Electron beam processing of flue gases: Clearing the air

Stricter environmental standards are demanding a system that simultaneously removes SO_2 and NO_x from the burning of fuels

by Norman W Frank and Vitomir Markovic

Much has happened over the past 5 years to establish the economic and environmental credentials of what could be a timely radiation technology — electron beam processing for the removal of pollutants from combustion flue gases.

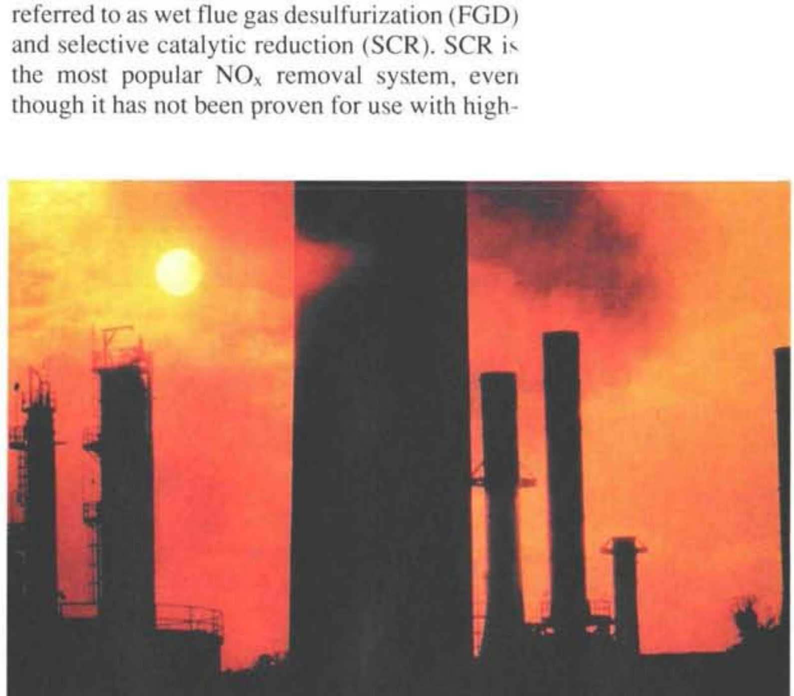
- Studies have indicated that the airborne transport of pollutants such as sulfur dioxide (SO_2) and nitrogen oxide (NO_x) are more widespread than previously thought.
- NO_x emissions are considered to be an equal cause of acid rain when compared to SO_2, a fact which is leading to the development of systems that simultaneously remove both gases.
- Many countries have passed more stringent air quality regulations which will require higher removal efficiencies.
- The use of byproducts from removal systems will be more important in the future to eliminate another waste problem which occurs from the sludges produced in many systems.
- The electron beam process has had extensive testing over the past 3 years, and many improvements have been made in its reliability and energy requirements.

It is easy to see why many countries are beginning to consider more stringent regulations to remove SO_2 and NO_x at the source of emissions — they recognize the transport and conversion that can take place in the atmosphere. *(See figure, next page.)* Emissions from combustion gases from a boiler can be carried many kilometers. Along the way, they undergo numerous conversions, as the SO_2 aerosols change into sulfuric acid and the NO_x aerosol into nitric acid. This then creates a wet disposal of sulfuric and nitric acids in rain, sleet, and snow. Currently, dry depositions of the original pollutants travel great distances from the source.

More stringent environmental regulations have been put into effect throughout Europe, Japan, the United States, Asia, and several Latin American countries. It is anticipated that increasingly stricter regulations will appear in the future, in light of continuing concerns over both sulfur and nitrogen pollutants.

It is further anticipated that meeting requirements for "ozone non-attainment" will require more stringent NO_x standards. This is already being seen in some of the coming regulations. It is foreseen that extremely efficient simultaneous SO_2 and NOx removal systems will be needed.

At the present time, the conventional technologies to reduce SO_2 and NO_x emissions are basically used for low-sulfur coals that are burned in Japan and Europe. These systems are referred to as wet flue gas desulfurization (FGD) and selective catalytic reduction (SCR). SCR is the most popular NO_x removal system, even though it has not been proven for use with high-



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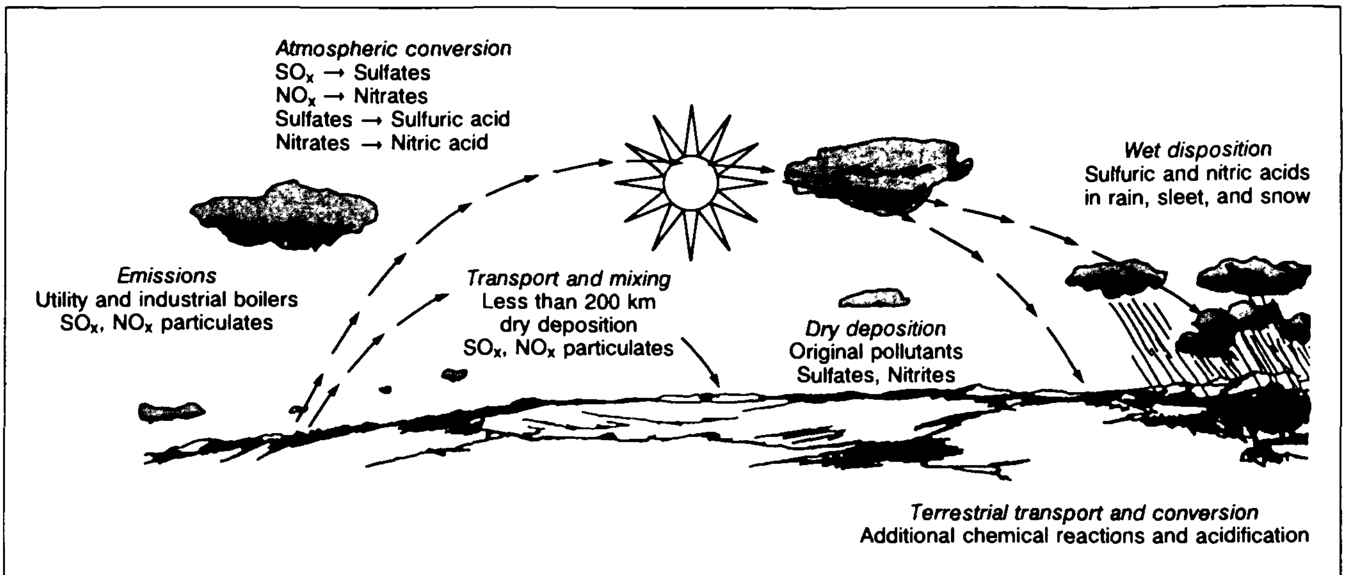


Atmospheric transport processes

sulfur coal. FGD and SCR are systems which require two different technologies integrated into a pollution control process for the boiler.

Therefore, it is important that systems utilizing a singular technology be developed to meet the future requirements for the *simultaneous* removal of both SO_2 and NO_x from both low- and high-sulfur coal and oil.

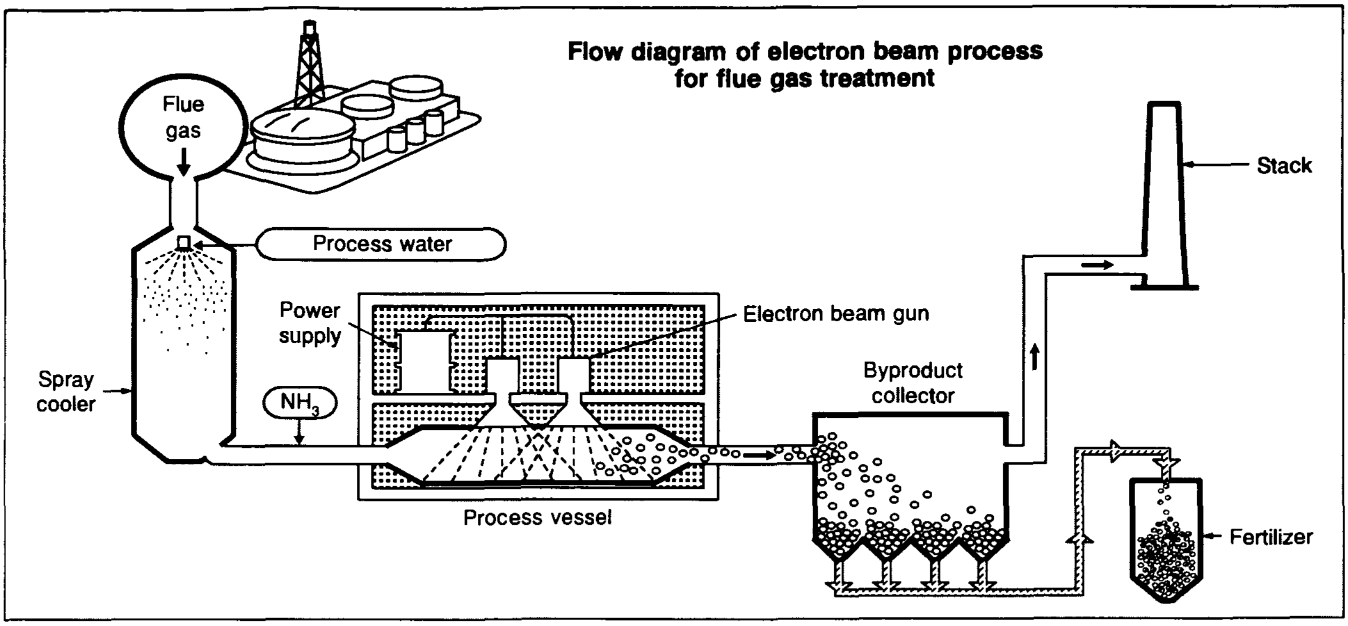
The electron beam process fits very well into this category since it is a system which utilizes the same basic technology to simultaneously remove both pollutants. *(See diagram.)* Japanese, German, United States, and Polish demonstration plants have shown that the system's total efficiency for SO_2 removal normally exceeds 95% and reaches 80% to 85% for NO_x removal. That level of efficiency meets the most stringent regulatory requirements.

NO_x removal requires more energy than SO_2 removal, which is why numerous studies have been done on the technique known as zone irradiation to lower the energy requirements for NO_x removal. Tests have been and are currently being conducted to minimize the energy input for NO_x removal. By utilizing zone irradiation, the results have shown that energy savings of 20% to 30% can be realized, which would bring the system into a very competitive range with other combined technologies. Work will continue on reducing the system's energy requirements.

Existing electron beam test facilities and demonstration plants have been built in a number of countries, and four test facilities remain in operation. They are being operated by the Japanese Atomic Energy Research Institute (JAERI) in Takasaki, Japan; the Institute of Chemistry and Nuclear Technology in Warsaw; KFK in Karlsruhe, Germany; and Ebara in Fujisawa, Japan. These test facilities are conducting programmes to improve the process and reduce energy requirements.

Many noteworthy accomplishments have been made in the past few years at the various research facilities and pilot plants:

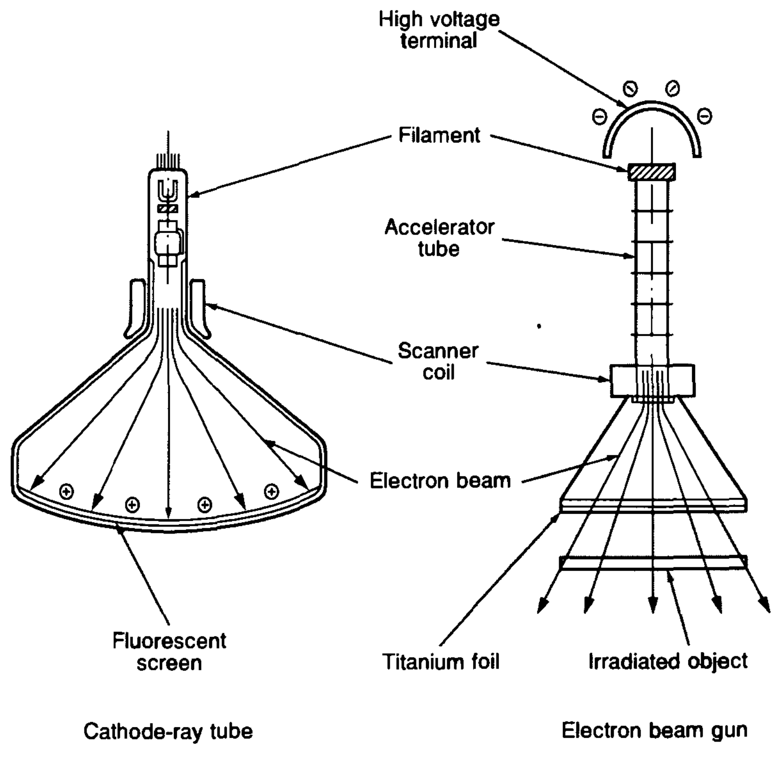
- The mass balances of both nitrogen and sulfur have been confirmed with the finding that about 22% of the nitrogen is released as N_2O.
- Duct configurations have been studied and tested so that different ones are available to suit the conditions.
- Zone irradiation has been tested and confirmed as a significant reducer of energy requirements.
- Different methods for avoiding the buildup of byproducts and duct clogging were analyzed and tested which will allow long-term operation of the process.
- Low NO_x concentrations in gases have been tested with good results.
- Testing is continuing on the removal of volatile organic compounds.
- Testing is continuing on incinerator gases; this is providing valuable information concerning the removal of other pollutants, such as hydrogen chloride (HCL).
- A recent report by the Electric Power Research Institute (EPRI) in the United States has shown that the electron beam process is being considered as one of the future simultaneous removal systems for SO_2 and NO_x.
- Existing electron beam accelerators have progressed to larger sizes (300-400 kilowatts) with good reliability for immediate use.
- The United States Defense Nuclear Agency is developing an accelerator in the size range of



The EB process: No NO_x or SO_2

The electron beam process, which is essentially a dry scrubbing process, removes two pollutants — SO_2 and NO_x — from combustion flue gases at the same time. Before entering the spray cooler, the flue gas is cleaned of fly ash by a standard technique. The gas then passes through the spray cooler where the gas temperature is lowered and the humidity is increased by the process water. The gas then passes through the process vessel where it is irradiated by beams of high-energy electrons in the presence of a near stoichiometric amount of ammonia which has been added to the flue gas prior to the irradiation zone. The SO_2 and NO_x are converted into their respective acids, and these acids are subsequently converted into ammonium sulfate and ammonium sulfate-nitrate. These are then recovered by an electrostatic precipitator. The byproduct is a useful fertilizer and can be used for agricultural purposes. The clean gases are then released to the atmosphere.

At right: The accelerator which creates the electron beam is a very well known piece of equipment to many people. One model of it, for example, is used throughout the world — a television set. An accelerator is only a more powerful cathode ray tube.



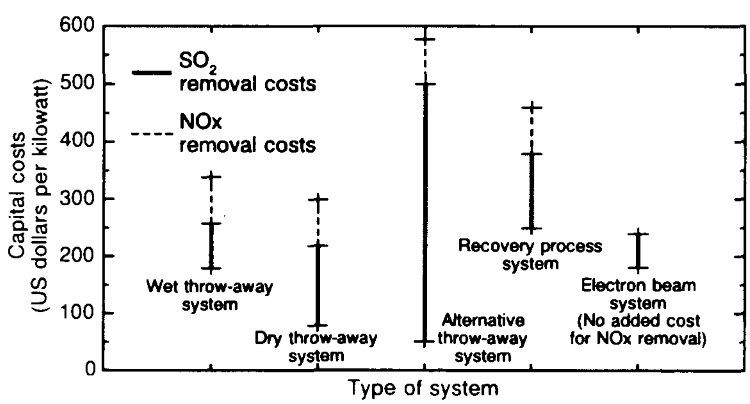
0.8 to 1.8 megawatts for use in air pollution control.

The economics of the process have been studied for various kinds of fuels which have different SO_2 and NO_x concentrations. It looks promising that the system will be available in the range of US $200 per kilowatt for the installed cost. From the tabulation of costs for existing conventional FGD systems, it can be seen that the electron beam process is competitive with all existing SO_2 removal systems. When factoring in the cost of an SCR removal system for NO_x, which is approximately US $80 per kilowatt, it can be seen that the installed costs for the projected electron beam process make it one of the most economical systems to install and operate in a power station. *(See graph, page 10.)*

More importantly, the system has been proven to be very effective with high-sulfur fuels. Countries that have high-sulfur crude oil,

Electron beam pilot and demonstration facilities for flue gas processing

Institution/Year	Volume flow rate	Accelerator	SO_2/NO_x raw gas concentration (ppm)	Temperature (°C)
JAERI 1981	900 l/h	1.5 MeV 20 MA	1000/5000	80-150
Institute of Nuclear Chemistry & Technology, Warsaw 1989	400 m^3/h Oil-fired	775 KeV 5.4 kW	0-1200 0-400	60-150
Karlsruhe Agate II 1989	1000 m^3/h Crude oil	500 keV 50 kW	400-1000 300-1000	60-120
Ebara Fujisawa 1991	1500 m^3/h Oil-fired and incineration gas	500 keV 15 kW	0-1000 0-200	65
INCT/Kaweczyn power plant 1992	20 000 m^3/h Coal-fired	500-700 keV 2-50 kW	200-600 250	60-120
NKK-JAERI Matsudo City 1992	Incineration gas 1000 m^3/h	900 keV 15 kW	SO_2-100 NO_x-100 HCL-1000	150
Ebara-JAERI Chubu 1992	12 000 m^3/h Coal-fired	800 keV 36 kW x 3 heads (= 108 kW)	800-1000 150-300	65
Ebara-Tokyo-EPA 1992	Auto-tunnel exhaust gas 50 000 m^3/h	500 keV 12.5 KW x 2 heads (= 25 kW)	NO_x 0 - 5	Ambient (20)



Note: Based on 300 megawatt system and 2.5% sulfur fuel.

Comparison of capital costs for flue gas processing

coal, or lignite can effectively use this system when generating electricity and still maintain an export market for the higher quality fuels. This could have a significant impact on both the environmental and economic conditions of several countries. It has already been shown that the higher the SO_2 content, the more economical the electron beam process becomes with respect to removing both the SO_2 and NO_x from the gases that will be emitted to the atmosphere.

Electron beam accelerators have progressed in reliability and efficiency throughout the years and many are currently in use in many other radiation processing applications. The power of today's accelerators for applications can go to 400 kilowatts per machine. It is anticipated that a conventional transformer-type accelerator of approximately 800 kilowatts will be available in the future. At the same time, pulse-type accelerators up to approximately 2 megawatts in size are being developed that could be utilized. The potential advantages of this type of accelerator would be its more compact size and its modular design, factors which would reduce the installation costs and shielding.

Using accelerators for radiation processing technologies such as cleaning up flue gases is reliable and simple. The systems are easy to install, use, and control and they are safe for operating personnel and the environment. There is no radioactivity produced during the operation, and when the system is switched off, there is no residual radiation.

With the growing interest in environmental preservation and remediation, the electron beam process for the treatment of combustion flue gases is creating interest worldwide, since it has numerous advantages over conventional systems and is a futuristic process. Moreover, the pollutants are converted into a useful agricultural fertilizer instead of a waste that requires additional disposal.

The process is ready for use now for removing SO_2 and NO_x from combustion flue gases. It is anticipated that its use will become widespread in years ahead. Current research and development programmes are producing many new improvements and innovations, for flue gas treatment as well as for other environmental applications. ❒