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Combating high Sulphur in the coal at Lakhra Power Plant

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WAPDA.

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1.0 Lakhra Coal Field

1.1 For the last 100 years or so, the occurrence of coal has been known at Lakhra in Dadu District of the Sind Province of Pakistan. In 1960's some drilling operations were undertaken by the Geological Survey of Pakistan (GSP) and according to its judgement th coal resource in the field spreading over an area of approximately 250 Sq. km was estimated at 240 million tonnes. Inspired by this information, a very large number of leases were taken out by different parties and small to medium-sized mines were establihsed. The present cumulative annual production by the public and private sector mining companies is over one million tonnes. Lakhra coal is being supplied to numerous brick kilns in the country as it is cheaper than the coals of the remaining three provinces i.e. Baluchistan, Punjab and North Western Frontier Province (NWFP).

1.2 No mentionable industry other than brick kilns uses coal in Pakistan, except a 15 MW thermal plant of the Water and Power Development Authority (WAPDA) near Quetta City, where Baluchistan coal is being utilised.

1.3 Several studies have been made in the past 20 years for large scale coal mine development at Lakhra with the specific purpose of power production. The latest detailed feasibility study has been conducted by WAPDA in 1985-86 through American consultants on a compact block of 62 Sq. km leased to Pakistan Mineral Development Corporation (PMDC). It has been determined that there are 174 million tonnes of in-place reserves and 123 million tonnes of recoverable reserves provided a predominant portion of the area is exploited through surface mining and some area through underground mining. This quantity can sustain a thermal plant of 700 to 800 MW capacity for 30 to 40 years. More caoal reserves exist in the un-investigated area and large blocks of additional power can be set up there.

2.0 Lakhra Coal Quality

2.1 The Lakhra coal happens to be lignitic in nature. It is relatively young and therefore possesses a lot of impurities. The most significant impurity is sulphur. A set of analyses of this coal is given below:-

Proximate Analysis

		Typical	Range		
Ash	%	28.7	15.94	to	41.87
Volatile Matter	%	37.9	32.15	,,	43.10
Fixed Carbon	%	33.4	23.68	,,	44.59
Sulphur	%	7.65	5.58	,,	9.85
GCV-Btu/lb		8,595	6,060	,,	10,615
Equil. Moist.	%	39.21	34.63	,,	50.06

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Ultimate Analysis

H_2O (Moisture)	%	32.00	Dry Basis		
Ash	%	19.52	26.17	to	41.87
H_2	%	2.45	2.76	”	4.44
C	%	33.04	35.61	”	59.95
N_2	%	0.75	0.66	”	5.47
S	%	5.20	5.58	”	9.85
0_2	%	7.04	7.59	”	12.84
C1	%	0.15	0.08	”	0.28
GCV-Btu/lb		5,750	6,060		10,615
Hardgrove Grindability Index-HGI		70	60		105

Forms of Sulphur			Dry Basis		
Total	%	7.65	5.58	to	9.85
Pyrite	%	4.24	2.89	”	5.72
Sulphate	%	0.47	0.10	”	1.56
Organic	%	2.94	1.43	”	3.86

Ash Composition Wt. %

SiO_2	43.6
Al_2O_3	27.2
Fe_2O_3	17.2
CaO	3.3
MgO	1.3
Na_2O	0.7
K_2O	0.7
TiO_2	1.9
P_2O_5	—
SO_3	3.9
Undermined	0.2
TOTAL:-	100.0

Fusion Temperature of Ash ^oF

	Typical	Range		
Reducing Atmosphere ^oF				
Initial	2054	1885	to	2443
Softening	2079	1892	”	2453
Hemispherical	2104	1896	”	2468
Final Flow	2225	2000	”	2508
Oxidizing Atmosphere ^oF				
Initial	2433	2254	to	2593
Softening	2461	2302	”	2621

Hemispherical	2492	2333	"	2631
Final Flow	2537	2395	"	2640

2.2 Several hundred samples were obtained from different coal seams and from different places in each coal seam, carefully packed and got tested in USA to arrive at average Design Coal characteristics.

3.0 Combustion Performance Characterisation

3.1 Two bulk samples of Lakhra coal were transported to USA in 1985 for physical combustion performance characterisation in the laboratories of a leading boiler manufacturer.

3.2 The first sample of 50 tonnes was taken in raw form and burn-tested for a few hundred hours in a simulated boiler to determine the slagging, fouling, corrosion and erosion properties of the combustion products. Flame stability under various loading conditions was examined. Abrasiveness of the coal was also tested. Bench tests were conducted to have complete analyses of the consituents of the unburnt coal and the ash obtained after burning the coal. The collectability of fly ash in an electrostatic precipitator was also measured.

3.3 The tests have indicated that the Lakhra coal has a severe slagging potential, medium to high fouling propensity, substantial corrosion potential and high erosion/abrasion capability. Therefore, the boiler design needs a particular attention. Conservative approach to address each characteristic would be required to attain a highly reliable conventional pulverised coal steam generating plant.

3.4 The second 50 tonne bulk sample of Lakhra coal was sent to a commercial washing plant in USA. After washing, a 35 tonne washed coal sample was obtained. It was sent to the same laboratories where the 50 tonne raw coal had been proviously tested to see if any visible change in the combustion characteristics had taken place in consequence of washing. The washing process demonstarated reduction of ash burden by 40% and sulphur content by 20%. Washing also improved the heating value per clean pound by about1100BTU. But there occurred substantial loss of fine coal in the washing thereby reducing the overall heat content by nearly 25% per tonne of delivered coal. The burn-test indicated that the slagging and fouling properties of the washed coal did not improve. They actually became slightly worse. It would, therefore, be uneconomical to use the washed coal in the boiler whose design will incorporate practically the same conservative approach as for the unwashed coal and 25% more raw coal would be required to produce the same amount of energy, the caost associated with washing notwithstanding.

4. Sulphur in the Coal

4.1 There are two major impacts of the sulphur content in the fuel. One is the potential of corrosion in the boiler. The other is the emission of sulphur dioxide from the chimney into the atmosphere, causing environmental pollution affecting human life, vegetation and sometimes aquatic life. The SO_2 emitted into the air travels to different directions and settles down on the earth, taking its toll in many ways.

4.2 Removal of sulphur is highly desireable both for protecting the boiler materials and the environment from the ill-effects of SO_2 and SO_3 generated in the furnace which when mixed with atmospheric humidity, surface water or rain, turn into sulphurous acid and sulphuric acid respectively as given in the following simple chemical formulae:-

i) $SO_2 + H_2O$ H_2SO_3 (Sulphurous Acid)

ii) $SO_2 + 1/2\ O_2$ SO_3 (Sulphur Trioxide)

iii) $SO_3 + H_2O$ H_2SO_4 (Sulphuric Acid)

5.0 Methods of Eliminating Sulphur

5.1 There are several methods and approaches of eliminating or reducing sulphur content from coal; they are:-

i) Coal washing before burning
ii) Chemical treatment during combustion
iii) Chemical treatment after combustion before exit to the atmosphere.
iv) Fluidised Bed Combustion Technology.

5.2 Each of the above systems is briefly discussed in the succeeding paragraphs.

i) Coal Washing

5.2.1 Quite often a Jig or a Heavy Media Washing Plant is used to wash the impurities of coal. However, cleaning of ash and other impurities is dependant on the miscibility in water of various coal components. Differing yields of clean coal are obtained in the two systems according to the separating gravity selected and the washability of coal. The Heavy Media system provides sharper separation though it is more expensive. Schematic Diagrams of the two systems are shown in the Figures 1 and 2.

5.2.2 As mentioned in the analyses charts earlier, the sulphur in the Lakhra coal is found in the following forms:-

i) Pyritic sulphur	=4.24 %	
ii) Organic sulphur	=0.47 %	
iii) Sulphate sulphur	=2.96 %	
TOTAL	=7.65 %	Dry Basis

5.2.3 In most washing plants it is only possible to remove a part of the inorganic sulphur (some pyrites and sulphates) which is more prone to washing. The organic form of sulphur is not susceptible to washing and therefore remains in the coal even after washing. In lignite, the high inherent moisture does not allow the pyritic sulphur to be separated from the coal. Thus washing is a means of only partial elimination of the sulphur contained in the coal. It may be interesting to note that there are only three known lignite washing plants operating in the entire world, one in W. Germany and two in the USSR. In the case of Lakhra lignite, the loss of coal is also substantial and the coal structure deteriorates after washing. Therefore, the benefits accruing from its washing are unable to justify the expenses and intricacies involved in the washing process. While the two systems described are able to cause meaningful cleaning, other methods in coal cleaning do not help sulphur removal to any appreciable degree. They are:-

a) **Wet Methods**

- Concentrating Tables
- Classfiers
- Launders
- Floatation

b) **Dry Method**

- Pneumatic cleaning

ii) **Chemical Treatment During Combustion**

5.2.4 In order to neutralise the SO_2 and SO_3 produced during combustion, lime dosing is done. The lime in solid form is mixed with crushed coal in a pre-determined ratio before both are pulverised together and pass into the furnace. Alternatively, lime can be separately fed in a powdered form into the furnace practically in the same manner as the pulverised coal. In both cases, when the coal burns, the lime reacts with the sulphur oxides and gives rise to sulphates, which are collected with the fly ash. This system is not very efficient and is normally applicable to coals with low sulphur content. Also the ash burden due to lime addition is substantially increased in the boiler furnace and the resistivity in the fly ash rises whereby the efficiency of electrostatic precipitators falls down.

5.2.5 Only a few power plants in the world use this system. A 600 MW power station in an environmentally sensitive area of South France (Gardanne) using 2% sulphur coal is employing this method. A simple diagram of the system is given in Figure 3.

iii) **Chemical Treatment of Flue Gases**

5.2.6 Upt to early seventies, even the developed countries like USA, Germany, UK, Canada and Japan etc, were not using any desulphurisation system for flue gases. At best, they tried to burn coals with very low sulphur to keep the environmental pollution at a depressed level. In this way the environmental pollution was steadily increasing. In the mid-seventies, the environmental protection agencies of Japan and USA enforced strict laws and no license to any utility was given for a new power station or expansion to an existing plant unless it complied with the regulations of SO_2 control to keep the air clearn. USA had a lot of lignite reserves, some of them containing high sulphur. The need for conserving oil and public opposition to the continued use of atomic energy in power plants obliged the American utilities to resort to te enhanced use of the available coals and also to desulphurise their combustion products. Now, it is mandatory in USA and Japan to use some kind of desulphurisation equipment in a power plant, even if the coal or oil contains ½% sulphur. Canada, UK, France and Germany are also seriously thinking of introducing the processes but due to the large expenses involved the adoption of the technologies is being delayed. Same is the case of he Eastern European countries. Scandinavians are extremely conscious of environmental pollution. Therefore, they have done pioneering work in this field. Some desulphurisation system developed by Sweden and Finland are gaining popularity in USA. A few desulphurisation systems are mentioned below:-

i) Calcium - Based (Lime/Limestone/Fly Ash) Wet Scrubbing.

ii) Magnesium - Based Wet Scrubbing

iii) Daul Alkali Wet Scrubbing

iv) Lime Spray - Drying (Swedish Technology)

v) Wellman Lord Process

Process Descriptions

5.2.7 Flue Gas Desulphurisation (FGD) is a term which applied to various chemicalprocesses for removing SO_2 from combustion products of coal. Most of these processes operate by contacting the flue gases with an alkaline slurry or liquid or even dry powder that absorbs and reacts with acidic SO_2.

5.2.8 The systems mentioned above are schematically shown in Figures 4 to 8. For purposes of general understanding of the readers it may be mentioned that the important chemical reactions that occur in lime and limestone scrubbing systems dictate the measurements needed for monitoring process performance. An important feature is the ratio between lime/limestone and sulphur which has to be carefully determined for each fuel. Quite often its range is 2 Lime : 1 Sulphur to 3 Lime : 1 Sulphur. The overall reactions are as follows:-

Lime Scrubbing

$$SO_2 + Ca(OH)_2 \longrightarrow CaSO_3 . 1/2\,H_2O + H_2O$$

(GAS) (SOLID) (SOLID) (Liquid or Vapour)

Limestone Scrubbing

$$SO_2 + CaCO_3 \longrightarrow CaSO_3 . 1/2\,H_2O + CO_2$$

(GAS) (SOLID) (SOLID) (GAS)

5.2.9 Other systems have varying details but they generally serve the same purpose i.e. sulphur dioxide removal to a greater or smaller degree. The products of chemical reaction are, however, different; some of them are throw-away in nature and serve as good landfill for land reclamation, while others are useful by-products that can be used in the manufacture of cement or as construction material

6.0 Lakhra Power Plant

6.1 WAPDA's feasibility studies were undertaken in the beginning of 1985 with the following basic parameters in view:-

i) A mine of 1.4 to 1.8 million tonnes per annum at the PMDC lease area in Lakhra.

ii) A power plant of 300 M.W.

iii) Environmental Impact Assessment of the two projects.

iv) Economic and Financial Analysis of the investment on the total project.

6.2 During the course of feasibility studies it transpired that coal reserves of over 120 million tonnes were available in the investigated area of 62 Sq. km and economies of scale could reduce the cost of coal per tonne and cost of energy per KWH if a large mine was developed for a correspondingly large power plant. It was calculated that a power plant of 700 M.W. could be supported by the mine producing about 4 million tonnes per annum. Technically and financially these were attractive but environmentally they posed some problems. The World Bank, USAID and the Asian Development Bank, who were the potential donors for the Lakhra power plant suggested that the World Bank guidelines set for the developing countries must be met as regards particulate and SO_2 emission as well as ambient ground concentration.

6.3 The 700 M.W. power plant running at 85% plant factor was able to meet the particulate emission levels through the installation of a high efficiency electrostatic precipitator..But uncontrolled SO_2 emission was exceeding the limit of 1000 tonnes per day fixed by the World Bank for two units, although the daily ambient ground concentration was found to be well below 500 microgram per cubic meter and annual geometric mean of 100 microgram per cubic meter. Therefore, there were two Options: (1) to desulphurise a part of the flue gases before entering the chimney or (2) to reduce the size of the power plant so that the uncontrolled SO_2 emission would remain below 1000 tonnes per day @ 85% plant factor. The option (1) would not only increase the capital cost of the power plant by 20-25% plus the operating cost but also pose many technical problems in operation and maintenance. In this situation the option(2) appeared more attractive as a power plant of 2x250 M.W. or 500 M.W. capacity satisfied the world Bank guidelines, without the installation of an FGD system. Subsequent analysis suggested that a conventional plant without sulphur removal would still threaten the lives of the people.

6.4 It has, therefore, been decided to drop the two units of 2 x 250 M.W. without desulphurisation equipment. Consequently all power units will either have flue gas desulphurisation (FGD) or will be based on Fluidised Bed Combustion Technology (F.B.C). Keeping this factor in mind, WAPDA has prepared a smaller scheme of 3 x 50 M.W units based on F.B.C., to be commissioned by 1990-91 in order to gain experience of Lakhra coal without causing environmental pollution. Plans are being made to install more F.B.C. units after 1990.

7.0 Main Features of 3 x 50 MW F.B.C. Units

7.1 The three units based on Fluidised Bed Combustion Technology proposed to be installed at Lakhra by 1990-91 will have three steam turbines of 50 M.W. each. The reason for selecting this size is the limited experience of the F.B.C. technology:-

The following chart shows a list of a few utility F.B.C. units operating in the World:-

Country	Name of Power Station	Approximate Size (MW)	Date of Commissioning	Type
U.K.	NCB(IEA-Services) Grimethrope	1 x 25	1980	PFBC
Phillipines	ACMDC Cebu	2 x 25	1982	AFBC
W. Germany	Afferde Power Station, Hameln	1 x 40	1983	AFBC

W. Germany	Stadtwerke Duisberg (Demonstration Plant)	1 x 96	1985	CFBC
USA	TVA Paducah Kentucky (Pilot Plant)	1 x 20 (no turbine-generator)	1982	AFBC (bubbling)
Sweden	Studsvik Research Centre	1 x 25		CFBC
Holland	Akzo (Hengelo) (Demonstration Plant)	1 x 35	1986	AFBC
China	Various stations	25 MW each	Recent	AFBC

7.2 Some larger power plants like a 110 MW plant at Nucla, Colorado in USA with Finnish collaboration using Circulating Fluidised Bed Combustion and another of 160 MW AFBC by TVA also in USA are under construction but they can at best be named as demonstration plants and a few years' experience will be needed before Pakistan can go in for a larger power station based on F.B.C.

8.0 Fluidised Bed Combustion

8.1 This is a special technology known for over 40 years for smaller industrial application but its utility application has started in recent years. Crushed Coal, particularly that containing high sulphur, and crushed limestone are fed onto a boiler bed made of a distribution plate, called reactor. The combustion air from a fan or a compressor is blown evenly from below through the distribution plate with the help of nozzles into the bed containing inert solid matter grains, coal and limestone. The distribution velocity is chosen so high that the solid matter particles are kept in suspension or in a 'fluidised state'. In the fluidised bed there are embedded some of the steam tubes for intense heat transfer. The vital chemical actions taking place in the bed in the following sequence:-

i) $CaCO_3$ (Limestone or Cal. Carbonate) — $CaO + CO_2$ (on heating) (Lime or Cal. Oxide)

ii) $CaO + SO_2 + 1/2\ O_2$ — $CaSO_4$ (Calcium Sulphate)

8.2 From the above it is evident that the purpose of the F.B.C. is to capture most of the sulphur dioxide in the furnace. The Calcium Sulphate formed over the bed and the ash obtained through combustion are channelled out of the bed continuously. Only the flue gases carrying fly ash, which are practically sulphur-free, leave the bed towards the upper part of the boiler.

8.3 The advantages of F.B.C. are:-

(1) Most of the Sulphur is removed in the bed. The flue gases inflict minimal high temperature corrosion to the boiler parts and there is very little SO_2 emission from the chimney.

(2) The furnace temperature is low and the ash does not attain fusion temperature. Therefore there is practically no slag build up around the steam and water tubes which remain clean on the fire side.

(3) The back-end of the boiler does not face the problem of corrosion even at low loads. Therefore, a lower flue gas exit temperature can be allowed, thus maximising thermal efficiency of the plant.

8.4 The major disadvantage in this system is the heavy erosion of the bottom tubes facing the fludising solids in the bed. To solve this problem, metal stubs are welded on the surface of the tubes.

9.0 Types of F.B.C. Systems

9.1 There are three main F.B.C. system :-

i)	Atmospheric	F.B.C. (or Bubbling F.B.C.)
ii)	Pressurised	F.B.C.
iii)	Recirculating	F.B.C.

9.2 Each system is briefly discussed in the coming paragraphs.

i) A.F.B.C.

9.2.1 As already briefly stated, the fuel (coal) is combusted in the presence of a bubbling bed of calcined limestone. The calcium in limestone reacts with sulphur dioxide produced in combustion to form calcium sulphate in a dry solid state. This eliminates the need of a flue gas desulphurisation equipment (FGD) that is required in a conventional unit.

9.2.2 Various low grade fuels can be used in the AFBC process because combustion temperature in the fludised bed is maintained by the voluminous heat-sink mass of bubbling lime-stone. Temperature of the bed is below the softening temperature of ash, which helps the bottom ash and the flyash to remain in a solid condition any where in the boiler. The problem of slagging and fouling, for which Lakhra coal has a high propensity, are virtually eliminated. Not a single soot-blower is needed in any part of the boiler.

9.2.3 A conceptual diagram of the AFBC (Bubbling Bed) is given in Figure 9. The major difference between fluidised bed coal combustion and pulverised coal combustion is the lower temperature of combustion environment of about $1550^{o}F$ in the bed vis-a-vis 2500^{o} - $2800^{o}F$ in the pulverised coal furnace. Bubbles of flue gas are fomed in the combustion process which rise through the bed causing very turbulent mixing of coal and limestone. Smaller limestone particles are picked up by the flue gases. These smaller limestone particles are collected in Cyclone-type dust-collectors and sent back to the fluidised bed. Re-injection of un-reacted lime and unburned carbon greatly increases the efficiency of sulphur removal and carbon burn-up.

9.2.4 A fluidised bed boiler includes the steam superheater within the bed, the waterwall enclosure to hold and contain the bed and water-cooled air distribution plate to support the bed. A more detailed configuration of a utility boiler based on AFBC technology is given in Figure 10. Some of the plants operating in utilities have steam temperatures of $495^{o}C$ ($920^{o}F$ to $980^{o}F$) and steam pressures of 60 bars to 120 bars (880 psig to 1750 psig) which are quite comparable with utility type boilers based on pulverised coal. The only problem is the lack of field experience on larger boilers.

9.2.5 A wealth of knowledge has been gained by the boiler manufacturer, the utility (TVA) and the EPRI (Electric Power Research Institute of USA) from the operation of a 20 M.W. equivalent AFBC facility, without a turbo-generator, installed at Paducah Kentucky, since 1982. Some of the operating results are given below:-

Load Changing

9.2.6 A decrease of air velocity and firing rate upto 20% is safe while reducing the load on the boiler as the bed temperature remains steady upto that level.

9.2.7 The recycling of flyash to the boiler bed proves useful in controlling bed temperature.

9.2.8 A combination of air decrease and flyash recycle increase can help in the reduction of load upto 40-45% without disturbing flame stability and chemical interaction.

Start-up Time

9.2.9 The plant has a start up compartment 'S', two compartments with boiling surface 'A&B' and two with superheated surface 'C&D'. A 'cold' start begins by charging the bed with stored material at a temperature of about 200^{o}F. Once charged, the start-up compartment is fluidised with air heated by an external oil-fired burner. Upon reaching 950^{o}F, coal is added to the compartment.

9.3.0 After two hours, the start up compartment 'S' reaches 1550^{o}F and compartment 'A' is ready for fluidising. After another three hours, compartment 'B' can also be fluidised. Compartments 'C&D' can then be fluidised in sequence. After 5 hours coal firing is attained in all the five compartments. Meanwhile steam raising has started and within a total of 7-1/2 hours, the unit is upto the operating pressure.

9.3.1 In a 'hot' start-up all compartments can be lit within 5 hours. Efforts are being made to reduce the starting time of the cold and hot starts. A schematic showing the compartments is given in Figure 12.

Erosion/Corrosion

9.3.2 Erosion takes place on the surface of the superheater tubes located in the bed. The steam tubes need replacement every four to five years. No corrosion takes place. Therefore, no special metallurgy or anti-corrosive material is required to mitigate this phenomenon.

SO_2 Emission

9.3.3 A sulphur capure of upto 90% can be achieved with a 2.5 Ca/S molar ratio. Further reduction upto 2:1 may be possible.

Problems and their Solutions

9.3.4 Some operation difficulties have been encountered in the TVA plant and their possible solutions have also been indicated. They are given in the following table:-

Operational Difficulties	Resolution
A. Bed Feed System	
1) Pluggage of transport Piping	1) Insure all coal is sizes 1/4" Insure surface moisture is 8%
2) Erosion/abrasion of system components	2) Utilize ceramic liners in pipe bends.
B. Recycle System	
1) Undersized initially	1) Increase size of recycle system
2) Erosion/abrasion of system components	2) Utilize ceramic liner in pipe bends.
C. In-bed heat transfer surface was over sized	Remove surface after better understanding of heat transfer coefficients
D. High air leadage	Use zero leakage air heater in future (tubular)
E. Cyclone tube erosion	Provide wear protection of equipment components.

9.3.5 A comparison between the emissions from the T.V.A's. A.F.B.C. Facility and a Pulverised Coal (P.C.) scrubber of a conventional boiler is given in the following Chart:-

	TVA AFBC	PC W/Scrubber
SO_X	90% Removal @ 2.5:1 Ca/S Mole ratio	90% Removal @ 1.1:1 Ca/S mole ratio
NO_X	0.35-0.40 Lb/10^6 BTU input	.6-0.7 Lb/10^6 BTU input
Particulate	0.05 Lb/10^6 BTU input	0.05 Lb/10^6 BTU input

9.3.6 The above data indicate that the AFBC boiler consumes relatively more limestone than the P.C. boiler for equal percentage of sulphur removal but a lot of damage due to corrosion is likely to be inflicted upon the boiler parts in the case of of P.C. unit before the flue gas is desulphurised, while the A.F.B.C. does not suffer from corrosion problem. No_x (Nitrogen Oxides), to which developed countries are becoming increasingly sensitive, are also emitted at a lower rate in AFBC because of low temperatures involved. Particulars emission is equally good in both the cases.

9.3.7 A single line diagram representing the complete AFBC boiler system is shown at Figure 12.

10.0 Pressurised Fludised Bed Combustion Boilers

10.1 In the AFBC boiler discussed in the preceding paragraphs the pressure in the furnace is only slightly higher than the atmospheric pressure. Therefore, the system is called Atmospheric Flidised Bed Combustion. The Scheme in Figure 13 shows a more complicated system called Pressured Fluidised Bed Combustion Process. In this case the Forced Draught Fan is replaced by a compressor coupled with a gas-turbine. The fluidising air enters the bed in the same way but the boiler furnace has a much higher pressure. The reaction between sulphur and lime is similar to the one in AFBC and the bottom ash is also taken out identically. The high temperature flue gases rise at a higher pressure and have to be cleaned in a dust collector. They are then led into a gas turbine which not only operates the compressor supplying the fluidising air but also runs a generator coupled to it, thus producing power. Cleaning of the flue gases helps in minimising both erosion and corrosion in the gas turbine.

10.2 The gases exhausting from the gas turbine are then taken into a waste heat recovery boiler which acts as feed water heater. The preheated water is at a low temperature and pressure. It is led to the pressurised fluidised bed for obtaining heat and ultimate conversion into superheated steam. This superheated steam then goes to operate an independent steam turbo-generator, producing more power.

10.3 The flue gases passing through the waste heat recovery boiler are not only free of particulates but also of sulphur while entering the chimney for exit into the atmosphere.

10.4 The relatively low combustor operating temperature used in PFBC would produce a low efficiency system if used in a simple gas turbine cycle only. However, by incorporating an appropriate steam turbine Cycle (combined cycle), additional coal can be burned in the combustor (P.F. Bed) increasing the plant output to about 4 or 5 times that of gas turbine, attaining an overall efficiency of 38% or 40%

10.5 When this system is fully developed, plants upto 250 M.W. can be designed but so far only a 25 M.W. unit is operating in U.K.

11.0 Recirculating F.B.C.

11.1 As the name implies, a circulting (or recirculating) fluidised bed boiler is a development of the fluidised bad combustor, allowing recirculation of a substantial portion of the unburnt carbon particles and unreacted lime that are carried away from the bed by the flue gases. Large cyclones are installed in the flue gas path to capture the relatively heavier particles, which are taken back to the fluidised bed for completion of combustion of coal and reaction of lime with SO_2 generated during combustion.

11.2 It is believed that the circulating bed technology allows operation with as high steam parameters as are applied in pulverised coal once-through (drumless) boilers. It differs from the AFBC in that the heavy ash recirculation ensures a higher combustion efficiency and it requires reduced auxiliary power. The remaining features of the boiler are practically the same. Figure 14 shows the conceptual construction of a 200-250 M.W boiler based on C.F.B. technology, while Figure 15 gives a flow diagram of lime/coal/ash/flue-gas system and the feed water/steam system.

11.3 The CFB can operate so effectively that only solid ash and calcium sulphate come out as a by-product with just a small amount of lime and residual carbon accompanying it. The ash consists of inert and non-corrosive matter which is well-suited for use as a cement aggregate and/ or construction material.

11.4 In essence, the C.F.B. ensures high sulphur retention, low NO_x formation, quick start-up and shut-down, high combustion efficiency and low construction volume.

11.5 The 95.8 M.W. CFB unit at Duisberg in West Germany installed in 1985 operates at a steam pressure of 2100 psig and 995°F. These parameters are practically the same as applicable to modern conventional pulverised coal-fired units. The added advantage in CFB is that low grade coal can be successfully burnt in it with minimal harm to equipment and environment. However, some years of operating experience are still needed to identify the problems associated with this technology, that holds a good promise for the poor quality lignite at Lakhra.

12. Conclusions

12.1 The technical problems associated with the burning of Lakhra lignite can no doubt be resolved by appropriate design of the conventional boiler of 250 to 350 M.W. range using pulverised coal ensuring high availability of the units. But in view of the potential SO_2 emissions caused by such a plant it is only prudent to avoid the conventional boilers as for as possible.

12.2 Maximum generation from Lakhra lignite should be based on F.B.C. technology.

12.3 Initially 50 M.W. size A.F.B.C. boilers would be highly desirable as they are proven. Later on, bigger CFB boiler would be available. Thus the 3 x 50 M.W. AFBC plant to be commissioned by 1990-91 is the most optimum approach to mitigate power shortage within the framework of world Bank's environmental guidelines. Subsequently, bigger F.B.C. units may be the only option to go with.

12.4 Another power plant of 2 x 50 M.W is being installed at Lakhra about 10 miles apart by the private sector for sale of energy to WAPDA. This station will have 3 x 35 M.W. A.F.B.C. boilers feeding steam into 2 x 50 M.W. turbines. This technology can also be applied for utilising the domestic coal in Punjab, NWFP and Baluchistan besides Lakhra and Thatta-Sonda coal fields in Sind causing minimal impact on the environment. Both public and private sectors need to participate in the national programme of fighting out the existing power crisis, with minimum drain on the Country's foreign exchange reserves.

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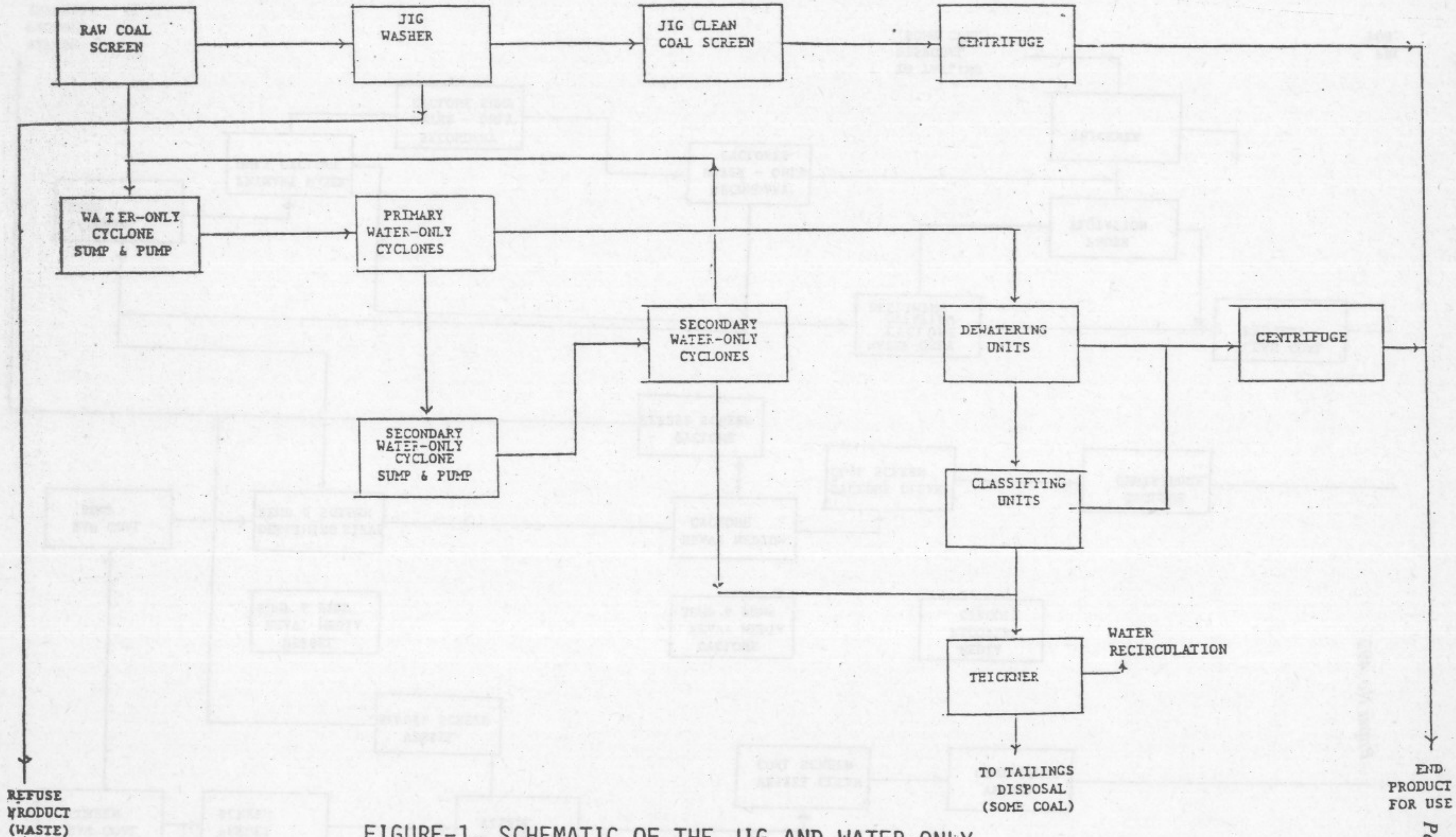

FIGURE-1. SCHEMATIC OF THE JIG AND WATER-ONLY CYCLONE CIRCUIT

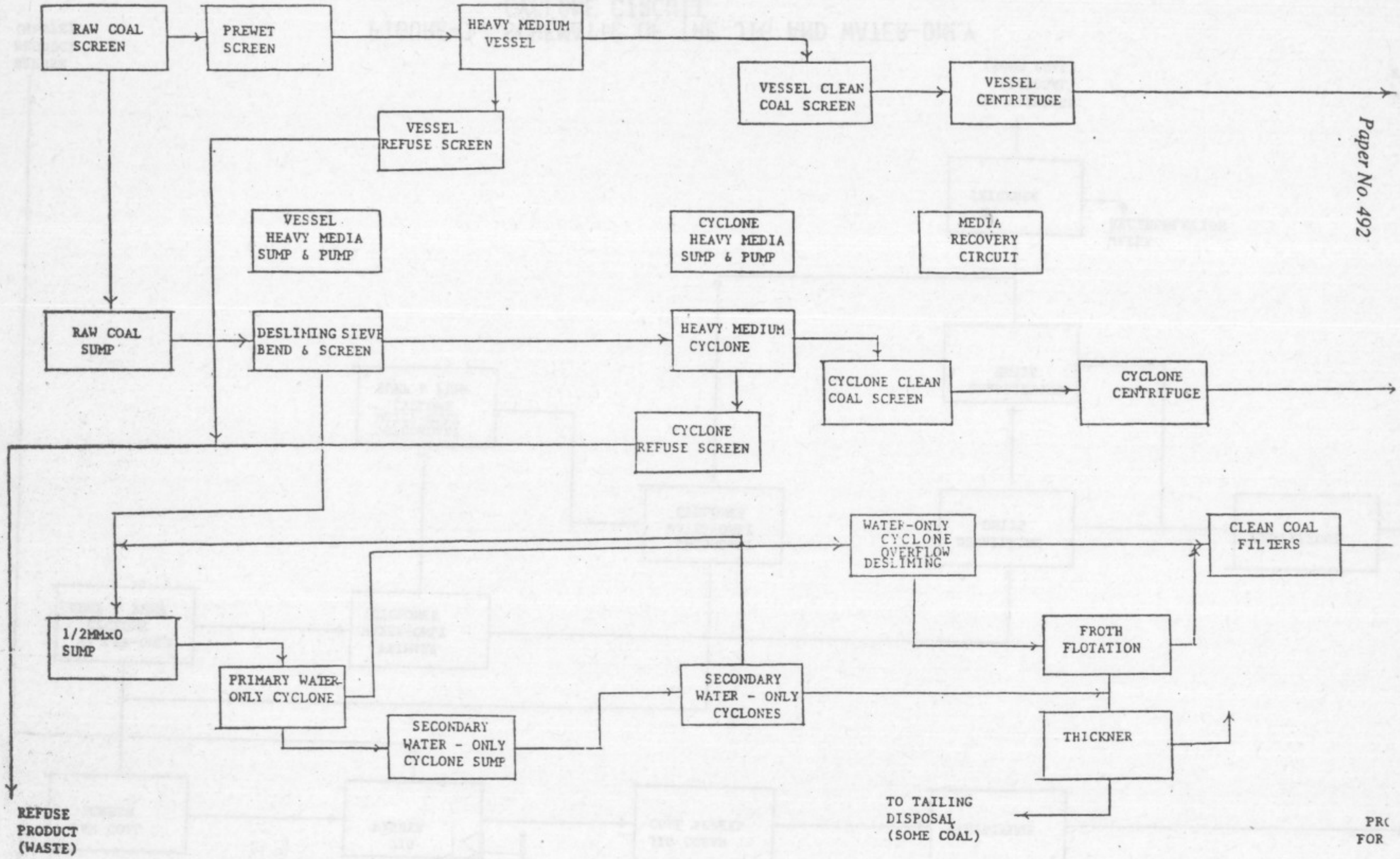

FIGURE-2. SCHEMATIC OF HEAVY MEDIUM VESSEL, HEAVY MEDIUM CYCLONE WATER-ONLY CYCLONE AND FLOTATION CIRCUIT.

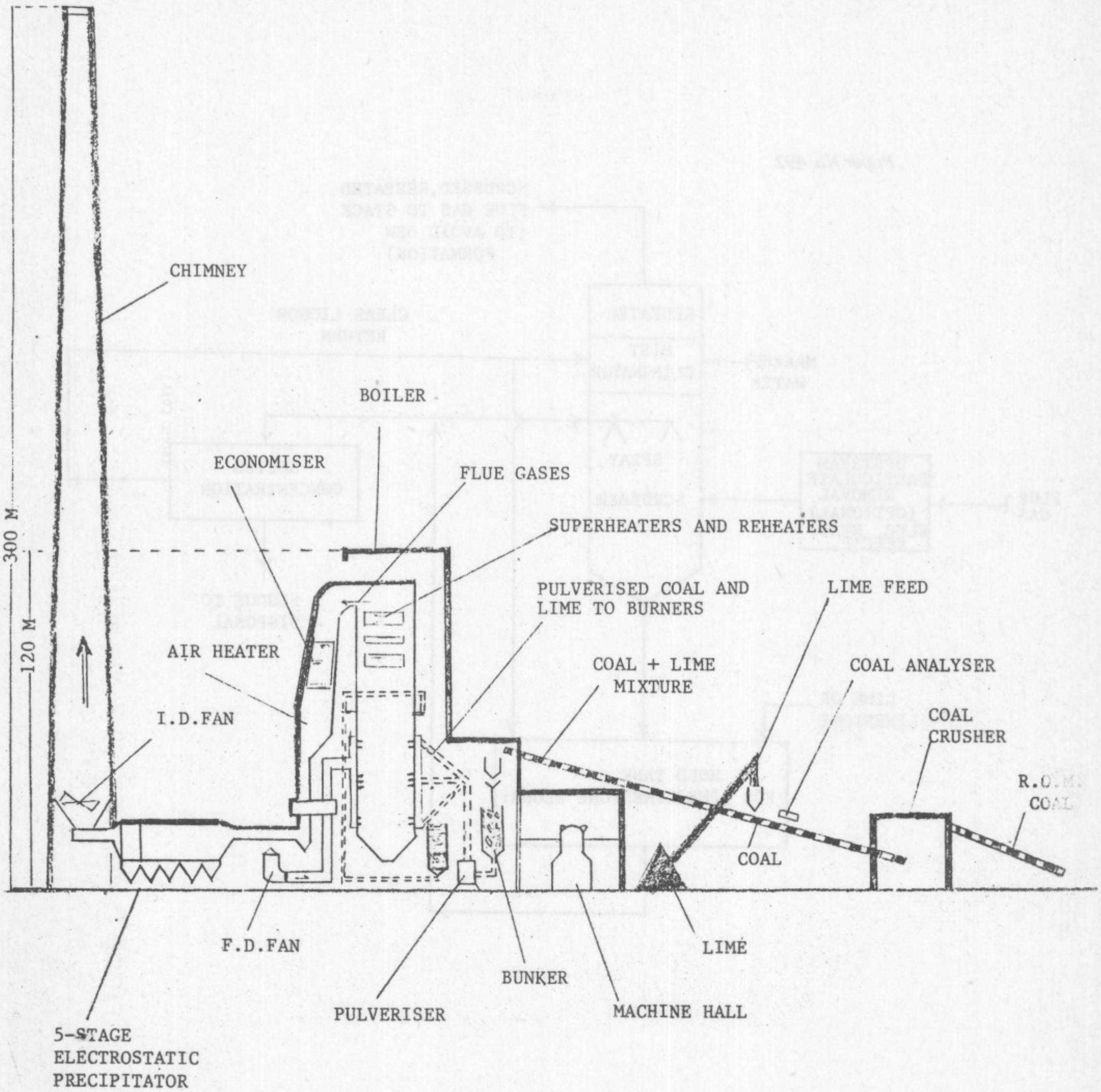

FIGURE-3. 600 M.W. COAL-FIRED POWER STATION IN SOUTH FRANCE (LIME DOSING WITH COAL)

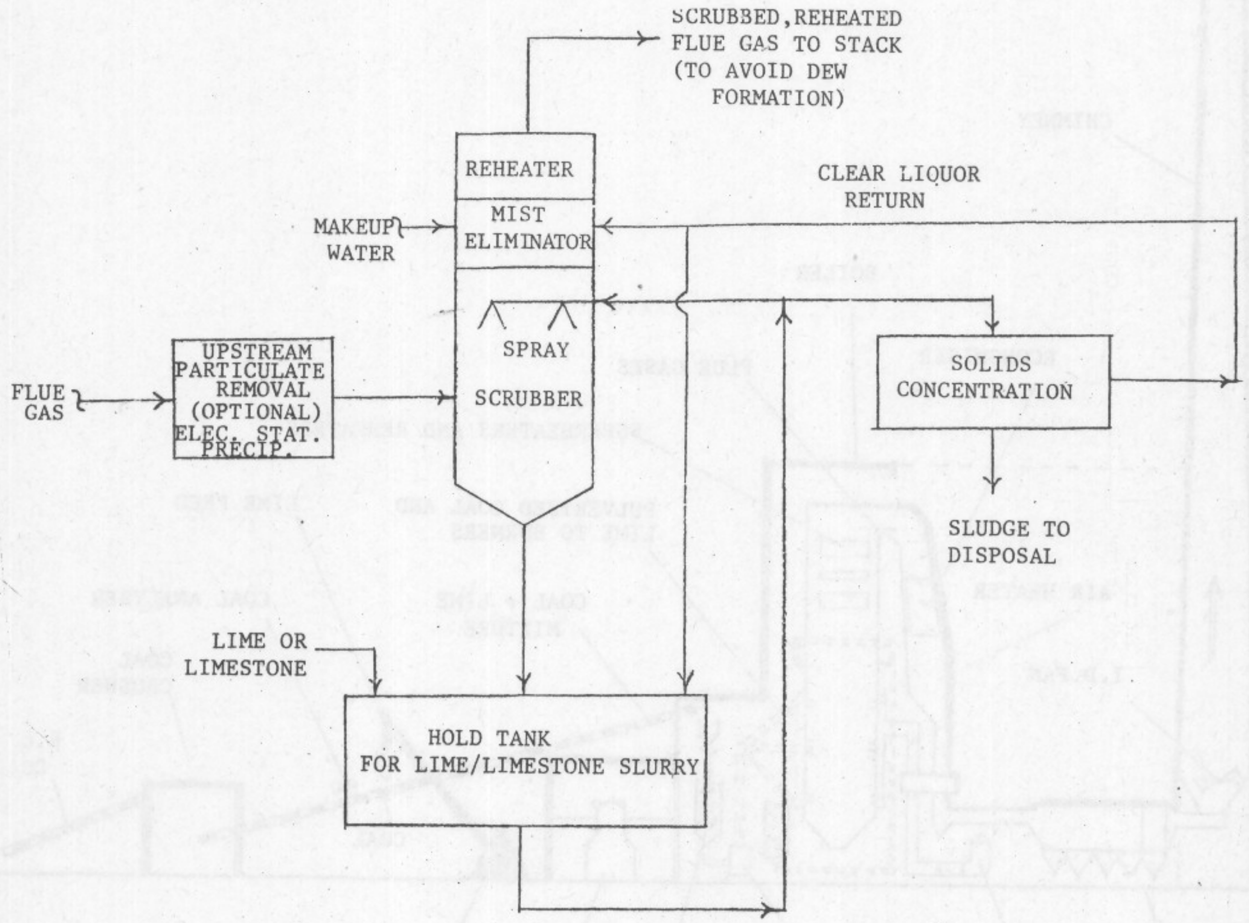

FIGURE-4. LIME/LIMESTONE WET SCRUBBING PROCESS SCHEMATIC (FLUE GAS DESULPHURISER)

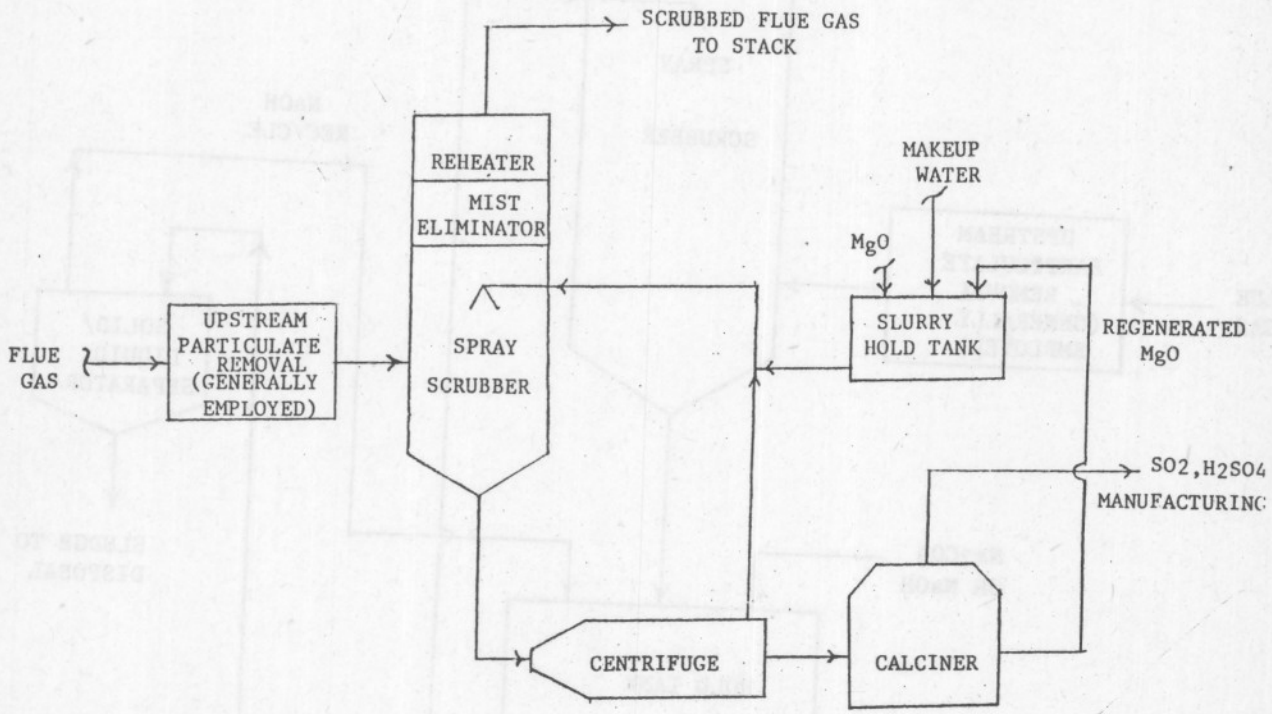

FIGURE-5. MAGNESIA WET SCRUBBING PROCESS SCHEMATIC.

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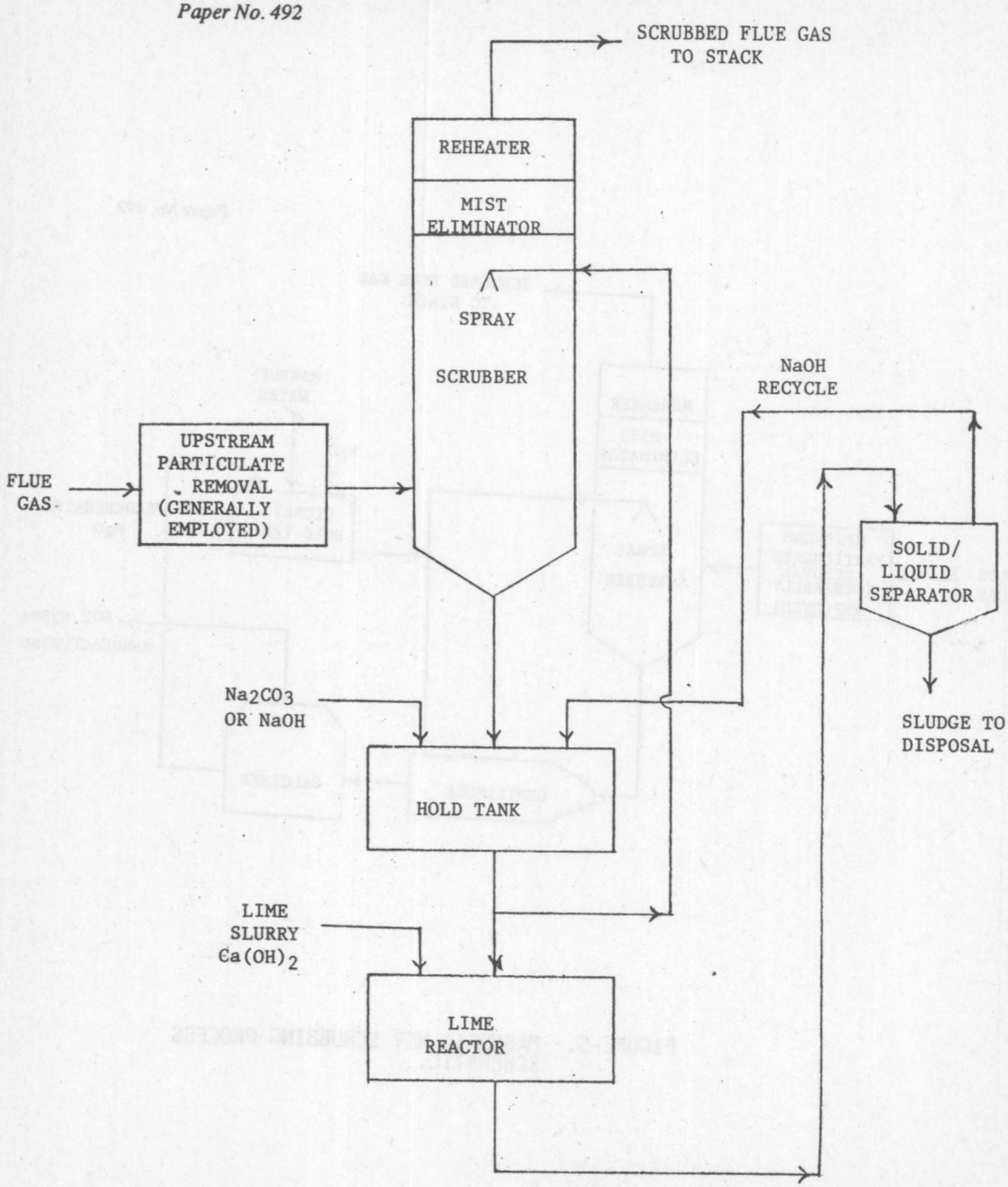

FIGURE-6. DUAL ALKALI WET SCRUBBING PROCESS.

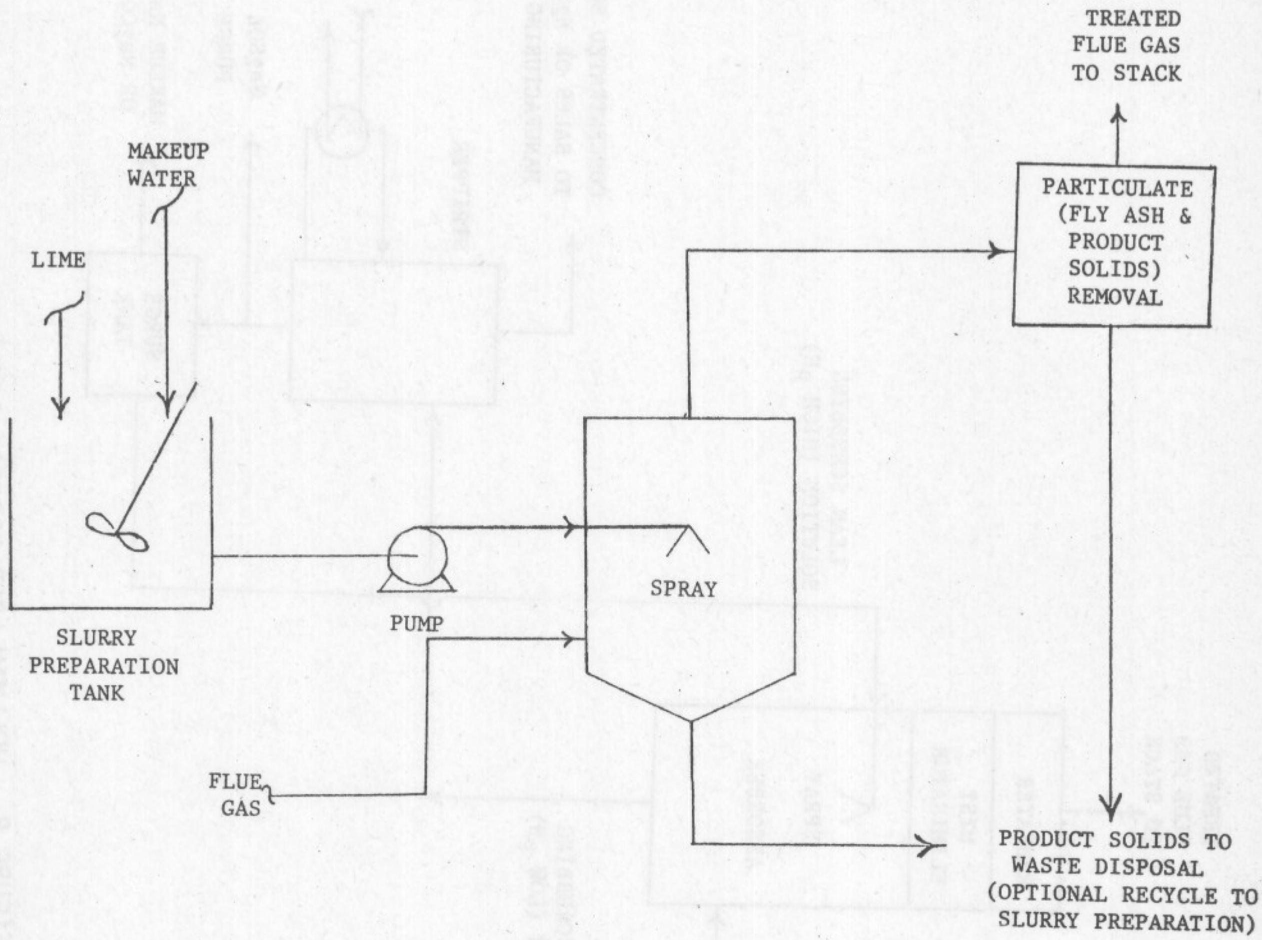

FIGURE-7. LIME SPRAY DRYING PROCESS SCHEMATIC

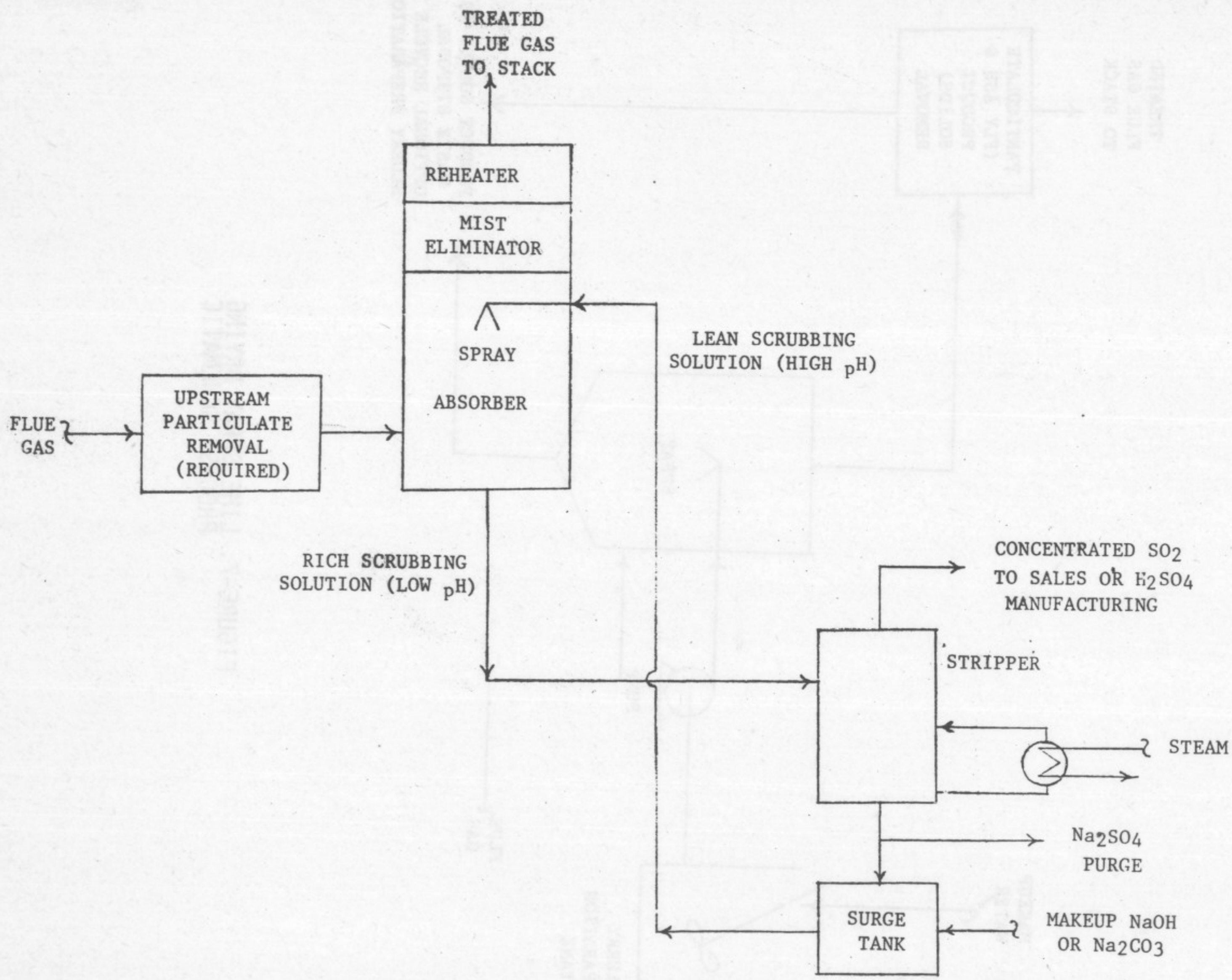

FIGURE-8. WELLMAN LORD PROCESS SCHEMATIC

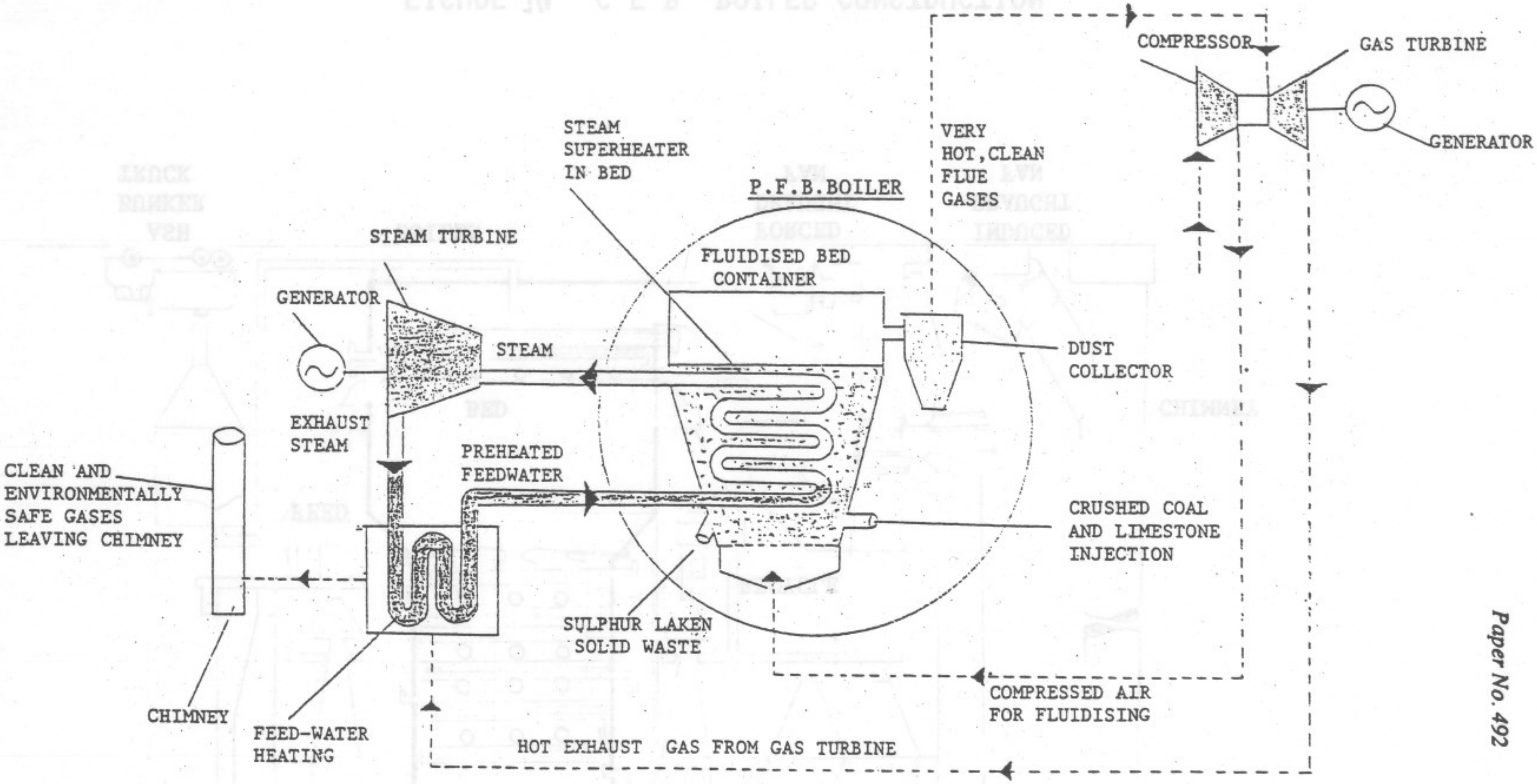

FIGURE-13. PRESSURISED FLUIDISED BED BOILER FLOW DIAGRAM.

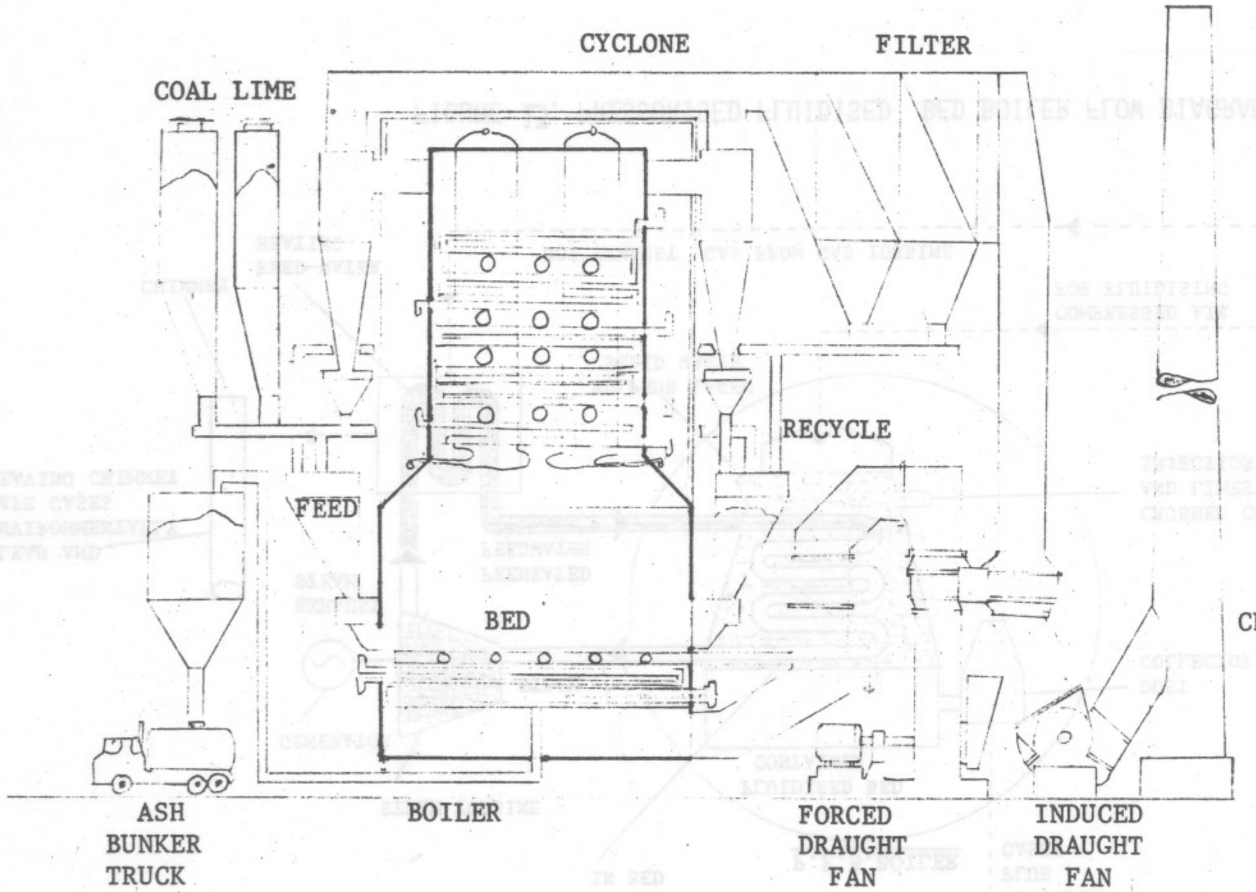

FIGURE-14 . C.F.B. BOILER CONSTRUCTION

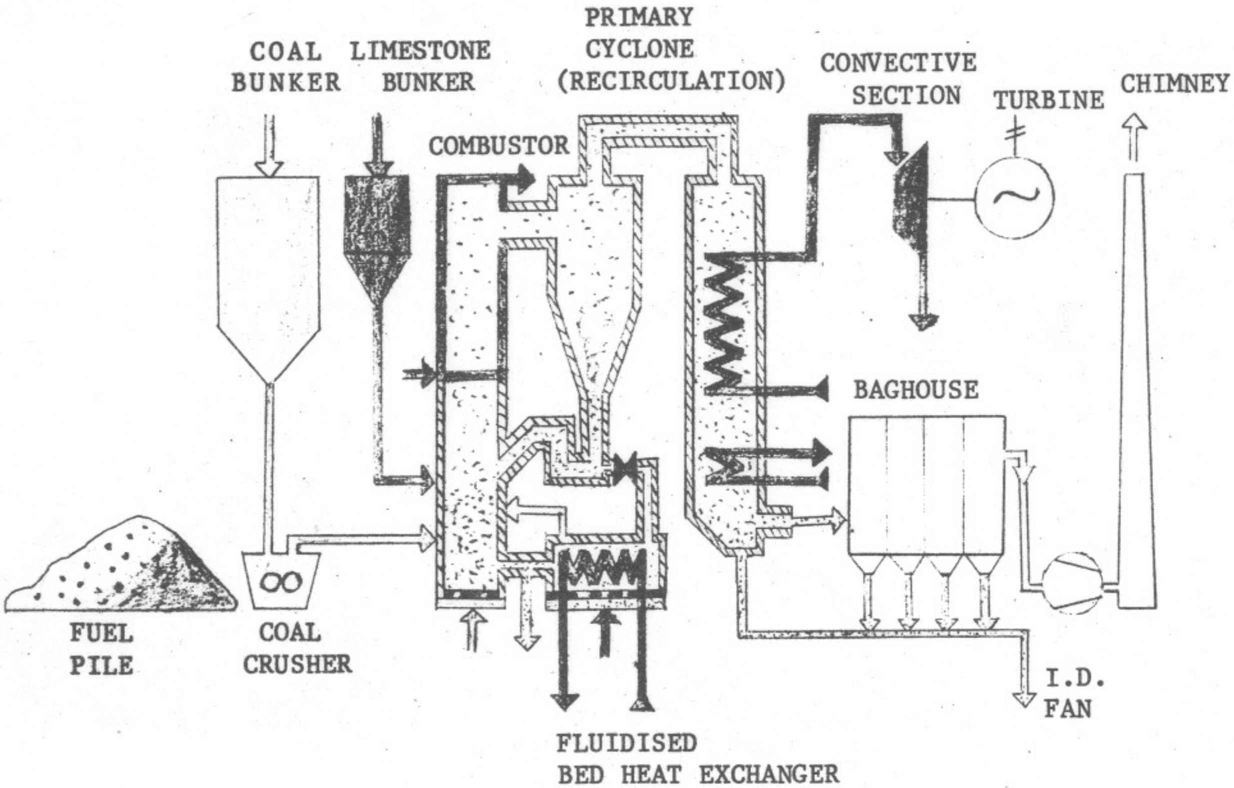

FIGURE-15. CIRCULATING FLUIDISED BED SCHEMATIC

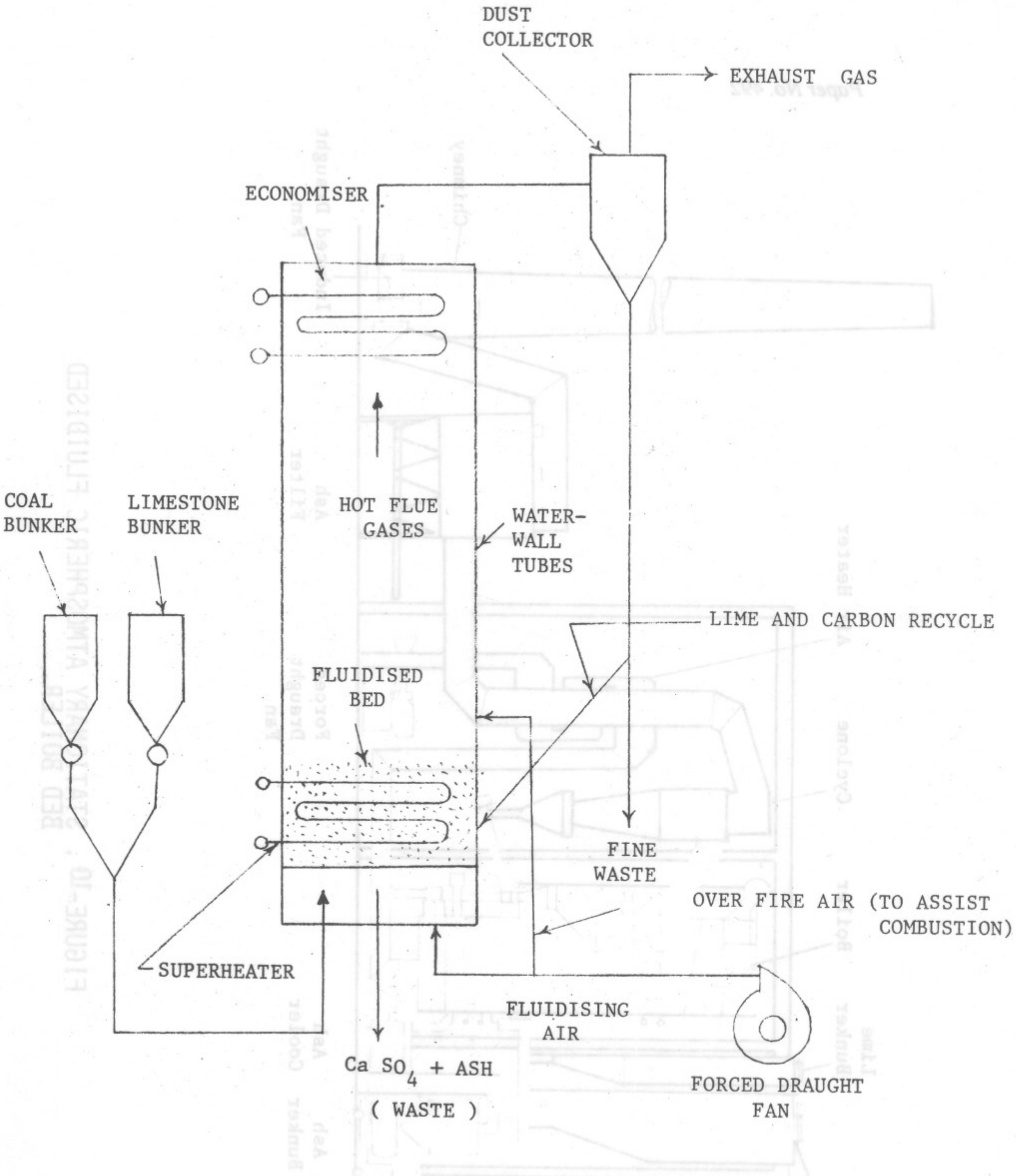

FIGURE-9 BUBBLING A.F.B.C BOILER
(CONCEPTUAL DIAGRAM)

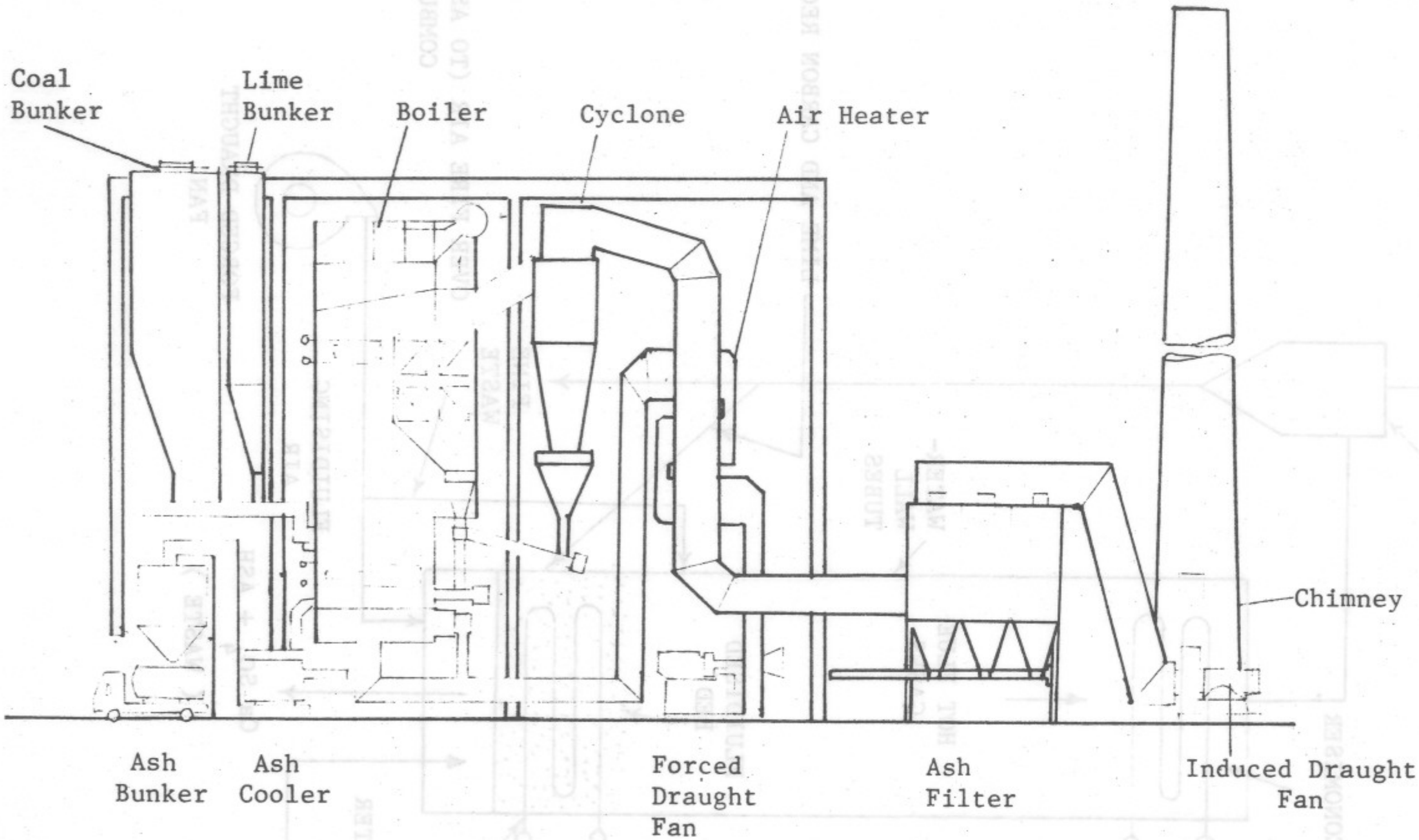

FIGURE-10 . STATIONARY ATMOSPHERIC FLUIDISED BED BOILER..

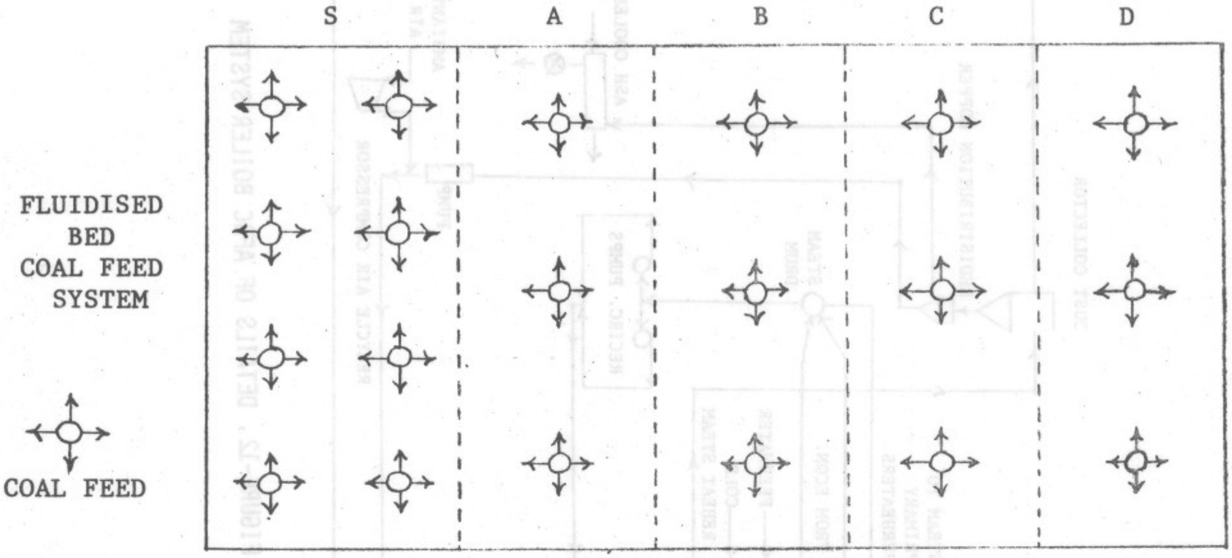

FIGURE-11. SCHEMATIC SHOWING COMPARTMENTS OF FLUIDISED BED COAL FEED SYSTEM.

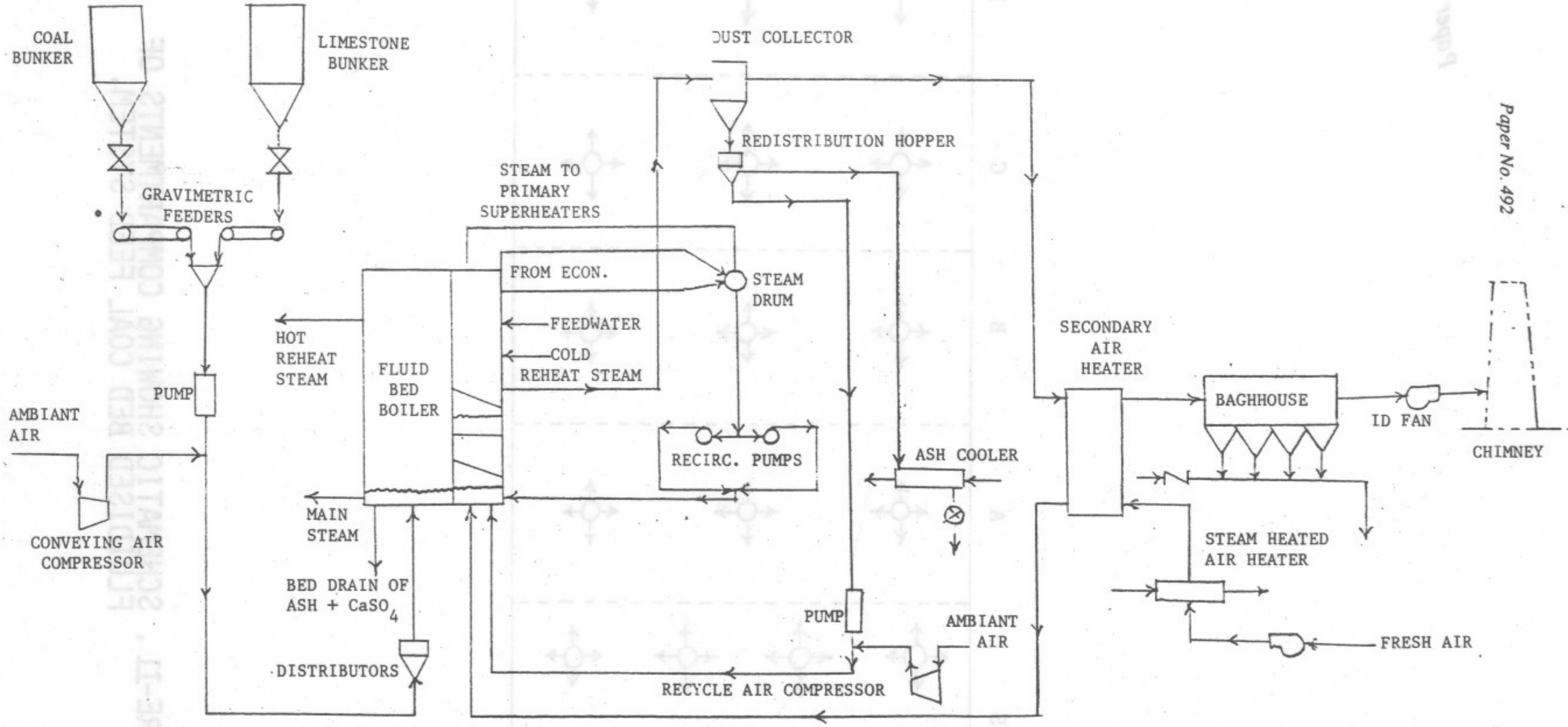

FIGURE-12. DETAILS OF AFBC BOILER SYSTEM