_2 and 85-90% for NO_x. In addition, a byproduct (90% ammonium sulfate and nitrate) has a commercial value and can be used as fertilizer or as a general soil conditioner.

This process is being tested at a large-scale pilot demonstration unit (PDU) installed at the Indianapolis Power and Light Company in Indianapolis, Indiana, USA. The operation of the PDU started in 1985. Its primary purpose is to demonstrate the feasibility of the process and to analyse the byproduct from the viewpoint of its utilization as an agricultural fertilizer.

Another demonstration unit is currently being tested by Badenwerk AG, Karlsruhe, Federal Republic of Germany. The unit started operating in December 1985. *(See accompanying photo.)*

The most important findings from these demonstration units are:

- Proof that the EB process is suitable for purification of flue gases
- Proof that the process can remove over 90% of SO_2 and up to 90% of NO_x from flue gases generated from burning of low to high sulfur coals
- Proof that commercial EB equipment can be used safely and with high reliability in a power plant environment.

The present demonstration units have been tested at flue gas flow rates equivalent to 3-5 MW of electric power. There is a general feeling that upscaling of the process by a factor of 10-20 is technically and economically feasible.

The advantages of the EB process, compared with chemical processes, can be summarized as follows:

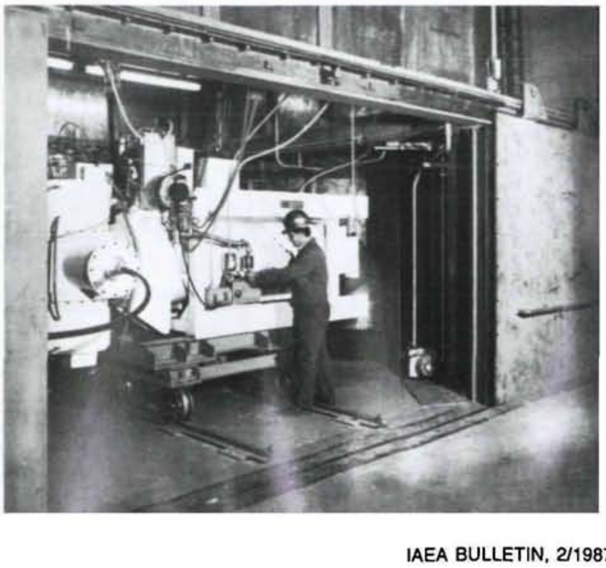
- It simultaneously removes SO_2 and NO_x in one stage, with one piece of equipment, and with one reagent
- It can meet the most stringent requirements for efficiency of removal
- It produces no waste that requires disposal
- It is a dry process (low maintenance cost)
- It requires no reheating of flue gas
- It is simple and safe to operate and maintain.

The most important disadvantages are:

- High cost of ammonia added in the process, which may be prohibitive for some countries (especially if it has to be imported)
- Limited possibility for the use of the byproduct as a fertilizer, especially in areas with mainly acidic soil.

EB accelerators in the energy range 300-800 kilovolt (kV) are used as radiation sources for processing of flue gases. Higher energy levels are not likely to be required for this application since penetration of electrons in

This demonstration electron accelerator is at Badenwerk AG in Karlsruhe, Federal Republic of Germany. Shown is the shielded cabin. (Credit: Badenwerk AG)



gases is sufficiently high at energies below 1000 kV. Also, experience has shown that dose distribution and inhomogeneity do not present a serious problem. The main problems to be solved, as far as EB accelerators are concerned, are reliability, efficiency of energy conversion, and availability of higher power units. The present status of EB accelerator manufacturing technology is matching industrial requirements for efficiency and reliability of operation. The energy and power levels of currently available accelerators are in the range of 300 kV/300-500 kilowatts (kW), and 600-800kV/120-240kW. These are suitable in multi-modular configurations for low- to medium-power boilers (up to about 100 MWe). Further upscaling would require large numbers of accelerators or development of very high-power units (1000 kW or more).

Cost effectiveness of the EB process

An exhaustive study performed in the USA in 1983 concluded that the EB process is marginally competitive with conventional scrubbers for desulfurization of flue gases. The critical factors are the cost of ammonia and the market value of the byproduct. Both can significantly vary from country to country. However, if removal of both SO_2 and NO_x is required, then, such was the conclusion, the EB process is highly competitive with a combination of conventional chemical processes.

Demonstration units in the USA and the Federal Republic of Germany have confirmed the economic viability of the process and have generated a sufficient amount of data for its evaluation from the viewpoint of economics.

Air pollution from combustion flue gases — "Acid rain"

The emission of SO_2 and NO_x into the atmosphere from coal- and oil-fired boilers in power plants and industrial installations has long been recognized as one of the main sources of environmental pollution. The damaging effect can be immediate within a limited area, resulting in chronic respiratory diseases, heart-lung problems, and deterioration of the environment. (It has been estimated that in the USA air pollution would result in about 10 000 deaths per year and in about 25 million respiratory disease cases per year).

The long-term effect, on a large geographical scale, is the consequence of photochemical conversion of toxic gases in the atmosphere into sulfuric and nitric acid that come down in the form of "acid rain". The ecological impact of acid rain is evident in the devastation of forests, earth flora, and acidification of lakes. Severe forest damage has been reported in the USA and Europe (typical examples can be found in the Federal Republic of Germany, where large forest areas have been destroyed in the regions of North-Rhine/Westphalia, and Baden Württemberg, for example). The problem is not limited to the industrialized world. It is also recognized in developing countries relying heavily on the use of coal for power generation. Acid rain is frequently reported, for example, in the southwestern part and on the east cost of China. In India, many large cities and land areas are heavily affected by air pollution.

The magnitude of the problem, which knows no boundary limitations, is best illustrated by figures of gas emissions. A single power plant with a capacity of 500 MW may consume about 250-300 tons of coal per hour. Depending on the sulfur content (varying from about 0.2% to 2%, and even up to 10%), the emission of SO_2 could be on the order of tens of tons per hour. It has been estimated that up to 1990 in the USA alone more than 50 million tons of SO_2 and NO_x gases will be released into the atmosphere each year by electric utilities and industrial boilers.

Pollution regulations and potential market for flue gas clean-up technologies. Regulations concerning permissible levels of SO_2 and NO_x in stack gases vary widely from country to country. The most stringent regulations are enforced by the Federal Republic of Germany, with many European countries following the lead. German legislation requires retrofitting all boilers larger than 110 MWe with SO_2 control systems (at 85% removal efficiency) by mid-1988. More than 100 units are already in operation or being installed. Another category of boilers in the power range 35-110 MWe will have to comply with regulations by 1993. In the FRG alone, about 370 boilers fall into this category.

Very stringent limits on NO_x were enacted in the country in 1984. As a result, several hundred units will have to be retrofitted with NO_x removal capacity during the period 1988-90.

Significant regulations concerning removal of SO_2 and NO_x have been imposed or proposed in Austria, Switzerland, Italy, Netherlands, Denmark, Finland, Sweden, and the European Economic Community, resulting in continent-wide efforts for abatement of environmental air pollution.

Regulations in the USA for SO_2 are more concerned with new sources than with existing ones, while NO_x limits are set so that it can be controlled in the boiler. India and China have also introduced legislation that will require installation of systems for removal of SO_2 and NO_x.

The present legislations and trends create a huge market for technologies able to control the concentration of toxic components in stack gases.

Growing interest in radiation processing. The use of radiation processing technology to fight environmental pollution from coal- and oil-burning plants is becoming increasingly attractive to IAEA Member States. Several countries have approached the IAEA with requests for information about the status of development and applications of this technology. Consequently, a group of experts was convened to assess the present status of the technology and to receive recommendations for future actions to be taken by the Agency for its promotion and transfer. This consultants' meeting on electron beam processing of combustion flue gases was organized and held in Karlsruhe, Federal Republic of Germany, 27-29 October 1986. It was attended by 55 participants from 13 Member States. The papers presented at the meeting are expected to be published by the Agency. Recommendations to the IAEA that were made at the meeting concerned activities in promoting information dissemination, technology transfer, and support for further work for research and development.