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MOVING GRANULAR-BED FILTER DEVELOPMENT PROGRAM

TOPICAL REPORT

BASE CONTRACT TEST PLAN

By

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1. INTRODUCTION AND PROGRAM OVERVIEW

The current moving granular-bed filter technologies are large, complex, and costly systems in terms of their capital investment, their operating and maintenance cost, and their impact on the power plant efficiency. They are not easily and effectively integrated into advanced power plant environments. In addition, their effectiveness as filters is still in question. Their apparent attributes, relative to ceramic barrier filter systems, result from their much less severe mechanical design and materials constraints, and the potential for more reliable, failure-free particle removal operation.

The Westinghouse Science & Technology Center has proposed a novel moving granular-bed filter concept, the Standleg Moving Granular-Bed Filter (S-MGBF) system, that overcomes the inherent deficiencies of the current state-of-the-art moving granular-bed filter technology. The S-MGBF system combines two unique features that make it highly effective for use in advanced coal-fueled power plants, such as pressurized fluidized-bed combustion (PFBC), integrated coal-gasification combined cycles (IGCC), and direct coal-fueled turbines (DCFT). First, the S-MGBF system applies pelletization technology to generate filter pellets from the power plant solid waste materials, and uses these pellets as a "once-through" filtering media to eliminate the need for costly, complex, and large filter media recycling equipment. This pelletizing step also generates a more environmentally acceptable solid waste product and provides the potential to incorporate gas-phase contaminant sorbents into the filtering media. Secondly, the S-MGBF system passes these pellets and the flyash laden power plant gas through a highly compact S-MGBF that uses cocurrent gas-pellet contacting in an arrangement that greatly simplifies and enhances the distribution of dirty gas to the moving bed and the disengagement of clean gas from the moving bed.

The S-MGBF development program is currently in the initial, Base Contract period of a four-phase program. The objective of the Base Contract period is to identify the barrier technical issues and demonstrate conceptual feasibility. The technical approach applied to achieve the Base Contract objective is to conduct 1) commercial plant conceptual design evaluation, in combination with 2) commercial technology assessment, and with 3) laboratory and bench-scale testing subtasks that focus directly on barrier issues. These three activities are performed in parallel to ensure that each has the appropriate perspective to provide significant results.

This document details the test plan to be performed during the Base Contract to demonstrate the basic feasibility of the S-MGBF with respect to the barrier technical issues.

2. SUMMARY AND CONCLUSIONS

The S-MGBF development approach is based on the conceptual design of a standard S-MGBF module with gas throughput sufficient to produce a system competitive with ceramic barrier filter technology. A previous topical report, Barrier Technical Issues, submitted to DOE in July 1991, in fulfillment of Task 1 of the Base Contract, assessed the technical issues for the concept and identified the barrier technical issues.

The S-MGBF development program must resolve two classes of barrier technical issues:

- The ability to generate sufficiently durable pellets by practical, economical pelletization methods that can be closely integrated into the advanced power plant,
- The ability to achieve sufficient levels of flyash removal with the compact, standard S-MGBF module to meet environmental standards and turbine protection needs.

A test plan has been devised that will resolve the barrier technical issues in the Base Contract period to the extent of demonstrating the feasibility of the concept. Three test activities are defined, one directed toward pellet production and durability, one directed toward filter cold flow modeling of the S-MGBF dynamics, and one directed toward high-temperature, high-pressure (HTHP) filter testing. The test plan document contains the following information:

- An explanation of:
  - The approach applied in the testing,
  - How test results will be interpreted.
- A conceptual design description of the component test facilities to be used.
- Descriptions of the test activities:
  - Objectives
  - Procedures
  - Permissible ranges of key parameters
  - Performance goals
  - Data to be collected
  - Test matrices
- Estimated cost of each of the test facilities and the cost of each test activity.

The test plan is constrained to consider test variable ranges that are feasible for competitiveness with ceramic barrier filters, and conditions that are representative of PFBC and IGCC. Actual PFBC and IGCC power plant solid waste materials and flyashes are desired for use in the testing, but backup materials are also identified if actual sources can not be obtained. The test plan is based in part on an evaluation of the alternative techniques and options for pelletization performed as part of Task 6, the Commercial Conceptual Design task. Both conventional, low-temperature pelletization techniques, and advanced, high-temperature pelletization approaches that may integrate more efficiently into the power plant are considered.

3. BASE CONTRACT APPROACH TO RESOLVE ISSUES

Testing in the Base Contract is highly focused to demonstrate technical feasibility with respect to the barrier technical issues, while later phases of the program address process performance improvements, advanced features, and economic optimization. The approach applied in the Base Contract is to select test conditions (design and operating parameters) that fall within the realm of acceptability for economical competitiveness with ceramic barrier filters, and that are representative of the PFBC and IGCC environments.

The test activities are:

- Pelletization Production and Durability
- Cold Flow Model Dynamics
- HTHP Filter Feasibility Demonstration

The first test activity, Pelletization Production and Durability, looks at two general alternatives for pelletization: conventional, low-temperature methods that use water and/or binders for pelletization; and high-temperature, high-pressure methods adapted from conventional techniques that have apparent power plant efficiency advantages. Testing of actual PFBC and IGCC wastes is desirable. Testing will be conducted initially at small scale using conventional pelletization approaches performed by commercial vendors of pelletization equipment. Westinghouse will conduct high-temperature, high-pressure pelletization testing using nonstandard, high-temperature pressing equipment. The testing will look at the durability of the pellets generated by standard durability tests, as well as by special durability tests that relate to the conditions the pellets must endure in the S-MGBF.

The second test activity, Cold Flow Model Dynamics, looks at the S-MGBF gas, pellet and flyash flow behavior under simulated large-scale conditions using a cold flow model designed to simulate HTHP conditions. The particle removal performance and pressure drop characteristics of the S-MGBF will be measured at conditions representing PFBC and IGCC environments (similar flyash loadings, flyash types, pellet-to-flyash mass ratio), with the gas flow limited to economically feasible ranges (3-6 ft/s through the standleg). Special S-MGBF design and operating features will be varied during the tests to determine their impact on the achievement of acceptable performance (pressure drop and flyash penetration). Local conditions within the filter will be observed to identify design and operating concerns and improvements.

The third test activity, HTHP Filter Feasibility Demonstration, is a proof-of-concept test of the HTHP S-MGBF performance based on the special design and operating features identified in the cold flow model testing. The HTHP testing is performed using PFBC or IGCC flyash materials re-injected into a HTHP gas stream. The HTHP test system is operated under oxidizing conditions only. The basic concept feasibility, primarily particle removal performance and pressure drop, are again demonstrated at representative conditions using economically limited test variables.

4. INTERPRETATION OF TEST RESULTS

The interpretation of the tests must be directed toward the feasibility issues of pellet durability and particle removal efficiency under operating conditions that are economically feasible in commercial operation, while achieving acceptable performance (e.g., pressure drop), and using commercially feasible pelletization techniques. Pelletization testing by commercial pelletization vendors ensures that realistic conclusions will be generated based on commercial experience. Adaptation of commercial pelletization techniques to non-commercial conditions (high-temperature and high-pressure) will require further development and assessment. Pellets must be sufficiently durable to survive the process handling, pressurization, feeding, S-MGBF flow, withdrawal, cooling, and depressurization only to the extent that both the particle emissions and pressure drop achieve acceptable levels. It is an added benefit, but not a necessary feature, if the pellets also have long-term, environmental stability for disposal.

Cold flow modeling will be carried out at a scale approaching the full-scale module dimensions (1/6-th of the commercial module diameter), and gas and particle flow will be scaled to high-temperature, high-pressure conditions by dimensional analysis and using available correlations. The performance of the cold model must be acceptable in terms of pressure drop, and particle emissions. Representative performance goals are, when scaled to HTHP conditions:

	PFBC	IGCC
Pressure Drop (psi)	3	6
Particle Emission (ppmw)	20	100

The HTHP testing will be at a smaller scale than the cold flow modeling (a factor of 2 smaller in standleg diameter), and will be interpreted directly with respect to particle removal efficiency and pressure drop. System operability and reliability will also be assessed in the testing, comparing startup and other transient condition limitations with those for ceramic barrier filters.

5. CONCEPTUAL DESIGN OF COMPONENT TEST FACILITIES

Conceptual designs for the S-MGBF cold flow facility and for the HTHP filter facility are shown, and descriptions of the major features are presented in this section. The Westinghouse Hot Press equipment that will be used in the program is also described.

5.1 Cold Flow Facility

Figure 1 is a conceptual layout drawing of the S-MGBF cold flow model. The central view of the vessel shows the vessel cross-sectioned internals. The dirty gas enters tangentially at the vessel aluminum top piece, and an optional radial inlet is also available. The pellets enter through a dipleg arranged axially at the top of the vessel. The gas flows cocurrently downward with the pellets through the Plexiglas cone section, then through the 1 ft diameter standleg section at a maximum design velocity of 6 ft/s. The volumetric gas flow rate of the cold model is 1/36-th of the full-scale, commercial module flow. At the exit from the standleg the gas turns to flow upward, disengaging from the pellets, and exits radially from the vessel. An alternative gas outlet is shown in the bottom Plexiglas section to provide flexibility for the outlet location. Use of this alternative gas outlet requires the two Plexiglas sections to be rearranged.

The standleg is supported by a ring located at the tip of the standleg, and this ring has eight holes inserted for the exit gas to pass through. The pellets flow out of the conical bottom of the vessel. The base of the standleg is designed so that alternative features may be added to assist in the disengagement of the gas from the pellets, and/or for limiting local fluidization and flyash entrainment.

The other two drawing views in Figure 1 show the two major Plexiglas sections and the aluminum top in two orientations, including the gas outlets and the instrumentation ports. The Plexiglas is 1" thick and the design pressure is 10 psig. Reinforcement beams also support the Plexiglas vessel wall. The three section drawings highlight the details of the top inlet piece, the gas inlets and outlets, the flanges, and the internal support piece for the standleg.

Figure 2 is a conceptual arrangement drawing of the cold flow facility showing the pellet feeding and withdrawal equipment arrangement within the high-bay test area. A storage and feed bin is located at the top, and a slide valve is used to shut off the pellet flow from the bin. The Plexiglas model of the S-MGBF is directly under the pellet feed bin.

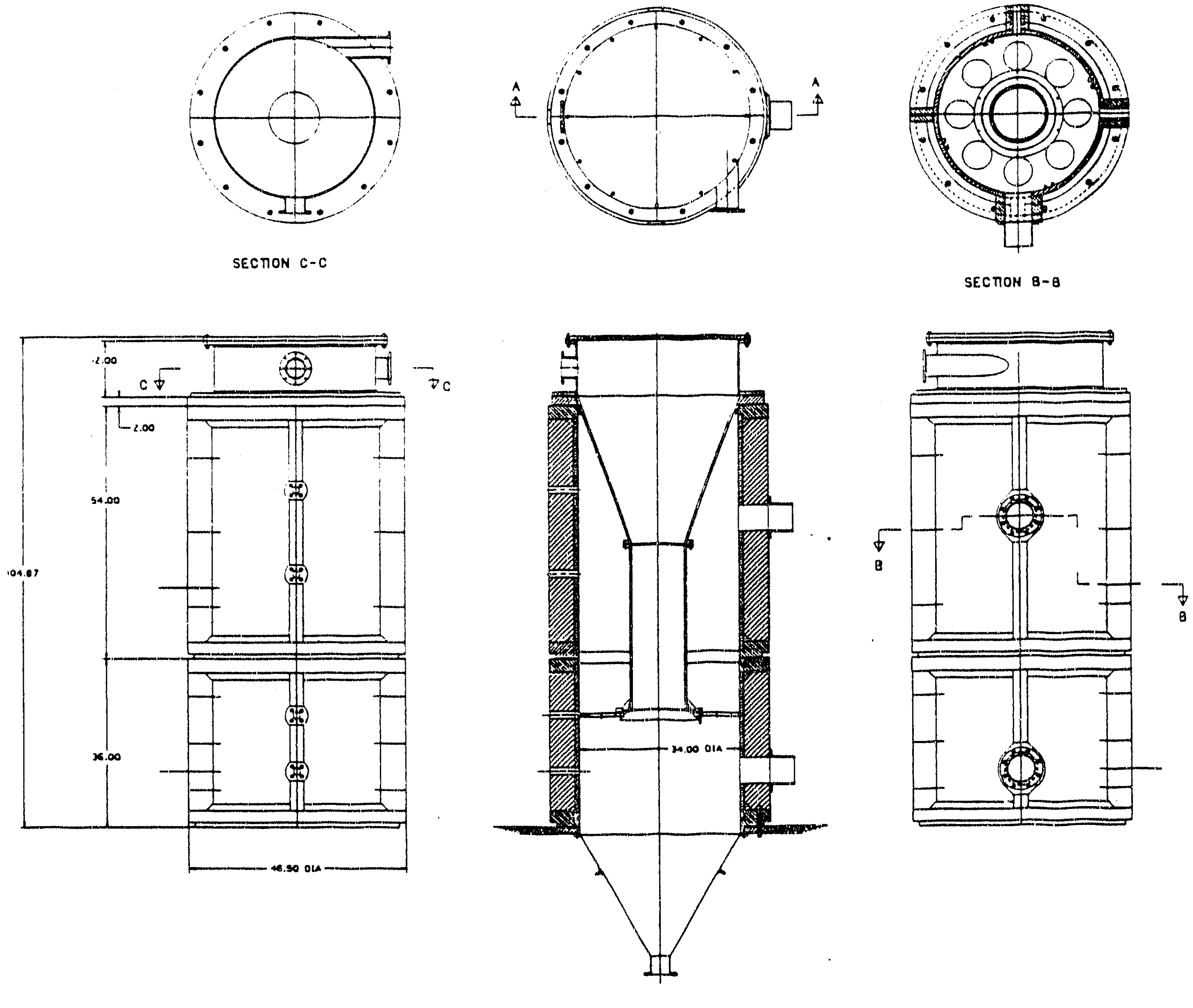


Figure 1 - Cold Flow Model Conceptual Layout

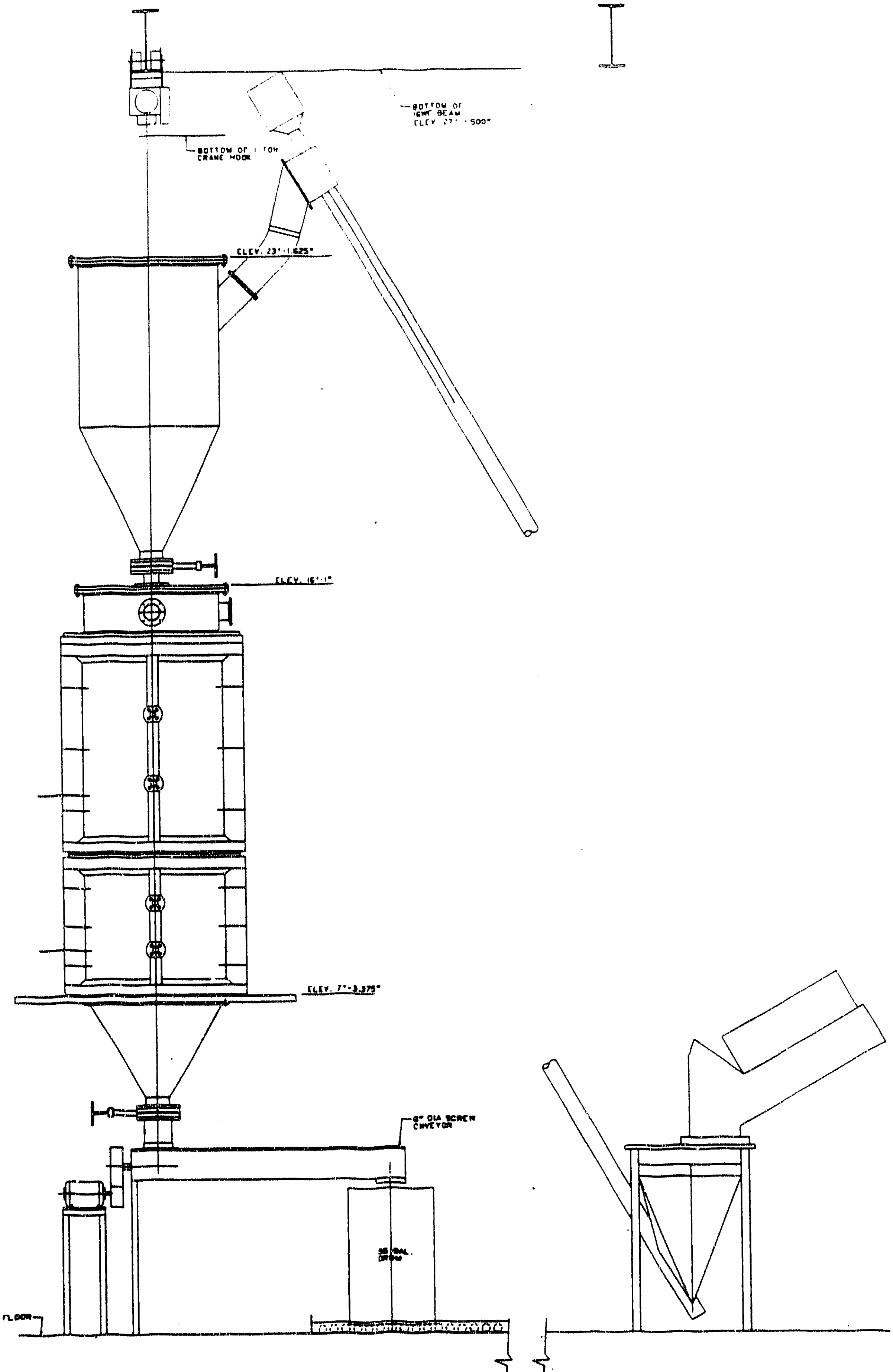


Figure 2 - Cold Model Facility Arrangement

The conical outlet from the cold model passes pellets into a screw conveyor that loads the pellets into 55-gal drums for storage and disposal. The screw conveyor controls the rate of pellet flow through the cold model. The drums are moved on the floor level conveyor. Various alternatives were considered for loading the pellets into the feed bin, including a flexible screw conveyor, a belt conveyor, and a load-and-lift method. The selected method is the load-and-lift approach, with the feed bin lowered to the floor level, loaded with pellets dumped from 55-gal drums, and then lifted by hoist to its feeding position above the cold flow model.

The P&ID for the cold flow model test facility is essentially represented by the HTHP facility P&ID shown in Figure 4. The major components are a new air blower system and air supply system; the Plexiglas model; the pellet handling, feeding, and withdrawal equipment, the flyash feeding system, and the air exhaust system with their associated flow controls and instrumentation for temperature, pressure, and pressure drop measurements. The air exhaust system includes a conventional filter that will collect particulate material as a batch collection for the determination of the S-MGBF flyash penetration.

The maximum flow rates of the major process streams in the test program are:

- Air flow: 283 acfm
- Flyash flow: 6 lb/hr
- Pellet flow: about 100 lb/hr

5.2 HTHP Test Facility

Figure 3 is a conceptual layout drawing and P&ID for the auxiliary systems of the S-MGBF HTHP test facility. The pressure vessel is an existing, refractory-lined vessel used for ceramic barrier filter testing. The pressure vessel head is a new design to accommodate the gas inlet and the support of the vessel internals. The essential vessel features are identical with those described for the cold model, except

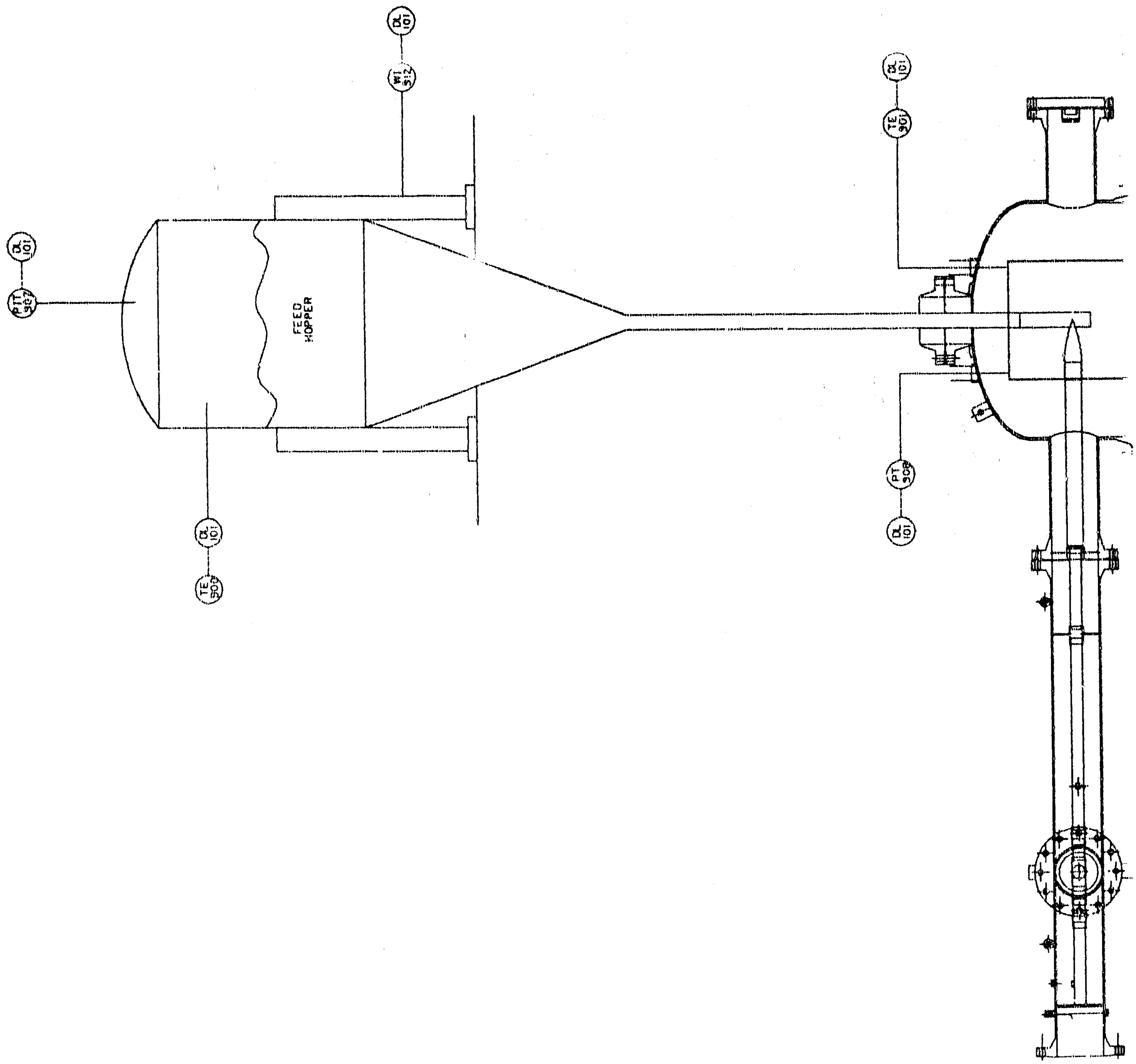
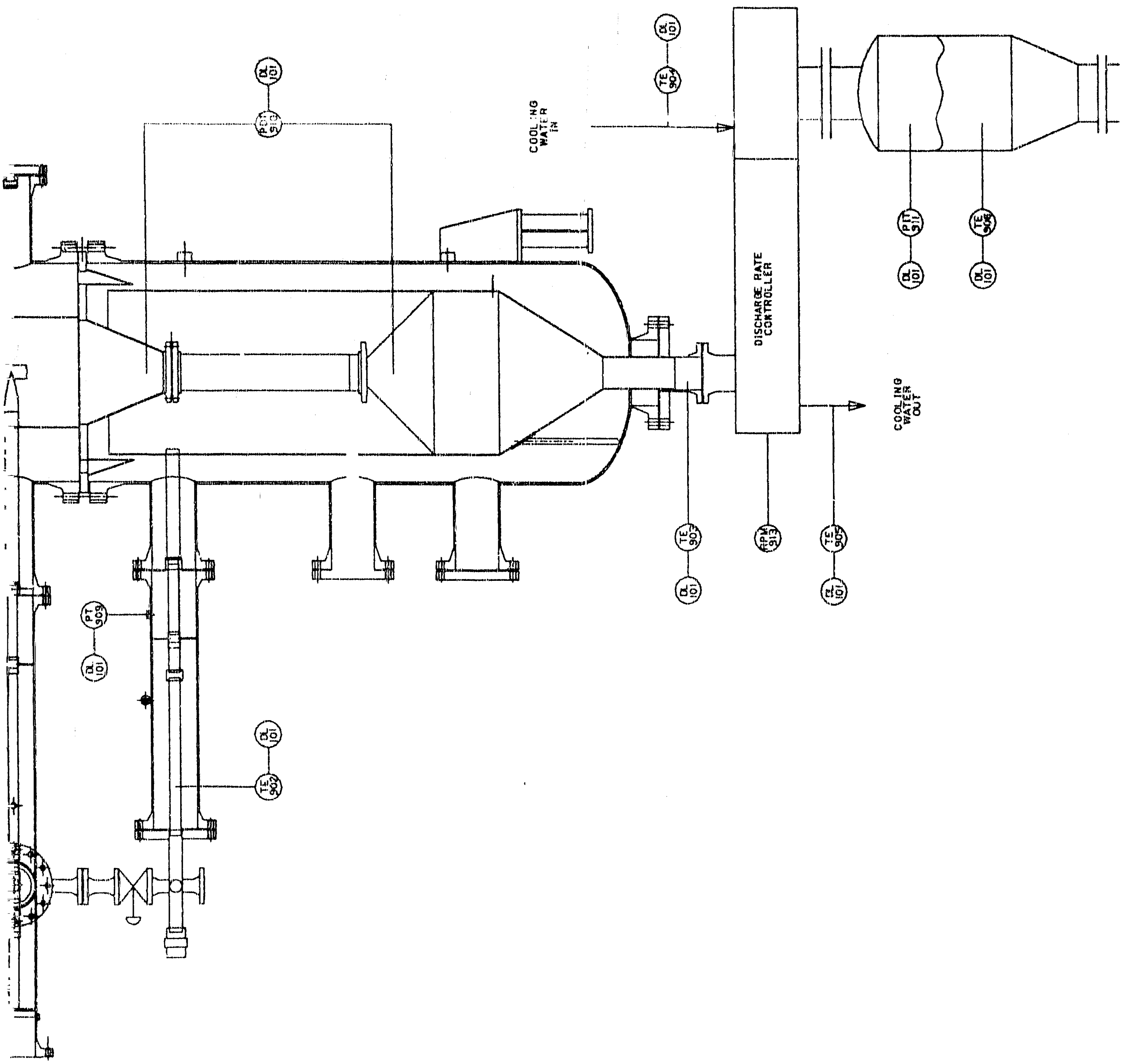


Figure 3 - HTHP Unit Conceptual Layout and P&ID



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the vessel and internals are designed for operation at 1600°F and up to 350 psig pressure. The dirty gas enters tangentially into the vessel. As in the cold model, an alternative radial gas inlet has been included in the head. The pellets and gas pass cocurrently downward through the high-alloy cone and standleg pieces, and gas disengagement occurs at the base region of the standleg. The standleg has a 6" diameter in this vessel, so the HTHP unit has 1/4 of the cold model actual volumetric flow. The pellets and collected fly ash pass out through the conical base.

The internal support structure within the vessel for the cone and standleg pieces is similar in design to the tube sheet used in the ceramic barrier filters. The expansion web accommodates the thermal expansion of the materials. The gas seals are located at the cold vessel flange.

Figure 4 shows the conceptual arrangement of the major equipment in the HTHP test facility. A batch loaded, pressurized pellet feed bin is located on the building roof, directly above the HTHP unit. The feed bin sits on a load cell to monitor the bin weight. A slide valve is placed below the feed bin to shut off the pellet flow. A high-temperature valve (e.g., water-cooled screw) controls the flow rate of pellets through the unit, and feeds the pellets into a pressurized storage hopper. Hot combustion gases are generated by a natural gas fired combustor, and flyash is injected into the combustion products before entering the filter vessel. A K-Tron screw feeder contained in a pressure vessel is used to control and measure the flyash feed rate. Water-cooled piping carries the exhaust gas from the vessel to the pressure letdown valve, and the building exhaust.

The P&ID for the HTHP test facility, as is shown in Figure 3, shows the two air compressors that can supply up to 1500 lb/hr of air at 200 psig, and the associated flow controls. A natural gas compressor supplies the high pressure natural gas for the combustor. The air stream is split so part of it goes to the combustor and part of it goes to the flyash feeder. The flyash feed is injected just downstream of the combustor so it can be heated before entering the upper end of the S-MGBF.

Figure 4 shows the P&ID for the various S-MGBF components. Provisions for measuring temperatures, pressures and differential pressures are available. A computer based data logging system is used to collect and display the data during testing and to reduce it after the test.

The maximum flow rates of the major process streams in the test program are:

- Gas flow: 71 acfm, or 820 lb/hr
- Flyash flow: 4 lb/hr
- Pellet flow: about 80 lb/hr

5.3 Westinghouse-STC Hot Press Facility

Westinghouse STC has two Vacuum Industries, Inc. vacuum or controlled atmosphere Hot Press Sintering Furnaces available for use in this program. The Hot Presses are used routinely for advanced ceramics processing development activities. In this program they will be used to simulate the performance of a high-temperature roll compactor, a briquetter, or a tabletizer, and to judge the feasibility of pellet production by a high-temperature technique integrated into the advanced power plant. The use of sintering additives is an option in the testing.

The Hot Press allows for the generation of single or multiple pellets under conditions of inert atmosphere at a controlled temperature simulating the PFBC or IGCC process temperature. The ram pressure is controlled to simulate the capabilities of conventional roll compactors and briquetters (pressures up to 2500 atm). The Hot Presses use RF-heating of a graphite die for temperature capabilities up to 4000°F, and are capable of extremely high compression pressures. Temperatures are

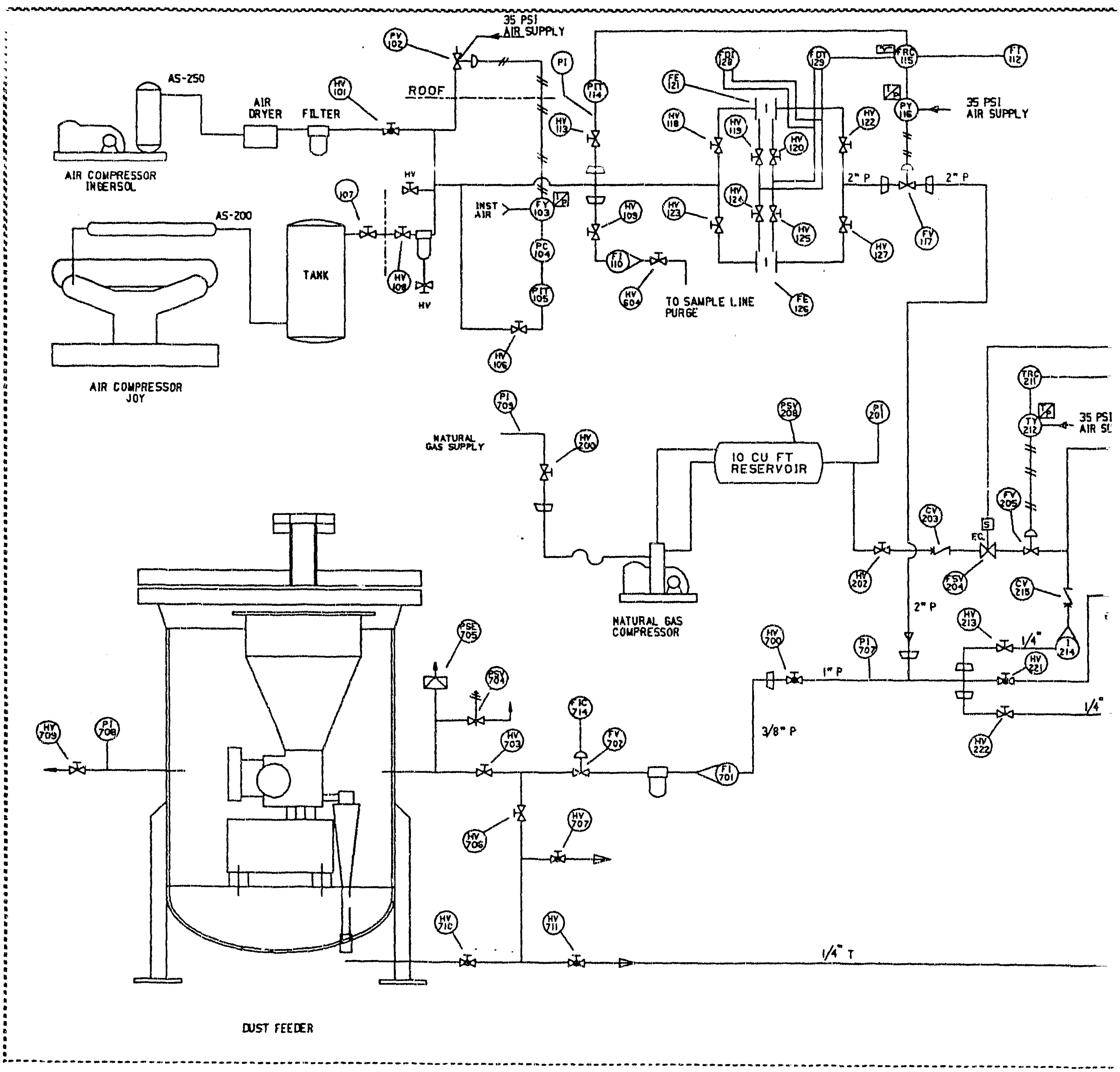
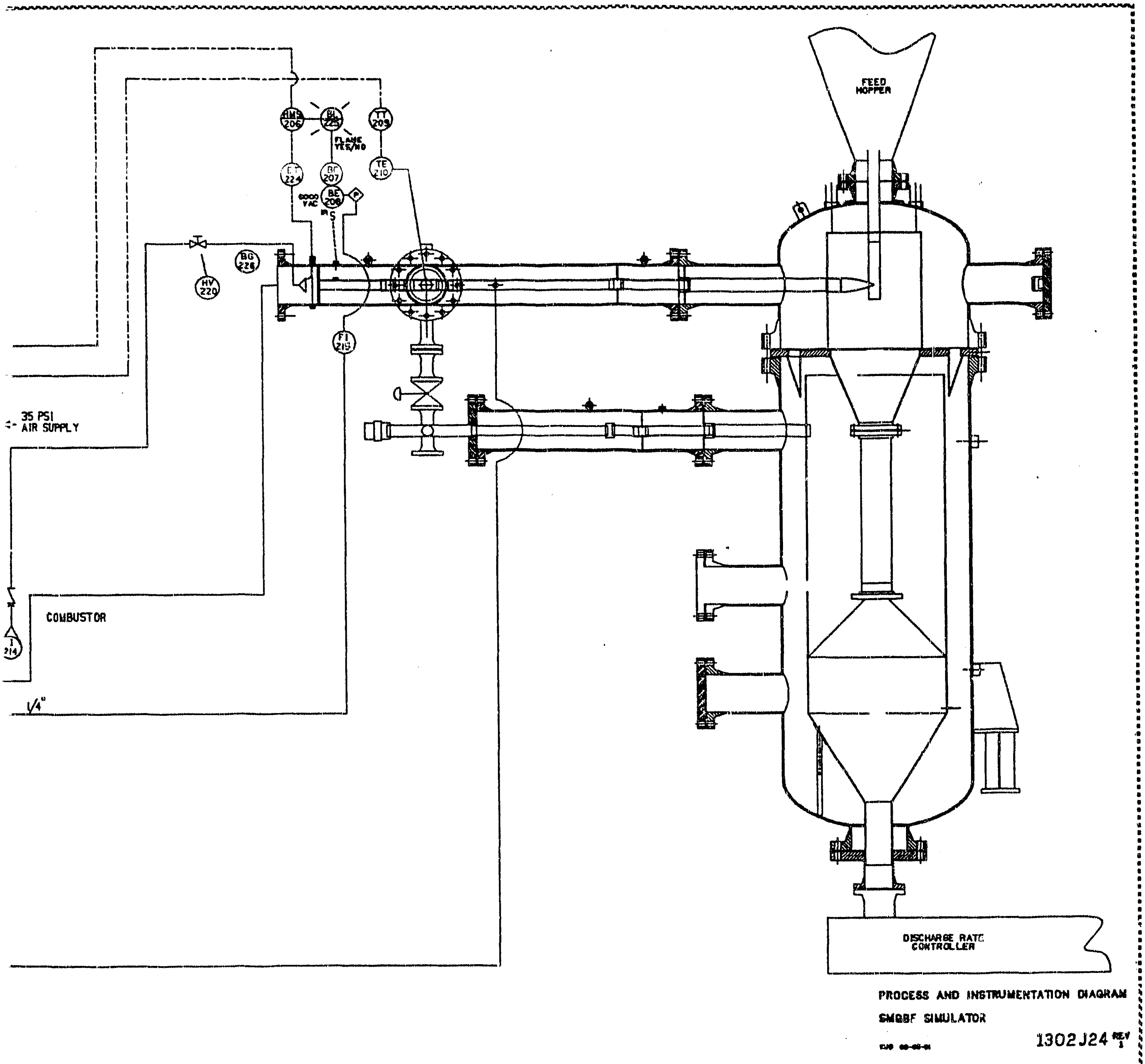


Figure 4 - HTHP Facility Arrangement and P&ID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35 PSI AIR SUPPLY
COMBUSTOR
1/4"
HV 220
BG 226
FI 215
TT 209
TE 210
BE 208
6000 VAC
FLAME YES/NO
DISCHARGE RATE CONTROLLER
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measured by standard radiation methods, or at the relatively low temperatures of PFBC and IGCC, by thermocouple probe. The smaller of the two Hot Presses is capable of 135 kW maximum ram force and can handle a maximum specimen diameter of 5 cm. The larger has a maximum ram force of 535 kW, and a maximum specimen diameter of 15 cm. The capabilities of the units are far beyond the needs of the test program.

6. DESCRIPTION OF PELLETIZATION PRODUCTION AND DURABILITY TESTS

Objectives

The objective of the pelletization test activity in the Base Contract is to identify feasible pellet production techniques and demonstrate durable pellet production. Conventional pelletization approaches are the main focus in the Base Contract, but the feasibility of high-temperature pelletization is also determined.

Approach

The approach followed in the Base Contract is outlined in the following steps:

- Obtain relatively small samples of PFBC and IGCC solid wastes (or representative substitutes).
- Conduct small-scale pelletization production tests at pellet vendor laboratories to evaluate alternative techniques for generating durable pellets based on the vendor standard durability tests.
- Conduct high-temperature pellet production tests at Westinghouse using Hot Press equipment.

- Assess pellet durability of the vendor-generated and Westinghouse high-temperature-generated pellets in tests using a consistent durability test representative of the needs of the S-MGBF system. Characterize the physical properties of the pellets showing promising durability.

- In the parallel Task 6, Commercial Conceptual Design evaluation, evaluate the comparative economics among the competing pelletization technologies that generate durable pellets.

- Procure a large quantity of representative PFBC and/or IGCC solid waste, or representative substitute, in sufficient quantity to meet the Base Contract cold model and HTHP test needs.

- Select two promising commercial pelletization approaches and contract pelletization vendors to produce a large batch of pellets sufficient for the cold flow model and HTHP test needs.

- Characterize the pellet properties generated in the large-scale production tests, and select one for Base Contract testing.

It is desirable to perform the cold flow testing and the HTHP testing using pellets generated from actual PFBC and/or IGCC wastes using pelletization techniques feasible for the concept. As a backup, if sufficient quantities of PFBC or IGCC wastes (or a representative substitute such as AFBC solid waste) cannot be obtained, or if sufficient quantities cannot be pelletized for the testing, either pellets generated at operating FBC power plants will be obtained for use in the testing, or particles will be purchased that simulate the pellets (e.g., commercial clay pellets/adsorbents, catalyst pellets, slag pellets, etc). If sufficient quantities of PFBC and/or IGCC wastes can be pelletized for the cold model and HTHP filter testing, then these test activities will also subject the pellets to durability tests that include the conditions of pellet handling, feeding, S-MGBF flow, withdrawal, and cooling. These process steps will be representations of commercial process steps.

Procedures

A survey has been conducted of the existing pelletization technologies and equipment vendors. The pelletization technologies can be classified into the following three categories based on application of pressure, binders, and the type of equipment: granulation, pressure agglomeration, and extrusion.

Granulation - The most common granulation devices are the rotating pan or drum granulators. The growth of granules relies primarily on binders and/or moisture. The same granulation process can also be performed in fluidized beds as well.

Pressure Agglomeration - The equipment in this category accepts fine particle feedstocks to form a compacted strip, sticks, or a defined briquet for densification and sizing requirements. Counter-rotating rolls are usually employed with or without binders. Specific equipment includes compactors, briquetters, and tabletizers.

Compactors require smooth or corrugated rolls to produce a sheet of densified material. This sheet may then be granulated or ground to a desired size and shape. Depending on powder properties, binders may be required and temperature may be applied. Briquetters utilize the same principles but uses pocketed rolls to densify and form the material into a specific shape. Tabletizers usually use specially-designed dies.

Extrusion - Extrusion works according to the principle of extrusion moulding. The product to be pelletized is pressed through the perforations of a die by means of rotating rollers. It is thus formed into strands of uniform cross-section and they are subsequently cut with knives into the desired pellet lengths. The pellets from extrusion are usually in cylindrical shape with diameters varying from 1/8 to 1/2 inches.

Most pelletization vendors contacted provide free feasibility tests in their laboratories employing equipment they market. The tests may include variation in operating conditions during pelletization, different equipment types, the requirement and type of binders, and pellets characterization. The pellet characterizations conducted by the vendors may involve hardness, crush strength, drop, and tumble tests. A small batch sample of 5-gal capacity is usually requested with a turnaround time of one to four weeks. Special tests can also be contracted with a fee. A large quantity of pellets can also be produced by the vendors under contract once the evaluation shows promises. The production cost for one ton of pellets ranges from $500 to $2000 depending on the vendor and the technique. The turnaround time is again about one to four weeks. Some of the vendors have prior experience pelletizing power plant solid waste and fluidized bed combustion solid waste.

There also have been prior pelletization studies with the solid waste from AFBC plants that are of interest to this program. The University of Iowa (Ames), has performed conventional pelletization tests with AFBC waste for the purpose of generating commercial-grade aggregate. Similar testing has been performed on the Chatham CFBC (Ontario Hydro) solid waste by Ash Management Engineering, Lexington, Kentucky. Both of these programs have been very successful at producing strong pellets at a small scale. Currently, a commercial CFBC power plant, the AES Thames Cogeneration plant, Uncasville, Connecticut, is pelletizing its solid waste on a continuous basis.

Combustors and gasifiers that operate in a slagging mode (e.g., the AVCO/Textron slagging combustor and the Texaco entrained gasifier) produce a large portion of their solid waste as coarse slag particles that are formed on water quenching. After drying and sieving a sizable stream of pellets may be available for direct use in the S-MGBF without the need for an additional pelletization step. Gasifiers that produce agglomerated ash waste (e.g., KRW and IGT fluidized bed gasifiers) may have a similar potential.

The vendors contacted cannot perform high temperature pelletization tests. High temperature tests will be carried out by Westinghouse employing existing high-temperature presses. The objective is to determine the effect of temperature, pressure and duration on the strength of the pellets with or without binders. If the results are promising, development of the high temperature pelletization technique will be conducted in the Option I phase of the program.

Operating Conditions

The operating conditions for pellet production tests conducted at vendor laboratories using different pelletization equipment and binders will be selected by the respective vendors based on their prior experience. Some vendors have significant experience handling AFBC ash, however, its properties may be substantially different from that of PFBC ash.

High temperature pelletization tests conducted at Westinghouse will heat the solid waste up to as high as process temperature and subject the material to various compressions levels for a range of holding times.

Permissible Ranges of Key Parameters

The PFBC/and or IGCC solid waste obtained should be representative of the mixed waste produced by the plant. The waste can be crushed to the size required to produce durable pellets, and water and/or binders can be used to levels that are economically feasible.

The pellet characteristics produced, such as size distribution, and shape relate directly to the pressure drop across the filter bed and the permissible gas velocity through the bed. It is expected that the pellet shape can range from spherical to cylindrical to irregular, depending on the technique applied, and acceptable mean particle diameters will range from 1/8" to 1/2". The size distribution around these mean diameters will reflect the characteristics of the pelletization techniques. The bed permeability will be sensitive to the pellet size distribution.

Data to be Collected

The type of pelletization technology and equipment, the binder type and quantity, and the curing conditions and duration used during tests will be collected. The pellet physical characteristics (size distribution, density, porosity, and shape) will be determined. The pellets will also be subjected to standard tests for hardness, crush strength, drop strength, tumble strength, and thermal decrepitation. Westinghouse STC will apply a standard ASME test procedure for pellet durability in the program.

Test Matrix

In tests conducted by vendors, the duration and number of tests will be selected and determined by the individual vendors based on their prior experience. As many as three vendors will be provided with waste samples for initial evaluation. Depending on the pelletization results, special tests may also be requested from vendors.

Table 1 lists the conditions of the high temperature Hot Press tests to be carried out at Westinghouse STC. The testing will concentrate on a single waste material, PFBC solid waste. The major parameters in the feasibility testing are:

- The simulation temperature
- The compaction pressure
- The duration of the compaction
- The extent of crushing of the solid waste material
- The use of additives to increase sintering

The Hot Press will be operated in an environment of high pressure nitrogen or carbon dioxide, simulating the actual process conditions and preventing decomposition of the solid waste, such as calcination of the $CaCO_3$ present in the sample. If PFBC solid waste is the subject material then the Hot Press temperature will be controlled at 1500°F. The Hot Press operator can monitor the volume of the specimen being pressed as a function of time at a given compaction pressure to determine the minimum compaction pressure required. The major test variables will be the extent of crushing, or pulverization of the sample, and the duration of the compaction cycle. Initial testing will consider the most optimistic case of minimal solid waste size reduction and short duration compression times, and will proceed to greater levels of pulverization, longer duration compaction, and the use of additive. The pellet durability will be assessed after each test to select the conditions required to achieve acceptable pellet strength.

The testing will be conducted in three series. The first uses the solid waste without size reduction, and without sintering additive, and determines the feasibility of pellet production -- the required compaction pressure and duration. Compaction pressures and durations are limited to those representative of commercial roll compactors and briquetters (pressures up to 2500 atm). The second series, Series B, looks at the pellet durability and fabrication feasibility if the solid waste is crushed or pulverized before pressing, repeating series A procedures. The final series, Series C, looks at the pellet durability and production feasibility improvements when an additive to promote sintering is added to the solid waste. A total of 20 tests will be conducted on the Hot Press equipment to scope out the required operating conditions and the process feasibility. The pellet durability will be judged using a standard ASME pellet test, and the pellet physical properties will be measured (density and porosity).

Table 1 - Westinghouse Hot Press Test Matrix

Solid Waste Source: PFBC

Series	Temperature (°F)	Size Reduction	Sintering Additive
A	1500	none	none
B	1500	pulverize	none
C	1500	pulverize	yes

7. DESCRIPTION OF COLD FLOW MODEL DYNAMICS TESTS

Objectives

The objectives of the Base Contract cold flow modeling tests are:

- Demonstrate acceptable performance (particle removal and pressure drop) at commercially acceptable operating conditions.
- Demonstrate physical integrity of pellets under mechanical transport conditions close to that of commercial application (mechanical feeding, moving bed of similar velocity, screw conveyor) at low temperature.
- Gain insights into operating characteristics, pressure drop profile, solids/gas flow pattern and distribution, solids flow control, operating modes, flyash re-entrainment and accumulation, fluidization at bottom of the standleg, and requirements for special design features to improve gas-particle disengagement at bottom of the standleg.

Procedures

The flyash feeder will be first calibrated with the flyash to be used in the tests. The screw feeder for pellet flow control will also be calibrated by feeding pellets into a 55-gal drum on a weight scale. The air flow into the cold flow model will be measured with a turbine flow meter.

A test matrix is shown in Table 2. Baseline tests without flyash injection are to be conducted first. The baseline tests are carried out at different gas face velocities through the standleg up to 6 ft/s in a static bed and in a moving bed at different bed velocities up to 0.02 ft/min (equivalent to a pellet flow rate of about 75 lb/hr). During this test series, the pressure drop characteristics across the standleg can be determined and possible fluidization at the bottom of standleg can be observed. The fluidization observation will determine whether special features will be installed at the bottom of the standleg during subsequent phases of tests. If desirable, smoke may be injected into the cold model for visual observation and video taping of gas flow pattern.

The pellets will be characterized before and after the baseline tests to determine the extent of pellet breakup after transport, handling, and S-MGBF operation. If particle breakup is excessive, only static bed baseline tests will be performed to minimize the material handling. For once-through operation, particle breakup during transport, handling, and operation will be tolerable in it does not result in excessive pressure drop and/or excessive particle emission.

The primary test program consists of tests with flyash injection in two different operating modes, continuous and on-off modes, at gas velocities of 3 and 6 ft/s and moving bed velocities of 0.01 and 0.02 ft/min through the standleg (equivalent to pellet flow rates of about 38 and 75 lb/hr, respectively). These conditions result in mass ratios of pellets to flyash of 5 to 20, representative of the pellet supply possible with PFBC operation without recycle of pellets. The flyash loading will be at a nominal value of 5000 ppm by weight. During

Table 2 - Test Matrix for Cold Flow Model Dynamics Tests

Test Objective	Gas Face Vel. (ft/s) 0	3	6	Moving Bed Vel. (ft/min) 0	0.01	0.02	Flyash Loading (ppmw) 0	5000	Pellet/Flyash Ratio
Pellet Integrity	*					*	*		NA
Baseline Tests		*		*			*		NA
			*	*			*		NA
		*			*		*		NA
			*		*		*		NA
		*				*	*		NA
			*			*	*		NA
Continuous Mode Operation		*			*			*	10
		*				*		*	20
			*		*			*	5
			*			*		*	10
On - Off Mode Operation		*				*		*	Trigger ΔP=15" H_2O
			*			*		*	Trigger ΔP=30" H_2O

the continuous mode of operation, the bed will move at a constant velocity. In an on-off mode of operation, the bed will be stationary initially to allow flyash to collect at the surface of the bed and the pressure drop to build up across the standleg. At a pre-determined pressure drop across the standleg, the bed will then be set in motion at a pre-determined velocity to allow pressure drop to decrease to a steady state value. The bed motion is again stopped and the cycle begins anew. This on-off operating mode is expected to increase the flyash collection efficiency and simultaneously decrease the pellet feed rate requirement.

The flyash collection efficiency will be evaluated by the difference between the flyash delivered and the flyash collected in the exhaust gas filter. Similarly, the flyash loading in the gas can be calculated from the flyash delivered and the gas flow rate. The moving bed velocity will be calculated from the weight collected in the 55-gal drum over the duration of the run. All pressure drops and gas flows will be monitored continuously and recorded for further analysis.

Permissible Ranges of Key Parameters

The gas velocity selected for the testing covers the range of permissible parameters based on economic competitiveness with ceramic barrier filters. The moving bed velocities and pellet-to-flyash mass flow ratios represent values that can be achieved in PFBC and IGCC applications without recycle of pellets.

Design features can be modified during the testing. For example, the tests may be carried out with or without special features to aid gas-particle disengagement at the bottom of standleg depending on the results of the baseline tests. The operating mode is also modified in the testing from continuous pellet flow to periodic, on-off pellet flow.

The operating and design condition range is limited as outlined below:

Pressure	- 15 psia
Temperature	- Less than 100°F
Operating Modes	- Continuous and on-off modes
Gas Face Velocities	- 3 to 6 ft/s through the standleg
Moving Bed Velocities	- 0 to 0.02 ft/min
Pellet/Flyash Mass	- 5 to 20 without pellet recycle
Flyash Loading	- Nominally 5000 ppm by weight
Pellet Material	- Pellets from PFBC or IGCC waste, or from representative substitutes.
Flyash Material	- PFBC or IGCC flyash

Performance Goals

The performance goals for the cold flow model testing are, when scaled to HTHP conditions:

	PFBC	IGCC
Pressure Drop (psi)	3	6
Particle Emission (ppmw)	20	100

The low-temperature flyash removal performance may differ greatly from the high-temperature performance where flyash may be more easily removed by the pellets, so the cold model testing can only be used as a qualitative indicator of particle removal performance.

Data to be Collected

The gas flow, solids flow, and pressure drop across the standleg will be continuously monitored. The flyash delivered will be determined through mass balance on the loss-in-weight dust feeder. The gas flow will be measured with a turbine flow meter and the pellet flow determined from the weight gain in the 55-gal drum located at the outlet of the screw feeder. The screw feeder will be calibrated beforehand for solids flow control. From those measurements, the flyash loading, the gas face velocity, the moving bed velocity, and the flyash collection efficiency can be derived.

Pressure drop profile across the standleg and the absolute pressure at dirty gas inlet and clean gas outlet will be measured with pressure transducers or gages for further analysis. Smoke injection for visual observation and video taping will also be employed to document some of the tests.

Visual observations of flyash accumulation patterns in the moving bed, local fluidization, pellet flow patterns, and regions of gas bypassing will be made. All of the observations made in the cold flow model will be scaled to HTHP conditions to provide interpretation of the results.

Test Matrix

The test matrix shown in Table 2 will be conducted for one pellet material produced for the test program. A single pellet integrity test will be conducted at the highest pellet flow rate, but without any air flow. This test will confirm the durability of the pellets under the moving bed handling and flow conditions. Six baseline tests follow the pellet integrity test. In the baseline tests there is no flyash contained in the air, and the tests provide measurements of moving bed pressure drop, indication of flyash generation from the pellets, and observations of local air streaming and bed fluidization.

The baseline tests are followed by two sets of tests that simulation SMGBF operation under two operating modes: continuous and on-off pellet flow. The continuous mode tests will be initiated by starting the moving bed first. Flyash injection will follow quickly. Depending on the moving bed velocity, and the migration velocity of flyash particles through the bed, the steady state should be established within several minutes to several hours. The establishment of the steady state can be determined from the pressure drop across the standleg. Each test run will include a steady state operating period of about 30 minutes, long enough to allow for an accurate determination of flyash mass balance. For the on-off mode, at least five cycles will be carried out. Depending on the rate of pressure buildup for different pellet materials, the time duration of each cycle will differ. It is estimated that the duration of on-off mode runs will last at least 60 minutes each.

A total of 12 tests will be performed during the simulation tests, with 8 tests in the continuous moving bed mode and 4 tests in the on-off mode. The six tests characterized in Table 2 will be performed, plus three replicate tests (two continuous and one on-off mode) performed at selected conditions listed in the table, and plus three tests (two continuous and one on-off mode) performed with special design features incorporated for improved gas-flyash disengaging. The total Base Contract cold model testing period will be about 6 weeks.

8. DESCRIPTION OF HTHP FILTER FEASIBILITY DEMONSTRATION TESTS

Objectives

The objectives of the Base Contract HTHP testing are:

- Demonstrate acceptable flyash removal performance at commercially acceptable, and representative operating conditions.
- Demonstrate physical and thermal integrity of pellets under conditions close to that of commercial application.
- Confirm performance and durability of some key high-temperature design features of the filter vessel internals.

Procedures

The test matrix for the HTHP testing, shown in Table 3, is similar to the test matrix for the cold model testing. The test operational procedures are also similar to the cold flow model procedures except for those aspects of the testing that are constrained by the HTHP test conditions such as unit startup and shutdown procedures. Baseline tests without flyash injection are to be conducted first. The baseline tests are carried out at different gas face velocities up to 6 ft/s in a static bed and in a moving bed at different bed velocities up to 0.02 ft/min, as in the cold model testing. During this test series, the pressure drop characteristics across the standleg can be determined. Also, the bed particles will be characterized before and after the baseline tests to determine the extent of pellet breakup after transport, handling, and high temperature exposure.

The primary test program consists of tests with flyash injection in two different modes, continuous and on-off modes, at gas velocities up to 6 ft/s and moving bed velocities up to 0.02 ft/min, parameter ranges identical to the cold model tests. The flyash loading will be at a nominal value of 5000 ppm by weight. The continuous and on-off operating procedures applied will be those developed during the cold flow model testing.

The flyash collection efficiency will be evaluated by isokinetic sampling of the outlet gas stream. The flyash loading can be calculated from the flyash delivered and the gas flow rate. The bed velocity will be calculated from the weight change of the feed bin over the duration of the run. All pressure drop and gas flow will be monitored continuously for further analysis.

Table 3 - Test Matrix for HTHP Filter Feasibility Demonstration Tests

Test Objective	Gas Face Vel. (ft/s)		Moving Bed Vel. (ft/min)			Flyash Loading (ppmw)		Pellet/Flyash Ratio
	3	6	0	0.01	0.02	0	5000	
Baseline Tests	*		*			*		NA
		*	*			*		NA
	*			*		*		NA
		*		*		*		NA
	*				*	*		NA
		*			*	*		NA
Continuous Mode Operation	*			*			*	10
	*				*		*	20
		*		*			*	5
		*			*		*	10
On - Off Mode Operation	*				*		*	Trigger ΔP=25" H_2O
		*			*		*	Trigger ΔP=50" H_2O

Pressure drop across the standleg and the absolute pressure at dirty gas inlet and clean gas outlet will be measured with pressure transducers or gages for further analysis.

Comparison will be made with the HTHP projections made from the cold model test results to identify possible behavior differences and to confirm expectations.

9. ESTIMATED COST OF TEST FACILITIES AND TEST PROGRAMS

Pelletization Production and Durability Tests

The materials and test operation labor for this task are estimated below:

	Materials ($1000)	Test Labor ($1000)	Total ($1000)
Initial Pellet Vendor Testing:	0	5	5
Large Scale Pellet Production:	0	10	10
High-Temperature Pellet Tests:	1	14	15
Pellet Characterization and Durability Tests (W-STC):	0	10	10
Total:	1	39	40

The material costs are in "direct" dollars, and the labor costs are in "total" dollars.

Cold Flow Model Dynamics Tests

The equipment costs and installation costs for the cold flow model facility are estimated below:

Equipment Item	Cost ($1000)	Installation Cost ($1000)	Total ($1000)
Cold Model Vessel	55		
Vessel Support	5		
Pellet Feed System	3		
Pellet Handling & Withdrawal	7		
Flyash Feed System	(existing)		
Exhaust Gas System	(existing)		
Instruments & Controls	10		
Total	80	30	110

The material costs are in "direct" dollars, and the labor costs are in "total" dollars. The testing labor cost (total dollars) is estimated to be $36,000 (6-week test period).

<u>**HTHP Filter Feasibility Demonstration Tests**</u>

The HTHP facility equipment costs and installation costs are estimated below:

Equipment Item	Cost ($1000)	Installation Cost ($1000)	Total ($1000)
Vessel Head	9	0	9
Vessel Internals	15	0	15
Pellet Feed System	30	15	45
Pellet Handling & Withdrawal	50	15	65
Flyash Feed System	(existing)		0
Exhaust Gas System	5	0	5
Instruments & Controls	15	5	20
Facility Structural Changes	20	10	30
Total	144	45	189

The material costs are in "direct" dollars, and the labor costs are in "total" dollars. The testing labor costs (total dollars) are estimated to be $40,000 (6 week test operation period).

Total Base Contract test program

The total Base Contract test facility and test program cost in total dollars is estimated to:

- Materials: $273,000
- Installation Labor: $75,000
- Operation Labor: $116,000
- Total: $464,000

END

DATE FILMED

9/15/92