

# CIRCULATING FLUIDIZED BED COMBUSTION USING WASTE ANTHRACITE CULM

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## ABSTRACT

Culm, the waste product from anthracite mining, is being utilized as a power plant fuel in northeastern Pennsylvania. This high-ash, low-heating value fuel is fired using circulating fluidized bed boiler technology. A discussion of the design and initial operating experience of a net 42 MW installation in Frackville, Pennsylvania is presented.

## INTRODUCTION

In the late 1980s a number of cogeneration projects commenced initial operation in northeastern Pennsylvania. These projects were developed for three common reasons: (a) the availability of an abundant fuel supply; (b) favorable electric purchase price for qualifying cogeneration facilities; and (c) commercial availability of circulating fluidized bed (CFB) boiler technology.

The Wheelabrator Frackville Energy Company utilizes anthracite culm fuel to generate and sell electricity to Pennsylvania Power & Light (PP&L) and low pressure steam to the Frackville Correctional Institute. The principal participants in the project are listed in Table 1. The facility commenced commercial operation in June, 1989. This paper provides a discussion of the facility and the initial operation experiences.

## CULM FUEL

The design of the facility was based on the selected fuel for combustion. Culm is a waste product from anthracite mining consisting of fine coal, shale and inferior anthracite. Culm is a high-ash coal with low volatility that requires some blending and crushing prior to being used in the boiler. Large stockpiles of culm are scattered in northeastern Pennsylvania as a result of many decades of anthracite mining. The Frackville facility is located adjacent to a blending/crushing plant that is supplied with fine coal and culm by off-road vehicles. The Frackville boiler uses culm with an average higher heating value (HHV) of 3500 Btu/lb (1945 Kcal/kg) that is crushed to pass 98% through a  $\frac{1}{4}$  in. (6.4 mm) screen. Table 2 provides more detail on the fuel analysis.

The size of the fuel is very important to the operation of the boiler. Since anthracite has such low volatile content, larger particles are difficult to completely burn within the dense bed. Also, if the fuel has a high percentage of fines, the particles will pass through the boiler with limited recirculation. Both conditions will result in reduced combustion efficiency. Pilot tests conducted by the boiler supplier, Keeler Dorr-Oliver, prior to construction resulted in the selection of  $\frac{1}{4}$  in.  $\times$  0 (6.4 mm) for the maximum fuel size.

The moisture content of the fuel can also dramatically impact the materials handling characteristics of

TABLE 1 PRINCIPAL PROJECT PARTICIPANTS

Owner/Operator	Wheelabrator Technologies Inc.
Engineering/Contractor	Rust International Corporation
Fuel Supplier	Pagnotti Enterprises, Inc.
Independent Engineer	HDR Engineering Inc.
Power Purchaser	Pennsylvania Power & Light
Steam Purchaser	Commonwealth of Pennsylvania
CFB Boiler Supplier	Keeler Dorr-Oliver (Tampella Keeler)
Turbine/Generator Supplier	Asea Brown-Boveri
Multi-clone/Baghouse Supplier	Wheelabrator Air Pollution Control
Ash Handling System Supplier	Allen-Sherman-Hoff Co.

the culm. With a moisture content of 2–6% by weight, the crushed culm is relatively easy to handle as a dust-free, free-flowing material. However, as the moisture increases to 8–10% by weight, the culm has a strong tendency to pack and agglomerate, creating serious problems in reclaiming and hopper bridging. Also, cold weather can create large frozen sheets of culm which are difficult to break up and problematic at transfer points and in storage silos.

Another interesting fuel issue with culm surfaced in the laboratory determination of the higher heating value. ASTM procedures call for a known quantity of benzoic acid to be added to the bomb calorimeter when high-ash fuels are being tested. This promotes complete combustion in the test apparatus, thereby allowing accurate determination of the fuel HHV. If this procedure is not followed, the results of the HHV determination can be as much as 10% less than the actual value. Of course, accurate fuel analysis is critical in the evaluation of boiler performance.

## FACILITY DESCRIPTION

### Fuel Handling

The Frackville facility receives properly sized fuel from the adjacent fuel preparation plant. A 6000 ton (5450 t) indoor pile provides for more than three days of fuel storage. A back-scratcher type over-pile reclaimer is used to feed redundant belt conveyers that transport culm to two 8 hr storage silos. Culm flows by gravity from each silo to its respective gravimetric feeder which discharges into a split pipe to feed each side of the furnace. Each feeder can supply 100% of the fuel input requirements, but both systems are normally operated. Limestone is fed to the boiler by two 100% capacity screw feeders from their respective lime

TABLE 2 FUEL PROPERTIES

Ultimate Analysis		Design	Range
Carbon		25.4%	23.0 - 27.0%
Hydrogen		1.0%	0.9 - 1.1%
Nitrogen		0.6%	0.4 - 0.7%
Oxygen		3.8%	2.5 - 4.0%
Sulfur		0.3%	0.2 - 0.3%
Moisture		2.6%	4.0 - 10.0%
Ash		66.3%	60.0 - 70.0%
HHV		3,500 BTU/lb (1940 kcal/kg)	2,800 - 4,200 BTU/lb 1,556 - 2,333 KCal/kg)

Size Distribution			% Passing Through
Inches (mm)	Mesh		
3/8" (9.5)	--		100%
1/4" (6.4)	--		98%
.078" (2.0)	10		48%
.033" (0.8)	20		24%
.012" (0.3)	48		9%
.006" (0.15)	100		4%
.003" (0.07)	200		1%

storage silo. The limestone is combined with the culm at the discharge point of the gravimetric feeders. With the split pipe arrangement there are four limestone/culm feed points in the lower frontwall of the combustor.

### CFB Boiler

As illustrated in Fig. 1, a single forced-draft fan supplies both primary and secondary air to the furnace. The primary air passes through a steam coil air heater and is preheated in a tubular air heater before entering the combustor through tuyeres in the furnace floor. The secondary air is used to cool the bottom ash from 1600°F (871°C) to 400°F (204°C) in the bed ash coolers. The combustor itself is of membrane waterwall construction and incorporates a center division wall half-way between the two sidewalls. Hot gases and circulating particles leave the combustor through two openings located in the corners of the upper rear wall. The entrained particles are separated from the gas stream in two large refractory lined cyclones. The solids are returned to the lower combustor through two refractory lined loop seals. The hot gases then pass across the superheater tubes where the steam is heated to 955°F (513°C). The gases turn downward and flow through the economizer and airheater to the air pollution control equipment.

### Power Generation

Up to 410,000 lb/hr (186,000 kg/h) of 1310 psig (90 Bar), 955°F (513°C) steam flows to the high pres-

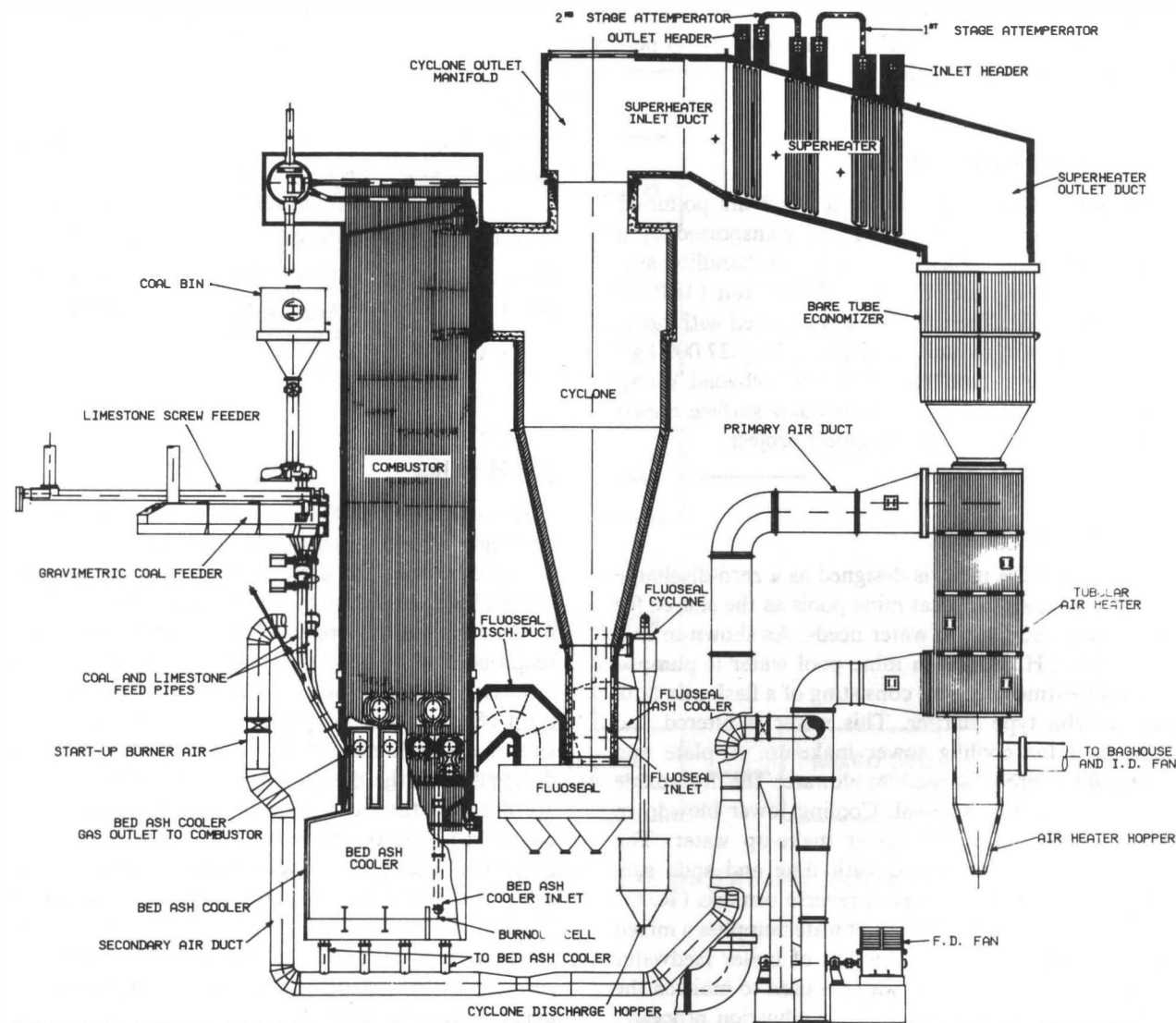


FIG. 1 FRACKVILLE CIRCULATING FLUID BED BOILER

sure inlet of a 48 MW turbine generator. The high pressure turbine operates at 8000 rpm and drives one end of the generator through a reduction gear assembly. The exhaust steam from the high pressure turbine passes through the low pressure 3600 rpm turbine and is condensed in the end-exhaust condenser. A portion of the steam from the high pressure turbine is sent to the Frackville Correctional Institute through a 2.8 mile (4.5 km) steam pipeline. The boiler/turbine system is operated to meet the steam requirements of the state prison facility while selling 42 MW of electrical power to Pennsylvania Power & Light.

### Air Pollution Control

The Frackville facility is designed and operated to control emissions of particulate, SO<sub>2</sub>, CO, NO<sub>x</sub> and hydrocarbons. The gaseous emissions are controlled by the operation of the combustor with the limestone being used to capture SO<sub>2</sub>. The particulate matter is collected in a 75% efficient multiclone followed by a pulse-jet type fabric filter. The multiclone collector was included because the grain loading leaving the boiler could be as high as 40 grains/acf. The eight-component fabric filter is equipped with Gore-tex fabric bags

to meet the stringent particulate emission limit of 0.012 lb/mm/Btu. A summary of the emission control performance is shown in Table 3.

### Ash Handling Equipment

All ash residue from the boiler and air pollution control equipment is collected and transported by a pressurized, dilute-phase pneumatic ash handling system. The ash is transported to a 2000 ton (1810 t) steel storage silo. The ash is then moistened with process wastewater in redundant 250 ton/hr (227,000 kg/h) rotary drum type mixers. Large off-road dump trucks return the ash to the previously surface mined areas as part of a land reclamation project.

### Water Treatment

The Frackville plant is designed as a zero-discharge facility and uses the local mine pools as the source for all process and cooling water needs. As shown in Fig. 2, the low pH, high iron mine pool water is pumped to a pretreatment system consisting of a flash mix tank and lamella type clarifier. This water is filtered and then used for cooling tower make-up. A plate and frame filter press is used to dewater the hydroxide sludge for landfill disposal. Cooling tower blowdown provides the source for boiler make-up water. The blowdown is first softened with lime and soda ash, filtered and passed through a reverse osmosis (R/O) system. The clean R/O product water supplies a mixed bed demineralizer for production of boiler feedwater make-up. The R/O reject water is used to moisten the ash residue remaining from the combustion process.

### INITIAL OPERATIONS

The Frackville facility experienced a number of start-up problems that extended the commercial operations date. In general, the longer start-up was a result of the learning curve created by the relatively new application of CFB technology using anthracite culm as a power plant fuel. In addition to getting the various plant systems to function according to design the facility had to pass a series of acceptance tests confirming the plant's capacity, efficiency and environmental performance. A summary of the results of the performance tests is shown in Table 3. The focus of the start-up activity centered around the reliable operation of the ash handling equipment and the efficiency of the CFB boiler.

TABLE 3 FRACKVILLE PERFORMANCE TEST RESULTS

Parameter	Guaranteed	Actual
Net Power Output	42,000 kw	42,433 kw
Net Plant Heat Rate	11,800 BTU/kwh (2,974 KCal/kwh)	12,248 BTU/kwh (3,087 KCal/kwh)
Particulate	0.012 lb/mmBTU	0.0085 lb/mmBTU
NOx	0.6 lb/mmBTU	0.2 lb/mmBTU
SO <sub>2</sub>	0.21 lb/mmBTU	0.15 lb/mmBTU

### Ash Handling

Initial operations indicated that there were several problems with the ash handling equipment that had to be addressed. The capacity limitation of the flyash removal system showed itself as continual high levels in the multi-clone hoppers. This particular pneumatic loop operated on timers to cycle between the two (2) airheater hoppers, three (3) multiclone hoppers and eight (8) baghouse hoppers. The problem was the result of the bulk density of the ash being significantly different than the design value. The problem was exacerbated by the fact that 75% of the flyash was being collected in just three of the thirteen hoppers. As can be seen in Table 4, the actual bulk density of the various ash streams varied significantly from the projected 40–50 lb/ft<sup>3</sup> (640–800 kg/m<sup>3</sup>). This capacity problem was corrected by adding a second flyash blower and running an independent line from the baghouse hoppers to the storage silo.

The other major issue with the ash system was the excessive wear observed in the bottom ash removal system. The high velocity of the coarse bottom ash caused erosion of the elbows. In some cases, a hole was eroded through the 1¼ in. (31 mm) thick, 400 brinell pipe bends in less than four days of operation. This extremely short operating life is obviously unacceptable. Changes were made in all the piping runs to eliminate any unnecessary bends and crossover valves. The old elbows were replaced with ceramic linings which have an operational life of four months and longer.

### Boiler Efficiency

Initial performance tests indicated that the boiler was operating at a lower efficiency than predicted by the manufacturer. While some of the difference was

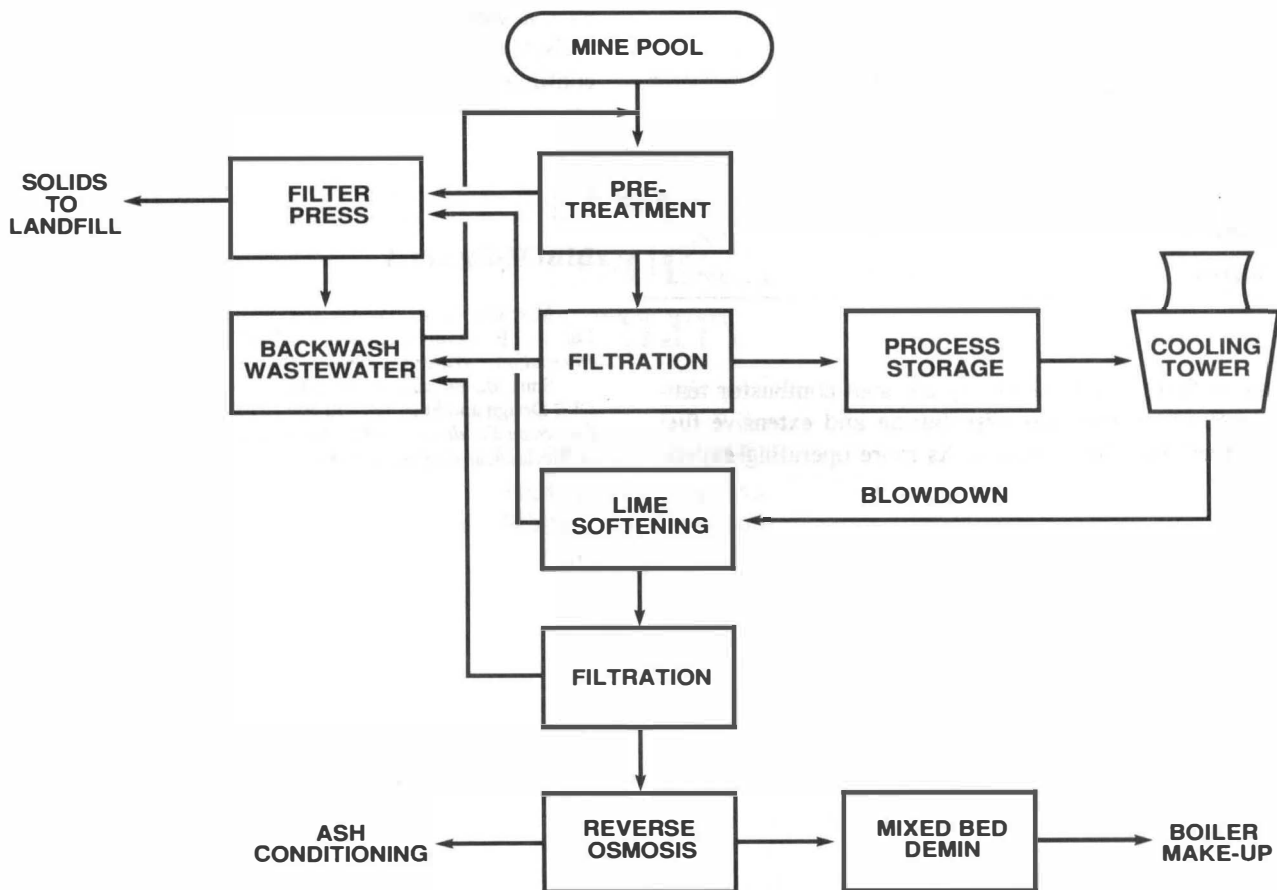


FIG. 2 SIMPLIFIED WATER/WASTE WATER FLOW DIAGRAM

attributed to slightly higher excess air and off-spec fuel, the major shortfall was caused by poor combustion efficiency. The unit was initially operated to maintain a combustion temperature of less than 1625°F (885°C). This value resulted from pilot plant studies that indicated potential problems with ash agglomeration at higher temperatures. However, in practice this low bed temperature resulted in a higher percentage of unburned carbon in the bottom ash than observed in the pilot plant.

To increase the combustion efficiency, changes were made in the operation of the boiler to raise the bed temperature closer to 1700°F (927°C). This was accomplished by continually removing dilute phase solids from above the loop seals at the base of the two cyclones. Removing these dilute phase solids has the effect of reducing the overall heat transfer rate inside the combustor furnace, thereby increasing the average bed temperature. The data shown in Table 4 shows

the loss on ignition results from tests on the various ash streams throughout the system. And while there was initial concern with the unburned carbon remaining in the bottom ash, the biggest carbon loss actually shows up in the multiclone ash. Hence, the more critical fuel size distribution issue concerns those smaller particles that pass through the main combustor cyclones without recirculation back to the dense bed.

## CONCLUSION

The commercial operation of the Frackville facility demonstrates the successful application of circulating fluidized bed boiler technology to use new waste fuels for a power generation. The most important lesson to be learned is that more effort should have been expended initially to fully evaluate the physical and chemical characteristics of culm. Culm is a very dif-

TABLE 4 TYPICAL ASH PROPERTIES

Location	Approximate Split of Total	Average Bulk Density lb/ft <sup>3</sup> (kg/m <sup>3</sup> )	% Loss on Ignition
Bottom Ash	45%	65 (1040)	2.0%
Loop Seal	15%	80 (1280)	1.8%
Multi-clone	30%	35 (560)	6.5%
Baghouse	10%	15 (240)	3.5%

ficult fuel to burn, requiring elevated combustor temperatures, proper size distribution and extensive fuel and ash handling systems. As more operating experi-

ence is gained at similar facilities utilizing new waste fuels, the applications for fluidized bed combustion will continue to grow.

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