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PULSED ATMOSPHERIC FLUIDIZED BED COMBUSTION

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Preface

This Quarterly Technical Progress Report presents the results of the work accomplished during the period July 1, 1992 through September 30, 1992 under DOE Contract No. DE-FC21-90MC27229, entitled "Pulsed Atmospheric Fluidized Bed Combustion."

PULSED ATMOSPHERIC FLUIDIZED BED COMBUSTOR DESIGN REPORT

Design Changes

The design of the Pulsed Atmospheric Fluidized Bed Combustor (PAFBC) as described in the Quarterly Report for the period April - June, 1992 was reviewed and minor modifications were included. The most important change made was in the coal/limestone preparation and feed system. Instead of procuring pre-sized coal for testing of the PAFBC, it was decided that the installation of a milling system would permit greater flexibility in the testing with respect to size distributions and combustion characteristics in the pulse combustor and the fluid bed. Particle size separation for pulse combustor and fluid bed will be performed by an air classifier. The modified process flow diagram for the coal/limestone handling system is presented in Figure 1.

The modified process flow diagrams of the fluidized bed/steam cycle and ash handling systems are presented in Figures 2 and 3, respectively.

Fabrication Drawings

Subsequent to finalization of the design, detail drawings were developed for fabrication of the fluid bed combustor vessel, pulse combustor water jacket, in-bed heat transfer modules, hot cyclone, ash recycle pipe and associated duct work. Refractory lined duct work for connection of the combustor vessel to the boiler has also been detailed.

Control Logic

The following is a brief description of the process and operation control logic.

Coal/Limestone Receiving System

A shovel loader will be used to transport coal from storage to a hopper (V-1). The coal is fed into a screw conveyor (C-1) by the hopper and the screw conveys the coal to the mill (C-F). From the mill, the coal drops through a chute into the air classifier (C-2). The air classifier separates the coal into two size categories namely 1/2" by zero and 28 mesh by zero. The fines (i.e., 28 mesh by zero) from the air classifier will be conveyed to the cyclone separator (S-2) atop the fines bin (V-3). The air required for the air classifier conveyor is supplied by a fan (F-1). The fines are separated from the conveying air in the cyclone and the fines drop into the bin. The conveying air proceeds from the cyclone to the main baghouse (S-6) and out to the atmosphere.

The coarse coal separated in the screen is fed into a screw conveyor (C-3) which conveys it to the inlet port of a bucket elevator (C-4). The bucket elevator conveys it to the

Figure 1 Coal/Limestone Handling System

Figure 2 Fluidized Bed/Steam Cycle

Figure 3 Ash Handling System

top of the coarse coal storage bin. The coarse coal is conveyed from the outlet port of the bucket elevator to the bin by a weigh feeder (C-5). The coarse coal bin (V-2) is provided with a bin vent filter (S-1) to control fugitive emissions.

Coal Receiving Procedure

During operation of the PAFBC, if the level in either the fines or coarse bin reaches low, an annunciation (audio-visual) will be initiated in the control room. Then, the receiving system will be energized manually.

Before the shovel loader dumps the first load into the hopper (V-1), the fan (F-1), screw conveyor (C-1), screw conveyor (C-3), and bucket elevator (C-4) have to be started.

If both bins are at or above high level, an attempt to start the receiving system will result in an annunciation (audio-visual) in the control room. If one or the other bin is at high, an attempt to start the receiving system will result in an annunciation.

If one or the other bin is at high level and the other one needs to be filled, the coal receiving system can be started after manually after adjusting the mill to increase the supply to the bin.

The event of one or the other bin being empty while the other is full is unlikely during normal operation since the combustion system consumes both fines and coarse proportionately. It is only during initial characterization that the disparity is likely to occur.

Non-availability of coal to charge the receiving system means a shutdown and any manual activities necessary for shutdown must be carried out.

Limestone Receiving System

Limestone will be received in pressurized blower trucks which will be connected to a pipeline at ground level and continuing to the top of the limestone bin (V-4). The limestone bin has a bin vent filter (S-4) through which the conveying air is filtered and exhausts to atmosphere.

Limestone Receiving Procedure

During operation, if the level in the limestone bin reaches low, an annunciation (audio-visual) will result in the control room.

The limestone bin has been designed to hold two (2) truckloads (approximately 32 tons) of limestone thereby providing about 32 hours of full load operation. The low level indicator in the limestone bin is essentially a reorder indicator and will be installed at the half capacity level of the bin. This means that when the low level annunciation is triggered, 16 hours of full load operation remains thereby providing 16 hours in which the next truck

load can arrive at the site. The low level annunciation also means that the limestone bin can receive a whole truckload of limestone.

In addition, a high level annunciation (audio-visual) will be installed and a bin empty annunciation will be provided.

The bin empty sensor will be placed at a level which allows enough limestone to be available (after annunciation) for a shutdown from full load. The bin empty sensor, apart from triggering an annunciation, will automatically initiate complete shutdown by stopping coal feed to both the pulse combustor and the bed. Other manual shutdown activities will have to be carried out after annunciation.

Pulse Combustor Coal (Fines) System

The fine coal from the fines bin (V-3) discharges through a standpipe into a screw conveyor (M-2) which is a metering feeder with a variable speed drive. Screw conveyor discharges into a small fluidized distributor (C-7) with six outlets. The standpipe is necessary to provide the head to seal against air escaping from the fluidized distributor and into the bin. The pulse combustor has six aerovalves and coal will be fed coaxially into the throat of each aerovalve in equal quantities. To this end, the fluidized distributor works like a circulating fluid bed entraining the coal in an air stream and leaving the distributor through six outlets each carrying an equal quantity of coal. From the six outlets, six lines connect to the six aerovalves. The conveying air is supplied by a blower (F-2) and constitutes part of the combustion air for the pulse combustor. The main combustion air is supplied by a fan (F-3) to the pulse combustor air plenum.

Pulse Combustor Feed Procedure

Gas will be used to startup the pulse combustor and coal will be phased in and gas stopped. To startup the pulse combustor, the main combustion air fan (F-3) will be started and then gas turned on. If for some reason the fan (F-3) trips during operation or startup, fuel supply (be it gas or coal) will be shut off automatically. In addition, if the flame sensor in the combustion chamber senses a flame-out, fuel will be shut off but the fan (F-3) will be left on.

To start feeding coal, first the fan (F-2) will be turned on and allowed to run up to operating speed and then the screw feeder (C-8 calibrated prior to operation) can be turned on. Both the air from F-2 and the speed of M-2 can be adjusted to regulate the feed from the fluidized distributor (C-7). If the fan (F-2) trips for any reason, screw conveyor (M-2) will automatically trip. If the flame sensor in the combustion chamber senses a flame-out, the screw conveyor (M-2) and the fan (F-2) will trip automatically.

The interaction between fine coal feed, limestone feed, coarse coal feed, SO_2 emissions and load variations is presented later in "Combustion/Load Control."

In the event of either M-2 or F-2 suffering a failure during operation, the other will stop and an annunciation (audio-visual) will result in the control room.

Coarse Coal/Limestone to Fluid Bed Feed System

Coarse coal and limestone are fed underbed at one point using an air conveying system. Coarse coal discharges from the bin through a standpipe into a variable speed metering screw conveyor (M-1). The screw conveyor (M-1) discharges into the air conveyor. The air for the air conveyor is supplied by a fan (F-6). Limestone discharges from the bin (V-4) through a standpipe into a metering screw conveyor (M-3). M-3 discharges into the same air conveyor that received the coarse coal from M-1. The air conveyor carries the coarse coal and limestone into the bed through the feed port.

Coarse Coal/Limestone Feed Procedure

The fan (F-6) will be started before screw conveyors (M-1) and (M-3) are started. The speeds of (M-1) and (M-3) will determine the calcium-sulfur ratio. The control logic is dealt with later in "Combustion/Load control". Most important perhaps, is that the fuel feed (gas or fine coal in the case of the pulse combustor and coarse coal in the case of the bed) will not be operable until the boiler circulation pump (P-2 or P-3) have been started and circulation established. In addition, a low water level indication in the boiler will initiate a fuel cutoff. If the operating boiler circulation pump fails, the other pump will go on line immediately during PC or bed operation. In the event of both boiler circulation pumps becoming inoperable during PC and/or bed operation, the fuel to both PC and bed will be cutoff. Fuel cutoff will be accompanied by stopping the FD fans and the ID fan. Fuel cutoff can be achieved by stopping the metering screw conveyors (M-1 and M-3 for coarse coal and limestone, M-2 for fines) and the conveying air fans (F-2 for fines and F-6 for coarse coal and limestone).

If either the feed screw conveyors (M-1, M-3) or the fan F-6 suffers a failure during operation, an annunciation (audio-visual) will result in the control room. If the limestone screw conveyor fails, a complete fuel cutoff (both PC and bed) will result. If the coarse coal feed screw fails, we can continue to operate the pulse combustor, if desired, and so limestone will have to be fed to the bed. If the coarse coal conveying fan (F-6) fails, the two screw conveyors will be stopped.

Fluid Bed and Boiler System

The pulse combustor has to be fired to heat up the bed and the bed vessel refractory and the cyclone refractory. However, if coal is used to fire the pulse combustor the bed has to be filled with limestone and fluidized to achieve sulfur capture.

To fill the bed, first, bed fluidization FD fan (F-4 or F-5) has to be started up and set at a desired fluidization velocity (just sufficient to distribute the material from the feed port out into the bed) and the limestone screw feeder and air conveyor fan have to be

started and the bed filled to the desired level. Once the pulse combustor is fired, bed fluidization air can be adjusted appropriately. Once the bed has reached 1500 degrees F the coarse coal feed can begin.

The bed has four drain ports serviced by two screw coolers (E-2 and E-3) that will discharge into the ash conveying line. The screw coolers can be started and stopped based on bed level and SO₂ emissions (which will dictate the need for fresh limestone). The vacuum ash handling system will have to be started before firing the pulse combustor or Fluid bed.

The hot gases from the freeboard of the PAFBC exit through the roof and enter the cyclone and from the exit of the cyclone travel to the firetube boiler and through the economizer and baghouse, ID fan and out the stack.

The catch from the hot cyclone is recycled to the bed through an aerated J-valve. The baghouse catch is dumped into the ash conveying line.

Feed water from the supply line is fed to the boiler through the economizer. A modulating valve will be used to maintain boiler level and minimum flow through the economizer.

From the boiler drum the circulation pumps draw the water and circulate it through the in-bed heat transfer surface and the pulse combustor's water jacket and the steam-water mixture returns to the boiler drum where the steam separates and exits.

Fluid Bed and Boiler Operation Procedure

Thermocouples will be required to be located at the following locations in the bed:

1. On the plate at strategic locations around the pulse combustor exhaust to ascertain the actual temperature of the plate. These thermocouples will be protected by the layer of dead bed material.
2. About 4 or 5 inches up in the dead layer of the bed and located around the exhaust of the pulse combustor to ensure that we indeed have a dead layer and that the pulse combustor exhaust plume is not stripping the dead layer.
3. In the bed.
4. In the freeboard.

Differential pressure sensors are necessary across 3 levels of the bed to ascertain bed level and pressure drop.

As described in coarse coal/limestone feed procedure, fuel cannot be fed to either PC or bed without starting the circulation pumps (P-2 and P-3). Other interlocks are as described in Coarse coal/Limestone feed procedure. In addition, the boiler will have a high pressure alarm annunciator in the control room. This annunciator will be set at a pressure less than the lowest safety/relief valve setting but higher than the maximum pressure that will occur in the drum due to load fluctuations and the lag time of the fuel feed system in reacting to a sudden reduction in load.

The fire tube boiler which doubles as a steam drum will have two level sensors, namely, a low level sensor that initiates fuel cutoff and alarm annunciations, and a sensor that controls the modulating valve.

In addition, there will be a backup low level indicator that only provides an audio-visual annunciation in the control room and operates on a completely independent circuit.

If one of the screw coolers fails the bed can still be operated with the other one (at reduced load). If both become inoperable a shutdown will have to be initiated.

Ash Handling System

The ash handling system is a self contained system consisting of an ash silo and a vacuum conveying line. The vacuum is created by a steam ejector and each ash drop out point is controlled by a pneumatically operated valve. The ash silo has a vent filter and air washer to clean the conveying air before releasing it to the atmosphere. The ash collects in the ash silo and will be disposed in trucks.

Ash Systems Operation

The ash system will be energized as a complete system prior to firing the pulse combustor or fluid bed. The various ash collection points (ash cooler discharges, boiler front and back dropouts, and baghouse dropouts) will be serviced in sequence by the ash system logic controller. Only one valve will open at a time to maintain vacuum in the conveying line. A fuel cutoff will put the ash system in standby mode and a manual override will permit ash disposal or bed draining when the combustors are shut down.

Combustion/Load Control

Calcium-sulfur ratio, or in other words the speed of the limestone metering feeder (M-3) will be regulated by proportion off the coal feeder and trimmed based on SO₂ level in the stack.

To regulate firing rate the pressure in the boiler will be used as the source signal. Increased steam demand results in a reduction in pressure in the boiler and will result in an increase in firing rate. A decrease in steam demand will result in an increase in boiler pressure and therefore a reduction in fuel feed rate.

Fine and coarse coal will be fired proportionally at full load and for various degrees of turndown, down to the minimum firing rate of the pulse combustor. Thereafter if further turndown is required the pulse combustor will be turned off and the fluid bed alone will be fired. Turndown in the fluid bed can be achieved by bed level reduction to expose heat transfer surface, thereby reducing the heat transfer coefficient involved.

Process and Instrumentation Drawings

The above control logic was used to develop complete process and instrumentation drawings (P&IDs) for all the different systems and control loops have been identified. In addition, the instrumentation required for data acquisition of all important parameters was included. The P&IDs were used to develop detailed instrument and valve lists to be used for procurement. Piping analysis was performed to identify optimum pipe sizes and specify balance of plant equipment such as fans and pumps. Blue prints of the P&ID's are included (Drawing nos: T1I00012, T1I00021, T1I00031, T1I00041 and T1I00050).

Balance of Plant

The mass balance and P&ID's were used in creating detailed specifications for each of the fans, pumps and screw feeders and ash disposal screw conveyors.

A detailed layout of the entire plant with reference to the location and space available at the final site (Clemson University's Power Facility) was developed. The layout is currently being reviewed by Clemson University. Factors such as skyline, noise, ease of operation and access were taken into account in designing the layout. Preliminary site specific information was obtained from Clemson and incorporated. The layout, both plan and elevation, is presented in drawing nos: T1L00000, T1L00010, T1L00020 and T1C00010. Piping layouts are presented in drawing nos: T1L00050 and T1L00060.

Procurement

The Detail Fabrication drawings were issued to the Fabricators and material procurement is in progress.

Procurement of long lead time items such as the circulation pumps, FD fans, pulse combustor water jacket, heat transfer modules, boiler, motor control center and some instruments is currently in progress.

The steam cycle components such as the Pulse combustor water jacket and the heat transfer modules are being procured from a Boiler Manufacturer certified to the appropriate sections of the ASME Boiler code.

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