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16019

DP/ID/SER.A/782
9 December 1986
ENGLISH

DEVELOPMENT OF LOW-CALORIFIC-AVALUE COAL TECHNOLOGIES

DP/BUL/81/005

BULGARIA

Technical report: Fluidized bed combustion for Low-Calorific-Value-High-Admixture Coals *

Prepared for the Government of Bulgaria
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Brian Locke
expert in coal processing and new energy technologies,
such as fluidized bed combustion and gasification

Backstopping officer: R. O. Williams, Chemical Industries Branch

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Vienna

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V.86-62992

I ABSTRACT

Title - Fluidized bed combustion for low-calorific-value -high-admixture coals

Number - DP/BUL/81/005/11-53/32.1.I.

Objective - to participate in and present a paper at the Workshop on low-rank coal utilization organized in conjunction with the Bulgarian Academy of Sciences and the V.I. Lenin Higher Institute for Mechanical and Electrical Engineering, Sofia, Bulgaria.

Duration - one week in Bulgaria

Main Conclusions and Recommendations

1. The workshop that brought together delegates from 18 nations was very effective in

   a) producing information on coal resources, particularly of low rank

   b) reporting information on approaches to using those coals

   c) enabling good people to meet who otherwise would not have done so - so they can communicate in future

   d) promoting discussion of problems, processes, issues and possible solutions

   e) encouraging both synergy and initiative in low-rank coal usage.

2. There should be another follow-up Workshop in two or three years' time for the reporting of progress in the interim and of plans for the future.

3. The recommendations made in May 1986, DP/BUL/81/005/11-51/32.1.I. were confirmed as valid. Work has already begun: and a new Institute is being built specifically for the Team concerned. Foreign fellowships and the provision of testing equipment will be useful.

4. There are plans for Bulgaria/North Korea collaboration for 1987, that are worth encouraging.

5. It is proposed to go into the matter, nationally, of improving the efficiency of energy use within industry. This will be a valuable concomitant to the development of supplies of energy to industry.

111 SUMMARY

This workshop was on the tenth anniversary of a UN sponsored international workshop on low-rank coals held in Bulgaria in 1976. Since then much progress has been made by many countries.

In Bulgaria work has been concentrated on pretreating and firing local low-rank, high-moisture, high-ash lignites. This was described. Delegates were taken to the opencast mine and the power station Dimo Ditchev, at Maritza East, where the developed technology was very successfully in operation.

Further, an interest has been taken in fluidized bed combustion, and the programme of work recommended by the author in May 1986 has begun. It should be continued.

Other countries' reports included accounts of geology and mining, boiler and other developments, and, in several cases progress with fluidized bed combustion.

This author presented a paper on the whole range of uses of fluidized bed combustion (fbc) techniques for burning low-calorific-value-high-admixture (lcvha) coals.

The existing connexions between Bulgaria and North Korea would form a useful basis for the collaborative programme that was proposed.

There was unanimous belief that a follow-up workshop in two or three years' time would enable a review to be made of the progress since this workshop. It has been an excellent occasion of discussion and synergy of ideas based on information reported.

IV THE WORK

The job description follows.

The principal purpose of attending the workshop was to present a paper outlining the scope and range of applications of fluidized bed combustion (fbc) technology to the usage in industry of low-calorific-value-high-admixture (lcvha) coals. The paper follows. Slides were shown illustrating the principles of fbc and its salient features. There were also photographs of actual industrial plant including various configurations of boilers, plus furnaces and dryers for agricultural crops and for clay for cement making. Illustrations of pressurized fbc plant were shown too.

Seventeen different nations participated and presented reports: and the names and addresses of the delegates form Appendix 2.

Although the timetable of the workshop was full owing to the number of papers, there was much discussion in large and small groups. The exchange of experiences and ideas for development was enjoyed by all, and believed to be valuable. Every delegate said that he or she would be returning home with fresh ideas to add into work.

The author also found the workshop stimulating. He left Bulgaria having agreed to send information or further advice, or to make useful connexions, for each of the delegates.

Discussions were also held with the Bulgarian organizers on the recommendations and programme in the author's previous report, DP/BUL/81/005/11-51/32.1.I; and on the need in Bulgaria for a campaign to improve the efficiency of energy usage in industry.

The opencast lignite mine and the Dimo Ditchev Maritza East No 3 840 MW power station were visited. These were described briefly in Report DP/BUL/81/005/11-51/32.1.I, of May 1986.

UNITED NATIONS

R. Williams|rp
18 September 1986

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO

JOB DESCRIPTION

DP|BUL|81|005|11-53|32.1.I

Post title	Consultant in fluid bed coal combustion technologies
Duration	Four working days
Date required	14 October to 17 October 1986 (subseq ntly 6)
Duty station	Varna, Bulgaria
Purpose of project	The main purpose is the development of technologies for the utilization of low rank coal for power generation.
Duties	To participate in and present a paper at the Workshop on Low-rank coal utilization organized in conjuction with the Bulgarian Academy of Sciences and the V I Lenin Hihger Institute for Mechanical and Electrical Engineering, Sofia, Bulgaria. The consultant is expected to write a brief report summarizing the information he has given to the Bulgarian scientists and making recommendations to the Bulgarian authorities and UNIDO on further developments of FBC technology in Bulgaria.

..../..

Qualifications Mechanical or chemical engineer with extensive practical experience in fluidized bed combustion technology of coal and operation and maintenance of FBC plants.

Language English

Background information The largest part of the energy needs in Bulgaria are satisfied by coal. This coal is of very low calorific value, high in ash and sulphur content and other impurities.

The plan of the Government of Bulgaria is to produce 43% of the electricity from these low rank coals by the year 1985. However, heavy envorinmental pollution associated with the combustion of these coals, make it imperative to develop efficient coal combustion technologies to prevent such heavy pollution.

Therefore, the Government has embarked on a R+D programme related to the improvement of coal combustion systems applied in existing power stations and to new and more advanced combustion technologies. Therefore, activities are underway for retrofitting power stations with coal precombustion treatment systems for which design work has been completed and tests have been carried out. Furthermore fluidized bed combustion of coal will be developed including the establishment of a pilot plant with 2 to 3 tons|hour capacity.

IV CONCLUSIONS AND RECOMMENDATIONS

A The workshop brought together delegates from 18 nations and was very effective both in subject matter and in the use of the time available. The results included:

a) the production of information on coal resources, particularly of low rank

b) the reporting of information on approaches to using those coals

c) the enabling of people to meet who otherwise would not have done so - so they will be able to communicate in future

d) the promotion of discussion of problems, processes, issues and possible solutions

e) the encouragement of both synergy and initiative in low-rank coal usage.

B Although the time was fully taken up with discussions on lcvha coal usage technologies, there was brief opportunity to talk with the Bulgarian hosts about their own programme. It is understood that the author's May 1986 recommendations are being followed. See report DP/BUL/81/005/11-51/32.1.I for details and background.

The Team is being transferred to its own premises, which are being built. There they will be able to expand the work on their pretreatment rig, and to install equipment for their fbc programme.

Accordingly it is recommended that the programme be continued and developed as outlined in May 1986. The good work done already is a useful basis for such extensions.

Foreign visits to selected hosts would be valuable to extend the experiences already gained abroad.

The provision of the test rig equipment would enable a flying start to be made in the practical work.

C Also the Team have plans for turning their connexions with North Korea into a collaborative programme. This should have advantages for both countries, and results should then be applicable more widely.

D In discussion about the way electricity and other forms of energy are used in industry, it was concluded that there was need to consider, in some depth, a national campaign for energy management, and the improvement of efficiency of energy usage in industry. The author was asked to return in May 1987 for this purpose.

E Finally a follow-up workshop in 1988 or 1989 would be expected to receive reports of interesting and useful developments made as a result of this workshop's interchange of ideas and stimulation of initiatives. Further it would be help to UNIDO in monitoring performance in relevant projects, and indeed of workshops such as this one.

WORKSHOP ON LOW RANK COAL UTILIZATION

Varna, Bulgaria, 14-17 October, 1986

FLUIDIZED BED COMBUSTION

FOR

LOW-CALORIFIC-VALUE-HIGH-ADMIXTURE COALS

Brian Locke, Cadogan Consultants, London

I INTRODUCTION

The main problems of developing coal -using processes concern the low-calorific-value-high-admixture coals (lcvha) that are widely distributed around the world. Generally the more developed nations have been able to evolve their industries on the basis of relatively "good" coals. Western Europe and USA, for example, were in a position to select from the various types of coal available for mining, those with analyses and burningcharacteristics that made them easiest and cheapest to use. Present-day availability of oil, natural gas and nuclear fuels increases the importance of fuel-using economics - when there is a range of choice - this means that only good coals are used in such areas.

As an example, Table 1 relates some characteristics of British coals with the words used to describe them. A "moderate" ash content would be between 5.1% and 7.5%; while any ash content above 15.1% is described as "very high". By contrast, much coal used in India contains ash in the range 30-45%; in North Korea there has been interest in using coals with ash contents of over 70%. The principal use for coal is for combustion in furnaces, mainly in steam boilers for power generation and industrial processing. Most of the plant involved - whether boilers, combustors, gasifiers or furnaces - has been developed for use with ash contents of under 30%.

Coals containing more ash will need both processes and plant to be especially adapted.

Fuel-using plant is designed on the basis of the calorific input required to perform the duty expected. The higher the ratio of ash to calorific content, the larger the plant has to be; the more important the removal of ash from heat transfer surfaces; the greater the need to prevent sintering of ash; the higher the heat-content of the ash removed from the furnace; and the higher the costs of grinding, maintenance, fuel transport etc., and of minimizing atmospheric pollution for any given plant output. So the entire economics profile of boiler and power plant - both capital and operating - becomes different the higher the ash content of the coal. Similar considerations apply to the water content of coal, especially to the proportion of it that cannot be removed before firing - and which therefore contributes to coal weight and becomes part of the furnace atmosphere.

Lcvha coals need an entirely different approach from that normally used for coals in the more industrialized countries.

II COAL CHARACTERISTICS

Table 2 shows the general relationships between volatile matter content, coke-type and age of coal, and the rank. Older coals are "high rank" and younger coals are "low rank". The classification system is used in Britain and applies generally to coal deposits worldwide. Figure 1 shows examples of test-cokes. Table 3 shows how the ranges of values of components of coal substance vary with rank. Figure 2 relates the main coal variables and is of especial interest because it extends right from the youngest lignitous coals of highest volatile and moisture content (and lowest calorific values) through to the oldest anthracites of highest carbon and lowest hydrogen and moisture contents.

Table 4 shows the ignition temperatures of solid fuels. Generally, the younger the coal, e.g. lignites, the lower the ignition temperature. This applies, too, to the fixed carbon. Also in the younger coals, the higher will be the inherent moisture (because of the greater porosity) and the higher the volatile content.

Matters such as ash content (including most of the sulphur) are not related to the age of the coal, but derive entirely from the geological history. In some cases, ash-forming minerals are found in bands separate from the coal strata, in which case coal cleaning is usually possible, using the specific gravity difference between coal substance and mineral. This is generally the case in West Europe and much of North America.

However, in other coal measures, such as in Bihar in India, much mineral material is finely divided and widely distributed throughout the coal substance - and this is difficult to separate by conventional coal washing techniques. There is usually extraneous ash too, but also difficult to separate using specific gravity difference, because the coal substance is denser on account of its high mineral content.

Details of three Bulgarian coals, given to the author, are shown in Table 5. They come definitely into the category of lcvha fuels, with (C+H)% figures of 20.0%, 29.5% and 31.8% - the non-combustible contents being 80.0%, 70.5% and 68.2%. The sulphur figures are low on the as-received basis, but represent 10%, 4.4% and 5.3% on combustible matter- which is high in terms of potential atmospheric pollution from oxides of sulphur.

The available lcvha coals differ from country to country. Some examples showing how widely the properties may vary, are:

(i) <u>China</u> - Sized and dressed coals in two ash content categories, under 32%, and (the majority) under 40%.

- Low grade coals - under 49%.

(ii) North Korea - Brown coals - up to c.41% ash (low moisture contents).
- Sapropelic coals - up to c.80% ash with very low moisture content.

(iii) South Korea - Anthracites - up to c.70% ash.

(iv) India - Bituminous coals - up to 45% ash.
- Lignites - e.g. Kashmir - ash 38% moisture 24%
e.g. Neyveli - ash 20%, moisture 50%.

(v) Pakistan - Bituminous coals, e.g. Quetta, Salt, Lakhra - ash 30%, sulphur up to 10%.

(vi) Brazil - Santa Catarina bituminous middlings - ash 40%.

(vii) Canada - Bituminous coals, e.g.
- Battle River - ash 14%, moisture 28%
- Grand Cache - ash 45%, moisture 8%

III USING LCVHA COALS

Bulgaria has its own very effective classification system and range of processes for lcvha coals, that will presumably be described by other authors.

In other countries, the coals with least convenient characteristics may well be allocated to the larger central power stations and, where ash chemistry allows, to cement plants. There is usually an economic trade-off between the costs of benefication (where that is possible) and those of transporting, and using, coals with ash that could have been reduced in proportion. Many coal suppliers are installing beneficiation plant where capital is available and its use justified.

It is presumed for the purposes of this paper, that lcvha coal has to be used as received.

The main problems include:

(i) moisture - extra handling cost, corrosion, hang-up in bunkers chutes and mills, reduced boiler gross thermal efficiency - and, where considerable, trouble with pf flame stability, also high stack gas dew point

(ii) ash - extra transport cost, wear of screens and mills, slagging of refractories, erosion and deposits on boiler tubes, load upon electrostatic precipitators, liability to external dust nuisance and, where considerable, trouble with ignition and pf flame stability

The subsidiary problems include:

(iii) sulphur - corrosion at the cool end of the boiler especially at part-load and below the dew-point, atmospheric SO_2 pollution.

(iv) chlorine - deposits on boiler tubes; difficulty when used for cement manufacture.

IV PROCESS POSSIBILITIES

The chief fundamental need is to separate calorific content from ash. Boilers and hot gas furnaces burn the hydrocarbons, leaving ash, using the hot flue gas directly. In the "two stage" approach, gas-making processes make a combustible gas as the first stage and burn that as the second stage. Carbonisation distils volatile matter for later combustion, leaving either coke or char depending on the caking properties of the coal -- and the ash remains in coke or char.

Where the chemistry of the ash poses problems, as may be the case with cement manufacture, then there is an incentive to pre-gasify, or to pre-combust, the coal before the gaseous products enter the kiln.

For boilers, where the main needs arise, ash contents of over 30% are generally not acceptable for mechanical stokers and are undesirable for pulverized fuel firing. Beyond pulverized fuel capability, then slagging cyclone combustion is one principal approach; fluidized bed combustion is the other.

1. Slagging Cyclone Combustion

The slagging cyclone is illustrated in Figure 3. There are two basic philosophies: in Europe to use the coal crushed to c. 1 mm and less, and in America to crush it to below 7mm. In both cases, the combustion temperature must be sufficient to melt the ash, which forms a layer of equilibrium thickness inside the water-cooled refractory lining of the combustion chamber. Coal particles can remain stuck to the gradually rotating ash layer until they have substantially completed combustion. In practice, ash with a flow temperature (in the range 50-100 poises) of over 1400^{0}C may be difficult to handle in such a plant.

In cyclone combustion, the ash/slag does not enter the boiler as such, although, of course, alkali metal chlorides may still be a nuisance.

It is also possible to fire pulverized fuel into a water tube boiler of design such that the ash melts and is discharged from the bottom as slag. Care needs to be taken with combustion chamber radiant heating surface, and control of flame shape and length.

2. Fluidized Bed Combustion

Fluidized bed combustion probably offers the most useful range of characteristics for lcvha coals, in the family of process configurations that are available. Most of the first applications have been for steam boilers, for process steam and for power generation. Sizes of up to some 300 tonnes/h of steam can be regarded as straightforward with ordinary fuels, and there should now be continuing steady progression in size up to the largest central power station requirements.

The general conclusion from experience with hundreds of plants over a number of years, is that once a fuel is introduced into the fluidized bed combustion chamber, then it can be burnt satisfactorily at high efficiency by the techniques available.

(i) Oxides of Sulphur and Nitrogen

The SO_2 can react directly with limestone by the exothermic reaction:

$$CaCO_3 + SO_2 + \tfrac{1}{2}O_2 = CaSO_4 + CO_2$$

However, if the temperature exceeds the equilibrium value (dependent on CO_2 partial pressure) for the endothermic calcination reaction:

$$CaCO_3 = CaO + CO_2$$

then it is the calcium oxide that becomes sulphated:

$$CaO + SO_2 = \tfrac{1}{2}O_2 = CaSO_4$$

The tendency is for limestone to become calcined in combustors operating at near atmoshperic pressure but not in combustors operating at several times atmospheric pressure. When calcination occurs, the particle becomes more porous, owing to CO_2 evolution, with the development of a large internal surface for sulphation. On the other hand, the final reaction product, calcium sulphate, is bulkier than the oxide and it may block the pores, form an impervious skin on the particle, and hinder further reaction. With dolomite, $CaCO_3MgCO_3$, endothermic decomposition and half calcination occur at temperatures several hundred degrees lower than that for limestone calcination, i.e. at well below combustor temperatures even at high pressures. The product is a mixture of calcium carbonate and magnesium oxide formed by reactions which can be represented as:-

Decomposition: $CaCO_3.MgCO_3 = (CaCO_3 + MgCO_3)$

Half-Calcination: $(CaCO_3 + MgCO_3) = (CaCO_3 + MgO) + CO_2$

The MgO produced by these reactions does not react with SO_2 under combustor conditions, but because it results from calcination it creates and maintains, during the lime-sulphation process, a high degree of porosity and accessibility to internal surface.

This facilitates absorption of SO_2 either at low temperature with calcium carbonate, or by reaction with calcium oxide at temperatures above the limestone calcination level.

Almost any degree of sulphur absorption can be achieved by the presence of sufficient calcium in the ash or of sufficient limestone or dolomite added to the bed. On the basis of Ca/S mol ratio, dolomites added to the bed are superior to limestones when operating under elevated pressure, but slightly inferior at ambient pressure. On a weight basis, on the other hand, limestones are superior to dolomites at ambient pressure. Other parameters which can have significant effect are bed temperature, gas residence time (i.e. bed depth divided by fluidising velocity), reactivity of the calcium mineral, particle size of the calcium mineral, and the pressure under which the combustion is conducted.

The most suitable operating temperature of the bed will generally be somewhere between 750°C and 950°C, depending on the particular application, and the fuel characteristics. In this range the formation of oxides of nitrogen is minimized, as also the emission of trace elements and the volatilization of alkali metal salts; slagging and clinkering are virtually eliminated; and the reaction of sulphur dioxide with limestone and dolomite is most effective, see Figures 5 and 6.

(ii) Heat Transfer

To maintain the bed temperature between 750°C and 950°C, it is necessary for heat to be removed continuously from the fluidized combustor. This can be achieved by immersing cooling tubes, carrying a working fluid such as water, steam, air, (or even specialist heat transfer fluids, such as diphenyloxide mixtures) in the bed. Alternatively, substantial quantities of excess air, over and above that required to maintain combustion, can be supplied to the bed to carry away the heat. The total heat transfer co-efficient between the fluidized bed and submerged cooling tubes, which comprises radiative and convective components, can be up to ten times higher than in conventional gas-to-surface heat exchange systems, depending on particle size. Figure 4 shows the effect of particle size and gas velocity on plant output. This means that fluidized combustion boilers need much less heat transfer surface than do conventional boilers.

Another factor which further increases the saving in heat transfer surface obtained with fluidized combustion, is that the whole of the surface of the tubes immersed in the bed is available for heat transfer, whereas only half of the surface of most of the tubing of a conventional pulverized-fuel boiler furnace is exposed to the combustion gases. Figure 7 shows a small water tube boiler converted to fluidized bed combustion.

V FLUIDIZED COMBUSTION APPLICATIONS

Fluidized combustion at ambient pressure is ideally suited to steam raising and hot water boilers, process heaters, dryers and incineration applications. The combustion bed may be used with or without heat transfer tube, according to whether the output is required as heated thermodynamic-working fluid, or just hot gas - and with or without deliberate sulphur retention, according to the sulphur content of the fuel material and the environmental pollution legislation. Much experience has become available since the new approach to fluidized combustion was inaugurated by the BCURA prototype shell boiler, which began work in 1969. That work was followed by several hundred boilers worldwide burning a large variety of solid, liquid and gaseous fuels in very many different configurations of plant. Fluidized combustors, being compact, can also be designed for operation at elevated pressures. Containment in a pressure vessel is straighforward. The bed is maintained at the desired operating temperature either by heat removal via tubes in the bed, or by the use of excess air; and the hot pressurised flue gases, after removal of particulate matter, can be expanded through a gas turbine for power generation. When operating at elevated pressure, the potential reduction in boiler size is considerable. The heat release per unit cross-sectional area of bed can be increased, broadly, in direct proportion to the increase in operating pressures - fortunately without incurring a proportionate increase in the amount of material elutriated from the bed. (See Figure 4). The heat release per unit volume of the bed is also increased, in proportion to the pressure, and needs to be contained within the limit of the proportion of heat that can be absorbed by tubes within the bed before the above-bed temperature rises above the required level. Because the rate of heat transfer in the bed does not rise with increase in pressure (or velocity) over the ranges appropriate to commercial plants, bed depth will have to be increased to accommodate the necessary heat transfer surface. This matter of geometry may be of more consequence than the small extra combustion pressure drop involved.

1. Pressurized Power Generation Cycles

As well as the Rankine cycle, as used in conventional power stations, where ambient pressure fluidized bed combustion is substituted for pulverized fuel firing, the combustion itself can also be under pressure as just outlined. The number of possible thermodynamic cycles is large, and can be classified into two groups. In one group the working fluid is air and/or combustion products; in the other group there are two working fluids - steam and combustion products. In all cases, calcium in the bed will retain a calculable proportion of fuel sulphur, so preventing its oxides from entering the flue gases. The production of oxides of nitrogen from pressurised fluidized combustors is also generally less than from fluidized combustors working at ambient pressure.

(i) Open Cycle Gas Turbine

This is the simplest cycle in which all the working fluid is used as fluidizing air, which is heated to turbine inlet temperature in passing through the bed. (See Figure 8). This cycle makes use of the very high heat transfer rates in a fluidized bed for the direct heating of the working fluid by the hot particles in the bed: however, all the working fluid has to be cleaned of particles before it reaches the turbine.

(ii) "Air Heater" Cycle

This is a derivative of the simple cycle and is shown in Figure 9. Air from the compressor is split into separate streams and most of it (up to some two-thirds) passes through tubes immersed in the fluidized bed, where it is heated to a temperature approaching the combustion bed temperature before being mixed with the cleaned products of combustion from the remaining air stream. Such a cycle involves a smaller combustor than does a simple open-cycle, and produces a smaller quantity of gas requiring cleaning, but demands sophisticated materials for the hot end of the air tubes. Combustion is carried out with a lower percentage of excess air than in the simple open-cycle. There are several configurations possible.

(iii) <u>Closed Cycle Gas Turbine</u>

In this cycle (Figure 10) the air heated in the tubes forms part of a closed cycle unit. Generally, such units operate at a lower pressure ratio than conventional gas turbines, but at a significantly higher pressure level. This leads to substantial increases in the heat transfer co-efficient between the air and the tube wall and hence to a reduction in the amount of heat exchange surface required. The combustor can either be pressurised, in which case the combustion gases pass through an open-cycle gas turbine, or it can operate at atmospheric pressure.

(iv) <u>Supercharged Combined Steam Gas-Turbine Cycle</u>

This type of cycle is illustrated in Figure 11. A gas turbine is "across" the combustion chamber, while steam generated in the boiler tubes, drives the steam turbine. Although there is scope for variation in the way in which the steam generating surface is disposed, there are fewer possible cycle variations than with the air cycles. This scheme is basically a high efficiency cycle and the main scope for ingenuity lies in transferring as much heat as possible from the gas turbine exhaust back into the steam cycle. Effectively the Rankine and Brayton cycles each contribute to generation efficiency; the combustion "beneficiates" the steam cycle.

Figure 12 shows the layout of one of the earlier British experimental pressurized plants. The NCB is now operating an 80 MW pressurized text plant at a coal mine in Yorkshire aimed at this combined cycle.

VI SPECIAL ARRANGEMENTS FOR LCVHA COALS

The higher the volatile content - the lower the rank of a coal - the easier ignition becomes, and the more easily it may be burnt to completion. Figure 13a illustrates this point.

High moisture content and the presence of fibrous material may often imply the need for the approach used in Bulgarian power stations for pre-treatment. High ash contents, however, make it necessary to take special measures to accommodate them and to ensure burn-out of particles. The flat-plate distributor and weir overflow of ash that works so well with coals of moderate ash content can easily become blocked with large particles or stones (See Figure 13b). Accordingly, various forms of sloping base plate, or its equivalent, have been used. Some examples constitute Figure 14, showing arrangements for discharging ash from the bed. Ash so removed may need to be classified, so that material with a significant carbon content can be re-injected. Figure 15 shows some ways of doing this.

1. Difficult burn-out coals

Where coal particles are light (as with lignites) or/and of low reactivity, as with anthracites, there may well be high carbon contents in carry-over and elutriated ash. There are several ways of increasing residence time, so as to encourage burn-out.

- (i) Circulation within the bed
- (ii) Recirculation within the boiler
- (iii) Recycling ash back to the boiler
- (iv) Multiple beds

Figure 16 shows both an example of a circulating bed combustor and its arrangement in a boiler. An extension of the same principle leads to the recirculation concept as shown in Figure 17.

Recycling involves returning material to the combustion system, as shown in Figure 18. A combination of recirculation and recycling is shown in Figure 19 of the "multi solids" system.

Multiple beds are the other way to achieve the same result, of duplicating residence time, not by recycling around the same bed, but by passing particles from one bed to another. Figures 20, 21 and 22 show three different approaches.

VII CONCLUSION

There is an interesting future ahead for the development of existing technologies to handle the large tonnages of lcvha coals that need to be burnt efficiently. Often they are being burnt very inefficiently at present - and sometimes with much atmospheric pollution, especially with old plants.

Techniques such as cyclone combustion, and particularly fluidized bed combustion, offer good starting positions, and much opportunity for steam and power generation with lcvha coals as programmes develop in Bulgaria and elsewhere.

In Bulgaria and other countries with lcvha coals there is much work to be done, and much benefit to be obtained.

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ACKNOWLEDGMENTS

This review paper draws upon the author's own experience and his previous papers, and also on work by many people around the world, especially,

H.R. Hoy et al	BCURA
P. Mills B. Beacham H. Lunn	CSL
J. Highley M.J. Fisher et al	CRE (NCB)

and the team at the VI Lenin Higher Institute of Electrical and Mechanical Engineering, Sofia, as regards Bulgarian coals.

U.K. Abbreviations

BCURA	British Coal Utilisation Research Association
BP	British Petroleum
CRE	Coal Research Establishment of the NCB
CSL	Combustion Systems Ltd., operated by BP and NCB
NCB	National Coal Board, now renamed British Coal

TABLE 2

THE COAL CLASSIFICATION SYSTEM USED BY THE NATIONAL COAL BOARD

(Revision of 1964)

Coals with ash of over 10 per cent must be cleaned before analysis for classification to give a maximum yield of coal with ash of 10 per cent or less.

Coal Rank Code			Volatile Matter (d.m.m.f.) (per cent)	Gray-King Coke Type*	General Description
Main Class(es)	Class	Sub-Class			
100			Under 9·1	A	Anthracites
	101†		Under 6·1	A	
	102†		6·1–9·0		
200			9·1–19·5	A–G8	Low-volatile steam coals
	201		9·1–13·5	A–C	Dry steam coals
		201a	9·1–11·5	A–B	
		201b	11·6–13·5	B–C	
	202		13·6–15·0	B–G	Coking steam coals
	203		15·1–17·0	E–G4	
	204		17·1–19·5	G1–G8	
300			19·6–32·0	A–G9 and over	Medium-volatile coals
	301		19·6–32·0	G4 and over	Prime coking coals
		301a	19·6–27·5	G4 and over	
		301b	27·6–32·0		
	302		19·6–32·0	G–G3	Medium-volatile, medium-caking or weakly caking coals
	303		19·6–32·0	A–F	Medium-volatile, weakly caking to non-caking coals
400 to 900:—			Over 32·0	A–G9 and over	High-volatile coals
400			Over 32·0	G9 and over	High-volatile, very strongly caking coals
	401		32·1–36·0	G9 and over	
	402		Over 36·0		
500			Over 32·0	G5–G8	High-volatile, strongly caking coals
	501		32·1–36·0	G5–G8	
	502		Over 36·0		
600			Over 32·0	G1–G4	High-volatile, medium-caking coals
	601		32·1–36·0	G1–G4	
	602		Over 36·0		
700			Over 32·0	E–G	High-volatile, weakly caking coals
	701		32·1–36·0	E–G	
	702		Over 36·0		
800			Over 32·0	C–D	High-volatile, very weakly caking coals
	801		32·1–36·0	C–D	
	802		Over 36·0		
900			Over 32·0	A–B	High-volatile, non-caking coals
	901		32·1–36·0	A–B	
	902		Over 36·0		

* *Coals with volatile matter of under 19·6 per cent. are classified by using the parameter of volatile matter alone; the Gray-King coke types quoted for these coals indicate the general ranges found in practice, and are not criteria for classification.*

† *In order to divide anthracites into two classes, it is sometimes convenient to use a hydrogen content of 3·35 per cent. (d.m.m.f.) instead of a volatile matter of 6·0 per cent. as the limiting criterion. In the original Coal Survey rank coding system the anthracites were divided into four classes then designated 101, 102, 103 and 104. Although the present division into two classes satisfies most requirements it may sometimes be necessary to recognize more than two classes.*

Notes

1. Coals that have been affected by igneous intrusions ("heat-altered" coals) occur mainly in classes 100, 200 and 300, and when recognized should be distinguished by adding the suffix H to the coal rank code, e.g. 102H, 201bH.
2. Coals that have been oxidized by weathering may occur in any class, and when recognized should be distinguished by adding the suffix W to the coal rank code, e.g. 801W.

TABLE 1

NATIONAL STANDARDS FOR VERBAL DESCRIPTION OF RANGES OF VARIOUS PROPERTIES OF BRITISH COALS

Description	Ash (per cent.)	Sulphur (per cent.)	Carbon Dioxide (per cent.)	Chlorine (per cent.)	Phosphorus (per cent.)	Arsenic (p.p.m.) As_2O_3)	Hemisphere Temperature of ash (°C.) in Reducing Atmosphere
Very high ..	15·1 and over	4·01 and over	2·51 and over	0·61 and over	0·071 and over	71 and over	1460 and over
High ..	10·1–15·0	2·51–4·00	1·01–0·60	0·31–0·60	0·031–0·070	31–70	1360–1450
Moderately high	7·6–10·0	2·01–2·50	—	—	—	—	—
Moderate ..	5·1–7·5	1·51–2·00	0·51–1·00	0·16–0·30	0·011–0·030	11–30	1210–1350
Moderately low	—	1·01–1·50	—	—	—	—	—
Low ..	2·6–5·0	0·51–1·00	0·21–0·50	0·06–0·15	0·0051–0·010	4–10	1110–1200
Very low ...	2·5 and under	0·50 and under	0·20 and under	0·05 and under	0·0050 and under	3 and under	1100 and under

Notes—(1) The steps between adjacent ranges indicate the degree of approximation to which each property should be reported. The figures are "on air-dried coal".

(2) Individual coalfields may tend to have their own characteristics. Thus, in Scotland and South Wales where most coals have sulphur contents of under 1·5 per cent., 1·9 per cent., for example, would be "high" rather than "moderate".

(By courtesy of the National Coal Board.)

TABLE 3

VARIATION OF CERTAIN PROPERTIES OF BRITISH COALS WITH RANK

Coal Rank Code	Carbon (d.m.m.f.) (per cent)	Hydrogen (d.m.m.f.) (per cent)	Volatile Matter (d.m.m.f.) (per cent)	Calorific Value (d.m.m.f.) (B.t.u./lb.)	Moisture (a.d.) (per cent)	Gray-King Coke Type	B.S. Swelling Number	Main Uses*
100	92–95	2·8–3·9	2–9	15300–15850	0·9–2·9	A	0	Closed stoves, horticulture, malting, boilers
201	91–93·5	3·7–4·3	9–13·5	15500–15950	0·6–2·0	A–C	0–4	Closed stoves, boilers
202–4	90·5–93	4·1–4·8	13·5–19·5	15600–15950	0·5–1·3	B–G8	1–> 9	Boilers, blending for coking
301	87–91·5	4·5–5·4	19·5–32	15300–16000	0·4–2·0	G4 and over	6–> 9	Blast-furnace and foundry coke
302, 303	86·5–91·5	4·4–5·4	19·5–32	14900–15900	0·7–4·0	A–G3	0–9	Boilers, carbonization (C.R.C. 302 only)
400	84·5–89·5	5·1–5·8	32–40	15[illegible]00–15900	0·9–2·5	G9 and over	5½–9	Blast-furnace coke, gas
500	83·5–88·5	5·1–5·8	32–40	14900–15700	1·0–4·5	G5–G8	3½–9	Blast-furnace coke, gas
600	83–88	5·1–5·8	34–42	14800–15600	1·5–6·0	G1–G4	3–8	Blast-furnace coke, boilers, open fires, gas
700	82–87·5	5·0–5·8	34–42	14550–15400	2·0–8·5	E–G	1–6½	Boilers, gas producers, blending for carbonization, open fires
800	80–86	4·9–5·7	34–45	14050–15050	3·0–14·0	C–D	½–4½	Boilers, open fires, gas producers
900	78·5–84	4·9–5·6	34–45	13600–14800	4·0–14·5	A–B	0–2	Boilers, open fires

D.m.m.f.—dry, mineral-matter-free basis; a.d.—air-dried basis. 1 B.t.u./lb equals 2·326 kJ/kg.

* In assessing the suitability of a coal for a specific use (*e.g.* coke manufacture), account has usually also to be taken of other properties (*e.g.* ash and sulphur). "Closed stoves" and "open fires" are domestic appliances.

(*By courtesy of the National Coal Board.*)

TABLE 4

IGNITION TEMPERATURES OF SOLID FUELS IN AIR

	°F.	°C.
Wood—bulk	540	282
—volatiles	1100	590
Coal—Bituminous Gas	700	371
—Bituminous Ordinary	750–800	400–425
Welsh Steam	880	470
Anthracite	930	500
Coke—Hard	930–1200	500–650
Gas	800–930	425–500
Fixed Carbon in—Bituminous Coal ...	760	404
—Steam Coal ...	870	466
—Anthracite	925	493

Note.—Ignition temperatures depend not only on the precise nature of the fuel but on the method of test, air movement, etc. All values are necessary approximate.

TABLE 5

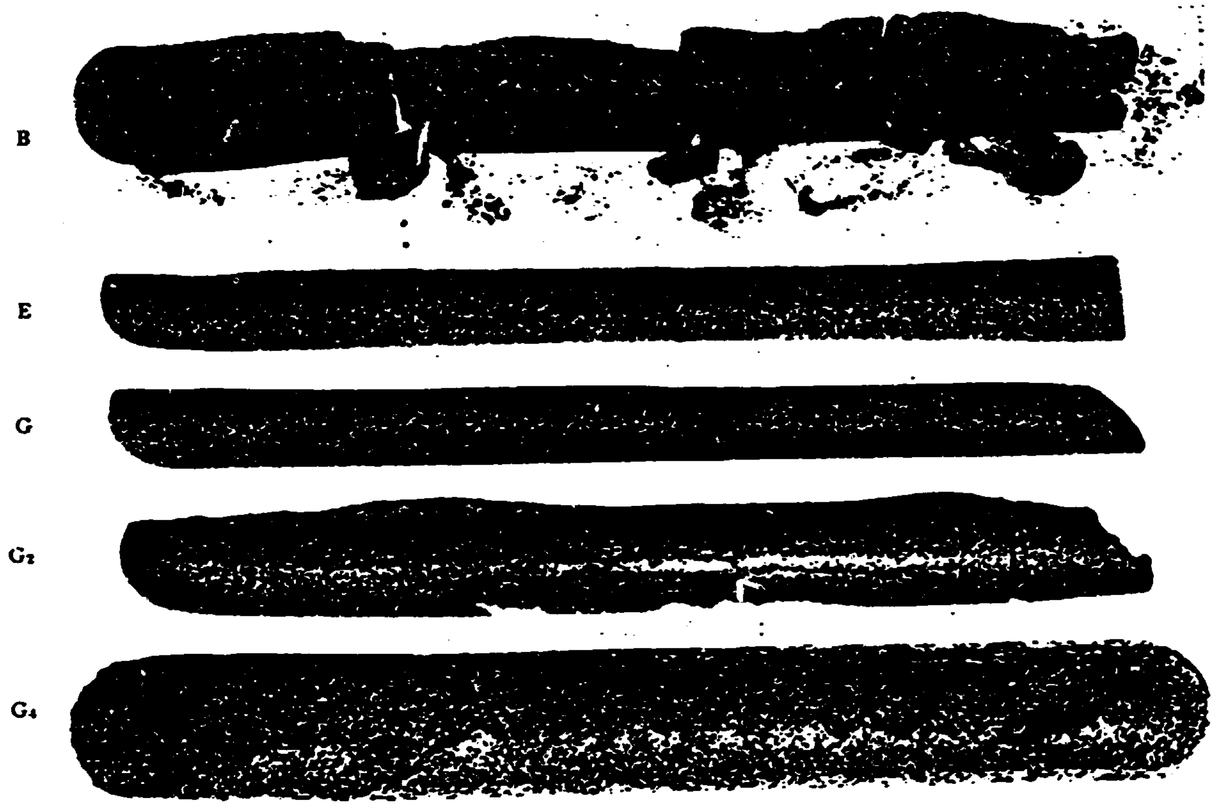
Relevant Bulgarian Coals

	Maritza - East lignite Coal	Pernik Brown Coal - high ash	Bobovdol Brown Coal
W_t^r %	55.0	16.0	16.0
A^r %	15.7	44.5	40.3
C^r %	18.4	27.1	29.6
H^r %	1.6	2.4	2.2
O^r %	5.5	8.4	5.9
N^r %	0.3	0.7	1.1
S^r %	2.0	1.3	1.7
Q_i^r kJ/kg	6000.0	10100.0	11300.0
t_1^L °C	1250 (1220 - 1300)	1240	1190 - 1240
t_2^L °C	1280 (1260 - 1300)	1320	1290 - 1300
t_3^L °C	1300 (1280 - 1300)	1350	1330 - 1360
t_1^{BB} °C	1050 - 1150	1050	1000 - 1120
t_2^{BB} °C	1150 - 1300	1190	1160 - 1215
t_3^{BB} °C	1200 - 1400	1230	1200 - 1270
kg/m^3	700 - 1100	700 - 1100	700 - 1100
V^{daf} %	60 - 64	50 - 52	50
W_h^r %	11.0	-	-
k_o^{BTU} -	0.83 - 1.22	0.9 - 1.2	0.9 - 1.2

Table 5 cont'd..

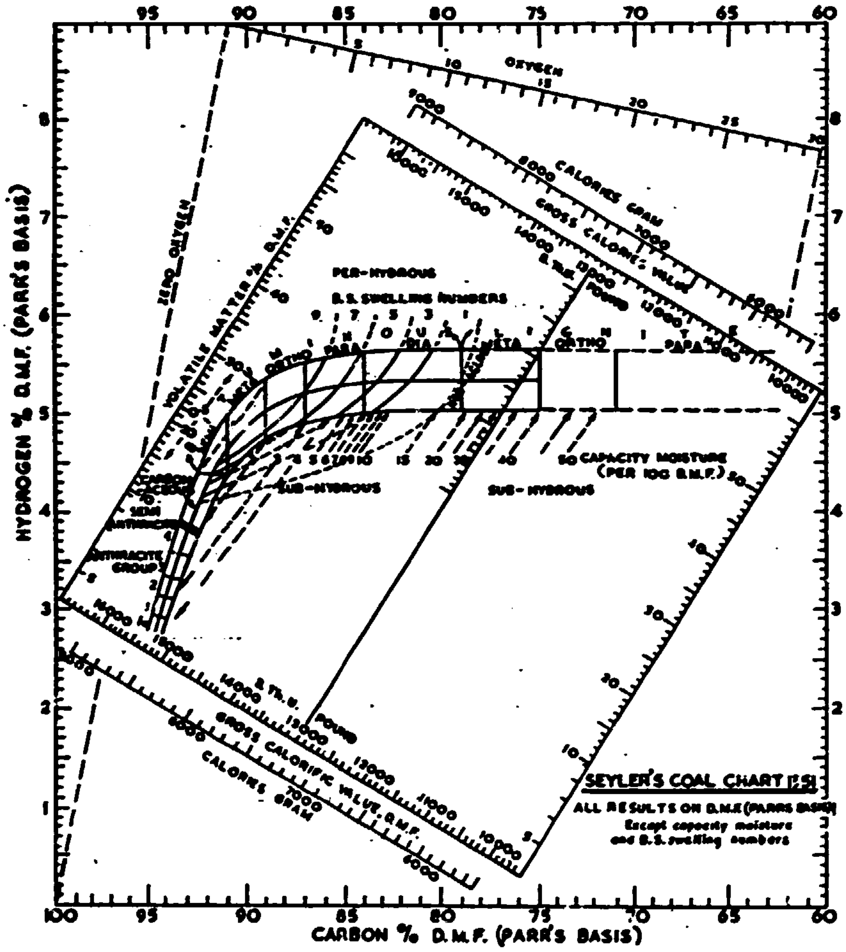
	Maritza - East lignite Coal	Pernik Brown Coal - high ash	Bobovdol Brown Coal
SiO_2 %	35 - 50	54 - 61	50 - 60
Al_2O_3 %	16 - 32	26 - 30	23 - 30
Fe_2O_3 %	2.5 - 5	1.5 - 5	1.- 3
CaO %	1.5 - 3.5	0.5 - 2.5	1 - 4.3
MgO %	7 - 20	5 - 10	9 - 18
Na_2O %	0.2 - 0.4	-	0.2 - 0.4
K_2O %	0.2 - 0.6	-	0.3 - 1.3
SO_3 %	2.5 - 15	1 - 5	0.8 - 3.5

FIGURE 1



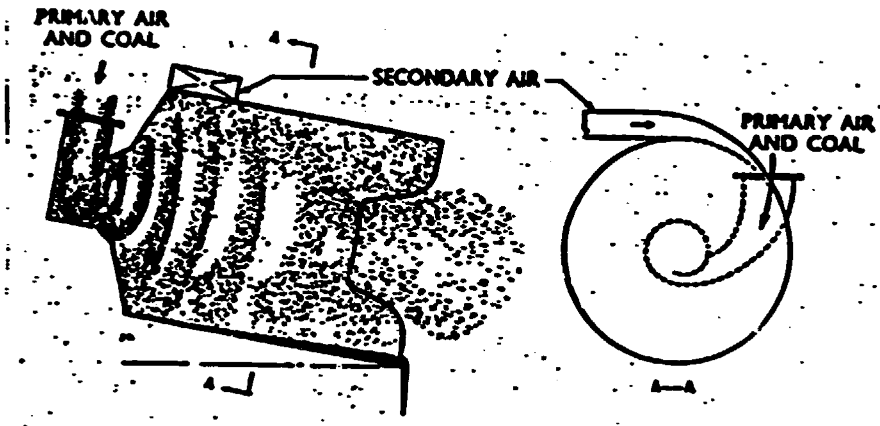
Selection of Standard Cokes of the Gray-King Assay.

FIGURE 2



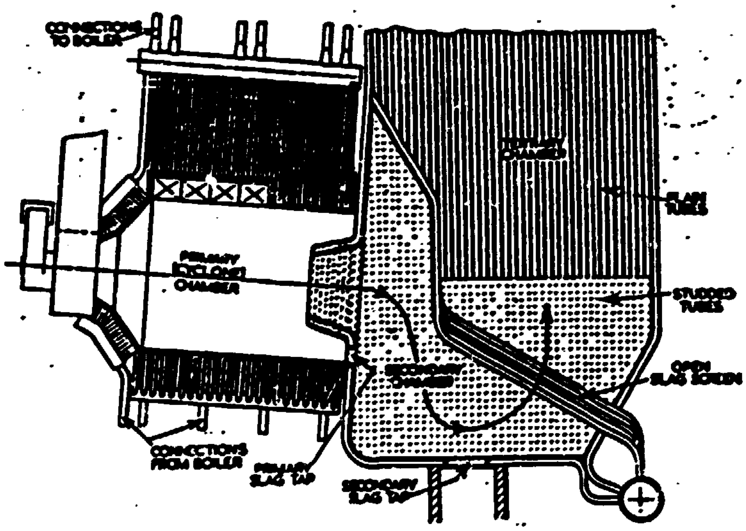
Seyler's Classification of Coal.

FIGURE 3



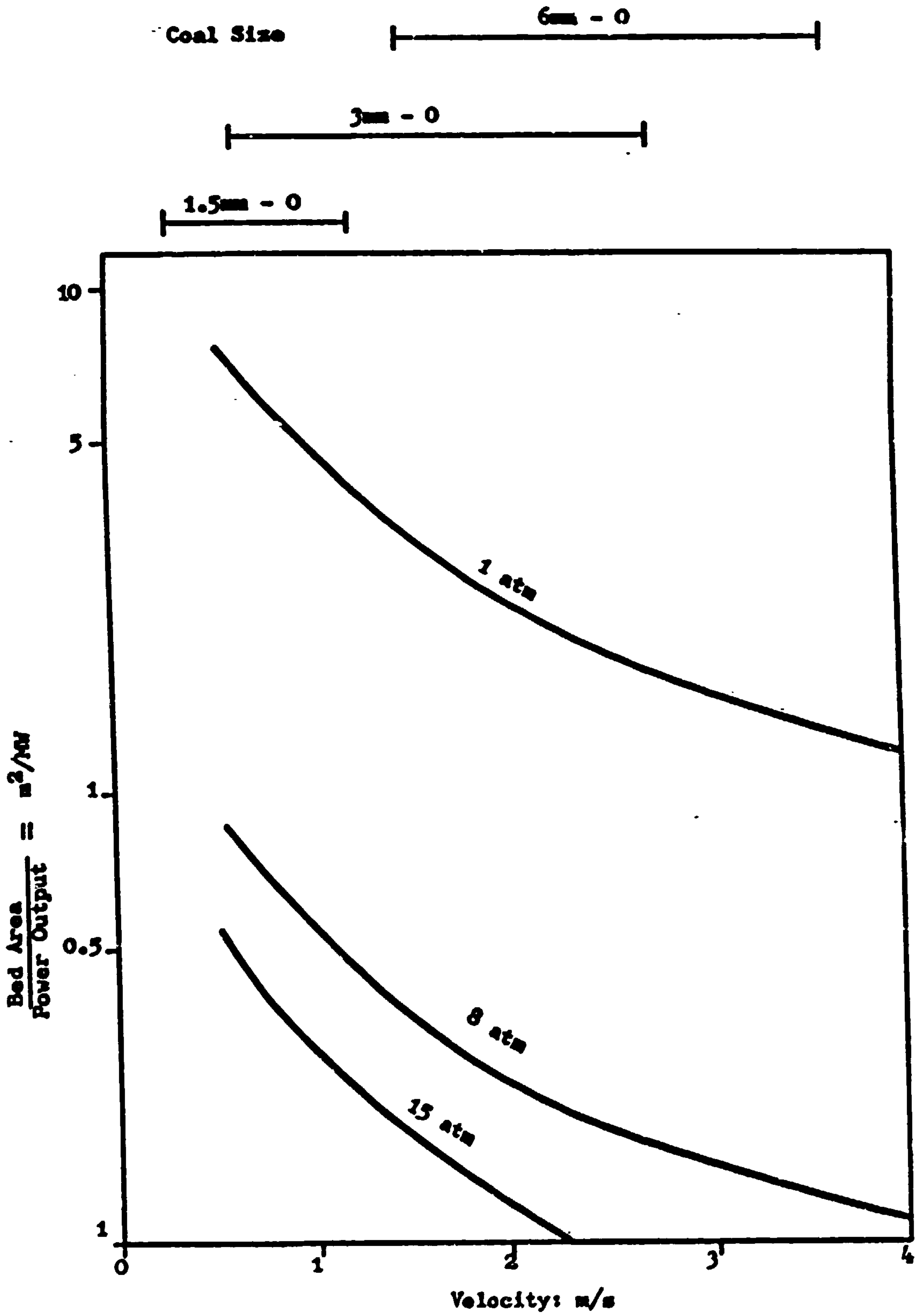
THE CYCLONE FURNACE

Simplified representation of a cyclone furnace



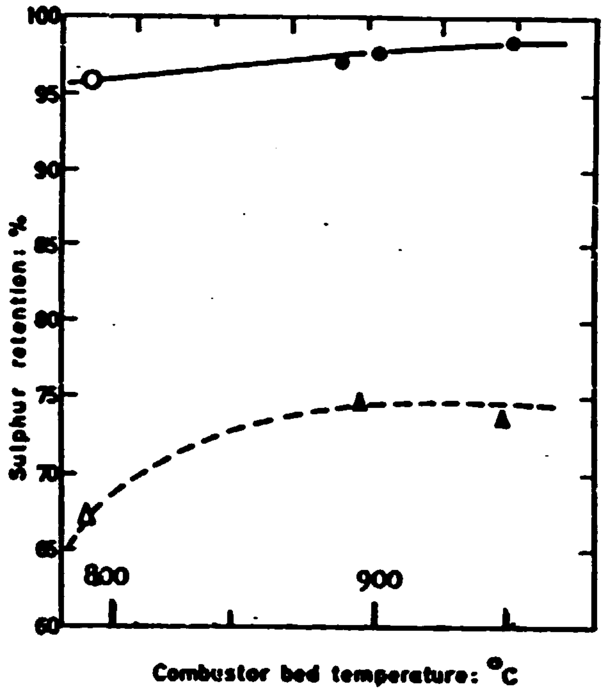
Cyclone furnace applied in firing a water-tube boiler.

FIGURE 4



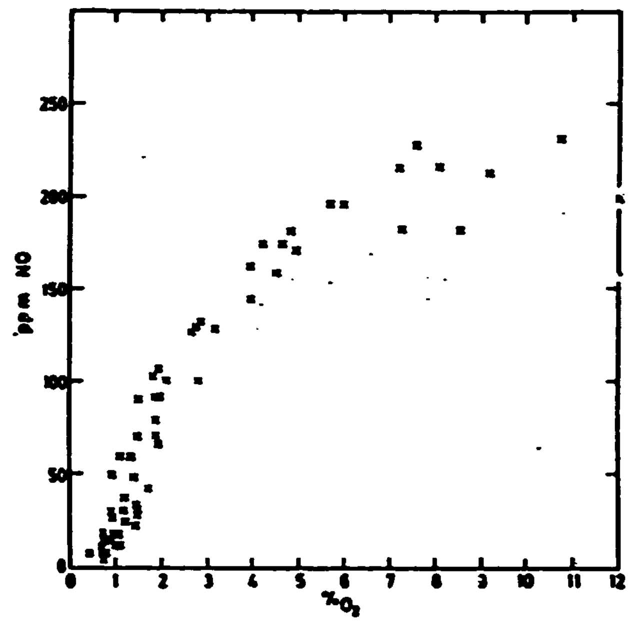
AREA OF BED/POWER OUTPUT v FLUIDIZING VELOCITY

FIGURE 5



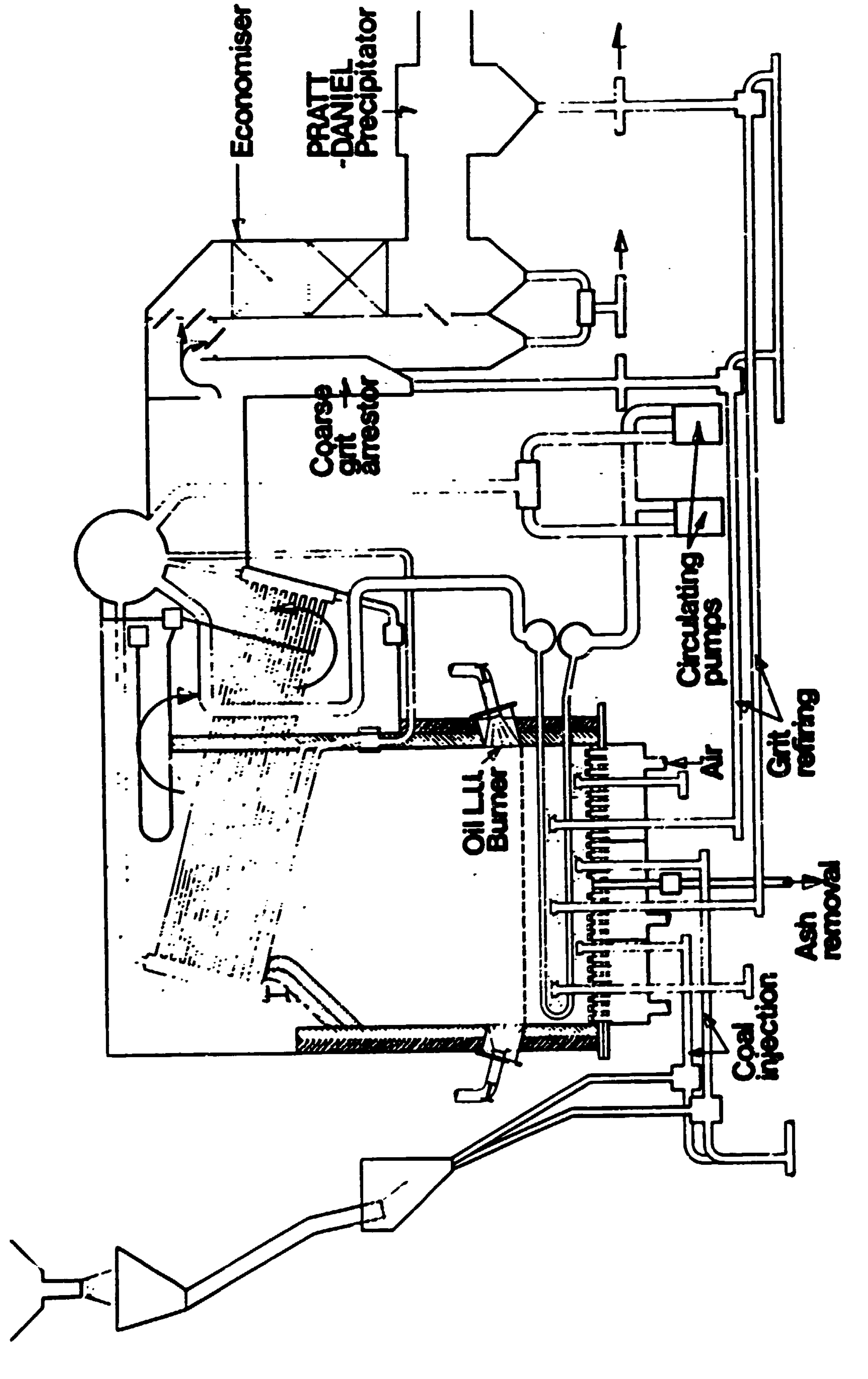
Effect of combustor temperature on sulfur retention in pressurized combustor. Upper curve: dolomite addition; Ca/S mol ratio is 2. Lower curve: limestone addition; Ca/S mol ratio is 2.

FIGURE 6



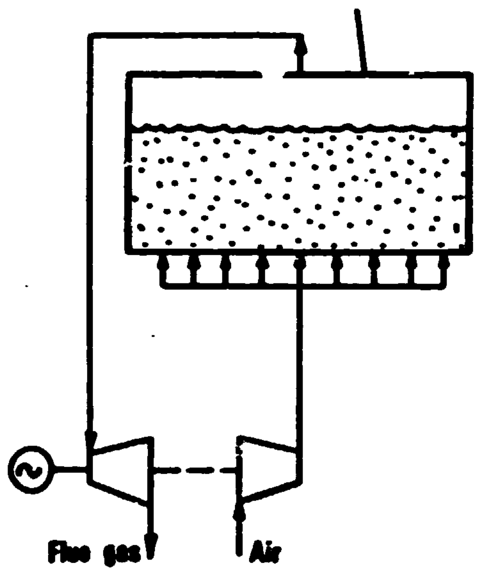
NO_x emissions from pressurized combustor.

FIGURE 7



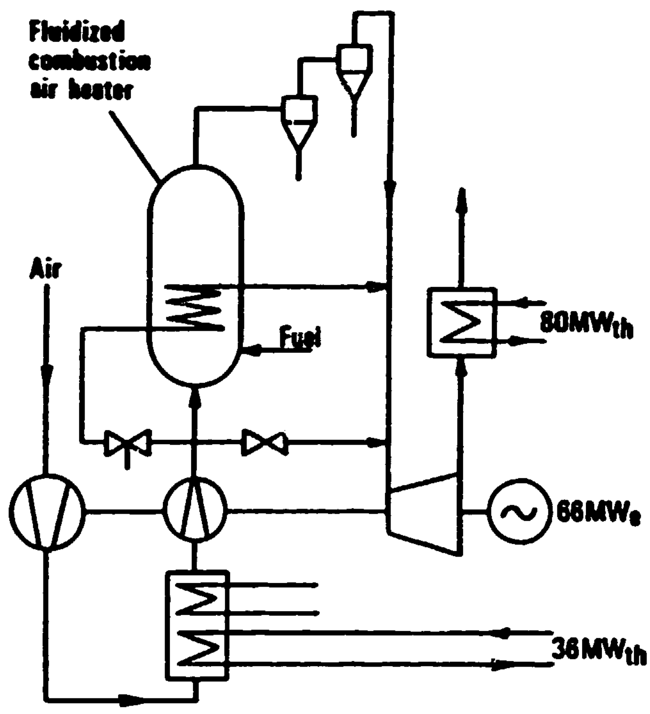
BCSL Fluidized Combustion Water-Tube Boiler

FIGURE 8



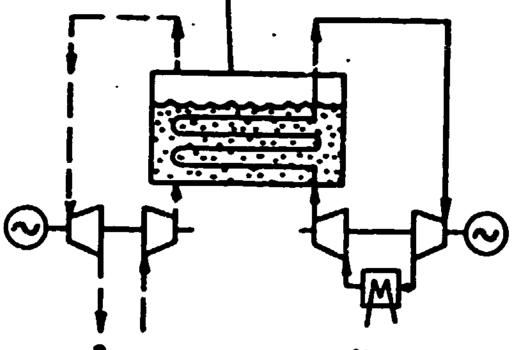
Simple open cycle

FIGURE 9



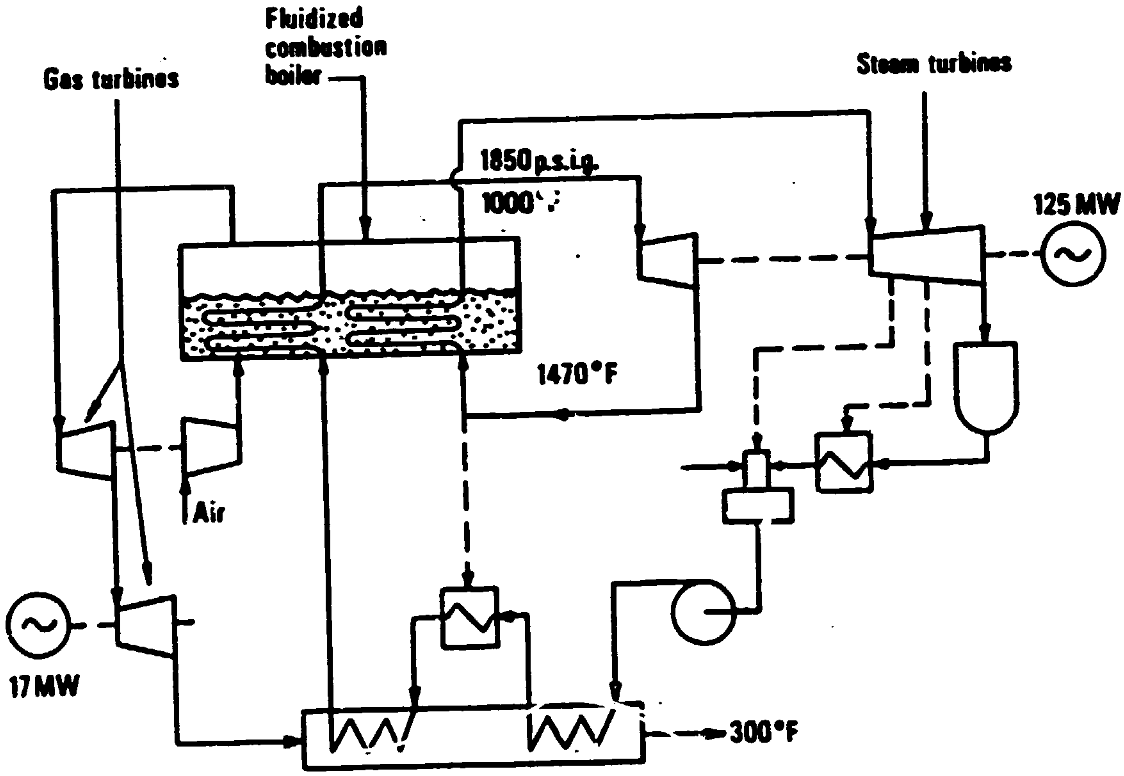
66 MWe Airheater cycle with heating recovery for district heating.

FIGUR



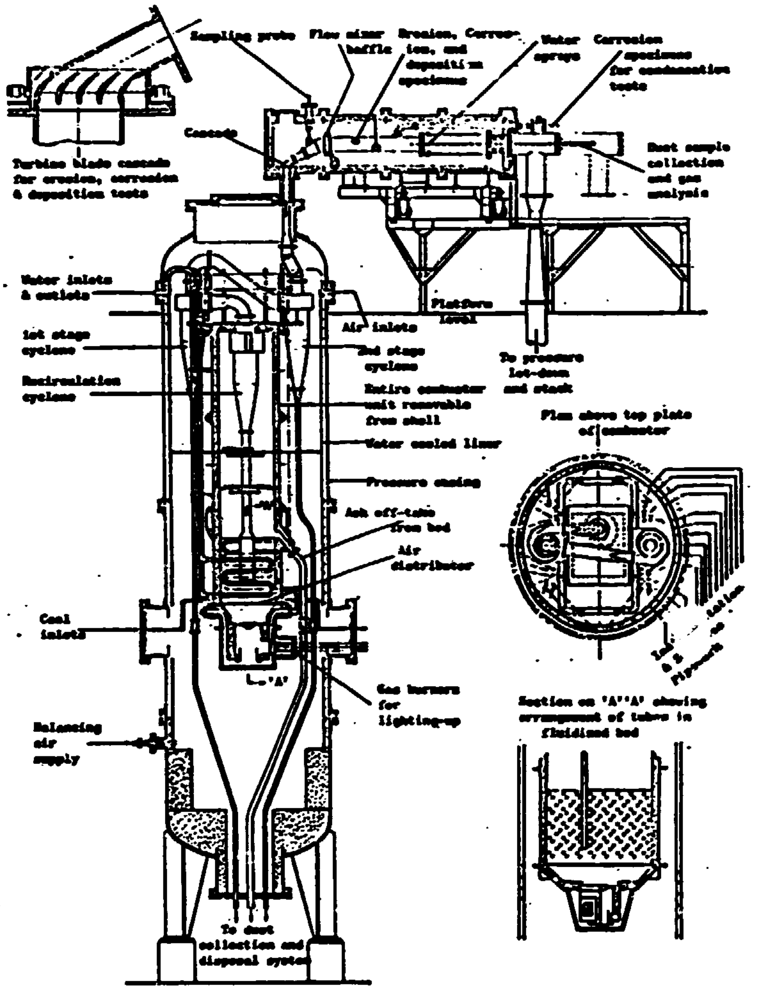
Supercharged closed cycle.

FIGURE 11



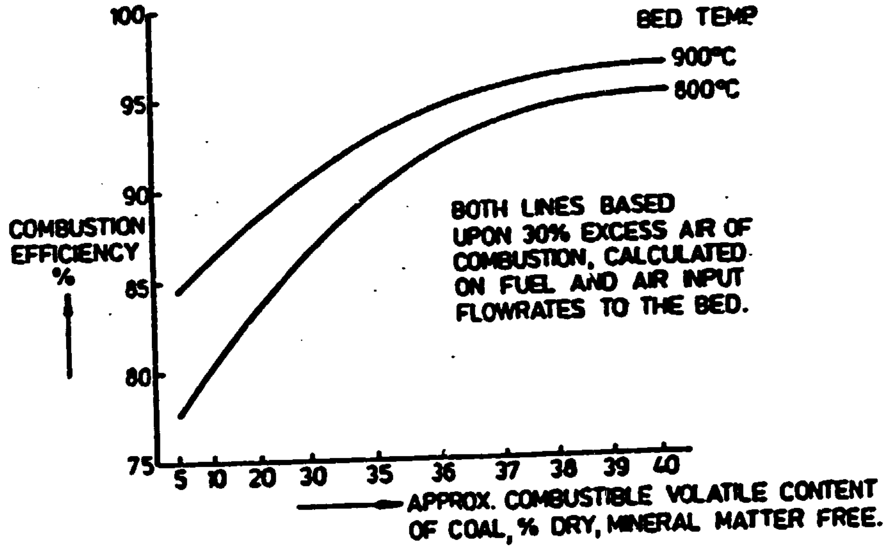
Supercharged combined steam gas turbine cycle

FIGURE 12



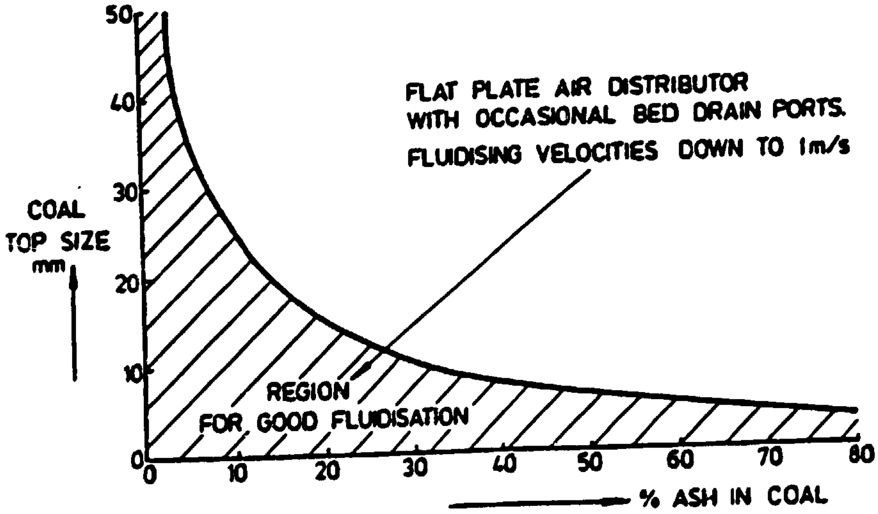
The 1220 x 610 mm pressurised combustor
(From Hoy H.R. & Roberts A.G. "Fluidized Combustion of Coal at High Pressures" AIChemE Mtg, San Francisco, December 1971)

FIGURE 13a



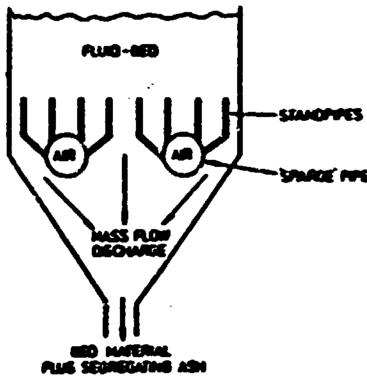
VARIATION OF COMBUSTION EFFICIENCY WITH COAL TYPE.

FIGURE 13b

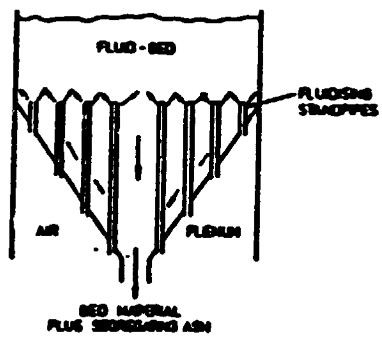


TOLERANCE OF FLAT PLATE AIR DISTRIBUTOR TO COAL SIZE AND ASH CONTENT.

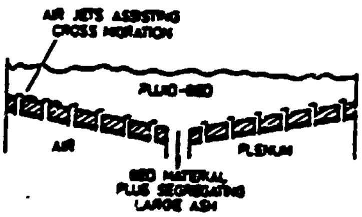
FIGURE 14



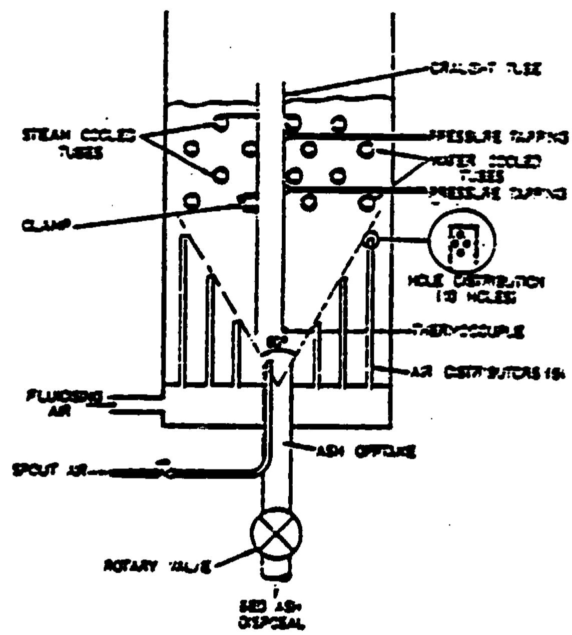
SPARGE PIPE DISTRIBUTOR AND MASS FLOW HOPPER



STANDPIPES ON A TAPERED BASE

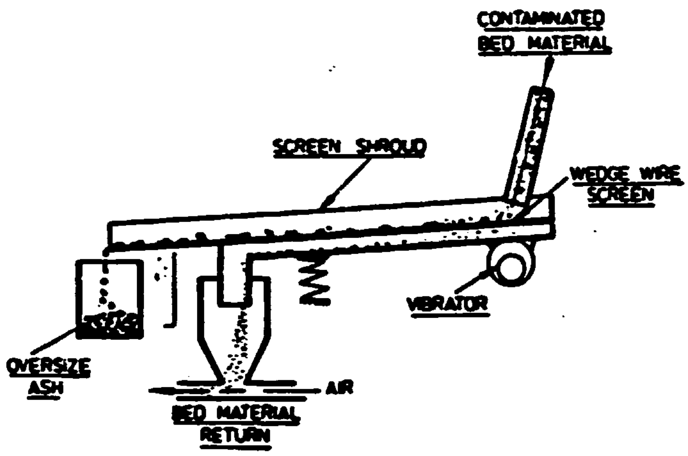


DIRECTIONAL STANDPIPES ON SHALLOW INCLINE

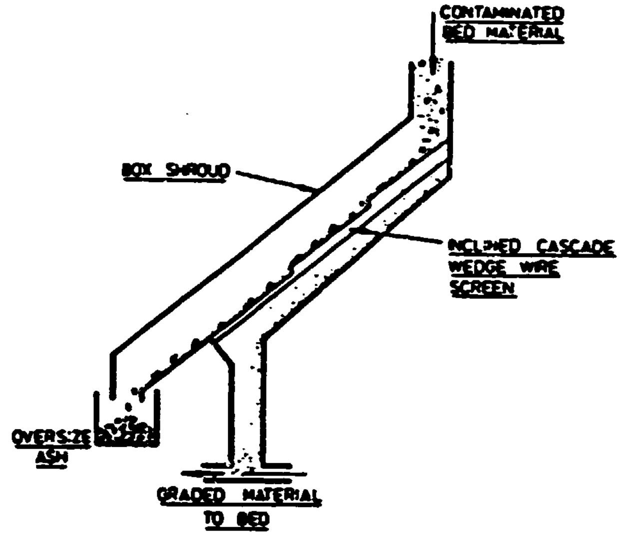


SPOUTED RECIRCULATORY BASE

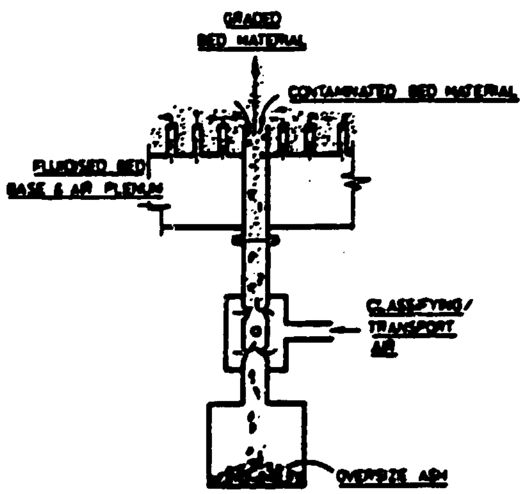
FIGURE 15



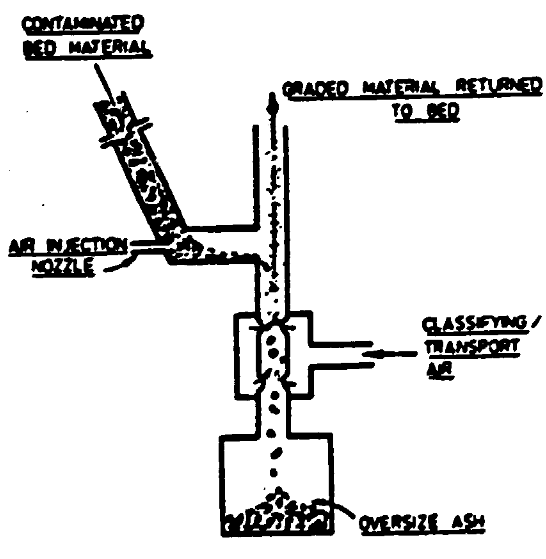
Vibrating Screen



Static Inclined Screen

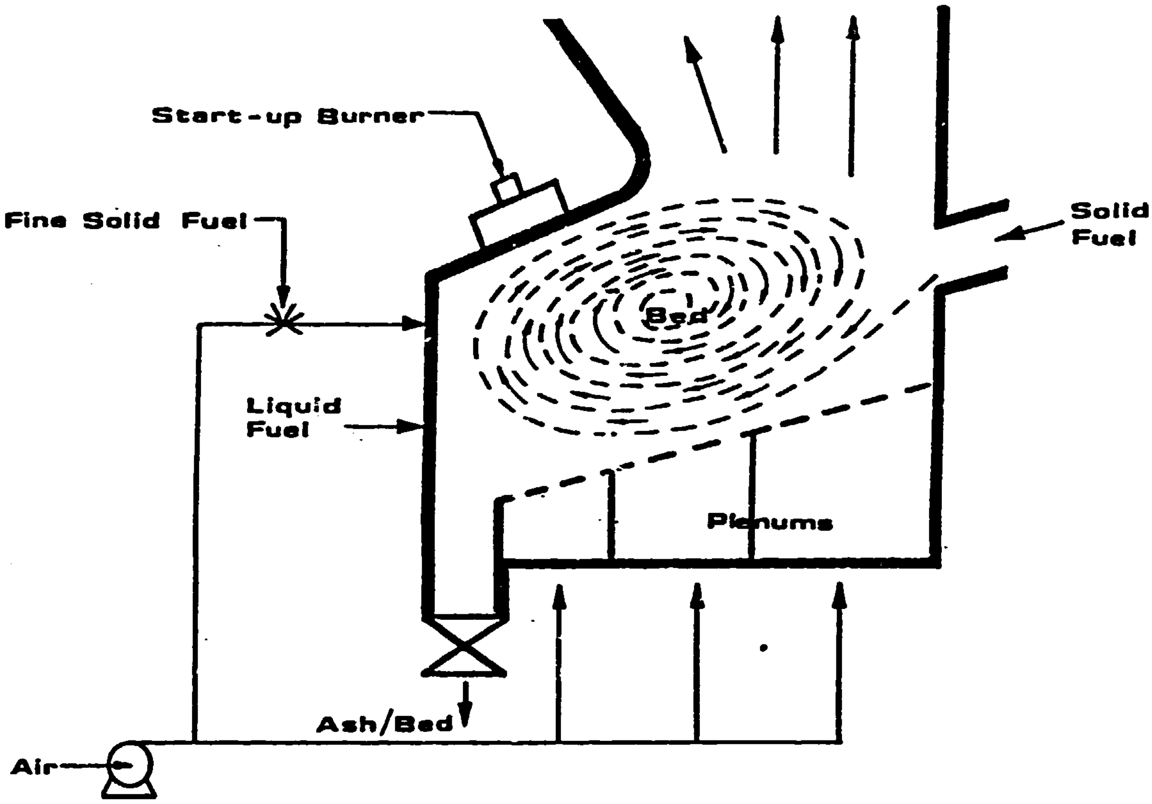


Air Classifier.

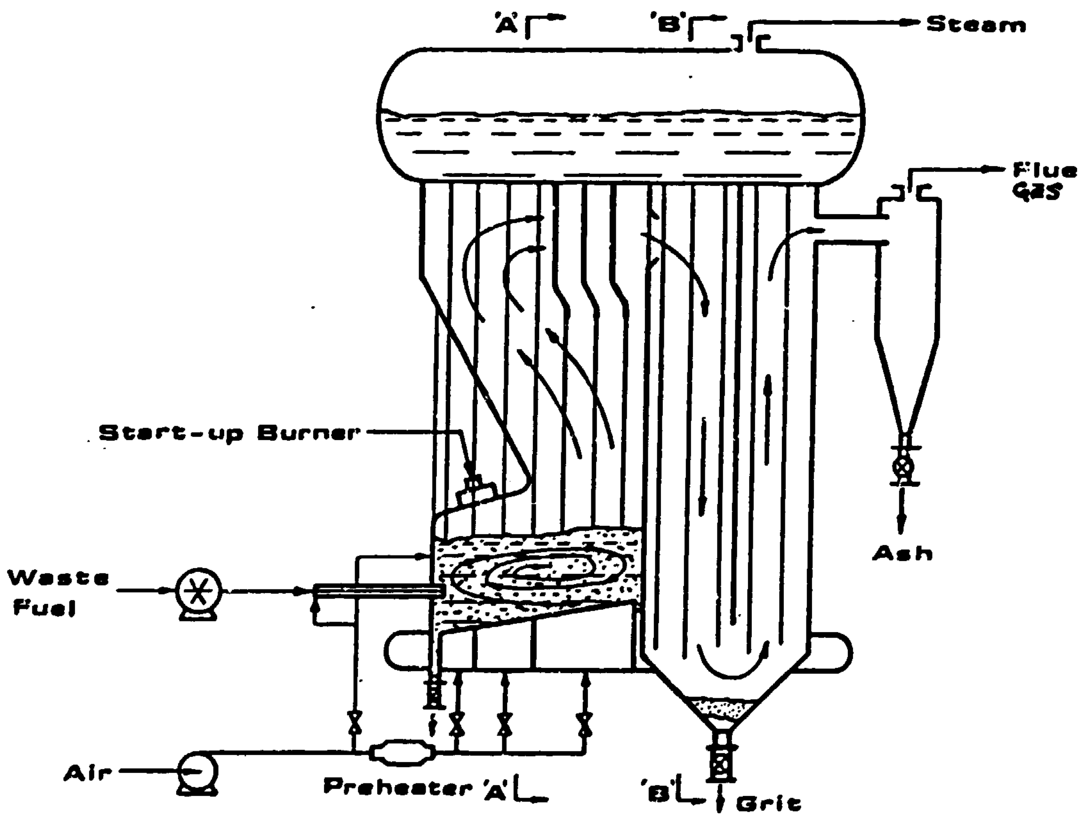


Externally Mounted Air Classifier.

FIGURE 16



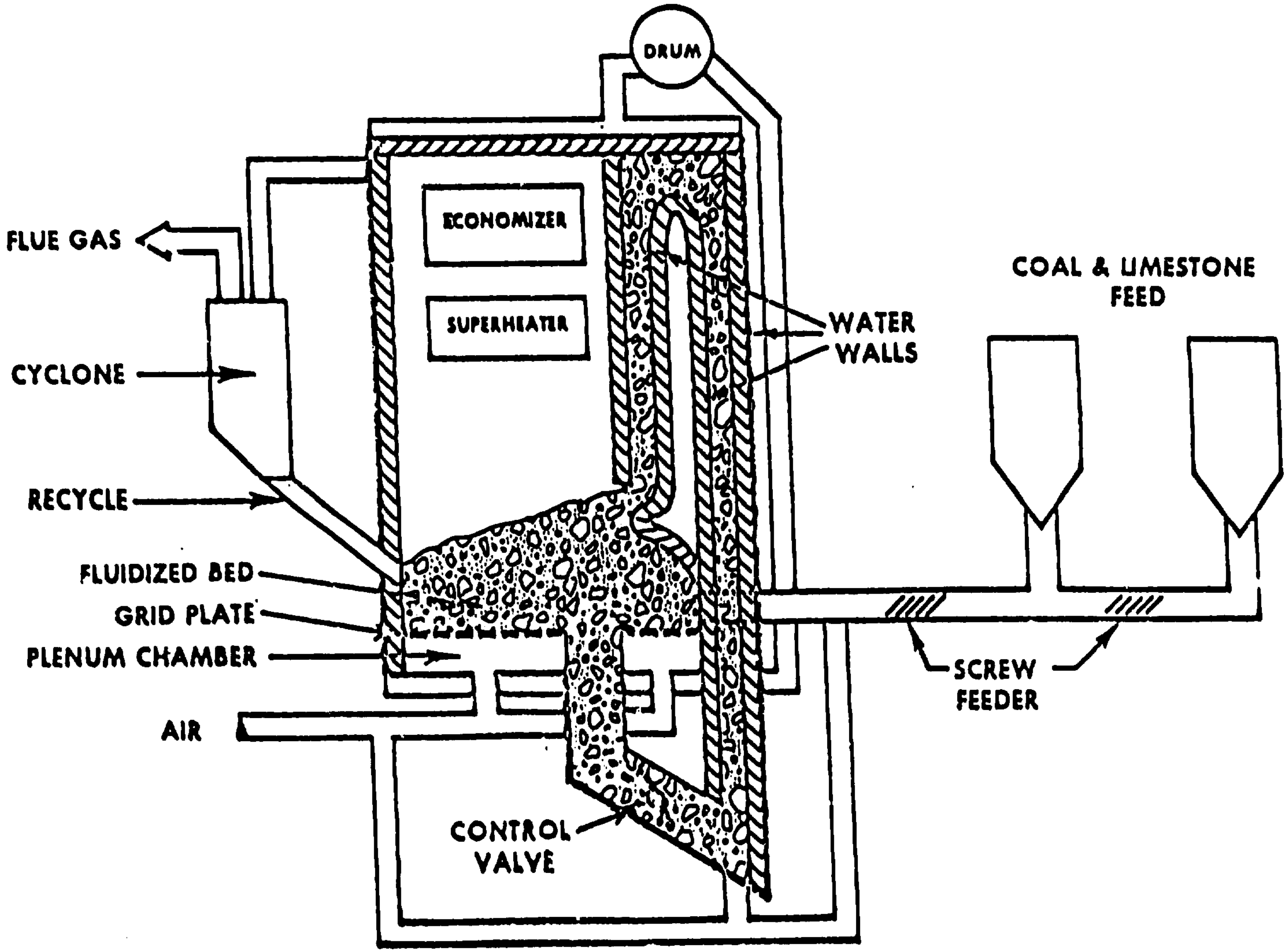
Circulating Fluidised Bed



Water Tube Boiler

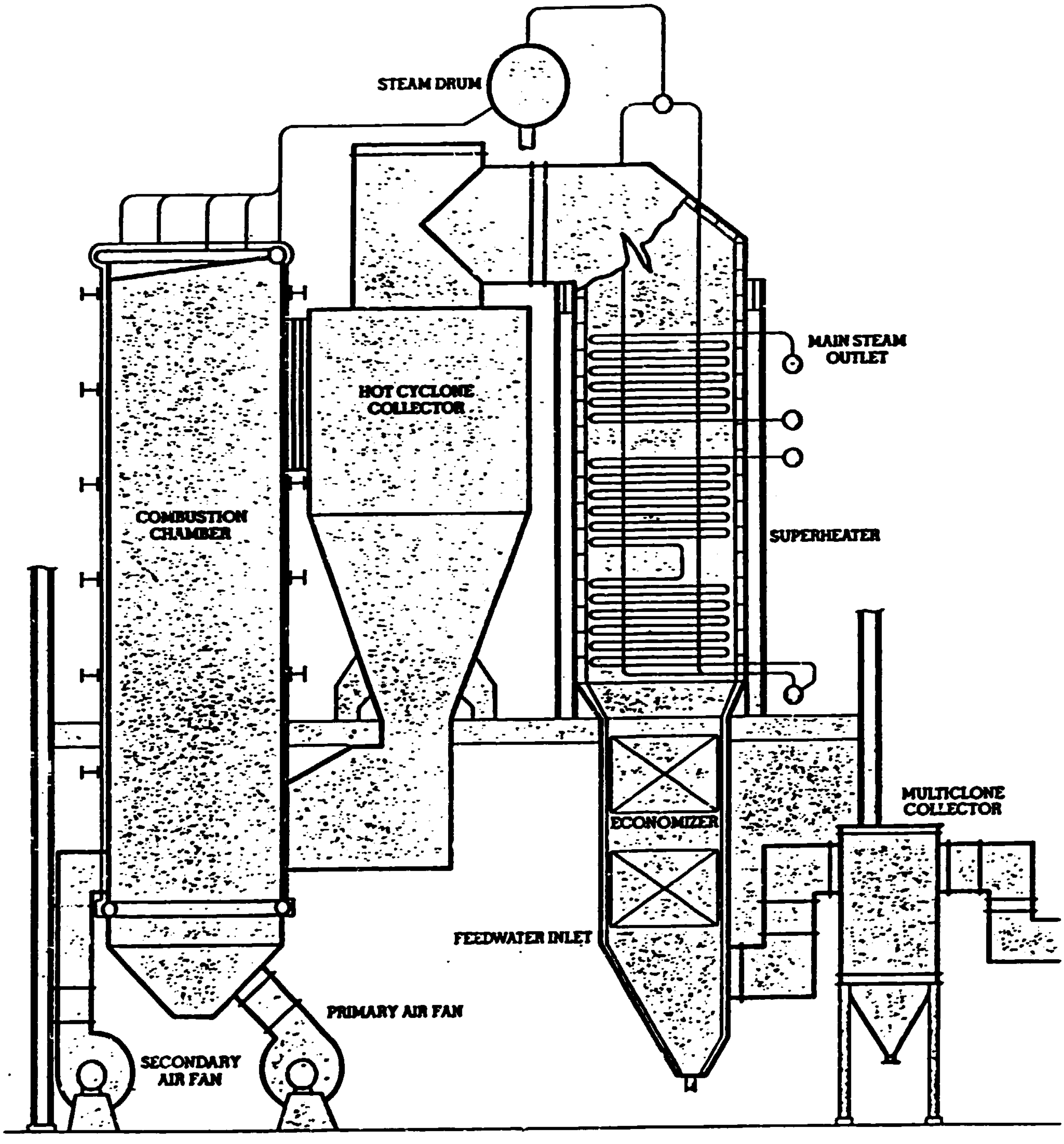
Deborah Circulating Bed Boiler

FIGURE 17



RECIRCULATION BOILER

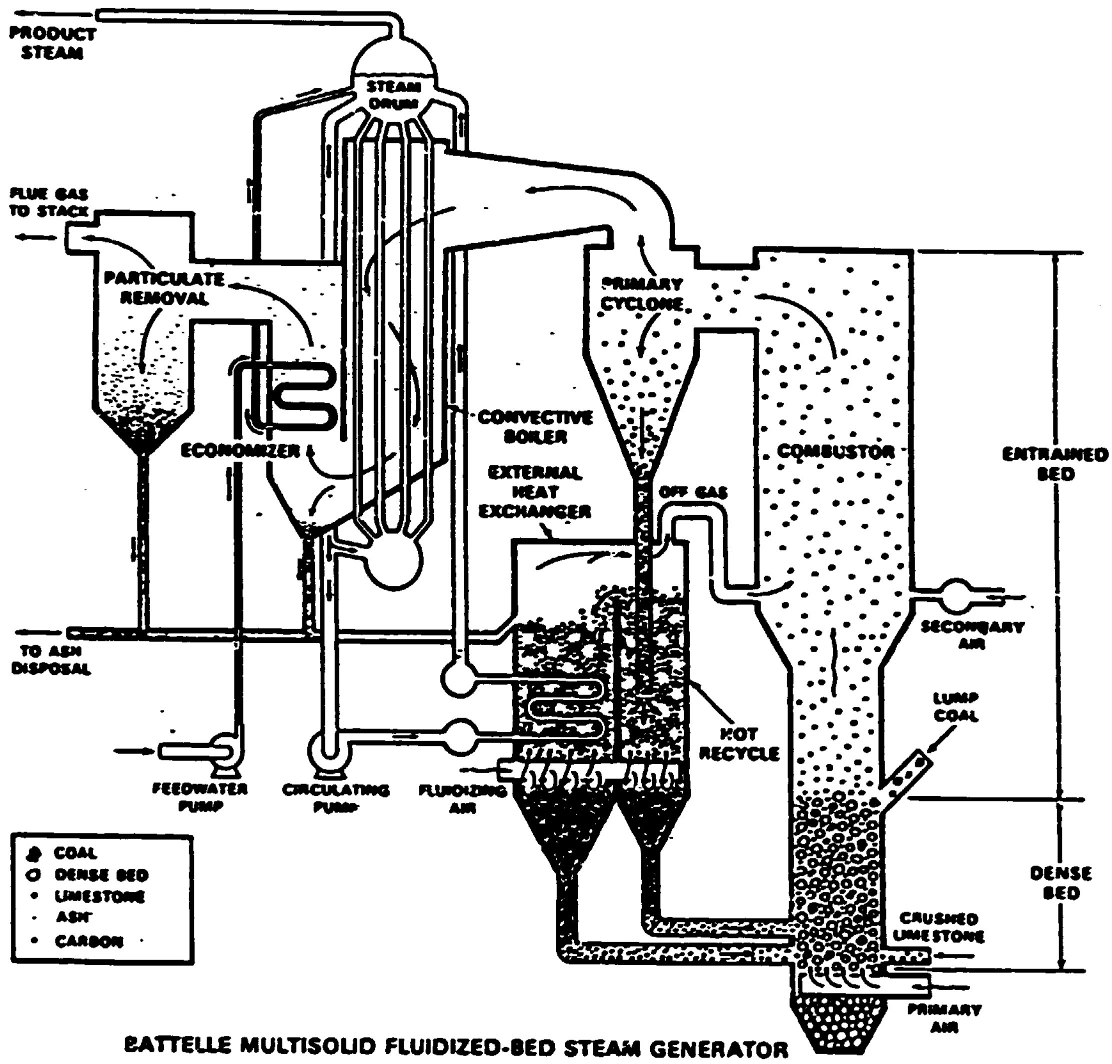
FIGURE 18



Side Elevation

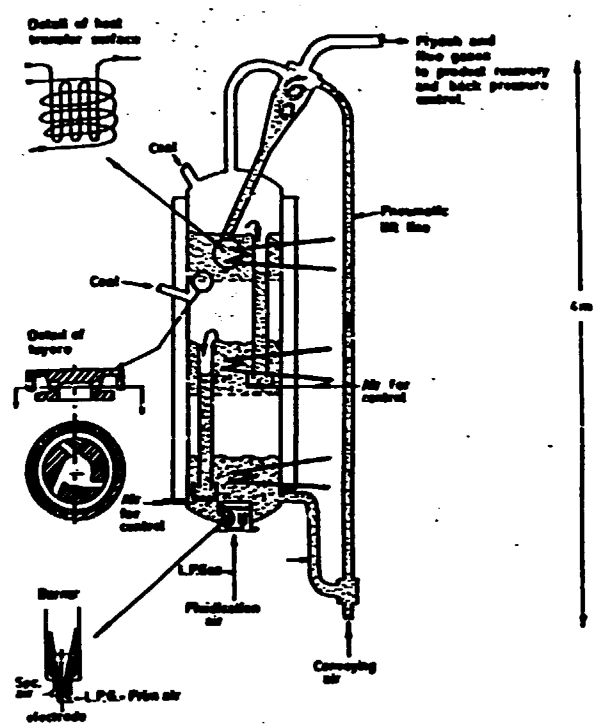
Pyroflow Fast Fluidised Bed Combustor

FIGURE 19

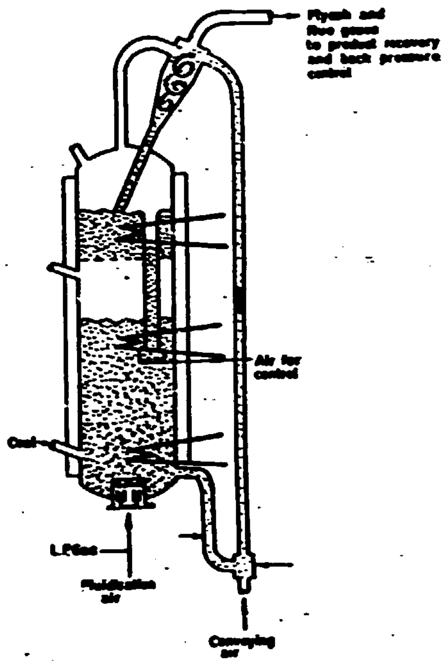


BATTELLE MULTISOLID FLUIDIZED-BED STEAM GENERATOR

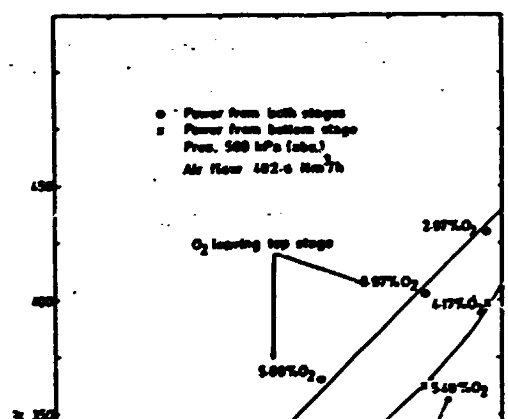
FIGURE 20



Multistage PFBC unit at Natal University

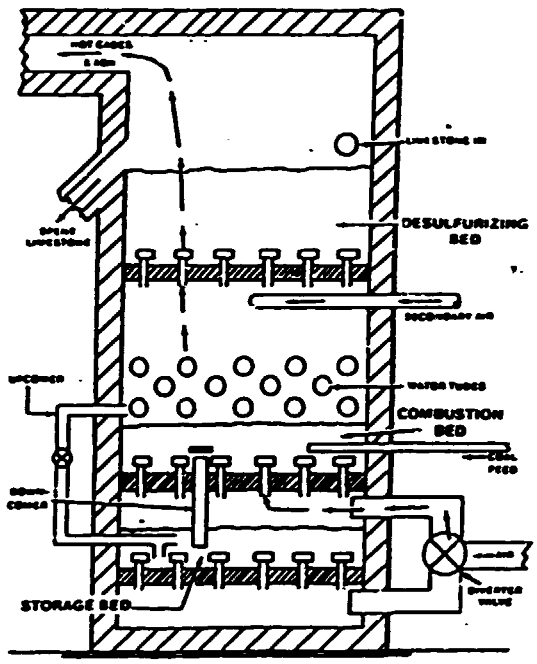


Two-stage PFBC configuration



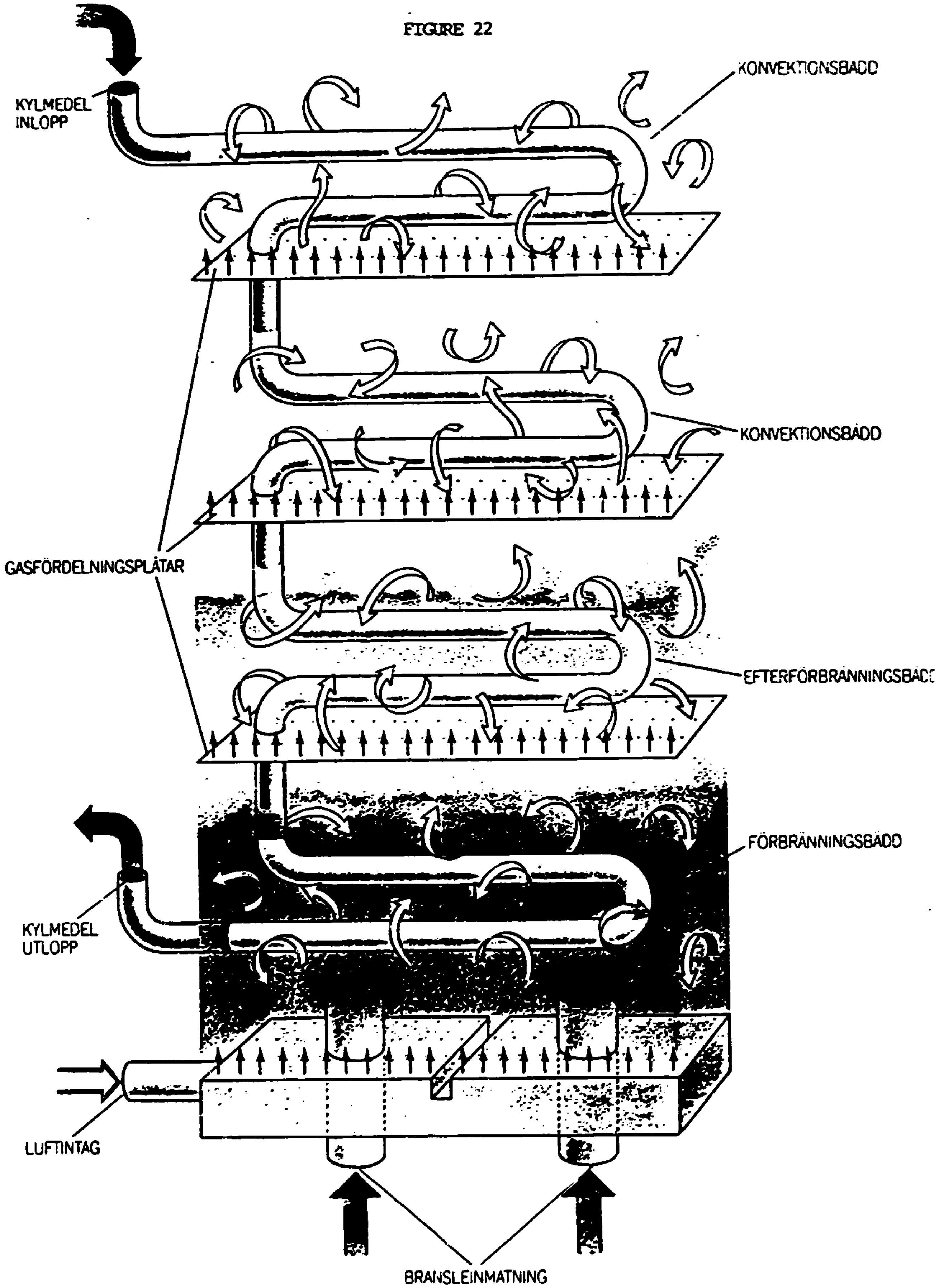
Power output of the two-stage PFBC unit at constant pressure and fluidising velocity

FIGURE 21



Cross-section of Wormser Grate

FIGURE 22



MULTIBED FBC - STAL LAVAL

Annexe 1

Chronology

11 October 1986	London to Sofia Meeting with Professor Moumdjian
13 October 1986	Sofia to Varna. Beginning of Workshop at the Energo 1 Establishment at the Drouzhba Complex.
13 - 17 October 1986	The Workshop
14 and 15 October 1986	Presentations of papers and reports. Discussions.
16 and 17 October 1986	Visits to opencast lignite mine and to the Dimo Ditchev Maritza East No 3 power station.
18 October 1986	Continuing discussions. Varna to Sofia. Sofia to London.
20 October 1986 onwards	Report and letter writing.