DOE/MC/27403--93/C0075

DE92 041035

DOE/MC/27403-93/C0075

York County Energy Parners, DOE CCI ACFB Demonstration Project

Authors:
Wang, S.
Cox, J.
Parham, D.

Contractor:
Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18195-1501

Contract Number:
DE-FC21-91MC27403

Conference Title:
U.S. Department of Energy First Annual Clean Coal Technology Conference

Conference Location:
Cleveland, Ohio

Conference Dates:
September 22-24, 1992

Conference Sponsor:
U.S. Department of Energy

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615)576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

YORK COUNTY ENERGY PARTNERS DOE CCI ACFB DEMONSTRATION PROJECT

S. Wang
Air Products & Chemicals, Inc.
7201 Hamilton Blvd.
Allentown, PA 18195-1501

J. Cox and D. Parham
Foster Wheeler Energy Corporation
Perryville Clinton Corporate Park
Clinton, NJ 08809-4000

ABSTRACT

The York County Energy Partners (YCEP) project, to be located in York County, Pennsylvania, will demonstrate the world's largest atmospheric circulating fluidized bed boiler under sponsorship of the U.S. Department of Energy's Clean Coal Technology I Program. The single ACFB boiler, designed by Foster Wheeler Energy Corporation, will produce 227 MWe of net electrical power and export approximately 50,000 lb/hr of steam. This paper explains how the technical challenges to the design of a utility-scale ACFB boiler were met and presents the innovative features of this design.

INTRODUCTION

The York County Energy Partners cogeneration project located in York County, PA will demonstrate the world's largest atmospheric circulating fluidized bed (ACFB) boiler under sponsorship of the US Department of Energy's (DOE) Clean Coal Technology I Program. The goal of the project is to demonstrate the technical and economic feasibility of applying circulating fluidized bed combustion technology at the 250 MWe scale for producing electrical power and steam in an environmentally acceptable manner while efficiently utilizing our nations coal resources. An artists rendition of the completed YCEP Cogen plant is presented in Figure 1. The single-train ACFB boiler, designed by Foster Wheeler Energy Corporation (FWEC), will supply 227 MWe of electrical power to the Metropolitan Edison Company (Met-Ed) and export approximately 50,000 lb/hr of steam to the J. E. Baker Company. The steam supplied by the YCEP project will reduce existing propane, natural gas, coal, and electricity consumption at the J. E. Baker Company, a producer of dead-burned dolomite which is used to manufacture refractory bricks for the steel and cement industry, specialty granular refractories for repairing and maintaining furnace linings, and agricultural products.

The YCEP Cogen Project will be located approximately 6 miles west of the City of York, PA in West Manchester Township. The project is situated adjacent to the J. E. Baker Company's dolomite operations, which is north of U.S. Route 30. As shown on the map in Figure 2, the 50 acre triangular site is bounded to the northeast by Emigs Mill Road (SR 4003), to the south by the Yorkrail railroad line, and to the northwest by the Briarwood Golf Club. The project will interconnect to Met-Ed's Jackson substation, which is located within 7000 feet of the project site and is capable of distributing the electrical power that will be produced.

A plot plan for the YCEP Cogen project is shown in Figure 3. Fuel delivery will be facilitated by direct access to the Yorkrail Company rail line. A loop track will be constructed to allow the coal to be unloaded on site. Sufficient space is allotted for 30 day storage of coal at the site.

A summary of the YCEP Cogen project information is given in Table 1. The ACFB combustor will be fueled with low sulfur (less than 2 percent) bituminous coal available locally in Western PA, MD, and W. VA. The scaled-up single ACFB boiler will generate 1,725,000 lb/hr of main steam at 2500 psig and 1005°F and 1,400,000 lb/hr of reheat steam at 442 psig and 1005°F. The estimated total cost of the YCEP Cogen project is more than $ 300 million dollars. A cost share of approximately $ 75 million dollars will be provided by the US DOE to sponsor the Clean Coal Technology Round I Demonstration Test Program.

A schedule of the milestones of the YCEP Cogen project is provided in Table 2 and as a Gantt chart in Figure 4. Adjustments to this schedule may be necessary to accommodate certain Department of Energy requirements which are not yet available to the project sponsor. Commercial operation is scheduled to begin by March, 1997.

Facility Description

A brief description of the overall cogeneration process is given below. For reference, Figure 3 provides a plot plan for the entire plant and Figure 5 provides a process flow diagram indicating how the major pieces of equipment are interconnected.

Fuel is fed to the base of the combustor along both the front and back walls and sorbent is fed to the base of the combustor along the front wall. A fuel and sorbent receiving and preparation system is incorporated into the plant design. Primary and secondary air flows to the combustor are provided by primary and secondary air fans. Before entering the combustor, these streams are preheated via heat exchange with the flue gases in the air heaters. The heart of the process is a circulating fluidized bed combustor in which the fuel is combusted while simultaneously capturing SO_2. Selective non-catalytic reduction of NO_x emissions is accomplished through injection of aqueous ammonia at the inlet to the cyclones. Solid particles entrained by the upflowing gas in the combustor exit the top of the combustor into cyclones which efficiently separate the flue gas from the entrained particles. The flue gas discharged from the cyclone is directed to the downstream convective section of the boiler and the captured solids are recycled to the base of the ACFB by means of standpipes, J-valves, and an INTREX^{TM} fluidized bed Integrated Recycle Heat Exchanger. The J-valves provide a seal between the positive pressure in the lower furnace where the recycle solids are fed and the near ambient pressure in the cyclones.

Coarse ash material (bed ash) accumulating in the ACFB is removed from the bed using a specially designed directional grid and a fluidized bed stripper cooler. The bed ash is cooled by the fluidizing air flow to the stripper cooler. This heated air stream flows to the combustor along with the fines that are stripped out. The cooled bed ash will be conveyed to a bed ash silo. Fly ash collected in the air heaters, economizer, and baghouse hoppers will be pneumatically conveyed to the fly ash storage silo. Depending on the beneficial use for the byproduct ash, the bed and fly ash streams may require additional processing to condition the ash.

A schematic diagram of the steam/water circuitry for the ACFB steam generation system is shown in Figure 6. Boiler feedwater is preheated in the economizer located in the convection heat recovery area. The preheated feedwater is then routed to the steam drum. From the steam drum, the pressurized water flows by natural circulation through the waterwall sections of the ACFB combustor and the INTREX^{TM} heat exchanger. Steam generated in the waterwall boiling circuits is routed to the cyclone enclosure walls, the convection heat recovery area enclosure walls, the primary superheater, and then on to the intermediate and finishing steam coils located in the

INTREX^{TM} heat exchanger. This superheated steam flow is expanded through a high pressure steam turbine. A portion of the steam exiting the high pressure turbine flows through a reheater located in the convective heat recovery area. The reheated steam is expanded through an intermediate pressure steam turbine to extract additional power.

A description of the major components which comprise the coal-fired ACFB cogeneration plant is given below.

Circulating Fluidized Bed Combustor

A process flow diagram for the YCEP cogeneration plant is shown in Figure 5. Figure 7 provides a side elevation drawing of the ACFB combustor/steam generation system. Coal and sorbent, such as limestone, are fed into the lower, refractory-lined portion of the atmospheric circulating fluidized bed where these feedstock materials are mixed with the bed material and initial combustion occurs. To support combustion of the coal, a substoichiometric amount of air is fed to the base of the unit and additional air is injected at two different elevations above the primary air feed location. The total air flow is approximately 20% in excess of stoichiometric requirements. Primary air enters through a specially designed air distribution grid. This process of staging the air flow to the combustor minimizes the formation of NOx within the unit. In addition, the relatively low operating temperature of the ACFB combustor of 1550-1650°F also minimizes NOx formation. The sorbent is fed to the bed to capture SO_2 formed by the combustion of sulfur-containing fuel. Calcium carbonate is calcined to calcium oxide *in-situ* which subsequently reacts with SO_2 and O_2 to stabilize the sulfur in the form of calcium sulfate. Maintaining the bed temperature at approximately 1600°F is also necessary for effective sulfur capture and to minimize sorbent consumption.

The upflowing combustion gases entrain the fine ash, char, and sorbent particles producing a net flow of solids up through the combustor. The combustor temperature is maintained by efficient transfer of heat from the gas-solid suspension to the waterwall tubes. Solids entrained from the bed, including unburned char and unreacted sorbent particles, are captured by hot cyclones and returned to the ACFB combustor. This promotes improved combustion and sorbent utilization efficiency. The recycled solids are also cooled upon passing through the steam-cooled cyclones and the INTREX^{TM} heat exchanger. A side elevation drawing of the INTREX^{TM} unit is given in Figure 8. The cooled recycle solids stream also helps to moderate the temperatures within the combustor. Coarse ash particles are removed from the bottom of the combustor as bed ash. Additional heat is recovered from flue gas and fine ash particles escaping the cyclones within the convective section of the boiler. The fly ash is captured in a baghouse before the cooled flue gas is exhausted through a stack.

Description of the Integration of Components

Fuel and Sorbent Preparation and Feed System

Bituminous coal is delivered to the site by rail and is stored in five 56 ft diameter coal storage silos with a 14 day storage capacity. The 2" x 0 size raw coal is then conveyed to crushers located at the top of the boiler building to be crushed to 1/2" x 0 size and stored in 4 in-plant coal silos. The crushed coal is extracted from the silos at variable rates, as required by the ACFB boiler, by gravimetric feeders and fed to both front and rear walls of the boiler.

Depending on the source of the raw limestone and dolomite, the sorbent would be either delivered by pneumatic truck or crushed at an adjacent site and pneumatically conveyed to two sorbent storage silos. Each silo discharges to one (1) 100% capacity gravimetric belt feeder. From the feeders, the sorbent is dropped into a bifurcated discharge hopper where the sorbent is divided into two streams. Four (4) 50% capacity sorbent blowers convey the sorbent to the ACFB boiler pneumatically and inject it to the boiler at the vicinity of coal feed points. The rate of sorbent feed is automatically adjusted if the SO_2 concentration measured at the stack exceeds a predetermined set point.

Draft System

The ACFB boiler is equipped with one (1) 100% capacity centrifugal primary air fan, one (1) 100% capacity centrifugal secondary air fan, two (2) 100% capacity centrifugal INTREX^{TM} heat exchanger blowers, two (2) 100% capacity positive displacement J-valve blowers, four (4) 50% capacity positive displacement sorbent blowers. The primary air and the secondary air are heated by the flue gas in two heaters arranged in parallel with multiple air and flue gas passes. With flue gas flowing on the inside of the vertical tubes, the gas side cleanliness is maintained without steam sootblowing. Balanced furnace draft is maintained by one (1) 100% capacity centrifugal induced draft fan. Part of the primary air bypasses the primary air heater and is used to fluidize the stripper/coolers and provide seal and sweep air for the fuel feeders. Part of the high pressure air from the J-valve blowers is injected into the transfer lines from the combustor to the stripper/coolers to assist solids movement into the stripper/cooler.

Baghouse

A 14-compartment reverse air type baghouse filter system will be used to clean the flue gas exiting the primary and secondary air heaters. The baghouse filter system is designed to remove particulates in the flue gas and maintain particulate emissions below 0.015 lbs/MMBtu. A design air-to-cloth ratio of two is specified with one compartment isolated for cleaning and one compartment out for maintenance. Each baghouse compartment has a hopper which is heat traced and has an 8-hour storage capacity. The ash collected in the hopper will be discharged to the fly ash removal system.

Spent Bed Material Cooling System

Coarse coal ash, spent sorbent, and calcium sulfate must be removed from the bottom of the ACFB boiler to control solids inventory in the lower region of the boiler. Directional air distributor nozzles are used on the furnace floor to direct coarse material to the drain openings on each furnace sidewall. Figure 9 illustrates the solid flow patterns along the base of the combustor which causes the bed ash material to drain to the stripper cooler and also maximizes the residence time of the large fuel particles in the combustor to reduce unburned carbon levels in the bed ash. Four (4) 50% capacity fluidized bed stripper/coolers are designed to selectively remove oversized bed material and return fine material back into the furnaces to increase the solids residence time. As illustrated in Figure 10, the stripper/cooler is a refractory lined box with three fluidized compartments; one stripper zone and two cooling zones. A fraction of combustion air is used to strip and cool the spend bed material to an acceptable temperature level for disposal. Sensible heat in the spent bed material is recovered by injecting the stripping and cooling air back to the furnace as part of the secondary air for combustion.

Ash Disposal System

The cooled bed ash will be conveyed to a bed ash storage silo via a pneumatic transport system. The bed ash collected during the pilot plant tests will be used to test different ash transport systems to determine the most reliable and cost effective transport system for the bed ash. The fly ash is conveyed from air heaters, economizer, and baghouse hoppers by dilute-phase pneumatic transport system to a fly ash storage silo.

Water Steam Circuitry

Figure 8 illustrates the components of the steam generation system that are incorporated in the ACFB design. The circulating fluid bed design is comprised of four distinct sections: the furnace, the hot cyclones, the INTREX^{TM} heat exchanger, and the heat recovery area (HRA). All four sections are top supported and are comprised of water or steam cooled enclosures. Use of integrally welded steam generating walls (MONOWALL®) as the enclosure is in accordance with modern design practice and provides both the required cooling and the structural support. The steam circuitry is designed for natural circulation and includes a single drum located above the furnace and between the furnace and cyclones. The boiler is designed to turn down to 40 percent of MCR capacity without firing auxiliary fuel and to have a steam temperature control range between 75% and 100% MCR load.

Boiler feedwater enters the unit at the inlet to the bare tube economizer located in the convection heat recovery area. Water flows through the banks of horizontal coils countercurrent to the flue gas, exiting at the outlet header. Feedwater is then routed to the steam drum. Steam generated in the boiling circuits is separated by the steam drum internals. The steam drum internals are designed to efficiently separate the steam/water mixture, and to insure that the steam leaving the drum is moisture free and of high purity. In addition, the drum internals distribute the flow of incoming water and steam throughout the drum to maintain even drum metal temperatures. The internals consist of horizontal centrifugal separators located along the side of the drum and unit Chevron drier assemblies arranged along the top of the drum.

Steam leaving the drum through the Chevron dryers is routed to the cyclone circular enclosure walls, HRA enclosure walls, the HRA primary superheater, and then on to the intermediate and finishing superheater coils located in the INTREX^{TM} heat exchanger. Two spray type attemperators are provided, located between the primary and the intermediate superheaters and between the intermediate and finishing superheaters to provide control of the final steam temperature. This type of attemperation will afford excellent control flexibility and will not adversely affect steam purity.

Reheat steam enters the unit at the reheater inlet header located in the parallel pass HRA. Steam flows through the reheater banks of horizontal coils countercurrent to the flue gas flow exiting at the outlet header. Reheat temperature control is achieved through simple flue gas flow proportioning thereby eliminating the need for spray-type attemperators.

Power Generation System

The YCEP Cogeneration plant will generate electric power by extracting shaft work from the high pressure superheated steam flow produced by the ACFB steam generating circuits. The turbine generator system includes high, intermediate and low pressure steam turbines connected to a generator. Main steam enters the high pressure turbine at 1,750,000 lb/hr, 1005°F, and 2500 psig. A portion (1,400,000 lb/hr) of the main steam flow leaving the expander at 590 °F and approximately 480 psig is reheated to 1005°F and is then fully expanded. Approximately 50,000 lb/hr of extraction steam is withdrawn from the intermediate pressure turbine at 200 psig and low pressure turbine at 50 psig.

Thermal DeNOx System

Low level emissions of NOx generated by the oxidation of fuel nitrogen within the ACFB combustor will be further reduced by decomposing NOx into N_2, O_2, and H_2O using non-catalytic reduction with ammonia. Aqueous ammonia will be injected directly into the flue gas in the (4) ducts connecting the cyclones to the combustor. At this location, the temperature of the flue gas at 100% MCR will be approximately 1630°F. At this temperature the NOx reduction reactions proceed at a sufficient rate to achieve a NOx reduction level of 50%. Since staged combustion and low combustion temperatures already contribute to significantly lower NOx emissions than achieved with conventional pulverized coal boilers, extremely low NOx emissions will be achieved by combining the two technologies.

Hot Model Burn Test

ACFB combustors are known for their excellent fuel flexibility. However, many fuel and sorbent characteristics, such as composition, reactivity, and friability will all impact the design and the performance of a ACFB combustor as well as the feed and the ash handling equipment. These factors must be thoughtfully addressed during the design stage to ensure the ACFB combustor and ancillary equipment will meet the performance guarantees.

Before the final design engineering for the YCEP Cogen plant begins, four (4) hot model tests will be conducted at Foster Wheeler Development Corporation's 1 MWth test facility at Livingston, New Jersey, using potential coals and sorbents considered for commercial operation. The ACFB hot model is constructed of MONOWALL® and consists of a 1'x2'x48' combustion chamber, MONOWALL®-enclosed cyclone separator and downflow heat recovery section. It is equipped with extensive temperature and pressure measurement instrumentation and gas composition analyzers to assess the combustion and emission characteristics of the FWEC ACFB combustor.

The key design information to be obtained from the hot model includes combustion efficiency, optimal temperature for sulfur capture, Ca/S molar ratio for 92% sulfur removal, emissions, and fly/bed ash ratio. In addition, ashes collected during the hot model tests will be used in various tests required by environmental permit applications as well as in ash conveying and conditioning tests for the selection of proper ash handling equipment.

Technical Challenges in Scale Up of ACFB Design

Evolution of ACFB Technology in U.S.

The size of the YCEP ACFB combustor represents a significant increase in scale over existing ACFB combustors. Figure 11 provides an illustration of how the size of single ACFB combustors constructed in the U.S. has grown over the past decade. This bar chart of net electrical generating capacity per ACFB boiler versus the year of start-up includes primarily the larger capacity units coming on stream in this period. Currently, the largest single ACFB boiler is the 150 MWe Texas-New Mexico ACFB. This unit will be superseded in 1993 by the 165 MWe Pt. Aconi ACFB. However, when the YCEP project is started up in late 1996, it will become the largest ACFB combustor, capable of generating 227 MWe of net electrical power and 50,000 lb/hr of export steam. This scale will be most representative for potential utility-scale ACFB applications.

A significant challenge in the design of the single combustor ACFB for the YCEP project was to anticipate the influence that the scale of the combustor would have on its design and performance. The following sections will discuss several important considerations in designing a 227 MWe ACFB combustor having maximum certainty of successful operation. The major design features to be discussed include:

- Flexibility of Thermal Design
- Solids Mixing / Feed Distribution
- Cyclone Separator Design/Configuration

Design of ACFB Waterwall Surface

In scaling up the design of ACFB combustors, proper thermal design is important to control the temperature within the combustor. A properly designed ACFB combustor will operate at uniform 1600-1650°F temperatures, which will permit combustion to take place below the ash fusion temperature while providing optimal SO_2 capture with calcium-based sorbents and reduced NO_x formation. This is achieved by balancing the heat released by the combustion process with the heat absorbed within the boiler. Heat absorption is achieved by withdrawing heat from the gas-solid suspension within the boiler, the cyclones, and INTREX™ heat exchanger. Adequate temperature control and solids distribution/mixing are essential to attaining high combustion efficiencies and minimal gaseous emission rates.

Since the fluidizing velocity of ACFB's is held constant, the cross-sectional area of the combustor increases proportionately with the firing rate. However, as the bed cross section increases, the ratio of bed volume per unit of wall heat transfer surface area increases. Figure 12 shows how this ratio (or cross-sectional area per unit perimeter) increases with combustor cross-sectional area. Therefore, as the cross-sectional area increases for a unit of a given height, the amount of heat that can be removed through the waterwalls becomes a smaller fraction of the firing rate.

One method of obtaining the total required heat transfer surface is to increase the combustor height; however, the heat transfer surface that is introduced with added height is least effective at removing heat. This occurs because the rate of heat transfer varies with the solid suspension density and the solid suspension density in the YCEP combustor decreases rapidly with height until reaching a constant value in the upper furnace. This results in a more predictable heat absorption in the upper furnace. Furthermore, a lower density in the upper furnace results in less heat release, which is consistent with the lower heat absorption in the upper furnace.

In the YCEP ACFB design, the required amount of heat is removed through addition of a water-cooled, full division wall extending along the entire height of the combustor. This development introduces additional heat transfer surface throughout the entire furnace height. The division wall reduces the ratio of bed volume to the heat transfer surface area to a value that is typical of existing, smaller ACFB combustors as shown in Figure 12. Figure 13 compares the division wall design with alternative large scale ACFB combustor designs.

Other advantages of the full division wall include:

- *More uniform temperature distribution in the ACFB.* In comparison with a single chamber design, the division wall will help to produce more uniform temperatures across the ACFB due to the more even distribution of heat transfer surface throughout the combustor cross section.

- *Lower unit height.* A full division wall will allow combustor height to be constrained to that required for the cyclones rather than that required to achieve the necessary waterwall surface. Capital cost savings result by eliminating the need for additional structural steel, platforms and building enclosures. Reduced combustor height will also typically result in a lower stack height.

Special design features included in the proposed furnace division wall include:

- *Pressure Equalization Openings*

Figure 14 illustrates the design of the division wall openings. From the furnace floor to a height of about 12 ft., the fins between adjacent division wall tubes are removed. This allows the tubes to be bumped sideways, in-plane, to form multiple openings. Additional openings are also provided in the upper furnace over a 12 ft. span beneath the cyclone inlet. The openings in the upper furnace are located beneath the cyclone inlets to minimize lateral cross-flow of solids through the openings. The division wall openings function to equalize the pressure on both sides of the division wall.

The pressure equalization openings eliminate differential forces on the division wall, which simplifies the mechanical design. Also, a uniform air flow can be maintained across the width of the unit. Excess oxygen in the flue gas can be monitored at a common location at the heat recovery area exit and secondary air flow can be modulated to maintain the desired excess air level. Independent monitoring and modulating controls for each side of the division wall are not required.

- *Wear Resistant Design*

At the pressure equalization openings the division wall tubing is protected with the same high conductivity, erosion resistant refractory used on the lower furnace enclosure walls, roof, cyclone inlet walls, and the cyclones. The phosphate-bonded, high-alumina refractory which contains stainless steel reinforcing fibers is mounted on a high density stud pattern to a thickness of 1/2 inch. All the tubes are kept in plan so as not to protrude into the gas/solids flow stream for direct impingement. In this manner, the division wall will be no different from the water cooled enclosure walls which also have openings for solids cooler drains and fuel, limestone, and secondary air feeds.

- *Differential Thermal Growth*

The division wall is welded where it penetrates the air distributor and is held in tension by springs fixed at the top of the unit. A gap is provided between the division wall and the front and rear walls of the furnace. Since the division wall is heated on both sides while the enclosure walls are heated only on one side, the average division wall tube temperature will be slightly hotter than that of the enclosure walls. The support arrangement with no mechanical attachment to the enclosure walls allows both the division wall and the enclosure walls to independently grow downward at their respective rates. Foster Wheeler has designed numerous steam-cooled full division walls on pulverized coal fired steam generators. Steam cooled division walls have more stringent design requirements for differential thermal growth than do water-cooled division walls.

<u>Solids Mixing / Feed Distribution</u>

Solid mixing plays an important role in determining the performance of ACFB combustors. As the combustor scale increases, changes in several design parameters can affect how well the fuel and sorbent are distributed in the combustor. Data taken from other commercial ACFB plants will be presented to show that poor solid mixing can result in inefficient plant operation and higher plant operating costs.

Table 3 lists factors which are thought to influence the degree of solid mixing in the lower region of ACFB's. These factors are placed in three categories: (a) mixing due to external solid recirculation, (b) mixing due to internal solid recirculation, (c) mixing limitations caused by solids feeder configuration and boiler dimensions.

Impact of Poor Solid Distribution

Table 4 lists the impacts of poor solid mixing / fuel distribution. Nonuniform fuel distribution results in increased consumption of sorbent to achieve the same SO_2 emission level and may also increase the NOx generation rate. With increased NOx generation, NH_3 consumption increases to achieve the same level of NOx emissions and the NH_3 slip (flow of unreacted NH_3) also increases. When burning coals containing chlorine, greater NH3 slip increases the potential for NH_4Cl formation. Poor fuel distribution will also lead to a reduction in combustion efficiency through increased hydrocarbon and CO emissions, and increased calcination heat losses. Nonuniform fuel distribution may lead to oxygen deficient reducing zones that cause bed agglomeration and slagging problems, and may produce local hot spots within the combustor.

Factors Affecting Sorbent Utilization

Table 5 lists a number of factors which are thought to influence sorbent utilization. The factors include: sorbent and fuel properties, solid mixing, combustor temperature, fuel and sorbent distribution, and cyclone grade efficiency. Important sorbent properties include the reactivity, friability, and feed size distribution. These properties will help determine how long the sorbent stays in the ACFB, how it is distributed between the lower and upper furnace, the extent to which the particle breaks apart to expose fresh CaO, and the reaction rate. Important fuel properties include: volatile content, reactivity, sulfur content and forms (organic, pyritic, sulfatic), and feed size distribution. The firing rate per fuel feeder will determine the local concentration of fuel at the feeder outlet. Increasing the firing rate per feeder will (for more volatile and reactive fuels) increase the reaction rate within this region, which will result in zones of low O_2 and high SO_2 gaseous concentrations and elevated local temperatures. Combustor temperature plays an important role due to the strong dependence of the sulfur capture reactions and combustion reactions on temperature. Sorbent distribution is also important to ensure a uniform concentration of unreacted CaO in the ACFB at the location where the SO_2 is released. The extent of solid mixing in the ACFB will help determine how well the fuel and sorbent are distributed. Finally, a cyclone with high capture efficiency for fines will retain the fine unreacted sorbent particles in the ACFB longer to react more completely. It should be noted that the YCEP ACFB boiler has a relatively short mixing zone, a distinct lower furnace bed that uses relativley coarse fuel and sorbent, as well as air swept fuel distributors, which promote more effective mixing in the furnace.

Comparison of York Feed Distribution Design with other ACFB's

Figures 15(a) and (b) compare the fuel feed distribution system designs of several existing ACFB's with the York design. In the first, the effectiveness of the fuel distribution systems are compared by representing each unit as a point on a graph of average firing rate per feeder (total firing rate/number of feeders) vs. upper combustor area per feeder. In the second, a comparison is made on a plot of average firing rate per fuel feeder vs. grid area per fuel feeder. ACFB combustor designs located toward the top and toward the right hand side of these figures should have greater mixing limitations and (other things being equal) would be expected to have less efficient SO_2 capture and higher limestone requirements. The shift in the relative arrangement of these units from Figure 15(a) to Figure 15(b) is due to different ratios of combustor area to grid area in different vendor's ACFB designs. The York(8) design with eight front wall feeders was improved upon by the addition of four back wall fuel and sorbent feeders. The improvement in the fuel distribution by adding four back wall feeders to the York ACFB design is evident by comparing the points labeled York(12), which includes the back wall feeders, and York(8) which does not.

Operating data taken at several other ACFB plants clearly shows that the fuel distribution can have a dramatic affect on the sorbent utilization efficiency (Ca/S ratio) while maintaining the same firing rate and sulfur capture. A parameter which quantifies how uniform or non-uniform the fuel is fed is simply the average firing rate per fuel feeder. Generally, the Ca/S ratio increases as the firing rate per feeder increases (or the number of feeders is reduced while maintaining the same total firing rate). Figure 16 shows sample data taken at an ACFB cogen facility. Ca/S molar ratio is plotted against average firing rate per feeder for two combustor temperatures and three different feeding configurations. In configuration (1) the fuel is evenly split between the two front wall and single loop seal feeder in the rear wall. In configuration (2), the fuel flow is split between the two front wall feeders. And in configuration (3), 100% of the fuel is fed through the rear wall loop seal. The unexpected drop in Ca/S ratio upon changing from configuration (2) to (3) is thought to be due to the much improved solids mixing and distribution resulting with loop seal feeding due to the large momentum flow of the recycle solids. This data clearly shows the strong influence that fuel distribution is expected to have on sorbent consumption. The YCEP design includes a return channel with multiple openings communicating with the combustor for optimal distribution of the return solids.

This and other data on the reduction in Ca/S ratio resulting from improved fuel distribution in several ACFB units burning similar types of fuel was used to estimate the potential reduction in Ca/S ratio due to addition of the back wall feeders to the YCEP project. A similar reduction in Ca/S on the order of 20-30% would be expected.

Cyclone Separator Design and Configuration

Another design issue important to the successful scale up of ACFB combustors is the design of the cyclone gas-solid separation system. As the size of the combustor increases, the mass flow of gas and solids exiting the top of the combustor to the cyclones increases proportionally (given same particle size, combustor height, etc.). One method of performing this separation with the increased flow of particle-laden gas is to increase the size of the cyclone. Unfortunately, as the cyclone size (diameter) increases the centrifugal force field is reduced (at the same gas inlet velocity) and the particle collection efficiency deteriorates. In the absence of high solids collection efficiency, smaller sorbent, carbon, and ash particles escape through the cyclone rather than being recycled to the combustor with the cyclone underflow. This would result in inefficient fuel and sorbent utilization and a reduction in inventory of particles capable of circulating and transferring heat. Another drawback of increased cyclone size is that the increased cyclone height may dictate increased combustor height for the solids recirculation system to function properly.

To enable high gas-solid separation efficiency with the YCEP ACFB boiler design the size of the cyclones was held similar to that utilized in smaller units. However, to accommodate the increased gas flow rate the number of cyclones was increased. The YCEP boiler will utilize four cyclones arranged as shown in Figure 17.

The cyclone separator designs features steam cooling and is an integral part of the steam superheat circuit. Steam cooling of the cyclones offers the following advantages:

- Faster unit start-up
- Reduced heat losses
- Reduced requirements for high-temperature refractory ductwork and expansion joints

Technical Innovation

The following section describes several innovative features of the ACFB system design:

INTREX^{TM} Integrated Recycle Heat Exchanger

The INTREX^{TM} heat exchanger is simply an unfired fluidized bed heat exchanger with a non-mechanical means for diverting solids. It will take advantage of the high heat transfer coefficients for tubes immersed in bubbling fluidized beds and will also operate advantageously with fine (200 micron) particles. Due to the fine recycle solids and the low fluidizing velocities (0.5 to 1.5 ft/s), tube erosion will not be a concern. The INTREX^{TM} heat exchanger allows for part of the heat released in the combustor to be removed outside of the combustor. This method of heat removal will eliminate the need for excessively tall combustors or the need to install furnace panels which protrude into the erosive flow in the combustor and are subject to excessive wear.

The INTREX^{TM} heat exchanger will be enclosed by the same water-cooled membrane construction used in the furnace. The integrated configuration will allow it to grow downward with the rest of the boiler steam/water pressure parts, minimizing differential thermal movement. Placement of serpentine superheater coils within the recirculated solids flow path enables the entire reheater to be located in a conventional parallel pass heat recovery area. Final main steam temperature will be controlled by spray water attemperation, while reheat steam temperature will be controlled by gas flow proportioning in the heat recovery area.

FWEC has extensive experience in the design of atmospheric bubbling fluidized bed (BFB) heat exchangers from the 46 BFB steam generators that it has designed and put into operation. Scale up of the INTREX^{TM} BFB is not an issue since the main cell in the 130-MW Northern States Power Black Dog unit is about four times greater in plan area than the largest INTREX cell in the YCEP ACFB. The INTREX^{TM} heat exchanger will be divided into four cells.

DOE Clean Coal I Demonstration Tests

In the demonstration test program proposed to the U.S. Dept. of Energy, a series of demonstration tests were specified to evaluate FWEC's ACFB technology for large-scale electric utility applications. The goal of the proposed test program is to determine the impact of important operating parameters and fuel characteristics on the design, operation, and performance of the ACFB facility and the costs of electric power production. Since the proposed 250 MW_e ACFB will become the largest single ACFB boiler in operation and even larger capacity units are anticipated for electric utility applications, the results of this test program will be important to both the technology evaluation and the design of larger utility-scale ACFB's.

Specifically, this demonstration program is designed to provide the following important information:

- Demonstrate unit start up and shut down capabilities and provide data and experience on ACFB boiler operation during these transients.
- Demonstrate ACFB boiler dispatching capabilities and constraints.
- Demonstrate ACFB boiler operation at full-load conditions for extended periods and continuous operation at part-load conditions.
- Provide quantitative results from a systematic study on the effects of important operating parameters and fuel characteristics on boiler performance which will aid in the optimum economic design and operation of future units.
- Identify constraints governing fuel selection based on test results from four different fuels.
- Provide guidelines for inspection and maintenance along with information on maintenance costs.

Included in the test program are specific operating tests to evaluate the effects of the following operating parameters on ACFB performance:

- Fuel size and quality
- Sorbent size and quality
- Fuel and sorbent rates
- Combustor temperature
- Excess air
- Primary/secondary air ratio

Specific boiler performance parameters to be quantified include:

- Boiler thermal efficiency
- Steam/Electrical Generation Capacity
- Ability to control steam temperature and pressure
- Ash production and quality
- Bed ash / fly ash split
- Unburned carbon losses in bed and fly ash
- Stack emissions: NOx, SO2, CO, VOC and particulate
- Power consumption of auxiliary equipment
- Percent SO2 capture and Ca/S ratio
- Control of bed inventory
- Combustor temperature profile

Tests are proposed for four different coals: the design coal (basis for combustor design) and three test coals having different properties from the design coal. The purpose of performing tests with coals having properties which differ from the design coal is to determine what range of coal properties can be utilized and the impact of fuel characteristics on the performance and operating economics of the ACFB. The same sorbent material would be used throughout all of the tests.

In addition to performing tests at 100% maximum continuous rating (MCR), tests would be performed to demonstrate operation of the boiler and other ACFB system components during start-up, shutdown, and dispatch of the facility. To demonstrate the capability of the system, a 30-day test with the boiler operating at a minimum of 96% MCR is proposed.

Environmental Considerations

The YCEP Cogeneration facility will be equipped with the necessary air pollution control equipment to meet the BACT determination.

Air Quality Controls

Under the Clean Air Act Amendments of 1990, the York County, PA area is determined to be marginally non-attainment for ozone. Other than ozone, there are no known ambient air quality problems in the immediate project vicinity. Sufficient prevention of significant deterioration (PSD) increment is available for both SO2 and NOx which will allow for approval of the air permit. Since the VOC emissions from the facility will be greater than 50 TPY, some VOC offsets will be required to comply with the ozone non-attainment.

Based on recent PSD air quality permits issued by PA Department of Environmental Resources (DER) Bureau of Air Quality for coal fired projects, the following minimum technical criteria are anticipated for the YCEP Cogen facility:

- Required SO_2 reduction will be 92% or greater. This level of sulfur capture can be achieved through addition of sorbent material to the ACFB.
- Required NOx reduction will be 50% or greater. This level of NOx abatement can be achieved through use of selective non-catalytic reduction with ammonia.
- Particulate emissions must not exceed 0.015 lb/MM BTU. Baghouse technologies will meet this requirement.
- The facility will be equipped with a continuous emissions monitoring system (CEMS) to monitor opacity, SO_2, NOx, CO_2, or O_2, and flue gas flow rate.

Solid Waste Management

The combustion of coal in the ACFB will result in byproduct ash generation. The fly and bed ash byproduct materials are dry and inert, consisting of a heterogeneous mixture of coal ash, calcium sulfate and calcium oxide. During full operation, a significant quantity of ash byproduct will be generated. Pilot plant tests are currently being conducted to quantify expected volumes of ash byproduct requiring disposal. Ash byproduct will be temporarily stored on-site in enclosed silos having 2000 tons storage capacity, then transferred into enclosed 20-ton trucks for transport to a location for beneficial reuse. Because of the ACFB ash byproduct's high lime content, its concentrations of silicon, aluminum, and iron, and its pozzolonic properties, beneficial uses for the material can be found; these include sludge stabilization agents, agricultural soil additives, and road bed aggregate. Air Products has investigated and found viable ash byproduct uses for the ash produced at two existing facilities which Air Products owns and operates.

Waste Water Disposal

The YCEP project is designed as a low-discharging facility, through the efficient recirculation and reuse of water in the process system. Waste water will be disposed of in two different means. The majority of facility wastewater will be discharged to Cordorus Creek from a proposed new point source location. Flows to be discharged in this manner include utility and process streams such as cooling tower blowdown, plant maintenance wastes, and storm water runoff. The resulting discharge will be raw makeup water within which the naturally occurring minerals (e.g., calcium, magnesium, sulfate) have been concentrated due to the evaporation of water in the steam process and cooling water systems. Remaining facility waste water (domestic sewage and demineralizer regeneration waste) will be treated at the York County Wastewater Treatment Plant. Prior to discharge of these waste water streams, they will be combined in a sump and adjusted for pH. The treated stream will then meet or exceed the existing York County Waste water Treatment Plant statutes and regulations, as well as BAT requirements.

Commercial Feasibility

Market Potential

The U.S. electric utility industry currently expects a market to develop, beginning in the next 10 years, for 100- to 300 MWe power generation units as add-on capacity and for repowering or retrofitting aging power plants. The YCEP project plant, rated at 227 MWe net, is sized to demonstrate FWEC's ACFB technology near the high end of this range. The NISCO (120 MW) project demonstrated FWEC's ACFB technology for petroleum coke at the lower end of this scale. The design, construction, testing, scale-up success, and documentation of both costs and operational experience with the YCEP Cogen project will provide utilities with information they will need to plan to replace or retrofit existing units, or to install new generating capacity in the near future.

The YCEP Cogen project represents a substantial scale-up from the largest operating single combustor ACFB. Upon completion of design, construction and start-up of the YCEP Cogen facility, the Clean Coal Technology 1 Demonstration Program will provide a database on the operating performance and cost from this unit. These tests will confirm performance specifications, determine operating costs, and determine operating conditions which minimize gaseous emissions. A database for the component material performance will also be compiled during this test period. This Demonstration Test Program will provide utilities with sufficient information to enable utilities and independent power producers to fairly and accurately evaluate FWEC's ACFB technology and permit further application of this technology. Since initial commercial orders would be very similar in design to the YCEP ACFB boiler, this would save engineering, design, and construction time and help reduce costs and expedite commercialization.

Conclusion

The systematic and collaborative approach followed by Air Products and Foster Wheeler Energy Corporation in the ACFB design and scale-up for the YCEP project will help guarantee the success of this important demonstration project. The pilot plant test program being conducted will serve to guarantee the performance of the commercial ACFB cogen plant. Furthermore, the review of the scale-up issues and the integration of components in the system was completed and new innovations were incorporated into the ACFB design. As a result of this development effort, we hope to demonstrate that FWEC's ACFB technology can be utilized at the utility scale (250 MWe) to reliably, economically and efficiently produce electricity and steam from U.S. coal reserves while having minimal impact on our environment.

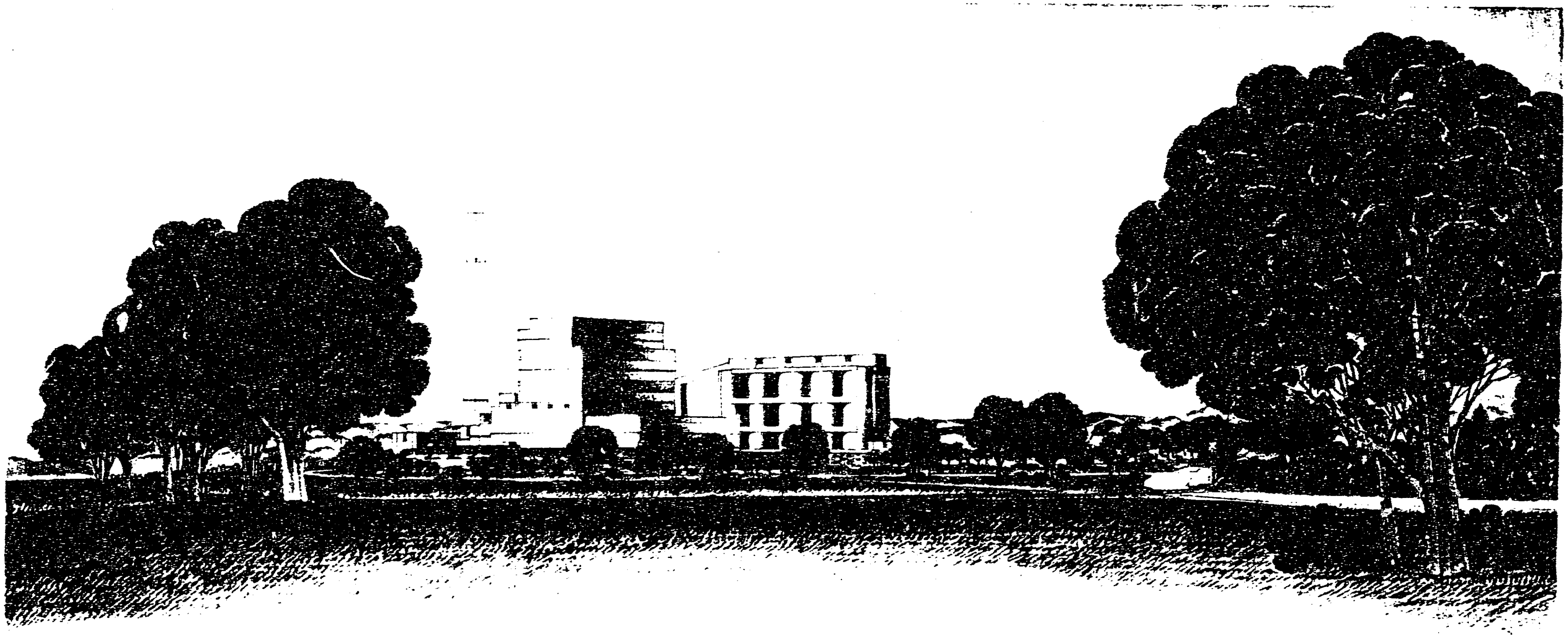

Figure 1. York County Energy Partners Proposed Cogen Facility.

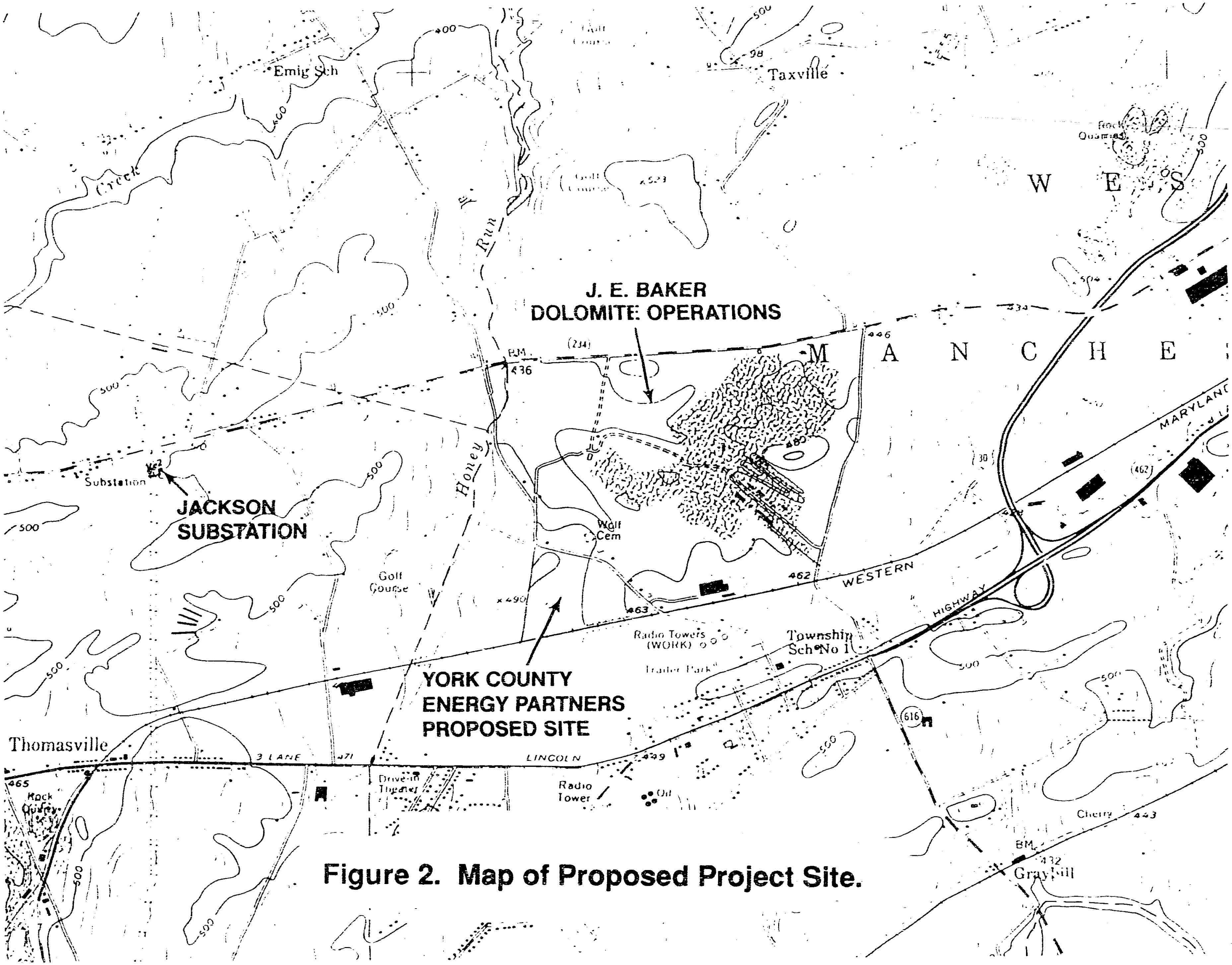

Figure 2. Map of Proposed Project Site.

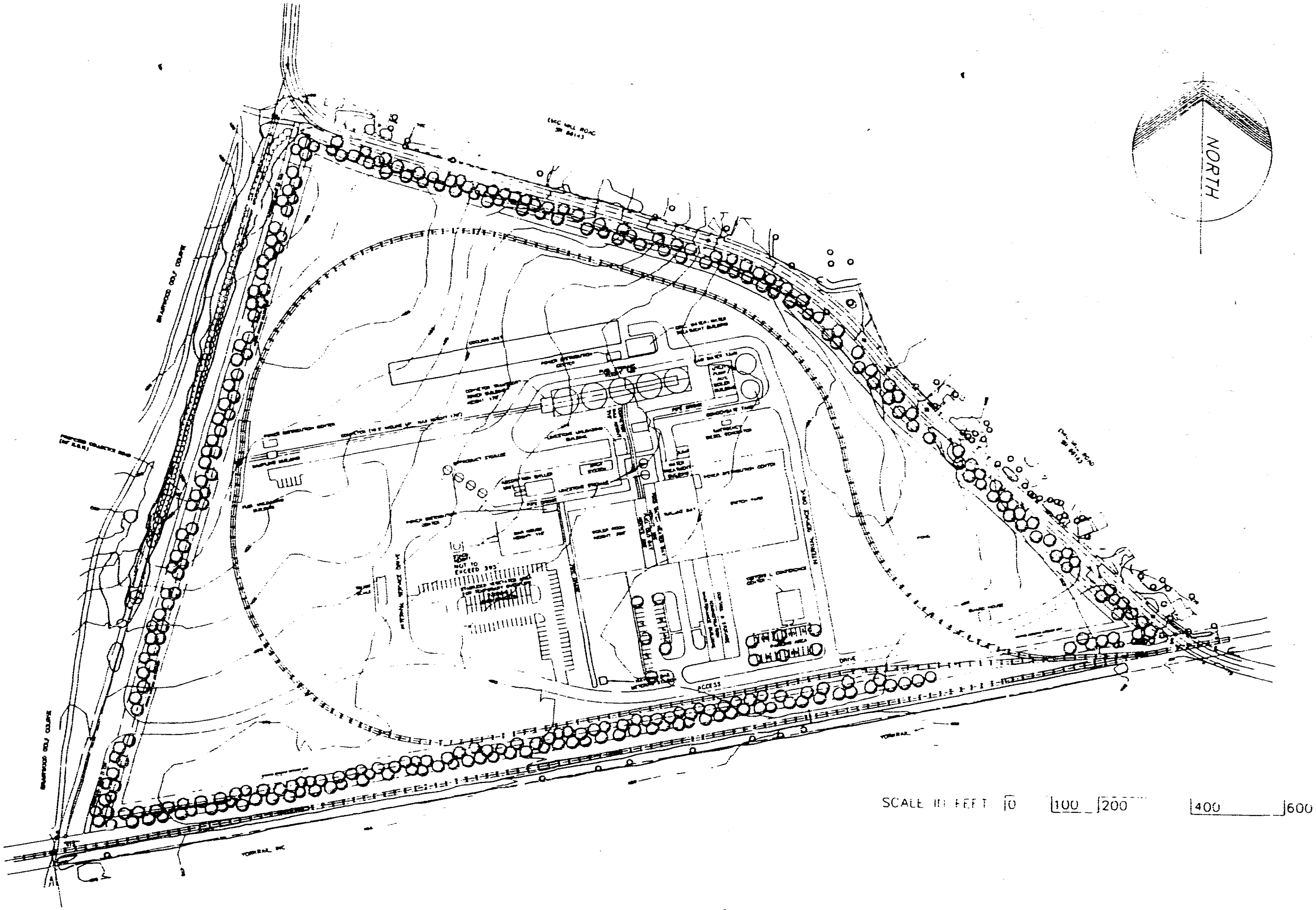

Figure 3. Plot Plan for YCEP Facility.

Table 1
YCEP Project Summary

Title:	York County Energy Partners Clean Coal Technology Round I Cogeneration Project
Proposer:	Air Products & Chemicals, Inc.
Location:	York County, PA
Technology:	Atmospheric Circulating Fluidized Bed Combustion
Applications:	Utility and Industrial Electric Power/Steam Generation, Repowering Existing Boilers or New Plants
Fuel:	Low Sulfur Western PA, MD, or W. VA Bituminous Coal
Size:	227 MWe net to Met-Ed 1,725,000 PPH/2500 psig/1005°F Main Steam, 1,400,000 PPH/442 psig/1005°F Reheat Steam
Steam Host:	J. E. Baker Co., York, PA 50,000 PPH Steam
Project Cost:	Greater than $ 300 Million
DOE Funding:	$ 75 Million

Table 2
York County Energy Partners Project Schedule

Major Milestones	Start Date	Completion Date
Submit Proposal		Oct., 1991
Negotiate Power Purchase Agreement	Dec. 10, 1991	Mar. 6, 1992
PUC Approval		Nov. 1, 1992
Environmental Permitting	Dec. 2, 1991	Dec. 15, 1993
Close Financing		Dec. 16, 1993
Prelim. Engineering	Oct. 1, 1992	Dec. 31, 1993
Design Engineering	Mar. 29, 1993	Apr. 14, 1994
Equipment Procurement	Feb. 18, 1992	Feb. 14, 1995
Boiler Steel and Boiler Erection	Sep. 1, 1994	Sep. 13, 1996
Initial Plant Check Out	May 21, 1996	Sep. 24, 1996
Synchronize with Grid	Feb. 7, 1997	Feb. 13, 1997
Performance Test	Feb. 14, 1997	Feb. 28, 1997
Commercial Operation		Mar. 3, 1997

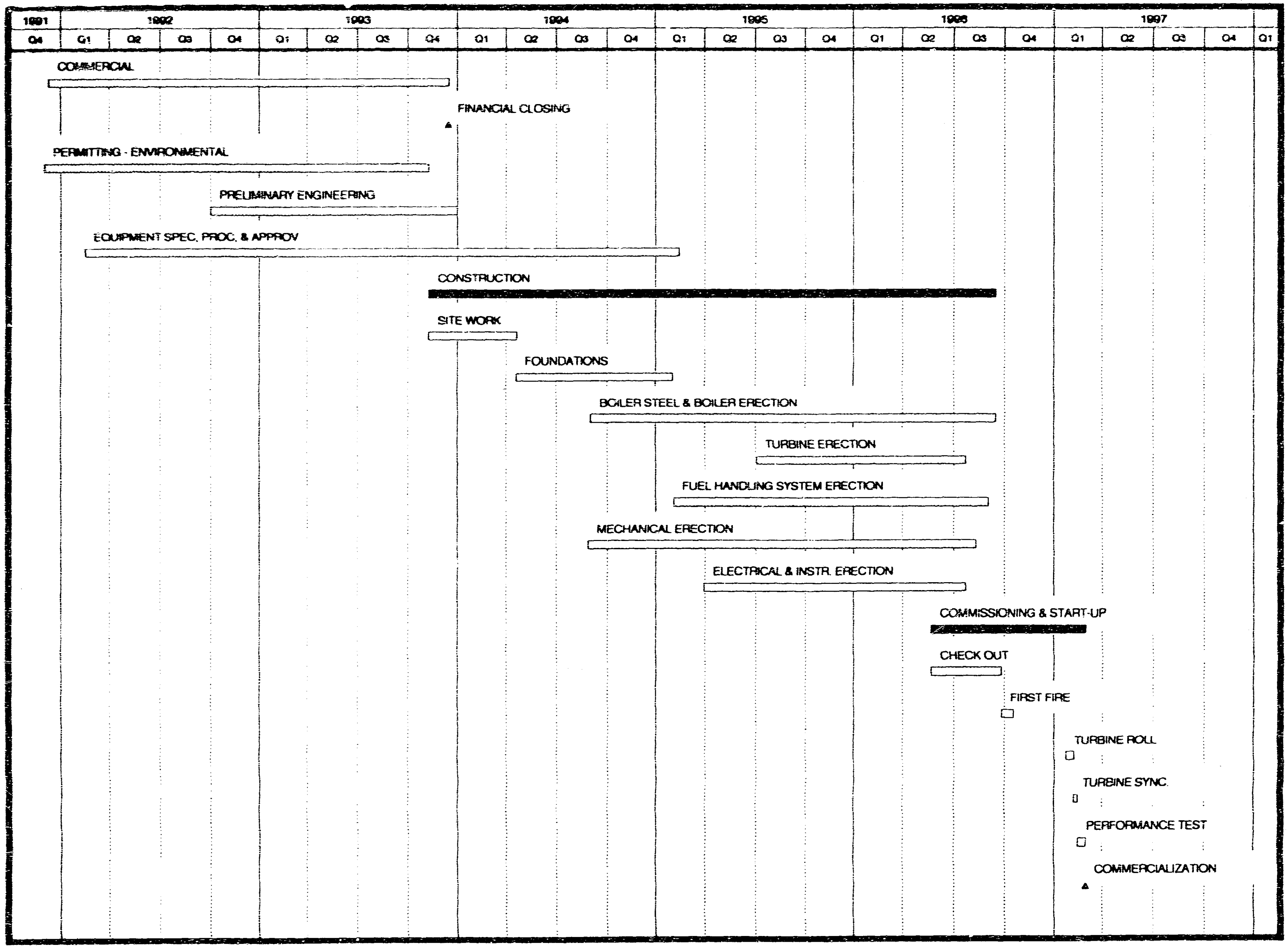

Figure 4. YCEP Project Schedule.

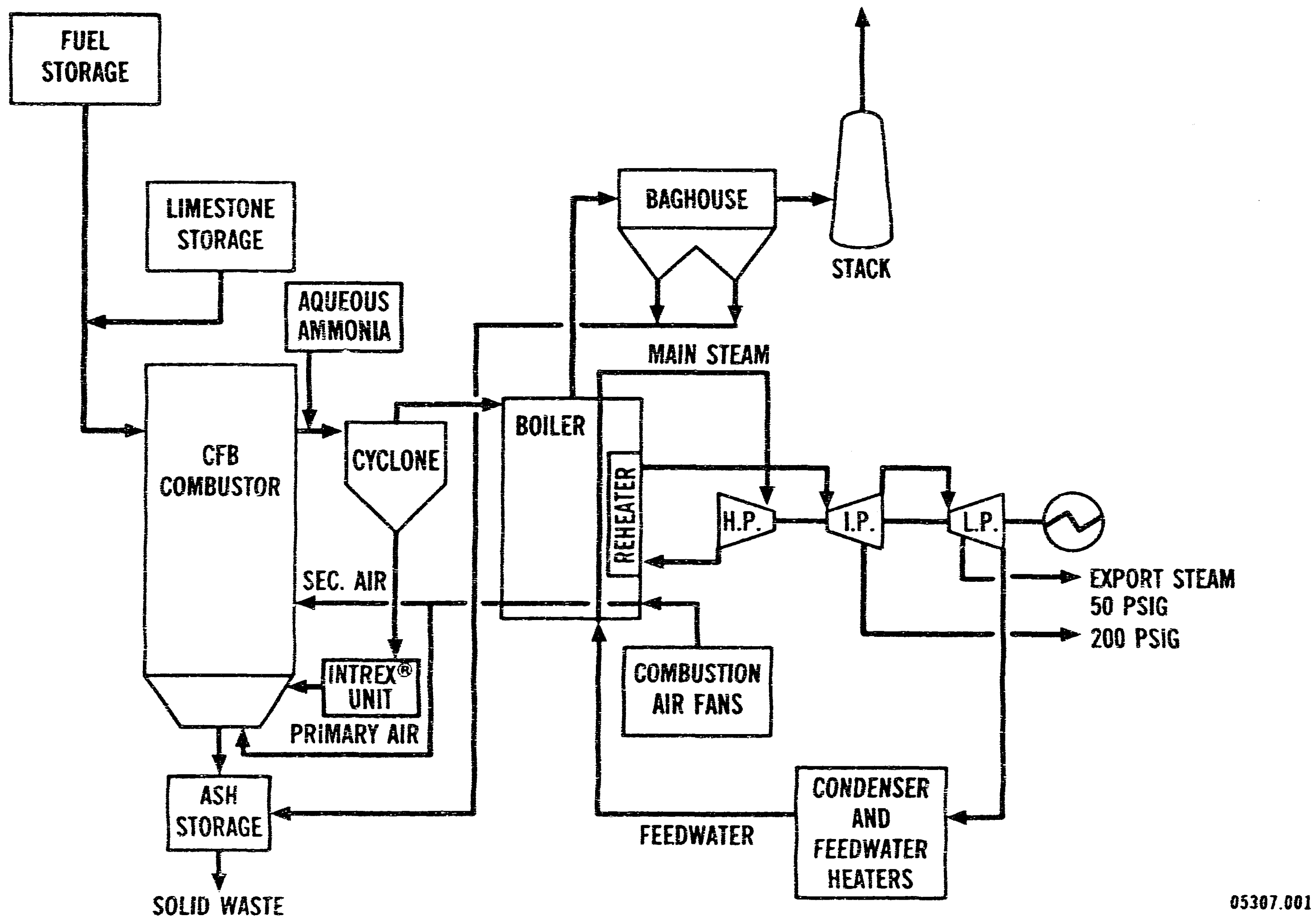

Figure 5. Process Flow Digram for YCEP Cogen Facility.

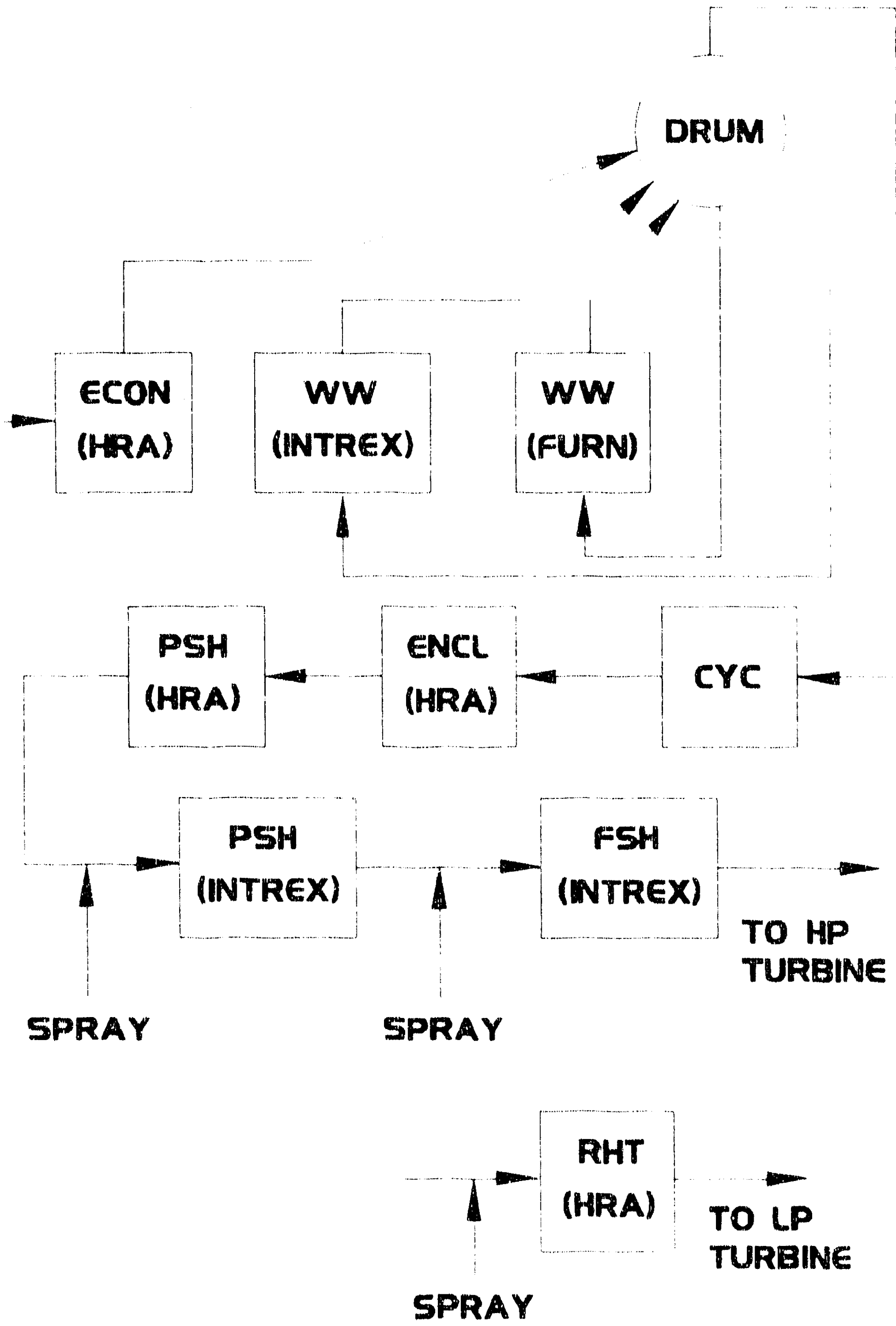

Figure 6. Steam/Water Circuitry.

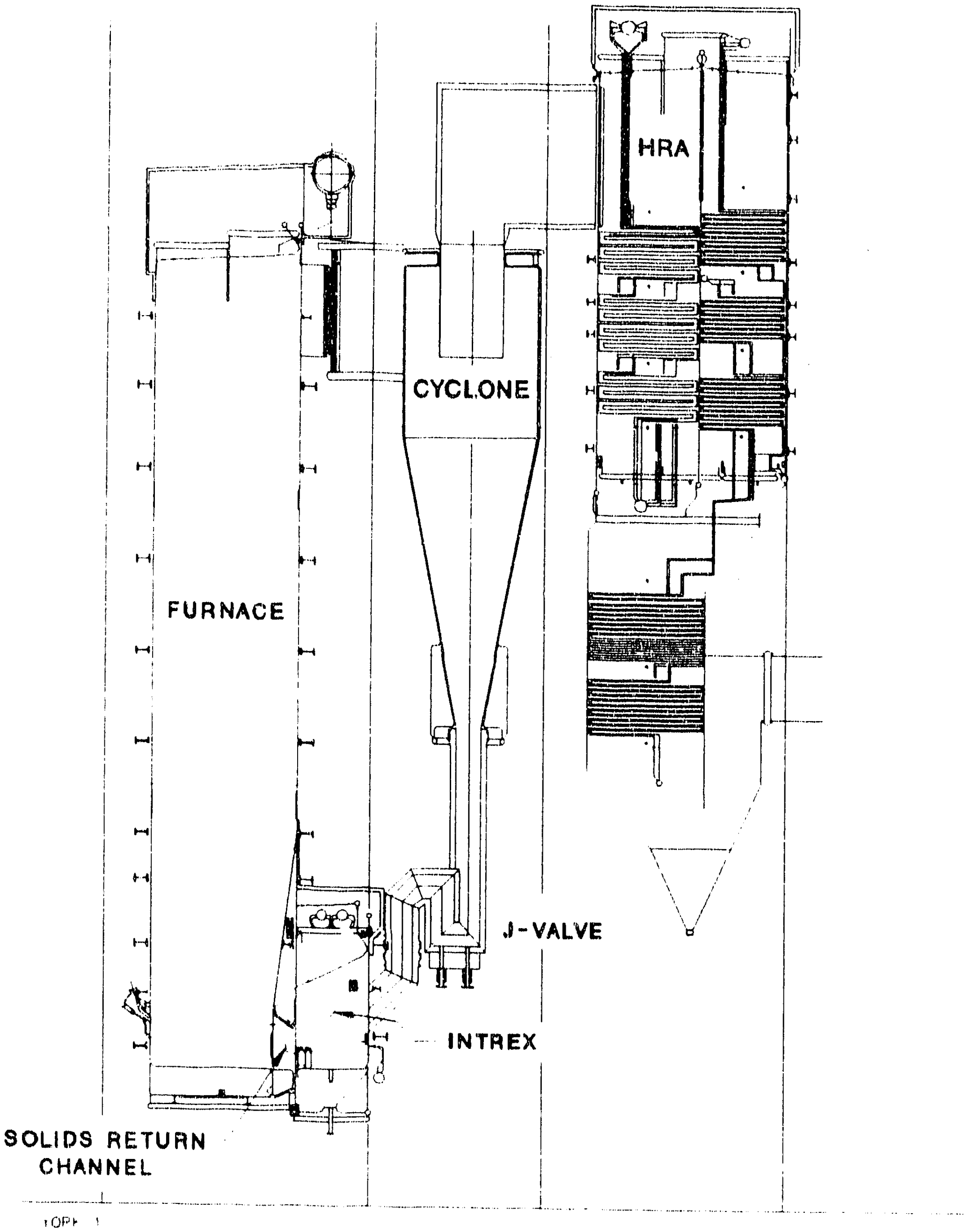

Figure 7. ACFB Steam Generator for Reheat Applications.

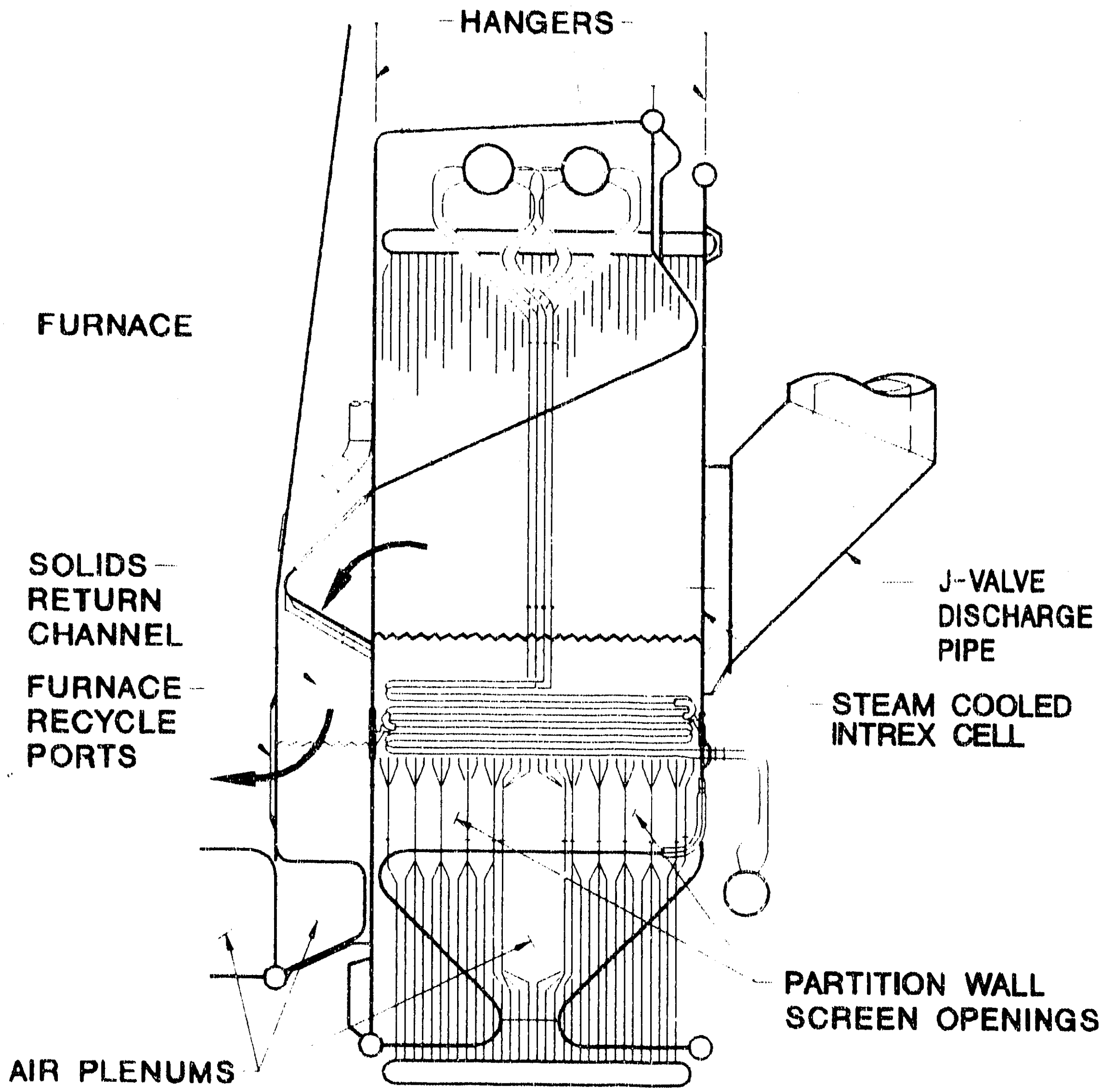

Figure 8. INTREX.

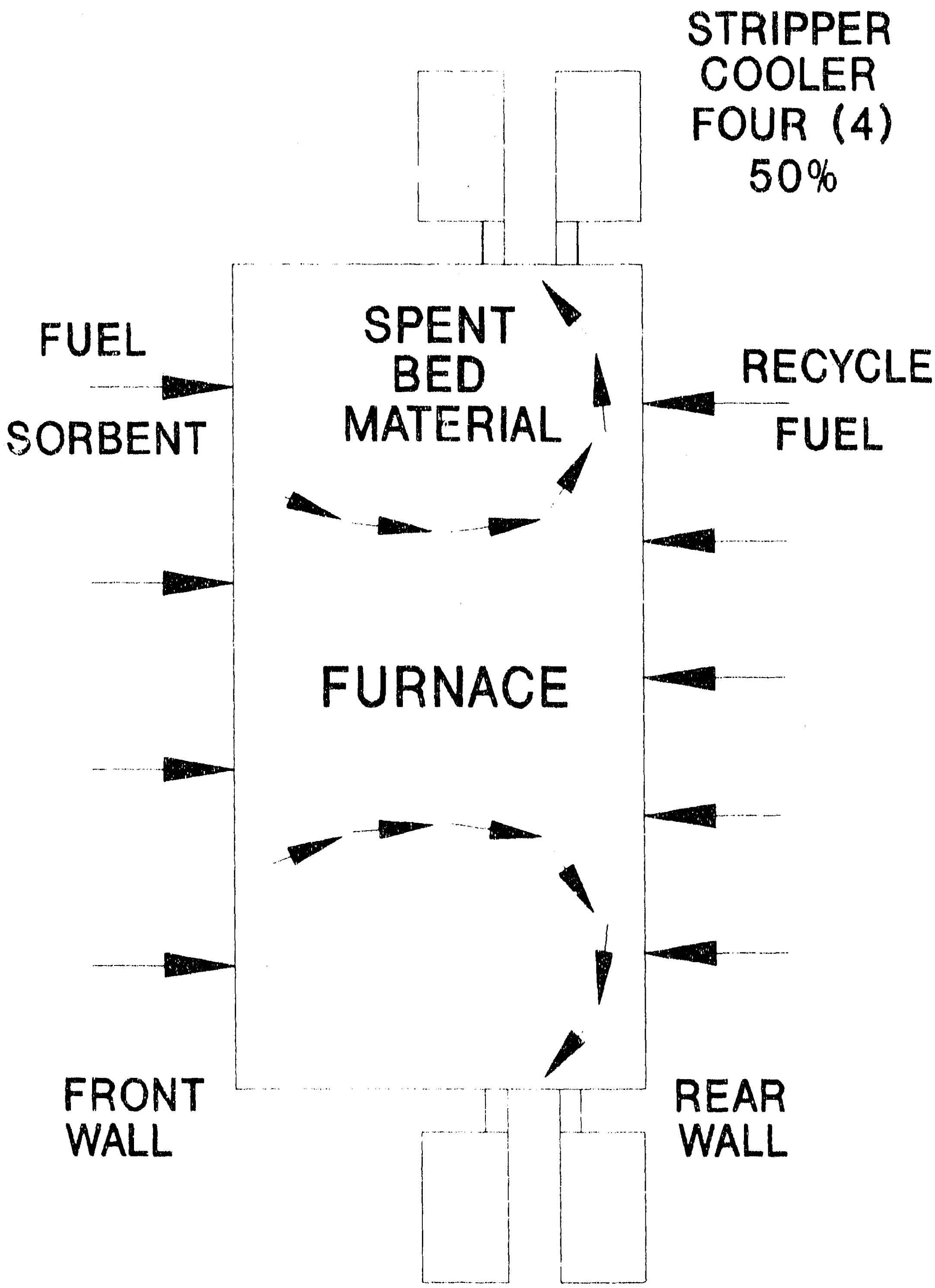

Figure 9. Solids Flow to Cooler.

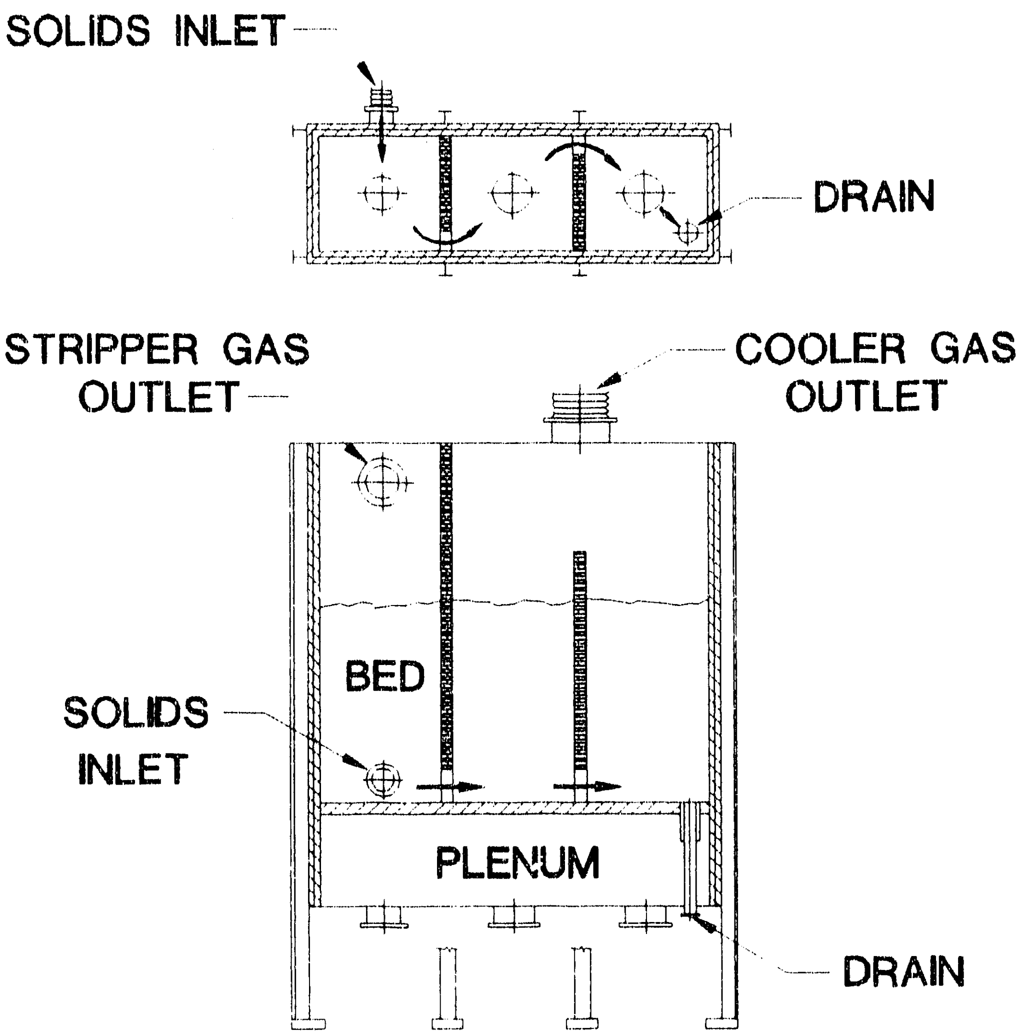

Figure 10. Stripper Cooler.

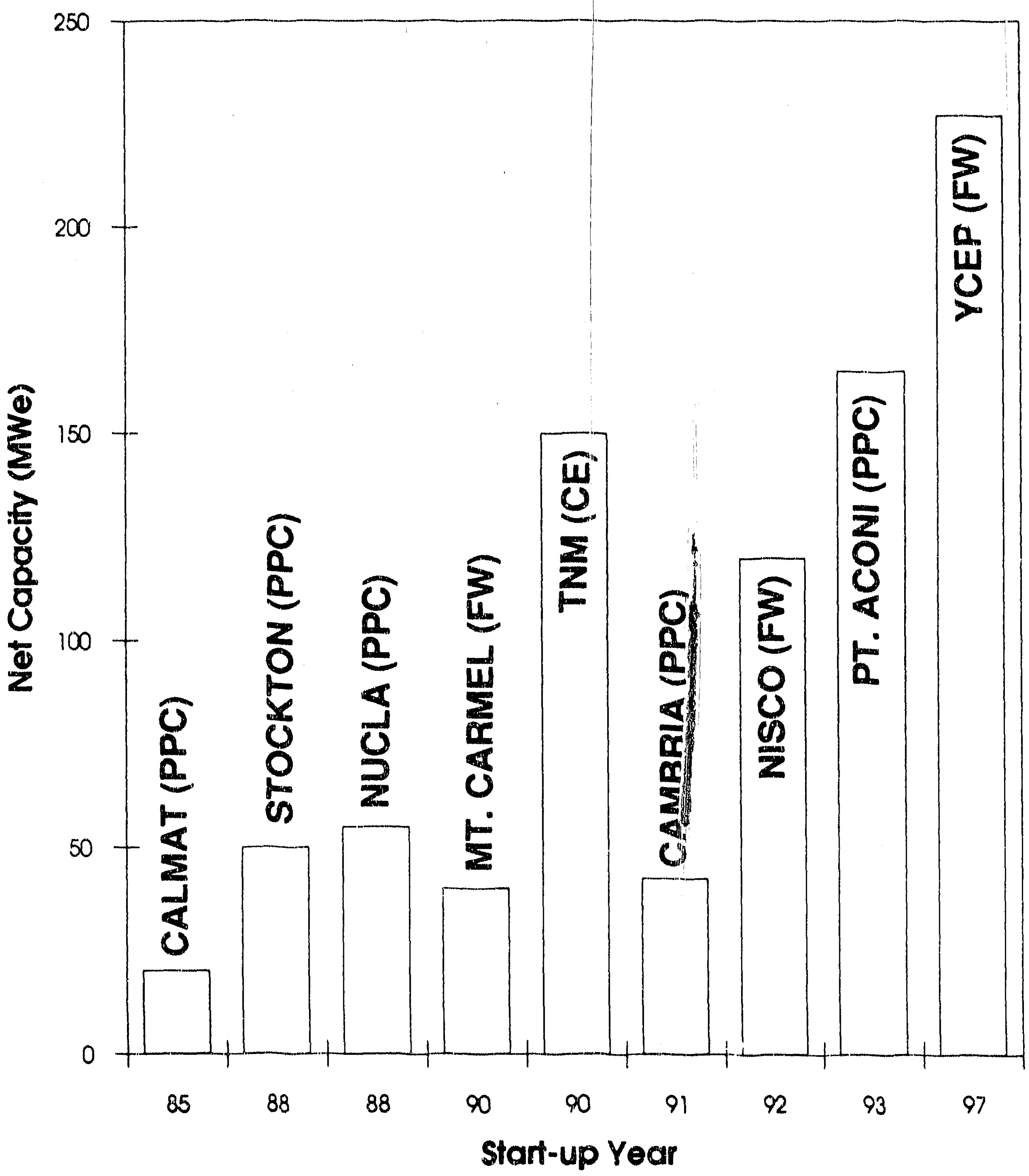

Figure 11. Evolution of ACFB Technology.

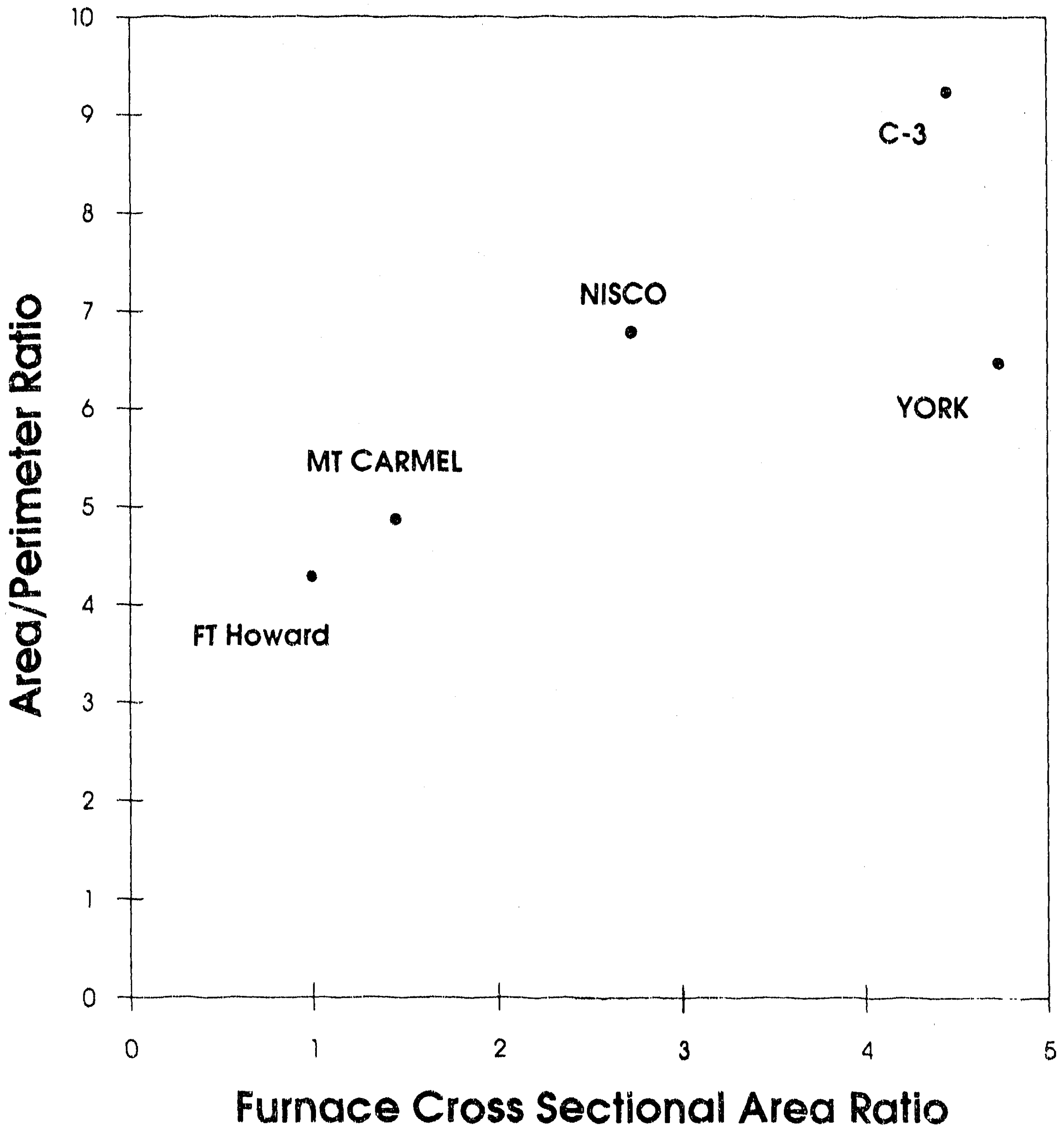

Figure 12. Division Wall Improves Furnace Area/Perimeter Ratio.

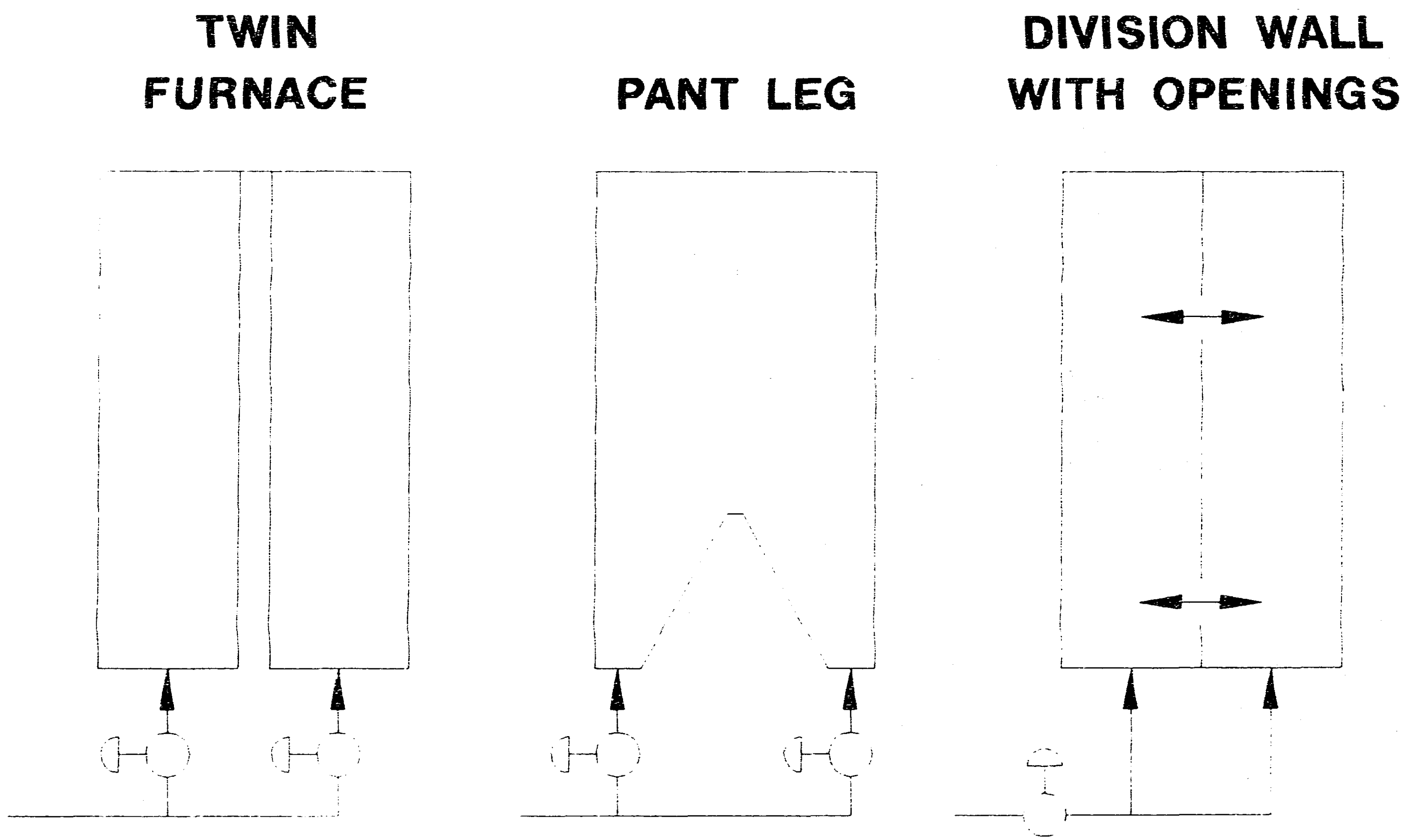

Figure 13. Large Scale ACFB Furnace Arrangements.

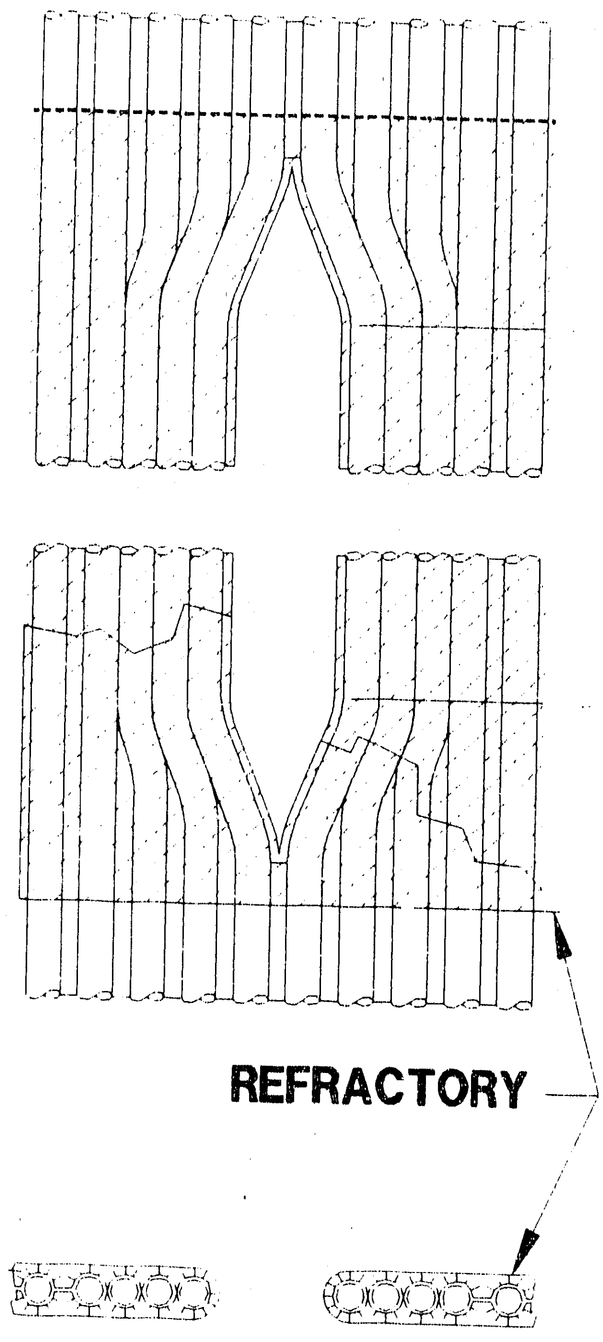

Figure 14. Division Wall Opening.

Table 3

Factors Affecting Solid Mixing

I External Solid Recirculation

- Gas Velocity at Grid
- Fine Solids Residence Time Based on External Recirculation
- Solid Particle Size (Attrition, Cyclone Efficiency, Feed Size)
- Momentum of Return Solids Flow and Number of Return Points
- Primary/Secondary Air Split
- Secondary Air Elevation

II Internal Solid Recirculation

- Fine Solids Residence Time Based on Internal Recirculation and Retention in Lower Bed
- Combustor Geometry - Front/Back Wall Taper
- Grid Nozzle Design

III Solid Feed Configuration

- Feeder Location (Wall, Loopseal)
- Combustor Depth
- Feeder Spacing

Table 4

Impact of Poor Solid Mixing

- Limestone Consumption Increases
- NOx Generation Increases
  - NH3 Consumption Increases
  - NH3 Slip Increases
  - NH4Cl Formation Potential Increases
- Combustion Efficiency Decreases
  - Agglomeration
  - Slagging

Table 5
FACTORS AFFECTING SORBENT UTILIZATION

- Sorbent Properties
  - Reactivity
  - Friability
  - Feed PSD
- Fuel Properties
  - Volatility
  - Reactivity
  - Sulfur content & forms
  - Feed PSD
- Combustor Temperature
- Firing Rate per Feed Point
  - Local O2 Concentration
  - Local SO2 Concentration
  - Local Temperature
- Sorbent Feed Distribution
- Solid Mixing in Lower Furnace
- Cyclone Efficiency

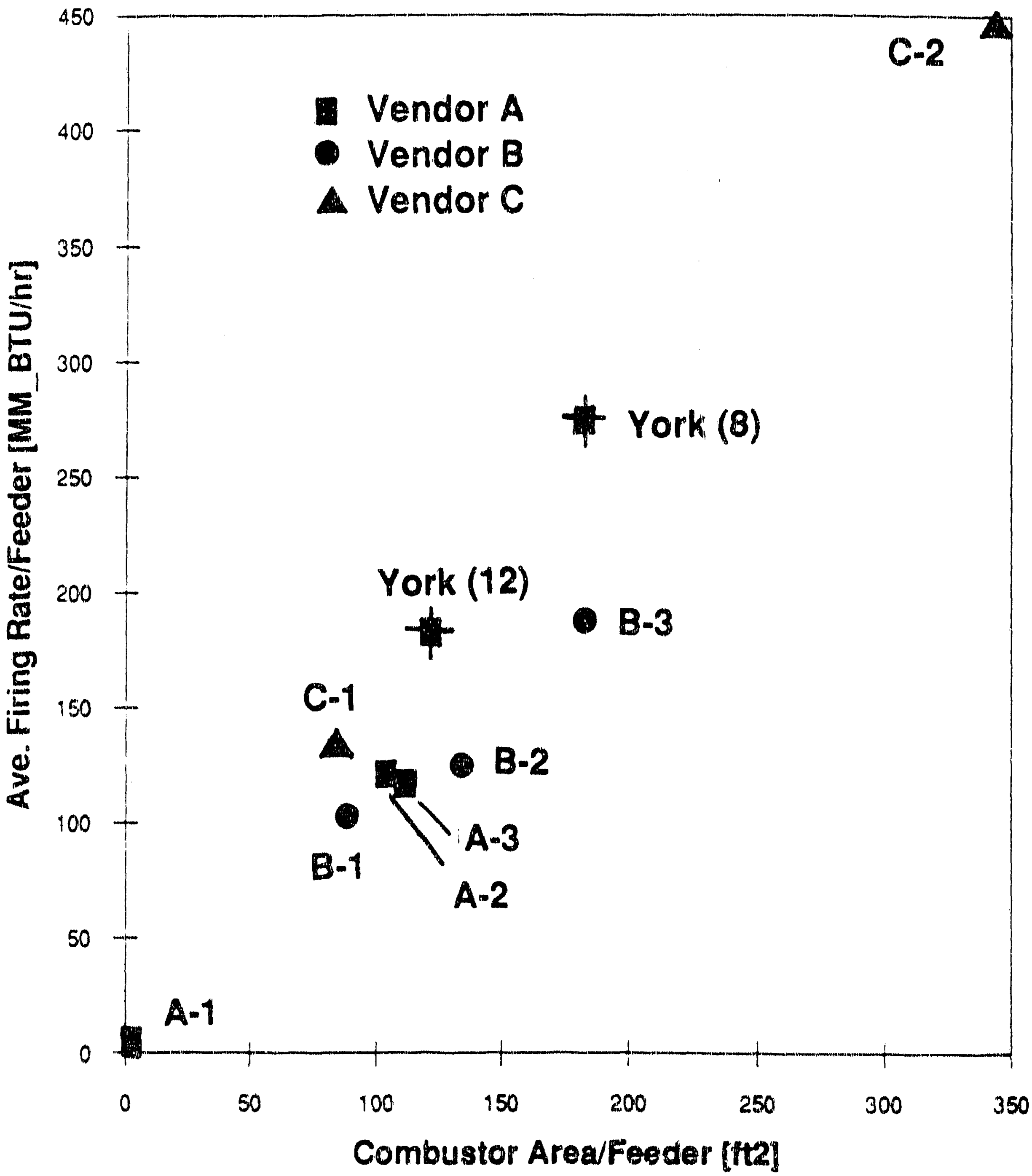

Figure 15(a). Comparison of Firing Distribution Based on Combustor Area.

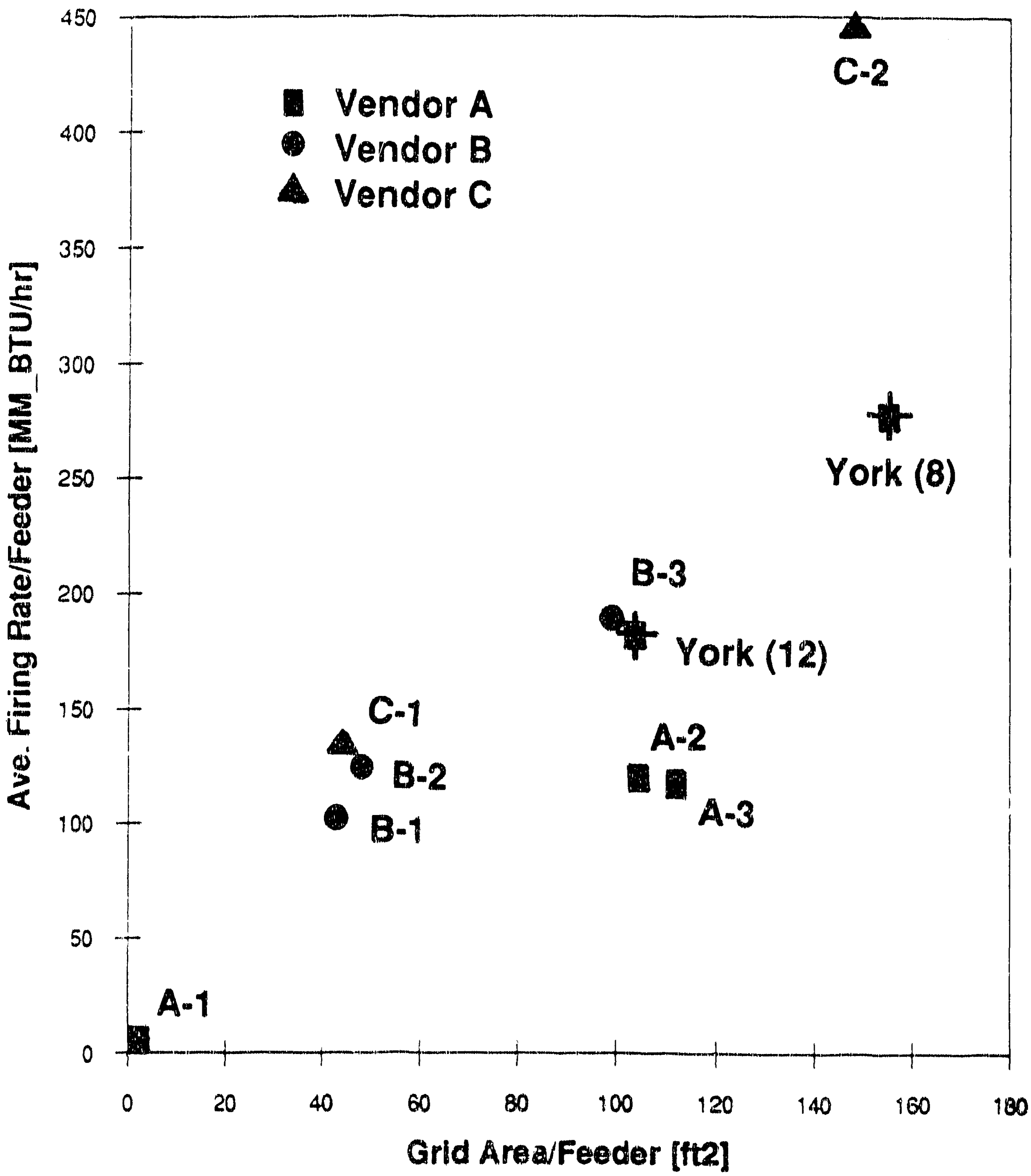

Figure 15(b). Comparision of Firing Distribution Based on Grid Area.

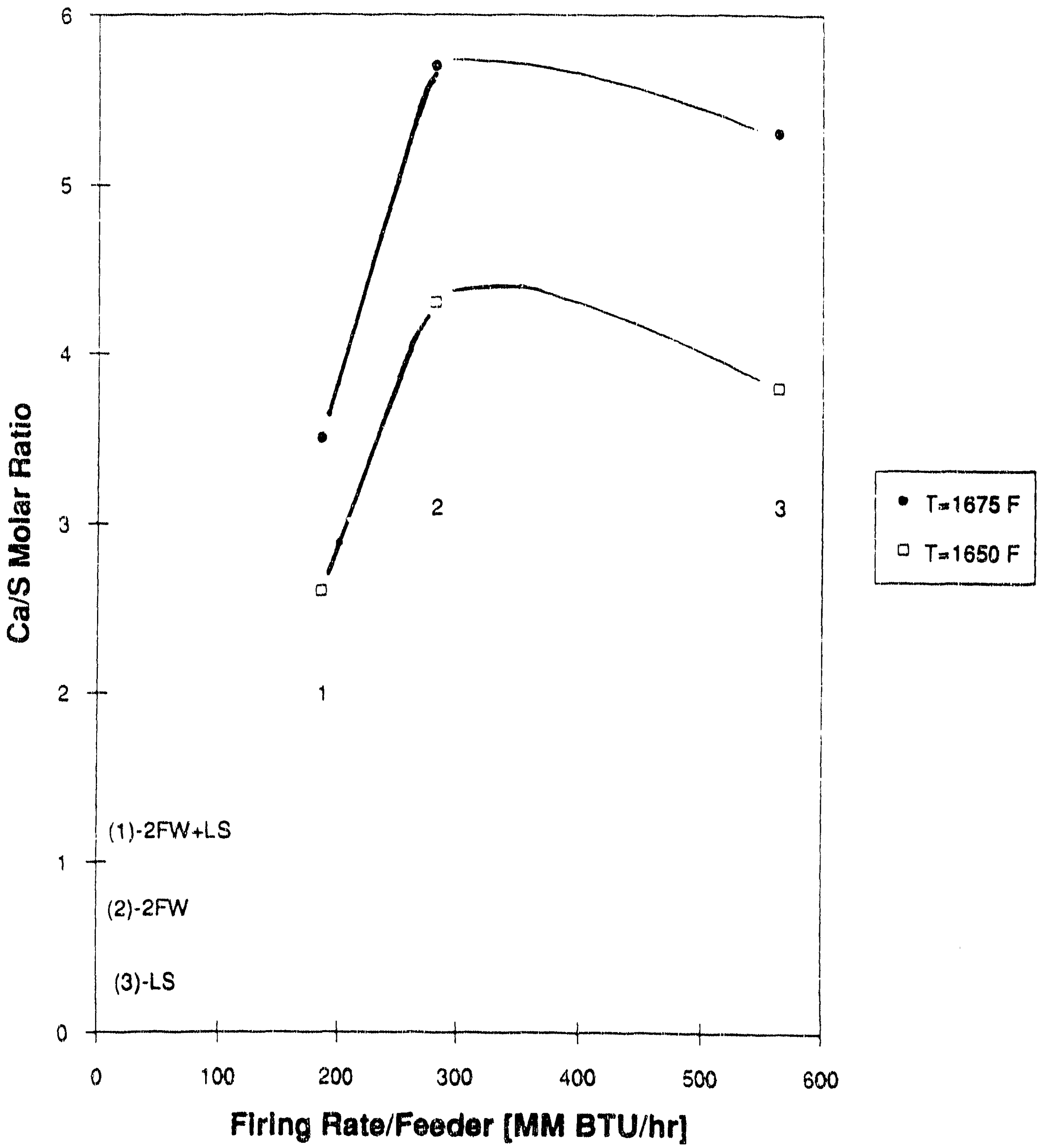

Figure 16. Effect of Fuel Distribution on Limestone Utilization in Unit B-3.

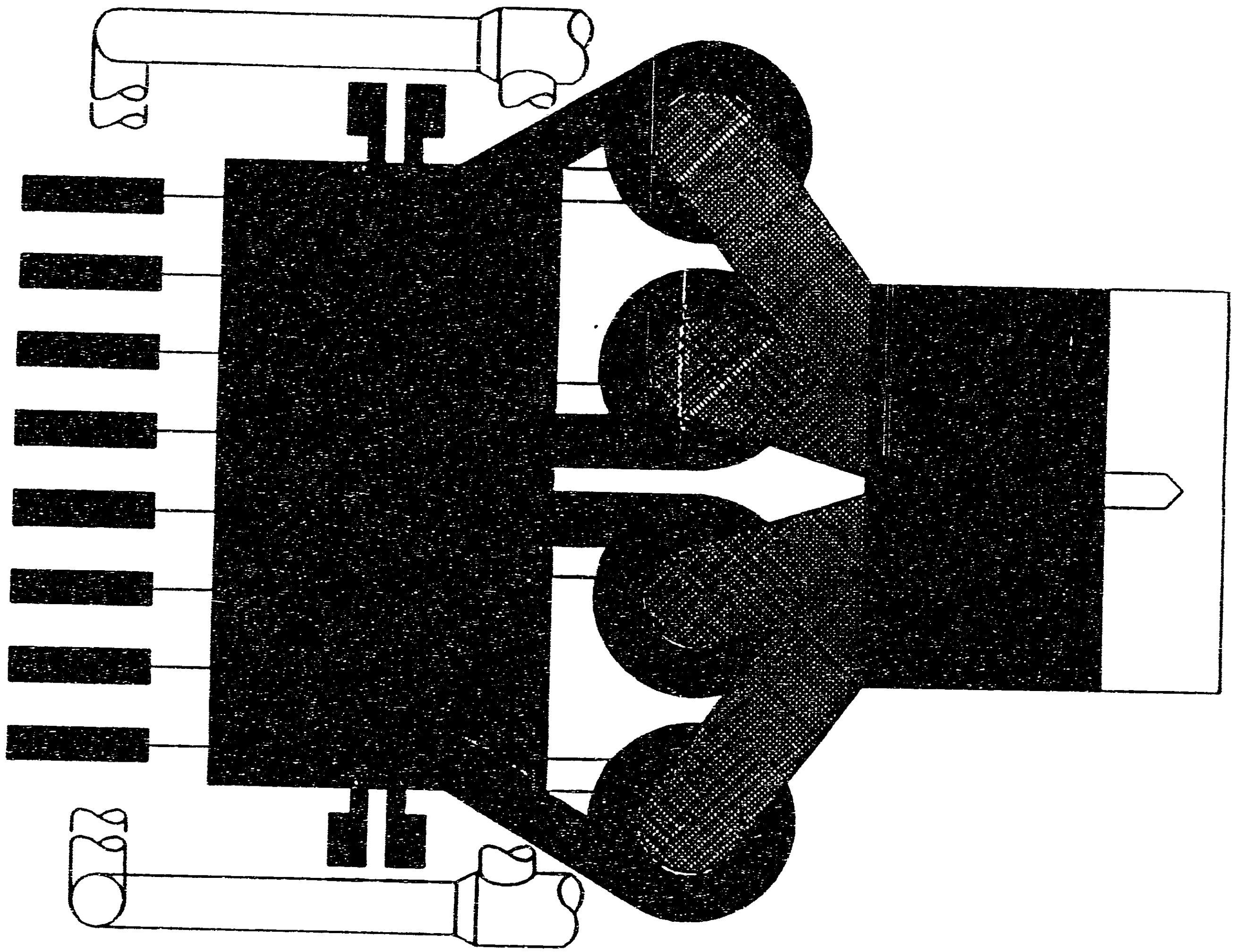

Figure 17. Cyclone Arrangement

END

DATE FILMED

11 / 10 / 92