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Project Summary

Experimental Study of High Levels of SO_2 Removal in Atmospheric-Pressure Fluidized-Bed Combustors

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Tests were conducted in an atmospheric-pressure fluidized bed combustor (FBC) having a cross-section of 1 x 1.6 m, for the purpose of demonstrating high levels of SO_2 removal when burning a high-sulfur coal and feeding limestone sorbent for SO_2 removal. The goal was to achieve SO_2 removals of 90-plus % with reasonable sorbent feed rates, through suitable reductions in sorbent particle size (to improve reaction kinetics) and increases in gas residence time (to increase gas/sorbent contact time), in a manner predicted by an existing mathematical model.

At particle sizes averaging from 800 and 1300 µm (mass mean), and with gas residence times of 0.5 to 1.5 sec, the measured SO_2 retention levels ranged from 88 and 98% when sorbent was fed at Ca/S molar ratios between 2 and 3. This result supports model predictions. Reducing sorbent particle size and increasing gas residence time results in modest increases in SO_2 removal over the range of conditions tested here. Increases in flue gas O_2 content also increased removals. Only one of the three sorbents considered for this project had the attrition resistance necessary to permit use in this testing, indicating that some sorbents will not be suitable for use in dense-phase FBCs.

Emissions of NO_x ranged from 130 to 236 ng/J during these tests. Particulate emissions following the cyclone but upstream of the baghouse ranged from 9 to 35 g/m³; after the baghouse, at the stack, the particle loading ranged from 0.4 to 22 ng/J.

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

Introduction

For FBCs to be competitive with conventional coal-fired boilers, the FBCs will have to be able to provide reductions in SO_2 emissions comparable to those possible with conventional boilers using scrubbers. These comparable reductions must be achieved at a competitive cost.

Some New Source Performance Standards (NSPS), which have been considered or promulgated for various coal-fired boilers, have envisioned SO_2 reductions up to 90% with high-sulfur coals. However, early experimental testing of FBCs had generally focussed on the earlier NSPS for large steam generators which had been promulgated in 1971 (520 ng SO_2/J). This earlier standard corresponds to a percentage SO_2 reduction of only about 80 to 85% with a high-sulfur coal. Little experimental work had been conducted with sorbent feed rates necessary to achieve reductions > 90%. Accordingly, there

Table 1. *Text Matrix for Tests 13-28[a] (Effects of Sorbent Particle Size and Gas Residence Time)*

Mass mean sorbent particle size (μm)	*800*			*1300*		
Gas velocity (m/sec)	*0.9*		*1.4*	*1.4*	*1.8*	
Bad depth (m)	*0.9*	*1.4*	*0.9*	*1.4*	*0.9*	*1.4*
Residence time (sec)	*1.0*	*1.5*	*0.7*	*1.0*	*0.5*	*0.75*
Ca/S	*2.0[b], 2.75[b]*	*2.0, 2.75*	*2.0, 2 75*	*2.0, 2.75*	*2.0, 2.75[b]*	*2.0, 2.75[b]*

[a]Conditions for all 16 tests: Illinois No. 6 coal (3.5% sulfur); Greer limestone; bed temperature 844 °C; excess O_2 5% (30% excess air); two coal/sorbent feed ports; and no carryover recycle.
[b]These tests were replicated, to yield a total of 16 tests.

was not a substantive data base in large pilot fluidized beds (FBs) to confirm how a requirement for 90-plus % reduction might impact the design of FBCs, and their capital and operating costs.

Earlier EPA-sponsored research at Westinghouse Research and Development Center had involved the development of a mathematical model predicting SO_2 removal in a FBC, based on sorbent/SO_2 reaction kinetics and on FB design and operating parameters. Using this model, it had been predicted that FBCs should generally be able to achieve high levels of SO_2 removal economically, if sorbent reactivity is sufficiently great (e.g., through decreases in sorbent particle size), and if the gas residence time in the bed (i.e., the gas/solids contact time) is sufficiently great, through a suitably increased bed depth and/or decreased superficial gas velocity. The reduced operating costs resulting from reduced sorbent feed requirements would more than compensate for increased capital costs associated with the larger, deeper combustors that would be needed.

The purpose of the current study is to demonstrate that high levels of SO_2 removal (>90%) can in fact be routinely achieved in FBCs with reasonable sorbent feed rates, if sorbent particle size and gas residence time in the bed are appropriately adjusted. This objective is to be met through a statistically designed test program on a reasonably large experimental FBC which has the flexibility to operate over the range of gas velocities and bed depths needed for this evaluation.

Experimental Equipment

The experimental FBC consists of a carbon steel shell lined with castable refractory to inside dimensions of 1 x 1.6 m. The unit can burn from 55 to 250 kg coal per hr. In-bed temperature is controlled by an air-cooled tube bundle. Crushed coal and sorbent are premixed and fed near the bottom of the bed. Flue gas leaving the combustor first passes through an overbed heat exchanger to reduce temperature, then through a cyclone and a baghouse to remove particulate. The baghouse is a reverse-jet pulse type containing 93 m^2 of Nomex cloth.

Test Program

The test program consisted of two segments. In the first segment (Tests 1 through 12), testing was carried out with one vs. two coal/sorbent feed ports, and with and without carryover recycle. The purpose was to determine how these parameters should be set for the remainder of the testing. The second segment (Tests 13 through 28) was designed to investigate the effects of sorbent particle size and gas residence time (i.e., the relationship of bed depth and gas velocity). The test matrix for this second segment is shown in Table 1, covering: two sorbent particle size distributions (mass means of 800 and 1300 μm); three superficial gas velocities (0.9, 1.4, and 1.8 m/sec); two bed depths (0.9 and 1.4 m); and two sorbent feed rates (Ca/S ratios of 2.0 and 2.75), expected to provide reductions in the vicinity of 90-plus % at these test conditions. The gas velocities/bed depths were selected to give nominal gas residence times in the bed ranging from 0.5 to 1.5 sec.

Usually, 6 hours of steady state operation was maintained for each test condition. During that time, SO_2, O_2, CO_2, and CO were monitored continuously in the flue gas, and grab samples for NO_x were taken. We chemistry of SO_2 and NO_x (EPA Method 6 and 7) was measured once each run t confirm the results from the instrument: A cascade impactor was used t determine the particle size distributio upstream of the baghouse, and EP. Method 5 was used to determine particl mass loading in the duct downstream c the baghouse. Coal, limestone, fly ash and bed material were sampled fc chemical analysis and determination c size distribution, as appropriate.

The tests were all conducted burnin Illinois No. 6 coal (3.5% sulfur) and usin Greer limestone. Of the three sorbent considered for this project, Greer was th only one having sufficient resistance t attrition/elutriation. Bed temperature wa held at 844°C, and excess air wa generally held at 30% (5% exces oxygen), although there were som limited, unavoidable variations. The test in the second segment (Tests 13-28 were conducted with two feed ports an without carryover recycle. The results c Tests 1-12 showed no significant benef either to sulfur retention or to combustio efficiency, of operating with one vs. tw feed ports, or with or without recycle; th selected options gave the best contrc over freeboard temperature.

Results

The SO_2 retentions observed durin the 28 tests ranged from 88 to 98%. A expected, within the range of condition tested here, the highest retention level were generally achieved with the greate: gas residence times (i.e., with deep bed and low gas velocities), the highes sorbent feed rates, the smaller sorber particle size, and the highest levels c excess air. Results of a multiple line regression analysis show that the SO retention increased: by about 2% as gas residence time was increased over the tested range; by about 2% as sorbent particle size was decreased; and by 3% as excess oxygen increased from 5.0 to 6.1% excess. As expected, the sorbent feed rate had the dominant effect (increasing SO_2 retention by 6% as the Ca/S increased from 2 to 3). The addition of fly ash recycle and increasing the number of feed ports from one to two, each resulted in a 2% increase in retention.

The fact that Greer limestone was the only sorbent of three candidates which had sufficient attrition resistance for these tests illustrates that some sorbents will not be suitable for use in dense-phase FBCs.

NO_x emissions during the 28 tests ranged from 200 to 300 ppm, or 130 to 236 ng/J. The highest NO_x levels were measured at the greatest excess air values. NO_x also tended to be higher when the SO_2 concentrations were lowest.

Particulate mass loadings upstream of the baghouse (after the cyclone) ranged from 9 to 35 g/m^3, with 15 to 25% of the particulate smaller than 10 µm. Particulate mass loadings at the stack (downstream of the baghouse) generally ranged from 0.4 to 22 ng/J. Particulate emissions below the NSPS of 13 ng/J were generally achieved for baghouse air-to-cloth ratios less than about 1.2 $m^3/min/m^2$.

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The complete report, entitled "Experimental Study of High Levels of SO_2 Removal in Atmospheric-Pressure Fluidized-Bed Combustors," (Order No. PB 89-194 187/AS; Cost: $21.95, subject to change) will be available only from:
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