CONF-9506162--47

DOE/METC/C-96/7202

High-Temperature Gas Stream Cleanup Test Facility

Authors:
J. Ontko
T. Chiang

Conference Title:
Advanced Coal-Fired Power Systems '95 Review Meeting

RECEIVED
NOV 29 1995
OSTI

Conference Location:
Morgantown, West Virginia

Conference Dates:
June 27-29, 1995

Conference Sponsor:
U.S. Department of Energy, Morgantown Energy Technology Center

DISCLAIMER

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, 175 Oak Ridge Turnpike, Oak Ridge, TN 37831; prices available at (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161; phone orders accepted at (703) 487-4650.

PA.7

High-Temperature Gas Stream Cleanup Test Facility

John S. Ontko
Ta-Kuan Chiang
Morgantown Energy Technology Center

OBJECTIVES

The High-Temperature Gas Stream Cleanup Test Facility (HTGSCTF) at the Morgantown Energy Technology Center (METC) will, when completed, provide a versatile platform for testing novel hot gas filtration concepts. Its flexible modular design can provide filter developers with data to characterize filter behavior under statistically controlled conditions. With one module currently in shakedown and components of a second on site, ready for construction, the facility will soon be available for joint ventures with Cooperative Research and Development Agreement (CRADA) partners.

BACKGROUND INFORMATION

Effective and economical hot gas particulate cleanup systems are essential to commercialization of advanced coal-fueled technologies. Pressurized Fluidized-Bed Combustion (PFBC) and the Integrated Gasification Combined Cycle (IGCC) require reliable particulate filtration both to ensure regulatory compliance and to protect expensive downstream components. To fully realize their inherent high thermal efficiencies, PFBC and IGCC filtration must be accomplished at elevated temperatures and pressures in an aggressive chemical environment. In addition, the pressure drop expended for filtration must not be excessive and the filters must have an acceptable life span. Thus aerodynamic, materials, and economic issues are all important to a successful design.

To aid in this effort, METC has undertaken the design and construction of a HTGSCTF. The facility's hardware and its capabilities are briefly described, followed by a discussion of the experimental methodology to be used.

PROJECT DESCRIPTION

The HTGSCTF consists of two modules capable of independent or parallel operation. They may also be cross-connected, if desired, if both are operating under combustion conditions. Consideration is also being given to operating one module under reducing conditions with synthesized gasifier product gas (Syngas). Modules may be operated at any pressure from atmospheric to the 550 kPa (80 psia) design pressure.

Both modules are controlled by two computer systems: one handles process monitoring and control, and the other is dedicated to high-speed data acquisition and control of the back pulse filter cleaning system. Process control may also be effected manually from the control room. Figure 1 is a schematic diagram showing

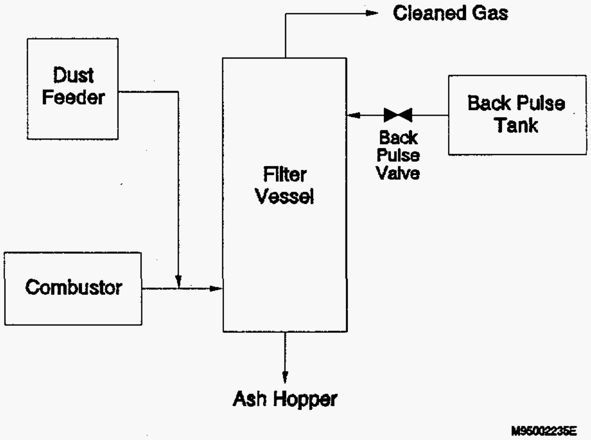

Figure 1. HTGSCTF Module Schematic Diagram

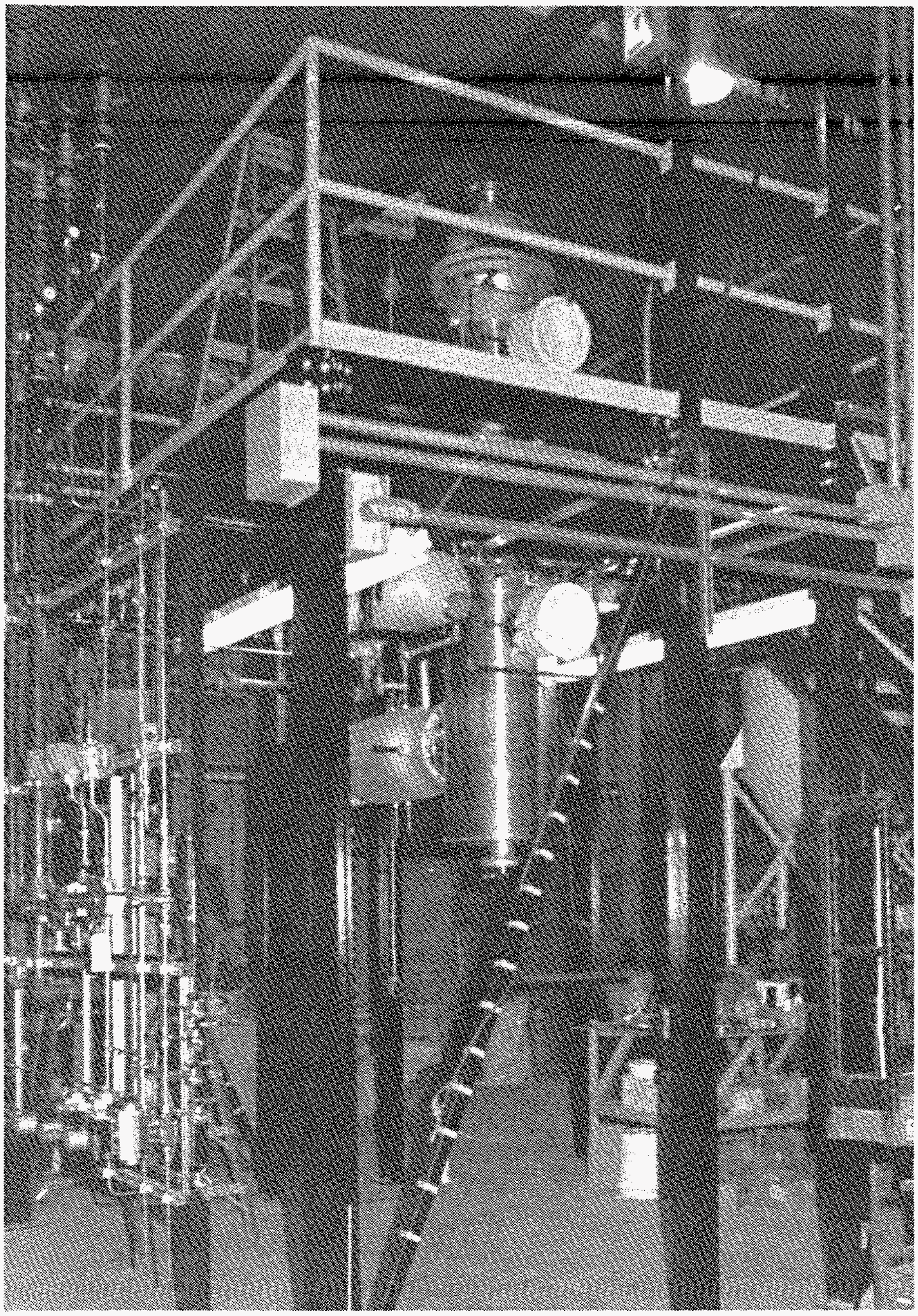

Figure 2. Module Under Construction

the major components of a module, and Figure 2 is a general view of a module under construction.

Combustor

The combustor consists of a refractory-lined pressure vessel, a burner nozzle, and the associated piping and instrumentation. Natural gas, primary air, and dilution air may be supplied up to the design pressure for a maximum throughput of 320 $\mathrm{kg \cdot hr^{-1}}$ (700 $\mathrm{lb_m/hr}$), or a maximum firing rate of 140 kW (480×10^3 Btu/hr). The combustion product temperature is adjustable by controlled heat loss and dilution air injection. A port is provided at the combustor discharge for introducing particulate material. The burner is a concentric tube axial flow swirl generator [1] (swirl number $N_{sw} = 0.78$) discharging into a diverging refractory nozzle. Combustion air mixes with fuel from radial ports in the annulus upstream of the swirl vanes. Testing at atmospheric pressure indicates the burner is capable of 8:1 turndown at stoichiometric conditions with good flame stabilization. A performance map over the entire range of pressure and equivalence ratio will be obtained during shakedown.

Filter Vessel

Figure 3 shows the filter vessel (without the head) in cross section. The vessel is mounted vertically and is refractory lined, providing a test volume 203 mm (8 in) in diameter by 3 m (10 ft) in length. The supporting structure has a stairway, deck, and an integral hoist to simplify filter change-out and maintenance. Filter mounting is provided by a water-cooled tube sheet that may be custom fabricated to accommodate the filter design under test. Eight ports are available for cooling water, back pulse jets, and instrumentation. Two flanges provided on one side of the vessel offer a choice of combustor mounting positions. Three nitrogen-purged viewing ports are furnished for remote observation via closed circuit TV; one of these may be sacrificed for additional instrumentation, if required. The dust hopper (not shown) is bolted to the lower flange and may be interchanged with a spare to provide substantially continuous testing.

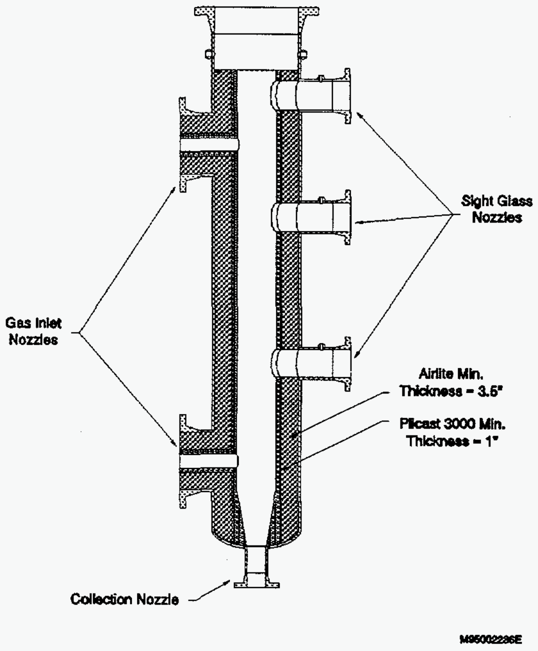

Figure 3. Filter Vessel Cross Section

Dust Feeder

The combustion product stream is seeded with particulate material by a loss-in-weight, twin-screw feeder mounted in its own pressurized vessel. Dust may be fed at rates of 23 $\mathrm{kg \cdot hr^{-1}}$ (50 $\mathrm{lb_m/hr}$) or more, depending on dust properties and the feed screws selected; the complete feed screw set range is available. Tests indicate that feed rate error is typically ± 4 percent full scale at the 95 percent confidence level. The feeder vessel is pressurized by nitrogen at 1.3 MPa (185 psia), which provides the motive power for conveying particulate material to the combustor dust port. The dust feeder supply hopper may be replenished while the vessel is pressurized. METC has a stock of fly ashes from various sources. Dust supplied by CRADA partners can also be used, if desired.

Back Pulse Cleaning System

The back pulse cleaning system consists of a nitrogen back pulse surge tank, four fast-acting back pulse valves, and a dedicated high-speed data acquisition and control computer. The system may be pressurized up to 3.1 MPa (450 psia), which gives a 5.6:1 back pulse to process pressure ratio when the system is operating at design pressure. Back pulse valve firing time and sequencing parameters are selected by the operator. The mass of nitrogen injected during each back pulse event is inferred thermodynamically from temperature and pressure traces from instrumentation in the back pulse surge tank. The tank is isolated from the high-pressure nitrogen header that supplies it, except while charging.

Experimental Methodology

The HTGSCTF has been designed to produce high-quality data. To extract the maximum information the precision of the instrumentation will allow, statistical experimental techniques will be used. It is expected that factorial experiments, response surface methodology, and times series analysis will be the mainstays of the project [2,3]. The best method to use will depend on the problem at hand, and will be worked out in consultation with the CRADA partner on a case-by-case basis.

Particle Capture

The overall particle capture efficiency, η, may be defined as the fraction of the incoming particulate mass that is captured. As was mentioned previously, the dust feed rate error is on the order of ± 4 percent full scale, so determinations of η will be of commensurate accuracy. Short of filter breaching, we expect $\eta > 0.99$ as a matter of course.

Study of the deposited dust cake should yield valuable insights into filter performance. METC has considerable expertise in particle technology, surface science, and gas-solid computational fluid dynamics (CFD). A new Particulate Control Technology Laboratory provides facilities for the evaluation of dust cake mechanical properties. Surface science services include, but are not limited to, particle size and distribution measurements, surface property evaluation, and chemical analysis. METC's two-phase CFD expertise [4] has been of proven value to filter system designers and software developers. While not dedicated solely to this project, CRADA partners have these capabilities at their disposal should they be required.

Pressure Drop

Figure 4 shows, in idealized form, the filter system conditioning process. The pressure drop, Δp, increases during time interval, Δt_1, from

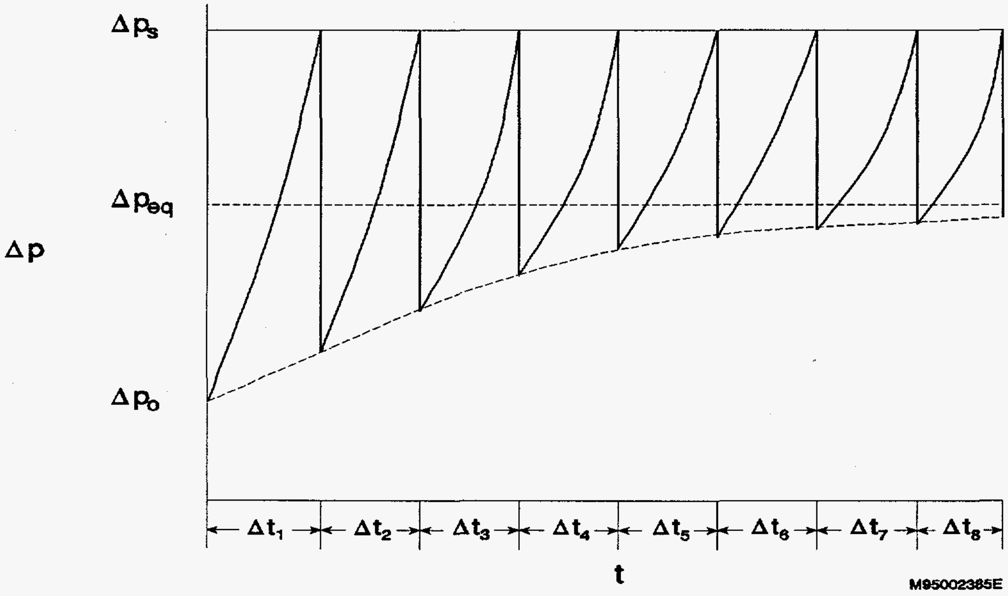

Figure 4. Idealized Filter System Pressure Drop History During Conditioning

Δp_0, the pressure drop associated with the virgin filter elements, to Δp_s, the back pulse trigger setpoint. The filters are then cleaned, reducing the pressure drop to a new minimum value $\Delta p_1 > \Delta p_0$. This process continues with $\Delta p_{n+1} > \Delta p_n$; eventually, it is hoped, a stable minimum equilibrium pressure, Δp_{eq}, is attained. Evidently, the pressure drop, Δp, at time, t, may be expressed as

$$\Delta p = \Delta p_0 + \Delta p_c \ , \tag{1}$$

where Δp_c is a function of time attributed to dust cake growth. By dividing Equation (1) by the superficial or face velocity $v_s = Q/A_s$, where Q is the gas volumetric flow rate and A_s the total filtration area, Williams, Hatch, and Greenburg [5] obtained

$$S = S_0 + K_2 W \ . \tag{2}$$

The use of Equation (2) is customary in fabric filtration; the specific resistance coefficient, $K_2 = \Delta p_c / v_s W$, where W is the so-called areal cake density, i.e., the mass of the filter cake divided by A_s. Assuming a constant inlet solids loading and $\eta \approx 1$, if K_2 were constant, S (or Δp) would increase linearly with time. Rather than being a constant, K_2 has been found to depend, among other things, on the dust cake porosity ε, the particle density ρ_p, the inlet cumulative particulate mass distribution Φ, the inlet dust loading, and the operational history of the filter system [6,7]. With rigid ceramic filters, there is some question whether a true Δp_{eq} is ever attained.

Let δ be the average bed (cake plus filter) thickness, κ the effective Darcy permeability, ρ_g the gas density, and μ the gas viscosity. For a Darcy's Law medium, it may readily be shown that

$$N_p = \frac{\delta A_s^{1/2}}{\kappa} N_{Re}^{-1} \ , \tag{3}$$

where the pressure coefficient $N_p = \Delta p \, A_s^2 / \rho_g Q^2$ and the Reynolds number $N_{Re} = \rho_g Q / \mu \, A_s^{1/2}$.

Equation (3) represents a generalization of Equation (2); both δ and κ may vary in complicated ways, as indicated in the previous paragraph. There may also be departure from Darcy's Law. Then Equation (3) no longer holds, though it still supplies two dimensionless variables useful for designing experiments. If we fix the inlet particulate mass distribution and its properties, but consider the inlet particle mass flow rate m and time, dimensional analysis and Equation (3) yield

$$N_p = f(N_{Re}^{-1}, \ N_L, \ \tau) \ , \tag{4}$$

where f is an unknown function to be estimated, $N_L = m/\rho_g Q$ is the loading number, and $\tau = tQ/A_s^{3/2}$ is the dimensionless time. Equation (4) provides a compact framework for the process control variables. Subtler effects involving Φ and operational history require careful consideration when designing a complete experiment.

FUTURE WORK

Upon completion of shakedown, one module of the HTGSCTF will be available for CRADA work. As scheduling permits, the second module will be constructed and put into operation. Interested potential CRADA partners are encouraged to contact the authors for further information.

REFERENCES

1. Beér, J. M., and N. A. Chigier. 1972. *Combustion Aerodynamics*, pp. 110-111. London: Applied Science Publishers.
2. Box, G. E. P., W. G. Hunter, and J. S. Hunter. 1978. *Statistics for Experimenters*. New York: John Wiley & Sons.
3. Box, G. E. P., and N. R. Draper. 1987. *Empirical Model-Building and Response Surfaces*. New York: John Wiley & Sons.

4. Syamlal, M., W. Rogers, and T. J. O'Brien. 1993. *MFIX Documentation Theory Guide*. DOE/METC-94/1004. NTIS/DE94000087. Springfield, VA: National Technical Information Service.

5. Williams, C. E., T. Hatch, and L. Greenburg. 1940. Determination of Cloth Area for Industrial Air Filters. *Heating, Piping, and Air Conditioning* 12:259-263.

6. Rudnick, S. N. 1978. *Fundamental Factors Governing Specific Resistance of Filter Dust Cakes*. Thesis. Boston: Harvard School of Public Health.

7. Dennis, R., and J. A. Dirgo. 1981. Comparison of Laboratory and Field Derived K_2 Values for Dust Collected on Fabric Filters. *Filtration & Separation* 18(5):394-396.