INTEGRATED LOW EMISSION CLEANUP SYSTEM FOR DIRECT
COAL-FUELED TURBINES (ELECTROSTATIC AGGLOMERATION)

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1. Objective

The objective of this contract is to investigate the removal of SO_x and particulate matter from direct coal-fired combustion gas streams at high temperature and high pressure conditions. This investigation will be accomplished through a bench-scale testing and evaluation program employing sorbent mixed with a coal-water slurry for SO_x removal, and an innovative particulate control concept. The particulate control device utilizes electrostatic agglomeration followed by a high efficiency mechanical collector (cyclone.)

The process goal is to achieve particulate collection efficiency better than that required by the 1979 new source performance standards. An additional goal is to demonstrate 70% SO_x removal efficiency.

2. Technical Approach

This research project is now in the second of a 3 phase (phase II) project. Phase II is to fabricate the combustor and particulate control devices and install the system at a test facility located at Research-Cottrell's, KVB Western Laboratory, Santa Ana, CA. There are three functional categories, or tasks which are to be completed in sequence. These tasks are itemized as follows:

1. Design, procurement, and installation.
2. Shakedown and startup.
3. Reporting.

CES (R-C, EST) is the Project Manager of the team effort by CES and KVB. KVB (R-C, EST - Western Laboratory) is the sub-contractor to CES for the design and construction of the combustor test facility. KVB will also operate the combustor and gas clean up system to be located at the Santa Ana laboratory. CES (R-C, EST) is responsible for the overall testing and evaluation effort including the design and construction of the electrostatic agglomerator and high efficiency cyclone.

3. Results/Accomplishments

Phase I of this contract has been completed. A topical report covering the Phase I effort has been submitted to DOE in March.

PARTICULATE CONTROL CONCEPT

The DCFT gas turbine operates at much higher temperatures than pressurized fluidized bed combustors. At these temperature levels the particulate is likely to contain liquidus species such as sodium sulfate and the potential for stickiness should not be underestimated. In view of this likely tendency, a particle control concept that utilizes a "flow-through" collection concept will offer an advantage that may not be available on barrier filters. Barrier filtration methods may be more prone to plugging at DCFT conditions when compared with flow-through devices such as cyclones.

However, cyclones are known to be deficient in the collection of particulate below 5 microns. Any concept that can help the growth of fine particulate into sizes larger than 10 microns should be promising.

One of the concerns relating to particulate charging is the effect of thermal ionization. The problem associated with thermal ionization is the potential for excessive current flow caused by the presence of an excessive number of thermally generated ions in the combustion gases. In the extreme case even a small voltage applied to a heavily ionized gas would cause runaway currents. Cooperman's⁽¹⁾ calculations however, indicate that excessive current should not be encountered up to 1500°F. Thus, a process limitation because of thermal ionization is not expected.

To test the process where thermal ionization may represent a significant service of ions the electrostatic agglomerator will be first tested during shakedown and startup using stainless steel components. These stainless steel components will provide information on the characteristics of the Electrostatic Agglomerator concept while avoiding sticky particles and thermally

generated ions. Thus comparison to an electrostatic precipitator, in terms of current voltage characteristics in particle charging can be more readily determined.

Once the metal internals verify that the electrostatic agglomerator concept is valid the temperature of the system can be raised to approximately 2100°F using high-voltage components fabricated of Hastelloy alloy. The stainless steel internals of the agglomerator that serve as guide plates, baffles, and tube sheets for the high-voltage components will be replaced with ceramic duplicate components.

A complete set of high voltage ceramic internals will replace the Hastelloy metal internals for temperatures above approximately 2100°F.

If, however, thermal ionization does occur, there are ways to deal with it depending on the extent of the problem. In the extreme case, where an independent electric field cannot be applied without provoking runaway currents, conditions actually exist which favor self operation of the concept: In the charging section ample thermal ions would be available to charge the particles, and in the agglomerating section, with appropriate electrode spacings, the thermal ion space charge could be adequate to drive the charged particles to the electrodes for contact agglomeration. Thus, even in the extreme case the ESA concept may be valid, although operation would be different from normal.

In the more likely case of little or moderate thermal ionization we have proposed the use of pulse energization to control the current flow. Pulse energization means the application of short-duration fast-rising, high-voltage pulses to a DC base voltage. This provides more degrees of freedom in controlling current production at a given base voltage than in normal DC operation. For example, the DC base voltage can be set below corona starting voltage. Corona starting voltage can be obtained by superimposing a pulsed DC voltage over the base while also controlling parameters of pulse repetition rate, pulse voltage, pulse rise time and duration. Particulate charging and migration,

and the resultant inter particulate contact are enhanced by the longer residence time of particulates in the agglomerator. A high efficiency cyclone follows the electrostatic agglomerator. The collection efficiency of advanced cyclone has to address the requirements of a 20 ppm outlet so that both turbine requirements and New Source Performance Standards could be simultaneously met.

The commercial ESA design for a 200 MW DCFT plant has an interelectrode clearance of 3 inches, and the plate height is 8 feet. A gas velocity of 25 feet per second was chosen in the design of commercial size agglomerator. The fabricability of ceramic internal parts was the main consideration. A vessel diameter of sixteen feet was considered to be the maximum practical size that could be used because of the 8-9 foot limitation on ceramic structural beams. Though presently limited to about 8' due to fabrication considerations, considerations of moment stress that could be tolerated by ceramics limit structural members to this maximum length. Two 9' ceramic members could be telescoped to provide the 16' span and hence the sixteen foot diameter limit on pressure vessels for this application. Once the cross section of ESA is defined, then the length depends on residence time. A length of 30 feet would result in a residence time of 1.2 seconds for a 25 ft/second velocity.

A pulsed energization system using nanosecond risetimes will energize each section. There will be four electrodes serviced by pulsed power for the 1.2 second residence time operation, and only two for operation with 0.6 seconds residence time. Reliable pulsed power supplies are now available in the industry and the design by Ion Physics Corporation will be utilized for these tests.

COMBUSTOR DESIGNS FOR TEST FACILITY

A CWS combustor with a thermal input of 150,000 - 300,000 Btu/hr was initially proposed by AVCO Research Laboratories for simulating gas turbine combustor conditions at the ESA inlet. However, it was later realized that such a small CWS combustor

would be difficult to operate reliably due to the large heat losses and difficulties associated with atomizing CWS at flow rates below 20 lb/hr. Another very important consideration was the heatup time requirements of the ESA. At the low thermal ratings, the time required to bring the ESA up to the operating temperatures was estimated to be more than 10 hours. In order to alleviate these concerns, the combustor rating was increased to 300,000 - 1×10^6 Btu/hr. The AVCO subcontract for combustor fabrication and test facility fabrication was changed over to the R-C, KVB Laboratory facility. A report on the combustor design specifications was issued to DOE under separate cover in July 1990. An overall schematic of the design is attached as Figure 1. The reactor specifications are as follows:

- a) operating temperature range 1600°F - 2500°F
- b) operating pressure: 10-15 atmospheres
- c) mass flow: 0.15 - 0.3 lbs/s (gas)
- d) fuels: CWS or natural gas

A summary of calculated gas temperature data for various loads and excess air levels are shown in Figure 2. The temperatures shown are the gas temperatures at the transition between the 5" and 2" section. These calculations show that the desired range of temperature (2500°F-1600°F) can be achieved by varying load between 100% and 50% and excess air between 5% and 100%.

The reactor is designed to provide a suitable residence time to complete combustion of large slurry droplets. Over the range of temperature operating conditions the residence time ranges between 0.4s and 1.0s. Burnout times for a 200 microns bituminous coal char range from 100 to 200ms at temperatures between 3000°F and 2200°F under 15 atm pressure and an average O₂ concentration of 5%.

The burner design and expected flow pattern is shown in Figure 3. The burner uses swirling flow to stabilize the flame and a curved quarl to delay impingement on the furnace wall. The burner can be fired on natural gas, coal/water slurry or if required, a combination of the two fuels.

Fig. 1. DOE - HTHP Combustor Matl - Carbon Steel

Figure 2. Calculated reactor exit gas temperatures.

A Parker Hannifin air atomizer designed for CWS will be used to atomize slurry (Figure 4). Two designs of the nozzle are being obtained, a conventional design and a reduced air flow design. The reduced air design uses about 25 lb/hr air which corresponds to a air/CWS rate of about 20%.

A list of flow, temperature, pressure and sampling instrumentation which has been installed on the combustor is given below:

- CWS mass flow rate and pressure
- Natural gas flow rate and pressure
- Atomizing air and pressure
- Staging air flow rate and pressure
- Combustor temperatures
- Combustor pressure
- Cooling water flow rate and exit temperature
- Combustor exit gas composition (O_2 , CO_2 , CO , NO_x , SO_2)

The flow rates and pressures will be controlled using a process control and monitoring program.

APPROACH TO HOT GAS CLEANUP EVALUATION

Particulate collection for the test facility consists of an electrostatic agglomerator followed by a Stairmand type high efficiency mechanical collector.

The electrostatic agglomerator is designed to handle flowrates between 30 - 80 acfm at the DCFT conditions of interest. Figure 5 is a schematic of the agglomerator concept. The ESA consists of a charging section and agglomerating section each comprised of 4 grounded electrode tubes. The high voltage sections are located concentrically within these tubes. A pulsed energization system will be used to energize the agglomerator. The agglomerating sections will have smooth hollow tubes as high voltage electrodes for providing uniform fields while the charging sections will have controlled curvature on the discharge electrodes for the provision of corona current. Flow can be controlled through any of the tubes

Figure 4. Parker Hannifin CHS Nozzle.

Figure 5 Schematic of Electrostatic Agglomerator

in each section. Residence time through ESA can thus be controlled between 0.5 to 3 seconds by a combination of flowrate and number of tubes.

The electrostatic agglomerator performance will depend on the nature of ash and its agglomerative behavior in addition to the parameters such as residence time, applied electric field strengths and the operating temperatures. Therefore the test program should include as variables temperature, gas velocity, residence time and the applied electrical pulsed energization levels as variables for a given process condition. Figure 6 is a schematic of how the agglomerator system components will fit together.

FUEL SPECIFICATIONS

It is estimated that 50 tons of coal water slurry will be required for Startup, Testing, and Analysis. Slurry will be manufactured and shipped in 55 gallon drums. Two drums per day will be emptied into a slurry supply tank, connected to the combustor. Slurry specifications are as follows:

- a) solids content: 65-70%
- b) particle size: 90% less than 75 μm
- c) ash content: 8-10%
- d) volatile content: 30%
- e) heating value: 9000 Btu/pound
- f) ultimate analysis to be provided.

4. Quarterly Results

The draft final report was completed and submitted in January 1992. The final report was approved as is in February 1992. Final contract closeout negotiations were completed. All deliverables have been satisfied. The contract terminated March 20, 1992.

Jay M. Quimby

Figure 6 Schematic of How Agglomerator Components Fit Together

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