APPLICATION OF THE CIRCOFLUID SYSTEM TO A CULM-FIRED RETROFIT

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ABSTRACT

The Archbald Power Cogeneration Facility is an anthracite waste (culm) fluidized bed combustion (FBC) facility located in Pennsylvania.

The low-grade fuel with a higher heating value of 7.9 to 12.5 MJ/Kg (3,400 to 5,400 BTU/lb) is converted to 90,000 Kg/hr (200,000 lb/hr) steam at 513°C/93 bar (955°F/1,335 psig). The steam is used to produce 20 MW of electricity and hot water for a nearby greenhouse. A Multisolid Fluidized Bed (MSFB) boiler had been selected to burn the culm. In the course of the startup period in 1988, a number of operating problems prevented reliable and continuous operation of the unit. The culm contains considerable amounts of potassium-based minerals and illite which, under deeply staged conditions, resulted in improper combustion and consequential clinkering.

In November, 1989, VKW, a Deutsche Babcock affiliate, was awarded a design contract to convert the existing unit to their Circofluid FBC system. Design work was preceded by a feasibility study and comprehensive combustion tests in Deutsche Babcock's test facility in Germany. Demolition and construction work began in January, 1990, followed by startup in late May and performance tests in November, 1990.

This paper discusses the basic combustion parameters, the design, and the major changes of the boiler and its ancillaries. Operating problems and solutions are identified, along with the boiler performance after conversion.

INTRODUCTION

Several anthracite culm-fired FBC boilers have been constructed in Pennsylvania during recent years. Culm is a by-product of the coal industry and is today being used as an energy source to provide heat and power to industry and utilities. In parallel, part of the mountains of culm located throughout Northeastern Pennsylvania will be eliminated and the land reclaimed. Fluidized bed combustion is regarded as the most suitable combustion technology to burn the low-calorific, low-reactive fuel.

The Archbald Power Cogeneration Plant is an anthracite culm FBC facility located north of Scranton, in Archbald Borough. The facility includes a 20 MW power plant and a greenhouse.

Riley Energy Systems constructed the facility on a turnkey basis, and will operate and maintain the plant under a 15 year contract. The FBC boiler is rated at 90,000 Kg/hr (200,000 lb/hr) output to a full condensing turbine generator. The boiler design parameters are outlined in Table 1. Electricity generated is sold to Pennsylvania Power and Light Company. Low-pressure steam extracted from the turbine will heat water for the integrated greenhouse facility. The Project is located on an undeveloped property comprising the Archbald culm banks. Approximately 600 tons per day of culm, as specified in Table 2, will be reclaimed from the piles, crushed and burned in the power plant. Limestone, as described in Table 3, is fed into the boiler to minimize sulfur emissions during combustion. Particulate emissions are controlled by a fabric filter baghouse. All residues generated by the facility will be non-hazardous and will be landfilled in abandoned coal mine pits located on-site.

MSFB BOILER

The Multisolid Fluidized Bed (MSFB) boiler which had initially been installed to burn the culm is depicted in Figure 1. The MSFB process has been described on several occasions and references should be used for a more detailed description (1).

Essentially, the combustor vessel is divided into two zones with different cross sectional areas. The lower reducing zone contains a dense bed of large particles of rounded silica gravel (approximately 13 to 19 mm, 1/2" x 3/4"). Fuel and limestone are added into this region and primary combustion air is introduced through an air distribution grid. The quantity of primary air is approximately 30% of the total combustion air, whereas the remaining 70% is provided to the upper oxidizing zone as secondary air (55%) and vent air (15%) from an external heat exchanger (EHE-). The dense bed normally operates at a superficial fluidizing velocity of about 7.6 m/sec (25 ft/sec) and the upper zone at 9.2 m/sec (30 ft/sec), respectively.

The hot combustion gas and recirculating particles leave the combustor and enter two parallel cyclones, where the heavier particles are separated from the gas stream and fall into the EHE. The hot gas passes through the convection zone, where heat is absorbed by the high and low temperature superheaters and convection walls. The gas then passes through the economizer and airheater before exiting the unit. The solids collected in the EHE are returned to the combustor either non-cooled through the hot recycle to control solids load, or cooled through cold recycle lines to control combustion temperature.

Steam is produced by two means simultaneously. First, steam is generated in the natural circulation combustor waterwalls and via a controlled circulation evaporator in the EHE in tubes submerged within a bed of fluidized sand and ash. Combustion air is supplied to the boiler by separate fans for primary, secondary, and EHE air through separate sections of the tubular airheater before entering their respective air plenums. The primary air is directed through a propane-fired duct burner for startup purposes. The flue gases leaving the boiler are drawn through the baghouse and discharged to the stack by an induced draft (ID) fan.

The boiler was first started up in 1988. Due to the significant departure of anthracite culm from fuels in previous fluid bed boilers, a number of severe operating problems occurred. The low fuel reactivity, deeply staged combustion, and insufficient combustor residence time resulted in poor carbon utilization. This, coupled with the high potassium and illite content of the ash, resulted in a sintering phenomena within the hot recycle system of the EHE and clinkering of the dense bed during fan trips. As a consequence, reliable operation at the desired steam output conditions could not be achieved.

To remedy these problems, a variety of potential solutions was investigated in detail, ranging from modifications of the existing combustor and its ancillaries to a complete exchange of the combustion system, which has finally been applied by adapting Deutsche Babcock's Circofluid System.

MSFB VERSUS CIRCOFLUID SYSTEM

The final decision to convert the MSFB unit to a Circofluid boiler was preceded by an engineering study in June 1989 to verify the mechanical feasibility of a conversion in the existing boiler structure. The study was conducted by VKW based on their previous FBC experience considering the very special combustion behavior of culm.

To emphasize the significant design changes, Figure 2 outlines the major differences between the MSFB and the Circofluid system based on the Archbald project.

Basically, a Circofluid boiler consists of two boiler passes which are connected by ash recycle cyclones. The first pass includes, in direction of the gas flow, the fluidizing air plenum, a dense bed zone of fuel ash, the freeboard and one part of the convection heating surfaces. The flue gas enters the cyclone at about 470°C (880°F). Most of the fly ash is captured there and then recycled through a siphon system to the dense bed. The remaining heating surfaces, i.e., economizer and airheater, are arranged in the second boiler pass.

The preheated combustion air is split into 70% primary air and 30% secondary air.

The most significant characteristic of a Circofluid boiler is the control of the combustion temperature. The dense bed temperature remains constant at approximately 870°C (1,600°F) over the entire load range. The bed is cooled by the cold cyclone ash. The recirculation ash flow is controlled by varying the air flow to the siphons. The heat absorbed by the recirculated ash is then transported through the freeboard and transferred to the convection heating surfaces before the cyclone. By this arrangement, almost 90% of the available heat is transferred in the first pass, whereas in the MSFB system the combustor heat duty is only 20%. For a more detailed description of the Circofluid process, refer to (2). In view of before mentioned system differences, the modification of the Archbald boiler required major changes of:

- the combustor and heating surfaces arrangement
- the ash recirculation system and
- the combustion air system

COMBUSTION TESTS

As the next step, a number of combustion tests were conducted in Deutsche Babcock's 2 MW (7 MM BTU/hr) Circofluid test facility in

August 1989. More than 100 tons of anthracite culm were burned by varying all important combustion parameters, such as temperatures, air splits, combustor velocities, and residence time to verify the previous assumptions on boiler design and performance. Under consideration of the given boiler and structure dimensions, the figures indicated in Table 4 with the expected boiler performance after conversion turned out to be the most favorable.

The combustion tests were followed by a review of the preliminary design and an in-depth cost analysis of the conversion, resulting in release of detail engineering in November 1989.

BOILER CONVERSION

Because of the great difference between the MSFB and the Circofluid system, the following process-related changes had to be made further illustrated in Figure 3:

Combustor

The combustor gas velocity in the old unit was about twice as high as in the Circofluid boiler. Therefore, the old combustor was completely removed and substituted by a new combustor and convection zone with more than double the cross-sectional area. Because of a generous initial spacing of the boiler support structure, this could be achieved without relocating any support steel.

Heating Surfaces

The EHE and the final pendant superheater were substituted by superheat and evaporator tubes in the convection zone above the freeboard. The existing low temperature superheater could be reused as an additional economizer section in the backpass.

Ash Recirculation

The low recycle temperature allowed for a significant reduction in the Circofluid recycle system size and weight. Two new cyclones were installed, along with the necessary recycle lines and siphon boxes.

Ancillary Equipment

Figure 4 outlines other process-related changes.

The maximum culm particle size of the MSFB unit had been 12.7 mm (1/2 "), whereas 9.5 mm (3/8") proved to be the optimum number for the Circofluid boiler. Further crushing is now achieved by two additional 100% secondary crushers. Two (redundant) drag chain feeders to the combustor were added to feed the culm to the siphon outlet chutes rather than separately to the combustor side walls.

New feedwater cooled combustor bottom and cyclone ash coolers recover a significant portion of the sensible heat of the solids. This allowed the existing vacuum ash disposal system to be utilized without additional ash conveying equipment.

The optimum combustion of the culm is achieved while maintaining a high primary air flow. Because of the differences in air split, pressure and arrangement, the installation of new air fans was determined as the most economical solution. To heat up the higher dense bed inventory of the Circofluid boiler, the capacity of the propane-fired startup burner was increased.

Along with the previously mentioned technology-related changes, further modifications were made to improve the unit efficiency and availability. These modifications included an extension of airheater surface to further reduce the exit gas temperature and expansion of the baghouse for improved on-line service.

CIRCOFLUID BOILER

Figure 5 depicts a more detailed view of the Circofluid boiler after conversion.

The fluidized bed is located in the lower portion of the waterwall combustor. It consists of a bed of ash, fuel, and limestone.

The fuel and limestone is fed into the bed through the ash siphon outlet chutes. The limestone sorbent reacts with the sulfur in the fuel to reduce the SO_2 emissions.

Primary air enters through the startup burner duct and the air distributors located below the fluidized bed.

NO_x emission control is accomplished by introducing secondary air to the freeboard above the dense bed at two levels.

The dense bed and the freeboard waterwalls are lined with thin, 1-1/2" refractory tiles to reduce both tube erosion and heat absorption by the waterwalls. This tile system has been selected because monolithic refractory systems were unable to meet the stringent warranty requirements specified by Riley Stoker. The low heat absorption in the furnace walls provides an almost adiabatic process for high combustion efficiency and limestone utilization at all loads without any support fuel.

The hot flue gas and recirculating ash particles pass over the superheater and evaporator tube banks before entering the parallel cyclones.

To maximize the freeboard residence time under the given height of the existing steel structure, controlled circulation evaporator tubes are arranged horizontally to minimize the height of the convection zone. The circulation is controlled through the evaporator by the existing EHE pumps after a rotor and motor upgrade. The two convection superheaters are connected by a crossover pipe where the steam temperature is reduced by a direct contact spray attemperator. After leaving the cyclones, the flue gas travels via an interconnecting duct through the old boiler backpass. Although the Circofluid boiler does not necessitate waterwalls in this section, the existing steam-cooled backpass walls were kept in place. Also, the former low-temperature superheater is now utilized as a second economizer. The gases then exit the unit through the tubular airheater.

The solids captured by the cyclones pass into the siphons, where fuel and limestone are added, and the mixture is then returned through the feed inlets. Cyclone ash which is not used for bed temperature control leaves the recycle system through overflow chutes and the cyclone ash cooler. Solids are further removed through the bottom ash coolers, the airheater, and baghouse hoppers.

BOILER CONTROLS

The boiler controls follow similar principles of controls applicable to conventional coal burning units. The significant differences are the combustor temperature, air, and SO_2 controls.

The dense bed temperature is a critical process parameter. It is controlled by the rate of solids recirculation from the siphons to the combustor.

The total combustion air is introduced at different locations with different pressure requirements: primary air used for combustor fluidization, secondary air to complete combustion and fluidization air for the siphons.

Limestone is fed with the culm in a prescribed ratio to control SO_2 emissions.

Other boiler controls are practically the same as for conventional boilers, like boiler master front-end and combustion control, furnace draft, steam temperature, feedwater flow, and drum level controls.

STARTUP

The air/gas side startup equipment includes a 14 MW (50 MM BTU/hr) propane-fired duct burner in the primary air duct before the fluidizing air plenum. Gases from the duct burner enter the dense bed through the air distribution nozzles at maximum 870°C (1,600-°F) and heat the bed to the proper temperature for culm feed permissive at 675°C (1,250-°F). By increasing culm flow, the fluidized bed temperature will be further raised while reducing the duct burner heat input. At approximately 815°C (1,500°F) the ash recycle system is placed into operation by starting up the siphon blowers for further temperature control, shortly followed by turbine synchronization and load increase.

OPERATING EXPERIENCE

All mechanical modifications and adjustments, together with necessary changes in the I&C system were achieved within a relatively short period of six months. The contract engineering commencing in November, 1989, was followed by demolition and reconstruction starting in January, 1990 with first culm firing in May, 1990. Table 5 outlines the complete modification schedule. First culm firing was followed by an extensive test and optimization period. Although only the boiler island had gone through major changes, the usual startup problems with the turbine generator system and the balance of plant had to be overcome, since the old boiler never operated at full steam output and for extended periods of time.

The experience with the new boiler is very encouraging. As with most of today's FBC boilers, the major startup problems were encountered in the ancillary equipment, such as failure of the bottom ash screw conveyors, which will be substituted by new chain conveyors, surge bin pluggage due to high surface moisture, and failure of evaporator pump seals.

All of these problems have been addressed during the first six (6) months of operation, along with the optimization of the control system and the combustor parameters. The boiler achieved full steam output in July, 1990, at the desired steam conditions. Commissioning and calibration of the emission monitoring system in August, 1990, verified that the NO_x and SO_2 emission limits can be easily achieved.

The boiler runs stable between 40% load and MCR without support fuel at full steam temperature. No adjustments to the heating surfaces or to the combustion system had to be made.

The tile and brick refractory system installed in the hot primary air duct, combustor and cyclones has performed very well with no major modifications or repairs required. Maintenance work has been limited to the replacement of a small area of bricks in the lower cyclone cone.

The boiler ASME performance test were conducted in late November, 1990. The test results in Table 6 demonstrate that the predicted performance was achieved.

REFERENCES

1. Place, W. J. and Bernston, K., "Circulating Fluidized Bed Combustion via MSFB", April, 1987, American Power Conference 49th Annual Meeting, Chicago, Illinois.

2. Tigges, K. D. and Kestner, D., "Experience with the Commissioned Operation of the Saarbrucken Circofluid Boiler", May 1989, proceedings of the 10th International Conference on FBC, San Francisco, California.

APPENDIX

TABLES AND FIGURES

Steam Flow	90,000 kg/hr	(200,000 lb/hr)
Steam Temperature	513°C	(955°F)
Steam Pressure	93 bar	(1,335 psig)
Feedwater Temperature	216°C	(420°F)
Sulfur Capture	85%	85%
SO_2 Emission, 7% O_2 dry	274 mg/Nm^3	(0.23 lb/MM BTU)
NO_x Emission	297 mg/Nm^3	(0.25 lb/MM BTU)
Particulate Emission	36 mg/Nm^3	(0.03 lb/MM BTU)

TABLE 1 Boiler Design Parameters

		Design	Range
Higher Heating Value, MJ/kg		9.86	7.9 to 12.5
	BTU/lb	(4,241)	(3,400 to 5,400)
Ash	% by weight	58.59	50 to 65
Moisture	%	5.35	max 10
Sulfur	%	0.31	max 0.4
Carbon	%	29.08	
Nitrogen	%	0.44	
Oxygen	%	4.73	
Hydrogen	%	1.50	
Fixed Carbon	%	27.57	
Volatile Matter	%	8.49	7 to 10

TABLE 2 Fuel Analysis

		Design	Range
Ca CO_3	% by weight	72.27	70 to 92
Mg CO_3	%	7.64	0.5 to 25
Moisture	%	0.74	0.5 to 20
Inert	%	19.35	4.5 to 20

TABLE 3 Limestone Analysis

Dense Bed Temperature	870°C	(1,600°F)
Freeboard Exit Temperature	960°C	(1,760°F)
Excess Air	28%	
Primary Air	70%	
Secondary Air	30%	
Combustor Residence Time	>4 sec	
Ca/S Molar Ratio	2.5	
Desulfurization	85%	
NO_x Emission, 7% O_2 dry	<120 mg/Nm^3 (0.1 lb/MM BTU)	
Combustion Efficiency	>95%	
Fuel Size	0 to 9.5 mm (0 x 3/8")	
Limestone Size	0 to 1000 micron	

TABLE 4 Combustion Test Results

- Feasibility Study June 1989
- Test Burns in Germany August 1989
- Engineering Release November 6, 1989
- Demolition January 2, 1990
- First Fire May 28, 1990
- MCR July 30, 1990
- Performance Tests November 28/29, 1990
- Emissions Compliance Test December 6, 1990

TABLE 5 Modification Schedule

	Guarantee	Performance Tests Range
Boiler Efficiency	83.21	83.75 - 84.51
NO_x Emission		
lb/MM BTU	0.25	0.03 - 0.07
SO_2 Emission		
lb/MM BTU	0.23	0.21 - 0.23
SO_2 Retention %	85	84 - 90

Adjusted for Design Fuel (4,240 BTU/lb)

TABLE 6 Boiler Performance

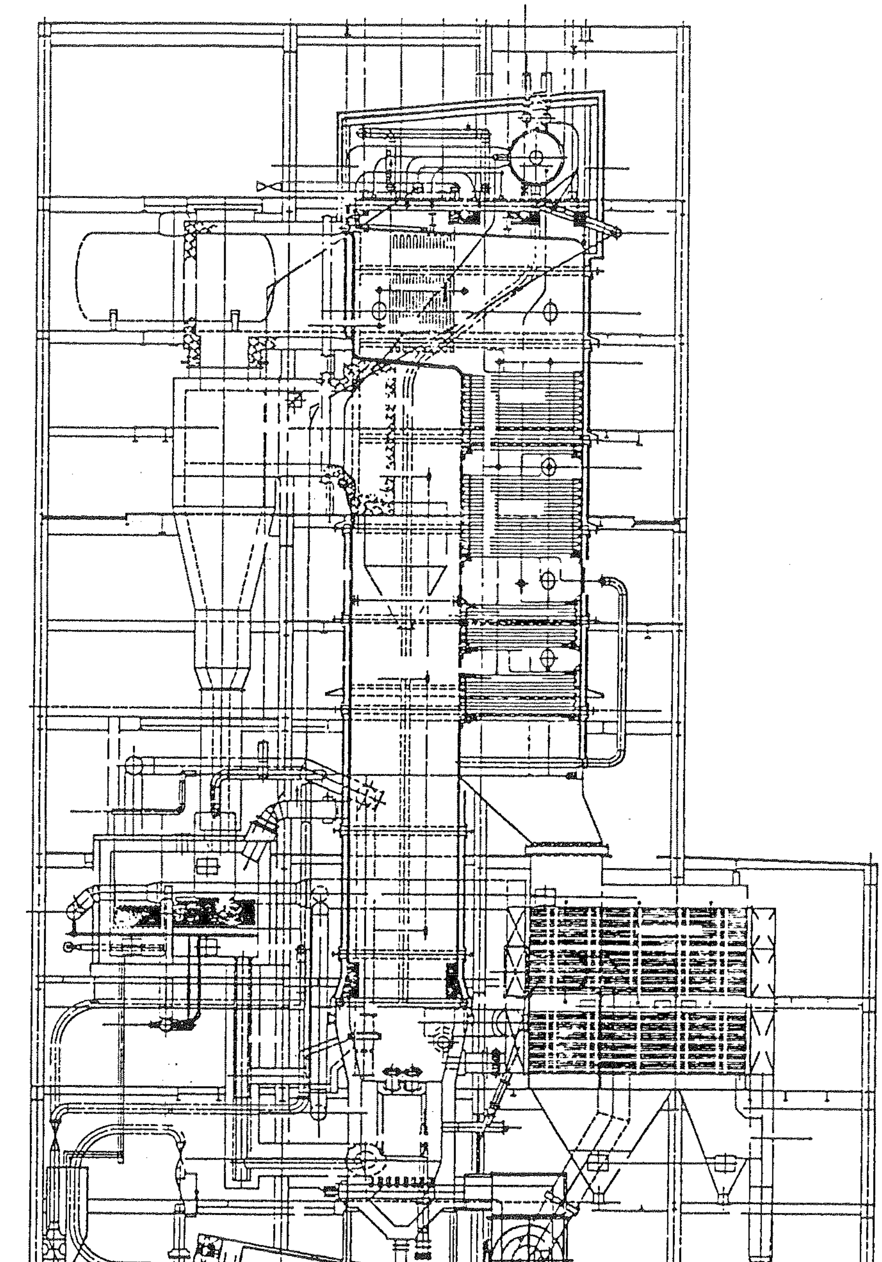


FIGURE 1 MSFB BOILER

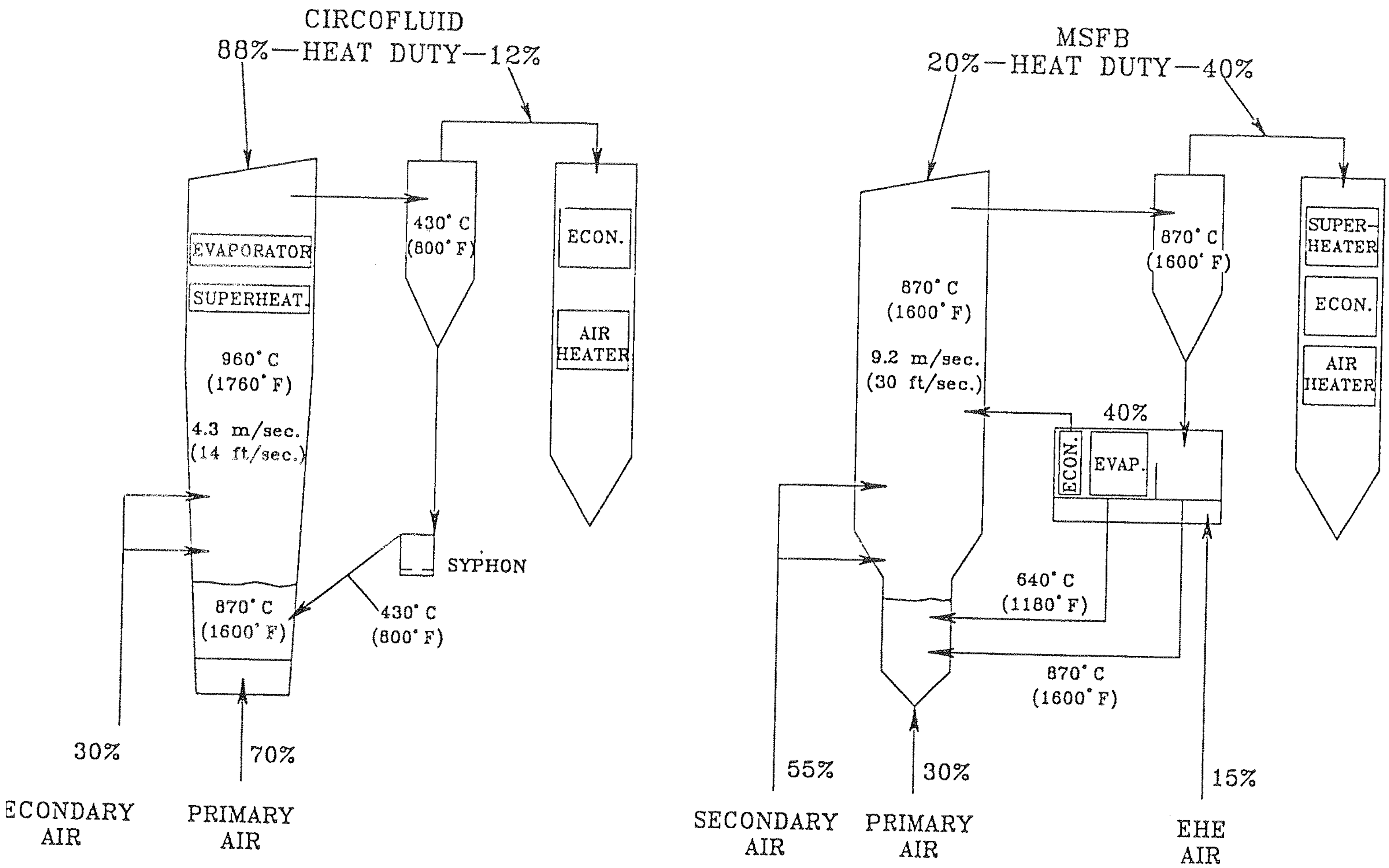
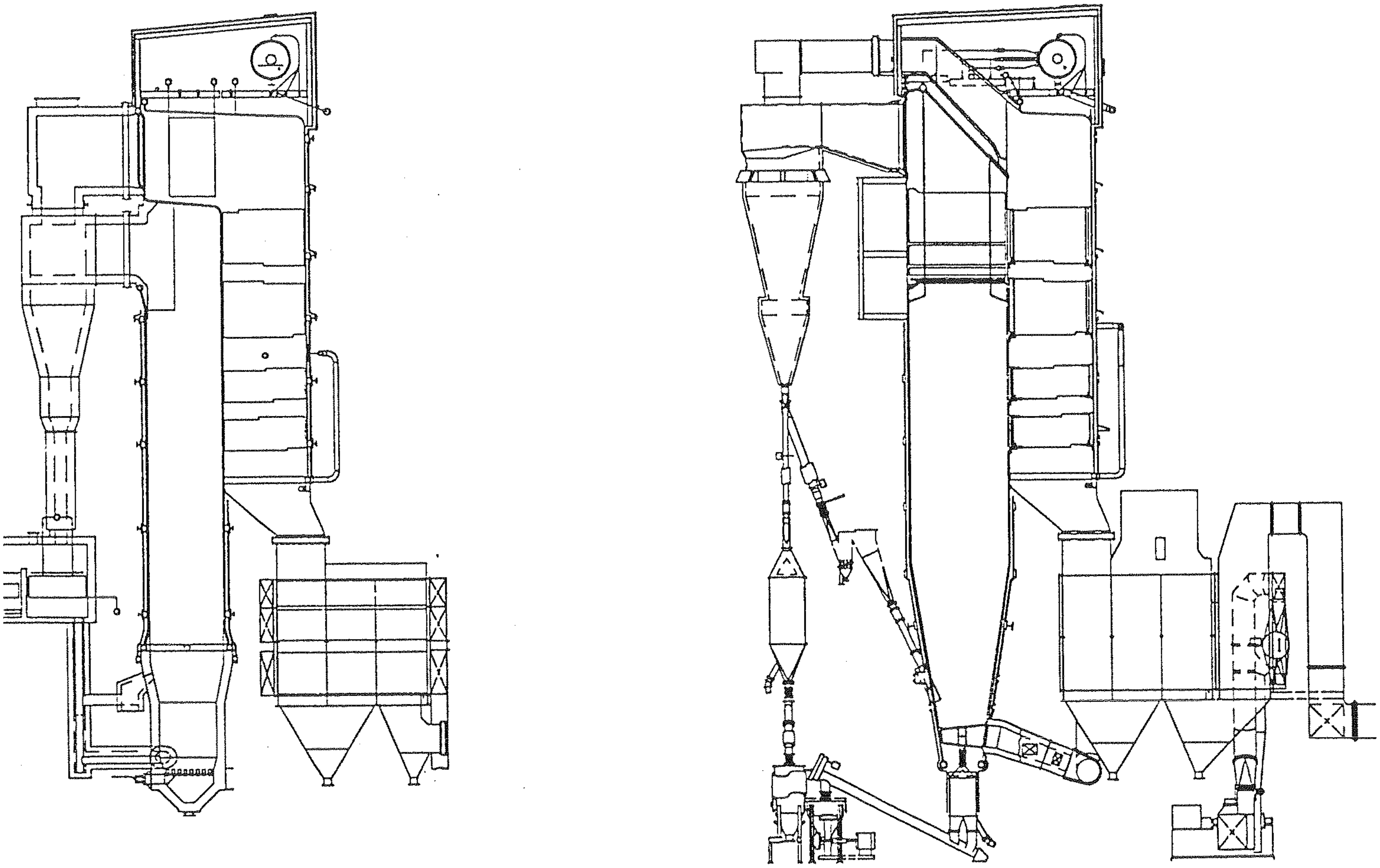


FIGURE 2 CIRCOFLUID VERSUS MSFB



MSFB CIRCOFLUID

FIGURE 3 CIRCOFLUID CONVERSION FOR ARCHBALD

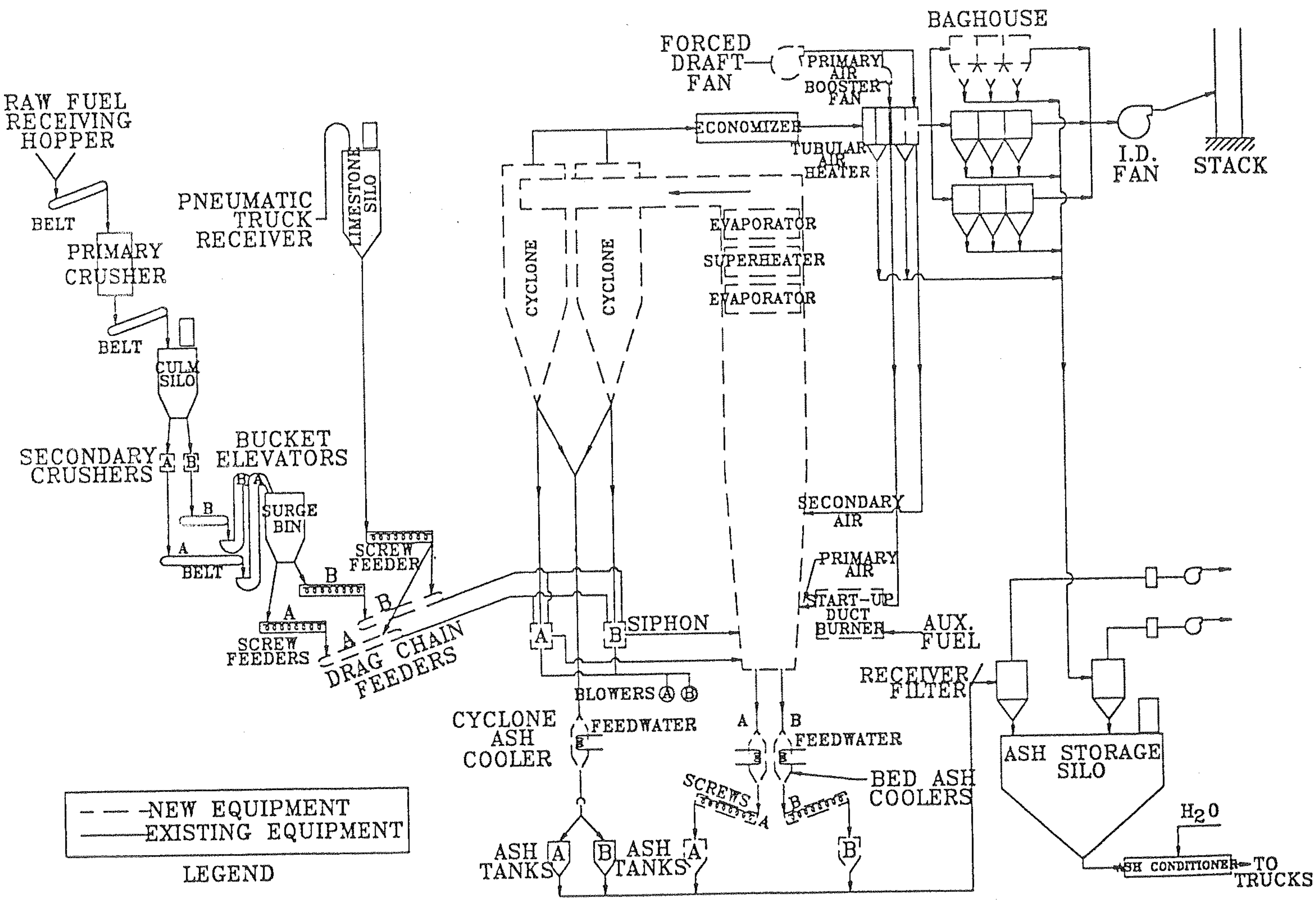


FIGURE 4 PROCESS FLOW DIAGRAM

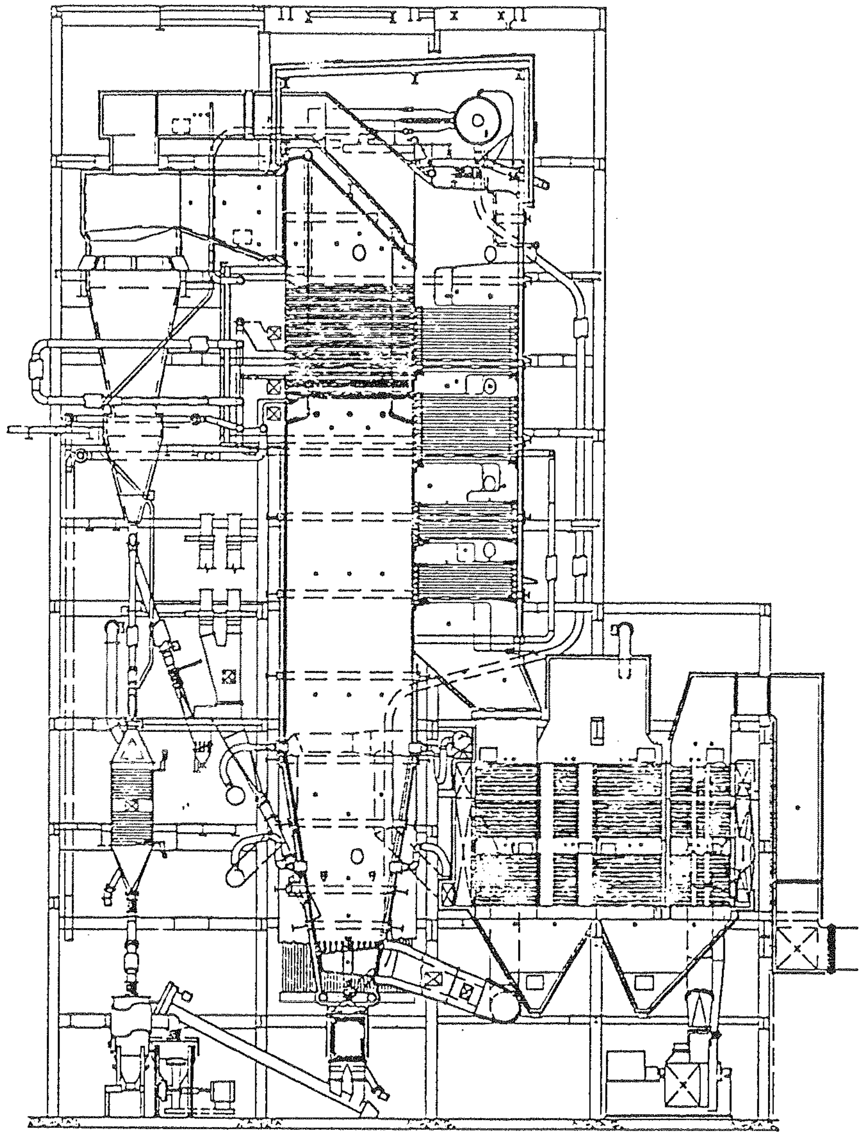


FIGURE 5 CIRCOFLUID BOILER