United States
Environmental Protection
Agency

Research and Development

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711

EPA/600/S7-89/003 Oct. 1989

EPA

Project Summary

Development of a Vortex Containment Combustor for Coal Combustion Systems

J. F. La Fond, M. P. Heap, W. R. Seeker, and T. J. Tyson

Major problems facing the conversion of oil - and gas-fired boilers to coal are derating, inorganic impurities in coal, and excessive pollutant formation (NO_x and SO_x). To alleviate these problems a combustion system is desired that has a high firing density, separates and retains fly ash, and is adaptable to viable pollution control technologies. The Vortex Containment Combustor (VCC) has been designed and tested with these objectives in mind.

An extensive literature review and the testing of two candidate isothermal systems preceded the design and construction of a bench-scale VCC.

Coal combustion tests were performed on the VCC to evaluate its performance in terms of ash retention efficiency, coal burnout, combustion stability, and slag and ash deposition. Results were very promising for both retention efficiency and combustion stability. Fuel injector modifications improved internal slag deposition conditions while maintaining acceptable carbon burnout levels.

NO_x control by staging and reburning technologies was evaluated in the VCC, along with sorbent injection for the control of SO_2 emissions. Both staging and reburning were shown to be effective techniques for reducing NO_x emissions in the VCC. Improvements in the sorbent injection approach are required to obtain an acceptable degree of SO_2 reduction.

Based on particle force balance expressions, scaling criteria have been established for the VCC. Also, the effect of scaling on system pressure drop and heat release on retention efficiency has been evaluated.

The VCC has performed successfully at bench-scale. Evaluation at a larger scale would be the next step toward bringing the VCC concept to fruition.

This Project Summary was developed by EPA's Air and Energy Engineering 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

The reduction of U.S dependence on foreign petroleum products can be accomplished in the near future only by increasing the use of coal in existing and new boilers and furnaces. Major problems facing the conversion of oil - and gas-fired boilers to coal are coal storage, boiler derating, inorganic impurities in the coal, and excessive atmospheric pollutant formation (NO_x and SO_x). Derating represents a particularly imposing obstacle to retrofitting with coal. To avoid derating a converted boiler or furnace, a combustion system is needed which will burn coal in such a manner that only hot clean gas will be introduced into the furnace volume. Such a system will also reduce the frequency of convective pass soot blowing and gas house cleaning. To meet the needs of such a coal combustion system, the following characteristics are desired: high firing density, the ability to separate and retain fly ash, and an adaptability to viable pollution control technologies. The Vortex Containment Combustor (VCC) has been developed with the objective of providing a system which possesses these characteristics.

Research Approach

The research approach to the development of advanced chambers for coal combustion has been carried out in three phases: (1) a literature review to determine the status of conventional cyclone combustion and advanced vortex systems not yet applied to combustion; (2) isothermal testing of combustor concepts to determine potential candidate systems and to investigate critical design parameters; and (3) bench-scale combustion and pollution control testing to determine the feasibility of an advanced vortex coal combustor. In addition to these three major areas of effort, scaling criteria have been developed in terms of ash retention efficiency performance, allowable pressure drop, and effect of heat release in preparation for scale-up to a larger system.

Concept Screening

The literature review revealed that relatively little fundamental research has been reported on the development of cyclone combustors. Based on available literature, a classification scheme has been proposed based on chamber geometry, aerodynamic flow pattern, and the dominant mode of burning. There are four generic classes of cyclone combustors: conventional, reversed-flow, symmetric double vortex, and free-burning. Over a decade of research has been carried out on advanced vortex devices by the Department of Defense at Wright-Patterson Air Force Base. The application of the Air Force work was on low-pressure particle separators for use on turbine-powered vehicles, high pressure systems for colloidal core nuclear reactors, and vortex mixing for thrust augmentation. Performance criteria for these vortex systems were similar to those of a Vortex Containment Combustor; i.e., separate and retain fine particulate matter; avoid wall deposition; obtain high vortex efficiencies with minimal input kinetic energy; and maintain a uniform cloud of particles within a volume. Guided by the work done at Wright-Patterson, two candidate systems were conceived and proposed as potentially successful coal combustors: a double-exhaust symmetric device, and a reversed-flow chamber.

Isothermal testing of the two candidate systems in plexiglas prototypes led to the adoption of the reversed-flow vortex chamber for further investigation. Particulate retention efficiency was extremely high (96-97% for coal smaller than 30 μm), and particle residence times appeared to be sufficient to support free-flight coal combustion. A parametric study revealed that the distribution of inlet air, exhaust extension into the chamber, and the location and method of coal injection are crucial to obtaining high retention efficiencies.

Bench-Scale VCC Design

The development of the reversed-flow vortex chamber into a Vortex Containment Combustor next involved the design and construction of a bench-scale coal combustor. Coal is injected into an "active zone" within the combustor and is held there by centrifugal forces until the coal particles devolatilize and burn. The resulting fly ash particles are selectively removed aerodynamically and deposited in a slag cone. The centrifugal force field holds the large coal particles in the combustion zone until combustion is complete.

The VCC was designed as a low-heat-loss system at firing densities comparable to conventional cyclone combustors. Multiple layers of refractory were used to maximize inner wall temperatures for slag removal. The design is modular to facilitate internal inspection and system repairs or design modifications.

Test Results

To establish the performance of the VCC, the following were measured: ash retention efficiency based on the amount of escaping ash; system pressure drop; exhaust CO concentration; carbon content of the slag and exhaust particulate matter; exhaust gas and refractory temperature; and ash/slag deposition on the refractory walls within the combustor. The retention efficiency results for a variety of coal types, sizes, and coal-to-natural-gas firing ratios were determined. For all cases when the total firing load exceeded 150,000 Btu/hr, the ash retention efficiency was over 94%. The system pressure drop was held under 3 in. H_2O. The carbon burnout was very high, with zero carbon content in the slag and typically less than 3% carbon in the fly ash (>99.9% combustion efficiency). Some undesirable wall deposition was observed initially, but was substantially reduced by a few simple injector modifications.

The VCC was also tested for its adaptability to conventional pollution control methods. Both staging an reburning combustion techniques wei tested and shown to be effective mear of reducing NO_x emissions from the VC(At a stoichiometric ration of 0.8, tł reduction of NO_x was 30 and 40% respectively, for staged and reburnir conditions. Attempts to reduce SO_2 wei also undertaken by injecting sorbei materials into both the exhaust streai and the combustion region. The result however, were not as successful as tł NO_x reduction techniques, with typic reduction of only 10% SO_2 whe injecting at a Ca/S of 2. It is felt that, wi conscientious design of the VCC exhau: successful sorbent injection can t achieved to reach acceptable SO_2 redu tion levels.

System Scaling

Scaling criteria have been establishe for the VCC based on desired partic retention efficiency and acceptab system pressure drop. When scaling up system by a volumetric factor, S, partic force balances reveal that the volumetı *firing rate must be held in proportion* the volumetric scale factor. In Stok regime, the critical particle cutoff defined by:

$$r_p = \frac{9}{2}\left(\frac{\mu r V_r}{\rho_p V_o^2}\right)^{1/2}$$

where:

r_p = particle radius,
μ = viscosity,
r = radial position of particle,
V_r = radial velocity of air flow,
ρ_p = particle density, and
V_o = tangential velocity of particle.

When all linear dimensions a increased by a factor of $S^{1/3}$:

$$r_{p,s} \propto r_p\left(\frac{S}{Q_i}\right)^{1/2}$$

where:

$r_{p,s}$ = critical particle padius of scal up system,
S = volumetric scaling factor, and
Q_i = inlet volumetric rate.

When scaling up in this fashic however, the system pressure drop expected to rise by a factor of $S^{2/3}$. Thı available static pressure will be t limiting factor to system scale-up. T effect of heat release on the VCC wh considering these same particle force balances is to lower the particle retention efficiency. Typically, the critical particle size cutoff will increase by a factor of approximately 8 compared to an isothermal system.

Summary

Test results of the VCC at the bench-scale are encouraging. Future work on the VCC concept could include more detailed isothermal testing to determine the accuracy of the proposed scaling criteria. Also, more extensive sorbent injection tests are required to successfully reduce SO_2 emissions from the VCC. Scale-up of the VCC to a larger system and engineering/economic analysis could help determine the feasibility of the VCC as an oil- and natural gas-to-coal conversion device.

J. F. La Fond, M. P. Heap, W. R. Seeker, and T. J. Tyson are with Energy and Environmental Research Corp., Irvine, CA 92718-2706.
***W. Steven Lanier** is the EPA Project Officer (see below).*
The complete report, entitled "Development of a Vortex Containment Combustor for Coal Combustion Systems," (Order No. PB 89-180 921/AS; Cost: $21.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S7-89/003