

INNOVATIVE TECHNOLOGY FOR THE CONTROL OF AIR POLLUTION AT WASTE-TO-ENERGY PLANTS

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ABSTRACT

Two innovative control technologies for air pollution from the combustion of municipal solid waste (MSW) are discussed. The system concepts of Selective Catalytic Reduction (SCR) and the Electron Beam (E-Beam) process are presented, along with the extent of demonstrated experience. Estimated capital and operating costs are calculated for each system for operation on a 1000 tons/day MSW mass-fired stoker/boiler.

Recent test results are presented for the E-Beam process for NO_x , SO_2 , and CO removal. In addition, an empirical model for NO_x and SO_2 removal by the E-Beam process is applied to flue gas compositions typical from the combustion of MSW.

INTRODUCTION

The recovery of energy from MSW has been practiced in Europe and Japan for several decades and is rapidly gaining favor in the U.S. as a preferred alternative to direct landfill disposal of MSW. At the same time, the growing number of waste-to-energy plants which are under construction or being planned has gained the attention of the local and state air pollution control agencies, especially in California and the northeastern states from New Jersey to Maine.

American waste-to-energy plants with capacities larger than modular systems operating prior to 1986 typically included only electrostatic precipitators (ESP's) for particulate control [1]. Today, a new waste-to-energy plant will be required in many states to install acid gas control, as well as advanced particulate control equipment, and some areas may require control of nitrogen oxides (NO_x) by the use of selective noncatalytic reduction, i.e., Thermal De NO_x .

Proven technologies for air pollution control at waste-to-energy plants include cyclones, ESP's, fabric filters, and lime spray absorbers. Other processes which have been used on a limited or demonstration basis include wet scrubbers, Thermal De NO_x , dry lime injection, electrostatically-assisted fabric filters, and automatic combustion control.

Innovative technologies for air pollution control are continually being developed. The purpose of this paper is not to provide a comprehensive discussion of all new technologies, but rather to discuss two technologies which are sufficiently demonstrated in other applications to yield a high probability of success in the control of air pollutants from the combustion of MSW. These processes are SCR for NO_x removal and the E-Beam process for removal of SO_2 , NO_x , HCl, and particulates. Two additional innovative technologies which are currently being constructed in Europe deserve mention in this paper: wet scrubbers for NO_x removal and

the addition of wet scrubbers, either two-stage or venturi-type, for advanced HCl removal in conjunction with dry scrubbers and ESP's [2].

CONCEPTUAL DESIGN BASIS

The characteristics of flue gas from the combustion of MSW vary depending upon combustor design and operation, and pollutant removal requirements vary depending upon site location and local, state, and federal air pollution control rules and regulations. For this paper, a moving grate type of mass burning system with a waterwall boiler sized to burn 1000 tons/day (37,800 kg/h) of unprocessed MSW is assumed, yielding a typical unabated flue gas composition (i.e., at the boiler convective section or economizer outlet) as summarized in Table 1 [3].

Air pollutant removal requirements are assumed to be 80% for NO_x, 90–95% for SO₂, and 95% or greater for HCl across the air pollution control system.

The basis for cost estimating is summarized as follows:

(a) flue gas flow rate—137,000 SCFM at 60°F (220,200 Nm³/h at 0°C)

(b) flue gas composition—as shown in Table 1

(c) unit cost for anhydrous ammonia—\$200/ton (\$0.22/kg)

All costs are expressed as 1985 dollars and include both direct and indirect costs. All equipment costs were extrapolated from data available from full-scale, or the largest demonstration units, built and operating.

SELECTIVE CATALYTIC REDUCTION

System Concept

A schematic of a typical SCR system is shown in Fig. 1. The majority (95% or more) of NO_x in flue gas from MSW combustion is in the form of NO [4].

The SCR process reacts ammonia (NH₃) with NO and O₂ to produce elemental nitrogen (N₂) and water. This is accomplished by injecting NH₃ into the flue gas and passing the flue gas over a catalyst bed. The catalyst bed is usually a fixed bed consisting of a titanium-based catalyst on an alumina-based substrate. The function of the catalyst is to effectively lower the activation energy of the NO decomposition reaction. This allows the reaction to proceed in a cooler part of the flue gas stream rather than in the furnace at the approximate range of 1500–1700°F (815–925°C) as required with Thermal DeNO_x. Two typical SCR reactor configurations are shown in Fig. 2 [5].

TABLE 1 UNABATED FLUE GAS COMPOSITION

CO ₂	9.2% dry volume
O ₂	10.2% dry volume
N ₂	80.6% dry volume
H ₂ O	16.0%
SO ₂	150 ppm, wet volume
HCl	700 ppm, wet volume
NO _x	250 ppm, wet volume
CO	100 ppm, wet volume
Particulate	1.5 (0.16) gr/SDCF (g/Nm ³)
Flue Gas Flow	137,000 (220,200) SCFM at 60°F (Nm ³ /h at 0°C)

The success of SCR in treating flue gas from MSW combustion will depend upon the effect of HCl on the catalyst, and the ability to maintain acceptable flue gas temperatures through the reactor. Some catalyst metals have been shown to be subject to rapid degradation and failure in the presence of HCl. While the severity of HCl attack would depend upon the HCl concentration, short-term tests have shown that exposure of certain proprietary SCR catalysts to 1000 parts per million (ppm) or more of HCl had no apparent effect on catalyst activity [6]. However, HCl concentrations can exceed levels of over 1100 ppm for over 3 hr at the location of the SCR catalyst [7].

Another potential problem results from placing the SCR reactor in a particulate-laden gas stream. The particulate may erode the catalyst and substrate material, and certain constituents in the particulate may poison or blind the catalyst. The use of an open type catalyst bed configuration, special catalyst formulations [8], and soot blowing should mitigate these possible adverse effects.

The optimum flue gas temperature range for SCR is 550–750°F (288–400°C). Lower temperatures yield slow reaction rates and higher temperatures result in shortened catalyst life. Thermal degradation of catalyst becomes significant above 850°F (455°C) and rapid failure will occur above 1100°F (594°C). In coal fired applications, the SCR reactor is typically located upstream of the air preheater and fouling of air preheater surfaces is a concern from the conversion of SO₂ to SO₃ and its reaction with unreacted NH₃. Flue gas temperature profiles in waste-to-energy plants can vary, not only from plant to plant, but also as a function of time in a given plant. In some cases, the SCR reactor may require location upstream of an economizer. This may create problems with access, increase the likelihood of economizer fouling, and make it more difficult to maintain an acceptable flue gas temperature through the SCR reactor. Recent work in Japan on a slip stream to a pilot SCR unit from flue gas exiting a dry

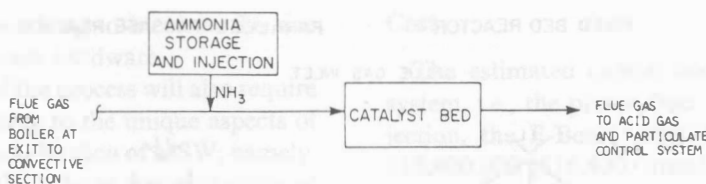


FIG. 1 SELECTIVE CATALYTIC REDUCTION

scrubber/ESP system is attempting to solve the potential adverse effects of HCl and particulate on the SCR catalyst while working in a lower temperature range, i.e., less than 390°F (200°C) [9].

Experience

SCR has been extensively applied to oil, gas, and coal fired boilers in Japan, and has been demonstrated on oil and gas fired boilers in the U.S. [10]. SCR has been applied on coal fired boilers in the U.S. on a limited basis, including pilot test facilities at the Arapaho Station in Denver, Colorado, and the Mitchell Station in Albany, Georgia.

System efficiencies of 90% or more have been achieved when operated within the prescribed temperature window and at stoichiometric ratios near 1.0 [11]. System efficiency has also been shown to be a function of catalyst age [11]. After 10,000 hr at the end of 1985, the catalyst in the pilot plant is still functioning; however, with the lower temperature, the cost of NO_x removal would be high [9].

Cost

The capital and operating costs for the SCR process are based upon an inlet NO_x concentration of 250 ppmwv, a 90% NO_x removal requirement, and a one-to-one mole ratio of NH₃ to inlet NO_x. For catalyst replacement costs, a two-year catalyst life is assumed. All other costs were estimated based on the conceptual design basis described above.

The estimated installed capital cost for the SCR system is \$3,000,000 (\$3,000/installed ton per day) and the estimated total annual operating and maintenance costs are \$1,100,000 (\$3.01/installed ton per year).

ELECTRON BEAM PROCESS

System Concept

The E-Beam process reacts NH₃, or lime, with NO_x and SO₂ in the presence of a high-intensity E-Beam. The E-Beam reactor is a steel vessel with a concrete shell for radiation shielding. Electron guns emit an E-Beam across the flue gas flow and provide the necessary activation energy for the NO_x reaction. Thus, the higher flue gas temperatures, as required for typical SCR and Thermal DeNO_x applications, are not required for this process. For this evaluation, the NH₃ version of the E-Beam process shown in Fig. 3 is assumed, rather than the version using the E-Beam reactor after the fabric filter and requiring an additional NO_x removal reactor, i.e., a wet scrubber and flue gas reheat [12]. The prescrubber is an open spray absorber which provides for humidification of the flue gas and removal of most of the HCl. The ammonium sulfate, chloride, and nitrate by-products which are formed in the prescrubber and E-Beam reactor are removed in a fabric filter and may be sold as fertilizer; however, the salability and price of the by-product is highly variable and site-specific in the U.S. fertilizer market. Another factor, the heavy metals content of the by-product, may also preclude its use as fertilizer.

The lime-based version of the E-Beam process [12] produces a stable residue and may be more suitable for MSW combustion applications, where the possibility of fertilizer sales is questionable and there usually is a reasonably-priced source of lime available.

The possibility of ammonium salts' plume formation is also avoided by using lime and the prescrubber would be designed as a typical dry scrubber for use as a back-up system for acid gas control during times the E-Beam would be off-line.

The largest E-Beam plant operated to-date is roughly one-sixth the size chosen for this evaluation. The critical item in scale-up of this process is the E-Beam equipment. The process suppliers and equipment man-

FIXED BED REACTOR

PARALLEL PASSAGE REACTOR

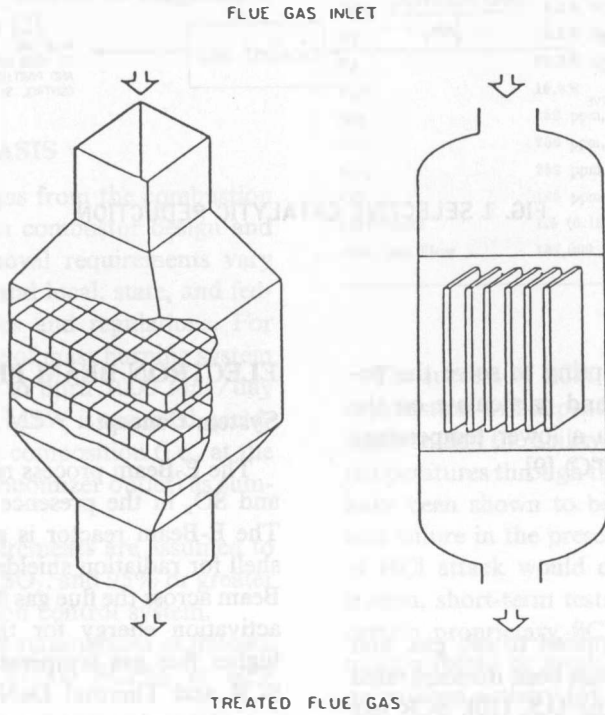


FIG. 2 ALTERNATE SCR REACTOR DESIGNS

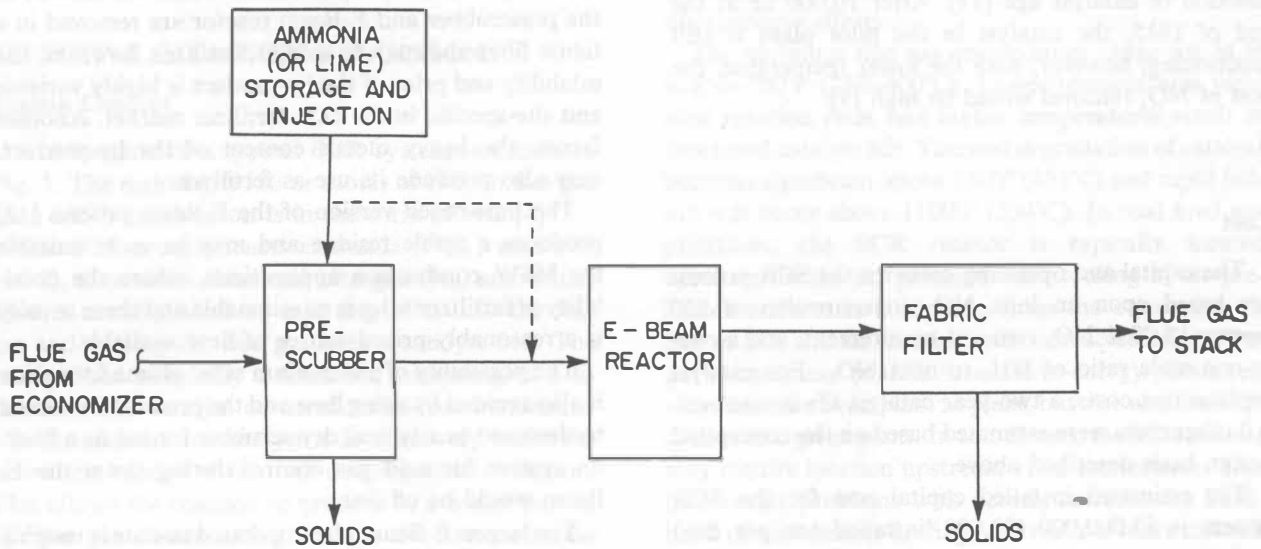


FIG. 3 ELECTRON BEAM PROCESS

ufacturers are currently working to increase the size and reliability of the E-Beam hardware.

Successful application of the process will also require that it be capable of adapting to the unique aspects of treating flue gas from the combustion of MSW; namely, the ability to remove relatively large concentrations of HCl as compared to SO₂, the varying NO_x/SO₂ ratio, and the ability to adapt to wide variations in flue gas temperature and composition. The moisture content of the flue gas is especially important for the E-Beam process.

Experience

The E-Beam process using ammonia has been pilot-tested on a steel plant sintering unit in Japan. The test program spanned a period of one year and was sufficiently successful to encourage further development [13]. A process demonstration unit (PDU) is now being operated under sponsorship from DOE and others [14]. In a one-year long program, the PDU will test the effectiveness of the process on a slip stream of flue gas from a coal fired power plant in Indianapolis, Indiana. The test facility is capable of extracting the slip stream either upstream or downstream of the power plant's ESP, thus enabling testing of the E-Beam process on a particulate-laden flue gas.

The E-Beam process using lime has been pilot tested at the TVA Shawnee Test Facility [15]. The test program was recently completed and demonstrated successful performance in the 80–90% removal range for SO₂ and NO_x on a coal-fired flue gas [12]. Using three inlet SO₂ concentrations from high to low sulfur coal, the data from the pilot plant allowed a model that relates the NO_x and SO₂ removal efficiency of the E-Beam process to the inlet to the E-Beam reactor NO_x and SO₂ concentrations and the absorbed dose to be developed [16]. Tables 2 and 3 have been developed to show estimates of SO₂ and NO_x removal based on flue gas compositions typical of MSW combustion. The dramatic effect of the changing SO₂/NO_x ratio in the flue gas from the combustion of MSW is evident. Also, the effect of HCl removal in the prescrubber must be evaluated for MSW combustion applications. Recent, November 1985, preliminary testing of an MSW-simulated flue gas at the PDU in Indianapolis, Indiana, showed that using NaOH and NH₃ as a substitute for Ca(OH)₂, medium (40–70%) to high (80 to > 90%) levels of both NO_x and SO₂ removal were achieved in the presence of HCl [17]. The flue gas composition tested was generally in the range of 1200 ppm SO₂, 1400 ppm HCl, 300 ppm NO_x, and 7% O₂.

Cost

The estimated capital cost for the entire E-Beam system, i.e., the prescrubber, reagent handling and injection, the E-Beam reactor and the fabric filter, is \$16,400,000 (\$16,400/installed ton per day). The estimated annual operating and maintenance cost is \$1,300,000 (\$3.56/installed ton per year). The O&M cost does not include a cost for by-product disposal or a credit for by-product sales. This cost element varies widely depending upon the application and may significantly affect the economic feasibility of the process. The by-product disposal or sales issue should be studied for each specific application to arrive at an appropriate cost or credit figure. All other costs were estimated based on the conceptual design basis described above.

SUMMARY

Waste-to-energy plants being planned for the Los Angeles area, and other ozone nonattainment areas in California, will be the first projects to consider these innovative technologies for NO_x control. However, from recent contacts with SCR vendors for the Los Angeles City Energy Recovery (LANCER) PROJECT [18], it appears that catalyst life in the flue gas from the combustion of MSW before the air pollution control equipment poses too large a risk for any process guarantees to be given to waste-to-energy plant system vendors. Also, operation at low temperature, i.e., at the fabric filter outlet, is still being demonstrated and could be too expensive, especially with its potential for a NH₄Cl plume opacity problem.

Thus, for the Irwindale (California) Resource Recovery Facility (IRRF), the E-Beam process was proposed as a candidate for Innovative Technology in the Summer of 1985 for the removal of NO_x, SO₂, and HCl. In addition, removal of CO and trace organics was proposed [19]. The use of the E-Beam as innovative technology to reduce emissions would be important for the IRRF, as emission offsets are difficult and expensive to obtain and the project is over 50 MW, i.e., requiring full offsets in the South Coast Air Basin in California. As for trace organics, favorable ionization potentials and recent data on vinyl chloride reduction by the E-Beam [20], point to the effort to determine if the E-Beam can destroy those trace organics emitted from a stoker/boiler fired with MSW. The preliminary testing of the E-Beam reactor at the PDU in Indianapolis, Indiana, showed limited CO removal (20–40%) on simulated flue gases in a short series of separate ex-

TABLE 2

Equation:
$$\frac{SO_2}{SO_{20}} = \exp \left[\frac{-2.5 D}{(1 + 0.0058 SO_{20})} \right]$$

Data:

Dose (Megarad)	Unabated ^a SO ₂ (ppm)	Before E-Beam (After dry Scrubber) ^b SO ₂₀ (ppm)	After Baghouse SO ₂ (ppm)	E-Beam Removal (%)	Overall Removal (%)
1.0	651	456	230	49.6	64.7
1.0	508	356	157	55.8	69.0
1.0	454	318	132	58.5	70.9
1.0	260	182	54	70.4	79.2
1.0	182	127	30	76.3	83.5
2.0	651	456	116	74.6	82.2
2.0	508	356	70	80.4	86.3
2.0	454	318	55	82.8	87.9
2.0	260	182	16	91.2	93.8
2.0	182	127	7	94.4	96.1

NOTES:

- a) Based on Gallatin Data, see Reference 7.
- b) Based on an average of 30% removal from dry scrubber only with SO₂ in MSW flue gas with HCl and lime as reagent from Cooper Engineers, Inc.'s report titled "Air Emissions and Performance Testing of a Dry Scrubber (Quench Reactor), Dry Venturi and Fabric Filter System Operating on Flue Gas From Combustion of Municipal Solid Waste in Japan", Table 6-1, page 105.

TABLE 3

$$\text{Equation: } \frac{\text{NO}_x}{\text{NO}_{x0}} = \exp \left[-0.12 D \frac{(1 + 0.058 \text{ SO}_{20})}{(1 + 0.0058 \text{ SO}_{20})} \right]$$

Data:

Dose (Megarad)	Before E-Beam		After Baghouse	Overall Removal (%)
	SO ₂₀ (ppm)	NO _{x0} ^a (ppm)	NO _x (ppm)	
1.0	456	287	116	59.5
1.0	356	271	116	57.2
1.0	318	266	117	56.0
1.0	182	250	127	50.9
1.0	127	245	137	43.9
2.0	456	287	47	83.6
2.0	356	271	50	81.6
2.0	318	266	52	80.6
2.0	182	250	65	74.8
2.0	127	245	77	68.5

NOTE:

a) Based on NO_x data from Cooper Engineers, Inc., Verification of CO, NO_x, and Non-Methane Hydrocarbon (NMHC) Emissions from a Reciprocating Grate Refuse Combustion Facility: The Chicago Northwest Waste to Energy Facility, September 1983.

periments [17], based on previous theoretical and experimental results [21, 17]. Further testing of the E-Beam process on simulated MSW flue gas will continue in Japan and at the PDU in 1986 [22].

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Key Words: Baghouse; Combustion; Efficiency; Emission; Environment; Equipment; Gases; Performance; Pollution; Scrubber; Technology; Treatment