Section 14

COMBUSTION/GASIFICATION IN THE LURGI CIRCULATING FLUID BED

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The paper discusses the application of the Lurgi Circulating Fluid Bed (GFB) Technology for utility companies in the United States of America and in West Germany.

Carbon conversion rates, emission data, application, potential and future developments are presented.

First results from extensive gasification tests funded by EPRI and Bonneville Power Administration (BPA), on US-liqnite coal and wood are presented.

INTRODUCTION

During the past several years, there has been an increasing interest in fluidized bed technology, and, more specifically in the Circulating Fluid Bed technology.

The Circulating Fluid Bed (CFB) is a highly efficient fluid bed reactor system wherein gas/solid reactions can proceed with a minimum of mass transfer resistances. It has been widely applied by Lurgi in the calcination of alumina and other materials. When coupled with well-designed components for the production of steam and/or low Btu gas, this technology is now also being applied to produce energy from the combustion and gasification of coal and wood as well as from various waste materials of high sulfur content and/or low heating value.

PROCESS DESCRIPTION, COMBUSTION

Typical Flowsheet, CFB-Power Plant

Combustion in a CFB system takes place in a vertical chamber called the combustor. The fuel and sorbent, usually limestone, are fed into the combustor, fluidized, and burned at temperatures of 1550-1650 °F. The sorbent is fine grained material which reacts with the sulfur dioxide released from burning the fuel to form calcium sulfate (gypsum). Bed material in the combustor consists primarily of mineral matter from the fuel, gypsum, and excess calcined sorbent. The mean particle size of the bed material is in the range of 50-300 microns. Figure 1 shows a typical Process Flow Diagram for the Lurgi CFB steam generator system.

The bed material is fluidized with primary air introduced through a grate at the bottom of the combustor and also by the combustion gas generated. The fluidizing velocity is relatively high, resulting in a comparatively low combustor cross sectional area. The suspended solids form a concentration gradient throughout the combustor which decreases gradually toward the outlet at the top. The combustion gas entrains a considerable portion of the solids inventory from the combustor. The entrained solids then are separated from the gas in one or more recycling cyclones located downstream of the combustor, and are continuously returned to the bed by a recycle loop. A controlled amount of solids from the cyclone can also be passed through an external fluid bed heat exchanger (FBHE) and returned back into the combustor. The very high internal and external circulating rates of solids, characteristic of the CFB, result in consistently uniform temperatures throughout the combustor, and the solids recycle system.

Because of the high difference between the gas and the solids velocity, the solids proceed through the combustor at a much lower velocity than the gas. The long residence and contact times, coupled with the small particle sizes and efficient heat and mass transfer rates, produce a high combustion efficiency. These effects also allow both the decomposition of sorbent and the subsequent capture of the SO_2 at a very low calcium to sulfur molar ratio.

Combustion air is fed to the combustor at two levels. About forty percent of the combustion air is introduced as primary or fluidizing air through the grate at the bottom, and the balance is admitted as secondary air through multiple ports in the side walls. Coal combustion thus takes place in two zones: a primary reducing zone in the lower section of the combustor followed by complete combustion using excess secondary air in the upper section. This staged combustion, at controlled low temperatures, effectively attenuates NO_x formation.

The flue gas exiting the recycling cyclone then enters a convective section containing steam generating surface. Typically, after the convective pass the gases are further cooled in an air preheater. After the air heater the flue gases are cleaned in a baghouse and vented to atmosphere via an induced draft fan.

Heat for steam generation is removed from the system in two main areas:

- a primary loop, where heat is removed from the solids circulating in the CFB system. Heat removal in this primary loop is achieved by:
  - heat absorbing surface in the walls of the upper combustor. This surface is used primarily for evaporation but can also be used for superheating.
  - heat absorbing surface located in the fluid bed heat exchanger. This surface is used for evaporation, superheating and reheating.
- a convective pass (backpass), where heat is removed from the flue gas. This generally contains economizer and superheater surface, and may contain evaporator and reheater surface as well.

Advantages of the CFB Process

Based on Lurgi's experience with the various types of fluid bed reactors, a number of significant advantages of the CFB can be noted:

- Improved heat and mass transfer rates. This results from several factors: higher gas/solid slip velocities, elimination of undesirable gas bubbles, generally smaller solids particle size, longer gas/solid contact times, and superior lateral gas/solids mixing in a less dense bed.

- Higher completion of chemical reactions as a result of improved transfer rates, uniform temperature profile throughout the reactor, and internal recirculation of incompletely reacted particles.

- More efficient utilization of reagents injected into the fluid bed, due again to better transfer rates.

- Reduced NO_x emissions due to lower combustion temperature and staged combustion.

- Reduced emission of unburned carbon monoxide and hydrocarbons as a result of improved heat and mass transfer rates and elimination of gas bubbles.

- Improved distribution of feed materials due to intensive lateral mixing of solids. Thus, typically only one or two solids feed points are required.

- Higher specific throughput per reactor cross sectional area. At a given gas flow rate the diameter of a CFB reactor will be much smaller than that of a conventional fluid bed. This difference in diameter leads to: simplified fluidizing grate and air distribution design, and less complex solids feed systems for adequate distribution of solids (limited number of feed points).

PILOT PLANT TEST DATA

A large number of coals and waste fuels have been successfully tested in Lurgi's 1,5 MWth CFB pilot plant operation. The tests have shown that for almost all fuels it was possible to establish conditions for high carbon burn-out while simultaneously achieving low SO_2 and NO_x emission levels. Table 1 shows representative fuels tested in Lurgi's pilot plant.

Carbon Burn-out

Carbon burn-out was consistently above 99 % (see figure 2). Excellent carbon utilization was achieved with low reactive coals, high ash coals and petroleum coke. The tests have shown that combustion efficiency is affected by the following factors:

- Combustion temperature. Carbon burn-out increases with combustion temperature.
- Bed density. At higher bed densities the solids retention time is increased. Longer residence times of the solids in the fluid bed result in higher carbon utilization.
- Excess air. Higher excess air ratio in the combustor will result in increased carbon burn-out.
- Particle size of solid fuel. The particle size distribution of bed material does not coincide with the size distribution of the fuel feed. Depending on the physical and chemical properties, various fuels will show different particle size of bed material compared to the feed.

  As a general rule, high-reactive coals of low ash content usually require less grinding than low-reactive coals with high ash contents.

  The optimum particle size of the fuel is best established experimentally based on carbon burn-out efficiency and bed material particle size obtained during combustion tests.

SO_2-Capture

SO_2 capture efficiencies in the range of 85 to 98 % have been achieved at calcium-to-sulfur molar ratios of 1.1 to 2.0.

Specific limestone utilization depends on several factors:

- Particle size and reactivity of limestone. Fine grained, highly reactive limestones will achieve better sulfur removal than coarser, less reactive limestones.
- Sulfur and ash content of the fuels. Specific limestone utilization is influenced somewhat by the sulfur content of the fuel, the ash content of the fuel and by the composition of the ash.
- Combustion temperature. Combustion tests have shown that the optimum sulfur dioxide capture occurs at about 1560 °F.
- Bed density. At higher bed density (i.e. at higher solids retention time) the SO_2 capture is improved.

NO_x-Emission

Formation of NO_x is suppressed at the low combustion temperature applicable to CFB operation. However, NO_x emission can still be high when the total fluidizing air is introduced through the grate as primary air. When only a portion of the total air is introduced through the grate as primary air and the rest is injected at a higher level as secondary air, a "staged" combustion is achieved. In this case, a reducing atmosphere is maintained in the lower section of the fluid bed, resulting in a substantial suppression in NO_x formation. In general, NO_x emission can be limited to 100 to 200 mg/Nm³. However, the actual NO_x data is dependend upon the Coal-Nitrogen content.

As can be seen on Figure 4 the Lurgi CFB design allows to achieve 200 mg/m³ SO_2 and NO_x simultaneously without the need for add on flue gas cleaning processes except an electrostatic precipitator or a baghouse for dust removal.

Application of CFB Technology

The application of CFB technology is depending upon a serie of factors which may vary for different countries. To demonstrate the potential of CFB application, the two szenarios present in the US and in West Germany, influencing the selection for new power plants will be discussed in the following.

Situation in West Germany

The situation present in West Germany for the electric power utility industrie can be described as follows:

- there is a need to utilize coal from West German sources which represents due to mining operation down to 3.000 ft depth a high price fuel
- the utility industry signed a contract with the mining industry to increase the consumption of German coal by 5 % per year, the so called century contract
- the environmental regulations will call in the near future for 200 mg/Nm³ SO_2 and 200 mg of NO_2/Nm³ (7 % O_2, dry flue gas) in the flue gas also for small plants
- due to small load growth and already committed nucler power plants there is no need to build large coal based power plants of sizes of 750 MWel as it was the case 10 years ago
- in addition political concepts call for small power plants with the possibility for district heating.

The above criteria calling for small plants with high environmental acceptability increase the price for small plants based on standard PC-Boiler technology tremendously because they need to desulfurize and to remove NO_x from the flue gas.

CFB technology allows the utility industry to comply with these requirements. This is demonstrated by the two Lurgi CFB untility units presently under construction in West Germany.

These are

- a 208 MWth plant for the Stadtwerke Duisburg AG
- a 109 MWth plant for the Stadtwerke Flensburg AG.

The data for the two plants are shown on Figures 5 and 6. Both units will be started up in 1985.

Environmental considerations have been the major reason for the decission of the two utility companies to build CFB units instead of conventional PC technology. Both companies have entered into negotiations with Lurgi to build additional CFB units. The Stadtwerke Duisburg AG intends to build Duisburg II, a 150 MWel unit. The Stadtwerke Flensburg AG is planning to build two more CFB units before the year 1993 in order to base the majority of their generation capacity on CFB technology. A letter of intent for Flensburg II has already been signed.

Units like Duisburg II of 150 to 200 MWel sizes, which Lurgi is offering at the moment, will be typical CFB Units for the German utility industry because of the following:

- the design can be modularized
- the units can be build and started-up within two to three years (Duisburg I, 2 years)
- the installation can be planned according to the load growth
- the Units require less space than conventional PC-Units with flue gas cleaning.
- the instrument costs for the units are lower than for PC-Units meeting the same environmental standards.

In addition CFB units fulfill:

- high carbon conversion rate (above 99 %)
- in situ desulfurization by limestone injection
- minimized NO_x-formation due to staged combustion at a low temperature
- low specific investment costs due to in situ emission-control
- good turndown ratio, (1:3)
- high environmental acceptability in terms of trace elements and minor compounds.

The situation in the United States of America is different to the above described West German situation.

Situation in the United States

- the presently active environmental regulations will become more stringent
- small plants will have to meet stringent environmental regulations as well
- about 70 % of the Nations total electricity generation will be based on coal by the end of the century
- there is an abundant availability of coals with high sulfur or high ash content, which cannot be economically utilized in today's generation units
- there is a large amount of coal rejects, ped coke and other rejects available which cannot be utilized in today's units
- small load growth reduces the need for large units and at the same time calls for small modular units which can be brought on line in less time to more closely follow load growth
- there is a large number of small utility companies generating electricity with diesel engines based on natural gas or oil, due to the unavailability of a technology which allows the operation of gas/diesel engines on coal.

Different from the situation in West Germany not environmental consideration but the potential to utilize low value fuel is at the moment the major driving force for CFB units in the United States. This will change as environmental regulations will become more stringent and the situation will be similar to the one in West Germany.

This situation is reflected by the two CFB Units which Lurgi and CE are executing based on their agreement to jointly market and sell fluidized bed technology in the US and in Canada.

These units are:

- 204 MWth single combustor unit for Scott Paper
- 35 MWth unit for American Lignite

The data for the two US plants are shown in Figures 7 and 8.

The plant for Scott Paper demonstrates the potential and the flexibility of CFB technology. The plant is designed to burn at 100 % load the following fuels:

- Anthracite culm
- Subbituminous coal
- petroleum coke
- No 6-fuel oil
- Natural Gas

In addition wood waste will be used as fuel.

In Canada CE and Lurgi are presently building a 60 MWth unit for New Brunswick Power Corporation based on coal and oil shale as fuel. Figure 9 shows the data of this plant. In this case the major insentive to build a CFB plant was the potential to burn oil shale and to obtain at the same time high environmental acceptability of the plant for free.

The environmental acceptability of the CFB technology is demonstrated in the Luenen-CFB plant, Lurgi's first CFB unit, 84 MWth, shown in Figure 10. The unit is in operation since 1982, achieving the data shown in Figure 11.

In the past year an intensive environmental test program was performed. The test program concluded by the Rheinisch Westfälischer Technischer Überwachungsverein (TÜV) funded by the Umweltbundesamt, a German authority, prooved once more the very high environmental acceptability of CFB units.

The major results of the program are:

Lime stone injection leeds to

- Desulfurization >90 %
- Removal of Chlorine >50 %
- Removal of Fluorine >90 %
- Removal of trace elements >90 %

staged combustion leeds to:

- NO_x-Concentration 200 mg/m³
- PAH-Concentration Nil
- Phenol concentration Nil

Figure 12 shows a trace element balance of the plant. It should be noted once more that the above values have been achieved by "in situ" methods without any add on gas cleaning technology except a state of the art baghouse.

CFB-Gasification

As indicated above there is a large number of small utility companies in the US operating small boilers and gas/diesel engines. These units can be converted from gas to coal applying the Lurgi CFB gasification technology.

The CFB gasification process shows the same features as discussed above. The CFB gasification was developed by Lurgi based on the outstanding experience gained in about 20 years of CFB technology.

The development was performed in Lurgi's CFB pilot plants. The larger pilot plant has the following dimensions:

- internal diameter 30 inch
- cross sectional area 4.2 ft^2
- height 30 ft
- thermal capacity (airblown) 1.5 MWth

In a large number of gasification test trials of more than 2500 hours of operation nearly all types of feedstocks such as:

- Biomass:
  - Red wood
  - Beechwood
  - Poplar wood
  - Recycle wood
  - Bark
- Coal:
  - Lignite
  - Caking coal
  - Non caking coal
  - High ash (60 %) coal
  - Petroleum coke

have been successfully gasified in the pilot plants.

In order to investigate the potential of CFB technology for conversion of gas or oil based units to coal, EPRI and BPA awarded Lurgi who also participates in this program to perform gasification tests in its pilot plant and to use these data as a basis for a feasibility study to develop the economics of such a system.

North Dacota Lignite and whole tree red wood chips from Oregon have been selected as feedstock.

The program has the following objectives:

- development of a databank for air blown coal and biomass gasification at ambient pressure
- development of economics for CFB based systems

During the tests the following was investigated particularly:

- carbon conversion rates at different temperatures
- inbed desulfurization with limestone injection
- carbon content in ash
- recycle of entrained particles in case of gas scrubbing
- composition of scrubbing water.

Duration of the tests:

- Lignite Coal 12 days
- red wood chips 6 days

During the two trials there was no outage because of the gasification system. During the lignite tests there was one plant standby due to a blockage in the pilot plants gas scrubbing system. During the wood tests no shut-down was necessary.

Figure 13 shows the carbon conversion of lignite and wood as a function of the temperature. As can be seen from the figure, carbon conversion rates above 95 % have been achieved. This number will be higher in a commercial plant mainly due to the following two reasons:

- reduced heat losses; commercial plants have heat losses of about 1.5 %, the pilot plant has 20 %
- increased cyclone efficiency; due to pilot plant specifics, the cyclone efficiency is far smaller than those of commercial CFB plants.

Figure 14 shows the desulfurization by limestone injection. As can be seen almost 95 % desulfurization was achieved by limestone injection. This number is close to the theoretical value. The remaining few percent represents the COS content which does not react with limestone.

The carbon content of the ash was as low as 0.5 - 1.5 %wt and allows direct disposal of the ash in case of wood gasification.

Table 3 shows a gas analysis obtained during wood gasification. The data demonstrate once more that no tar and oil is present in the gas. During the entire program no tar or oil has been produced at all.

Further results will be presented in the near future.

State of Technology

CFB gasification units for the production of low Btu fuel gas are commercial available.

The contract for Lurgi's first commercial scale CFB gasification Unit based on biofuel was signed in April 1985. The data of the unit is shown in Figure 15.

The unit is being build for the Pölser Zellstoff AG in Pöls, Austria and will go on line in 1986. The unit will convert bark and sludge into a low Btu fuel gas which is used to fuel the existing lime kiln.

Summary

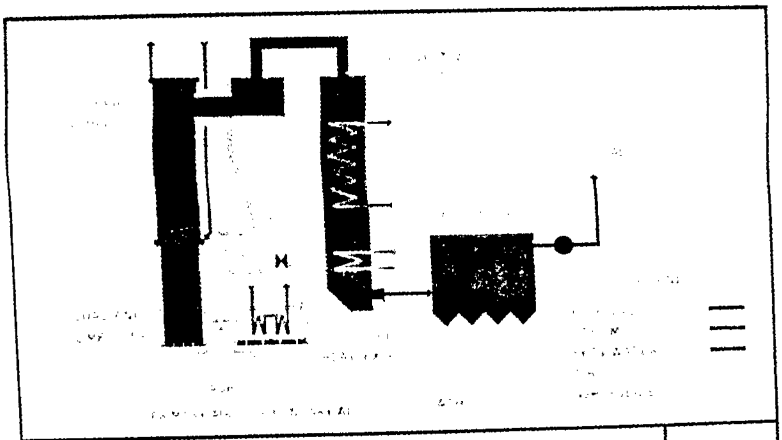
CFB technology in available as a commercial prooven system. Large units are and larges ones will go into operation in 1985. The systems are designed for a variety of fuels meeting the most stringent environmental regulations without the need for add on expensive and troublesome flue gas desulfurization and NO_x revmoval technology. The technology is available up to 200 MWe per module which can be installed within 2-3 years allowing to invest in new load according to the loadgrowth.

The CFB gasification is commercialy available for small units. Test funded by EPRI and BPA in the CFB pilot plant have been extremly promissing. Based on its CFB experience Lurgi in offering this system with all commecial guarantees and has placed its first contract in April 1985 for a CFB gasification plant.

TABLE 1

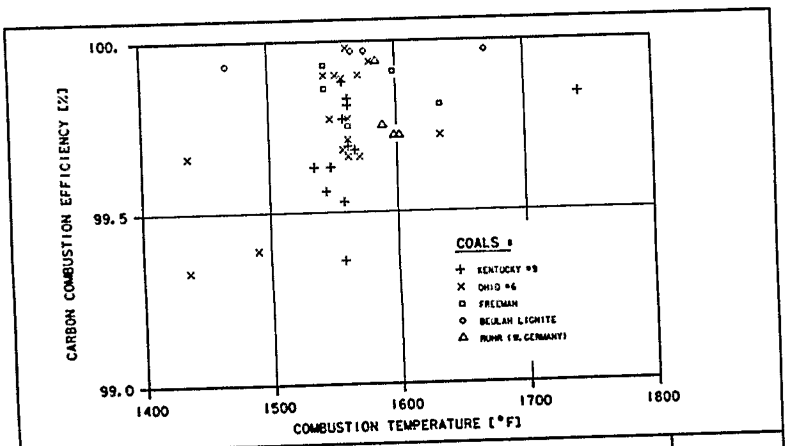
Representative Fuels tested in Lurgi's Pilot Plants

Material	Approximate Composition % Ash	% S	% H_2O	HHV Btu/lb
Ohio Coal	10	5	5	11,600
Ruhr Coal	19	1	2	11,600
California Lignite	26	1	30	5,000
Wood Bark	2	1	55	8,000
Hog Fuel	2	nil	40	5,000
Waste Coal	37	1	12	6,000
Anthracite Culm	45	1	15	4,000
Petroleum Coke	1	5	1	14,000
Gasification residues	50	-	-	14,000
Industrial Sludges	30	1	60	2,500
Spent Sulfite Liq.	7	4	40	5,000



TYPICAL FLOW SHEET
FOR CIRCULATING FLUID BED BOILER SYSTEM

Figure 1



COMBUSTION EFFICIENCY OF COAL IN THE CFB

Figure 2

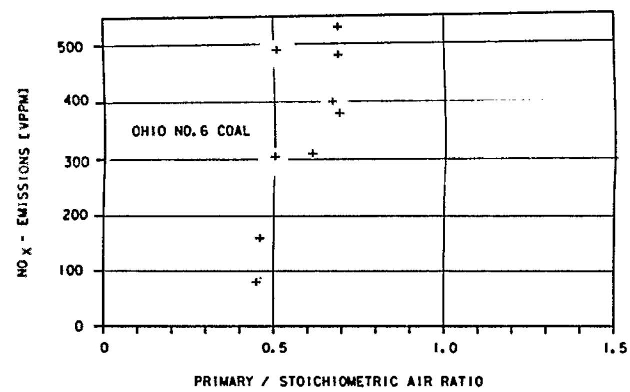


Figure 3 NO_X - EMISSIONS WITH STAGED COMBUSTION IN THE CFB

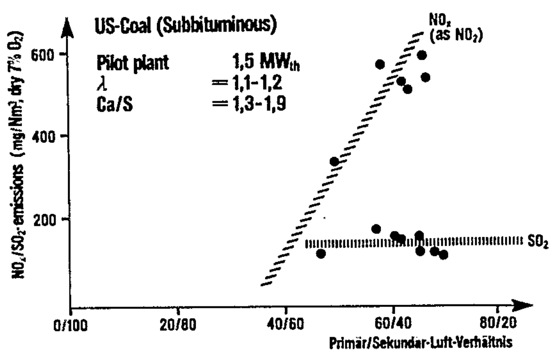


Figure 4 Emissions, staged CFB-Combustion

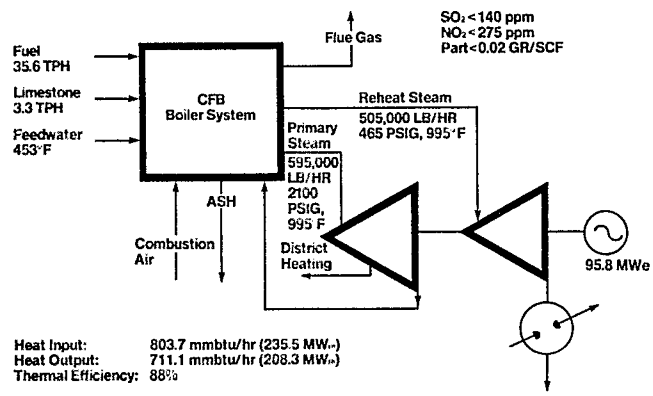


Figure 5 **Duisburg CFB - Heat Balance**

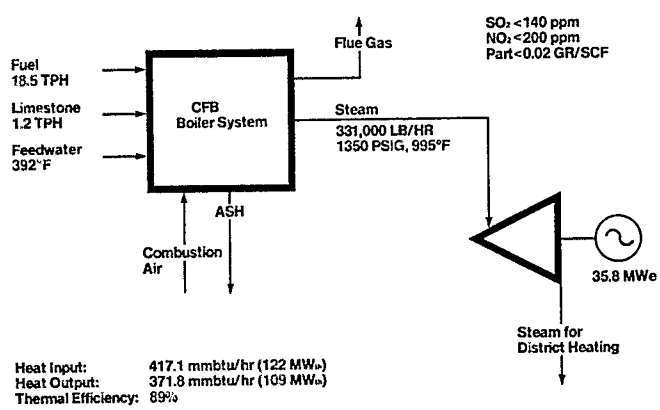


Figure 6 **Flensburg CFB - Heat Balance**

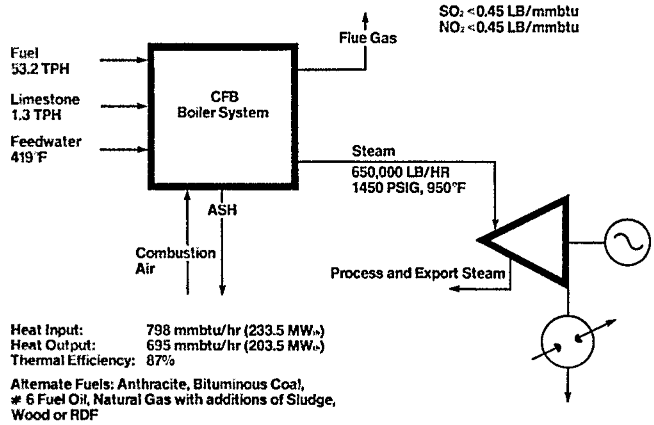


Figure 7 **Scott Paper Co. CFB – Heat Balance**

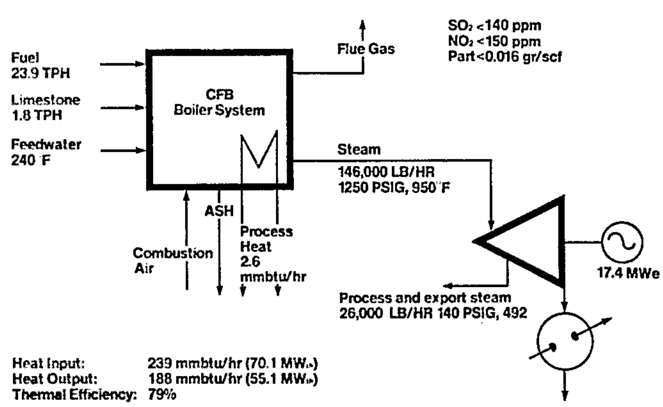


Figure 8 **American Lignite CFB – Heat Balance**

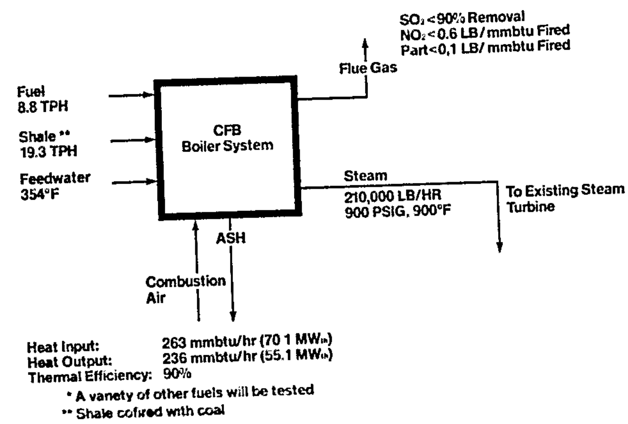


Figure 9 **Chatham CFB - Heat Balance**

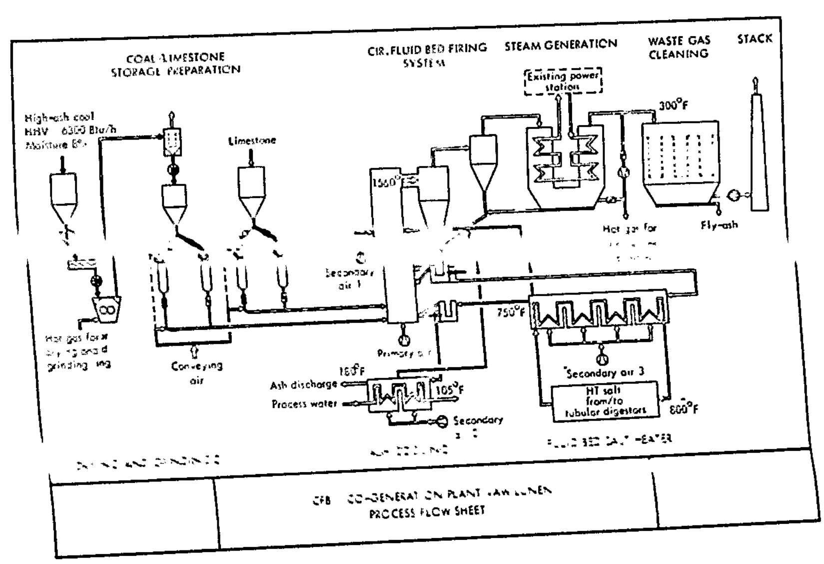


Figure 10

Operating Results Lünen CFB-Power Plant

Coal throughput until October 1984	300 000 t
Working hours until October 1984	17 000
Availability	> 90 %
Thermal efficiency	88-90 %
Emissions (in mg/Nm³):	
SO_2	< 200
Ca/S molar ratio	2.0
NO_x	< 200
HCl	< 100
HF	< 5
Dust	< 50
Sulfur removal efficiency	95 %

Figure 11

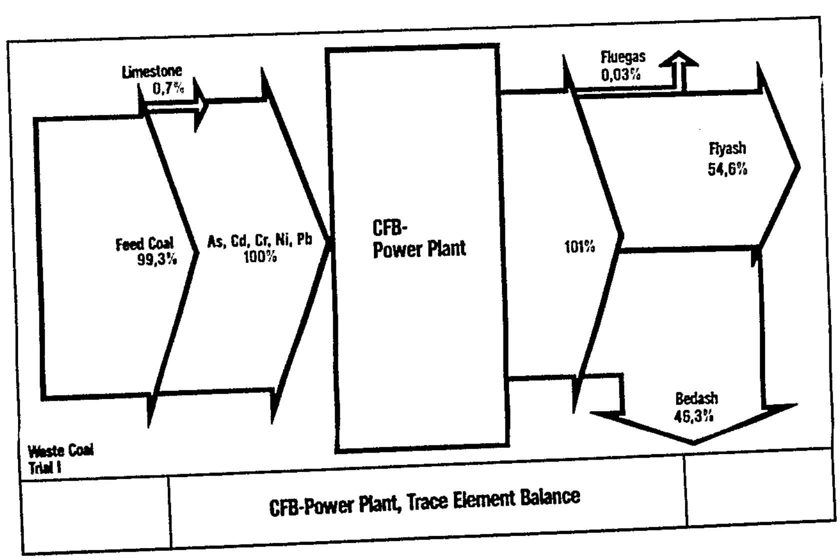
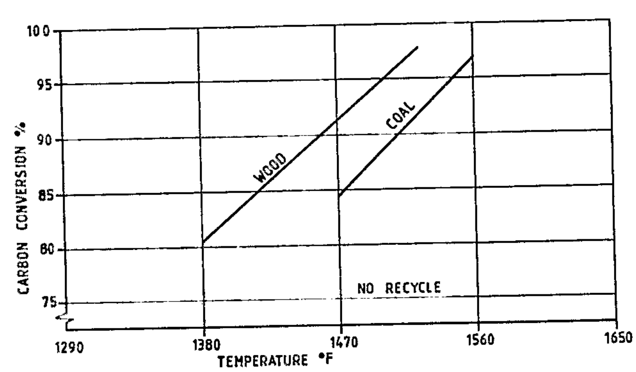
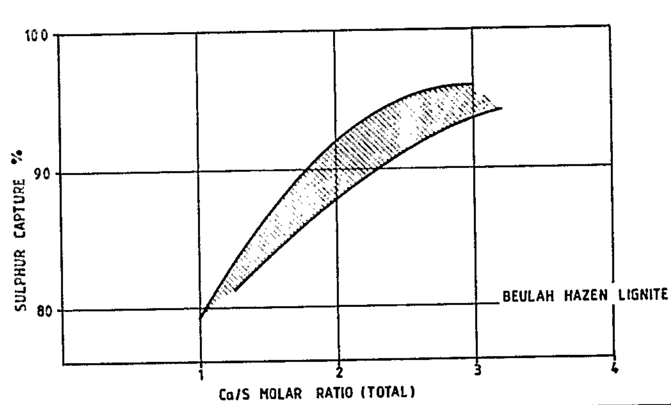


Figure 12



CFB-GASIFICATION, CARBON CONVERSION

Figure 13



CFB IN SITU DESULPHURISATION

Figure 14

CFB GASIFICATION

□ Technical data, Pölser Zellstoff A.G.

o Plant thermal capacity (net)	27	MW
o Bark feed (60% moist.)	35,000	lb/h
o Sludge feed (70% moist.)	3,700	lb/h
o Fuel gas production	536,000	scf/h
o Total heat content	172	Btu/scf
o Lime kiln capacity	225	t/d
o Fuel oil equivalent	22,000	t/y

Figure 15