THE RAPIDLY EXPANDING U.S. MARKET FOR INDUSTRIAL SCALE FLUIDIZED BED COMBUSTION

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The market potential for industrial scale fluidized bed combustion is reviewed The market penetration to date of commercial units is updated and the development status of various near commercial systems is given.

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Introduction

In the past decade the rising prices of both oil and gas have changed the way coal is viewed as the fuel of choice in new industrial/commercial boilers. In addition, pollution regulations have changed the way the combustion process is carried out and cleaned up. This paper examines the penetration of fluidized bed combustion, a new boiler technology, into the industrial boiler market.

The Industrial Boiler Market

a. Oil Fired

We define the industrial/commercial boiler as one not primarily built for the purpose of generating power. In addition we will refer to the commercial/industrial segment as the industrial market in this paper. Using data from a government sponsored survey,[1] Table 1 lists the distribution by size of the oil fired industrial boiler population in the U.S. Most of the total capacity lies in the size range of 1.5 to 250 MM Btu/hr. The number of units is quite large at over 100,000 boilers. In terms of oil use, the table shows that about 3 million Bbl/day (bpd) are consumed at 50% capacity utilization. The impact of potential sales on the coal market is inferred from the coal equivalent of about 270 million tons per year (TPY).

Coal can be delivered to an industrial user for under $2/MM Btu while oil costs over $5/million Btu. This is the driving force for selection of coal firing over oil firing for a new facility. In some instances, the case can be made for installation of a coal fired boiler as a substitution for or retrofit to an existing operating oil burning unit on the basis of rapid payback.

b. Gas Fired

The distribution of gas fired units is given in Table 2. Here too, the preponderance of the fuel usage is in the 1.5-250 MM Btu/hr range. The coal equivalent is 300 MM TPY at 50% utilization of capacity. There is some tilt to very large gas fired units and it is assumed this is due to the use of gas turbines in combined cycle cogeneration applications.

The price of gas has been controlled at a low level relative to oil and few substitutions of coal for gas have taken place. However, the realities of the marketplace are being felt and gas prices are catching up to oil prices. The gas fired boiler market will soon show economic incentives to convert to coal firing similar to those of the oil fired market.

c. Coal Fired

The data for coal-fired units is shown in Table 3. There would be no change in total coal use as fluidized bed combustors become more common. The cost of FBC and other coal-fired units are roughly the same. However, there may be incentives to switch from pulverized coal-fired or stoker coal-fired units to fluidized bed units for reasons of fuel availability and ease of meeting emission standards. These advantages of fluidized bed firing will be discussed below.

Impact on Coal Sales

If fluidized bed combustion can make significant inroads in the industrial boiler market, it will noticeably impact the overall coal industry. Table 4 shows the tonnage mined and used over the last several years. We are now mining about 850 million TPY. The potential available from industrial sales is a 500 million TPY increase or some 60%.

Fluidized Bed Combustion (FBC)

In FBC processes, coal is burned in a bed of noncoal solids such as sand, limestone, ash, or alumina. The combustion process is carried out below 1700°F, typically at 1550°F, and a long residence time is provided to ensure complete burnout. Table 5 lists a set of advantages of FBC. Since the combustion temperature is relatively low, nitrogen fixation is minimal. NO_x emissions from FBC are nearly always below 0.6 lb/MM Btu and typically 0.4 lb/MM Btu. At the low temperatures employed, fouling and slagging are not encountered. As a result of the long residence time combustion, volatile matter content is not a critical fuel characteristic. Therefore low-vol fuels can be employed. As a flame does not have to be sustained, low heating value fuels such as high ash coals and waste sludges can be burned. The low temperature of the FBC bed is ideal for the capture of sulfur by limestone; FBC can be run with high sulfur coals while complying with emission regulations. The used limestone is dry and can be disposed of with the ash. There is no sludge. The system is readily adaptable to industrial scale. The coal feed does not have to be finely ground, and coal in the stoker size range is a typical feed. The ability of various units to handle coal under 35 mesh varies. The finer sizes generally contribute to carbon losses. Flue gas particulates are cleaned up with a baghouse.

Figure 1 is a diagram of a fluidized bed combustion boiler. In this unit, coal is burned in a fluidized bed of limestone at 1550°F. The coal is stoker grade and is fed over the bed by stoker spreaders. Limestone in the bed reacts with SO_2 so that the flue gas is desulfurized. As the temperature is lower than those of other combustion systems, the driving force for heat transfer is less. However, this is more than compensated for by the increased heat transfer of the bed solids to the steam tubes immersed in the bed.

FBC Systems in The Market Today

A number of FBC systems and manufacturers are vying for market share and sales right now. These are surveyed below with a brief description of the design features of each. Many of the units are in operation or under construction in their first commercial application.

a. Foster Wheeler Boiler Corp. - Livingston, N.J.

Figure 1 is a schematic of a Foster Wheeler FBC boiler. Coal is fed to a bed of limestone using a spreader stoker feeder. The system uses in-bed tubes and is equipped for reinjection of fly ash to improve burnout. Recent changes to the Georgetown boiler pictured included addition of refractory to the freeboard and revision of the fly ash reinjection system. The boiler has been operating in an urban setting since 1979 meeting all emission requirements. Boiler efficiency has been about 80%.

U.S. and Canadian sales are presented in Table 6. In addition, some 250,000 pph has been sold overseas. Foster Wheeler is actively marketing its units from 40,000 pounds per hour of steam (pph) to 600,000 pph.

b. Johnston Boiler Co. - Ferrysburg, Michigan

A Johnston packaged fire tube FBC unit is shown in Figure 2. The fluidized bed can be either sand or limestone depending on whether desulfurization is required. Coal is fed just below the top of the bed and means are provided for carbon reinjection from the settling chamber. A 40,000 pph unit in Ohio has some 10,000 hours of operation behind it and is being run with one operator provided by the boiler owner.

Table 7 is a listing of sales and installations in the U.S. to date. About 900,000 pph has been sold. Johnston offers fire tube packaged units from small sizes to 50,000 pph. Water tube units are being offered up to 70,000 pph based on the design of a successfully operating 10,000 pph unit in England; two small units have so far been sold in the U.S.

Additional FBC units sold by other vendors are listed in Table 8.

c. Struthers Wells Corp. - Winfield, Kansas
Battelle Laboratories - Columbus, Ohio

A variation on conventional FBC operations is the deliberate entrainment of bed material overhead. Heat is then extracted from the bed solids and the solids are returned to the bed. The Battelle - Struthers system shown in Figure 3 is an example of this operation variously called circulating bed, entrained bed, or fast fluidized bed combustion. Coal is fed into the combustor section which contains a conventional fluidized bed and a circulating solids component. The circulating solids, typically sand, are taken overhead with ash and fine limestone. They are then separated from the ash and limestone in a primary cyclone and dropped into a second fluidized bed containing heat transfer surface. The cooled sand is then returned to the combustion zone. Separation of heat transfer and combustion functions gives the potential for greater flexibility of operations.

Using Battelle technology, Struthers Wells Corp. designed and built a 50,000 pph unit for Conoco dedicated to steam production for heavy oil recovery. The unit has been operating since winter, 1981 and has logged over 2000 hours.

Struthers is offering units for enhanced oil recovery, cogeneration using hot air, and process heaters with commercial terms. Battelle is currently licensing this technology for industrial boilers.

d. Curtiss-Wright Corp. - Woodridge, New Jersey
E. Keeler Boiler Co. - Williamsport, PA

Curtiss-Wright is operating a 20,000 pph unit designed to burn anthracite culm. A simplified flow diagram of the system is shown in Figure 4. The fluidized bed contains steam generating surface and provision for reinjection of cyclone fines for enhanced carbon burnup. As a considerable amount of waste solids are generated from the low heating value fuel, a fluidized bed ash cooler is added to maintain high thermal efficiency. The boiler can operate efficiently using 3100 Btu/lb fuel. The unit started up in fall, 1981 and has logged 3,500 hours.

Custiss-Wright is marketing the unit in the U.S. and overseas for low heating value fuels. In addition they are marketing a line of atmospheric FBC units using an air cycle cogeneration system. The cogeneration equipment combines the technology developed for steam generating atmospheric FBC with Curtiss-Wright's work on pressurized FBC which also uses an air system.

Dorr-Oliver worked on the Shamokin boiler as a subsidiary of Curtiss-Wright Corp. but it is now a subsidiary of Kennecott Corp. Via an exclusive arrangement with Dorr-Oliver, E. Keelar Co. offers field erected boilers of the same design as the Shamokin unit in sizes of 50,000 to 200,000 pph. A line of modular shop assembled units (two shop assemblies per boiler) is available from 30,000 to 80,000 pph.

e. Combustion Engineering - Windsor, Connecticut

A schematic of the Combustion Engineering boiler installed at the Great Lakes Naval Station near Chicago is given in Figure 5. The unit is equipped for superheat and has operated at rates up to 55,000 pph while meeting all emission requirements. The coal handling and feeding system has been revised to yield a simpler, more reliable system and the unit is being operated as a four section boiler for purposes of turndown. The Great Lakes unit has logged over 2,000 hours since startup.

C. E. is offering units warranted as to steam capacity, temperature and pressure. Boilers up to 500,000 pph can be obtained.

f. Energy Resources Co. (ERCO) - Cambridge, Massachusetts

ERCO is to start up a 50,000 pph oil field steamer unit in fall, 1982. The design of the unit is based upon work done in their 20,000 pph test facility (Figure 6). ERCO's system features a proprietary underbed feed system which minimizes coal distribution problems in the bed.

ERCO is offering its oil field steamer units in the U.S. It also has a fire tube system developed for high ash coals which it will soon be starting up overseas. The fire tube units are for the 10,000 - 50,000 pph size range.

g. Wormser Engineering Inc. - Woburn, Massachusetts

The Wormser Grate system, shown in Figure 7, uses a pair of superposed fluidized beds. Coal is burned in a fluidized bed of sand at a temperature designed to give good burnout. The gases then pass through a fluidized bed of limestone in which desulfurization is effected. Space is afforded for a third section which is used for storage of combustion bed material when the unit is in a turned down mode. The system is said to be particularly well suited for minimizing NO_x emissions by virtue of its staged processing configuration.

A 70,000 pph unit is scheduled for startup in mid-1982 in a Texas beef processing plant. A 20,000 pph retrofit to an existing oil fired boiler is also scheduled. Wormser is offering units up to 100,000 pph.

h. Pyropower Corp. - San Diego, California

Pyropower Corporation is an equal shareholder corporation of General Atomic and Ahlstrom, who originally developed the technology. A schematic of the boiler is shown in Figure 8. The system uses a recirculating bed process with no external fluidized bed heat exchange. A membrane wall combustion chamber and refractory lined cyclone enclose the recirculating bed. Hot gases exit to convection heat transfer surface and the unit is suitable for retrofit applications.

Pyropower is constructing a 50,000 pph unit for the oil field steamer market. The unit, located near Bakersfield, California, is due to startup at the end of 1982. Ahlstrom has successfully been operating a 200,000 pph unit in Finland since 1981. The Finnish unit is fueled with peat and wood but has been used for coal burning tests. Pyropower is marketing the system in sizes to 400,000 pph.

i. Lurgi Corporation - Belmont, California

Lurgi uses a recirculating fluidized bed as pictured in Figure 9. Coal is burned in a fast fluidized bed which is carried overhead to a hot cyclone. The underflow can be routed back to the bed or to an external fluidized bed heat exchanger. The system pictured in Figure 9 will heat a molten salt heat transfer fluid as well as raise steam. Lurgi's boiler design comes from extensive experience in using fast fluidized beds for other industrial applications.

Although no units have been sold in the U.S., the plant shown in Figure 9 is in startup with a capacity of 83 MWth. Lurgi is offering boilers in the U.S. in sizes over 50,000 pph.

j. Stone and Webster Engineering Corp. - Boston, Massachusetts
Foster Wheeler Boiler Corp. - Livingston, New Jersey

The Stone and Webster solids circulating boiler concept is pictured in Figure 10. Solids are drawn off the bottom of the bed, entrained by air upwards through a water wall riser and returned to the bed. Fine limestone is used for desulfurization and is removed from the unit with ash through the overhead system. Stone and Webster and Foster Wheeler are offering the system in sizes ranging upwards of 50,000 pph.

Application to Power Generation

The fluidized bed combustion concept can be applied to power generating systems. Toward that end, Tennessee Valley Authority (TVA) and Electric Power Research Institute (EPRI) have sponsored a 200,000 pph unit to specifically test FBC operations and systems required for that application. The unit is located at TVA's Shawnee station near Paducah, Kentucky and has accumulated several hundred hours of operating time.

Conclusions

The potential market for fluidized bed combustion systems is very large. There are, and will continue to be, incentives to replace gas and oil fired units with coal fueled units. A number of fluidized bed combustion systems are available. The marketplace will decide which fits best into each application and which is the most cost effective.

References

1. T. Devitt, P. Spaite, and L. Gibbs, Population and Characteristics of Industrial/Commercial Boilers in the U.S., EPA-600/7-79-178a, August, 1979, NTIS No. PB80-150881.

TABLE 1

Distribution by Size of Oil Fired Industrial Boilers

Size MM Btu/hr	Number of Units	Total Capacity MMM Btu/hr	MM(1) Bbl/day	Coal Equivalent(2) MM tons/yr
1.5 - 25	93,083	551.4	1.10	105.0
25 - 250	11,254	663.4	1.33	126.3
250 - 500	341	114.3	0.23	21.8
>500	78	74.1	0.15	14.1
Total	104,756	1403.2	2.81	267.2

1. Based on 50% load factor and 6.0 MM Btu/Bbl
2. Based on 50% load factor and 23 MM Btu/ton

Source: Reference 1

TABLE 2

Distribution by Size of Gas Fired Industrial Boilers

Size MM Btu/hr	Number of Units	Total Capacity MMM Btu/hr	MMM[1] Cubic ft/day	Coal[2] Equivalent MM tons/yr
1.5 - 25	112,099	598.4	7.2	114.0
25 - 250	10,860	677.6	8.1	129.0
250 - 500	339	112.6	0.4	21.4
500 - 1500	103	77.1	0.9	14.7
>1500	40	172.8	2.1	32.9
Total	123,441	1638.5	18.7	312.0

1. Based on 50% load factor and 1000 Btu/ft^3

2. Based on 50% load factor and 23 MM Btu/ton

Source: Reference 1

TABLE 3

Distribution by Size of Coal Fired Industrial Boilers

Size MM Btu/hr	Number of Units	Total Capacity MMM Btu/hr	Coal[1] Equivalent MM Tons/yr
1.5 - 25	28,558	122.9	23.4
25 - 250	5,383	405.4	77.2
250 - 500	338	108.5	20.7
>500	97	99.6	18.9
Total	34,376	736.4	140.2

1. Based on 50% load factor and 23 MM Btu/ton

Source: Reference 1

TABLE 4

U. S. Coal Industry Production and Consumption

Year	Production Millions of Tons/Year	Consumption Millions of Tons/Year
1979	776	742
1980	824	789
1981	802	844
1982	880	868
2000	2000 (1)	

1. Requires an average annual growth rate of 4.7%.

Source: Trade Literature

TABLE 5

Advantages of Fluidized Bed Combustion

- Low combustion temperature (1500-1700°F)
  - Low NO_x
  - No fouling or slagging
- Fuel flexibility
  - Low vol fuels - pet coke, anthracite
  - Low heating value fuels - high ash, sludges
- Sulfur capture by limestone
  - No stack gas scrubber
  - No sludge, dispose with ash
- Adaptable to industrial scale
- Small rather than pulverized coal

TABLE 6

Foster Wheeler U.S. Fluidized Bed Steam Generator Projects

CUSTOMER	CAPACITY lb/h	PRESSURE psig	TEMPERATURE °F	FUEL	START-UP DATE
Georgetown University Washington, D. C.	100,000	275	Saturation	Bituminous coal	1979
Canada - Dept. of Defense Summerside, Prince Edward Island	2 at 40,000	125	Saturation	Bituminous coal	1983
Ashland Petroleum Company Catlettsburg, Kentucky	2 at 325,000	450	700	Gas (CO, SO_2)	1983
Kentucky Agricultural Energy Corp. Franklin, Kentucky	2 at 60,000	600	Saturation	Bituminous coal	1982
Idaho National Energy Laboratory Idaho Falls, Idaho	2 at 67,500	150	Saturation	Sub-bituminous coal	1984
TOTAL	1,085,000				

TABLE 7

U.S. Orders for Johnston FBC Packaged Boilers

QUANTITY	CAPACITY lb/hr	DESIGN PRESSURE PSI	FUEL	BOILER APPLICATION	JOB LOCATION
1	40,000	200	Coal	Soy Bean Processing Plant	Marion, Ohio
1	20,000	250	Gas Fuel Oil Coal	Electronics Manufacturing Plant	Charlotte, N. Carolina
2	2,500	30	Coal	School Heating	Spencer, Indiana
1	2,500	150	Coal	Manufacturing Plant	Fortville, Indiana
1	1,500	30	Coal W.T.	University Demonstration	Roanoke, Virginia
1	1,500	30	Coal W.T.	Technical Center	Warren, Michigan
1	20,000	300	Wood	Lumber Mill	Crestview, Florida
1	10,000	150	Coal	Alcohol Distillation Plant	Bardstown, Kentucky
3	50,000	250	Coal Fuel Oil	Food Processing Plant	Napolean, Ohio
3	50,000	300	Coal	Food Processing Plant	Maxton, N. Carolina
1	50,000	150	Coal Fuel Oil	Food Processing Plant	Salisbury, Maryland
9	40,000	150	Coal "Gob"	Rendering Plant	Newbury, Indiana
2*	20,000	300	Coal, Oil Gas	School Heating	Rhode Island
1*	20,000	200	Coal, Gas	Paper Mill	Massachusetts

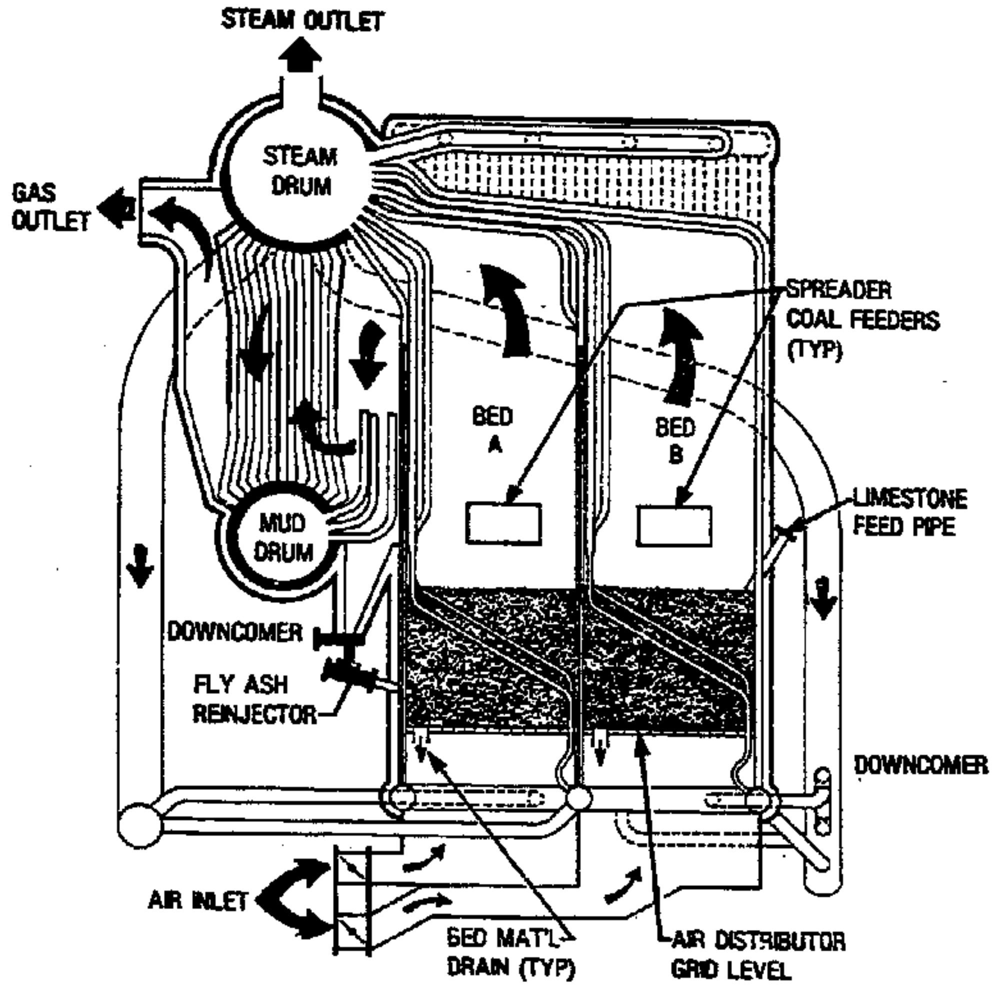
TOTAL - 870,000

* Probable

TABLE 8

Additional FBC Units

Vendor	Capacity lb/h	Pressure psig	Temperature °F	Fuel	Location	Startup Date
Battelle-Struthers	50,000	2,435	80% Quality	Coal	Uvalde, Texas	end, 1981
Curtiss Wright	20,000	200	Saturated	Anthracite Culm	Shamokin, Pennsylvania	fall, 1981
Combustion Engineering	50,000	365	560	Coal	Great Lakes Naval Station (Chicago, Ill.)	fall, 1981
Energy Resources (ERCO)	50,000	2,450	80% Quality	Coal	Maverick County, Texas	fall, 1982
Wormser Engineering	70,000	700	Saturated	Coal	Amarillo, Texas	mid-1982
Wormser Engineering	20,000	200	Saturated	Coal	Lowell, Massachusetts	1983
Pyropower	50,000	2,500	80% Quality	Coal	Bakersfield, California	end, 1982
Babcock and Wilcox	200,000	2,400	1000	Coal	Paducah, Kentucky	spring, 1982



FOSTER WHEELER FLUIDIZED BED STEAM GENERATOR
GEORGETOWN UNIVERSITY
100,000 lbs./hr 675 psig. Design Pressure
Saturated Steam

Figure 1

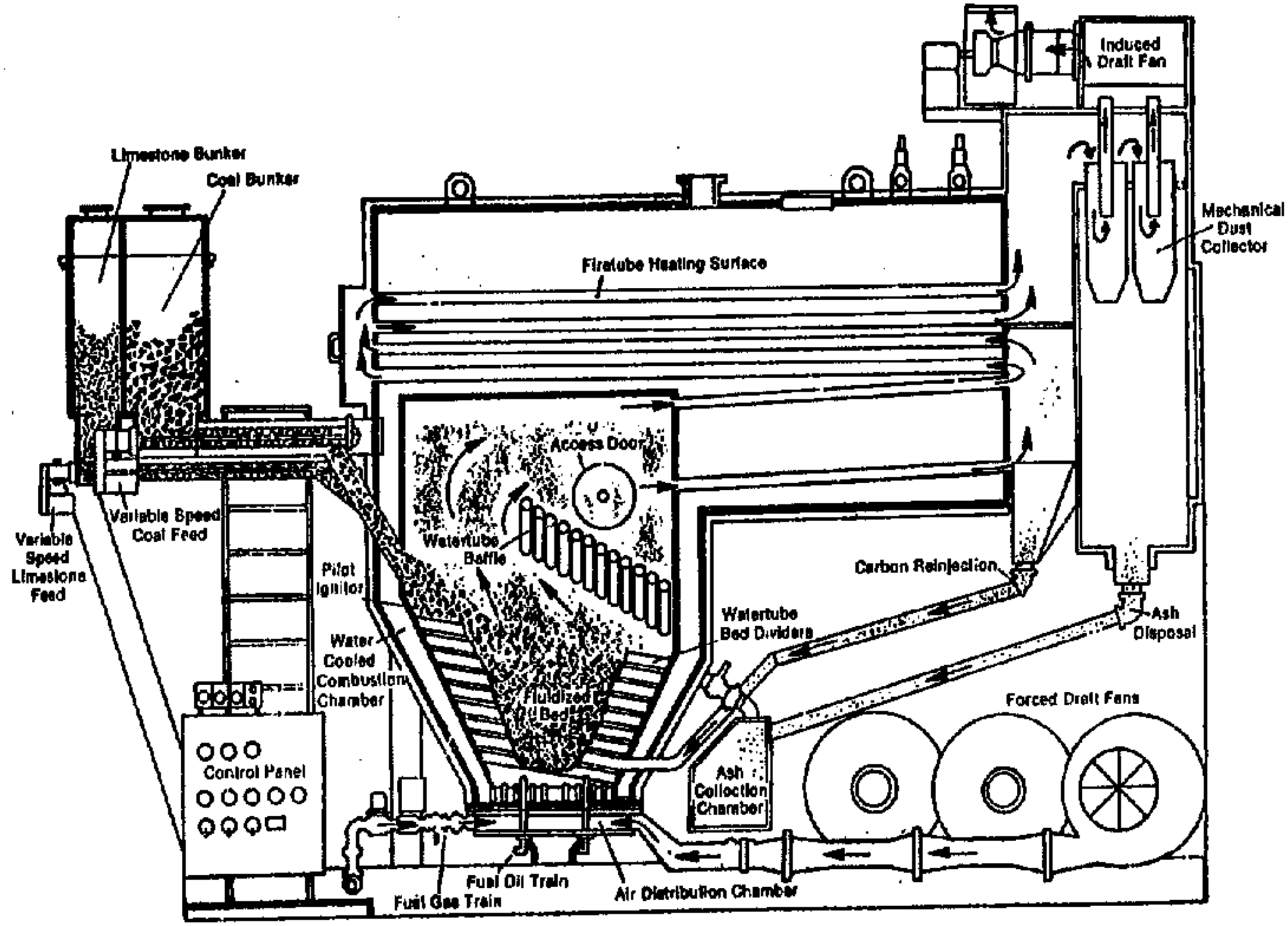
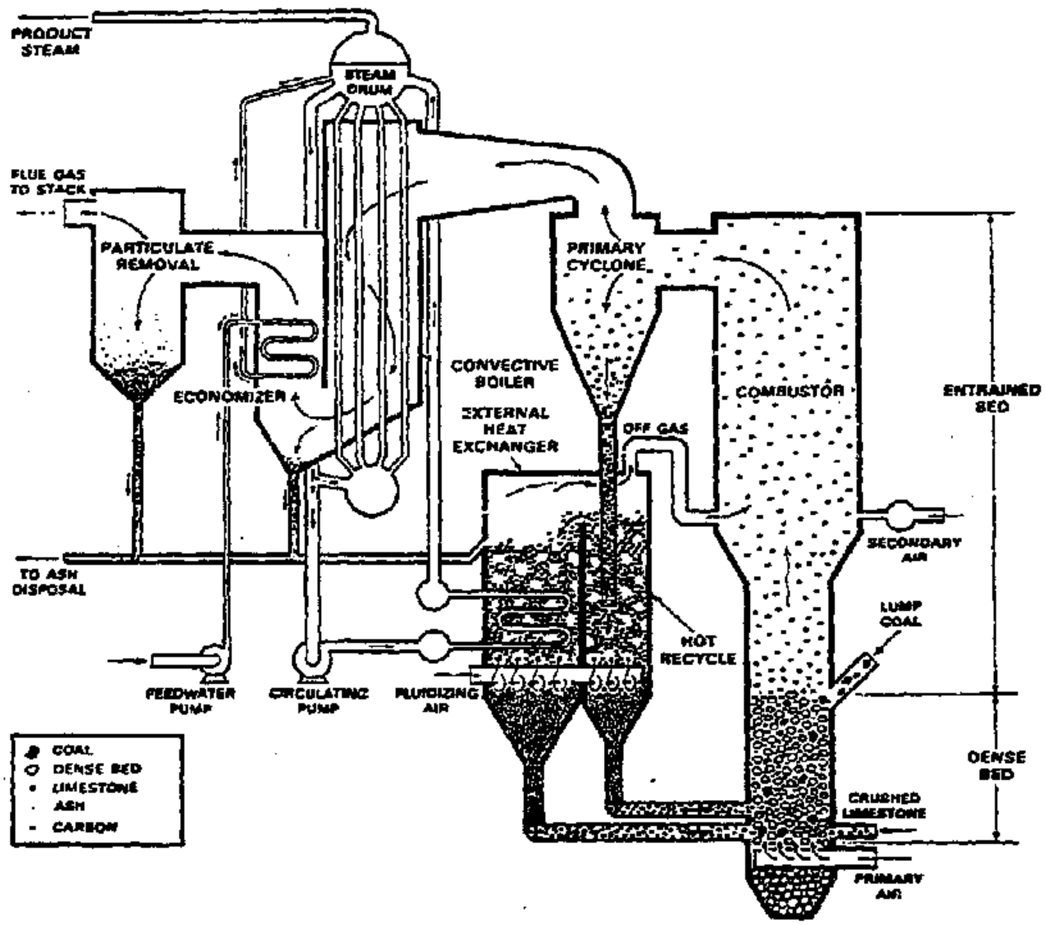


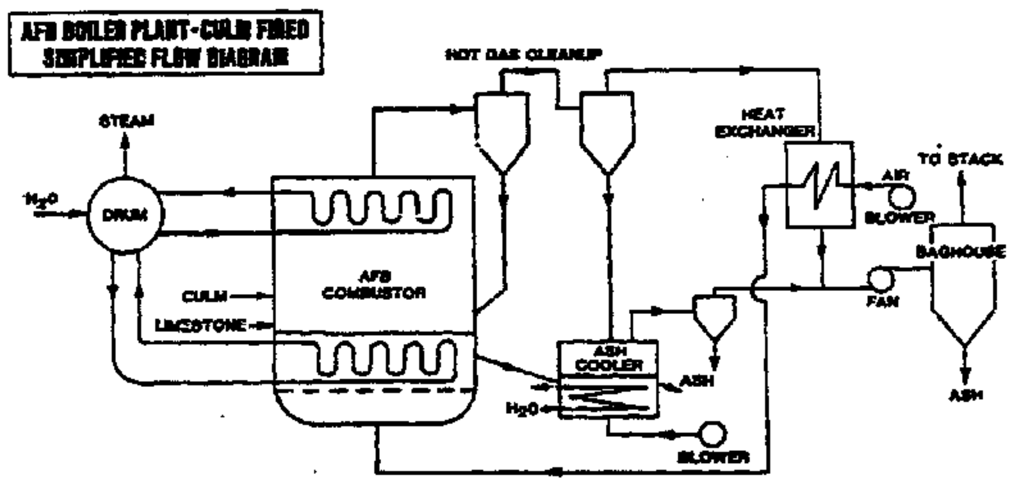
DIAGRAM OF JOHNSTON FLUIDIZED BED BOILER

Figure 2



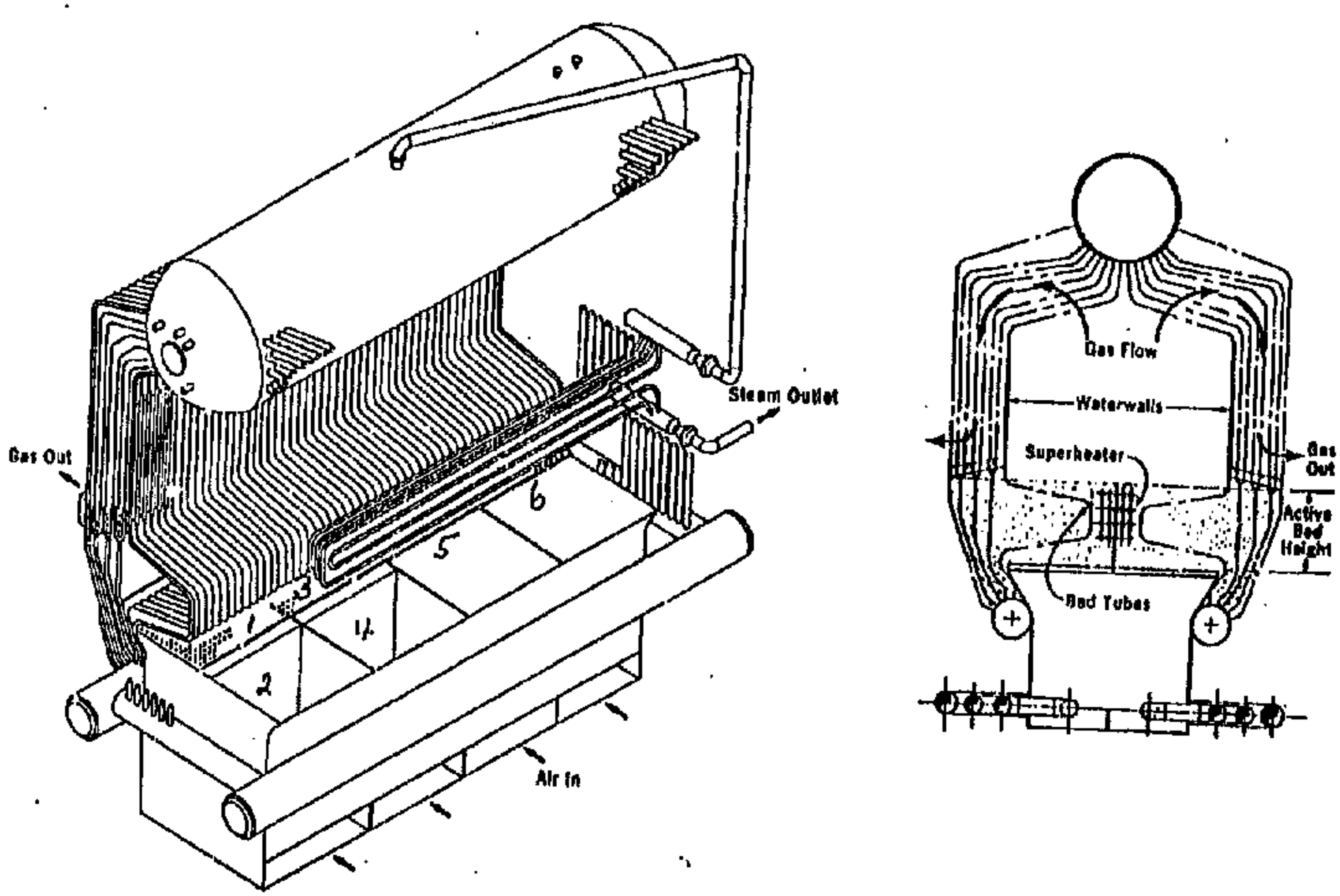
BATTELLE MULTISOLID FLUIDIZED-BED STEAM GENERATOR

Figure 3



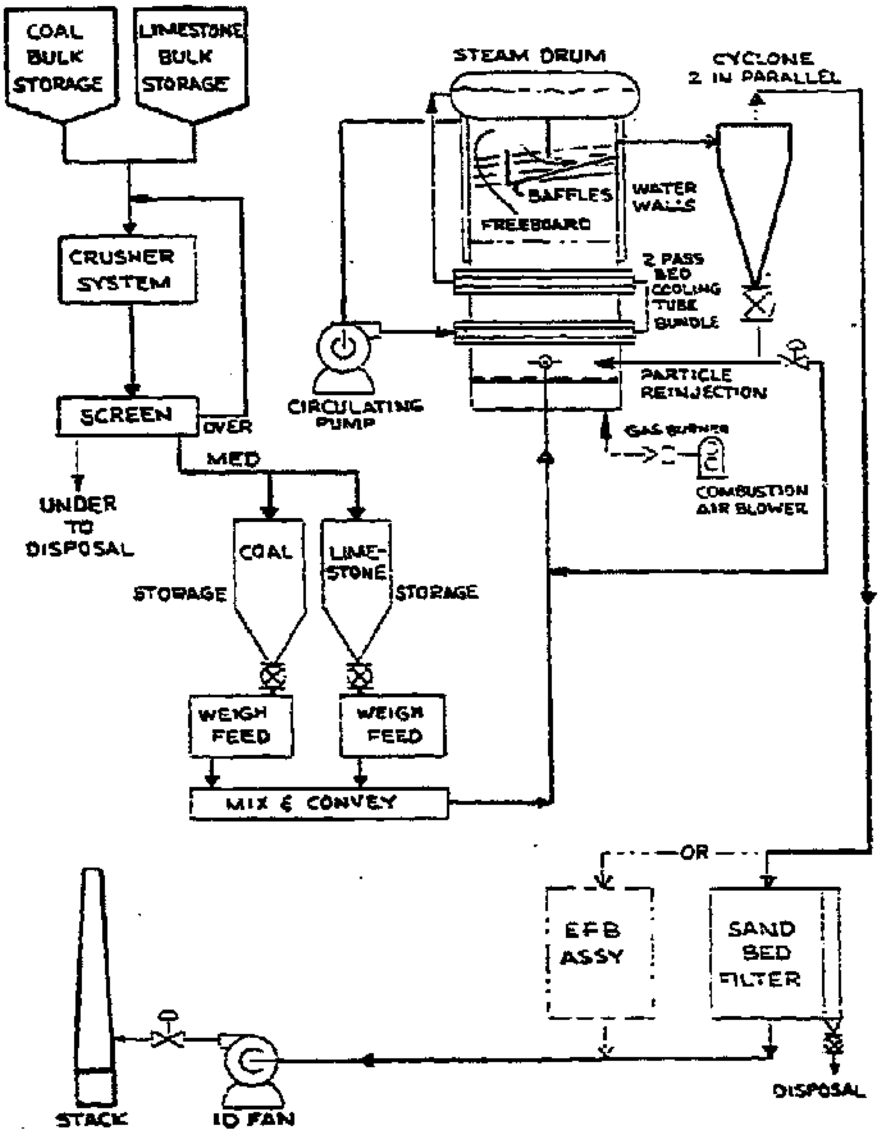
CURTISS-WRIGHT FBC FOR ANTHRACITE CULM

Figure 4



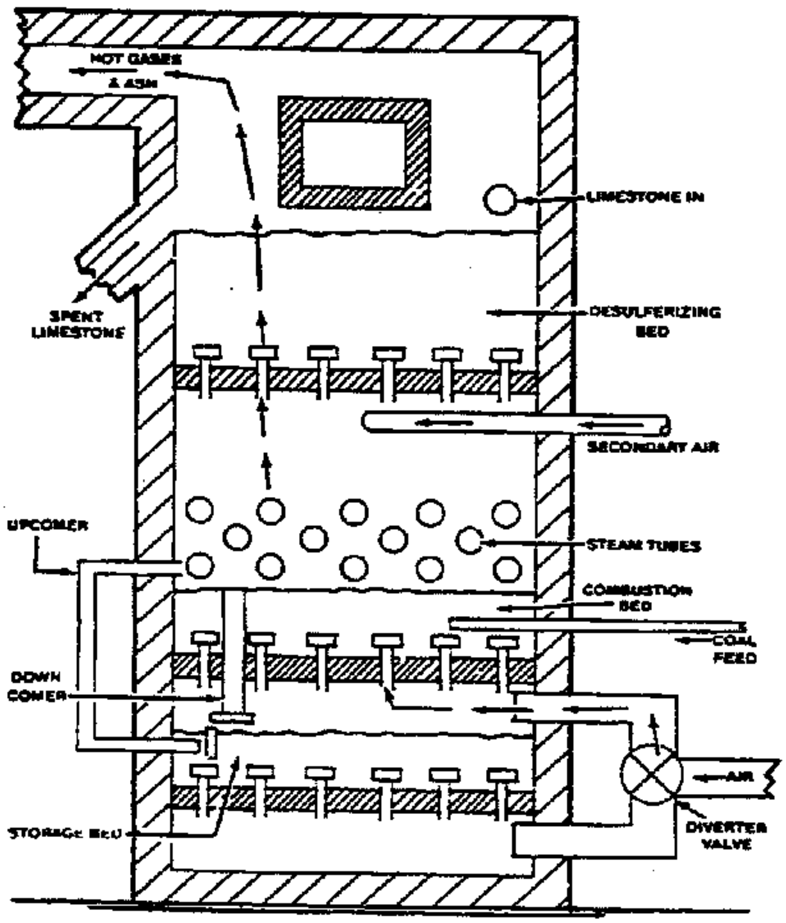
COMBUSTION ENGINEERING FBC BOILER

Figure 5



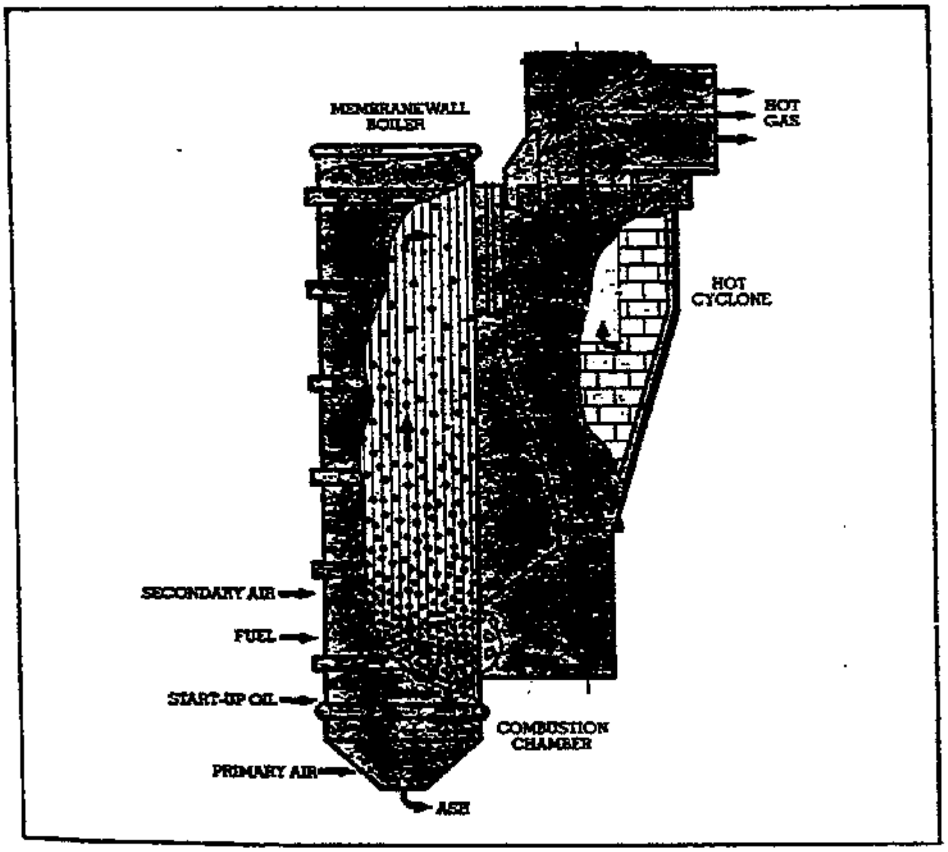
PROCESS FLOW FOR THE ERCO 20,000 LB/HR FLUIDIZED BED COAL COMBUSTION PLANT

Figure 6



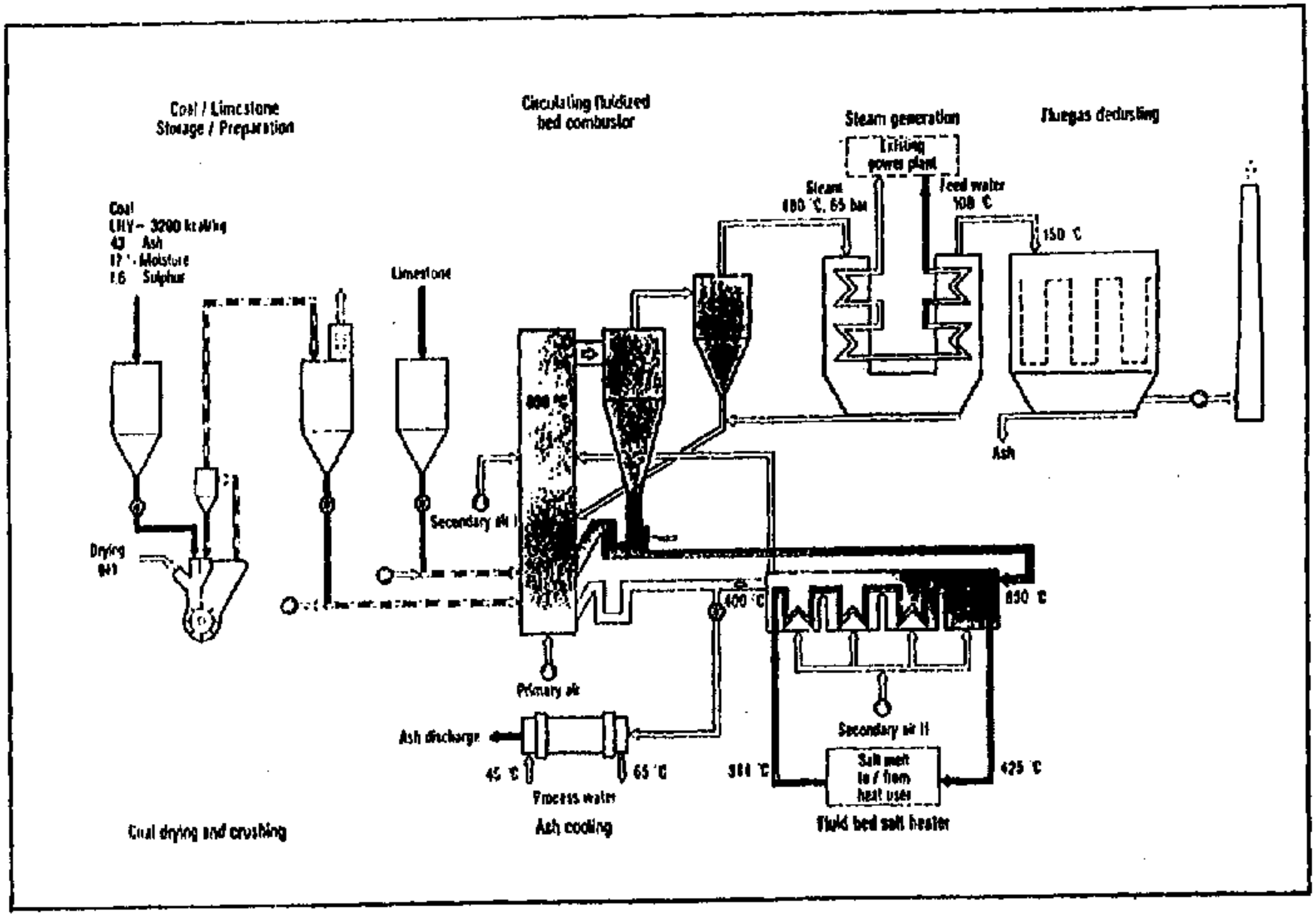
SCHEMATIC OF WURMSER GRATE FBC

Figure 7



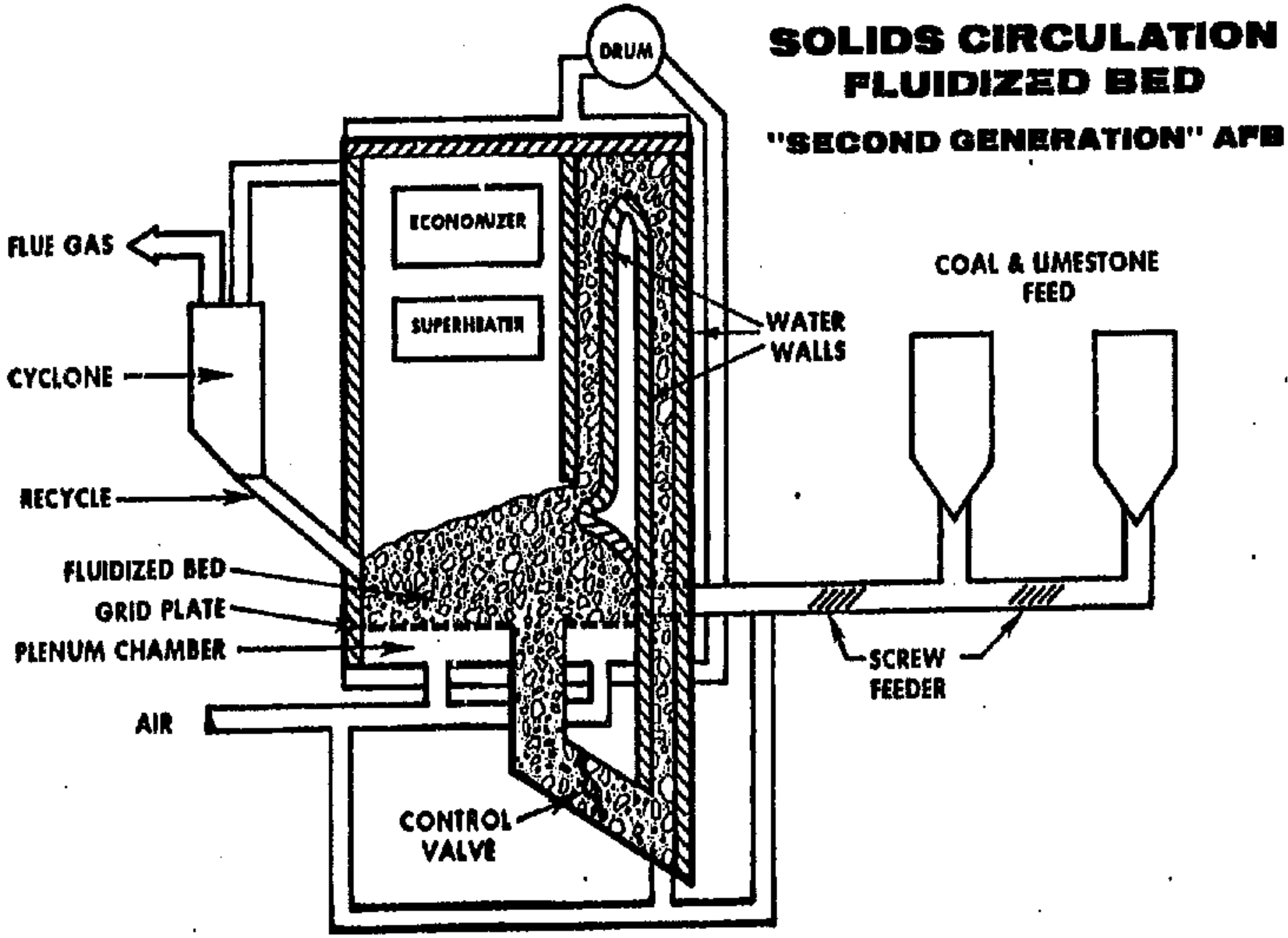
PYROPOWER FBC BOILER

Figure 8



LURGI CIRCULATING FLUID BED FOR
HEATING A SALT MELT AND PRODUCING STEAM

Figure 9



STONE AND WEBSTER SOLIDS CIRCULATING BOILER

Figure 10