FLUIDIZED BEDS — HERE TO STAY AND EXPERIENCING GROWTH EVERY DAY

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Fluidized beds continue their rapid upward growth and acceptance throughout both the industrial and utility sectors and will continue to be the increasingly prevalent answer to our energy needs in the long term. The reason is simple. The fluid bed, after many years of development, has demonstrated its ability to reliably burn the widest range of inexpensive solid, liquid, and gaseous fuels while meeting the most stringent emission requirements and show its attractiveness on a capital cost basis. Typical fluid bed boiler systems have demonstrated payback periods of one to three years, which most customers find attractive. The second generation fluid beds (circulating fluid beds) now on the market have eliminated most and minimized other problems encountered in the earlier bubbling bed designs.

BACKGROUND

The origin of fluidized bed combustion is generally traced to the Winkler gas generator developed during the early 1920's in Germany. In the 1940's the petroleum industry used fluid beds for the catalytic cracking of crude oils. From there it was applied in the steel industry for ore roasting and in waste disposal for incinerating solid, liquid and gaseous wastes. In the late 1950's and early 1960's the National Coal Board in Great Britain studied the technique as an improved method of burning coal. Extensive fluid bed combustion research and development continued in England in the mid 1960's. At the same time, engineers in China, the third ranking coal producing country in the world after the U.S. and Soviet Union, were doing work on fluidized bed boilers to promote the use of locally available, mostly poor quality, solid fuels. China today has over 2,000 fluid bed boilers burning poor quality fuel — low in BTU content and as high as 70% ash. China's FBC boilers have demonstrated the essential characteristics of industrial boilers — operational reliability and economical viability.

The driving force behind burning coal in the United States in a fluid bed was related to the solution to emissions control but has been strengthened by its ability to burn a wide range of low cost opportunity fuels with reduced slagging and fouling versus other alternatives. Stoker-fired units must have fuel sized properly and a limited amount of fines. Pulverized units are sensitive to ash fusion temperature, fuel moisture, ash content, sodium content and volatile content.

It was not until 1970, with the passage of the Clean Air Act, that the impact of the fluid bed's capabilities came to the forefront. With this new found concern for SO_2 and NO_x control, the government's FBC program began to grow. This was further promoted by increased oil and gas prices and the oil embargo of 1973. Fluid bed became the technology to burn a cheaper fuel - coal - and meet NO_x requirements via lower temperatures of combustion and SO_2 requirements via limestone addition directly to the furnace. Expensive downstream scrubbing was thus eliminated. Refer to Figures 1 and 2 which demonstrate NO_x formation sensitive to combustion temperature and that combustion temperature will have little or no impact on the SO_2 generated.

Figure 3 depicts the different temperatures generated by a traditional pulverized coal burner, a low NO_x burner, and AFBC operating temperatures. You'll note that even the significant temperature differences between the combustion processes is not enough to eliminate the formation of SO_2. Thus, AFBC seeks to operate in a temperature regime that maximizes the capture of SO_2 within the bed itself. Figure 4 shows how establishing the proper operating temperature maximizes the sulfur capture and allows good combustion efficiency. It is this combination of low temperature and ability to absorb SO_2 within the combustion process that makes the fluidized bed combustor an exciting and growing technology to meet the needs of future steam generation in an environmentally acceptable manner.

The first generation bubbling beds were used mostly in the 60's and 70's. Second generation circulating bed development stated in the early 70's by Battelle Development Corporation in Columbus, Ohio (licensed exclusively in the industrial and utility sector by Riley Stoker Corporation), by Lurgi in Germany and by Ahlstrom in Finland. They were commercialized in the late 1970's and early 1980's and this is the technology that is most prevalent today. Approximately 100 fluid bed boilers, bubbling and circulating, are sold, under construction or operating in the United States to date. They are burning coal, wood chips and/or sludge. DOE states that accurate numbers are difficult to track exactly since "It has taken off so fast, we don't have the true numbers."

Power, February 1985, reports that there are currently at least 52 companies offering fluidized bed boilers of one form or another for commercial application. The list of 52 organizations represents the combined worldwide market including U.S., European and Japanese efforts.

The offerings range in size from the very small packaged sizes as small as 2,000 pph to sizes up to 1,100,000 pph. The 52 obviously all feel they have a market to compete in. It clearly demonstrates that "everyone wants to get into the act" as this technology continues to grow. Some suppliers will concentrate on smaller packaged units, others on larger units, some in the industrial areas, others in the utility sectors. There are suppliers offering only bubbling beds, while others are offering circulating beds. Certain suppliers will even try to find their niche with specific opportunity fuel(s). Whatever your application, it will not be as difficult as choosing 1 out of 52. Most likely there will be only a few that might meet your requirements. You then must decide which one fits your requirements best from a technical and economic standpoint. The first decision you must make, however, is whether to *choose fluid bed* as the technology you need.

FLUIDIZED BED SYSTEM - DEFINITION AND GENERAL PROCESS DESCRIPTION

In fluidized combustion, fuel is injected and burned in a "fluidized bed" of particles. These particles consist of combustible particles, limestone, sand and other inerts. These solid particles are suspended in a high-velocity air stream passing upward from below, causing turbulence and rapid mixing of the particles. The surface is no longer well defined and bubbles of "gas" similar to those found in a boiling liquid rise through the bed. A bed in this state is said to be fluidized. The fluidizing air activates the bed to provide the time, temperature and turbulence required for efficient combustion.

Gas or oil preheat burners warm the bed to between 1000 and 1300F. This depends on the type of fuel fired as well as the combustor manufacturer. When at the desired temperature, the burners shut off and the fuel is added, either above or below the bed to maintain combustion. Temperature is maintained normally between 1500 to 1600°F. This temperature has been shown to maximize the reaction between limestone and sulfur dioxide released during coal combustion; the two combine to form calcium sulfate (gypsum). Also this temperature is below the creation of most nitrogen oxides and lower than the ash softening temperature which minimizes the possibility of slag formation and fouling.

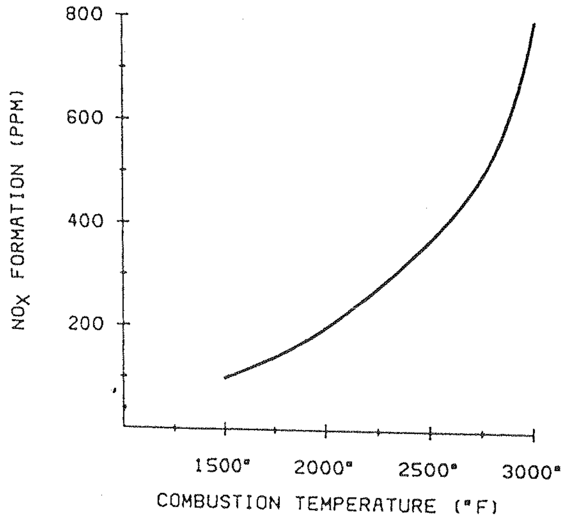


Figure 1

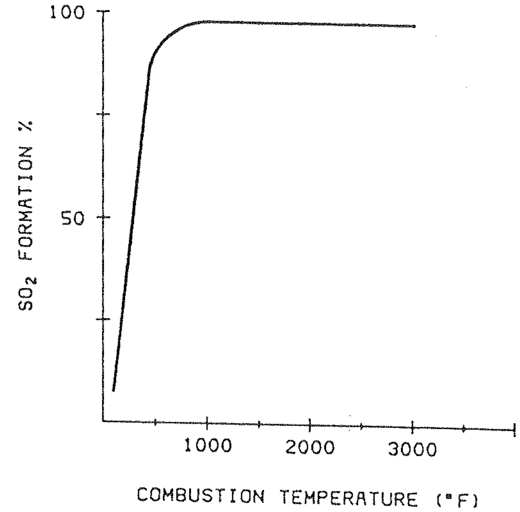


Figure 2

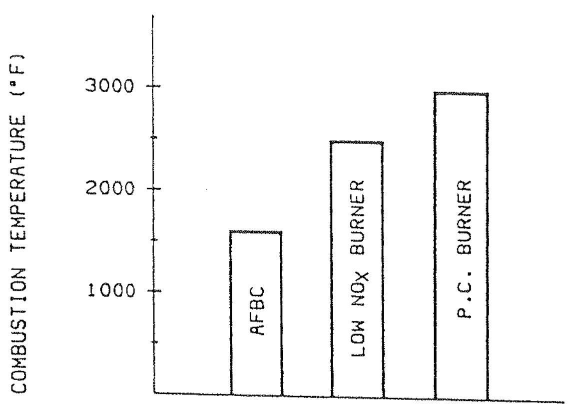


Figure 3

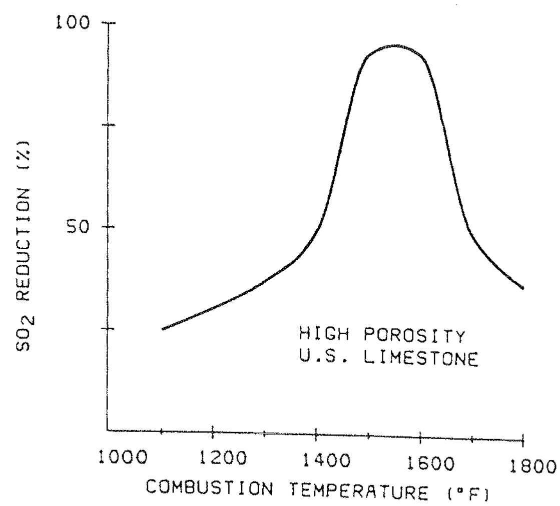


Figure 4

The bed media act as a massive heat sink, and temperatures can be controlled to within a few degrees. Heat transfer from the particles to the tubes or walls is rapid, but due to turbulence heat transfer from the particles back to each other is also rapid to maintain overall bed temperature.

Heat transfer is divided into two major categories, traditional gas to steam and the newer concept of solids to steam. Solids heat transfer occurs in several ways. Heat can be transferred to in-bed tubes, via an external heat exchanger or to heat exchanger tubes in the freeboard area above the combustion area. The remaining steam is created in waterwalls, a conventional boiler or waste heat boiler.

Particulates are usually collected via a cyclone downstream of the combustion and sent back to the combustor. Final particulate cleanup is usually accomplished via a baghouse or sometimes an electrostatic precipitator (Europe), prior to discharge to the stack similar to a conventional boiler system. See the attached Figure 5 showing the "Process Description" of the Battelle Multi-solid Fluidized Bed Combustor.

Process Description

MSFBC is the only system which has large dense bed material and find entrained bed material, hence the name "Multisolid" (Figure 5). The entrained bed material absorbs heat as it passes through the combustor and the recycle rate is established to control the combustor temperature. The entrained solids are separated from the flue gases by high efficiency primary cyclones and flow into the External Heat Exchanger (EHE).

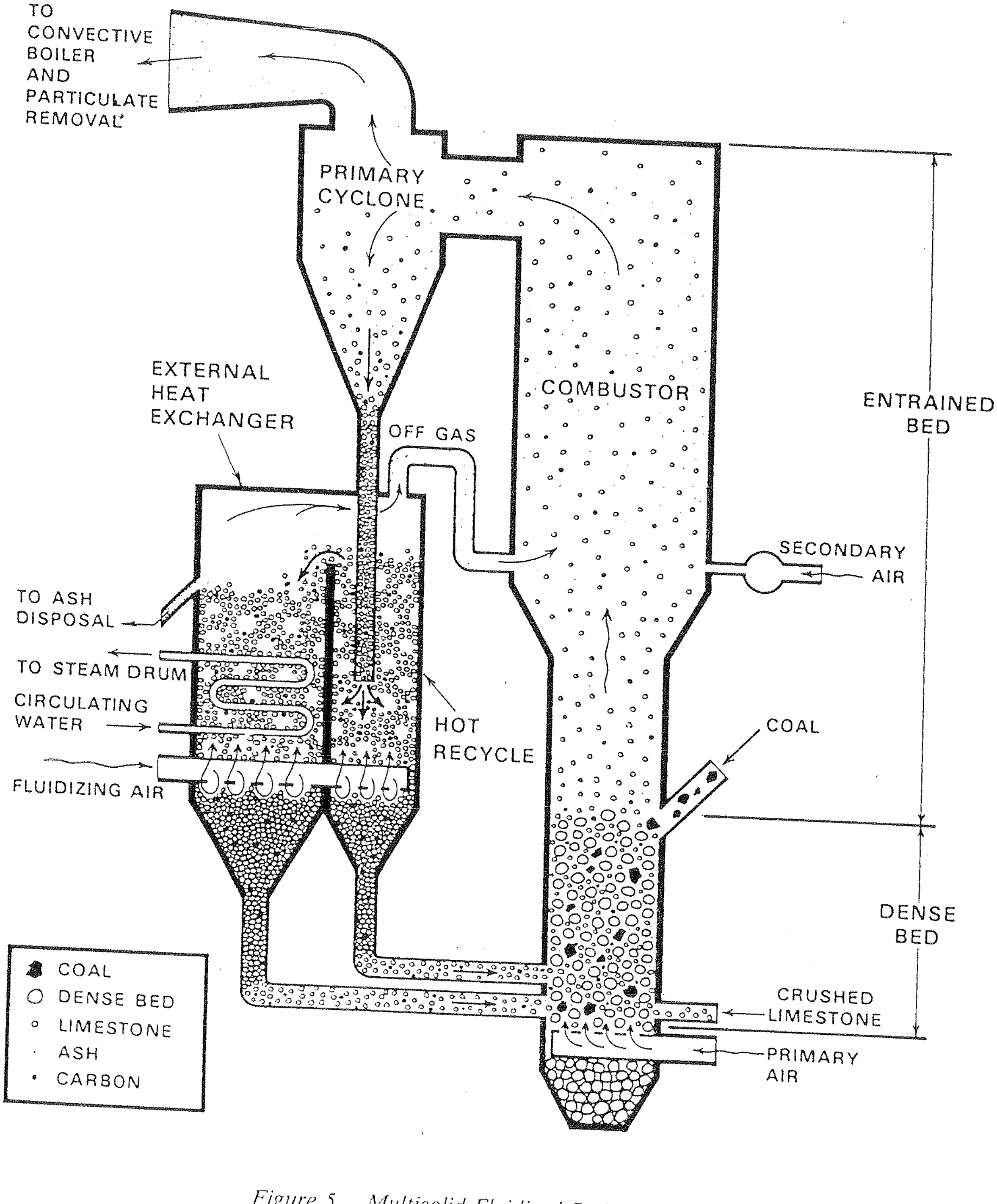


Figure 5 Multisolid Fluidized Bed Combustor

TYPES OF FLUIDIZED BEDS

Fluidized beds are classified according to two main process variables.

a. Pressure

b. Fluidizing air velocity

The first classification breaks fluid beds into either pressurized fluid beds (PFB's) or atmospheric fluid beds (AFB's). Pressurized units operate as high as 175 psig in the combustor. Atmospheric units operate essentially at atmospheric pressure. During the 1970's both received attention from a technical standpoint. Pressurized units are aimed at large utility units and encountered developmental problems during the 1970's. These units theoretically increase efficiency and reduce the size of units for a given output.

This technology is beyond the scope intended here, but suffice it to say that its development is possibly at least ten years behind the AFB's.

The classification of types of AFB's can be further broken down into bubbling beds, circulating beds and the multisolid fluidized bed (combining bubbling with circulating fluid beds).

In distinguishing between the three types of atmospheric fluidized beds, refer to Figure 7. The basic difference between the bubbling bed and circulating bed is related to the gas velocity within the combustor. Note in Figure 7 the "classical fluidized bed" or bubbling bed was intended to be designed so that particles would remain in the combustor (similar to a stoker). Consequently, a maximum gas velocity of 8-10 ft/sec had to be used along with particle reinjection rates of almost 90% to achieve combustion efficiencies required. Since heat transfer within the bed was approximately three times the rate for the convection section of boilers, heat transfer via in-bed tubes was used and load response was usually controlled by adjusting the bed height. Erosion and corrosion of in-bed boilers as well as scale-up problems were quickly demonstrated with these first generation units when applied to conventional power plant applications in the industrial and performance ranges.

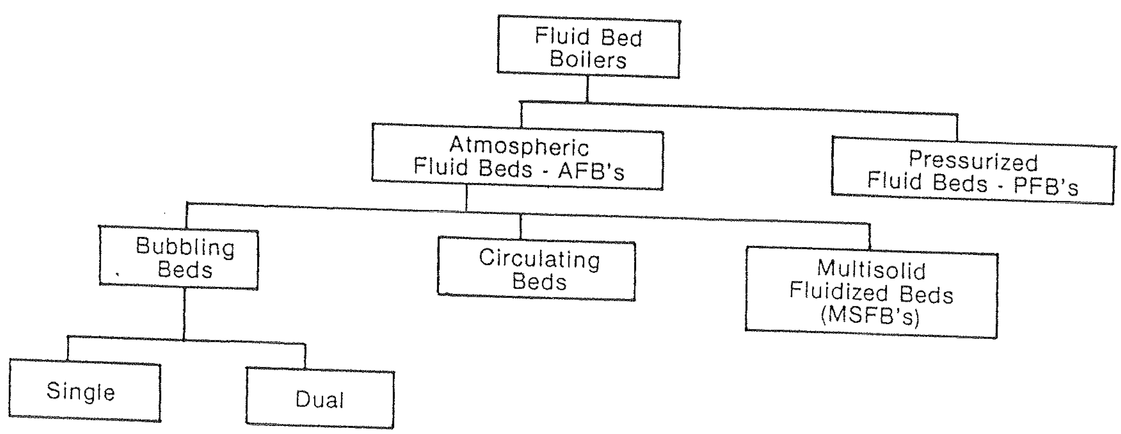


Figure 6 Types of Fluid Beds

Another adaptation of the bubbling bed design is a dual bed design as shown in Figure 8 separating combustion of coal in the lower bubbling bed at higher temperatures and desulfurization in the upper bubbling bed and using its economy of size retrofit existing oil and gas fired boilers. Problems that may be encountered are all those connected with the bubbling bed design with additional complications (twofold!). Steps taken to lower NO_X via lower uniform temperatures for combustion in the latest circulating bed designs is not utilized here. Consequently, NO_X levels may not be optimized in the system.

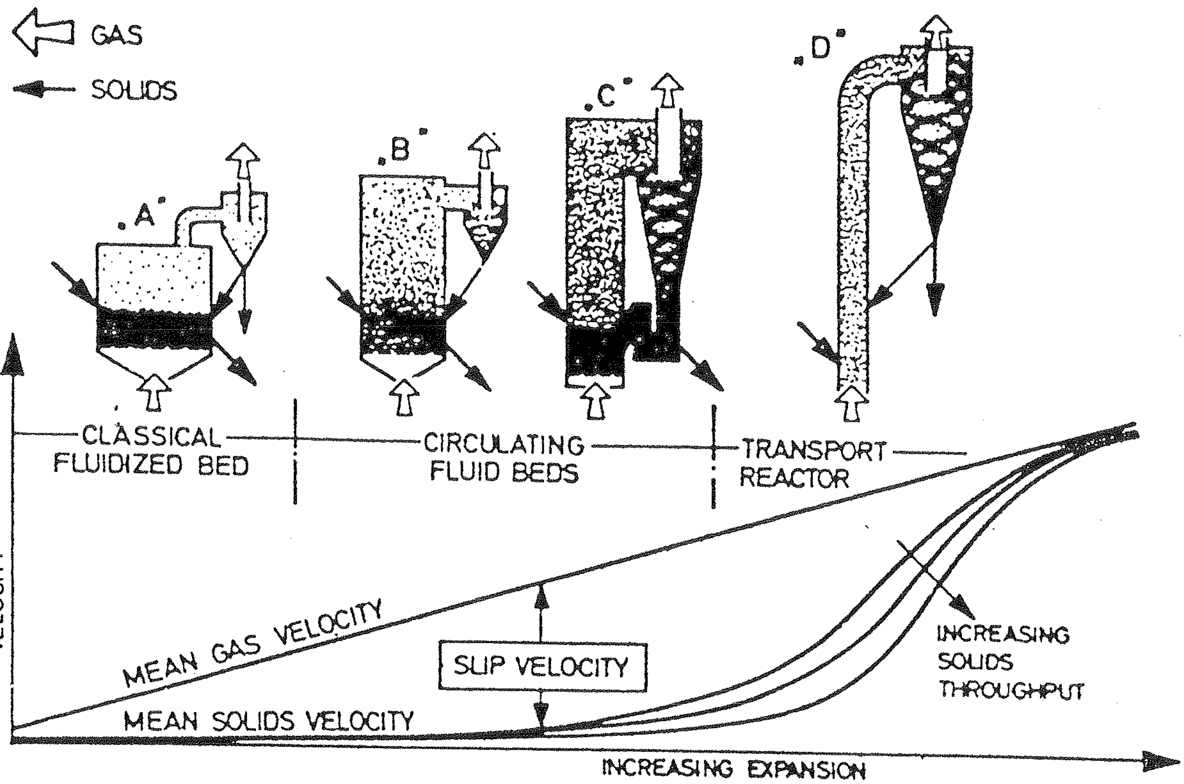


Figure 7

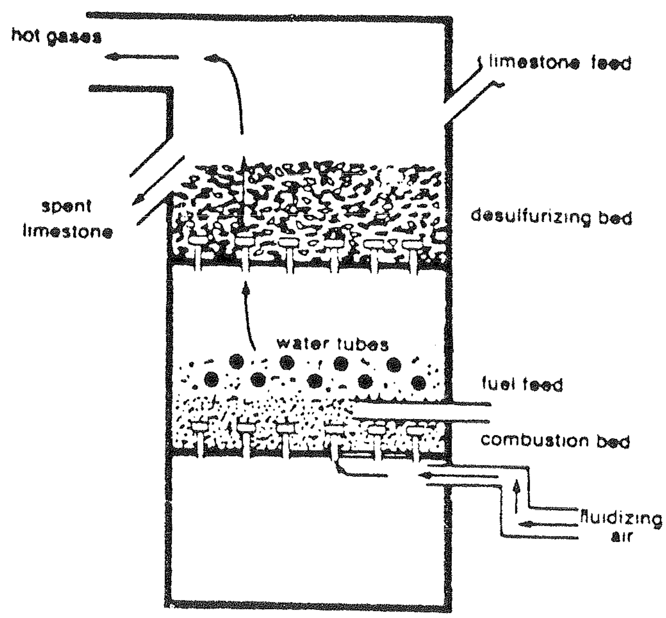


Figure 8 Dual Bed Unit

To overcome the inherent problems associated with the bubbling bed units, a second generation of fluid beds were developed in the early 1970's and which emerged in commercial operation in the late 1970's and early 1980's were the circulating fluid beds and the multisolid fluidized bed systems. The pioneers in this endeavor were Battelle in Columbus, Ohio; Lurgi in Germany and Ahlstrom in Finland.

Battelle's technology of the MSFB (Multisolid Fluid Bed) is marketed via licenses with Riley Stoker Corporation for industrial and utility steam applications and Struthers Wells for the enhanced oil recovery applications (Battelle also licenses Foster Wheeler Power Products in England for applications in Europe and Riley sublicenses Mitsui Engineering and Shipbuilding for Japan and several Asian countries. Pyropower markets Ahlstrom's system in the U.S.; CE and Lurgi have a joint venture in the U.S.

Refer once again to Figure 5 and note that when we move out of the bubbling bed range of 6 to 10 ft/sec up to typical circulating bed velocities of 15 to 20 ft/sec, we see little changes in the solids velocity to a certain point. What that means is the residence time in the combustor will be maintained as we go up in velocities to a point where the mean solids velocity starts to increase. Once this starts to increase, we then start losing residence time resulting in poorer SO_2 capture and poorer carbon utilization. This is typical of the Pyropower and Lurgi designs. This maximum velocity is usually around 20 ft/sec. The Multi Solid Fluid Bed design, as developed by Battelle, combines the concepts of bubbling bed and circulating bed. Refer to Figure 9 which shows the system of superimposing a bed of dense material on an entrained bed. The dense bed of larger particles operates as a bubbling bed to hold down the entrained bed creating tremendous turbulence and excellent distribution in the lower part of the combustor. It allows the system to operate further towards the transport mode velocitywise (i.e. along the line of the the high combustion efficiency achieved with pulverized coal firing). Typical velocities are upward of 30 ft/sec and with a dense bed there is no decrease in residence time over other circulating bed technologies. See Figure 10.

Load response, in these second generation designs, is controlled by velocity change, fuel content in the mass and/or by passing the hot material around the heat transfer surfaces.

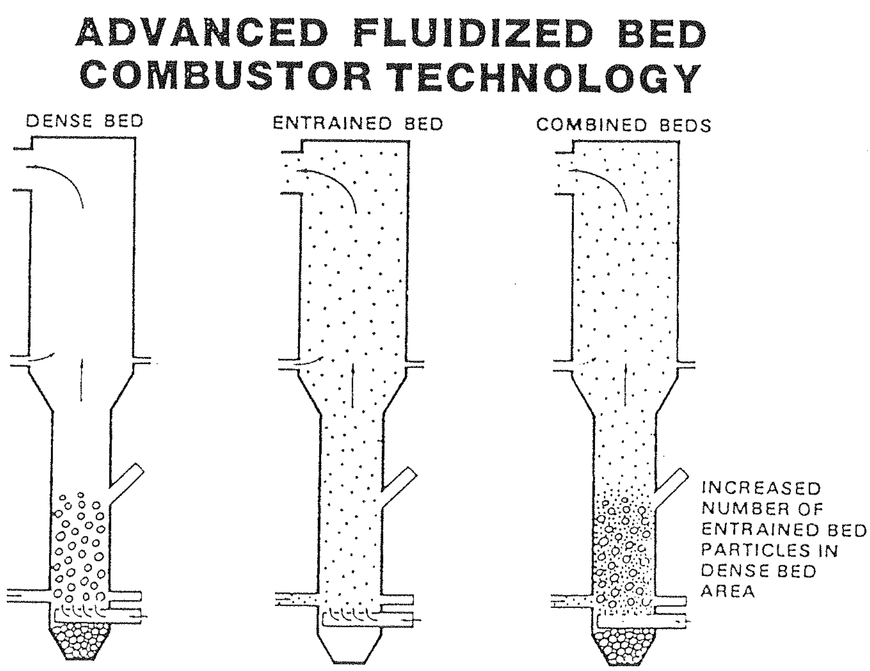


Figure 9 MSFB Multi Solid Fluid Bed

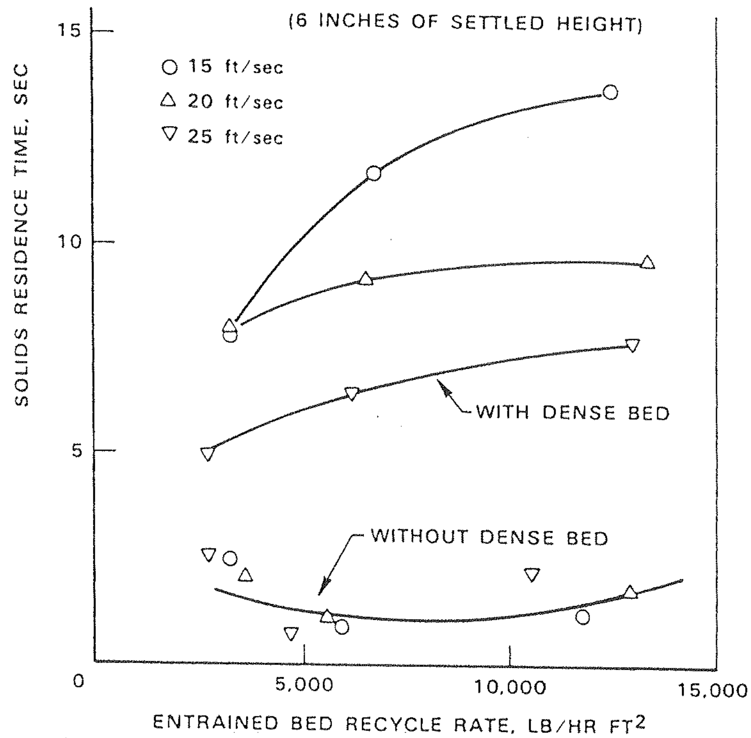


Figure 10

WHY DO I WANT A FLUIDIZED BED?

The first decision you as a user must make is why do I need and/or want a fluid bed for my application.

The following offers several reasons usually provided for choosing fluid bed over the alternates of stoker and pulverized systems:

- More than any other type of combustion system, FBC systems are flexible in their ability to burn practically any combustible material.

  Material and fuels which have been successfully burned in FBC units include:

Coal of all types	Natural gas
Pelletized wood wastes	#2 & #6 oil
Pelletized paper wastes	Peat
Sawdust	Asphalt shingle wastes
Shredded rubber	Petroleum coke
Industrial waste oils	Oil shale
Anthracite culm	Fruit pits
Wood chips	Rice hulls
Alcohol mash waste	Sewage sludge
Paper mill sludge	Municipal refuse
Carpet wastes	Coal washing wastes
Biomass wastes	Sulfur-laden waste gases
Vegetable composts	Paint sludges
And others	Industrial wastes

  Because of its abundant availability, coal will ultimately have the greatest application for FBC utilization.

- Range of fuel variations rule of thumb can be taken as follows:
  - a) ± 5 to 10% Pulverized firing
  - b) ± 10 to 15% Stoker firing
  - c) ± 25 to 30% Fluid bed
- The range on fuels has been shown with fluid beds to handle
  - a) Moisture nil to 80%
  - b) Ash nil to 90%
  - c) Heat values from 500 to 15,000 Btu/lb
- PC can handle other liquids and gases, stoker other solids but fluid bed can handle all fuels with minimal effect on efficiency and output.
- Fluid beds have a solid waste product which is easier to dispose of in landfill or can be used as roadbed material or construction material as well as other uses.
- Due to lower temperature and better distribution in a fluid bed you have:
  - a) Much improved NO_x control
  - b) Minimal fouling and slagging potential
  - c) Thermally homogenous combustion - Lower potential for local hot or cold spots
  - d) Prevented vitrification of the ash particles, causing them to be less abrasive than ash from stokers or PC fired units
- Meet stringent SO_2 emissions without expensive downstream scrubbing equipment
- Heat transfer 4 to 6 times greater than radiative or convective heat transfer - Boiler volumes can be reduced
- Better load response
- Turndown - Below 50% PC generally needs supplemental fuel - With stoker 4 to 1 achievable - with fluid bed 4 to 1 or better
- A much smaller furnace volume since extra furnace volume is not required to allow ash to cool below its softening temperature before flow through convective heat-transfer surfaces
- Heat retention in bed allows fast restart
- Manpower - more maintenance required on PC and stoker than fluid bed
  - more operators needed for stoker due to scrubbing equipment
  - operators require more training for PC units
- More auxiliary equipment required with PC units - pulverizers, deslagging equipment, etc.

Once a fluid bed is chosen, reasons for choosing circulating fluid beds over conventional bubbling beds are:

- High turbulence and gas solids mixing, strong solids backmixing and continuous solids recirculation all help promote uniform combustor temperature and high combustion efficiency (carbon utilization) about 99% vs. 95% in bubbling beds
- Smaller plan area since unit operates at higher velocity
- Since operating at higher velocity, they require fewer feed points and, lateral distribution is improved

- For high sulfur fuels the limestone requirement is less due to increased residence time with circulating beds. Limestone has been shown to be 40 to 60% of bubbling bed requirement.
- No in-bed tubes for heat transfer in the combustion zone which caused erosion problems with bubbling beds.
- Thermal efficiency 2 to 3% higher
- Load change of 5 to 10% per minute
- More easily staged to limit NO_X
- Increased flexibility in turndown and load following since restarting on bed slumping is not required
- Circulating beds are capable of 2 to 3 times the fuel throughput per unit base area due to higher combustion air velocities

Reasons given by customers choosing the MSFB (Multi Solid Fluid Bed) once they have decided on circulating fluid bed are:

- Fuel range characteristics and sizing is wider with the MSFB due to the combination of the bubbling bed and circulating bed (dense bed)
- Sorbent range characteristics and sizing is wider with the MSFB due to the combining of the bubbling bed (dense bed) and circulating bed
- More choice of "opportunity fuels" which improve operating economics
- Less crushing and drying required of fuel and sorbent means lower first cost, less horsepower usage, and less complicated handling equipment
- Higher velocity due to presence of dense bed allows better distribution laterally while still maintaining the same or higher residence time
- External heat exchanger as a gently fluidized bed provides the high heat transfer while minimizing erosion and corrosion of tubes in higher velocity environment
- Higher turndown achievable with the MSFB. Better than 6 to 1 achievable

Early applications of AFBC demonstrated its ability to burn fuel in an environmentally acceptable way with adequate combustion efficiencies. This basic AFBC process evolved into several design types - ranging from a bubbling bed with its low velocities and high freeboards, to a dense phase recirculation of solids to enhance retention time and carbon burnout. Figure 11 shows the AFBC types with their respective design criteria.

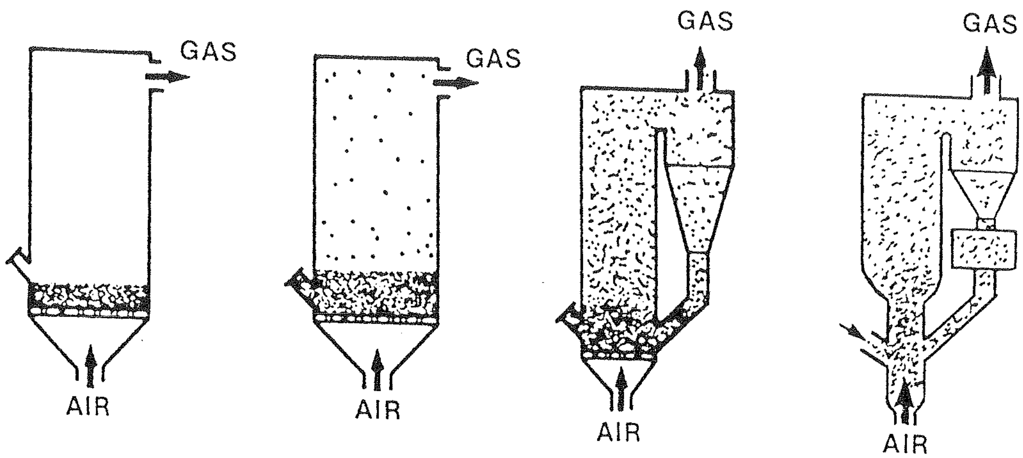
ECONOMICS

Initial capital investment for fluid bed units and associated fuel handling equipment is higher when compared to gas or oil systems. However, the pay back period is usually 1 to 3 years since gas and oil is three or four times more expensive on a dollars per million Btu basis.

Cost comparisons with stoker or pulverized systems depend on fuel characteristics. Low sulfur coal firing, not usually requiring scrubbing is less expensive than FBC systems. High sulfur coal (more than 3 percent) installations needing scrubbers to meet local air pollution standards cost about the same as FBC equipment. Buying low sulfur coal may be 3 times more expensive than high sulfur fuel which is readily available in certain areas of the country. Facilities with large amounts of combustible waste also find fluidized bed systems economically attractive.

Refer to Tables I, II, III attached which show general cost comparisons on a first cost installed basis and also operating costs. In two to five years as more experience is gained on circulating fluid bed systems we will find that the FBC systems will be competitive to boilers without scrubbers, since capital costs, operating costs as well as maintenance costs are, in general, higher than for other systems versus an FBC system.

The cost of an FBC system depends on size, steam pressure and temperature, fuel type field erection vs. shop fabrication and other factors. The installed capital cost of the fluid bed combustion unit, superheater, convection bank, economizer, air preheater will generally cost $25 to $35 per lb. of steam produced per hour. Fuel handling, sorbent handling, ash handling and auxiliaries all need to be added to the above. Bubbling beds and conventional CFB units require extensive fuel and sorbent crushing and drying not needed with an MSFB.



	STOKER	BUBBLING	CIRCULATING	MSFB
FIREBOARD HEIGHT	8-10 FEET	10-20 FEET	30-60 FEET	30-60 FEET
SUPERFICIAL VELOCITY	4 FPS	8 FPS	15 FPS	30 FPS
EXCESS AIR	20-25%	20-25%	10-15%	10-15%
Ca/S RATIO	N.A.	3:1	2.2:1	2.2:1
COAL SIZE	1-¼″ × ¼″	¼″ × 0	½″ × 0	2″ × 0
TURNDOWN	4:1	3:1	3:1	6:1
COMBUSTION EFFICIENCY	85-90%	90-95%	99%	99%
NO_X EMISSIONS	400-600 PPM	300-400 PPM	100-200 PPM	100-200 PPM
SO_X CAPTURE	N.A.	80-90%	90+%	90+%

Figure 11 Comparative Design Criteria

RELATIVE INSTALLED COSTS
125,000 lb/hr BOILER (± 30%)

TYPE	COST
STOKER	BASE
STOKER	1.7
DEEP BED	1.7
BUBBLING BED	1.6
CIRCULATING	1.6
2-STAGE PROCESS	1.6

Table I

RELATIVE OPERATING COSTS
125,000 lb/hr BOILER (± 30%)

TYPE	COST	
	Horesepower	Fuel
STOKER	BASE	BASE
STOKER WITH SCRUBBER	1.50	1.00
DEEP BED	1.10	1.00
BUBBLING BED	1.15	1.00
CIRCULATING	1.15	.80
2-STAGE PROCESS	1.25	.80

Table II

ECONOMIC CONSIDERATIONS

- COMPETITIVE TO BOILERS WITH SCRUBBERS
- COMPETITIVE TO BOILERS WITHOUT SCRUBBERS IN TWO TO FIVE YEARS

Table III

ENVIRONMENTAL EMISSIONS

NSPS VERSUS AFB

(1lb/MBtu)

POLLUTANT	EXISTING UTILITY NSPS[1]	EXISTING INDUSTRIAL NSPS[2]	PROPOSED INDUSTRIAL NSPS[3]	AFB EMISSIONS
NO_X	.6	.7	.7	.2-.5
SO_X	REDUCTION OF 70% 90% AS MINED WITH MAX. OF 1.2	1.2	PROPOSAL PENDING	.7-1.2
PARTICULATE	.03	.1	.05 (W/O FGD)	.01-.05

[1]250 MBtu/HR AND GREATER
[2]250 MBtu/HR AND GREATER
[3]100 MBtu/HR AND GREATER

Table IV

EXPERIENCE

Fluid bed technology has become an acceptable and reasonable solution to production of energy in the form of steam and electricity and will continue to grow. The key is the ability to burn essentially all fuels and to meet the most stringent emissions requirements. We previously discussed the multitude of fuels emphasizing the coals that can and will be burned due to the abundance of these fuels. Other fuels not mentioned also have been burned either alone or in conjunction with other fuels in various tests. Often, there is not enough of these particular fuels to burn alone but they can all be burned in conjunction with other fuels. The fluid bed in general and MSFB in particular is very forgiving and a multitude of fuels can all be burned simultaneously. The important point to remember is that the fluid bed is designed optimally to burn a specified fuel or fuels and, consequently, you should provide the potential vendor with as close as possible a mix for his design calculations. Municipal solid waste, sewage sludge, hazardous wastes, shredded tires, RDF, industrial wastes. paint sludges can and have been burned in a fluid bed, but the key to remember is to burn cheap fuel(s) and produce the steam or electricity required.

Attached in Table IV from the DOE shows "Environmental Emissions". Note how well the AFB's do at meeting emission requirements.

The growth is being seen in the U.S. in both the industrial and utility sectors. In the industrial sector there has been activity in the automotive, pulp and paper, food industry as well as chemical and petrochemical.

Remarkable progress has been made in 15 years since 1970. As we saw above, the U.S. was slower getting started due to an abundance of premium fuels.

Key milestones in the U.S. fluid bed installations are shown in Table V.

Year	Project	Type Fluid Bed	Description
1976	Rivesville	Bubbling Bed	30 MW DOE Utility Demo Unit. First commercial size, multicell AFB - 300,000 lbs/hr firing coal
1979	Georgetown University	Bubbling Bed	100,000 lbs/hr funded by DOE Steam requirements for heating and air conditioning. High sulfur coal in environmentally acceptable manner. (See Figure 12)
1981	Shamokin Area Shamokin, PA	Bubbling Bed	23,400 lb/hr burning anthracite culm. Process steam sold to papermill.
1981	Northern States Power	Bubbling Bed	First utility retrofit
1981	First Circulating Fluid Bed	Circulating Fluid Bed	Conoco, Uvalde, Texas 50 MM BTU/hr First circulating fluid bed in U.S. was of the MSFB (Multi Solid Fluid Bed) design developed by Battelle and licensed to Struthers Wells for enhanced oil recovery applications. Also licensed to Riley Stoker for industrial and utility steam applications. It burned five different coals including high ash coal plus a petroleum coke with high sulfur content. Demonstrated ability to meet California emission standards. (See Figure 13)
1982	TVA 20 MW Utility	Bubbling Bed Demo Unit Demo Unit	First large scale high pressure and temperature utility service demo unit
1984	TVA 160 MW Demo Unit (B.B.)	2 Bubbling Beds 1 Circulating Bed	Three major utility commitments
	Northern States Power Black Dog Unit (B.B.)		
	Colorado Ute Circulating Solids		First Utility circulating fluid bed
1984	Scott Paper Company	Circulating Bed	Largest single industrial unit committed. 650,000 lbs/hr to burn anthracite culm.

Table V Major U.S. Milestones

Year	Project	Type Fluid Bed	Description
1984	ADM (Archer Daniels Midland)	Circulating Bed	Largest total capacity Order 4 @ 425,000 lbs/hr Order 2 @ 477,000 lbs/hr Burning bituminous coal
1984	General Motors	Circulating Bed	General Motors purchased 3 units during 1984 to burn bituminous coal. Also future industrial waste and paint sludge will be burned in these units. Two by Riley Stoker for Fort Wayne @ 150,000 lbs/hr each (see Figure 14) and one by another supplier for Pontiac @ 300,000 lbs/hr.
1986	General Motors	Circulating Bed	First circulating fluid beds in the automotive industry will be started up by Riley Stoker Corp. at General Motors in Fort Wayne, Indiana. (See Figure 14)

Table V Major U.S. Milestones (cont'd)

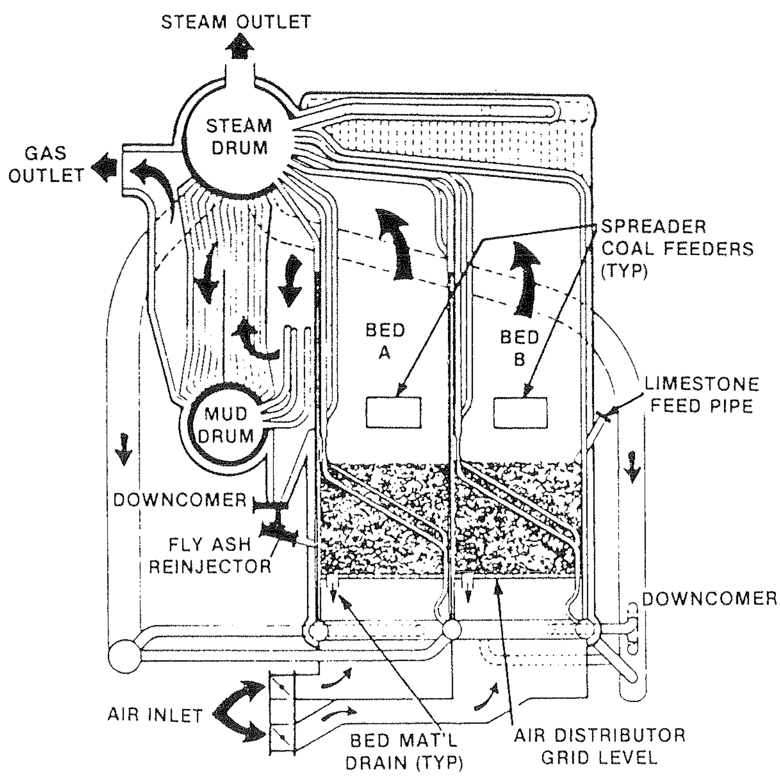


Figure 12 Georgetown University

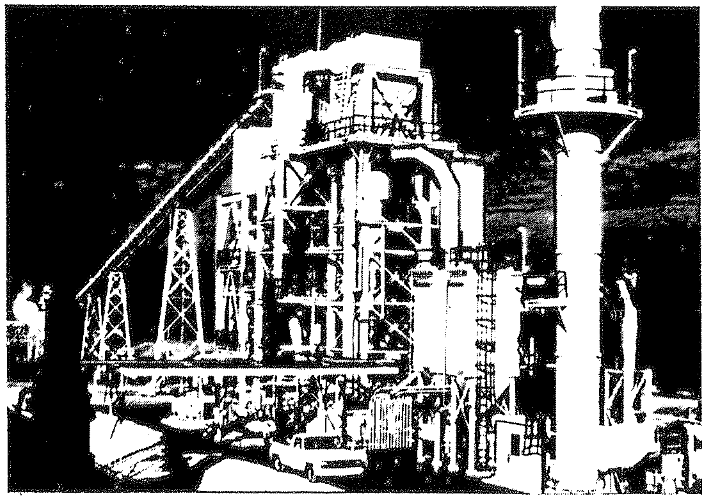
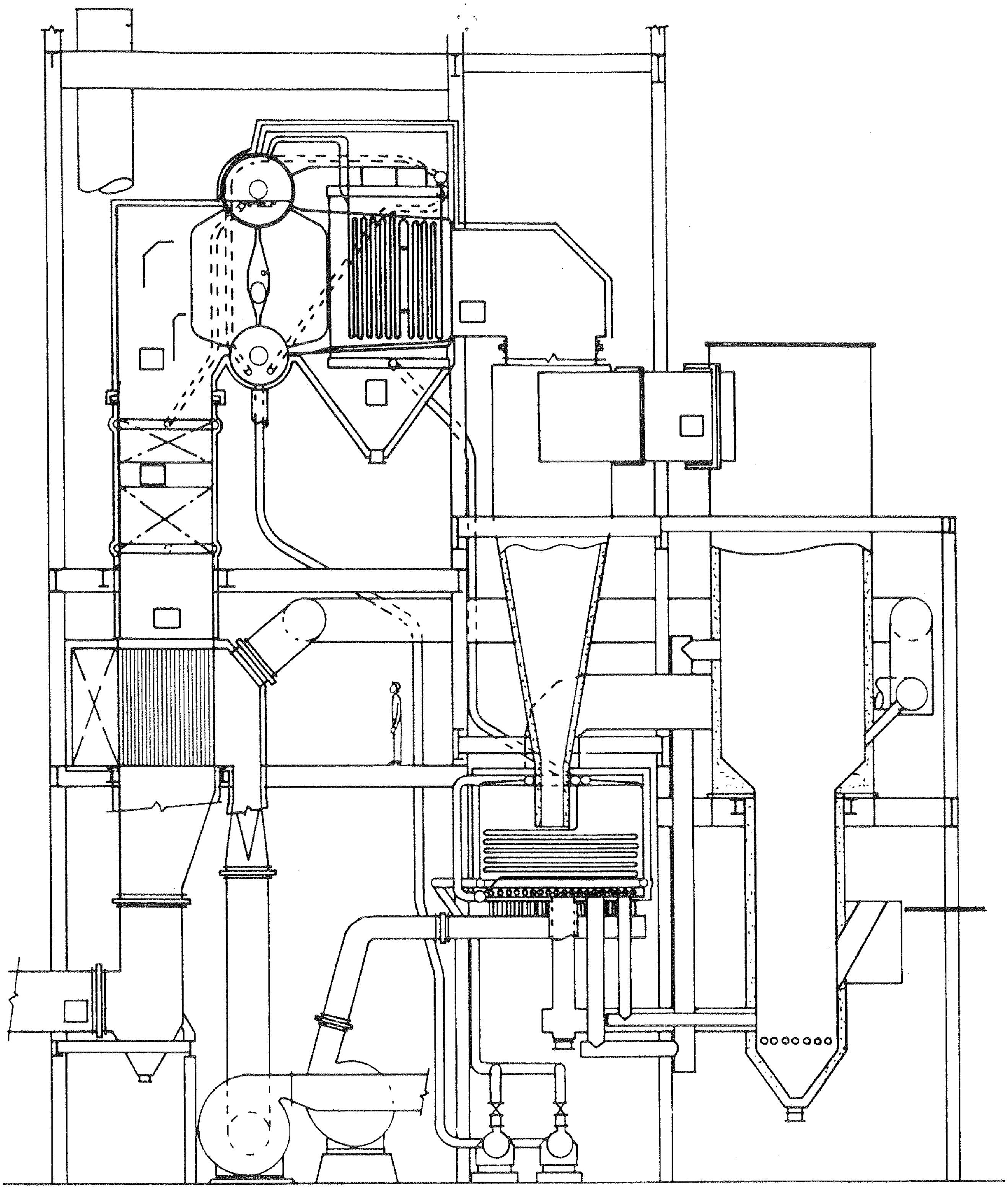


Figure 13 Conoco - Uvalde, Texas. First U.S. Circulating Bed (MSFB)

Forty percent of all boilers reported sold in CY, '84, were fluid bed boilers. Note in Table VI that in calendar year 1984, 13 circulating fluid beds were sold (12 to industry and one to the utilities). Of the 12 to industry, three were to the automotive industry. Most of the units have coal as the primary fuel. Most of the experience overseas is with peat and wood waste. They have burned some coal but have adopted initial designs for wood or wood wastes. Battelle's extensive testing program started in 1973 logged a major portion of its program on coal. The Conoco, Uvalde unit (the first Battelle MSFB unit in operation) burned several different coals as well as petroleum coke. Kerry Coop, the second MSFB unit at Kerry Coop Dairy in Ireland, was designed to burn coal but also demonstrated ability to burn several other fuels, including peat, wood wastes and other on-the-spot market fuel.

NAME	NO.	PPH ea (000)	OP PSIG	SAT °F	PF	AF
ADM	4	425	1250	900	Coal	X
ADM	2	477	1250	900	Coal	X
GMTC Fort Wayne	2	150	700	755	Coal	Oil
Ultrasystems Maine	2	218	1250	955	Wood	X
GM Pontiac	1	300	1460	955	Coal	Gas
Co. Ute	1	925	1510	1005	Coal	X
Scott Paper	1	650	1450	950	Coal	Oil
Total	13	5,265				

Table VI CFBC - CY 84



GENERAL MOTORS CORPORATION
Fort Wayne, Indiana
Two 150,000 lbs/hr—700 psig operating—755F
Multisolid Fluidized Bed Combustion Steam Generators
Fired by Bituminous Coal (Future Refuse)
Argonaut Architecture & Construction, Consulting Engineers
RILEY STOKER CORPORATION WORCESTER, MASSACHUSETTS

Figure 14

Item	Circulating Bed	Bubbling Bed	Rotary Kiln
Cost			
Capital	$	$ + scrubber $$ (double) + extra feeders + foundations	+ scrubber + afterburner
Operating	$	$ + more feeder maintenance + more limestone + scrubber	$$ + more auxiliary fuel + kiln maintenance + scrubber
Pollution control			
POHCs	In minimum-temperature combustor	In high-temperature combustor or afterburner	In afterburner
Cl,S,P	Dry limestone in combustor	Downstream scrubber	Downstream scrubber
NOx, CO	Low due to turbulence, staged combustion	High: bubbles bypass and poor fuel distribution	High NO_X: hot afterburner
Upset Response	Slump bed; no pollution	Bypass scrubber pollution released	Bypass scrubber pollution released
Effluent	Dry ash	Wet ash sludge	Wet ash sludge
Feeding			
No. of Inlets	1-solid 1-liquid	5-solids 5-liquids	1-solids 2-liquids
Sludge Feeding	Direct	Filter/atomizer (5 each)	Filter/atomizer (2 each)
Solids Feedsize	Less than 1 in.	Less than to in.	Larger, but shredded
Fly-Ash Recycle	Inherent (50 to 100 x feedrate)	Difficult mechanical/pressure (10 x feedrate max)	Not done
Unit size			
Land area	Smaller	Larger (over 2X)	Larger (over 4X)
Efficiency			
Thermal, %	78	75	70
Carbon, %	98	90	-
Feeder, hp	Minimum	High	High

Reference 4

Table VII Circulating Bed Incinerator Vs. Conventional Incinerator

Regarding the burning of hazardous wastes in a circulating fluid bed, testwork has been performed in a circulating fluid bed and they demonstrated that a circulating bed waste incineration can operate economically with combustion efficiency more than 99.99%. The testwork demonstrated that the following benefits can be realized:

- Destruction of hazardous components
- Retention of acid gases such as HCL
- Reduction of volume
- Recovery of heat
- Recovery of valuable chemicals

The unit is a circulating fluid bed of the designs discussed above. Limestone addition is made to the bed to control acid gases without costly wet scrubbers. A comparison between the circulating bed, bubbling bed and rotary kiln as shown in Table 7 shows the potential for circulating beds to burn hazardous components.

SUMMARY

Optimizing the production of energy is a concern of all of us. Producing energy in a technically sound and environmentally acceptable manner at the minimum cost is vital. Fluidized bed systems are "here to stay and experiencing growth every day". The ability of fluid bed in general and particularly the second generation circulating fluid beds to demonstrate the "fuel flexibility" that this technology possesses is in evidence today. Not only can the circulating fluid bed reduce fuel costs by 50 percent or more via selection of inexpensive fuels, but also meet the most stringent U.S. and State of California emission standards while rendering a readily disposable dry waste product.

Capital costs and operating costs for circulating beds are in line with bubbling beds and have been shown equal or better than conventional boiler systems while offering better load following and turndown capabilities with overall thermal efficiency comparable to pulverized coal fired systems.

Close to 500 attended the recent "Eighth International Conference on Fluidized Beds" from 23 countries compared to under 30 at the "First International Conference" in the late 1960's.

Circulating fluidized beds have come a long way evidenced by the purchase of 13 units in 1984 alone. The large industrial leaders have purchased or are presently considering purchasing circulating fluid beds. Everyone today burning fuels to produce steam and/or electricity, whether industrial, commercial or utility, is finding fluid beds an attractive means to achieve their goals.

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