AP42 Section 1.2

Chap 2 Ref 4 Chap 4 Ref 13 AP-42 Ref 3

83-53.3

OPERATING EXPERIENCE AT THE SHAMOKIN CULM BURNING STEAM GENERATION PLANT

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For Presentation at the 76th Annual Meeting of the Air Pollution Control Association
Atlanta, Georgia June 19-24, 1983

INTRODUCTION AND BACKGROUND

For more than 150 years, the coal industry of Northeastern Pennsylvania has produced over 5 billion tons of anthracite coal. Along with this coal, however, has come the production of refuse which miners have dumped on the mountainsides, disfiguring the landscape and generally polluting the environment. This anthracite refuse, commonly known as culm, amounts to 16 million tons and rises to more than 600 feet in the Shamokin Pennsylvania area alone. Winds gusting over the waste bank scatter flinty chips like BB shot. Fires break out spontaneously, smolder, then flicker to life again.

This anthracite culm refuse---dirty, dull black, low in carbon, mixed with earth and tunnel rock---is now seen to be a low cost alternate energy source. More than 1 billion tons of this low quality fuel are presently in this Pennsylvania region and its ability to be effectively combusted has been demonstrated at the Shamokin Steam Generation Plant. The high ash content, high moisture, low heating value fuel characteristics of the culm makes combustion in conventional boiler systems difficult. However, the burning of culm in the Shamokin fluidized-bed boiler has demonstrated this technology to be a cost effective technique of culm energy utilization in an environmentally acceptable manner.

Fluid bed technology has been used commercially since the 1940's. Although it has not been used widely in the U.S. for steam production, it has had commercial application in the fields of commercial processing, heat-treating, and mining and metallurgy. The fluid bed combustor is essentially a vessel or furnace which contains a mixture of solids (coal, rock, ash) and limestone. Combustion air is blown into the bed through a bottom grate-like distributor and the resulting bubbling mixture is suspended within the upward-moving air stream much like a boiling fluid. Combustion of the culm in this turbulent solid/gaseous mixture results in high heat release, high combustion efficiency, and excellent heat transfer to the in-bed steam generating tubes.

At Shamokin, the addition of the sulfur retaining sorbent material (limestone) produces a chemical reaction at normal combustion temperatures which results in excellent sulfur capture in the bed. Operating experience has demonstrated that sulfur dioxide (SO_2) emissions from the plant are being controlled and limited to levels one-half of the New Source Performance Standard (NSPS) for boilers over 250 million Btu/hr of 1.2 lbs. per million Btu. Also, because of the relatively low combustion temperatures (1550^{o}F), nitrogen oxide (NOx) emmissions are being controlled to a level well below the NSPS for anthracite coal of 0.7 lbs per million Btu. Flue gas particulate emissions are controlled by two stages of cyclones and finally by a pulse-jet bag filter and are one-fourth of the State limit of 0.4 lbs per million Btu. Flyash and bed bottom ash from the plant is dry and is disposed as landfill in an adjacent environmentally controlled storage area.

The quantity of ash produced by the plant is considerable and its ultimate disposal is being evaluated by the Shamokin Area Industrial Corporation (SAIC). Potential use of the ash includes fill for strip mines, construction-block fabrication or as road cinders. Also, about 25% of the ash is alumina, a source of aluminum. Currently, ways to extract it economically are being investigated by SAIC.

PLANT DESCRIPTION

Basis of Design

The boiler plant was designed to supply 23,400 lb/hr of 200 psig saturated steam by pipeline to an adjacent factory owned by Cellu Products Company. The factory, which is about 200 yards from the boiler plant, uses the steam to reprocess paper and does not return condensate. Steam demand is on a variable basis, 24 hours a day, 7 days a week, 50 weeks a year.

The design parameters for the fuel are shown in Table 1. The fuel was to be delivered to the plant sized by the collier supplier to minus 4 inches. Based upon bench scale tests on a variety of anthracite culm samples, the fuel had to be crushed to minus 4 mesh size for good combustion. Likewise, the tests required that the limestone be sized to minus ¼ inch for effective SO_2 control.

Environmental emmission requirements for the plant were to be consistent with regulatory requirements and these are shown in Table 2. In summary, State emission limits governed and these were 0.4 $lb/10^6$ Btu for particulates, 20% for opacity, and 1.2 $lb/10^6$ Btu for SO_2.

Equipment and Systems

The boiler plant as shown in Figure 1 is made up of five basic sections as follows:

- Receiving, Preparation and Storage
- Fluidized Bed Boiler System
- Steam/Feedwater Systems
- Environmental/Emission Controls
- Process control and Instrumentation

Receiving, Preparation and Storage

Culm is delivered to the plant by truck and piled in an area immediately adjacent to the boiler plant. A front end loader is used to transfer the culm to a conveying, crushing and screening system. The system crushes and classifies the culm to ¼ x 0 and includes a recycle of oversized material back thru the crusher to assure proper sizing. A 32 hour supply of the prepared culm is contained in a storage silo and from this point is transported to a 4 hour capacity culm feed bin.

Limestone is delivered by truck and is conveyed pneumatically to a one-week supply storage silo. From the silo, the limestone is conveyed to a feed bin which contains approximately one day's supply.

Screw feeders are used to feed both the limestone and culm. Feed rates are varied through the use of variable speed motor drives. Control is tied to steam demand, combustion temperature, and an SO_2 emission feedback signal.

Fluidized Bed Boiler System

The boiler system is the Keeler/Dorr-Oliver MKFS FluoSolids Boiler unit which was developed for the Shamokin project. The balanced-draft design is based on the use of natural circulation, completely water-cooled furnace and vertical-bed tubes, and was designed to generate 23,400 lb/hr of saturated steam at a pressure of 200 psig. Boiler design parameters are listed in Table 3 and its configuration is illustrated by Figure 2.

The fluidized bed boiler has both water wall and in-bed tubes which generate approximately half of the steam capacity. The other half of the steam is generated by recovering the heat from the combustion gases in a convection section. The furnace or bed area is divided into three zones each with its own air supply. The primary zone covers 64% and the other two bed sections split the remaining 36% of the bed equally. The primary zone does not contain in-bed tubes whereas the secondary zones do contain in-bed tubes. The secondary zones are defluidized during turndown conditions and during startup.

An over-bed oil burner is provided for startup purposes and is positioned in the furnace sidewall to fire down on the primary zone bed area. A soft coal feed system was added to aid in startup operation. Soft coal is first brought to its combustion temperature which, in turn, brings the bed up to culm combustion temperature.

Included in the boiler system is an ash cooler which is a fluidized bed containing in-bed cooling coils. Sensible heat from hot ash is recovered and transmitted to the boiler feedwater. The ash cooler has its own air supply system and cyclone. Ash is pneumatically conveyed to a bottom ash storage bin.

Also included in the boiler system is an air preheater. The air preheater is a shell and tube type where the hot gases flow inside the tubes reducing temperatures from 660°F to 350°F while heating combustion air to 425°F on the shell side.

Steam/Feedwater Systems

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Steam/Feedwater Systems

City water is used as the source for boiler feedwater. A zeolite softening system is utilized to initially condition the water for boiler use and this is followed by a deaerator for oxygen scavenging prior to pumping into the boiler steam drum. Provisions are included for the addition of sodium sulfite and amine chemical treatment. Treated water is stored in a 3000 gallon storage tank.

The design condition calls for 20,000 lb/hr of exported steam. The as-generated pressure level of 200 psig is reduced to 150 psig for the user. Approximately 10% of the steam generated is used internally by the plant for boiler blowdown, deaerator, and equipment drivers. The user does not return condensate, hence, the water treating system is sized for full feed capacity.

Environmental/Emission Controls

The three major air pollutants generated by the bombustion of culm are sulfur dioxide (SO_2), nitrogen oxide (NO_x), and particulates. Various control means were included in the design to mitigate these emissions.

Sulfur dioxide emissions are controlled through the use of limestone as a sorbent which is added directly to the bed and mixed with the culm as discussed earlier. Sulfur gas released from the combustion of the culm reacts chemically with the limestone to form CaO and $CaSO_4$. These solid particles then end up in the culm ash. Limestone is fed at a rate of 1 lb. to every 10 lbs of culm to achieve the desired 88 percent sulfur capture level.

Emissions of oxides of nitrogen are controlled primarily through proper management of flame temperature. There are two basic contributors to NO_x in the combustion flue gas---thermal NO_x which is associated with the generation of NO_x compounds at elevated temperatures from atmospheric nitrogen and fuel-bound NO_x which is associated with the release of NO_x compounds from the fuel during combustion in high temperature oxygen-rich zones. Culm is low in nitrogen content (less than 1%) and therefore does not pose a fuel-bound NO_x problem. Thermal NO_x is controlled by virtue of the relatively low combustion temperature (1450°F - 1650°F) which is well below the 1800°C level at which thermal NO_x generation becomes a serious problem.

Particulates are controlled by two stages of cyclones followed by a baghouse. The first stage or primary cyclone is of conventional design and is refractory lined. It is the primary element in the flue gas clean-up chain and it recycles unreacted particulates and ash back to the combustor. This recycling improves combustion efficiency and limestone utilization. Gases leaving the primary cyclone enter twin secondary cyclones for further cleaning. Only one of the secondary cyclones is used during boiler turn-down conditions to maintain cyclone efficiency. Ash from the primary and secondary cyclones is discharged to the ash cooler and the cleaned flue gases are discharged to the air heater before entering the baghouse. The baghouse is a conventional pulse-jet fabric filter system containing 324 Nomex bags (4665 ft^2 effective area) configured in an 18 x 13 bag arrangement and was designed to provide an outlet grain loading of 0.04 gr/acfm.

Fugitive dust is controlled throughout the plant by the use of vent systems, dust collectors, and vent filters strategically located at conveying, transfer, and storage points. Both bottom ash and fly ash are trucked off-site to a nearby storage area.

Process Control and Instrumentation

The boiler control and safety interlock system is a computer-based system which is typical of industrial coal fired facilities. Boiler control is set to steam demand and bed temperature, combustion air flow, and bed height are the basic parameters for load following. A preset logic within the computer system integrates the required culm feed rate with the basic parameters.

In general, the culm feed rate is adjusted to maintain bed temperture and the limestone feed rate is roughly controlled according to a preset limestone to culm ratio. Feedback from an SO_2 analyzer fine-tunes this ratio to regulate and control sulfur capture.

Monitoring and control equipment are provided to continuously analyze opacity, CO, CO_2, O_2, NO_x, and SO_2. The flue gases are sampled after the secondary cyclones. The equipment includes a Horiba model OPE-115 CO monitor; an I.R. Industries model 7700 analyzer for O_2, CO & CO_2; a Thermo Electron model 10 analyzer for NO_x; a Thermo Electron series 40 analyzer for SO_2; a Thermo Electron gas conditioner and a Data Test opacity meter.

Besides these controls, numerous temperature, pressue, flow and level sensing devices are utilized throughout the plant to conduct performance and material and heat balance calculations as well as provide data logging functions via the computer control system.

OPERATING EXPERIENCE

General

The boiler plant began operation in mid August of 1981 and has accummulated approximately 9200 hours of operating time to date. The Shamokin Steam Generation Plant is a demonstration facility and as such was committed to a long term test program. The test program included requirements for operation over a full range of variables. Bed temperatures were varied betwen 1450°F and 1650°F; fluidization velocities were varied between

3.5 and 5.5 ft/sec; bed depth
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Initial Operations

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3.5 and 5.5 ft/sec; bed depth was varied between 3 and 5 feet; bed zones were varied from 1 to 3; and the culm-to-lime feed ratio was varied from 14:1 to 10:1.

Initial Operations

Startup of the plant was generally considered good for a facility of this type. However, two critical problems did surface with respect to the combustor's inability to reach and then maintain proper combustion temperatures. The first problem was resolved thru the use of a soft coal during startup, to supplement the startup oil burner, and thereby achieve a satisfactory culm combustion temperature. Maintenance of bed temperatures was achieved by adding refractory to the bed wall tubes thereby reducing heat loss from the bed to the water walls.

Shakedown tests followed the startup sequence and the intent of these were to exercise the unit over its full range of operational variables. These included variations in bed temperature, fluidization velocities, bed depths and fluidized zones. Neither boiler efficiencies nor sulfur capture were determined during shakedown.

Parametric and Extended Operations

Long term operations of the plant began in October 1981 and have continued to the present with completion of all planned tests expected by September 1983. Various minor mechanical and system problems have occurred throughout this program, however, the plant has performed exceptionally well with the low-grade culm fuel.

Operation thus far have consisted of 17 parametric runs which were designed to check the boiler capabilities over its complete range of variables. This has been followed by operation in a load-following mode to supply steam on an as-required basis to the user Cellu Products with excursions to suit operational test requirements.

No major problems have been experienced during these extended operations and parametric test sequences. Availability of the boiler plant has been on the order of 85% with planned inspections being the major cause of outages. An operational running factor of about 98% has been demonstrated with short duration interruptions resulting from water and electric utility supply failures as well as minor equipment failures being the primary causes for the interruptions.

The control of emmissions has been demonstrated to be well within regulatory requirements for the full range of testing. Emissions of particulate matter, opacity, SO_2, NO_x and CO are presented in Table 2 in conjunction with applicable State and Federal standards. The Federal New Source Performance Standards (NSPS) apply to units that are capable of firing more than 250 million Btu/hr heat input of fossil fuel. The Shamokin facility is capable of firing 33 million Btu/hr of fossil fuel, and therefore, NSPS are not applicable.

NO_x test data show emissions to be about 150ppm (0.45 lb/10^6 Btu) due to the lower flame temperature associated with fluidized-bed combustion. There are no applicable State or Federal NO_x emission standards, however, we have compared actual emissions with Federal limits for illustrative purposes. Similarly, there are no CO emission standards. Test data show CO emissions ranging between 20 and 90 ppm (0.09 lb/10^6 Btu).

SO_2 removal has exceeded the 88% design requirement with sulfur capture in excess of 90% being the norm. Ca/S ratios have ranged between 2½ and 4 for the full range of parametric tests conducted. Typically, the plant operates at a 10:1 culm to lime ratio using a low grade limestone having a calcuim carbonate level of 60. Better quality limestone sorbents have been used in the plant and these understandably have resulted in improved sulfur capture and removal. SO_2 emissions have generally ranged between 100 and 200 ppm (0.54 lb/10^6 Btu) at normal lime feed rates while with increased lime feed rates emissions of 100ppm or less were easily attained. These measured SO_2 levels are well below the present State Best Available Control Technology standard of 1.2 lb/10^6 Btu. It is recognized that anthracite culm does not have a high sulfur content ($<$ 1%) and therefore does not cause significant problems with respect to its removal. Accordingly, SAIC has plans in the near future to fuel the plant with a high sulfur (5%) soft coal to evaluate the plant's performance in this regard.

Particulate emissions have been maintained well within the 0.4 lb/10^6 Btu limit, however, problems have been experienced with the baghouse. Leakage past the bag seals is the basic problem and an earlier replacement of the silicone seals has not proven adequate. SAIC will, at the next scheduled outage, change to viton seals at each of the 324 bags. A secondary problem of selected bag wear has been observed which indicates some channeling of flow through the 18 x 18 bag grid. Worn bags will be replaced at the forthcoming outage and it is planned to replace these bags both with the present Nomex bags and with Nomex bags coated with Permaguard. In general, baghouse operation has been acceptable which has resulted in low stack opacity and no visible plume. Observed data has shown a collection efficiency of 99 percent and particulate emission rate of 0.07 to 0.10 lb/10^6 Btu. The observed opacity is also well below the State standard of 20%.

SUMMARY

After 9200 hours of operation it can be concluded that low grade anthracite culm refuse fuel can be properly combusted in a fluidized-bed boiler. The Shamokin Culm Burning Steam Generation Plant has demonstrated environmental compliance while operating over a wide range of operational variables. As changes in equipment and materials are implemented and other fuels are combusted, it is expected that a further demonstration of the Plant's capabilities will be realized.

TABLE 1 : Ul
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Concentratio

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Constituent

Carbon

Hydrogen

Nitrogen

Oxygen

Sulfur

Ash

Higher Heating Value, Btu/lb.

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TABLE 1 : Ultimate Analysis of Shamokin Anthracite Culm

Concentration % (dry basis)

Constituent	Design Case	Actual
Carbon	27.02	24.15 - 26.59
Hydrogen	1.42	.89 - 1.04
Nitrogen	.66	.47 - .56
Oxygen	3.48	3.06 - 5.33
Sulfur	.57	.30 - .94
Ash	66.85	67.3 - .74
Higher Heating Value, Btu/lb.	4012	2700 - 4164

TABLE 2: Comparison of Emissions with Limits

Pollutant	Actual	Emissions State Limit	Federal Limit (1)
Sulfur Dioxide, SO_2	100-200 ppm (0.54 $lb/10^6$ Btu) (4)	500 ppm (dry basis) (1.2 $lb/10^6$ Btu) (3)	1.2 $lb/10^6$ Btu
Nitrogen Oxides, NO_x	50-300 ppm (0.45 $lb/10^6$ Btu) (4)	-	0.7 $lb/10^6$ Btu (2)
Particulates	.07-.10 $lb/10^6$ Btu	0.4 $lb/10^6$ Btu	0.1 $lb/10^6$ Btu
Opacity	8-10%	20%	20%
Carbon Monoxide, CO	20-90 ppm (0.09 $lb/10^6$ Btu (4)	-	-

(1) Federal Limit for Larger Boilers --- 40 CFR Part 60, Subpart D, New Source Performance Standards for Fossil Fuel Fired Steam Generators over 250 x 10^6 Btu/hr. Shamokin Boiler is 33 x 10^6 Btu/hr.

(2) Standard is for anthracite coal; there is no NO_x emission standard if more than 25% coal refuse is used.

(3) Based on State regulation, Chapter 127, and DER BACT determination for new such facilities.

(4) Calculated average equivalent values.

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Fluid Bed Boile

Steam Flow
Steam Condition
Bed Dimensions
Bed Height
Fluidizing Velocity
Bed Temperature
Sulfur Capture
Turndown (steam)
Convection Area
Furnace Area
Freeboard Height
Furnace Volume

TABLE 3

Fluid Bed Boiler Design Parameters

Steam Flow	23,400 lb/hr
Steam Condition	200 psig
Bed Dimensions	10 x 10 ft
Bed Height	3-6 ft
Fluidizing Velocity	3.5 - 6 ft/s
Bed Temperature	1450 - 1650^{o}F
Sulfur Capture	88%
Turndown (steam)	2.5 - 1
Convection Area	2966 ft^2
Furnace Area	1360 ft^2
Freeboard Height	16 ft
Furnace Volume	2100 ft^3

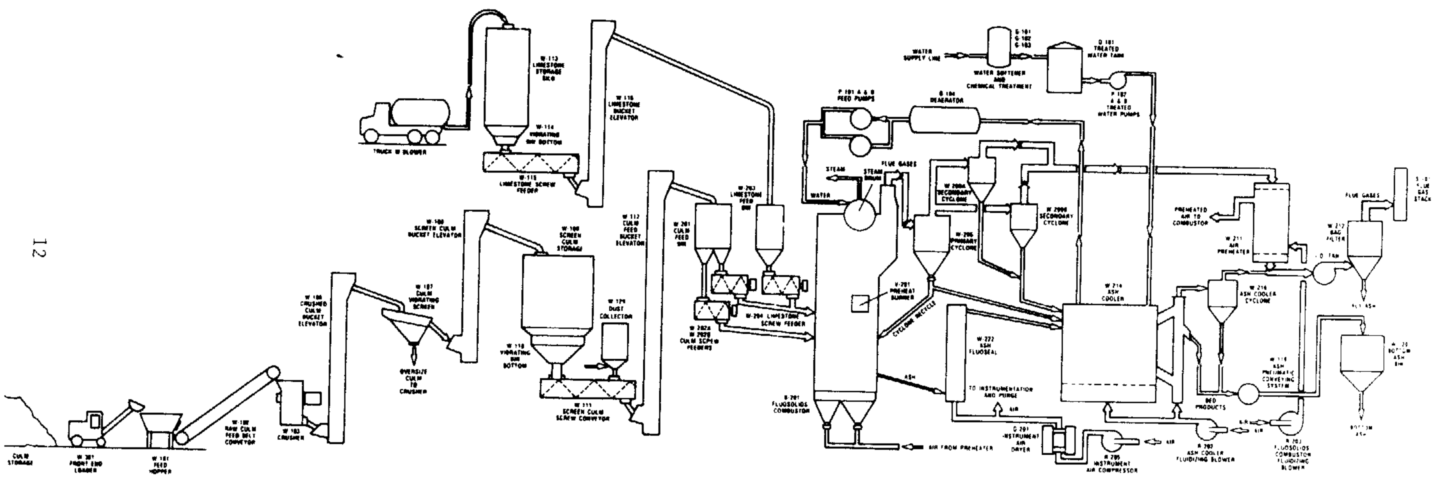

FIGURE 1
EQUIPMENT AND FLOW DIAGRAM

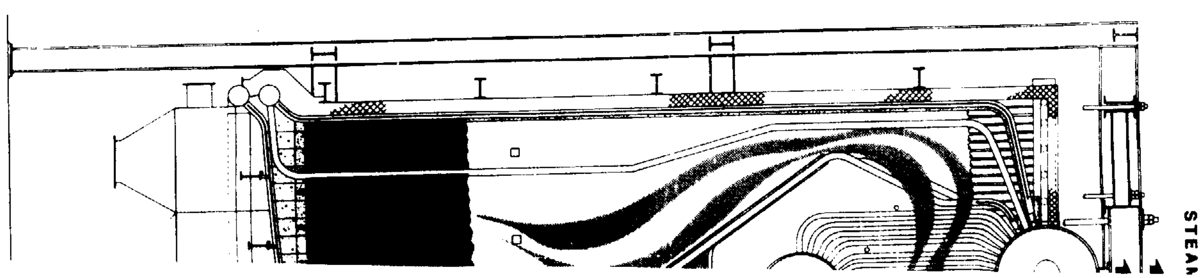

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FIGURE 1
EQUIPMENT AND FLOW DIAGRAM

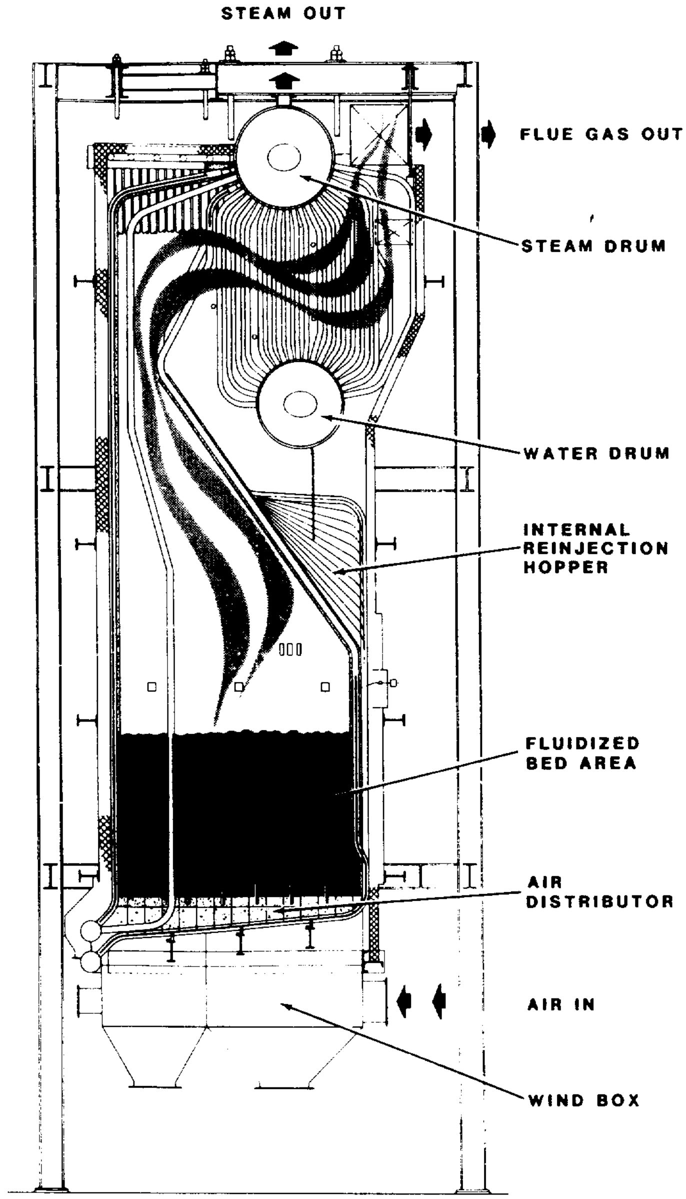

FIGURE 2
KEELER/DORR-OLIVER MKFS FLUOSOLIDS BOILER

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