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Project Summary

Measurement of High-Temperature High-Pressure Processes—A Summary Report

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The major focus of this program was on particulate sampling in advanced coal conversion technologies. Work performed was to assess and develop the technology required to perform high-temperature high-pressure particulate sampling. In addition to the effort denoted to development and testing of an HTHP sampler for the EPA/Exxon Miniplant, experience was gained in design aspects of HTHP sampling equipment and testing procedures. A background study and planning effort was directed toward possible future sampling efforts in a coal gasification facility. A state-of-the-art review of HTHP sampling was also performed. As a means of documenting the materials collected, a bibliography of articles, reports, and books relating to HTHP sampling was compiled. Further, a mailing list of persons interested in this technology is included in the final report.

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

Overview of the Problem

Sampling for particulate matter in hostile environments is a technology that is still in the early stages of development. The need for these techniques, however, is yet to be fully realized. High-temperature or high-pressure (HTHP) sampling is integral to the resolution of environmental concerns resulting from the development of emerging energy conversion technologies. There are also potential applications for HTHP sampling in current technologies, including those in the petrochemical industry.

The major focus of this program was on particulate sampling in advanced coal conversion technologies. Those technologies of particular interest were pressurized fluidized-bed combustion (PFBC) and coal gasification (CG). Although CG received attention during this program, far more effort was devoted to PFBC.

At present it has become more and more evident that the successful development of a PFB combined-cycle power system hinges on the ability to produce a clean gas stream. The reasons for providing a clean gas stream are two-fold: (1) from an environmental point of view, low levels of particulate emissions must be achieved so that limits set by the EPA and state regulatory agencies can be met; and (2) more importantly to the power system developer, the hot gas stream must be sufficiently free of particulate matter to allow for long turbine life. In general, it cannot be conclusively stated that meeting one criteria automatically satisfies the other in all cases. A lot depends on the required control level of environmental emissions in a given location and the particular design constraints of the turbine in question. Nevertheless, this all points to the fact that HTHP particulate and gaseous cleanup systems must be developed to provide for high thermodynamic efficiency (by cleaning at elevated temperatures and pressures) and long system life (by maintaining low levels of erosive and corrosive materials). The report focuses predominately on those aspects related to particulate collection.

To develop cleanup systems to meet environmental and turbine standards, it is necessary to perform stream sampling both upstream and downstream of each cleanup stage. In so doing, the removal efficiency of each stage can be determined. The measurements must be accurate and comprehensive. Not only must total stream particulate loading be measured, but also particle size distribution must be determined. It is well known that the particle size distribution strongly affects the erosion and deposition of turbine components. In addition, the chemical composition of the particulate is important from the standpoint of corrosive reactions that can occur within the cleanup system and on turbine surfaces.

Hence, it is clear that the sampling system must be accurate, reliable, and allow for post-examination of the sample. The system should provide the capability to survey across the duct to determine nonuniformities in particulate concentrations and particle size stratification.

The system constraints defined above all point to the selection of an extractive sampling approach for the purpose of developing advanced power systems. *In situ,* laser/optical approaches to particulate measurement are currently under development. Most of these methodologies are yet to be proven in HTHP environments. Once they are fully developed, they will be extremely useful tools, but in many applications their primary function will be for monitoring system upsets on an operational power system. In addition, their operation is generally based on the principle of optical light scattering to determine an optical diameter. The more conventional extractive approaches discussed here collect and size particulate matter on the basis of particle aerodynamic diameters. This parameter directly correlates to the operational function of inertial and non-inertial cleanup devices (cyclones, barrier filters, and granular beds) and the turbine itself.

The arguments delineated previously for the selection of an extractive approach to particulate sampling for the development of PFBC power systems can easily be extended to the development of other coal conversion technologies currently under development such as low-Btu gasification combined power cycle and magnetohydrodynamic (MHD) coal conversion technologies.

Summary of Work Performed

The purpose of work performed was to assess and develop the technology required to perform HTHP sampling. Efforts were put forth in several directions. The major emphasis of this program was on the development of HTHP sampling hardware for coal energy conversion technologies. Other activities included the development of special purpose sampling hardware for coke oven sampling, a versatile probe for sampling conventional/combustion processes at EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC (IERL-RTP) experimental facilities and the HT calibration of series cyclone trains for the EPA Source Assessment Sampling System (SASS). The information in the report concentrates on the findings of those activities related to coal conversion technologies.

The major portion of work performed included the development of sampling hardware and subsequent testing in a PFBC test rig. These efforts were eventually brought to fruition at the Exxon Miniplant in Linden, NJ, in March 1977. Two test series were performed at duct conditions at 9 atm and 1350°F.

Valuable experience was gained in the design aspects of HTHP sampling equipment and testing procedures. These related to probe design, sampling procedures, and data analysis. The highlights of the information obtained are explained in more detail in the full report.

In addition to the emphasis placed on PFBC sampling, a background study and planning effort was directed toward possible future sampling efforts in a CG facility. A survey was performed to identify likely test sites and determine what sampling requirements and problem areas would be encountered. This, in turn, led to a study of how best to sample gas streams containing tar vapors. Several methods were proposed for separating and collecting these tars from the solid particulate matter present. A design exercise led to a proposed system for sampling in a CG process stream.

Concurrent with the experimental tasks performed at the Exxon Miniplant, a state-of-the-art (SOA) review of the HTHP technology was performed. The activities carried out under this portion of the program were also varied. They included a study of practical techniques for measuring stream variables such as pressure, temperature, and velocity. A comprehensive telephone survey was carried out to determine the possible future applications and requirements for HTHP sampling. The survey included special sampling problems that might be expected to occur in practice.

Other SOA review activities included a detailed study of problems associated with the selection of materials for HTHP probes. Material problems occurring in the reducing atmospheres found in CG systems present a much more severe problem than those associated with oxidizing environments such as those in FBC applications. Highly corrosive gases, such as H^2S, present at elevated temperatures pose substantial problems to the HTHP probe designer in selecting metals capable of withstanding these exposures.

Finally, as a means of documenting the materials collected, a bibliography of articles, reports, and books relating to HTHP sampling technology and selected coal conversion technologies was assembled and is contained as an appendix in the full report. In addition, through the various contacts established in the course of the project, a mailing list of interested persons was prepared. This mailing list is also an appendix in the full report.

General Findings and Recommendations

The major effort conducted was a demonstration of the extractive HTHP sampling approach at the Exxon Miniplant. Test conditions were 9 atm and 1350°F. The major findings of this portion of the program are summarized below.

The first of two test series demonstrated that the PFBC test stream could be successfully contained using a concentric tube sliding seal approach in conjunction with a double gate valve arrangement for sampler isolation while not in use. (See Figure 1.) Procedures for probe insertion, sampling, and withdrawal were successfully demonstrated during the different test runs.

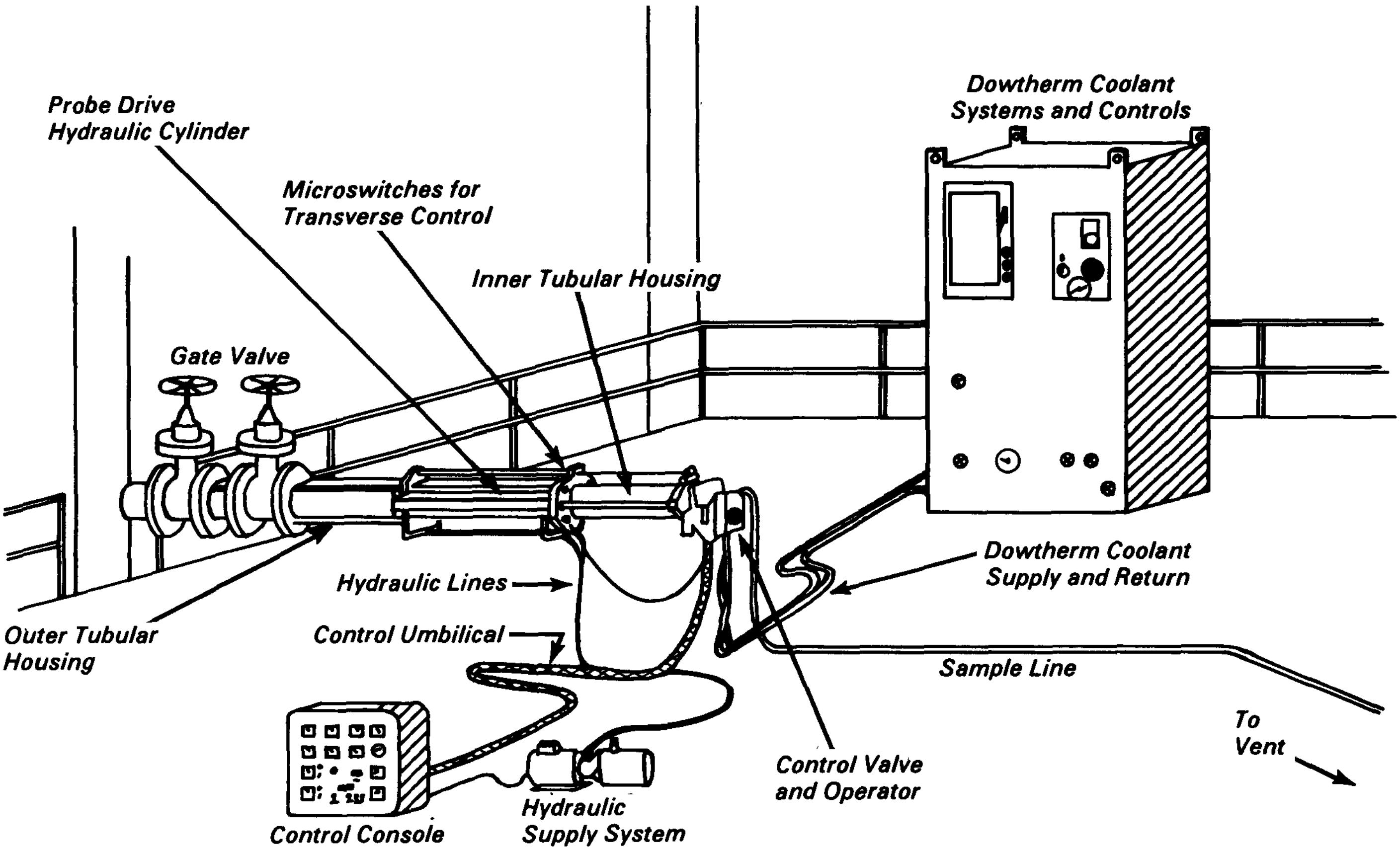

Figure 1. *High-temperature, high-pressure (PFBC) sampling system.*

Test gases were cooled using a Dowtherm cooling system to a nominal 450°F, and conventional impactor and filter designs were used. During the demonstration tests, particulate samples were collected both on a series of seven impactor plates (two runs) and also on a thimble filter (one run). Repeatability of test data using the two impactor test runs was judged as good to excellent. Particulate matter was collected during the two impactor runs over a size range of 0.3 to 30 μm. This material was subsequently examined photomicrographically and analyzed chemically. Results of this analysis yielded no unexpected results.

A second test series was conducted to examine the possible occurrence of alkali metal condensation during sample cool down prior to collection. The sampling probe was reconfigured so that the sample first passed through a scalping cyclone and total filter combination at test stream conditions. Subsequently, the sample was cooled by the Dowtherm cooling system followed by a second total filter. If alkali metal condensation had occurred then it was expected that the downstream filter catch would show a larger alkali metal content. Chemical analysis failed to show any significant alkali metal condensation effects although these limited results were by no means conclusive.

The Exxon results demonstrated that the methods developed and the results produced were wholly satisfactory for this application. Had the technology been demonstrated at the time, cyclones calibrated for HTHP operation would have proven more versatile and eliminated the need for cooling prior to collection.

The experience of the Exxon sampling program, especially with regard to hardware development and the results of the SOA survey, pointed to various conclusions regarding the universality of future sampler designs. Owing to the wide range of test stream conditions (including temperature, pressure, gas composition, particulate loading, stream velocity, and duct diameter), the impact upon standardization of design is great. It was found that design requirements tend to be nonstandard, thus sampler designs require custom design approaches in response to the particular set of above mentioned parameters.

These broad design requirements inevitably lead to new engineering problems and a consequential custom engineered system. Based on experience gathered during this program, the costs of engineering, designing, calibrating, and acceptance testing of these systems are deemed to be very high. As a result, the development costs of one-of-a-kind systems are high with subsequent cost reduction occurring on duplicate systems if they are required.

Some new approaches to HTHP sampling system design were identified. Future systems can conceivably be built at lower cost with greater versatility and safety by using a "total enclosure" design approach in which the traveling probe is totally isolated, thus eliminating the need for sliding seals. It was concluded that HTHP cyclones need to be developed and tested as a means of increasing the allowable sampling time over that of impactors. Where a cooling system may be required to condense water and acid constituents, a water mist approach may prove simpler and less subject to maintenance problems than the Dowtherm system used at Exxon.

In addition to these improvements, new forefronts of research and development were identified. The next challenging problem confronting HTHP sampler developers is that of CG emissions sampling. Problems such as separation and collection of tars, selection of probe materials compatible with corrosive reducing atmospheres, and explosion hazards must be overcome. These problems are not simple and will be overcome only through diligent research and development programs.

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The complete report, entitled "Measurement of High-Temperature High-Pressure Processes—A Summary Report," (Order No. PB 82-196 932; Cost: $13.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

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