Performance Testing and Improvements to Fluid Bed Coal Fired Power Plants

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Abstract

The operating experience is described based on the following cogeneration plants:

Five boilers of 425,000 lb/hr, 1310 psig, and 900°F (193,000 Kgms/hr, 9032 KPa, 482°C) generating a total of 150 MWe at Decatur, Illinois. Start-up February 1987.

Three boilers of 477,000 lb/hr, 1310 psig, and 900°F (217,000 Kgms/hr, 9032 KPa, 482°C) generating a total of 120 MWe at Cedar Rapids, Iowa. Start-up November 1988.

One boiler of 410,000 lb/hr, 1300 psig, and 955°F (186,000 Kgms/hr, 9,000 KPa, 513°C) generating a total of 42 MWe at Frackville, Pennsylvania. Start-up September 1988.

One boiler of 355,000 lb/hr, 1300 psig and 955°F (163,364 Kgms/hr, 9000 KPa, 513°C) generating a total of 40 MWe at Colstrip, Montana. Start-up April 1990.

The first two plants mentioned above are running basically on Illinois No. 6 coal with a 3 to 4.1% sulfur content. Emission trials have been run for SO_2, NO_x and particulate matter.

Pilot plant tests of other coals, bituminous and anthracite waste, RDF, TDF and petroleum coke have been carried out in the 8,000 lb/hr CFB pilot plant which was at Williamsport, Pennsylvania.

The plant at Frackville is for burning 70 tone/hour of anthracite culm of 3500 Btu/lb (8155 KJ/Kgm) with up to 70% ash.

Pilot plant tests were carried out on 180 tons of material. This plant was commissioned in September 1988.

The practical experience of running these plants is described, as well as the parametric test results which will have been gathered. Concerns such as emissions, erosion, availability and control response is discussed.

Alternative methods of ash cooling using Shallow Fluid Bed Coolers and Conveyors (SFBCC) are presented and discussed.

Introduction

The first application of this fast or circulating fluid bed (Reference 1) by Keeler and Dorr-Oliver (K/D-O) were the five boilers of 425,000 lb/hr (193,000 Kgm/hr) units at Archer Daniels Midland Decatur plant where they fed four ASEA 30 MW back pressure turbines at 1310 psig and 900°F (9032 KPa, 482°C) and one condensing 30 MW turbine being fed with the 165 psig (1138 KPa) steam from the back end of the high pressure turbines.

In order to prove the design and establish the emissions from this and future plants, a pilot plant was built at K/D-O's Williamsport, Pa facility. The pilot plant was built of 3 ft (1 m) diameter but with a full scale height (same 70 ft) in order to model full time residence time in a period of 10 months from design to start-up.

This plant was first used to burn Illinois #6 which has a sulfur content of up to 4.1% but was then used to establish the design data for a proposed (at that time) plant to burn anthracite waste (culm) of a declared calorific value of 3500 Btu/lb (8155 KJ/Kgm) and 60-70% ash.

This led to the contract for the Frackville cogeneration plant for generating 42 MWe net from a stand alone 410,000 lb/hr (186,364 Kgm/hr) boiler of 1300 psig, 955°F (9,000 KPa and 515°C).

Subsequently Bechtel, San Francisco, negotiated a contract with K/D-O to build a 355,000 lb/hr CFB unit at Colstrip to burn sub-bituminous waste. This unit was started up and acceptance was carried out in eight days from first coal in Spring of 1990.

I. CFB Pilot Plant Testing

The engineering design parameters for these CFB boilers were verified inside the 3 ft diameter (1 m) by 70 ft (21.3 m) high CFB pilot plant shown schematically in Figure 1.

This diagram shows the arrangement of fluidizing the dense bed with primary air introduced in the bottom of the reactor where the dense bed is fluidized at modest velocities and then adding the lower secondary air at the dense bed surface about 3 ft (1 m) above the tuyeres together with the recycle material from the cyclone and fluoseal circuit. Further, upper secondary air is introduced 3 ft (1 m) above the dense bed in order to establish the final velocity which supports the lean phase particle cloud in the upper portion of the reactor.

In this manner, a distinct lean phase of particles is supported above the traditional bubbling bed with a distinct interface between them. The dense bed density is in the range of 40 to 60 lb/ft (640-960 Kgm/m) and the lean bed density is two orders of magnitude lower. The upper part of the reactor has five steam generating tubes up the reactor together with a membrane panel of three tubes with welded fins at the lower part of the reactor, the middle and the top through which water is passed and heat transfer calculated by calorimetry. The heat transfer coefficients may therefore be measured at the bottom, middle and top of the boiler. These coefficients typically range from 50 Btu/ft /hr/^{O}F at the bottom to less than 20 Btu/ft /hr/^{O}F at the top, depending on the solids loading in the lean phase section of the reactor. The lean phase density may be controlled by the primary /secondary air ratio and secondary air placement and velocity.

The lean phase particles in the gas then pass from the top of the combustor into an involute entry but high efficiency cyclone which separates out 99+% of the particles for return to the dense bed by way of the fluoseal, a "J" shaped pressure seal which is independently fluidized to allow the particles to pass. A small heat exchanger loop is arranged in the cyclone dip leg so that by monitoring the heat extracted and the temperature drop across it, the mass flow of particles may be calculated.

The hot gases pass from the cyclone exit to a waste heat boiler, which is connected into the combustor steam generating tubes, so that a total of about 8500 lb/hr (3864 Kgm/hr) of saturated steam may be generated at a pressure of 125 psig (862 KPa).

The unit has a further refinement insofar as the bottom ash may be dropped through a hot ash control valve to a classifier which strips the fines out of the bottom ash before the larger stones are passed to the cooling ash screw. This feature has been particularly useful when running with regular coals with under 15% ash because it maintains the desired ash level in the upper part of the combustor.

The plant was extensively instrumented with load cells on the fuel, limestone and ash bunkers as well as pressure and temperature sensors around the circuit. The plant is controlled by a commercial distributive control system as used in the full size plant but with some 186 instruments, which is rather more than a commercial unit.

In addition, a gas analyzer room is equipped with extractive analyzers for oxygen, CO, CO_2, SO_2, NO_x, and hydrocarbons. The oxygen reading may be compared to an in-situ zirconium probe type unit positioned in the exit of the combustor for comparison purposes. All of these readings are fed to the DCS system in real time. The plant may be run in manual or automatic control, and normally four hour tests were carried out in automatic after a 24 hour bed build up and turnover pre-run to establish steady state bed chemistry conditions.

Pilot plant design criteria for fuel and limestone feed, fluidizing velocity, air distribution, gas/solids residence time, cyclone design, combustion temperature, staged combustion conditions, combustor height etc. are the same as in the commercial size plant. Consequently, the gas/solids hydrogravimetric parameters are similar for both plants, giving accurate scale-up data for pilot plant to commercial plant. Combustion conditions, emissions control, ash distribution and combustor heat transfer distribution up the whole height for the pilot plant closely match the commercial units. However, the absolute heat transfer numbers tend to be higher in the pilot plant, particularly in the lean phase region, due to the refractory wall acting as a black body radiator behind the particle cloud. A suitable correction is applied in order to establish the correct heat transfer coefficient that will be experienced in the full size boiler. In addition, the chemical composition of samples of solid particles in the CFB system, as well as in the bottom ash and baghouse ash streams, are the same as for the commercial plant. A comparison between Decatur plant design and performance figures measure at the pilot plant is presented in Table 2. The commercial plant performance data is presented elsewhere in the paper.

II. Decatur Plant Description

A plan view of the ADM plant is shown in Figure 2. Elevation sectional views of the progressive designs from ADM to Montana are shown in Figure 3. A plant description and a material flow description follow.

Coal is received at the north end of the plant via a rotary railcar dumper or by truck. Run of mine (R.O.M.) coal is delivered to the plant where it is crushed to 3/4 inch x 0 (20 mm x 0) size for feed to the boilers. the coal is then conveyed by belt conveyors either to the coal crushing system or the coal storage, also at the north end of the plant.

Coal is stored in a unique 260 ft (80 m) diameter hemispherically shaped composite structure. the exterior membrane of the structure is a PVC coated woven fabric, and is referred to as an "airform". After attaching the airform to a circular ring foundation, the airform is inflated to form a hemisphere. Urethane insulation is then sprayed onto the interior surface of the pressurized airform. Reinforcement bars are attached to the urethane insulation, and high strength ready mix shorcrete is sprayed to complete the insulated, rebar reinforced concrete structure. Blowers remained in place to maintain a constant pressure until completion of the project. Storage capacity in the dome is approximately 45,000 tone or a 15 day supply.

A rotary stacker-reclaimer is installed inside the dome to transfer coal to and from the kidney shaped storage pile. When coal is removed from the storage dome it is transferred by belt conveyor to the crushing system and then from the crushing system by belt conveyor to the coal bunkers. The coal bunkers, which contain 20 hours of fuel or approximately 520 tons each, are located in front of the boilers inside the boiler building. coal is distributed to the bunkers by a tripper conveyor.

The limestone is received from dump trucks, already prepared to the correct size of 1/8" x 0 (3mm x 0). The limestone is conveyed either to the limestone storage silos by bucket elevator or to the limestone bunkers by an en masse conveyor system.

Note that all coal and limestone are stored or handled indoors after removal from the railcar or truck. From the day bunkers the coal and limestone then drop through standpipes, which provide the gas seal between the bunkers and the combustion chamber, into feeders which control flow to the boilers.

A detailed discussion of the boiler train will be given in another section of this paper.

Steam leaving the boiler at 1310 psig and 900°F (9032 KPa and 482°C) supplies four back pressure turbines. Extraction from the turbines is at 420 psig, 650°F (296 KPa, 343°C) and is used for feedwater heating and sootblowing. The turbines exhaust at 175 psig (1206 KPa), and this steam is used in Decatur's grain processing facilities to produce electric power in a condensing turbine-generator set and for district heating at a local community college.

Bottom ash is removed through the classifiers into two water cooled screws. Ash is removed from the boilers by four vacuum transport systems. Two of the systems are for fly ash and two are for bottom ash. The concept of two systems for each type of ash is a matter of redundancy and economics. Ash from the boilers is stored in ash silos at the northwest end of the boiler building prior to disposal.

III. Decatur Boiler Description

Figure 3 is a side elevation of the three boiler designs and associated equipment. Table 1 indicates the important design parameters for the boilers.

The Decatur plant fires 100% R.O.M. coal fuel during normal operations at 50% - 100+% steam load. Supplemental fuel firing is not employed in this load range. Limestone is fed into the combustion chamber with coal to capture the SO_2 generated when the high sulfur coal is fired. The limestone feed rate is automatically controlled to maintain 90% SO_2 capture at all times. The R.O.M. coal is crushed at the Decatur plant to minus 3/4 inch x 0 (20mm x 0) and the limestone is delivered to the plant sized 1/8 inch x 0 (3 mm x 0).

Coal leaving the standpipes (the standpipe provides the gas seal between the boiler and the bunkers) enters two gravimetric weigh belt type feeders. Limestone leaving the standpipes is conveyed from the limestone bunker by two screw type feeders. The screws discharge into the outlets of the gravimetric feeders, where coal and limestone mix and fall by gravity into the bed. The feed system is 100% redundant; i.e., one system is designed to supply enough fuel and sorbent and distribute it properly to operate the boilers at 100% capacity.

The boilers are of gas tight welded wall construction. all the evaporative duty is transferred in the water walled combustion chamber, eliminating the need for convection (generator) banks.

Preheated primary air is introduced into the dense substoichiometric bed through tuyeres via a water walled air plenum, which is an integral part of the boiler. Preheated secondary air is introduced at two elevations.

The membrane walls of the combustion chamber blow the secondary air level are lined with refractory due to the substoichiometric chemistry and the high degree of turbulence in this region.

There are two overbed, gas start-up burners, one on each sidewall. The combined duty for the two start-up burners is 58 MW (200 Mm Btu/hr) or approximately 40% of capacity. These burners are only used for start-up purposes. Gas is not fired when the boiler is running with coal fuel in the 50% - 100+% steam load level. The burners heat the bed to 800°F (427°C) after which coal is introduced and the heat-up continued at a controlled rate in deference to the thick refractory, particularly in the cyclone and fluoseal.

Flue gas from each boiler passes through two cyclones which operate at 1600°F (870°C). Solids collected by each cyclone are recirculated into the dense bed at the bottom of the boiler through two fluidized solids recirculation systems (fluoseals), which maintain the return flow of solids into the combustion chamber while preventing combustion gases from escaping directly into the low pressure chambers in the cyclone tailpipes. Each solids recirculation system maintains the gas pressure seal using two legs of fluidized solids, which are analogous to water legs in a manometer. Constant air flow is supplied to the fluoseals and no special controls are required to maintain the recirculation of solid particles. However, air flow control to each section of the fluoseal ensures correct operation.

Ash can be removed from four locations: 1) the bottom of the combustor, 2) the recirculation system, 3) the air heater hoppers, and 4) the baghouse. Solids from the bottom of the boiler flow into two ash classifier/coolers which use combustion air to separate the coarse fraction for disposal and a fine fraction which is recirculated into the boiler. Fine ash may be removed from the other locations via standard hopper type connections. The coarse fraction passes into two inclined water cooled screws which gave problems from the start-up.

Gas leaving the cyclones goes to a pendant type superheater on to a bare tube economizer, air heater, baghouse, I.D. fan, and out the stack. Provisions have been made to install a multiclone separator between the air heater and baghouse, should Decatur switch to higher ash waste type fuels.

For a more complete description, see references 2 and 3.

IV. Decatur Start-up

Unit one first fired coal fuel on February 21, 1987. Five hours after initial coal feed, the unit was operating at 70% of design capacity. The unit was on line for 30 days of operation from initial coal firing until the scheduled two-week shutdown for complete inspection of CFB combustion chamber, cyclones, recirculation systems, superheater, downstream equipment, steam drum, headers, etc. The initial coal firing date for unit two was two months after unit one.

A typical cold start-up for a Decatur boiler requires about 16 hours to heat up the refractory materials from ambient to 1600°F (870°C). Refractory materials are used inside the combustion chamber, the brick lined hot cyclones, the fluoseals which are constructed of brick and refractory, and the refractory lining in the superheater and in the back end equipment. The maximum refractory heat-up rate of 100°F/hr (55°C/hr) is maintained at all times during cold start-up to allow time for the thermal expansion of the refractory materials. This start-up time may be much reduced in the new larger CFB boiler (1.1m lbs/hr of steam) being built at Decatur at this time, as it has a water cooled cyclone.

The average availability for all boilers after 13 months was 83.5% including all time, and 90.6% if one excludes planned outages (see Table 7).

The main problem in maintaining availability has been tube erosion, particularly at the silicon carbide shelf to membrane wall interface above the secondary air. At first, excessive erosion in the form of wire cuts were experienced in 1500-3000 hours. Erosion research in the form of modeling as well as experimentation in the boilers has led us to move the interface up higher and to metal spray the tubes above the interface with nickel chrome carbide. Other manufacturers have now combatted this problem by kinking the tubes out at the interface to allow the free fall of downwardly flowing particles. This is an excellent solution.

Failure of roof tubes also highlighted serious erosion in that area which was unexpected. This was cured by refraction coating the front portion of the roof with silicon carbide after studding.

V. Performance Data

The performance tests for acceptance of the project by the client occurred on April 16-17, 1987 within eight weeks of initial coal start-up. Unit one was tested by an outside testing firm hired by ADM. Boiler efficiency was 85.4% and the total boiler system duty was 93.2% of design duty. Combustion efficiency for the two performance tests was 98.6 - 98.7%. As the contractual efficiency was 83.3% and over 90% capacity had been reached, ADM officially accepted the boilers. The cumulative average availability for each of the five CFB boilers at Decatur was 95 - 98% for the first 12 weeks operating. The ADM boilers are designed to operate at 50% load with 100% coal firing. Operations in Decatur confirm that this is easily achieved.

The boilers had provision for extra heating surface and in view of the initial load range of 91-93% comfortably achieved by boilers 1 and 2 (partly due to low feed water temperature), it was decided to add heating surface to the finwalls in the combustion chamber to achieve full load. It was at this point that we could get a good fix on the comparative heat transfer data from the pilot plant compared to the full size boiler. While we knew from theoretical considerations that a correction was necessary, the absolute number was difficult to establish without a full size benchmark.

Subsequently, in September 1987, performance tests were carried out when the boiler (No. 3) was operating over design capacity. The results (Tables 5 and 6) show that the units will run up to 445,000 lb/hr (202,273 Kgm/hr) between 85.5-86% efficiency, and the sulfur capture with 3.7% S coal is between 91.5-91.7% at a Ca/S mol ratio of 1.9-2.4.

The official EPA tests were carried out in August 1988 on boilers 4 and 5 when burning a 2.5% sulfur coal, and the sulfur capture was lower at 88.7-89.7% with a Ca/S mol ratio of 3.5. This illustrates the greater difficulty of absorbing sulfur with the lower sulfur content coals.

NO_x emissions were quite low in all tests, at 0.36-0.52 lb/M Btu (253-323 ppm) against a limit of 0.6 lb/M Btu. This design could always achieve low NO_x figures and a subsequent design for Nipon Steel of Japan guaranteed lower than 100 ppm NO_x.

The baghouses reduced particulate to 0.024 lb/M Btu (0.0103 Mg/MJ) against a limit of 0.03 lb/M Btu.

VI. Frackville Pilot Plant Tests

Two series of tests were carried out on anthracite culm. The first of these tests were carried out on 1/4" x 0 (6mm x 0) material with a bomb calorimeter heating value of 3380 Btu/lb (7875 KJ/Kgm). An energy balance on the pilot plant test runs indicated a heating value of 3771 Btu/lb (8786 KJ/Kgm) which agrees closely with HHV estimates based on the chemical content of the fuel samples as calculated by the DuLong method. This "enhanced" heating value agrees with earlier work on the DOE sponsored Shamokin project (Ref. 4) which, generally speaking, indicated the fuel had about 10% more heating value in it than the bomb calorimeter indicated (or had released).

The first series of tests indicated that an unusual amount of the ash (and this fuel is 60-70% ash) had to be withdrawn from the bottom of the combustor as bottom ash. This is presumedly because the ash is in a flat shaped form and does not easily fluidize or break up even from 1/4" x 0 (6mm x 0).

Because the bottom ash proportion was high and the carbon content therein also high, we designed a fluidized bed combined burn-up cell, ash cooler and classifier to replace the classifier, and water cooled screws fitted after the ash out valve on the pilot plant. The heated air and fines from this unit is piped back to the combustor as secondary air.

The second series of tests were carried out on fuel in the range of 2994 to 5538 Btu/lb (6975-12902 KJ/Kgm), and 180 tons were burned in all. The following conclusions were drawn from the tests.

Combustion efficiency for the culm fuel was 87.8 to 94.5%, based on the bomb HHV and 1/8" x 0 (3mm x 0) showed no improvement over 1/4" x 0 (6mm x 0). The full size boiler design was predicted at 93%.

The SO_2 emissions from the fuel which had sulfur in the range of .25 to .35% are reduced to a minimum of 0.18 lb/SO_2/MBtu (88 ppmv) by feeding limestone with Ca/S in the range of 4:1 to 5:1. The Ca/S feed ratio was higher than expected due to the low concentration and, therefore, partial pressure, of sulfur in the fuel and combustor.

NO_x emissions with 1/4" x 0 (6mm x 0) culm feed are reduced to less than 0.16 lb/NO_2/MBtu (145 ppmv) by staged combustion within the CFB combustor. 1/8 x 0 (3 mm x 0) culm feed gave higher emissions in the range 0.19 - 0.48 lb/NO_2/MBtu (166 ppmv). CO emissions are no greater than 0.06 lb/CO/MM Btu (87 ppmv) at 20-30% excess air fed. Hydrocarbons were essentially zero.

These tests gave us confidence and essential data to design the full size boiler, particularly with regard to the ash coolers/secondary air heaters, which are an integral part of the plant. The elimination of the water cooled screws was particularly attractive. The work proving out this concept was done in 1987 and, subsequently, a patent was granted (Ref. 5).

VII. Frackville Plant

The Frackville cogeneration plant is a stand alone 42 MW net output plant built literally on an anthracite culm pile in Frackville, Pennsylvania.

The culm pile has been surveyed to have at least 20 years of available fuel for the plant and is conveyed by a conveyor up to 3 miles lone to a fuel preparation area. This area has three vertical hammer type crushers which reduce the culm to 1/4" z 0 (6 mm x 0) and supply it to a culm storage shed with a stacker reclaimer which has 10,000 tons capacity. The culm is conveyed to the boiler house which has two day bins of 580 tons capacity. The fuel is then supplied to the boiler which is arranged as shown in Figure 5.

The fuel is fed into the boiler via standpipes acting as pressure seals before the two weigh feeders, each of which has 100% MCR capacity of 70 tons/hr. The fuel slides down fuel pipes to the top of the 3 foot (1 m) deep dense bed in the bottom of the combustor, where it burns. Limestone is dropped down the same fuel feed chutes being fed by screws to the end of the coal weigh feeder.

The combustor incorporates a dense bed/lean phase operation similar to ADM. In addition, two fluidized bed ash coolers are included which have a burn-up cell in the first part followed by three cooling cells, as the section shows in Figure 5.

All the secondary air goes through these coolers which heat it to 500-600°F (260-315°C) and cool the ash to 350°F (177°C) before it is conveyed away by dense phase conveyors. The performance of these coolers was particularly satisfactory, as this was the first time a combined carbon burn-up cell and stripper-cooler had been combined on a large boiler.

The terminal conditions for this plant are 410,000 lb/hr at 1300 psig and 955°F (186,000 Kgms/hr, 9000 KPa and 513°C) so a three stage convective superheater with two stages of attemperation is employed.

In order to avoid fin-wall heat transfer surface, the combustor chamber had a center division wall with openings incorporated to equal any pressure difference that might occur on either side.

Because of the high ash loadings with this fuel, designed at 3500 Btu/lb (8154 KJ/Kgm) (ASTM bomb) and 70% ash, the back end employs a multiclone before the baghouse, which has a particulate emission requirement of 0.012 lb/M Btu (.004 grains/acfm.

The plant was started up in August 1988, and the acceptance test included a 72 hour test. This was passed but not before we nearly put the fire out with 2600 Btu/lb culm.

VIII. Montana One Plant

The section of this unit is shown on Figure 3 and incorporates lessons learned from ADM and Frackville, which can be seen by comparing the three design cross-sections. The most obvious difference is the "top-hat" roof section that was primarily incorporated to avoid erosion of roof tubes that was only cured at ADM and Frackville by refractory coating the roof. This addition also added considerably to heating surface which avoided some of the fin-wall surface added to ADM to correct the heat absorption referred to above.

The sub-bituminous waste being burned at Colstrip was not of sufficiently high ash to warrant the use of the secondary air cooled stripper-coolers, so the design incorporated classifiers on each side which were larger than ADM's, in order to get more recirculation of fines back to the bed.

The units were put on coal in the spring of 1990, after a twenty-two month order to start-up schedule. The boilers immediately achieved about 105% of full load rating and the preliminary testing was so satisfactory that Bechtel and K/D-O decided to continue the first coal run into the formal acceptance test. This was completed at an average of 103% of full load within required emissions after eight days of operation from first coal. As a result of this operational experience, Bechtel ordered two units for Scrubgrass from the newly formed Tampella Keeler.

IX. The Shallow Fluid Bed Cooler and Conveyor

Many high ash fuel plants are now in operation using the old concept of cooling the bottom ash with water cooled screw conveyors. These water cooled screws have proven to be a high cost maintenance item which sometimes can cause a plant shutdown. To retrofit the existing CFB boiler with new stripper-coolers and combustors that take most, if not all (Frackville was all) of the secondary air, would require a major boiler and plant redesign, an expensive and lengthy outage, and an uncertain outcome (in so far as the operators have to learn new operating procedures).

To overcome these problems, we have used the shallow fluid bed heat exchanger concept first conceived by Professor Douglas Elliott of Aston University in the UK to engineer water cooled bottom ash conveyors as shown on Figure 6. Many shallow fluid bed heat exchangers have been used in waste heat recovery plants designed by the author. In fact, a waste heat boiler using this concept was installed at Alcoa's Massena plant on a reverbitory furnace. This plant won the "Award for Energy Innovation" from the DOE in November 1985.

In this arrangement (see Figure 6), the bottom ash flow from the CFB boiler is controlled by a refractory lined heat-resistant steel valve installed in the down pipe. This controls the flow of ash into the shallow fluid bed cooler that may be incorporated into the casing of the existing water cooled screw (provided it is a horizontal screw). The hot ash is fluidized by flue gas ducted from after the baghouse, though a hot gas fan before being blown into the cooler. The reason for using flue gas is that this design does not allow the small amount of carbonateous material in the ash to burn and cause agglomerations. The ash flows over the shallow water cooler fluid bed heat exchanger as it is conveyed to the weir at the exit end, where it passes to the conventional ash system through two flap valves at about 350-400°F. The hot flue gas is then ducted back to the boiler ahead of the air heater.

This arrangement of ash cooler recovers about one-third of the heat back to the boiler system in the recirculated gas, and two-thirds to the water from the heat exchanger. This water may be feed water in which case heat is fully recovered into the boiler system, but it may also be the same water that was used in the water cooled screw and go through a heat dissipation circuit. We are currently working on an arrangement to use this heat to dry the coal.

This arrangement has the merit that it can be retrofitted easily (and therefore economically) into the existing plant with limited space in a very short time using much existing equipment (like the water cooled screw conveyor cases). The increased efficiency and reduced maintenance is considered by some operators to be very attractive, and we expect to have the first units in operation at a 100 MW plant by year end (1995).

References

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3. "ADM Conversion to Coal", A. M. Leon, et. al., First International Conference on Circulating Fluidized Beds, Halifax, Nova Scotia, Canada, November 1985.

4. "Performance of a Fluidized Bed Steam Generator Burning Anthracite Culm", H. S. Kwon et al., Seventh International Conference on Fluidized Bed Combustion, October 1982, Philadelphia, PA.

5. "Ash Classifier-Cooler-Combustor", Patent by Michael J. Virr, U.S. Patent No. 4,969,404.

TABLE 1

Boiler Design Conditions

	Decatur	Cedar Rapids	Frackville	Montana
No. of Boilers	5	3	1	1
Steam Capacity lb/hr (Kgm/hr)	425,000 (193,000)	477,000 (217,000)	410,000 (186,364)	355,000 (163,364)
Operating Pressure @ S.H Outlet, psi (KPa)	1,310 (9,032)	1,310 (9,032)	1,300 (8,963)	1,300 (8,963)
Operating Temp. °F (°C)	900 (482)	900 (482)	955 (512)	955 (512)
Fuel	Midwestern Coal	Midwestern Coal	Midwestern Coal	Sub-bituminous Western Coal
Fuel Size inches (mm)	-3/4 (-20)	-3/4 (-20)	-1/4 (-6)	-1/4 (-6)
Higher Heating Value Btu/lb (KJ/Kgm)	9,600 (22,368)	9,600 (22,368)	3,500 (8,155)	7,105 (16,555)
Sulfur (% wt)	4.1	4.1	0.35	2.6 - 4.4
Sorbent	Limestone	Limestone	Limestone	Limestone
SO_2 Emissions lb/M Btu input (Mg/MJ)	1.2 (.517)	0.85[1] (.360)	0.19 (.082)	0.67 (.289)
CA/S Ratio	2.0/1	2.0/1	8.0/1	2.84/1
Particulate Emissions lb/M Btu input (Mg/MJ)	0.03 (.0129)	0.03 (.0129)	0.012 (.00517)	0.03 (.0129)
Turndown (Steam Flow)	2 to 1	2 to 1	2 to 1	2 to 1
Efficiency Guaranteed	83.3%	83.3%	79.6%	80.29%

[1] or 90% capture, whichever is less

TABLE 2

CFB Performance Data for Unit No. 1 and 3 Foot Diameter Pilot Plant Firing Illinois No. 6 Coal

	ADM Decatur Design	K/D-O Pilot Plant
Combustion Efficiency, %	98.5	99.4 - 99.7
Boiler Efficiency, %	85.4	**
Boiler Duty, MM Btu/hr	422	4.71
(MJ/hr)	(445,210)	(5,000)
SO_2 Emissions, lb/MM Btu	1.2*	.32 - .52
(ppm)	(607)	(162 - 263)
NO_2 Emmissions, lb/MM Btu	0.4	.29 - .39
(ppm)	(281)	(204 - 274)
CO Emissions, lb/MM Btu	0.05	.05 - .06
(ppm)	(63)	(63 - 76)
HC Emissions, (ppm)	(10)	None Detected
Fuel Analysis (% as received basis)		
C	53.50	60.90
H	3.69	4.61
S	4.10	3.25
N	1.03	1.11
O	6.91	7.29
Ash	14.00	9.68
H_2O	16.80	13.60
HHV, Btu/lb	9,600	10,970
(KJ/Kgm)	(23,368)	(25,560)

* The plant is designed to achieve the lower SO_2 emission levels of either 90% SO_2 capture of 1.2 lb SO_2/MM Btu.

** Boiler efficiency for the pilot plant system is much lower than for a commercial plant because of the small size of the boiler.

TABLE 3

Typical Analysis of Fuel and Limestone

Decatur Coal

R.O.M. Illinois No. 6
Crushes to 3/4 inch x 0
(20 mm x 0)

Ultimate Analysis, Wt %

Carbon	56.5
Hydrogen	3.7
Sulfur	3.7
Nitrogen	0.9
Oxygen	9.4
Ash	9.4
H_2O	16.4
CV	10,440 Btu/lb (24,325 KJ/Kgm)

Proximate Analysis

Moisture	16.4
Volatile Matter	36.1
Fixed Carbon	38.1
Ash	9.4

Frackville - Anthracite Culm

Carbon	20.8
Hydrogen	1.24
Sulfur	0.32
Nitrogen	0.64
Oxygen	2.43
Ash	71.16
H_2O	3.41
CV	3,500 Btu/lb (8,155 KJ/Kgm)

Limestone

1/8 inch x 0
(3 mm x 0)

Dry Basis, Wt %

$CaCO_3$	89.5
$MgCO_3$	2.2
Inert Material	8.3
Wt % Moisture	0 - 2

TABLE 4

CFB Boiler Performance Data

	ADM Decatur Plant Design	ADM Decatur Typical July - Present	Frackville Plant Design
Combustion Eff., %	98.5	98.6 - 99.0	93
Boiler Eff., %	85.4	85.5 - 86.0	79.6
Steam Capacity lb/hr (Kgm/hr)	425,000 (193,181)	445,000 (202,273)	410,000 (186,363)

TABLE 5

Decatur Emissions Measured by On-line Gas Analyzer

Steam Production Rate - 434,000 lb/hr (197,273 Kgms/hr)
September 1987

SO_2 Emissions

	S. Capture, %	MM Btu/ lb SO_2	CA/S	lb Sorbent/lb Coal
9/11/87	91.7	0.6 (303 ppm)	2.4	0.31/1
9/30/87	91.5	0.6 (303 ppm)	1.9	0.20/1

NO_x Emissions	CO Emissions
0.36 lb NO_2/MM Btu (253 ppm)	0.09 lb CO/MM Btu (100 ppm)

Decatur EPA emissions test boilers 4 and 5, August 1988
(Preliminary results from outside test engineers)

	Capture %		lb/MM Btu (ppm)		
	No. 4	No. 5	No. 4	No. 5	Ca/S
SO_2	88.7	89.7	0.46 (206)	0.43 (200)	3.5
NO_x	86.3	85.9	0.52 (323)	0.52 (333)	
CO	0.03 (34 ppm)	0.03 (31 ppm)			

Particulates 0.024 lb/MM Btu (0.0103 mg/MJ)

Note: Sulfur in coal 2.3 - 2.42%, 11,362 - 11,633 Btu/lb
(26,475 - 27,105 KJ/Kgm)

TABLE 6

ADM - Decatur Units 1 To 5
Boiler Availability Through May 6, 1988

Unit Number	Hours in Period	Hours Not Available	Hours Available	% Available
1(E)	9168	711.0	8457	92.2
1(I)	10731	2274	8457	78.8
2(E)	8562	392.0	8170	95.4
2(I)	9618	1448.0	8170	84.9
3(E)	6998	1448	5550	79.3
3(I)	6998	1448	5550	
4(E)	6692	548.5	6143.5	91.8
4(I)	6860	716.5	6143.5	89.6
5(E)	3090	155.0	2935	95.0
5(I)	3228	293.0	2935	90.9
All (E)	34510	3254.5	31255.5	90.6
All (I)	37435	6179.5	31255.5	83.5

(E) = Excluding Planned Outages

(I) = Including Planned Outages

Note: Unit 3 has had no planned outages

FIGURE 1

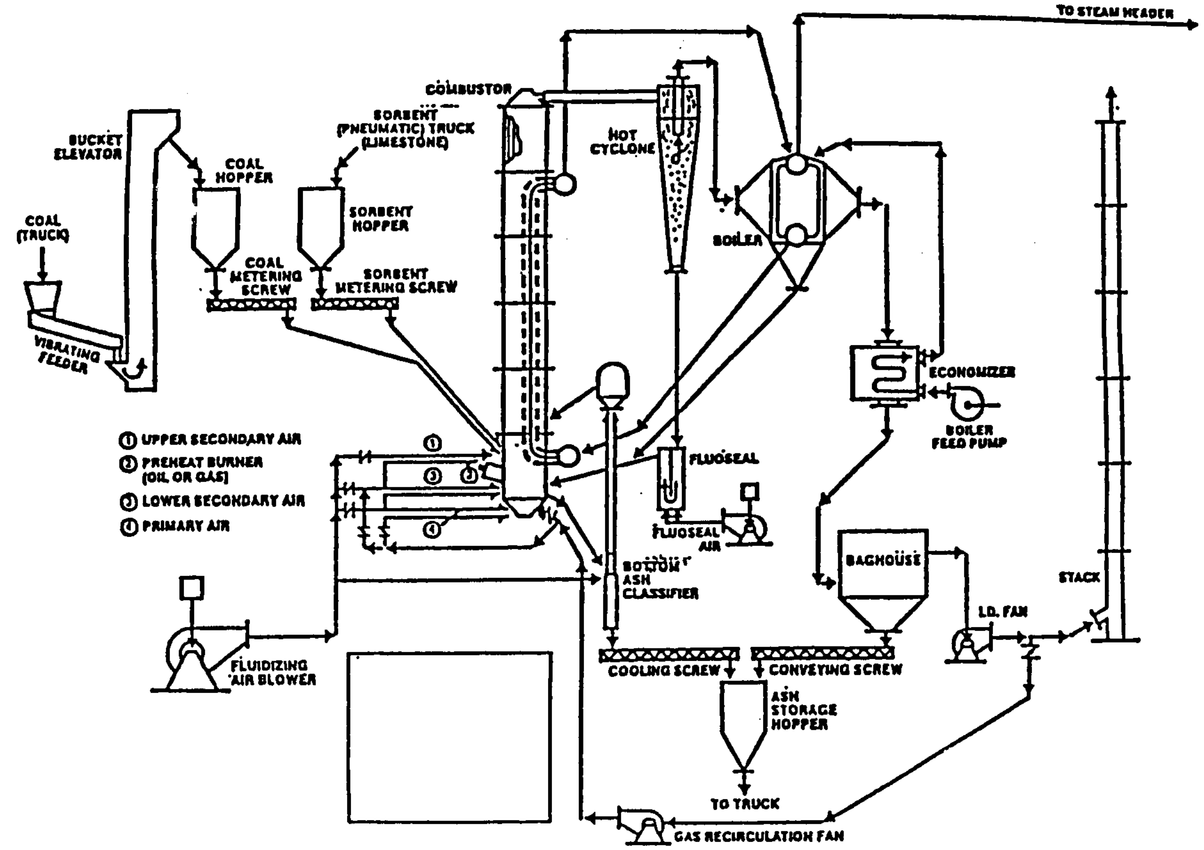
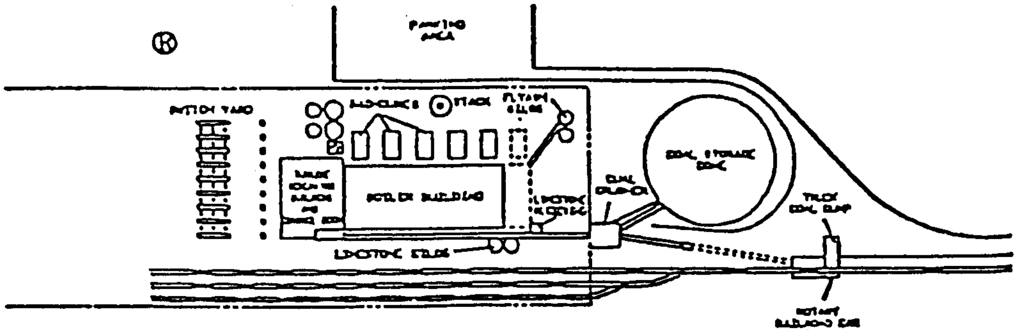
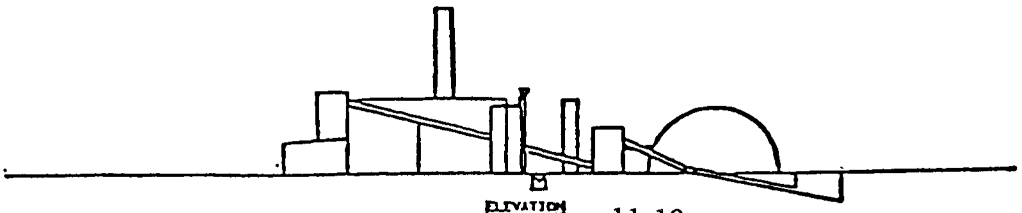


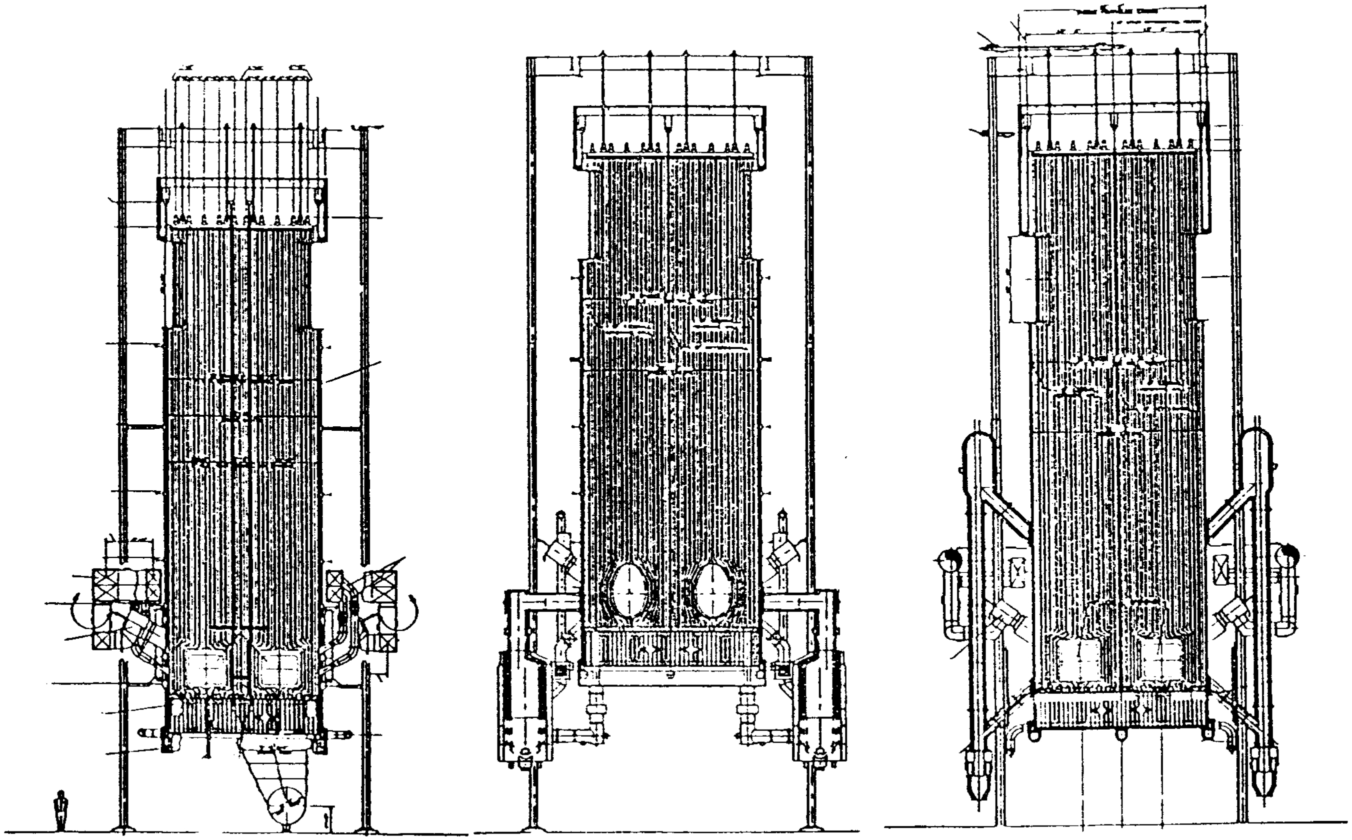
FIGURE 2



PLAN VIEW



ELEVATION



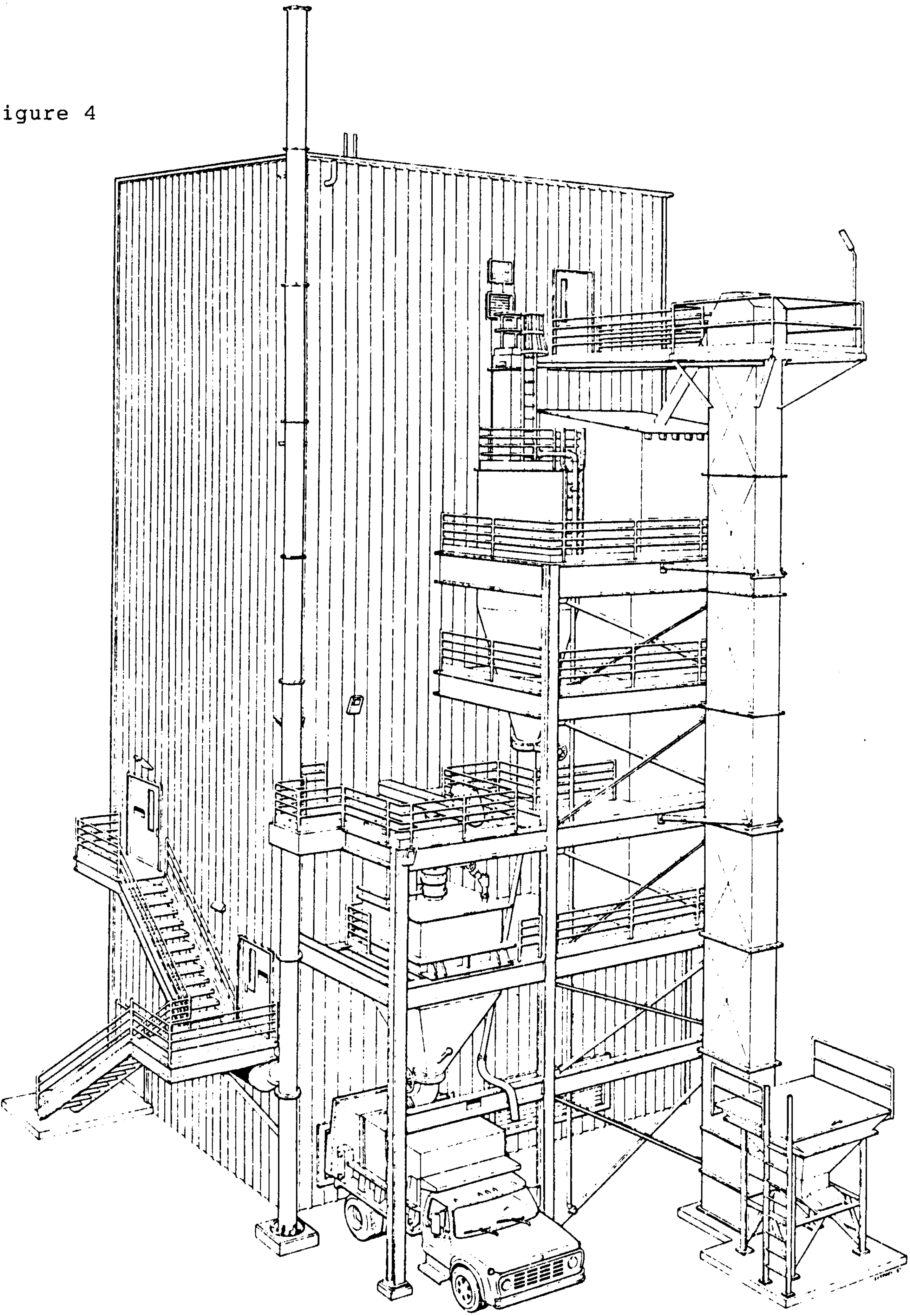
ADM.
DECATUR

FRACKVILLE,
PENNSYLVANIA

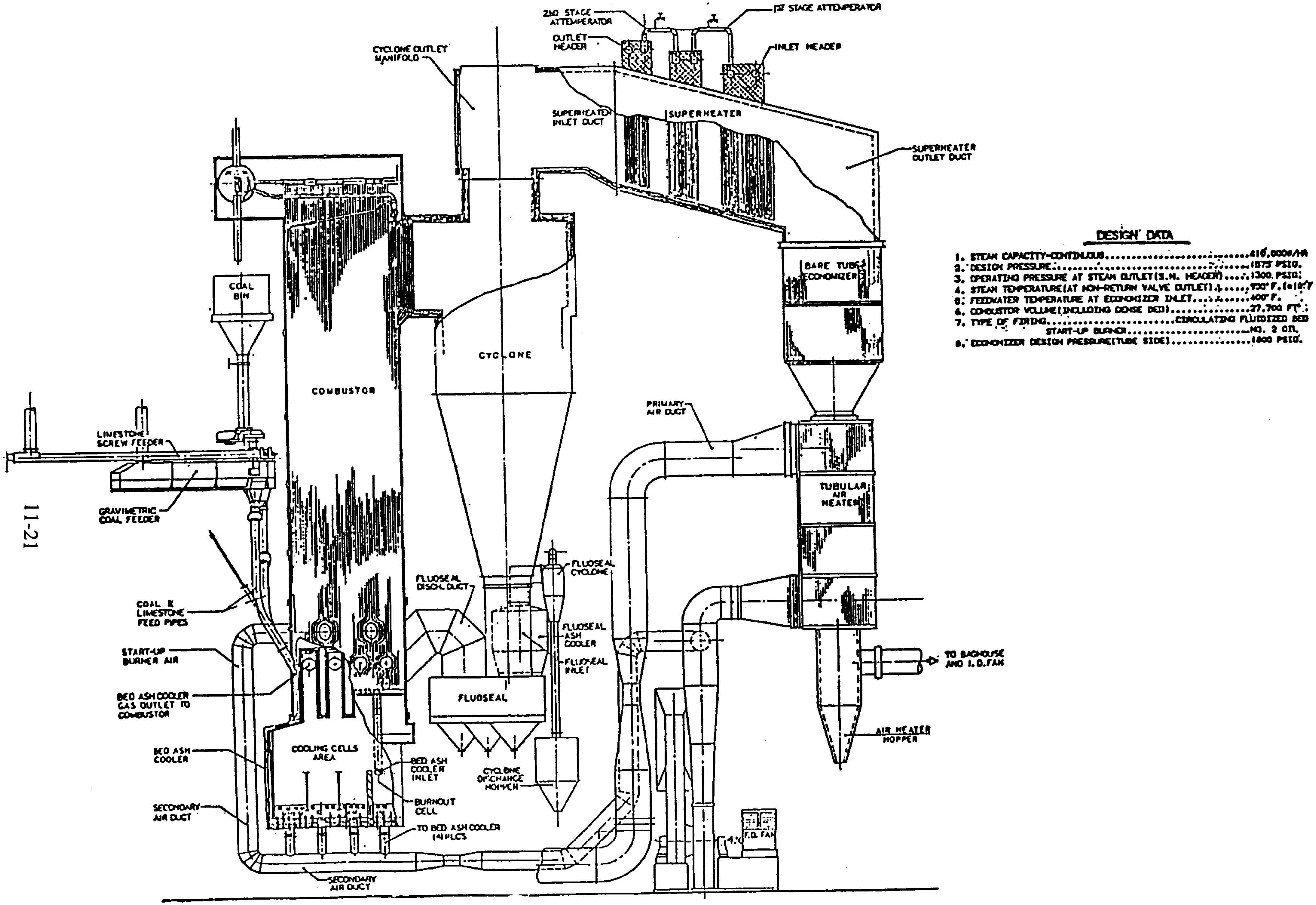
COLSTRIP,
MONTANA

FIGURE 3

Figure 4



KEELER / DORR-OLIVER CIRCULATING FLUID BED PILOT PLANT
WILLIAMSPORT, PA.



DESIGN DATA

1. STEAM CAPACITY-CONTINUOUS........................410,000#/HR
2. DESIGN PRESSURE........................1575 PSIG.
3. OPERATING PRESSURE AT STEAM OUTLET(S.H. HEADER)........1300 PSIG.
4. STEAM TEMPERATURE(AT NON-RETURN VALVE OUTLET)........950°F.(±10°F)
5. FEEDWATER TEMPERATURE AT ECONOMIZER INLET........400°F.
6. COMBUSTOR VOLUME(INCLUDING DENSE BED)........27,700 FT³
7. TYPE OF FIRING........................CIRCULATING FLUIDIZED BED
START-UP BURNER........................NO. 2 OIL
8. ECONOMIZER DESIGN PRESSURE(TUBE SIDE)........1800 PSIG.

FIGURE 5

FRACKVILLE, PA CIRCULATING FLUID BED BOILER

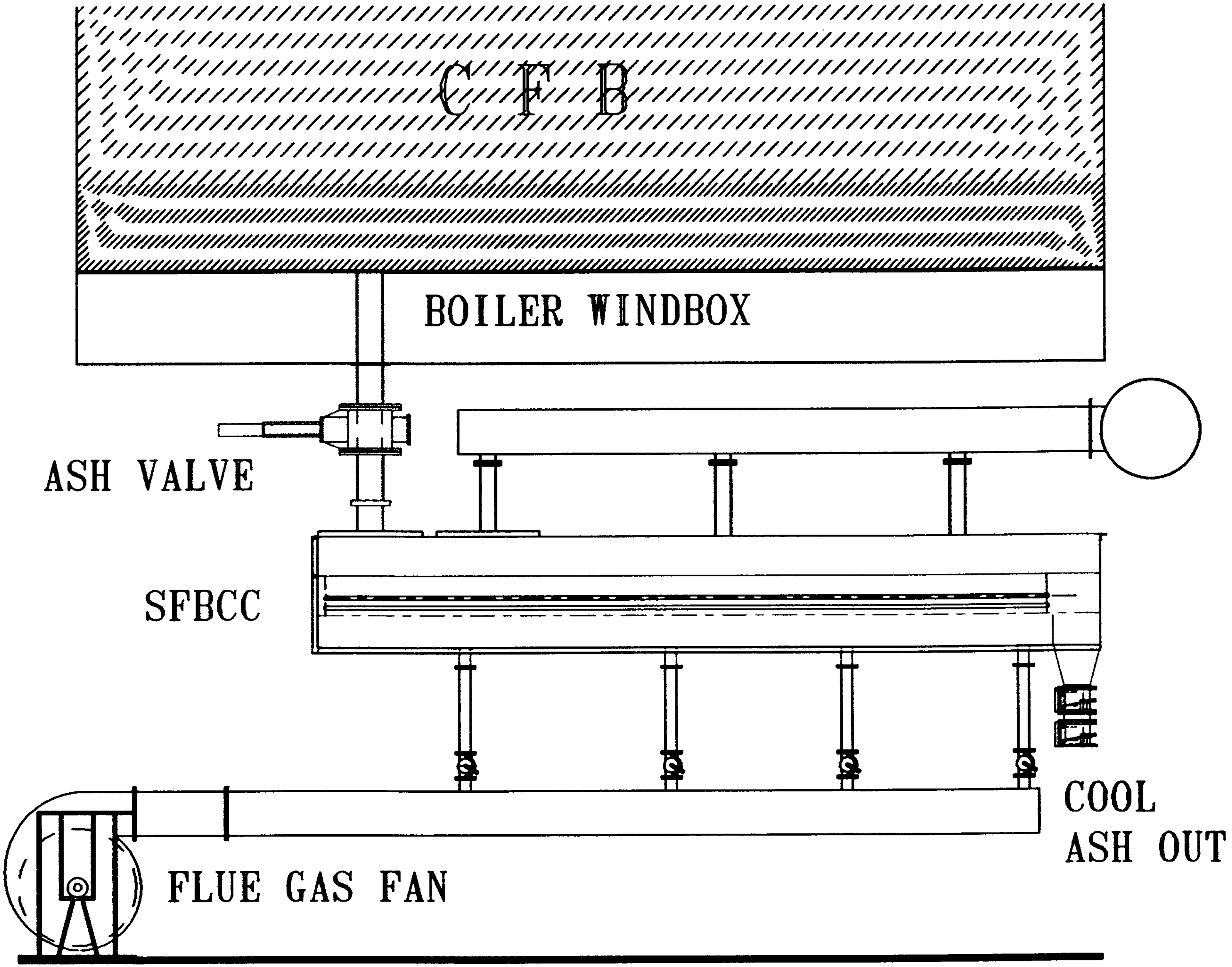


FIGURE 6 SHALLOW FLUID BED COOLER AND CONVEYOR