EPA

United States Environmental Protection Agency

Office of Reseach and Development

Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

EPA-600/7-77-013

February 1977

EPA AND ERDA HIGH-TEMPERATURE/ HIGH-PRESSURE PARTICULATE CONTROL PROGRAMS

Interagency Energy-Environment Research and Development Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into seven series. These seven broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The seven series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally--compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

REVIEW NOTICE

This report has been reviewed by the participating Federal Agencies, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/7-77-013
February 1977

EPA AND ERDA HIGH-TEMPERATURE/HIGH-PRESSURE PARTICULATE CONTROL PROGRAMS

by

R.A. Kennedy, H. Dhillon, and J.B. Truett

The Mitre Corporation
Metrek Division
McLean, Virginia 22101

Contract No. 68-01-3539, Task 4
Program Element No. EHE623

EPA Project Officer: Dennis C. Drehmel

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

FOREWORD

The U.S. Environmental Protection Agency (EPA) and the U.S. Energy Research and Development Administration (ERDA) are engaged in research and development on methods for removal of particulate matter from gases at elevated temperature and pressure. Success in this endeavor is important for reasons of health and ecology, for protection of process equipment, and for energy conversion efficiency. Some of the advanced energy processes have excellent environmental potential. Development of these processes is especially dependent on solution of the particulate problem. This document, describing the related EPA and ERDA programs, is part of the effort to affect interagency coordination in the continuing development work.

ABSTRACT

This report describes and compares current projects sponsored by the U.S. Environmental Protection Agency (EPA) and the U.S. Energy Research and Development Administration (ERDA), relating to the control of particulate matter in fuel gas streams at high temperatures (1000 to 2000 F) and high pressures (5 atmospheres and greater).

The purpose of the description is to document each project indicating the sponsor, contractor, funding, project officer, duration, milestones, and to provide a narrative statement of objectives and the technology involved. Project descriptions are intended to provide a basis for identifying any overlap or duplication and to indicate areas which are not addressed by either Agency. Description of these projects was obtained from documentation provided by the two Agencies and from discussions with Agency contractor representatives.

The project descriptions and the discussion of possible overlap or omissions which follow is organized to consider particulate control in the three categories of: (1) particulate characterization and aerosol mechanics, (2) instrumentation and measurement, and (3) control technology development. Conclusions and recommendations are reached regarding the questions of overlap and omissions, and the general subject of interagency coordination. Introductory material reflects the respective roles of EPA and ERDA and the rationale and options relating to particulate control through hot gas cleanup at elevated pressure.

The overall effort for control of particulate matter at high temperatures and pressure includes four projects sponsored by ERDA and eight projects sponsored by EPA.

Comparison of the EPA and ERDA activities for possible overlap and omissions is summarized in the conclusions which indicate that there is little evidence of any overlap or duplication. Since the composite effort of both Agencies is not large, some important areas of interest are not addressed. Most of the projects listed above fall in the category of control technology development. There are no projects exclusively dedicated to characterization and study of aerosol mechanics although one such study sponsored by EPA has recently been completed and some characterization work is done at ERDA incident to advanced energy systems development. Development of instrumentation is limited and does not extend to the range of 1000 psig at which some processes are expected to operate.

Recommendations note the need for close cooperation between EPA and ERDA to coordinate present activities, provide for exchange of information, and plan future programs.

CONTENTS

TABLES

SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) and the U.S. Energy Research and Development Administration (ERDA) are both engaged in research and development on methods for removing particulate matter from fuel and combustion gas streams at high temperatures (1000 to 2000 F) and pressures (5 atmospheres and higher). However, the primary orientation of the two agencies' programs differ significantly.

EPA's principal interests are to insure that human health and the environment are adequately protected from the adverse effects of particulate emissions, and that technological methods are available for controlling such emissions to acceptable levels. From EPA's standpoint, such control technology does not necessarily have to operate at conditions of high temperature and pressure (HTP), although HTP operation may be more efficient and more economical.

One of ERDA's principal interests in particulate removal from hot pressurized gases relates to the capability of using such gases (produced by gasification or combustion of coal and other solid fuels) to drive turbines and other equipment without introducing the large thermal inefficiencies attendant to cooling and depressurizing the gas for particulate removal at ambient temperatures prior to combustion. If the particulate-laden gas stream enters a gas turbine without particulate removal, the resultant decrease in turbine blade life would probably adversely affect the economics of operation. Another of ERDA's primary interests is insuring that the exhaust gas from the turbine and other combustion processes meets emission standards for particulate matter.

1.1 EPA Involvement in HTP Particulate Removal

EPA's work on HTP particulate removal is part of its R&D program for particulate control. The overall program includes assessment of the effects of pollutants on human health and welfare; development of technological measures for controlling the release of environmental pollutants; and monitoring and controlling of the release of particulate matter into the environment. Since a major portion of man-made particulate pollutants are associated with energy conversion and utilization facilities, EPA has focused its attention mainly on steam/electric power plants (among the various stationary sources of atmospheric pollutants) and on the automobile (among mobile sources). The present report deals only with stationary sources.

The current emission standards for fuel combustion facilities are expressed as pounds of particulate matter per million Btu of heat input. The current emission limit from new stationary sources is 0.1 pound of particulate matter per million Btu of thermal energy released by combustion processes. The ambient air standard is imposed in terms of the concentration of "total suspended particulate" per cubic meter of air. Although the size distribution of the particulate is not reflected in these standards, the health and environmental effects of particulate pollutants are related to the size distribution as well as the chemical composition of the particulate.[1] Very fine particles can by-pass the body's respiratory filters and may produce adverse health effects by penetrating deep into the lungs. Small particles (0.1 to 1μ in size) also reduce the atmospheric visibility. In view of these characteristics of small particles, EPA is considering the establishment of standards for fine particulate emissions and ambient concentration.

Earlier EPA work has demonstrated that particulate removal to meet existing emission standards for combustion processes can be accomplished by application of available equipment to exhaust gases under the moderate temperatures and pressures at the stack (end-of-system cleanup). EPA recognizes, however, that particulate removal can be performed, partially if not totally, within the energy conversion system, and that within-system cleanup may be accomplished with greater efficiency and less expense than end-of-system cleanup. Such within-system particulate removal may be performed with the gas stream at high temperature and pressure, or at high pressure and reduced temperature. One objective of EPA's Particulate Control Program is to identify effective combinations of these three approaches to particulate control: removal at HTP, removal at high pressure and low/moderate temperatures, and removal at the moderate end-of-system temperatures and pressures.

The requirements of improved thermal efficiency and equipment protection have caused ERDA to concentrate on the monitoring and control of particulate at high temperatures and pressures. The success of these efforts can be expected to reduce the requirements of control technology at the exhaust end of the gas turbines. At this time, cyclones, electrostatic precipitators, and fabric filters are being used effectively for removing particulate from gas streams at low to moderate temperatures and pressures. However, the control equipment has to handle very large volumes of gases at reduced temperatures and pressures. This consideration is a major incentive for EPA's efforts in the area of HTP particulate control technology. In addition, the use of HTP clean-up systems would eliminate the

problems of recovery of specific compounds that could be combusted in the process to form non-particulate pollutants. These compounds include tars and oils (high sulfur), ammonia, hydrocarbons, phenols, etc.

EPA's interest in particulate pollutants is motivated by the undesirable effects of particulate matter on the environment. However, EPA recognizes that any steps taken to reduce the concentration of particulate in fuel gas streams within the fuel processing and utilization cycles will result in the minimization of the cleanup effort needed at the point of release into the atmosphere. The interrelation between in-process cleanup and end-of-system cleanup forms the basis for coordination between the particulate control activities of EPA and ERDA.

1.2 ERDA's Involvement in HTP Particulate Removal

A major element in ERDA's mission is to enhance the utilization of domestic fuel resources. Toward this end, ERDA has undertaken extensive programs for producing synthetic fuel gases through the utilization of gasifiers and power generation by fluidized bed combustors. Innovative advanced power systems (combined gas-steam turbine cycles, etc.) are being developed for efficient utilization of these systems. It is very desirable to maintain the pressure and temperature of the fuel or combustion gas stream at high levels (pressures up to 1000 psig and temperature upto 2000 F). Despite significant improvements in the synthetic gas production process, it is probable that the synthetic fuel gas from most of the production processes will contain some suspended particles of various sizes.

The equipment utilizing this fuel or combustion gas at high temperature and pressure is generally a gas turbine. Excessive concentrations of particulate tend to

damage the blades of the turbine through erosion, corrosion and deposition. The efficiency of the turbine could decrease as a result of this damage. Although the size range, concentration, and velocity of particles that cause turbine damage have not been established conclusively, particles larger than 2 microns (μ) in size appear to be more harmful than smaller particles.

It is possible to clean up the fuel gas stream adequately at moderate temperature and pressure by using the existing control technology for low temperature/pressure operation. Lowering the temperature and pressure of the fuel gas stream lowers the thermal efficiency of the system. Moreover, the volume of gas increases when the pressure is decreased. Therefore, the requirements of high termal efficiency, gas turbine protection, and the possibility of cleaning a smaller volume of gas make it very attractive to employ control technology that operates efficiently at high temperature and pressure.

1.3 Presentation and Categorization of EPA and ERDA Activities

The objective of this report is to review the ongoing and planned activities of EPA and ERDA pertaining to HTP particulate control, and to determine any overlaps between these activities. Since EPA and ERDA are operating relatively independently, it is entirely possible that there may be some problem areas which are not addressed by either Agency. A number of such instances are identified in this report.

Recognizing the potential benefits of high temperature/pressure particulate clean-up, each Agency has undertaken RD&D efforts in this area. ERDA's activities

are generally ancillary to its efforts dealing with the development of gasifiers and fluidized bed combustors. EPA has initiated a few major efforts concentrating exclusively on the development and demonstration of high temperature/pressure particulate clean-up technology.

The overall program for R&D in the high temperature/pressure particulate clean-up covers three major sub-areas. These are:

(1) Particulate characterization and aerosol mechanics (physical and chemical properties, particle collection mechanisms);

(2) Measurement and instrumentation (for observing mass and volume concentration, particle size distribution, and particle velocity) for high temperature/pressure operation; and

(3) Control technology (particulate removal devices) for operation in high temperature/pressure gas streams.

The ERDA and EPA activities are discussed in terms of these categories in Sections 4.0 and 5.0 of this report. The rationale for the selection of these three activity categories is presented in the subsections immediately following.

1.3.1 Particulate Characterization and Aerosol Mechanics

A comprehensive knowledge of the physical and chemical characteristics of particulate at high temperature and pressures is essential for developing effective measurement instruments and particulate removal equipment under these conditions.

Since ERDA's major incentive for the control of particulate at HTP is associated with the protection of equipment receiving the particle-loaded gas streams, the major emphasis in ERDA programs is placed on the prevention of

damage to turbines and other equipment by particulate matter. Nevertheless, the need for protecting the environment is also germane because of present or future standards for particulate emissions. It is possible that stringent New Source Performance Standards may be established for the emissions of fine particulate. Some of these particulates may be the result of reactions in the turbine which produce secondary particulate. In addition, the constituents of the fine particulate (too small to be considered harmful to turbines) may include hazardous materials such as lead, mercury and arsenic.

The preceding remarks highlight the need for comprehensive characterization of the particulate content of fuel gas streams at high temperature and pressure. This characterization will involve statements concerning the particle size distribution, the chemical content of particles and the identification of gaseous components which can be expected to transform into secondary particulate either in the turbine, in the heat recovery and exhaust system, or after the exhaust gases are released to the atmosphere.

Characterization of the aerosol will provide an indication of the magnitude of the HTP particulate problem in terms of (1) the potential damage to the power generation equipment through erosion, corrosion, and deposition; and (2) the expected impact on air quality of the particulate emissions from the power generation system, and the resultant effect on human health, the ecology, and esthetics. A detailed knowledge of the magnitude and the nature of the HTP particulate control problem can be significant in the development of an effective control strategy for preventing equipment damage and evironmental quality deterioration while maintaining high energy conversion efficiency.

In the context of effectiveness of control technology, it is important to study the mechanics of particulate behavior under conditions involving high temperatures and pressures. Physical properties such as resistivity of particles, and phenomena involving thermal ionization and reentrainment need to be more completely understood in order to optimize the utilization of the particulate control technologies.

The need for characterization of particulate at high temperature and pressure did not arise until particulate control under these conditions became a necessity on account of advanced power systems. EPA has already undertaken significant efforts dealing with measurement instrumentation and control technology development for particulate at HTP. However, the activities pertaining to the characterization of particulate under these conditions have not gained momentum.

1.3.2 Measurement and Instrumentation

In the development of direct combustion systems involving gas turbines, it is important to undertake real-time monitoring and analysis of the particles in the fuel gas stream to record the mass loading (or volumetric loading) and the size distribution of the particles entering the gas turbine at high temperature and pressure. An evaluation of the performance of HTP particulate control technology also requires a reasonably accurate measurement of the particulate loading and size distribution at the inlet and outlet of the control equipment.

In the vicinity of the turbine inlet, pressures as high as 500 psi and temperatures ranging from 1000 F to 2000 F can be encountered. In such severe conditions, mechanical devices such as hot wire anemometers either fail quickly

or become inaccurate with the passage of time. Instruments utilizing mechanical sampling techniques perturb the volume being monitored, and affect accuracy of measurement.

The measurement methods used for collection of fractional efficiency data are based on various procedures including inertial impaction, optical counting, condensation nuclei counting and diffusion batteries. Because of the severe conditions associated with high temperature/pressure particulate control equipment, techniques other than the optical counters are not very effective in measuring equipment efficiency.

1.3.3 Control Technology

Although no specific standards have been set for allowable particulate loadings for gases used for driving gas turbines, it is generally agreed that the lifetime and performance efficiency of gas turbines can be increased by reducing the particulate content of the gas stream (particulate larger than 2μ are considered more harmful than smaller particles). As an example, some typical particulate loading specifications are listed in Table 1. Electrostatic precipitators (ESP), scrubbers, and fabric filters have been successfully used for removing particulate from exhaust gases at moderate levels of temperature and pressure, but not under HTP conditions. Lowering the temperature and pressure of the turbine inlet gas stream for the purpose of facilitating particle removal by using proven techniques would result in a large loss of energy. Therefore, it is highly desirable that the particulate removal be carried out at high temperatures and pressures in order to maintain high thermal efficiency of the fuel conversion processes (coal gasifiers,FBC, etc.).

TABLE 1. TYPICAL TURBINE SPECIFICATIONS

Turbine Manufacturer	Particulate Loading (Maximum Allowable)
United Aircraft[3]	0.8 pound/10^6 scf low Btu fuel gas (or ~ 12 ppm)
Westinghouse[3]	0.03 percent (in fuel oil) (or 300 ppm by weight)
General Electric[3] (for aircraft-type turbines)	30 ppm by weight in fuel gas (10 micron maximum)
Brown Bovari	1-2 ppm by weight (in gases entering turbine)
ERDA*	0.75 grains/scf (or ~ 2.6 ppm by weight) in 0-2μ range
(*See PON FE-7, Section 4.3)	0.001 grains/scf (or ~ ppb by weight) in 2-6μ range

The increased prospective utilization of combined gas/steam turbine/electrical generating systems, coal gasification and synthetic gaseous fuels has intensified EPA's interest in HTP particulate removal technology. The economic and operational incentives for the utilization of HTP particulate removal technology (e.g., improved fuel utilization efficiency, combustion of some harmful compounds, and the need to handle a smaller volume of gaseous products make HTP particulate removal appear attractive for EPA.

Specific ERDA projects are described in Section 4 and EPA projects in Section 5.

SECTION 2

CONCLUSIONS

1. No overlaps.

   There does not appear to be any significant overlap or duplication of the EPA and ERDA programs. The relatively small size of the ERDA program provides little opportunity for duplication, in itself.

2. Significant gaps exist.

   The combined EPA and ERDA effort on particulate control at elevated temperatures and pressure is not large (Average combined expenditures are less than $2 million per year for contract effort). Gaps or omissions in the combined activities are most evident in the characterization of particulates and the study of aerosol mechanics, both of which might be considered to be fundamental to the development of a strong information base for control technology.

3. Both Agencies have a common interest in solving the overall problem of particulate control

   EPA's role in the control of particulate centers on potential harmful effects of the emissions while ERDA's orientation is directed at the protection of equipment employed in advanced energy systems and in increasing system efficiency. However, each Agency has a substantial stake in the other's main purview of responsibility. The successful development of advanced energy systems will have an important bearing on future energy-related emissions. In a similar manner, the health and ecological effects of these advanced systems must be environmentally acceptable if they are to be implemented. Each Agency has an interest in the solution of the particulate problems that fall within the primary responsibility of the other.

If any of these problems remain unsolved, there will be no advanced system nor will the expected benefits in health, ecology, or energy self-sufficiency be realized.

4. Increased interagency coordination is needed.

The interagency interest in the particulate control problem will require continued coordination in these programs. If the small size of the ERDA activities can be attributed to their recent inception, it may be expected to grow in the future. New developments in the field of advanced energy systems may also stimulate this growth. Increase in the attention given to the particulate problem will require a corresponding need for increased coordination if programs are to be efficiently planned without duplication and without serious omissions and if maximum use is to be made of the resulting technical data.

5. Equipment protection requirements can be expeditiously established.

Determination of health and ecological effects may required substantial lead times due to the need for observations covering long spans of life. Equipment requirements, however, may be ascertained more expeditiously. Determination of these equipment requirements would set a bottom limit which would narrow the field of consideration and allow concentration of effects study resources.

6. HTP particulate cleanup not essential for meeting emission standards.

Particulate cleanup of hot pressurized gases is not an absolute environmental requirement. Removal of offending materials at any point prior to discharge will satisfy environmental considerations. Early cycle cleanup

may be more efficient because of reduced volume and may allow energy extraction which would not be practical otherwise. Environmental interest in the point of cleanup is a function of the efficiency of particulate removal, along with whatever energy penalties may be avoided. EPA's interest in the hot pressurized cleanup technology is based upon the assumptions that advanced energy systems have a good potential for environmental advantages and that these systems will require early cycle cleanup to avoid unacceptable energy penalties or equipment damage.

7. ERDA does not have centralized programs for particulate control RD&D. Unlike EPA, ERDA's research and development activities are not organized around particular pollutants or pollutant control technologies. Consequently, there is no centralization of responsibilities within ERDA for the control of particulates at high temperatures. Unless a focal point is established and functioning at ERDA, program coordination will require contact with a number of ERDA research and development offices.

SECTION 3

RECOMMENDATIONS

1. Increase interagency coordination.

   Both EPA and ERDA will probably continue to pursue programs in particulate control. With growth of developments in advanced energy systems, the size of this activity may increase from its present level. Efficient planning of these programs will require close cooperation and coordination.

2. Focus responsibilities for coordination.

   Due to the organizational structure of ERDA and the more immediate interest of EPA in health and ecological effects, EPA may well be the more logical organization to take the lead and initiative in establishing necessary channels for coordination.

3. Coordinate future program plans.

   Interagency coordination in particulate control need not be limited to after-the-fact disclosures of program activities or the exchange of data. Joint planning of future activities could include discussions and recommendations for assignments of particular developments. Projects aimed toward filling identified gaps should receive priority attention.

4. Facilitate technology transfer between agencies.

   In addition to the interagency coordination of activities discussed above, technology transfer should not be neglected. Specific or special provisions for accomplishing this transfer is appropriate to any coordination discussions which are held.

SECTION 4

ERDA PROJECTS

ERDA has five specific projects identified as addressing the subject of HTP particulate characterization, measurement, or control. These are identified in Table 2 and summarized in the following sub-sections. Specific projects are described in a consistent format, insofar as possible from available information.

In addition to these five specific projects, it should be noted that there are many other ERDA programs associated with development of energy systems. These programs may include requirements for hot gas cleanup incident to operation of experimental equipment. The program descriptions which follow are those primarily devoted to particulate control research and development.

4.1 Characterization and Aerosol Mechanics

Of the many ERDA programs devoted to the primary objective of developing advanced energy systems, several include particulate characterization tasks. While these programs have other primary objectives, the characterization activity is pertinent to HTP particulate control. This portion of the applicable programs is briefly described below.

- At Argonne National Laboratories some studies pertaining to chemical characterization of particulate in the combustion gases generated by a coal fired, pressurized FBC are being undertaken. This characterization work is done incident to the evaluation of the effects of operating variables in the bench scale plant on response variables in the flue gas, including particulates. Particulates are collected from two series cyclone separators, a sintered steel filter and a final bag filter.

TABLE 2. ERDA HIGH TEMPERATURE/PRESSURE PROJECTS

	Title	Contractor	Funding ($K)	Milestones
1.	Particulate Analysis Instrumentation	Leeds & Northrup	75	1/77 Completion
2.	Particulate Measurement in FBC Systems	Spectron Development Laboratories	17	12/76 Completion
3.	Centrifuge Gas Cleanup System	Mechanical Technology, Inc.	151	5/77 Completion
4.	ESP Development and Test	Not Awarded	--	1/77 Contractor Selection Expected
5.	Moving Bed, Granular Bed Filter	Combustion Power Company	928	12/77 Complete Phase I

Chemical characterization is oriented toward collecting data relating to study of additive entrainment under various operating conditions.

- The Exxon Research and Engineering Company is collecting characterization data in conjunction with its Miniplant (FBC) work. This characterization work has commenced within the last twelve months and has not yet been compiled in any of the papers describing Miniplant operation. The data available to date is limited and reported only in the monthly reports submitted to the ERDA Fossil Energy Division sponsoring the FBC development.
- Work at the ERDA Morgantown Research Center includes atmospheric FBC development. Particular attention is devoted to the combustion of residual mining wastes not suitable for firing in conventional systems. Various pulverized coals are also being tested. Chemical characterization data is being developed in conjunction with the FBC operation. This characterization is not intended exclusively to determine the character of the process off-gases, as the particle composition is also indicate of operating conditions such as combustion efficiencies.
- At the ERDA Grand Forks Research Center, data on particle resistivity is being acquired as a part of ESP operation studies. Particle characteristics are also being studied within the Fluidized Bed Combustion Wet Scrubber Program.

4.2 Measurement and Instrumentation

Recognizing the potential of measurement devices employing optical properties, ERDA is currently undertaking two activities in this program area. These projects are described below.

PROJECT TITLE: PARTICULATE ANALYSIS INSTRUMENTATION FOR FLUIDIZED-BED COMBUSTION SYSTEMS

Contract Number: E(949-18)-2412

Contractor: Leeds and Northrup Company
North Wales, Pennsylvania

Total Funding: $106,200

Period of Performance: May 1976 to May 1977

Sponsoring Division: Office of Fossil Energy, ERDA

Project Officer: Mr. John Geffken

Purpose: To examine the feasibility of monitoring equipment to evaluate particle characterization in gas streams at high temperatures and pressures.

Objectives:

(1) Adapt an existing measurement technique (low angle forward optical scattering) to the harsh fluidized bed combustion environment;

(2) Calibrate and test the instrumentation at the Argonne National Laboratory's pressurized fluidized-bed combustion unit, followed by demonstration of the unit on the Curtis Wright small gas turbine unit; and

(3) Evaluate the performance for potential commercial application.

Description of Technology: This instrument utilizes a Leeds and Northrup low-angle forward scattering technique instrument package for simultaneous measurement of particle size and velocity. This device will be directly interfaced with a data sorter (mini-processor) to provide on-line statistical information, which can be used in a real-time mode or stored for later interpretation.

The measuring device will be developed to operate at temperatures in the range 1,500 - 2,000 F, and pressures up to 10 atmospheres. This package is a potentially useful analytical tool for fluidized-bed combustion research as an accurate on-line monitoring device for determining the efficiency of particle filtering systems essential for the commercial deployment of PFBC systems using gas turbine cycles. In the program, special attention would be focused on the quality and cleanliness of viewing windows under high pressure, high temperature, high particle loads, and a highly turbulent gas stream.

Activities: This project involves the performance of the following six tasks during the period of performance.

Task 1: Application Analysis and Instrument Optimization

Task 2: Instrument Design and Manuals

Task 3: Fabrication and Assembly

Task 4: Check Out and Test

Task 5: Installation and Training Support

Task 6: Data Evaluation

PROJECT TITLE: PARTICLE MEASUREMENT IN FLUIDIZED-BED COMBUSTION SYSTEMS

Contract Number: E(49-18)-2413

Contractor: Spectron Development Laboratories, Inc.,
Costa Mesa, Calif.

Total Funding: $17,219

Period of Performance: April 1976 - December 1976

Sponsoring Division: Office of Fossil Energy, ERDA

Project Officer: Mr. John Geffken

Purpose: To examine the feasibility of an advanced diagnostic technique to make particle field measurements in fluidized bed combustion systems.

Objectives:

(1) Test the capability of a Spectron Development Laboratories Particle Morphokinetometer (PM) to obtain particle size and velocity measurements in the output train of a FBC at Argonne National Laboratories;

(2) Determine operational limitations in terms of particle loading in the flow, light scattering outside the sample volume, and environmental limitations including window contamination, window flange creep, and window deformation due to high temperature and pressure; and

(3) Analyze acquired data by comparing particle size distribution and mass estimates with other available sampling techniques, and estimated instrument sensitivity to variations in particle content.

Description of Technology: The particle morphokinetometer involves the mixing of two equally intense coherent light beams at an angle. The interference of the two beams produces a set of well defined equally spaced interference fringes. The light scattered by a particle traversing the fringe set is modulated according to the size and position of the particle. The particle size is determined by the ratio of the amplitudes of the modulated scattered intensity to the average scattered intensity. The signal time period is a measure of the particle velocity.

Activities: This project has the following milestones:

- design and installation of windows and flanges on the output train of a FBC at Argonne National Lab (ANL) (completed in October 1976)
- instrument operation for both cold and hot FBC flows for four weeks at ANL by SDL and ANL personnel (completed November 1976)
- report summarizing data and instrument evaluation by ANL and SDL personnel (due December 1976)

4.3 Control Technology

The major projects in ERDA's high temperature/high pressure particulate control technology effort are described below:

PROJECT TITLE: STUDY OF CENTRIFUGE GAS CLEAN-UP AND SEPARATION SYSTEM

Contract Number: E(49-18)-2428

Contractor: Mechanical Technology, Inc.
Latham, New York

Total Funding $151,000

Period of Performance: May 1976 to May 1977

Sponsoring Division: Materials & Power Generation, ERDA

Project Officer: Mr. W. Fedarko

Purpose: To examine the feasibility of centrifuge systems for gas particulate clean-up and gas constituent separation in coal conversion processes, with special emphasis on HTP operation of centrifuges.

Objectives:

(1) Determine the effectiveness and process economic advantages of centrifuges (alone or in combination with cyclones) for removal of particulates from the gas stream generated by coal combustion or coal conversion processes.

(2) To evaluate the effectiveness and process economics of the centrifuges for separation of gas constituents is also an objective of this project.

(3) To study the technical performances of centrifuges as a function of various operating conditions (flow rates, degree of purity, pressure, temperature, etc.) up to pressures of 1,000 psig, temperatures of 1500 F, and flow rates as high as 200,000 scfm.

Description of Technology: In this process, centrifuges will be utilized for separating particulate from the low-Btu gas stream produced by a gasifier. In equipment to be tested, a centrifuge is combined with a cyclone for separating fluids of different specific gravities or for separating suspended particles from a gas stream, by utilizing the centrifugal force generated by the rotary motion.

The substitution of centrifuges for other methods of removing particulate from high- and low-Btu gases should result in better separation factors, thereby producing fuels of higher purity at lower costs. Centrifuges are more compact and require less energy than present particulate removal facilities. If the upper temperature and pressure limits and particulate removal efficiencies are acceptable for the process clean-up, the centrifuge systems could offer an effective and economical alternative for HTP particulate clean-up.

Activities: In this project the following activities and time schedules are planned:

(1) Determine centrifuge capabilities in terms of flow rates, clean-up efficiency and reliability at high temperatures and pressures (to be completed in early 1977).

(2) Study the process economics, including the initial and operating costs, involved in employing centrifuges for particulate removal and separation of gases at HTP (to be completed by (May 1977).

(3) Study the effect of centrifuge size, velocity, diameter, length, casing design, materials, method of suspension, drive, controls, and number of stages (series and parallel) on the technical performance and economy of centrifuge systems (to be complete in May 1977).

(4) Prepare optimized conceptual designs of appropriate centrifuge systems, giving engineering details, expected performance, power requirements and estimated costs (to be completed by May 23, 1977).

PROJECT TITLE: GRANULAR BED FILTER DEVELOPMENT

Contract Number: EF-77-C-01-2579

Contractor: Combustion Power Company

Total Funding: $928,306

Period of Performance: January 1977 - December 1977

Sponsoring Division: Office of Fossil Energy, ERDA

Project Officer: Mr. John Geffken

Purpose: The purpose of the first phase of this contract is to determine the scientific and engineering principles upon which granular bed filteration operates. In particular, the granular bed filtration process will be analyzed theoretically and evaluated.

Objectives:

(1) To determine the scientific and engineering principles upon which granular bed filtration operates.

(2) To predict the effects and inter-relationships of Granular Bed Filter (GBF) design variables.

(3) To predict the filtration performances of the GBF from a given set of design variables.

Description of Technology: Combustion Power Company, Inc., was awarded a contract to perform an intensive program to determine the scientific and engineering principles upon which granular bed filtration operates. The first phase of the program will develop the theoretical analysis of the moving bed granular bed filtration process and perform verification testing at ambient temperature. Specifically, work will be performed on cold testing and mathematical modeling. The cold flow facility will be designed with the provision for subsequent hot flow testing. If successful, the program will continue with a series of hot mode tests, and construction and operation of a process development unit scale MB-GBF to show its commercial applicability. Subsequent phase (e.g. hot flow tests) will be scheduled to insure that the GBF program continues on a timely basis. Hot gas cleanup is necessary for commercial application of pressurized fluidized bed combustion, GBF is one of the most viable contending systems. Application is also seen in coal conversion plants.

Activities: This project involves the performance of the following seven tasks during the period of performance.

Task 1.1 Theoretical Analysis of Granular Bed Filtration Process

Task 1.2 Calibration of Particle Sampling Equipment

Task 1.3 Dust Loading and Sampling Calibration Test Set-Up

Task 1.4 Cold-Flow Model Design

Task 1.5 Cold-Flow Model Test Set-Up

Task 1.6 Cold-Flow Model Tests for Design Variables

Task 2 Front Face Cleaning

PROJECT TITLE: ELECTROSTATIC PRECIPITATORS DEVELOPMENT AND TEST OPERATIONS DEMONSTRATIONS (PROGRAM OPPORTUNITY NOTICE)

Contract Number: PON FE-7

Contractor: Not yet selected

Total Funding: Undetermined

Period of Performance: Contractor selection expected by January 1977. No other details available at this time.

Sponsoring Division: MERC (ERDA)

Project Officers: Mr. Charles Grua, Mr. Corell Shale

Purpose: To develop and demonstrate by test operations, electrostatic precipitators for particulate removal from gaseous fuels produced from coals at temperatures in the range 1000 F to 1800 F and at pressures ranging from one atmosphere to 450 psi.

Objectives:

(1) To demonstrate by test operations an improved electrostatic precipitator capable of high temperature operation with acceptable collection efficiency.

(2) To enhance the utilization of low-Btu gas as a substitute for natural gas by extending the state-of-the-art of purification methods, and to improve the efficiency of gas turbine or combined cycle power plants through the removal of particulates from low-Btu gas at high temperatures and pressures.

(3) To demonstrate that improved ESPs can attain particulate removal efficiencies of 99.5 percent to 99.9 percent, and clean low-Btu gas such that it contains less than 0.75 gr/scf of particulate in 0-2 micron range, and less than 0.001 gr/scf in the 2-5 micron range.

Description of Technology: The particulate loading specification for gas turbines require a high removal efficiency for particulate in the size range of 2μ and larger. Electrostatic precipitators which operate very effectively at moderate temperatures and pressures can be expected to be utilized successfully at high temperatures and pressures provided the desirable properties of the collection equipment and particulate can be maintained under these severe conditions. The ESPs have a low pressure drop, high efficiency for small particulate, and possess the ability to handle both gases and vapors for high volume flow. The collected particulate can be removed easily.

The steps in the electrostatic precipitation of particulate are:

- place a charge on the particle to be collected

- attract the particle to the collector which has opposite charge,
- neutralize the charge at the collector and remove the collected particle.

At high temperatures, the particle resistivity may be low enough to cause excessive reentrainment. Also, the particulate may generate thermionic emissions, thereby diminishing the charge on the particles, and a resultant drop in collection efficiency may occur. The material used for electrodes may not be able to withstand the severe conditions. This may result in misalignment of electrodes, non-uniform charging, and failure of the electrode material.

If the problems listed above can be tested through the use of superior design, improved material, and better operation procedure, ESPs may turn out to be as effective at high temperatures and pressures as they are at moderate levels of temperatures and pressure.

Activities: This program will include the following activities (milestones not yet scheduled):

(1) One or more improved versions of electrostatic precipitators will be tested in conjunction with a coal gasifier.

(2) The precipitator design and characteristics will be improved until it is capable of displaying adequate particulate removal efficiency at high temperatures (up to 1800 F) and high pressures (up to 450 psi).

(3) The demonstration of the capabilities of an improved ESP for HTP particulate removal will be carried out in conjunction with a gasifier. This gasifier may either be owned by the contractor or be provided by the Morgantown Energy Research Center of ERDA.

PROJECT TITLE: WESTINGHOUSE SHOCK TUBE (INACTIVE)

The project described below is not currently active and consequently not properly considered as a part of the ERDA program. Mention is made here as a matter of convenience in the belief that it will be of interest to the reader. The work completed, and that which may be initiated in the future, could provide a significant contribution in establishing particulate requirements for turbine operation.

The project, recently completed by Westinghouse, was sponsored by the ERDA Division of Fossil Energy under contract E(49-18)-1514. The work was associated with Advanced Coal Gasification for Electric Power Generation conducted July, 1975 through June, 1976. This low-Btu gasification project was done in conjunction with the Public Service Company of Indiana.

The Westinghouse particulate study objective was to define the particulate tolerance of turbine blades necessary for development of equipment to be used in the low-Btu gasification process.

Determination of particulate tolerance is accomplished in an erosion prediction process using a combination of mathematical models and experimental data. A unique feature of the technique concerns the use of a shock tube to produce experimental data for the erosion and deposition models. The shock tube provides for acceleration of measured amounts of particulate along with Doppler laser measurement at the point of impingement on the test blades, adjustable to various impact angles.

The shock tube experimentation was restricted to low temperature gas streams. However, the operators believe that heating the shock tube may

be controlled to produce an aerosol suitable for examination of gas streams in the 2000 F range. While proprietary development is reported as continuing, the technique remains a possible condidate for future joint development.

4.4 General Comments on ERDA Programs in the HTP Particulate Removal

ERDA's work in the area of HTP particulate control is oriented primarily toward prevention of the damage that might be caused to the turbine by the particulate which are allowed to enter the turbine. Consequently, the measurement techniques and particulate removal mechanism being developed, tested, and demonstrated by ERDA are designed to address the particulate fraction which falls in the 2μ and larger size category, although it is recognized that the lower end of the size range of particles that might damage turbine equipment is not yet firmly established. While it is entirely possible that some pollutants in the vapor form might also cause damage to the turbine, the current efforts are directed mainly at particulate control as a means for minimizing the erosion, corrosion and deposition problems in gas turbines.

The ERDA program does not currently include a substantial effort for characterization of particulate matter found in the gas streams entering the gas turbine, in terms of its chemical and physical properties. However, an increase in characterization work is planned on completion of construction of those pilot plants which will produce hot gas streams. This characterization will be done as part of the operational experimentation.

In the area of measurement instrumentation, ERDA has two projects in progress. These activities are aimed at the development, testing, and demonstration of measuring devices using optical scattering techniques for in-situ installation. Coupled with on-line data processors, these devices are capable of yielding

simultaneous measurements of particle size distribution, concentration and velocity. In terms of operating ranges, these devices cover temperatures up to 2000 F and pressures up to 10 atmosphere. The temperature parameter is adequate for most anticipated uses, but the pressure range may be inadequate, because ERDA is about to start testing and demonstrating particulate control equipment at pressures as high as 1,000 psig. Therefore, it would be desirable to extend the pressure limit on the operation of these measuring devices.

ERDA is currently engaged in testing and demonstrating the capabilities of centrifuges and ESPs for particulate removal at high temperatures and pressures. In the absence of well-accepted specifications for allowable particulate loading and size distribution for gas turbines, it is difficult to select the most effective techniques for particulate removal at high temperatures and pressures. A knowledge of these specifications will also give some indication concerning the impact of turbine exhaust gases on the ambient air (in terms of particulate concentration).

SECTION 5

EPA PROJECTS

EPA currently has eight active projects that address the control of particulate matter at HTP conditions. These are identified in Table 3 and are summarized in the following subsections. It is noted that seven of the eight ongoing projects are components of EPA's Particulate Control Program; the other is part of the Fluidized Bed Combustion Program and is identified as such.

5.1 Characterization and Aerosol Mechanics

In the past, EPA's major interest in the characteristics of particulate matter has centered on the effects of such material on the environment and human health. Emphasis has consequently been placed on the characteristics of particles in ambient air. One study on the mechanics of aerosols at high temperature and pressure was recently completed (August 1976) (Reference 2). At present, EPA has no active projects on particulate characterization at HTP conditions.

5.2 Measurement and Instrumentation

EPA funded one project on measuring particulate parameters at HTP conditions during FY 1976. The original specifications of this project were as follows:

PROJECT TITLE: MEASUREMENT FOR HIGH TEMPERATURE/HIGH PRESSURE PROCESSES

Contractor: Acurex/Aerotherm Division

Total Funding: $ 90,000 (FY 76)
$120,000 (FY 77)
$ 70,000 (FY 78)
$ 25,000 (FY 79)
$ 25,000 (FY 80)

Period of Performance: October 1975 to October 1978

TABLE 3. EPA HIGH TEMPERATURE/PRESSURE PROJECTS

	Title	Contractor	Funding ($K)	Milestones
1.	HTP Measurement	Aerotherm Acurex	90 (FY-76) 120 (FY-77) 70 (FY-78) 25 (FY-79) 25 (FY-80)	10/75 Measure/Develop 9/78 Final Report
2.	Hot ESP	Cottrell Environmental Sciences	137 (FY-75) 284 (FY-76)	4/76 Define Stable T&P 1/77 Demonstrate Feasibility 1/78 Complete Pilot Scale 4/79 Complete Demo
3.	HTP Filtration	Aerotherm Acurex	593 (FY-76)	8/76 Primary Evaluation 9/77 Verification
4.	Ceramic Filter Materials	Westinghouse	240 (FY-75)	3/76 Demonstrate Feasibility 7/77 Complete Pilot Test 10/78 Complete Demo
5.	New Concept for HTP Collection (Dry Scrubber)	Air Pollution Technology	431 (FY-76)	8/76 Primary Evaluation 9/77 Verification
6.	Assessment of Granular Bed Filter Technology	Air Pollution Technology	140 (FY-76)	8/76 Primary Evaluation 9/77 Verification
7.	Granular Bed Filter	Exxon Research	150 (FY-76) 300 (FY-77)	7/77 Complete System Study 7/78 Complete Demo
8.	Collection Mechanisms (Aerosol Mechanics)	Air Pollution Technology	50 (FY-75) 300 (FY-76)	Phase 1 - Completed 1/77 Final Report Phase 2 - Underway 2/78 Final Report

Sponsoring Division: Particulate Technology Branch, IERL-RTP, EPA

Project Officer: Mr. William R. Kuykendal

Purpose: This project is being conducted for the purpose of evaluation, development, field testing and application research of high temperature, high pressure measurement techniques necessary for HTP particulate control technology development.

Objective: The first technical objective of this project is to develop measurement instrumentation needed for measuring the mass loading, size distribution and velocity of particulate in gas streams at high temperatures and pressures.

The second objective is to develop measurement support for the evaluation of particulate control technology being developed by IERL.

Description of Technology: The technical approach being followed in this project is similar to that adopted for the Method 5 particulate train. This train consists of a water jacketed probe which collects the sample and directs it into a cyclone. The cyclone is followed by an impactor, a filter, and an impinger (for condensible products). The outlet from the impinger is connected to a pump which delivers the dried sample to a dry gas meter.

In the first phase, technology development will concentrate on the testing and demonstration of a short-term measurement system for particulate and gaseous concentration. The second phase will involve a three year effort aimed at the development of an optimized measurement system for particulate at HTP.

Activities: The activities in the two phases of this program are described below.

Phase I

Develop an acceptable measurement system for the measurement of particulate and gaseous concentration/composition data at high temperatures and pressures (due for completion in October 1976).

Phase II

Develop an optimized system for the measurement of particulate and gaseous concentration/composition data at high temperatures and pressures (due for completion by October 1978).

5.3 Control Technology

In fulfilling its responsibility to develop and demonstrate particulate control technology, EPA is currently conducting the following projects that address the control of particulate matter in HTP gas streams.

PROJECT TITLE: DEVELOP HIGH TEMPERATURE AND PRESSURE ELECTROSTATIC PRECIPITATOR (ESP)

Contractor: Research Cottrell

Total Funding: $137,000 (FY 1975)
$284,000 (FY 1976)

Period of Performance: April 1976 to April 1979

Sponsoring Division: Particulate Technology Branch, IERL-RTP, EPA

Project Officer: Mr. Leslie E. Sparks

Purpose: The purpose of this project is to determine the suitability of electrostatic precipitators for particulate cleanup at high temperatures and pressures.

Objectives: There are two phases of this project, with the following objectives:

Phase I

(1) To define the temperature-pressure regions in which stable electrostatic precipitator operation is possible.

(2) To determine the temperature/pressure conditions in advanced energy processes, both for synthetic fuels and combustors.

Phase II

If there is sufficient overlap between the system (advanced energy processes, synthetic fuels) requirements and ESP operating conditions, the objective of this phase will be to develop high temperature/pressure ESP's.

Description of Technology: EPA's major interest is focused on fine particulate removal, and there have been some doubts about the effectiveness of ESP's in removing fine particles from the gas stream. In the case of these small particles, the main particle charging mechanism, "field charging" makes up for the lack of diffusion charging in the case of particles which are smaller than 1/2 micron. Under moderate operating conditions (pressure and temperature), the ESP's display minimum collection efficiency for particles in the size range 0.1 to 1.0 microns.

Activities: The activities involved in this project include the following:

(1) Determine corona characteristics at temperature up to 2000 F, and pressures up to 500 psi in combustion gas and fuel gas environment. In particular, determine the impact of high temperature on particle resistivity, thermal ionization, re-entrainment and critical pressure.

(2) Identify the temperature/pressure limits for stable ESP operation, by conducting batch operation of a single tube pilot precipitator.

(3) Develop and operate a multiple prototype module in continuous operation mode.

PROJECT TITLE: THE DEVELOPMENT OF HIGH TEMPERATURE, HIGH PRESSURE PARTICLE CONTROL BY FILTRATION

Contractor: Acurex Corporation/Aerotherm Division

Total Funding: $593,000

Period of Performance: August 1976 to August 1978

Sponsoring Division: Particulate Technology Branch, IERL-RTP, EPA

Project Officer: Dr. D. C. Drehmel

Purpose: The purpose of this project is to support the development of filtration as a technique for removing particulate from the high temperature/pressure gas stream generated by gasifiers and combustion (pressurized FBC).

Objectives: The following are the major objectives of this project.

(1) To develop filtration procedures for ensuring that the gas turbines using gases generated by gasifiers and pressurized FBCs are protected from the suspended particles in these fuel gases.

(2) To determine the suitability of the filtration concept as an effective means for controlling suspended particulate at high temperatures and pressures.

(3) To develop a pilot scale HTP filtration device.

(4) To carry-out an economic analysis of full scale filtration systems.

Description of Technology: Filtration is one of the most reliable techniques for removing suspended particles from gaseous streams. However, the severe conditions represented by high temperatures and pressures require careful

consideration in the selection of materials and designs for filters to be used in this environment.

The most promising candidates for filter material are ceramics (silica, alumina, zirconia, etc.), which can be woven or felted into a gas filter. Abrasion in weaves can be reduced by high temperature coatings and novel weaving techniques.

Activities: This project will be conducted in two phases. The activities in each phase are listed below.

Phase I - Preliminary Evaluation

(1) Carry out theoretical studies concerning filter operations under high temperature and pressure conditions.

(2) Select and obtain test materials for filters; design, fabricate and construct test apparatus.

(3) Conduct experiments and collect data.

(4) Analyze data and carry out an economic analysis of filtration as a means for HTP particulate control.

(5) Conduct bench scale testing of the selected filtration system.

Phase II - Verification

(1) Plan experiments for verifying the results yielded by Phase I.

(2) Conduct experiments, collect data, analyze data and generate results pertaining to the validity of the indications yielded by the preliminary evaluation.

PROJECT TITLE: DEVELOP CERAMIC FILTER

Contractor: Westinghouse

Total Funding: $240,000 (FY 1975)

Period of Performance: March 1976 to October 1976

Sponsoring Division: Particle Technology Branch, IERL-RTP, EPA

Project Officer: Dr. D. C. Drehmel

Purpose: To determine the suitability of ceramic filters as a means for removing particles from combustion and fuel gases for the purpose of protecting gas turbines and the environment.

Objective: The overall objective of this project is to develop and demonstrate ceramic filters for removal of particulate matter from gas streams at high temperatures and pressures.

In the first phase of this project, the objective is to demonstrate the feasibility of using such filters under severe conditions represented by high temperatures (up to 2000 F) and pressures (up to an undetermined level).

Description of Technology: Cyclones (or centrifuge), scrubbers, ESPs and fabric filters are the four particulate removal techniques in use at this time. Various design, material and operational problems have resulted in the first three techniques being relatively less successful in cleaning HTP gases. Fabric and bed filters have consistently shown acceptable levels of performance even under extreme conditions. Because of the severe operating environment, the selection of a durable material for filters has been a prime objective of researchers dealing the HTP control technology.

Westinghouse has tested a ceramic filter developed by Horizons Inc. The results have been satisfactory, in terms of collection efficiency, operating reliability, and durability of the equipment. Contrary to original expectations, the pressure drop in the ceramic filter was not very high. Initial indications are that it would be feasible to use ceramic filters for removing particulate from gases at high temperatures and pressures.

Activities:

(1) Demonstrate the feasibility of using ceramic filters for particle removal from gaseous streams at high temperatures and pressures (already completed).

(2) Completed pilot tests involving the use of ceramic filters for removing particles from HTP gases (due March 1977).

(3) Conduct a demonstration of a particulate clean-up system using ceramic filters (due for completion in October 1978).

PROJECT TITLE: NEW CONCEPT FOR HTP COLLECTION (DRY SCRUBBER)

Contractor: Air Pollution Technology (APT) Inc.

Total Funding: $431,000

Period of Performance: August 1976 to August 1978

Sponsoring Division: Particulate Technology Branch, IERL-RTP, EPA

Project Officer: Dr. D. C. Drehmel

Purpose: To develop an innovative technique for controlling fine particulate at high temperature and pressure.

Objective:

(1) To conduct theoretical and experimental studies aimed at the development of a new concept for fine particulate control at high temperature and pressure.

Description of the Technology: The technology to be examined is a "dry scrubbing system" for controlling fine particulate matter in a gas stream. The system provides for contacting the fine particle-laden gas to be cleaned, with large (diameter of 100μ or more) collector particles. The collectors (large particles) are introduced in a contactor unit consisting of a venturi like device allowing injection of the collectors in the venturi throat. Agglomeration of the fine and large particles will allow removal in a subsequent separator designed for high efficiency removal of large particles. A gravity settler and virtual impactor are to be evaluated for the separation step. The system will be examined at the bench and pilot scales. Regeneration and recycle of the collector particles is planned as part of the system but is to be evaluated independently of the bench and pilot demonstrations. These demonstrations will be operated at high temperature and low pressure in the expectation that the impaction mechanism is not specifically dependent on pressure. Collector particles to be used will include ash particles, large agglomerates of fine particles, and metal beads.

Activities

The technical objectives of the project will be completed in two phases:

Phase I: Preliminary Evaluation of the Dry Scrubbing Concept

1. Theoretical calculations of the mechanism of fine particle collection through use of relatively large particles (8/76 - 11/76);
2. Bench scale experiments to evaluate the concept (8/76 - 3/77);
3. Economic analysis based upon the theoretical calculations and bench scale experiments (2/77 - 4/77);
4. Investigation of the energy and cost relationship as a function of temperature and pressure (3/77 - 5/77);

Phase II: Verification of Fine Particle Collection

1. Formulation of a verification test plan (5/77 - 8/77);
2. Design of a 500 SCFM Model (6/77 - 12/77);
3. Test of the 500 SCFM Model (12/77 - 6/77); and
4. Economic analysis of dry scrubber operation based on data obtained in test of the Model (6/77 - 8/77).

PROJECT TITLE: ASSESSMENT OF GRANULAR BED FILTER TECHNOLOGY

Contractor: Air Pollution Technology (APT) Inc.

Total Funding: $140,000

Period of Performance: September 1976 to June 1978

Sponsoring Division: Particulate Technology Branch, IERL-RTP, EPA

Project Officer: Dr. D. C. Drehmel

Purpose: To evaluate the existing granular bed filter systems for assessing the suitability of this technology for particulate control at high temperature and pressure.

Objective: The objectives of this project are:

(1) To evaluate the status of the current granular bed filter technology.

(2) To assess the adequacy of granular bed filters for meeting the particulate clean-up requirements of various advanced energy systems.

Description of Technology: In order to maintain high thermal efficiency and protect the turbines in advanced power systems, it is necessary to remove the particulate from the gaseous fuel stream at high temperatures and pressures. Along with ESPs, fabric filters, and centrifuges, granular bed filters offer the potential of effective and reliable service under these conditions.

Under other EPA projects, there is performance data concerning existing granular bed filters (including the Rexnord filter). These data indicate relatively poor performance in removing fine particles (1μ in size). The Combustion Power Company (CPC) granular bed filter not available for test at this time.

The assessment of the performance of various existing granular bed filter systems will lead to the development of engineering models and design equations for predicting filter performance. These systems will be designed for operations at pressures up to 15 atmospheres and temperatures up to 1100 C.

Activities: This project is being conducted in two phases. The following activities are scheduled:

Phase I

Study the literature pertaining to empirical and theoretical information concerning granular bed filters. (Due to be completed by September 1977).

Phase II

Carry out field sampling, and conduct detailed costs at two granular bed filter installations selected as a result of Phase I study. Determine the effectiveness and characteristics of these two systems. Prepare a final report by June 1978.

PROJECT TITLE: PARTICULATE CONTROL IN PRESSURIZED FBC-GRANULAR BED FILTER APPLICATIONS

Contractor: Exxon Research and Engineering Company

Total Funding: $150,000 (FY 76)
$300,000 (FY 77)

Period of Performance: December 1976 to December 1978

Sponsoring Division: IERL, RTP, EPA

Project Officer: D. B. Henschel

Purpose: To design, develop and demonstrate a granular bed filter for particulate clean-up of combustion gases produced by a pressurized, fluidized coal combustion bed.

Objectives: The major objectives of this project are:

(1) To establish operational feasibility of granular bed filters under pressurized FBC operating conditions.

(2) To optimize the performance, and measure the long-term effects associated with an expandable sand type granular bed filters.

(3) To demonstrate the ability of granular bed filters to meet EPA emissions standards by cleaning fuel and combustion gases at high temperatures and pressures.

Description of Technology: In a pressurized FBC, the combustion gases are at pressures up to 10 atmospheres and temperatures up to 1600 F. The particulate in the combustion gases must be removed before the gases go into a gas turbine. The system being developed by Exxon involves two stages of cyclones followed by a Ducon granular bed filter between the FBC and the gas turbine inlet. Particles retained by the granular bed filter are periodically removed by "blowing back" with compressed air.

Activities:

(1) The installation of a Ducon bed filter is scheduled for completion by December 1976.

(2) The filter will be checked out during the period December 1976 to May 1977.

(3) The filter operation will be carried out over a 15 month period (May 1977 to August 1978). During this time period, efforts will be made to measure the performance of the Ducon granular bed filter and optimize its particulate removal efficiency. Maintenance of high removal efficiency over an extended period of time will be an objective during this period. The extension of equipment life will also be a target.

(4) Starting in March 1977, an alternate HTP particulate removal system will be selected, designed and installed. The checking out and operation of this device will be completed by December 1978.

PROJECT TITLE: EFFECTS OF HTP ON PARTICLE COLLECTION MECHANISMS

Contractor: Air Pollution Technology (APT) Inc.

Total Funding: $350,000

Period of Performance: December 1975 to November 1977

Sponsoring Division: Particulate Technology Branch, IERL-RTP, EPA

Project Officer: Dr. D. C. Drehmel

Purpose: To conduct theoretical studies of aerosol mechanics at HTP followed by laboratory experimentation.

Objectives: The objectives of this project are followed in two phases:

Phase 1

To determine the effects of temperature, pressure and particle diameter of aerosols on various particle collection mechanisms, and to identify useful collection mechanisms through theoretical studies.

Phase 2

To conduct laboratory scale experimentation to fill the gaps and reduce the uncertainties identified in the theoretical study results produced in Phase 1.

Description of Technology: This project does not concern a particular or specific technology in the sense that would apply to development of instrumentation or a collection or removal device.

The project is intended to develop analytical techniques for studying the high temperature and pressure aerosol mechanics which will in turn provide the data necessary for development of particulate control technologies. These gas mechanics are imperfectly understood with the uncertainties

representing a significant gap in the capability to develop associated measurement and control devices.

Activities:

(1) Phase 1 has been completed with a Final Report scheduled in January of 1977.

(2) Phase 2 is underway with completion scheduled for November of 1977 and a Final Report in February of 1978.

5.4 General Comments on EPA Programs in the HTP Particulate Control Area

Although EPA's interest in HTP particulate control is related only indirectly to the development of advanced energy systems using gasification or fluidized beds, the Agency has a strong interest in the development of HTP particulate control technology because of the potential environmental impact of the emissions from gas turbines and other energy conversion equipment. EPA's major concern is to ensure that adequate control systems are available at the time needed for application to new energy conversion technology.

EPA considers it highly desirable to have specifications for allowable particle concentration and size distribution for gas turbines. Such specifications would make it possible for EPA and ERDA to determine the extent of commonality that exists between their respective requirements for HTP particulate control systems. For instance, the requirements for gas cleanliness for turbine protection are believed to depend on turbine design and may be less stringent than for environmental protection. Even if the turbine specifications for total particulate loading are more stringent than that for environmental protection, the emissions

from turbines may include a high proportion of small particles ($<2\mu$) and the environmental impact of these emissions may be disproportionately serious (relative to total emissions).

An attractive feature of high temperature/high pressure particulate cleanup is the smaller volume of exhaust gases prior to combustion. However, the severe environment at the turbine inlet may result in low collection efficiency and equipment reliability. Therefore, a detailed cost benefit study should be performed to evaluate the economics of HTP particulate clean-up as compared with particulate removal under moderate conditions.

EPA's current efforts in the area of HTP particulate control technology development are principally concerned with filters, electrostatic precipitators, and granular beds. Cyclones and centrifuges are not being addressed by any of EPA's ongoing projects.

SECTION 6

COMPARISON OF ERDA AND EPA PROGRAMS

The preceding sections describing the Agencies' high temperature and pressure particulate control activities are organized into the categories of:

- Characterization and Aerosol Mechanics,
- Measurement and Instrumentation, and
- Control Technology

This same organization is employed in this comparison which is directed toward identification of any overlaps or duplication among the projects and discussion of the gaps or omissions. As will be noted, little if any overlap is detected, while a comprehensive program coverage is yet to be achieved.

6.1 Characterization and Aerosol Mechanics

6.1.1 Overlaps

While EPA has recently completed one study of HTP aerosol mechanics and has another currently under way, neither Agency is currently pursuing programs for characterizing particulate matter in terms of chemical composition or size distribution. ERDA's work in this area is confined to whatever is done incident to, or as a part of, development work in advanced energy processes. This report is not inclusive of all such ancillary work which may have produced characterization data, or will in the future. In the absence of specific characterization programs, there is no evidence of overlaps except as may or may not occur casually in the advanced energy systems research, development, and demonstration.

6.1.2 Gaps

Since EPA has a single current project on aerosol mechanics, and neither EPA nor ERDA have current characterization projects, gaps in this area include all necessary characterization and study of aerosol mechanics which has not been completed. Without attempting to enumerate all the potential gaps, characterization of the hot gas streams from all promising gasification and pressurized fluid bed combustion processes would seem to be likely candidates. This would include data on physical and chemical characteristics of particulate matter and on aerosol mechanics up to 2000 F and 1000 psig; and for the various fuels used by the advanced energy processes.

6.2 Measurement and Instrumentation

6.2.1 Overlaps

The EPA program does not include instrumentation test or evaluation which is in any way similar to the two ERDA sponsored devices under investigation. There is no evidence of overlap or duplication.

6.2.1 Gaps

The collective instrumentation programs of EPA and ERDA includes only the three devices described. It seems probable that there are many more devices and measurement techniques worthy of evaluation. More specifically, two of the three devices mentioned are designed for pressures up to ten atmospheres. The need for measurement of hot gas streams to 1000 psig will be required.

6.3 Control Technologies

6.3.1 Overlaps

Both EPA and ERDA have projects for the development of hot ESP's. No other areas of potential duplication have been identified.

Two separate programs in the development of electrostatic precipitators do not necessarily constitute an overlap even if the devices are intended to operate on similar hot gas streams, provided the precipitator mechanics or technology differ significantly. The ERDA program is in the procurement stage, not under contract, and information regarding details of operation is not available. Consequently, whatever duplication may exist between the two programs cannot be assessed at this time.

6.3.2 Gaps

Seven of the programs reported herein may be included in the general category of control technology development. The technologies include electrostatic precipitators, granular bed filters, ceramic materials, a dry scrubber and a centrifuge. Gaps in this development and evaluation include those possible devices not being considered, and the limiting characteristics of the hot gas streams to which the devices might be applied. Pending the success achieved in the development which is underway, it does not appear obvious that any specific areas are being neglected at this time. The effort and attention being accorded the problems of control technology probably exceeds the level of additional work needed in characterization, instrumentation, and in establishing the requirements for protection of human health, the ecology, and equipment which will receive the hot gas streams.

REFERENCES AND BIBLIOGRAPHY

1. Dhillon, H. and H. Mahar. Alternate Control Strategies for Fine Particles. The MITRE Corporation, METREK Division, (M76-76), August 1976.

2. Rao, A. K., M. P. Schrag, and L. J. Shannon. Particulate Removal From Gas Streams at High Temperature/High Pressure. Midwest Research Institute. EPA-600/2-75-020, August 1975.

3. Fulton, R. W. and S. Youngblood. Survey of High Temperature Clean-Up Technology for Low Btu Fuel Gas Processes. Aerotherm Report 75-134, January 1975.

4. Perkin, H. C. Air Pollution. McGraw Hill and Co., 1974.

5. Whitby, K. T. and B. Cantrell. Atmospheric Aerosols - Characteristics and Measuremental Sensing and Assessment. Las Vegas, Nevada, September 1975.

6. Waggoner, A. P. and R. J. Charlson. Aerosol Characteristics and Visibility. Final Report, EPA Grant # R-800-665, 1975.

7. Altshuller, A. P. Principal Species in Atmospheric Fine Particulate Matter. Minutes of Meeting, EPA Air Pollution Chemistry and Physics Committee, Alexandria, Va., 1975.

8. Altshuller, A. P. Characteristics of the Chemical Composition of the Fine Particulate Fraction in the Atmosphere (Draft). U.S. Environmental Protection Agency, Research Triangle Park, N.C.

9. Hiddy, G. M. Characterization of Aerosols in California, (ACHEX). Final Report to Air Resources Board, State of California, Vol. I-IV, 1974.

10. Abbott, J. H. and D. C. Drehmel. Control of Fine Particulate Emissions from Stationary Sources. U.S. Environmental Protection Agency, IERL-RTP, Chemical Engineering Progress, December 1976, p. 47.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-77-013		

4. TITLE AND SUBTITLE	5. REPORT DATE
EPA and ERDA High-Temperature/High-Pressure Particulate Control Programs	February 1977
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
R. A. Kennedy, H. Dhillon, and J. B. Truett	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
The Mitre Corporation Metrek Division McLean, Virginia 22101	EHE623
	11. CONTRACT/GRANT NO.
	68-01-3539, Task 4
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	Final; 6-11/76
	14. SPONSORING AGENCY CODE
	EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer for this report is D. C. Drehmel, Mail Drop 61, 919/549-8411 Ext 2925.

16. ABSTRACT The report describes and compares current projects sponsored by EPA and the U.S. Energy Research and Development Administration (ERDA), relating to the control of particulate matter in fuel gas streams at high temperatures (1000 to 2000 F) and high pressures (5 atm and greater). The descriptions document each project (indicating the sponsor, contractor, funding, project officer, duration, and milestones) and provide a narrative statement of objectives and technology involved. Project descriptions provide bases for identifying overlap or duplication, and indicate areas not addressed by either Agency. Descriptions were obtained from documentation provided by the two Agencies and from discussions with Agency contractor representatives. Comparison of EPA and ERDA activities for possible overlap and omissions is summarized in the conclusions which indicate that there is little evidence of any overlap or duplication. Since the composite effort of both Agencies is not large, some important areas of interest are not addressed. No projects are dedicated exclusively to characterization and study of aerosol mechanics; however, one such EPA-sponsored study was completed recently. Some characterization work is done at ERDA, incident to advanced energy systems development. Development of instrumentation is limited and does not extend to the expected 1000-psig operating range.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Fuels Gases Particles	Air Pollution Control Stationary Sources Particulate Control High Temperature High Pressure Fuel Gas Streams	13B 21D 07D

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	52
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)