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CASE HISTORY ARCHBALD POWER

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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. As another benefit, 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. A simplified flow diagram is illustrated in Figure 1. Refer to Appendix for figures and tables.

Riley Energy Systems constructed the facility on a turnkey basis. The FBC boiler is rated at 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 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 Multi-Solid Fluidized Bed (MSFB) boiler which had initially been installed to burn the

culm is depicted in Figure 2. 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 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 25 ft/sec and the upper zone at 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 initially fired 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 were 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 as to converting 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, a Deutsche Babcock affiliate based on their previous FBC experience considering the very special combustion behavior of culm.

To emphasize the significant design changes, Figure 3 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 800°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 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 reference (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

BOILER CONVERSION

As the next step, a number of combustion tests were conducted in Deutsche Babcock's 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.

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 contract engineering in November 1989.

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 4):

- Combustor

The old combustor was substituted by a new combustor and convection zone with more than double the cross-sectional area.

- Heating Surfaces

The EHE and the final pendant superheater were substituted by superheat and evaporator tubes in the convection zone above the freeboard.

- 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 5 outlines other process-related changes made (new equipment in dotted lines).

The maximum culm particle size of the MSFB unit had been 1/2" whereas 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 before 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 6 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 SO₂ 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 attenuator. 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.

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 engineer

ing commencing in November 1989 was followed by demolition and reconstruction starting in January 1990 with first culm firing in May 1990. Table 3 outlines the complete modification schedule.

OPERATING EXPERIENCE

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 so far is very encouraging. As with most of today's FBC boilers, the major startup problems were encountered in the ancillary equipment, like 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.

Most of these problems have been remedied 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 boiler ASME performance tests were conducted in late November 1990. The first test results in Table 4 demonstrate that all guarantees are well met.

TABLE 1 Boiler Design Parameters

Steam Flow	200,000 lb/hr
Steam Temperature	955°F
Steam Pressure	1,335 psig
Feedwater Temperature	420°F
Sulfur Capture	90%
SO ₂ Emission, 3% O ₂ dry	0.23 lb/MM BTU
NO _x Emission	0.25 lb/MM BTU
Particulate Emission	0.03 lb/MM BTU

TABLE 2 Fuel Analysis

	<u>Design</u>	<u>Range</u>
Higher Heating Value 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

TABLE 3 Modification Schedule

- 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 Test November 28, 1990
- Emissions Compliance Test December 6, 1990

TABLE 4 Boiler Performance

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

	<u>Guarantee</u>	<u>Nov. 28 Test</u>
Boiler Efficiency	83.21	83.85
NO _x Emission, lb/MM BTU	0.25	0.08
SO ₂ Emission, lb/MM BTU	0.23	0.20
SO ₂ Retention %	85	90

REFERENCES

1. Place, W. J.; Bernston, K.; "Circulating Fluidized Bed Combustion via MSFB"; American Power Conference 49th Annual Meeting; Chicago, Illinois; April 1987.
2. Tigges, K. D.; Kestner, D.; "Experience with the Commissioned Operation of the Saarbrücken Circofluid Boiler"; proceedings of the 10th International Conference on FBC; San Francisco, California; May 1989.

APPENDIX

SIMPLIFIED DIAGRAM OF ARCHBALD PLANT

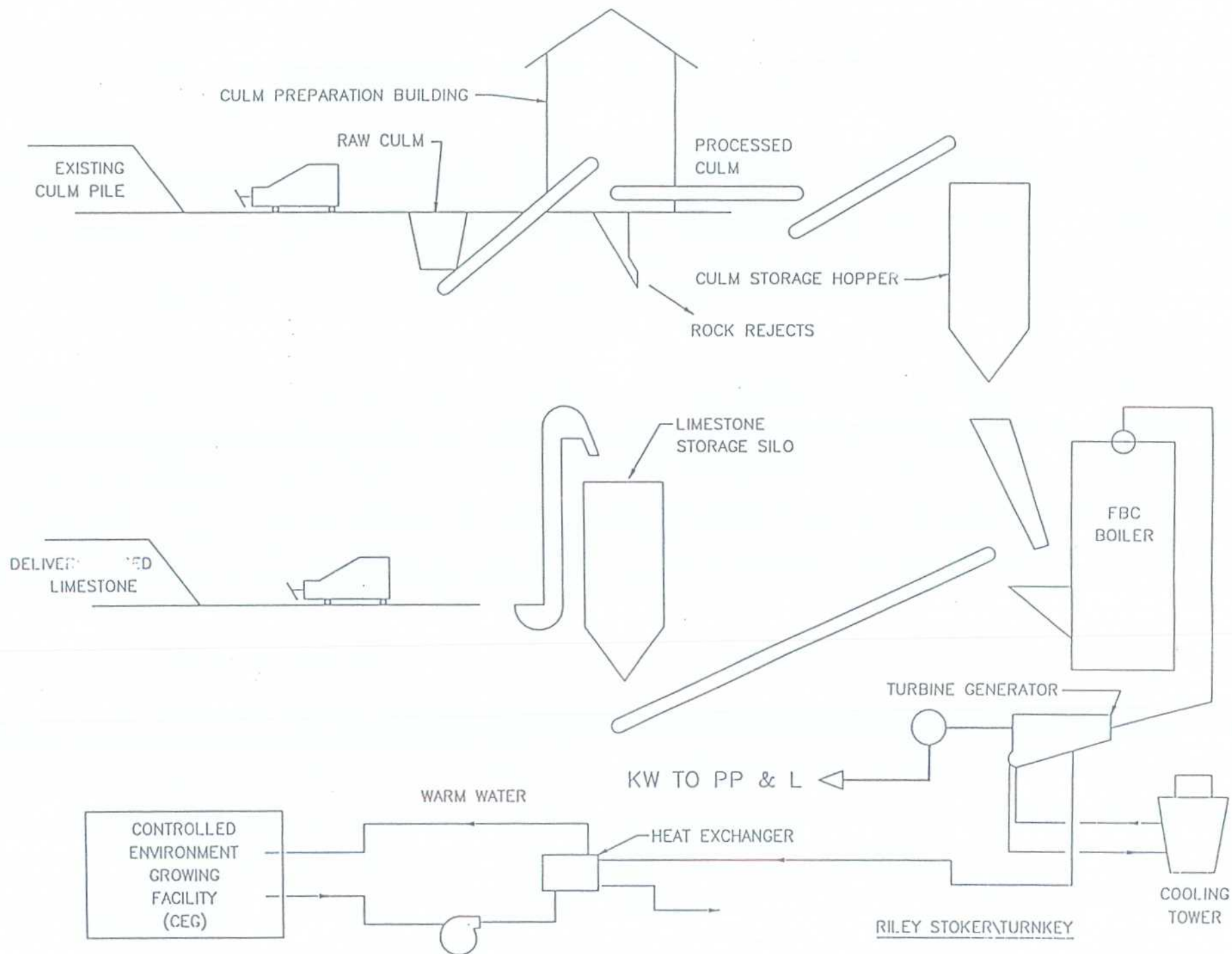


Figure 1

MSFB BOILER
(Detailed Side Elevation)

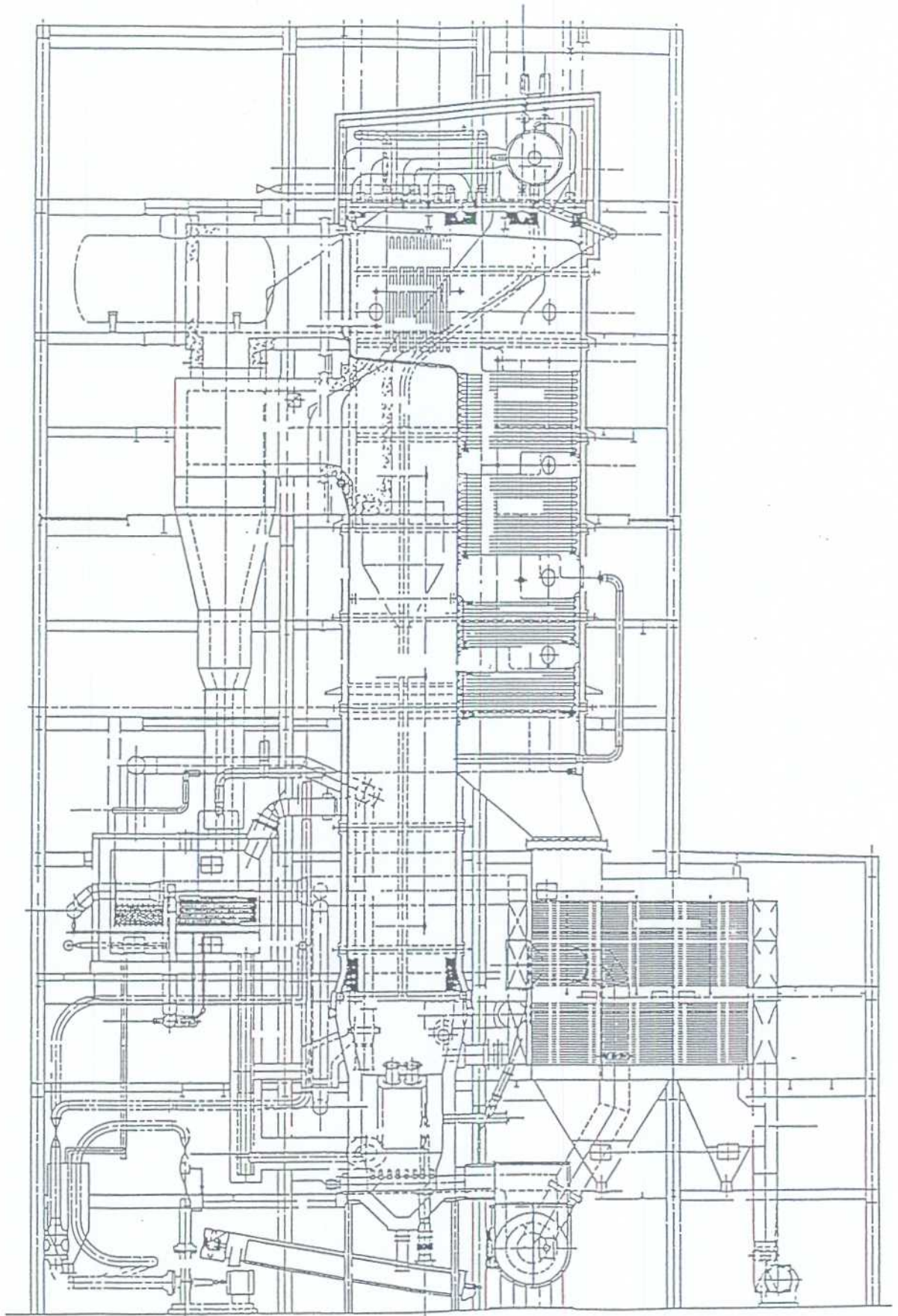
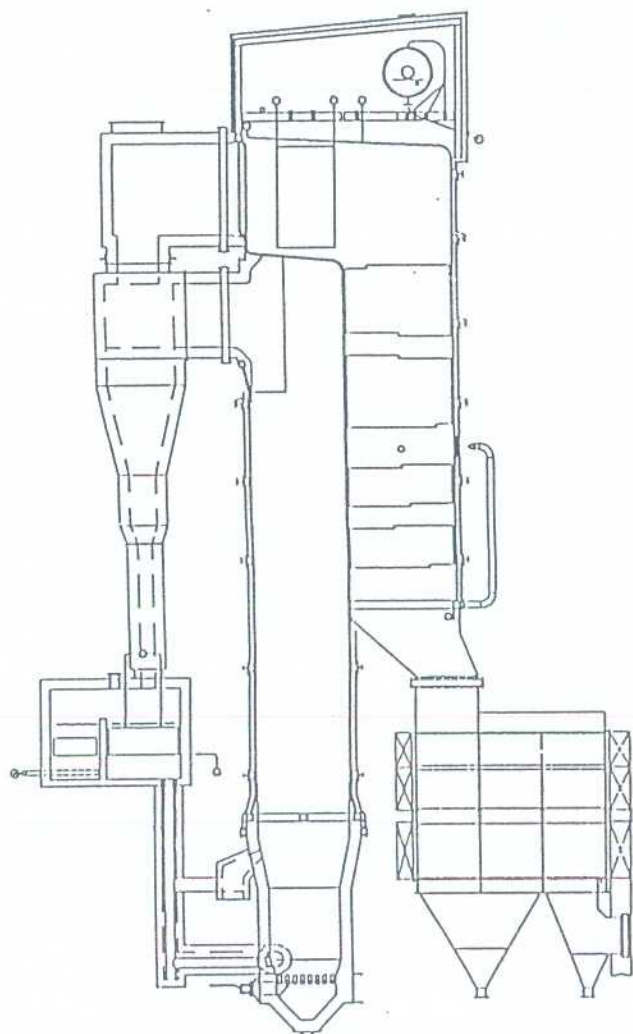
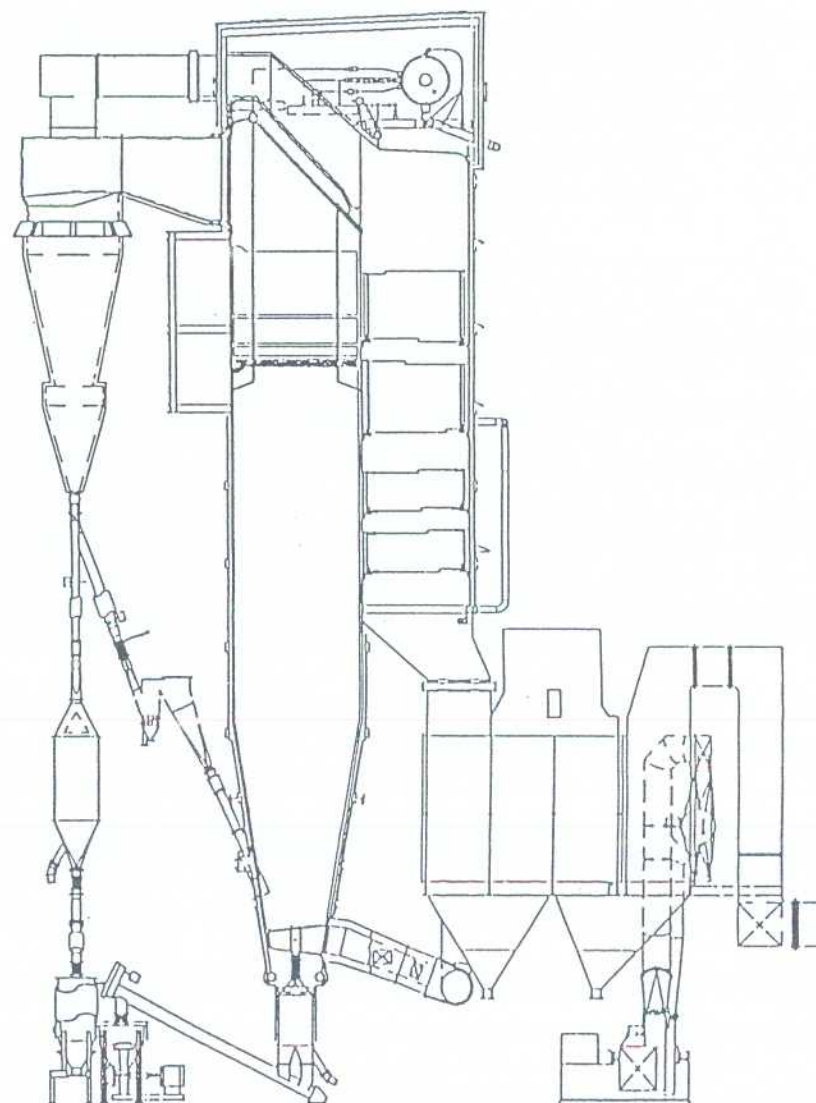


Figure 2

CIRCOFLUID CONVERSION FOR ARCHBALD

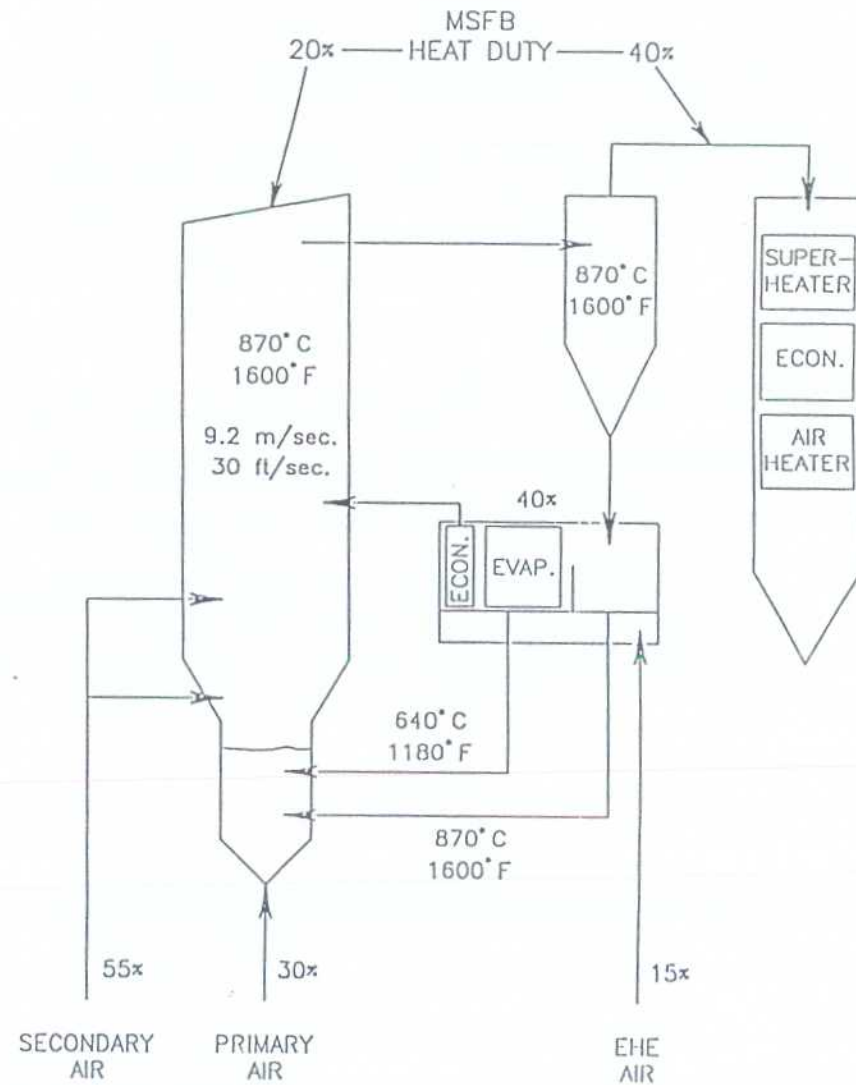
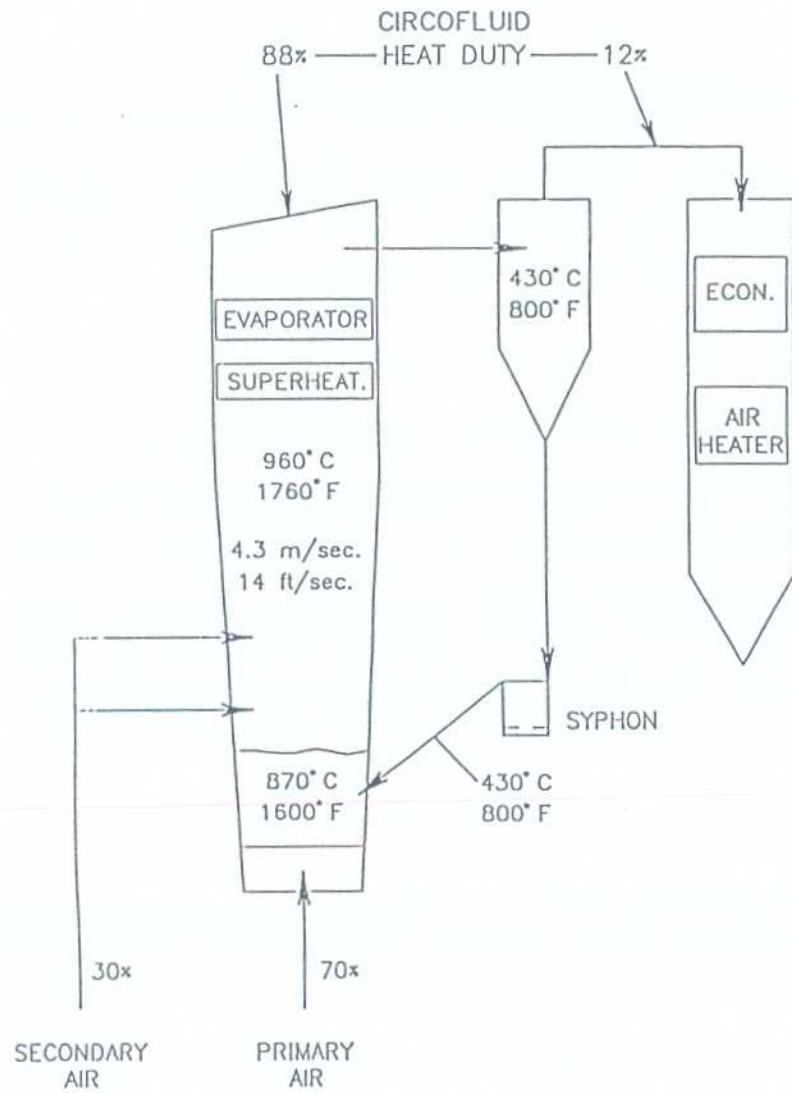


MSFB



CIRCOFLUID

CIRCOFLUID VERSUS MSFB



THE ARCHIBALD PROJECT
ARCHIBALD, PENNSYLVANIA
RILEY STOKER CORPORATION
PROCESS FLOW DIAGRAM

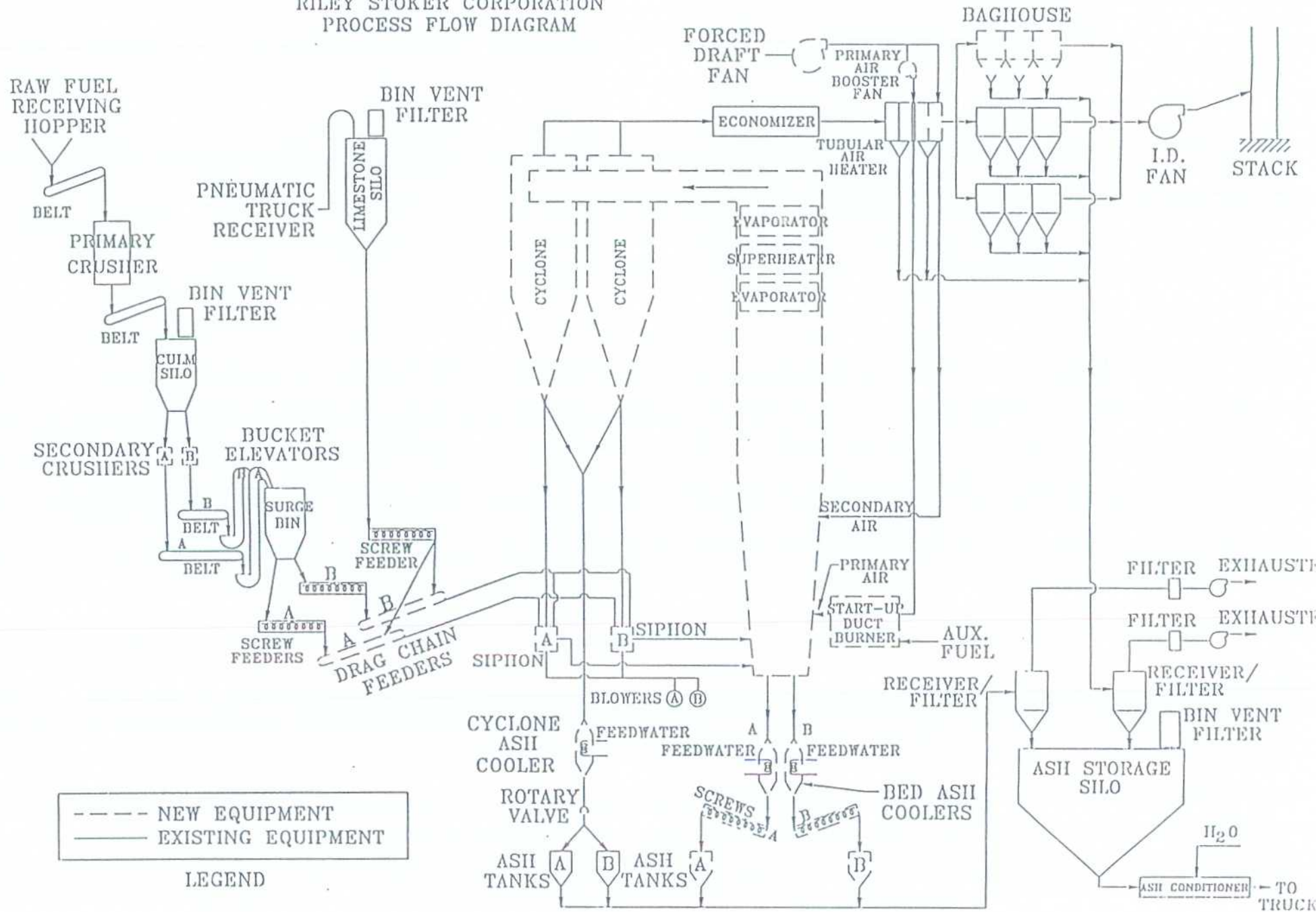


Figure 5

CIRCOFLUID BOILER
(Detailed Side Elevation)

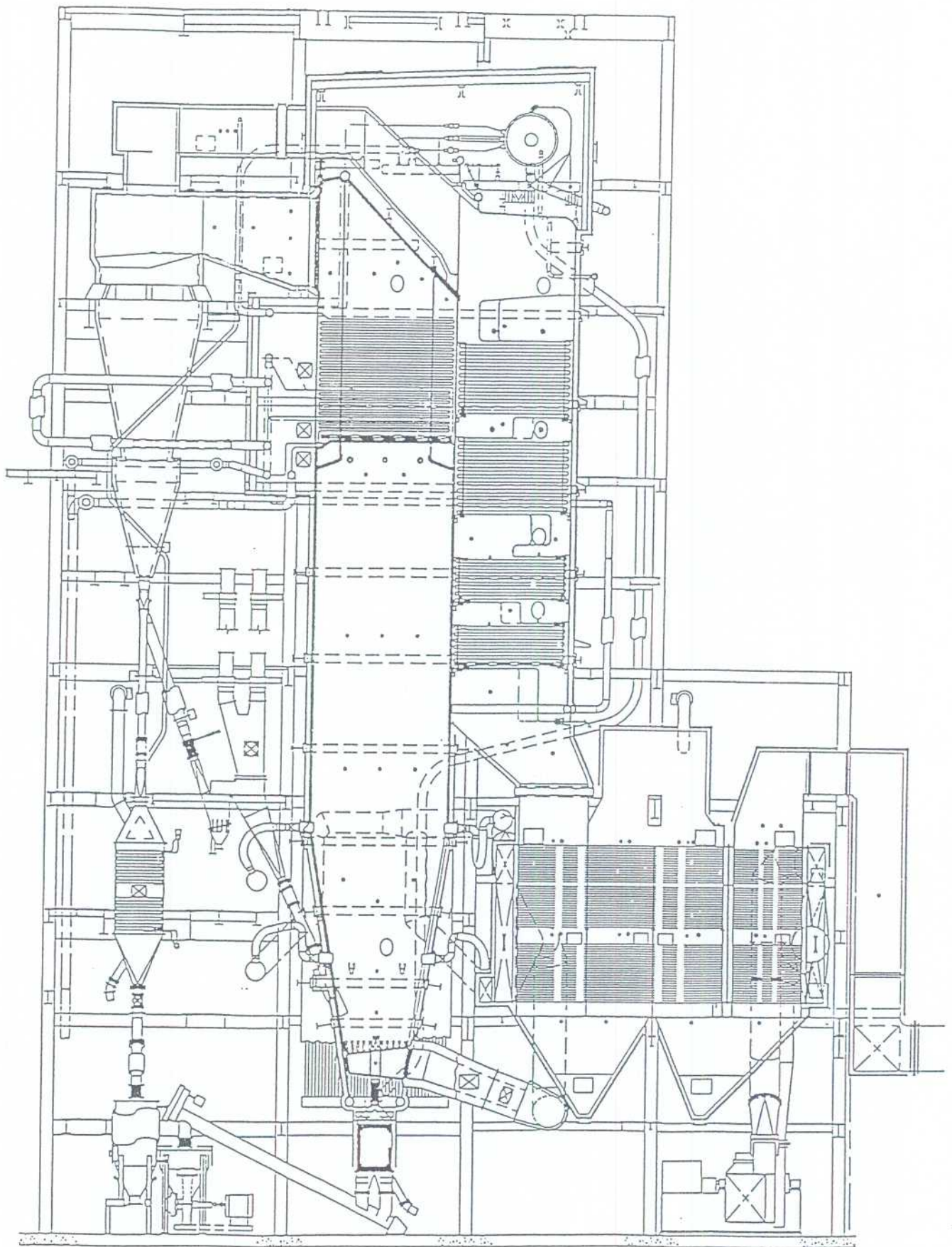


Figure 6

