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Project Summary

Environmental Aspects of Fluidized-Bed Combustion

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This report is a summary of the complete project report entitled "Environmental Aspects of Fluidized-Bed Combustion." The report is organized according to environmental media and specific pollutants of concern. Emissions data and results of biological testing of FBC emission stream samples, where available, are presented and discussed. This report represents work completed or data available through late 1979.

Comprehensive emissions data from FBC processes are limited. Those data which are available have, in general, been obtained through sampling and analysis of effluent and emissions streams from bench-top or other pilot-scale units under controlled operating conditions. Conclusions drawn regarding FBC environmental impacts must be considered preliminary and should be verified in future testing.

Data that are available have indicated that FBC technology is a viable alternative to conventional coal combustion. Adverse impacts on health or the environment appear to be minimal and are, at worst, no different from impacts associated with conventional coal combustion systems. Future testing and emissions analysis are needed to further quantify and assess these impacts.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Multimedia (air, water, and land) environmental impacts of fluidized-bed combustion (FBC) are discussed in this report in the context of available emissions data and current or proposed key research. To demonstrate the potential benefits and possible disadvantages of the two alternative approaches to using FBC technology, the environmental aspects of atmospheric and pressurized FBC systems are discussed concurrently.

Figure 1 is a schematic diagram of an FBC unit that illustrates potential emission/effluent/solid waste sources. The major source of air emissions is the boiler flue gas. Minor fugitive emission sources include material transfer operations and coal and sorbent storage piles. Liquid effluent sources include boiler blowdown, cooling tower blowdown, boiler water treatment wastewater, equipment cleaning waste, and runoff or leachates from materials storage and solid waste disposal areas. The liquid waste sources are not expected to be much different from those associated with conventional power plants or industrial boilers; however, flue gas desulfurization (FGD) liquid waste can be avoided with FBC technology because *in situ* sulfur dioxide (SO_2) reduction is possible. Also, the quantities of leachate and runoff from materials and solid waste storage areas may be greater than those of conventional systems because more sorbent is used in FBC than in FGD. Solid wastes emanate from collection of flue gas particles, which consist mostly of coal ash, but more importantly, from withdrawal of spent bed material, which is

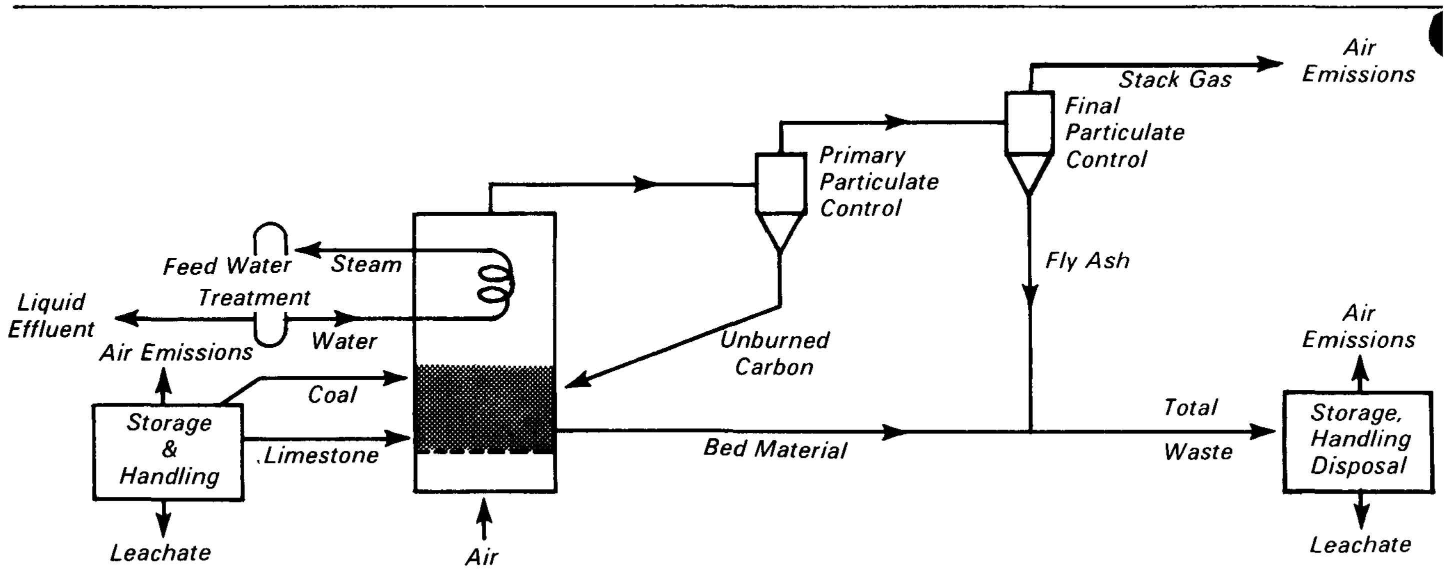

Figure 1. *FBC flow diagram.*

partially sulfated limestone or dolomite. Typically, for a high sulfur coal with a limestone (calcium) to sulfur (Ca/S) ratio of about 4.0, FBC solid wastes are one-third fly ash and two-thirds spent bed material.

Air Emissions

Sulfur dioxide control in FBC is a dual-purpose technology that incorporates gaseous pollutant reduction with combustion for raising steam. The fuel being used is burned in the presence of a sorbent material, usually limestone or dolomite, for *in situ* desulfurization.

An excess of sorbent, beyond that theoretically required for a specific percentage of SO_2 removal, is needed because the dense sulfate layer, which forms first on the outside of the particles, retards the diffusion of SO_2 gas into the interior of the sorbent particles. The keys to low Ca/S requirements are that: the diameter of the particles be small (which requires an appropriately low gas velocity); the pores be large enough to avoid blockage with sulfate near the mouth of the pore; and gas residence time be increased.

Higher gas residence times can be obtained by increasing the bed depth, decreasing the superficial velocity, or both. Increasing the bed depth increases the fan power requirements, whereas decreasing the air velocity decreases the power density, requiring larger bed areas and more complex feed systems. Thus, there is a tradeoff between capital (plant area and feed systems) and operating costs (sorbent use, fan power). The effects of operating conditions on SO_2 removal are summarized in Table 1.

Available experimental data on desulfurization in FBC have been obtained from bench-scale to small industrial-scale units, as well as by thermogravimetric analysis and mathematical projections. In general, experimental results have shown that atmospheric fluidized-bed combustion (AFBC) can achieve 90 percent SO_2 reduction with Ca/S ratios as low as 2.6 using a high reactivity sorbent. Reductions in SO_2 emissions from pressurized fluidized-bed combustion (PFBC) of 90 percent have been observed with a Ca/S ratio of less than 1, although the typical range is between 1 and 2.

Future research in FBC SO_2 control will emphasize the confirmation of SO_2 control capability in large-scale units. In addition, to verify theoretical predictions and provide guidance for future system design, the influence of gas residence time and sorbent particle size in large demonstration units must be documented. Cost/benefit tradeoffs associated with maximizing or minimizing these parameters must also be defined.

Other investigations that are of prime importance are those focusing on the assessment of limestone characteristics and availability as well as sorbent regeneration and alternative sorbents.

Nitrogen Oxide Control in FBC

Nitrogen oxide (NO_x) emissions from fluidized-bed combustion of coal are generally lower than those from conventional systems. Design and operating factors that influence the formation and reduction of NO_x in FBC are listed in Table 2, which indicates the general trend of the effect of FBC operating conditions on NO_x emissions.

The kinetics of NO_x reduction are not well defined to date. The low NO_x emissions from FBC are inherent to the system. A quantitative correlation beyond the trends shown in Table 2, is not predictable at this time.

Research on characterization of the mechanisms of NO_x control in FBC are proceeding. An alternative operating mode that can be used to reduce NO_x emissions even further is two-stage combustion. In conventional systems the application of staged combustion has resulted in 30 to 50 percent NO_x reduction. Further testing is required to

Table 1. *Operating Conditions Affecting SO_2 Removal*

Variable increased	*Effect on SO_2 removal efficiency*
Sorbent reactivity	*increase*
Gas phase residence time	*increase*
Sorbent particle size	*decrease*
Pressure	*increase*

Table 2. Operating Conditions Affecting NO_x Emissions from FBC

Variable increased	*Effect on NO_x emissions*
Temperature	*increase*
Gas phase residence time	*decrease*
Excess air	*increase*
Pressure	*decrease*
Fuel nitrogen content	*increase*
Coal particle size	*decrease*

define the NO_x control potential of two-stage combustion in FBC systems.

Other techniques that could be considered for further NO_x control in FBC include flue gas recirculation and ammonia/urea injection. Further testing is required to determine the incremental NO_x reduction that can be expected under these optional operating conditions.

Particulate Emissions from FBC Systems

Particles emitted from a fluidized-bed boiler are a combination of fly ash from the coal, unburned carbon, and elutriated sorbent. Particulate emissions from a fluidized-bed boiler will be controlled in a manner similar to that of conventional boilers. A primary particulate control device, usually a cyclone, is used to collect larger particles that have the most significant carbon content. This primary cyclone catch is often recirculated to the boiler to attain greater combustion efficiency and improve SO_2 reduction efficiency. An alternative method for increasing carbon use is to feed the collected material to a secondary FBC chamber called a carbon burnup cell (CBC).

The particles that pass through the primary cyclone are collected in a final control device. Final particulate control has not yet been demonstrated on AFBC units; however, conventional particle control devices should be adequate to meet present and planned emission standards. If high levels of control are desired, electrostatic precipitators (ESPs) or fabric filters will most likely be applied. If lower efficiency is acceptable, a multitube cyclone may be sufficient. Pressurized systems may require greater control efficiency because of strict limitations on the amount of particulate matter that can be tolerated in the flue-gas-driven turbine that supplies about 20 percent of the PFBC output. There is some conflict of opinion on allowable levels, and the effect of particulate level on turbine life needs to be further investigated. Research efforts to demonstrate the capability of various final particulate control devices applied to FBC systems are planned as part of ongoing technology demonstration programs.

Trace Element Emissions to Air from FBC

Because fluidized-bed combustion is carried out at temperatures well below those of conventional combustion systems, it is possible that trace element emissions will differ. The presence of sorbent material in the combustion bed adds another factor whose contribution to trace element emissions is unknown.

There are limited trace element emissions data from FBC units. To date, the most comprehensive sampling and analysis of FBC emissions has been the EPA-sponsored Level 1 environmental assessment conducted at the Exxon Mini-plant PFBC. Trace element analysis of particulate material entrained in flue gas was conducted on size-fractionated samples obtained using a Source Assessment Sampling System train. Both spark source mass spectrometry and atomic absorption spectrometry were used for elemental analysis. Similar programs are planned at the B&W-EPRI/Alliance, Ohio, AFBC facility and at the Georgetown University atmospheric fluidized-bed boiler.

Solid Waste Generation from FBC

Solid residue from the fluidized-bed process consists of spent bed material (largely calcined and sulfated sorbent withdrawn from the combustor) and a mixture of fly ash, spent sorbent, and unburned carbon collected in the particulate control device.

The amount of solid waste generated is a function of the fuel and sorbent characteristics and the level of SO_2 control and particulate control. The major variables and their general effect on the amount of residue generated are listed in Table 3.

In most cases, disposal of solid waste from FBC systems is expected to be performed by landfilling the material. The environmental impact of this method of disposal is under investigation. The primary sources of potential environmental degradation are the leachate formed by rainwater runoff and percolation after landfilling, and the heat release from the material upon initial contact with water, because of hydration of the CaO in the waste. Limited data on leachate generation and transport/transformation phenomena are available.

One of the most definitive evaluations of the potential contamination from FBC waste was performed by Westinghouse Research Laboratories. Leachates were generated using distilled, deionized water in laboratory shake tests for a variety of FBC wastes. The resulting leachate concentrations were then compared with drinking water standards (National Interim Primary Drinking Water Regulations, and U.S. Public Health Service's Drinking Water Standards).

Conclusions from this study included:

- No water pollution is expected from the leaching of those trace-metal ions for which drinking water standards exist because the leachate itself meets drinking water standards.
- The total dissolved organics are below detection limits.
- Potential problems with the leachates are the high concentrations of calcium (Ca), sulfate (SO_4), pH, and total dissolved solids (TDS) that are above drinking water standards.
- The addition of 20 wt percent fly ash to the spent sorbent improves leachate quality. Thus, codisposal of spent sorbent and ash can reduce the adverse environmental impact.
- The environmental impact is reduced by room-temperature processing with water to eliminate a potential heat release problem.

These conclusions have been corroborated by results of other studies. In general, data indicate that FBC solid residue will not be a hazardous pollutant.

FBC solid waste could be a useful byproduct. Because of the high amount of unused lime (CaO) in the waste, its uses as a cement supplement, agricultural additive, building material, and road aggregate have all been explored, and results are promising. As larger quantities of waste become available from operation of larger demonstration

Table 3. Operating Conditions Affecting Quantity of Solid Waste Generated

Variable increased	*Effect on quantity of waste*
Ca/S molar feed ratio	*increase*
Sorbent reactivity	*decrease*
Gas phase residence time	*decrease*
Sorbent particle size	*decrease*
Percent SO_2 removal	*increase*
Percent coal sulfur	*increase*
Percent coal ash	*increase*

plants, the resource recovery possibilities can be more thoroughly assessed.

Water Effluents from FBC

Although no supportive data are currently available, water discharges from FBC units are expected to be similar to effluents from conventionally fired boilers. The sources include boiler feedwater treatment wastes, boiler blowdown, cooling tower blowdown, fireside and waterside operational cleaning waste, and drainage from materials storage piles.

The major differences between the two technologies are expected to be runoff or leaching from materials storage and spent solids disposal sites and equipment cleaning wastes. Other streams should be similar because they involve components and operations that are equivalent for the two systems.

Radioactive Pollutants Associated with FBC

Radioactive contaminants, contained in emissions to the atmosphere or in solid waste residues, can be released to the environment from combustion of coal. Under the Clean Air Act Amendments of 1977, the Environmental Protection Agency (EPA) is instructed to review all pertinent data to determine whether emission of radioactive pollutants into ambient air poses a threat to public health. EPA is empowered to establish, implement, and enforce limitations, standards of performance, or other requirements sufficient to mitigate the potential hazards from such emissions. The EPA Office of Radiation Programs (ORP) is conducting this review of all relevant, available information. In support of ORP, samples collected by GCA/Technology Division during environmental assessment programs at the Exxon Miniplant PFBC were analyzed for selected isotopes. The data show higher radioisotope concentrations in the relatively fine particles collected by the final control devices. Cascade impactor measurements show that the particles entering the final control device are 95 percent by mass less than 4 μm and 50 percent less than 2 μm. Secondary cyclone catch typically has a volume median diameter (determined by Coulter Counter) of 17 μm and the third cyclone catch typically has a median diameter of 4-6 μm.

Data illustrating the flow of the isotopes through the system show that most of the radioisotopes are emitted as part of the spent combustion bed solids or in the cyclone catch. Radioisotopes escaping the plant in the flue gases at Exxon (or in a commercial plant) would probably be 1 to 20 percent in the final particulate control device catch. This area requires further investigative effort.

Bioassay Testing of FBC Emissions

Conclusive results from bioassay testing of FBC emission/effluent streams are not yet available because of limited testing, different and in some cases incomparable analysis methods, and continually changing protocols and procedures for performing bioassays. The data that are available generally indicate mutagenic response to airborne particulates and ecological effects test response to coal, spent solids, and collected fly ash material. In general, based on limited comparative results, health and ecological effects from FBC waste streams are not expected to be greater than those resulting from conventional combustion.

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The complete report, entitled "Environmental Aspects of Fluidized-Bed Combustion," (Order No. PB 81-217 630; Cost: $9.50, subject to change) will be available only from:
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