REPORT REPORT REPORT REPORT

Advanced Coal Technologies for Power Generation in India

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Foreword

This report has been prepared by Prof. V. M. Krishna Sastry and Prof. A. K. Kolar of I.I.T. Chennai as part of an ongoing NIAS energy project on Options in Electric Power Technology, being carried out in collaboration with Carnegie Mellon University, Pittsburg, U.S.A.

Clean Coal Technologies have been identified as among the most important areas for the NIAS technology assessment study, along with biomass, transmission and distribution and oil and gas. Among the conventional energy resources available in India, coal plays a leading role, as it contributes about 70% to the total energy generation in the country. With the world moving towards more and more stringent controls on pollutants in order to protect the environment, and the fact that India can not get away from coal as an energy source for several decades to come at least, the need to integrate clean coal technologies into our energy development plans assumes paramount importance. The authors have clearly and concisely discussed the various technologies available, their present status, the developmental efforts that have been undertaken, and the need to implement them. I have great pleasure in releasing this report as forerunner to other reports in this series which are to follow shortly. We are grateful to Carnegie Mellon University for the partial financial support provided for this project.

Roddam Narasimha
Director, NIAS

Abbreviations

AFBC	Atmospheric Fluidised Bed Combustor
PCBC	Pressurised Circulating Fluidised Bed Combustor
CFBC	Circulating Fluidised Bed Combustor
DVC	Damodar Valley Corporation
CCUT	Clean Coal Utilisation Technologies
CFCs	Chloroflorocarbons
CWS	Coal Water Slurry
ESPs	Electro-static Precipitators
FBC	Fluidised Bed Combustion
FETF	Fuel Evaluation Test Facility
FGD	Fuel Gas Desulphurisation
FGR	Fuel Gas Recirculation
GCU	Gas Clean Up
GHG	Green House Gases
GT	Gas Turbine
GWP	Global Warming Potential
HCV	High Calorific Value
HRSG	Heat Recovery Steam Generator
HTHP	High Temperature High Pressure
IGCC	Integrated Gasifier Combined Cycle
LCV	Low Calorific Value
LDA	Lurgi Dry Ash
MCV	Medium Calorific Value
MHD	Magento Hydro Dynamics
PC	Pulverised Coal
RPM	Respirable Particulate Matter
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
SPM	Suspended Particulate Matter
TET	Turbine Entry Temperature

Executive Summary

1. Introduction

The increasing population and raised aspirations for better standards of living complemented by the need for accelerated industrialisation to achieve high rates of economic growth has made energy in general, and electricity in particular, a critical factor in our national development. Electrical power generation has increased from about 5000 MWe in 1947 to about 86,000 MWe in 1997, almost 70% of this being contributed by coal based thermal power plants. It is projected that about 10,000 MWe needs to be added every year for the next 10-15 years to facilitate expected rate of economic growth. A judicious mix of technologies based on fossil (coal, lignite, oil, natural gas) and nuclear fuels, water and renewable sources like the sun, wind and biomass will be required to meet the future national energy demands. Coal, the most abundant fossil fuel in our country, will be the main fuel for power generation for several more decades.

Environmental issues associated with coal utilisation are (i) "Enhanced" greenhouse effect due to emission of carbon dioxide (CO_2) and Nitrous oxide (N_2O), (ii) "acid rain" effect due to the Sulphur dioxide (SO_2) and Nitric oxide (NO_x) emissions and (iii) harmful effects on human, marine and plant life due to emission of noxious gas, particulate matter, and trace elements. There is an urgent need for technologies which use coal with high energy efficiency and at the same time meet the prescribed environmental standards.

Indian coal reserves are unique in that they have very high ash (> 35%) and low sulphur (< 0.6%) content except for small reserves of Assam coal which have high sulphur (3-5%) content. Most of the coal technologies developed or presently under development in the world are based on low ash-high sulphur content fuels. Hence it is very important from our national perspective to carefully study available technologies for efficiency and environmental acceptability, adapt only relevant technologies and develop them further for commercialisation, apart from encouraging novel indigenous technologies. Any new coal technology must satisfy the four Es: Efficiency, Environment, Economics and Employment-generation.

2. Energy Extraction from Coal

The two fundamental processes for extraction of energy from coal are (i) Direct Solid Combustion such as conventional Pulverised Coal (PC) Combustion or the emerging Fluidised Bed Combustion (FBC) and (ii) Indirect combustion through Coal Gasification followed by coal gas combustion.

Fluidised Bed Combustor is a "three-in -one device" characterised by highly desirable features of multi-fuel capability, pollution (SO_2 and NO_x) control, and energy conservation. All the four members of this family, namely Atmospheric Fluidised Bed Combustor (AFBC), Circulating Fluidised Bed Combustor (CFBC), Pressurised Fluidised Bed Combustor (PFBC) and Pressurised Circulating Fluidised Bed Combustor (PCFBC) have the potential for clean power generation. Additionally, PFBC and PCFBC systems operating in a combined cycle mode (Rankine and Brayton) have the potential for overall plant efficiencies of the order of 40 - 45% compared to the 33 - 37% efficiencies offered by power plants based on Conventional PC firing, AFBC and CFBC operating on a single (Rankine) cycle.

Coal gasification, at pressures up to 40 atm and suitable temperatures, results in a low calorific value (4 - 7 MJ/Nm^3) gas mixture of CO and H_2 which can be burnt and expanded in a gas turbine for power generation. In an Integrated Gasifier

Combined Cycle (IGCC) plant, this is supplemented by steam turbine power generation using steam generated from the gas turbine exhaust gases. Three types of coal gasifiers are in different stages of demonstration and commercialisation in the world : Fixed Bed (Moving Bed) Gasifier (e.g. the LURGI Dry Ash System), Fluidised Bed Gasifier (e.g. KRW system) and Entrained Bed Gasifier (e.g. Shell and Texaco systems). Each of these technologies is suited to a particular type of coal, and under specific operating conditions gives the desired quality of product coal gas.

3. Coal Utilisation Technology

3A. Clean Coal Utilisation Technologies

A number of technologies based on coal combustion / coal gasification/combination of coal combustion and coal gasification aimed at environmental acceptability and high efficiency have been under development for almost three decades. Four of these are proven commercial technologies while the rest are in different stages of development and demonstration as noted in the Table ES-1.

3B. Other Advanced Technology

Supercritical Boiler Technology is commercialised in several countries with overall plant efficiencies of 43 - 45% and with DENOX and DESOX systems. There is negligible interest in India in the technology at present. Slagging combustion

TABLE ES-1: STATUS OF VARIOUS TECHNOLOGIES

Technology	Worldwide Status	Status in India
A. PC Firing with SO_x and NO_x Control Systems	Commercialised	NO_x control commercialised SO_x control not in use
B. AFBC Power Plant	Commercialised upto 165 MWe (USA)	2x10MWe units operating
C. CFBC Power Plant	Commercialised upto 250 MWe (France)	1x 30 MWe unit commissioned by BHEL-LURGI Maharashtra (1997)
D. PFBC Power Plant	Demonstration units upto 130 MWe (Sweden, Spain, USA, Japan)	Bench scale R&D at BHEL and IIT Madras
E. (i) IGCC Power Plant	Demonstration units upto 250 MWe (USA, Netherlands)	6.2 MWe demo plant at BHEL, 600 MWe Conceptual design at IICT Hyderabad ; Gasifier pilot plants at BHEL and IICT; Proposal for a 250 MWe demo plant by CSIR with the Government
(ii) Hybrid IGCC Power Plant	Pilot plant R&D (UK)	No activity
F. Fuel Cell based PFBC Power Plant	Advanced R&D	On-going R&D in fuel cells
G. MHD based Combined Cycle Power Plant	R&D suspended in Russia and USA, on-going in Israel	Pilot Plant in BHEL, R&D terminated
H. PC Fired Supercritical Power Plants	Commercialised upto 1000 MWe	Not in use
I. Slagging Cyclone Combustion Technology	Advanced R&D	Lab Scale Studies R&D terminated

technology has the special feature of burning high ash coal at very high temperatures in a primary chamber where molten ash slag can be removed before allowing almost ash-free hot gases to enter a secondary chamber to generate steam. After laboratory scale studies, this technology has been abandoned because of the inadequate flowing ability of Indian molten ash.

4. Coal Beneficiation

Coal Beneficiation has been identified as essential for Indian high ash non-caking (power grade) coals to improve the power plant performance and reduce overall costs. Coal washeries to supply clean coal to power plants more than 1000 km from the coal mines have been made mandatory from June 2001. Three coal washeries were proposed at Piparwar, Bina and Kalinga. One is in operation. Standard benefication technology is available. However technology improvements are needed to increase the amount of ash removal. Pre-combustion physical cleaning of coal to reduce sulphur is not practised as it is not essential at present.

5. Coal Water Slurry (CWS) Combustion

CWS combustion has great potential for application in Indian power plants, primarily for oil substitution, as a support fuel in low load flame stabilisation and load sharing. R&D on CWS preparation and combustion have been conducted at laboratory level at CFRI, Dhanbad and in the Fuel Evaluation Test Facility (FETF) in BHEL, Tiruchy. Presently BHEL, CFRI, NTPC and IIT Madras are jointly involved in the preparation of a proposal for the demonstration of CWS combustion using high sulphur Assam coal in an operating Thermal Power Station.

6. Repowering Technology

Old power plants with a total capacity of about 20000 MW_e are at the end of their projected life (25-30 years) and need to be shut down unless a Renovation and Modernisation Scheme is adopted partly involving retrofitting. Such a national program is in place in India. However a far more advantageous technique of extending the life of old power plants is "Repowering" them with more efficient and environmentally friendly furnace-boilers. The advantages are higher efficiency, better pollution control, less gestation period, and possibly less cost in addition to extension of life by another 20-30 years. CFB boilers are excellent candidates for such "repowering" of old PC fired boilers. Several successful projects have been implemented abroad, especially USA. There is a great potential for this technology in our country and needs to be seriously pursued.

7. Plan of Action

7.1 Clean Coal Utilisation Technologies

With the Indian coal having an unique combination of high ash-low sulphur content, any new coal utilisation technology must address the difficulties associated with large amounts of dry ash (which is characterised by its high erosiveness) or molten slag while keeping in mind the advantage of handling acceptable amounts of SO_2 emission. The large amount of coal that is to be handled (because of its low calorific value) must also be taken into account while selecting the most appropriate technology. The unique Indian coal characteristics assume great significance in the context of any new technology as most of the technologies developed or under development are specifically aimed at handling low ash-high sulphur coals. Transplantation of such technologies without adequate testing with Indian coals would lead to major difficulties.

Following are the "proven technologies" for high ash-low sulphur coals :

Technology A : Conventional PC Firing with tangential firing and FGD and DENOX systems if required for pollution control. Both sub-critical and supercritical PC based power plants are state of the art technologies.

Technology B : AFBC Power Plants with fuel flexibility, inherent SO_2 and NO_x control capabilities with co-generation possibilities.

Technology C : CFBC Power Plants with superior characteristics of fuel flexibility, inherent SO_2 and NO_x control, and co-generation possibilities.

While PC fired sub-critical boilers, AFBC and CFBC power plants offer an overall plant efficiency of 33-37%, super-critical PC fired boilers have already established good performance with overall plant efficiencies between 40-45%.

First generation PFBC Combined cycle plants are in the initial stages of commercialisation with overall plant efficiency projections of up to 45% for the second generation designs. IGCC power plants are in an advanced state of development and as of today no demonstration unit (up to 250 MW_e) has been successfully operated for long durations with (claimed) potential efficiencies of the order of 48-50%. In particular, long duration demonstration of IGCC plant with high ash content and high efficiency is still to become a reality.

In view of the above it is prudent for India to immediately resort to (i) large scale adoption of proven technologies, (ii) construction of demonstration plants (of reasonable size) of near-term-technologies, and (iii) concerted R&D efforts leading to demonstration plants of long-term-technologies. Additionally R&D efforts must be accelerated in futuristic technologies. Accordingly the following plan of action may be seriously considered :

Implementation of Clean Coal Utilisation Technologies

(i) Promotion of AFBC and CFBC power plants with a strong directive that all future power plants in a certain capacity range (for example 100-250 MW_e) should adopt these technologies within a short time frame.

(ii) A first generation PFBC combine cycle power plant in the 70-150 MW_e range must be immediately established for technology demonstration with high ash coal, and for development of high temperature high pressure (HTHP) particulate control systems. The HTHP system development will also contribute towards the development of IGCC technology.

(iii) An IGCC power plant of suitable capacity (70-150 MWe) based on the Fluidised Bed Gasifier technology must be immediately established to demonstrate its suitability for Indian high ash coals and to prove the claim of carbon conversion efficiencies greater than 90% and overall plant efficiencies greater than 45% during long duration operation.

Technology Development

(i) Pilot scale pressurised Circulating Fluidised Bed Combustion (PCFBC) and Pressurised Circulating Fluidised Bed Gasifier (PCFBG) facilities must be established for technology feasibility studies.

(ii) Development of DENOX and HTHP particulate control systems and other system components must be encouraged.

(iii) Detailed design study must be initiated for a large power plant (500 MWe - 1000 MWe) based on first generation PFBC and IGCC technologies for possible commercialisation 7-10 years from now.

(iv) A comparative study of second generation (advanced) PFBC and IGCC technologies for application to Indian coals must be carried out.

Basic Research

In spite of the admirable developments in Coal Utilisation Technologies, a considerable gap exists in the understanding of basic processes of combustion, gasification, pollution control, ash and material behaviour, dynamic behaviour of power plant systems and system optimisation. Co-ordinated efforts must be initiated among academic and research institutions, national laboratories and industry R&D establishments to fill this knowledge gap.

7.2. Supercritical Boiler Technology

Supercritical boiler technology has been commercialised in some countries with overall plant efficiencies of 43-45%. Steam conditions have gone up to 320 atmosphere and 620° C with associated advances in material technology. When adopted with DESOX and DENOX systems, this technology will meet our goals of high efficiency and low pollution. A serious consideration to adopt this technology as an immediate solution is highly desirable.

7.3 Coal Benefication Technology

Development of advanced technology and associated basic research for removal of ash from coal to the extent of 10-20% or more must be encouraged. Pre-combustion, coal cleaning technology to remove sulphur must be developed.

7.4 Coal Water Slurry (CWS) Combustion

Implementation of Technology

Demonstration of CWS preparation, transportation and combustion as a support fuel in an operating thermal power plant must be carried out.

Technology Development

Developmental efforts must be initiated for technology advancement in the areas of CWS preparation, wet grinding circuit, pumping, transportation, atomisers and burner systems.

Basic Research

Basic research must be encouraged to study the effects of nature of coal, coal particle size distribution and coal-water loading ratio on the viscosity, stability and atomisation characteristics of CWS, transportation characteristics in long pipelines and optimum atomiser and burner design.

7.5 Repowering Technology

An old power plant of 100 - 120 MWe capacity must be repowered with a CFB boiler for technology demonstration. Incentives must be offered to owners of old boilers/power plants to go in for repowering with suitable technology.

1. Introduction

Our nation faces a challenging energy scenario involving complex interaction among such factors like energy consumption pattern, standard of living, energy resources, energy utilization technologies, energy efficiency and environment. It is internationally accepted today that the annual per capita energy consumption is a reliable indicator of the standard of living in a society and on this basis it is imperative that we have to raise the production and consumption of energy very substantially in the coming years. While energy is consumed in several different forms, energy in the form of electricity has been recognised as the safest and most convenient. Therefore generation of electrical power assumes great significance in the context of socio-economic growth of our nation.

The national energy demand has been rapidly increasing in recent years to cope with the rising aspirations of an ever increasing population to attain higher living standards. Fulfilment of this demand is however associated with increased environmental damage leading to long term consequences. Thus energy and environment can be considered as the two critical factors influencing our national economic development. This should make us take a close look at the various energy technologies that are in use today so that new and improved energy technologies could be identified and developed. On the basis of four Es, namely, Efficiency, Environment, Economics and Employment, i.e. new technologies must be energy efficient, environmentally friendly, economically viable and employment-generating.

A four-way strategy to meet our future energy requirements is as follows :

(i) Development of new technologies to utilise the conventional energy sources in a more efficient and environmentally acceptable manner;

(ii) Development of complementary technologies to harness the renewable energy from the sun, wind, ocean, earth and bio-mass to complement the conventional sources;

(iii) Development of energy conserving (saving) and (more) energy efficient devices/techniques; and

(iv) Management of the available energy in the most optimal way possible through proper energy management including demand side measures.

Even a brief look at our national energy scenario is sufficient to realise that to meet tomorrows energy demands, India today needs to urgently plan for a judicious mix of advanced technologies based on fossil fuels (coal, lignite, oil, natural gas), nuclear fuels, small scale hydro and renewable energy sources supported by a strong energy management programme and a well-focused, goal oriented, time bound energy policy.

1.1 Present Scenario

Presently India has an installed power generation capacity of about 86000 MWe, (by March 1997). Approximately 70% of this is coal based. Hydro electric power contributes about 25%, nuclear power about 2.5%, wind energy about 1%, and the rest is contributed by gas and diesel based captive power plants. About 420 billion units of energy (kWh) were generated during 1997-98. With this capacity installed, we still have a 13% peak power shortage in 1997-98 and a 10% energy shortage in the country with a 22% T and D loss. It is now projected that we should add anywhere between 10,000 to 15,000 MWe per year in the next 10 years to cope with the enhanced energy demand. Considering that the gestation period is anywhere from 2 to 8 years for the construction of various kinds of power plants, it is very clear that atleast in the short term our power requirements will be met by well established conventional technologies with possible technological modifications to meet the environmental standards. During this period it is imperative that R&D efforts be intensified in advanced fossil and nuclear fuel technologies, environmental pollution control technologies, and renewable energy technologies, aiming at large demonstration plants leading to their commercialisation at the earliest.

1.2 Energy Resources

India possesses huge reserves of coal and lignite of the order of about 230 billion tonnes (80 billion tonnes proven) of which about 300 million tonnes was mined last year. Our crude oil reserves are estimated to be about 700 million tonnes of which about 30 million tonnes were extracted during 1997-98 leading to a crude oil import of about 40 million tonnes to meet the total annual requirements of about 70 million tonnes. Natural gas reserves have been identified in some areas of the country and are estimated to be about 700 billion cubic metres. Very little of this is being presently used for power generation. However the prospects for increased use of this natural gas in one of the most efficient technologies, namely combined cycle power generation, is very promising.

A vast majority of our coal resources however is of a very low grade with more than 40% mineral matter (ash) content resulting in various difficulties in handling, transporting and using coal for power generation. This disadvantage is mitigated to a considerable extent by the fact that the sulphur content of the coal is generally less than half percent resulting in lower amounts of sulphur-di-oxide (SO_2) emission to the environment. The challenge that this coal poses to clean thermal power generation demands modifications and improvements in the conventional technologies, and development and adoption of new technologies, with due regard to efficiency and environmental issues.

1.3 Environmental Issues

Environmental concerns associated with coal utilisation are basically with respect to three issues: "enhanced" greenhouse effect due to Carbon dioxide (CO_2) and Nitrous Oxide (N_2O), "acid rain" effects of Sulphur Oxides (SO_x) and Nitric Oxides (NO_x), and health related effects of Suspended and Respirable Particulate matter, SO_x, NO_x and certain trace elements like Arsenic and Mercury.

Greenhouse effect has received increasing attention since the early 1980's. It is in fact a natural phenomenon referring to the warming of the earth's surface, caused by the effect that water vapour and certain trace gases in the atmosphere have on the earth's radiation balance. Of the solar "short wave" radiation that reaches the earth, about two-thirds is absorbed and the remainder is reflected back into space as infra-red "long wave" radiation. Certain gases known as Green House Gases (GHG) absorb some of this long wave radiation and reflect it downwards to warm the earth's surface. Without this natural greenhouse effect, the average surface temperature of the earth would be about 30 - 33°C lower than it is today and the world would be uninhabitable. The GHGs include (predominantly) water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and in recent years, the Chloroflorocarbons (CFCs) and their substitutes. Water vapour is the most active component of the atmosphere, responsible for about 75% of the natural greenhouse effect.

Water vapour concentration in the atmosphere so critical in the overall climatic system, is largely determined by natural conditions. Human activity has had little, if any, effect on the atmospheric concentrations of water vapour.

There is a concern that the Greenhouse effect is being altered, in fact "enhanced", due to the increased concentration of GHGs resulting from human activities. It is claimed that this "enhanced" Greenhouse effect leads to "Global Warming", an increase in the surface temperature of the earth. It was earlier suggested that doubling the level of CO_2 in the atmosphere would lead to a 5-6°C rise in global surface temperature. However, more recent studies suggest this temperature rise might be in the range of 1-3°C.

Increased level of CO_2 in the atmosphere may be attributed to fossil-fuel combustion, deforestation, cement manufacture and changes in agricultural practice. However it should be appreciated that the concentration of CH_4 and N_2O in the atmosphere have also gone up considerably due to various factors like increased rice production in wet paddy fields and other agricultural activity, waste disposal, decomposition of vegetation, release from coal mining activities, leakage from natural gas pipelines and biomass burning. Coal's contribution to the "enhanced" greenhouse effect of CO_2 is about 20%, half of which arises from power generation. The contribution is much less with respect to CH_4 (7%) and N_2O.(5%). However it is to be noted that the Global Warming Potential (GWP) of CH_4 is about 15-17 times that of CO_2, that of N_2O is 280-310 times and that of CFCS, about 7900-8500 times.

There are several uncertainties in the science of climate change and a lack of conclusive evidence of global warming attributable to the Greenhouse effect. The nature, the severity, and the perception of greenhouse - related impacts will vary greatly world-wide, which means that every country must consider its responses in the context of its needs.

It is important that realistic measures are adopted globally to minimise the emission of GHGs, if global warming effect were to be conclusively proven in the future. Hence the efficiency of fossil fuel combustion must be increased, which along with energy-efficient equipments in house-hold, commercial and industrial applications, will ensure more useful energy per unit of fossil fuel burnt.

Emission of SO_x and NO_x is inevitable when sulphur and nitrogen-bearing coal and oil are burned for power generation. A problem arises when these gases, under favourable climatic conditions, combine with water vapour in the atmosphere to produce sulphuric and nitric acid which come down to earth as "acid rain". Such recycle of SO_x and NO_x in the form of acids has caused serious damage to plant life, marine life and human life. Deforestation and large scale extinction of marine life in some parts of the world have been attributed to acid rain. The gases themselves are harmful to human health, their ill effects ranging from headaches, cold and cough to serious lung related problems, sometimes leading to cancer under severe exposure conditions.

Particulate matter emitted primarily from coal-based thermal power plants ranges from submicron size unburnt carbon and ash particles to those up to 100μm in size. The Respirable Particulate Matter (RPM) is easily inhaled by humans leading to respiratory diseases. The Suspended Particulate Matter (SPM) forms suspensions leading to general degradation of atmosphere especially in the vicinity of the thermal power plant. It is also possible that the particulate matter carries certain undesirable trace elements from the original fuel with associated harmful effects.

Particulate matter emission is a serious issue for Indian coal because of its high ash content which is in the range of 35-50%. It is estimated that by the year 2006-2007, coal requirement for power generation will be about 430 million tonnes and hence about 170 millions of ash will be produced. Close to 80% of this will be Fly Ash (ESP ash) for which large scale use has to be found. The rest is removed as Boiler Ash (bottom ash). From a technological point of view, particulate emission can be very efficiently controlled by Electrostatic Precipitators (ESPs) and bag houses with an efficiency of 98-99%.

Tables 1.3.1 and 1.3.2 summarise the present National Ambient Air Quality standards and the pollution standards for thermal power plant emissions. It is to be noted that emission standards for NO_x and SO_x in terms of amount per unit exhaust gas volume or unit thermal input are not specified. Table 1.3.3 presents the emission standards of coal-fired thermal power plants for some selected countries. The World Bank stipulates SO_2 in ambient air and in emissions for projects aided by it. For all Bank projects, SO_2 concentration in ambient air should not exceed 100 µg/m^3 (annual arithmetic mean) in and around the plant. However the maximum 24 hr peak value could be in the range of 500 - 1000 µg/m^3. SO_2 emissions are limited to a maximum of 500 tonnes/day for "unpolluted" (ambient air containing SO_2<50µg/m^3) areas, and 100 tones/day for "highly polluted" (ambient air containing SO_2≅100µg/m^3). No projects can be setup in areas with ambient air containing SO_2>100µg/m^3.

TABLE 1.3.1: NATIONAL AMBIENT AIR QUALITY STANDARDS

	SO_2 µg/m^3	NO_2 µg/m^3	SPM* µg/m^3	RPM** µg/m^3	CO µg/m^3
Industrial Area	120	120	500	150	5.0
Residential, Rural and other area	80	80	200	100	2.0
Sensitive Area	30	30	100	75	1.0

TABLE 1.3.2: THERMAL POWER PLANT

(i) Stack Height Requirement for SO_2 Control

Power generation capacity	Stack height (metre)
Less than 200/210 MWe	$H = 14 (Q)^{0.3}$ where Q is emission rate of SO_2 in kg/hr, H = Stack height in metres
200/210 MWe or less than 500 MWe	220
500 MWe and above	275 + Space provision for EGD system

(ii) Particulate Emission Standards

Power generation Capacity	Particulate matter emission
Less than 210 MWe	350 mg/Nm^3
210 MWe and above	150 mg/Nm^3

TABLE 1.3.3: EMISSION STANDARDS FOR THERMAL POWER PLANTS (FOR DIFFERENT COUNTRIES)

COUNTRY	SPM	SO_2	NO_x	CO
	(mg/Nm^3 of Effluent Gas)			
AUSTRALIA	250	–	2500	500
DENMARK	150	–	–	–
FEDERAL REPUBLIC OF GERMANY	100 (Lignite Coal)	2845	–	250
	150 (Hard Coal)	–	–	–
ITALY	–	2000	–	–
JAPAN-URBAN	200	500	767	–
JAPAN-RURAL	400	2500	–	–
UK 100-500 MW_E	50	400-2000	650	–
>500 MW_E	50	400	650	–
USA	45	1900	950	–

2. Energy Extraction from Coal

The fundamental chemical process that is used for extraction of energy from coal is combustion in two ways : (i) Direct solid coal combustion such as Conventional Pulverised Combustion or Fluidised Bed Combustion and (ii) Indirect combustion with Coal Gasification (which is basically the result of incomplete combustion of solid coal) followed by coal gas combustion.

2.1 Pulverised Coal (PC) Combustion

Presently the most common method of energy extraction from coal for power generation is its combustion in a furnace cum boiler of a power plant, Fig 2.1.1. The coal is in a pulverised form, its size being less than 100 microns leading to the method being referred to as PC firing/PC technology. The combustion gases which are at a temperature of approximately 1500^{o}C transfer heat to the water flowing through the water walls of the furnace to generate steam which subsequently is superheated in heat exchanger tubes hung in the uppermost zone of the furnace. The exit gases pass through a heat recovery column containing an economiser for pre-heating water, and an air heater for pre-heating air, before passing to the exhaust chimney through an electrostatic precipitator (ESP). Super-heated steam is sent to the steam turbo-generator for power generation. The super-heated steam conditions for a

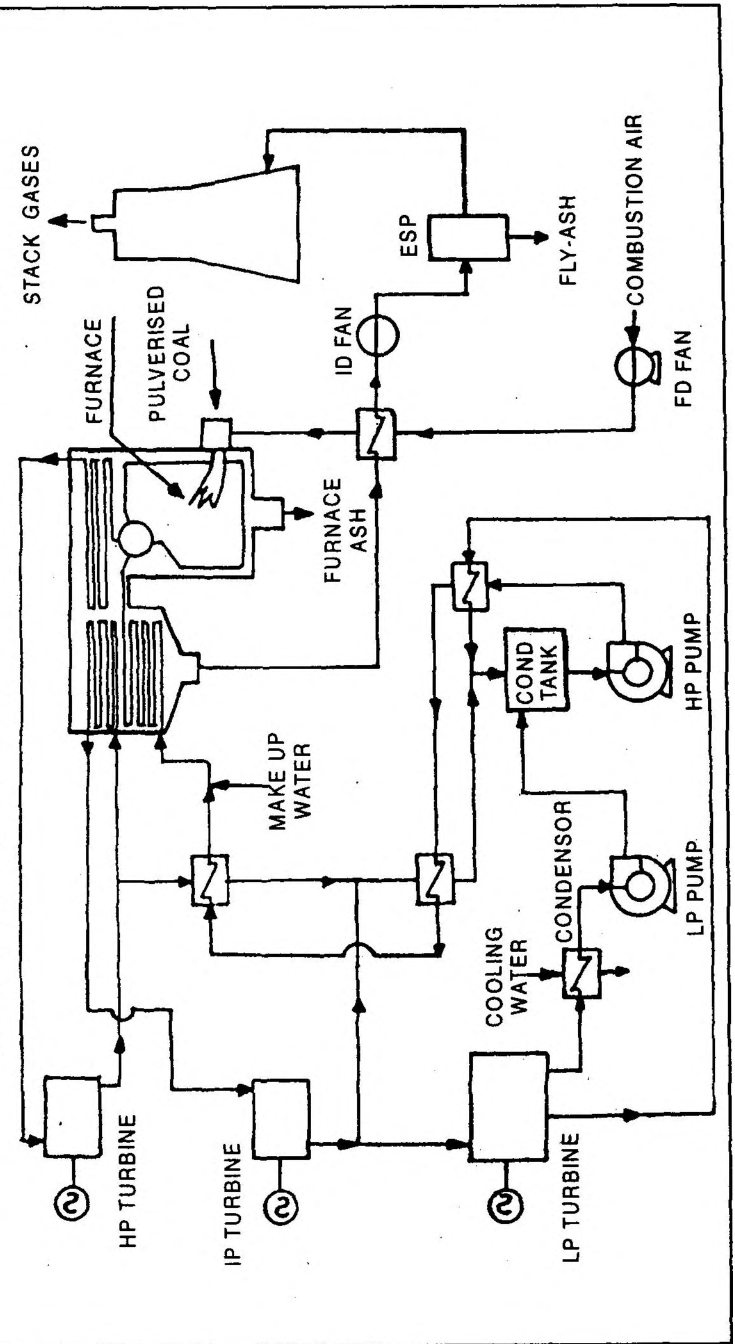


FIG. 2.1.1 CONVENTIONAL PULVERISED COAL BASED POWER PLANT

sub-critical PC boiler are generally in the range of 530 to 560°C and 140 to 180 bar pressure. The steam flow rate depends upon the capacity of the boiler and is generally in the range of 3 to 4 tonnes per hour of steam per MWe. The combustion efficiency of these power boilers is of the order of 99% while the thermal efficiency (boiler efficiency) is of the order of 80-90%. However overall plant efficiency which is the ratio of energy available at the bus-bar to the fuel energy input is of the order of 33 to 37%. Recently super-critical boilers have been commercialised operating above the steam critical pressure of 221 bar and are known to perform with an overall plant efficiency close to 45% in some cases. The design, operation and maintenance of these sub-critical and super-critical boilers are well established. Life extension procedures are also in vogue to extend useful life of boilers whose normal retirement age is 25 to 30 years.

The major drawbacks of the conventional PC technology are :

(i) Very low energy efficiency wherein almost 63 to 67% of input energy is wasted. In addition, vast amount of heat rejected to the environment because of the system inefficiency results in thermal pollution of the immediate environment.

(ii) Enormous amounts of undesirable gases (SO_x, NO_x, COx and N_2O) are exhausted to the environment with deleterious consequences on the health of the human, animal and marine life.

(iii) Emission of very large amounts of ash (oxides of Si, Fe, Al, K, Na, Ca) and toxic trace elements (Pb, As, Hg, Va) leads to undesirable consequences on the environment.

2.2 Fluidised Bed Combustion (FBC)

Fluidised Bed Combustion of coal is now a well established technology for steam generation in many countries. This involves burning of crushed coal (top size 6mm) in a bed of limestone ($CaCO_3$) / dolomite ($CaCO_3.MgCO_3$), / sand or ash particles which are kept in a vigorous state of motion within the furnace by an upward flow of air through it. The fluidised bed operates between 800 - 1000°C (850°C being the most common) and upto pressure of 15 ata. The limestone absorbs SO_2 that is emitted during coal combustion thus lowering the amount of exhaust SO_2. Additionally the combustion temperature (which is much lower than that of PC firing) results in reduced NO_x emissions. Thus FBC technology has the potential to overcome the twin environmental problems of SO_2 and NO_x simultaneously without any additional equipment. The thermal efficiency of the boiler based on FBC is however similar to that of PC boilers, namely 80-90%. A major feature of FBC is the proven possibility of burning fuels of variable quality, as also different fuels in the same combustor leading to "fuel flexibility" and "co-firing". However, it should be mentioned that low combustion temperature which results in low NO_x, also leads to high N_2O formation which is inevitable. With this concept, four variants of FBC technology have been identified as in Table 2.2.1 and are in various stages of development and commercialisation. The variants are based on the pressure of operation (atmosphere or pressurised upto 15 atm) and fundamental gas-solids dynamics in the bed (bubbling or circulating), Fig. 2.2.1(a&b). While all the four members of the FBC family are fundamentally efficient and clean, it is very well recognised that CFBC has better pollution control performance than the bubbling bed (AFBC). Further, a pressurised bed (PFBC and PCFBC) can be adopted in combined cycle power plants to obtain a high overall plant efficiency of the order of upto 43% as compared to 33-37% efficiency for conventional PC firing, AFBC and CFBC based power plants operating on a single (Rankine) cycle alone. It would appear that Pressurised Circulating Fluidised Bed (PCFB) based power plant will be the ultimate in terms of efficiency and environmental performance. It is not an exaggeration to state that a FBC boiler is a *"three-in-one device"* incorporating pollution control, multi-fuel capability and energy conservation characteristics.

2.3 Coal Gasification

As an alternative to direct coal combustion, coal can also be converted into a gas which can then be burnt in a gas combustor to release the thermal energy. This process is known as

FIG. 2.2.1a BUBBLING FLUIDISED BED BOILER

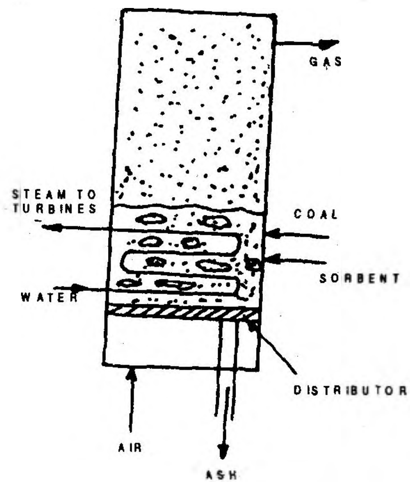


FIG. 2.2.1b CIRCULATING FLUIDISED BED BOILER

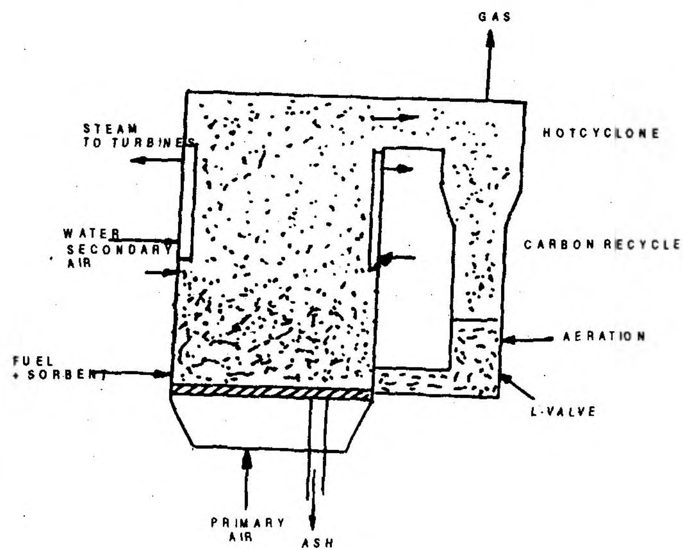


TABLE 2.2.1 SIGNIFICANT FEATURES OF THE VARIOUS TYPES OF FBC

	Fluidized Bed Combustion			
	Bubbling Bed		Circulating Bed	
	Atmospheric (AFBC)	Pressurized (PFBC)	Atmospheric (CFBC)	Pressurized (PCFBC)
Pressure –	1 ata	Upto 16 ata	1 ata	upto 16 ata
Temperature –	840 -1000°C	840 -1000°C	840 - 1000°C	840-1000°C
Fluidizing Velocity –	2 - 4 m/s	0.8 - 1.2 m/s	4 - 8 m/s	4 - 6 m/s
Average Bed Material Size –	≅ 1000 μm	≅ 1000 μm	≅ 200 - 350 μm	200 - 350 μm
Fuels –	Multifuel	Multifuel	Multifuel	Multifuel
Combustion Efficiency –	90 - 99%	≅ 99%	≅ 99%	≅ 99%
Thermal Efficiency –	80 -85%	≅ 80 - 85%	> 85%	> 85%
Overall Power Plant Efficiency –	33 - 37%	40 - 42%	33 - 37%	40 -42%
Pollutant Emission Control –	Very good	Excellent	Excellent	Excellent
Application –	Industrial Boilers, Power Generation, Co-generation	Combined Cycle Power Generation, Co-generation	Industrial Boilers, Power Generation, Co-generation	Combined cycle Power Generation, Co-generation
Status –	Commercialized upto 300T/hr steam and 160 MWe	Demo plant upto 80 MWe in initial stages of commercialisation	Commercialized upto 350 T/hr steam and 250 MWe	Developmental

gasification. It basically involves converting the carbon (C) in the solid coal to a gaseous mixture of carbon monoxide (CO), Hydrogen (H_2), Methane (CH_4) and CO_2. This is achieved by allowing coal to chemically react with steam, and air / oxygen in a reactor operating at a suitable pressure and temperature. Under appropriate conditions the oxygen in the supply combines with a part of the carbon in the coal to release enough heat to support the endothermic gasification reaction as follows :

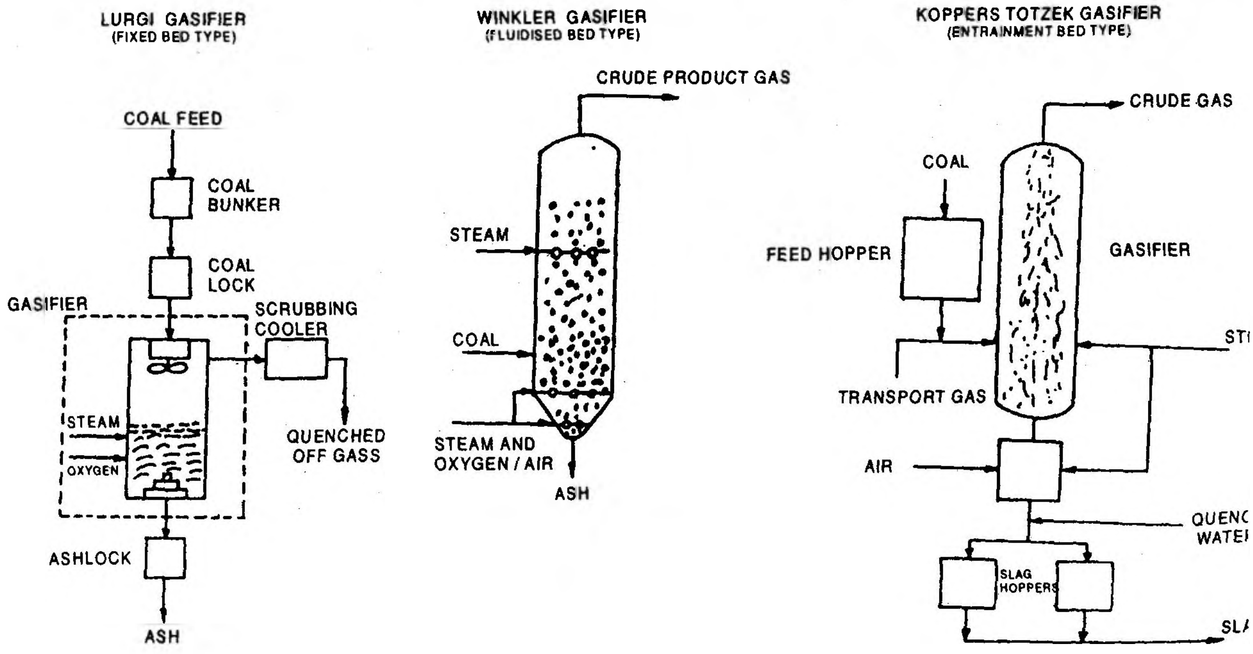
$$C(\text{Solid}) + H_2O\ (\text{Steam}) \rightarrow CO + H_2\ (\text{product fuel gas})$$

The product gas is referred to as syngas (short for synthetic gas) or coal gas which usually also contains small amounts of methane (CH_4). If air is supplied as the oxidant this product gas also has a large amount of nitrogen in it and therefore its calorific value is low (4-7 MJ/Nm^3) leading to it being called a low calorific value (LCV) gas which is suitable for combustion and power generation. On the other hand if oxygen is supplied, the product gas has a higher calorific value of the order of 15 -20 MJ/Nm^3 leading to it being called medium calorific value (MCV) gas. This gas can be further processed and upgraded by further hydrogenation to result in a high calorific value (HCV) gas with a calorific value of the order of 35 - 40 MJ/Nm^3 which is very close to that of natural gas (which is 94% CH_4). The composition of the product gas and therefore its calorific value depends very much on the pressure and temperature of the gasifier, the steam to coal ratio, coal particle size and the air-coal particle contact dynamics. It is very well established that higher the pressure, higher will be the methane component leading to high calorific value of the product gas. On the other hand higher the temperature, higher will be the ($CO + H_2$) composition.

The product gas also contains substantial amounts of impurities like hydrogen sulphide (H_2S), COS, Ammonia (NH_3) and Hydrogen Chloride (HCl) which are to be removed from the product gas before gas combustion. The amount of H_2S and COS in the product gas can be decreased by using a sorbent (limestone) in the gasifier itself which is possible in a fluidised bed gasifier. When the gasification temperatures are high NO_x is formed thus necessitating denoxing of the product gas before combustion. This gas cleaning stage is the crucial one which makes this technology "environmental friendly" imparting to it the potential for application in clear power generation.

Depending upon the gas-solids contact, gasifiers are generally classified into three categories (i) Fixed Bed Gasifier (also called Moving Bed Gasifier) (ii) Fluidised Bed Gasifier and (iii) Entrained Bed Gasifier, Fig.2.3.1. Each of these gasifying processes has its own design and performance characteristics which are suitable to a particular type of coal giving a particular composition of the product gas, Table 2.3.1. Hence it is important that before selecting anyone of these processes the

FIG. 2.3.1 CLASSIFICATION OF GASIFIERS



candidate coal characteristics and the desired product gas composition be kept in mind.

2.3.1. Fixed Bed Gasifier (Moving Bed Gasifier)

A bed of coal particles is supported on a stationary grate through which the oxidant (air or oxygen) is made to flow upwards at high temperatures. The coal is continuously fed from the top so that it comes into contact with the upward moving product gases in a countercurrent fashion. The coal undergoes drying, devolatalisation, combustion (to release the heat required for gasification) and finally gasification at the bottom of the bed. The operating pressure of this gasifier may go upto 40 bar and the temperatures could be as high as 1200°C depending on the coal ash fusion temperature. The ash and the unburnt carbon at the bottom of the bed are continuously removed in a dry form for stable operation. This gasifier is the most well established, successful and widely used in the world today, the Lurgi Dry Ash (LDA) gasifier being a prime example. More than 200 such gasifiers are in commercial use in different parts of the world. A variation of this is "the slagging bed gasifier" wherein molten slag at about 1400°C has to be removed from the gasifier and quenched with water.

2.3.2 Fluidised Bed Gasifier

The Fluidised Bed Gasifier is based on the concept of fluidisation of solid particles in a reactor by upward moving

TABLE 2.3.1 GASIFICATION TECHNOLOGIES

	Texaco	Destec	Shell/ Prenflo	BGL	HT Winkler	KRW/IGT U Gas/Brit. Coal Kellogg Trans/FW
Bituminous	√	√	√	√	some	
Subbituminous/ Lignite	√	√	√	some	√	√
High S	√	√	√	√	√	√
Low S	√	√	√	√	√	√
High Ash					√	√
High Ash fusion Temperature		needs flux (Usually limestone)				

TABLE 2.3.2 OPERATING PARAMETERS OF GASIFICATION PROCESSES

	Fixed Bed (Moving Bed) (Lurgi)	Fluidised Bed (Wrinkler)	Entrained Flow (Koppers-Totzek)
Gas exit temperature, °C	580	700	1290
Pressure, bar	30	atm	atm
Feed capacity, GJ/ (h. gasifer)	750	800	380
Coal size, mm	2 - 50	0 - 5	< 0.1
Fuel Value, MJ/ Nm^3	12.3	10.7	11.6
Product Utilisation Equivalent Synthesis gas, nM^3/1000 kg coal	1884	1596	1845
Equivalent SNG, (CH_4), nM^3/1000 kg coal	529	413	462

gases as mentioned in section 2.2 above. The coal particle size and the upward moving oxidant (air /oxygen) and steam are such that a vigorous gas-solid motion exists within the reactor bed resulting in very thorough mixing. The temperatures are generally less than the ash fusion temperature so that the ash that is formed is in a dry form. In fact, the first gasifier developed by Winkler in the 1920's was of this type. The product gas contains a large amount of fly ash which is to be removed in the downstream cyclones. Limestone can be used in the bed for removal of sulphurous compounds released from the fuel.

2.3.3 Entrained Bed Gasifier

In this gasifier coal in a powdered form is injected into the reactor along with the oxidant and steam generally at the top of the reactor. Thus the coal is "entrained" in the downward moving gas with which it mixes thoroughly. The product gas and the molten slag are removed at the bottom of the reactor. The gas-solid contact being very efficient, the total residence time of the reactor is very small and at the high bed temperatures of 1600^{o}C the product gas contains a high percentage of $CO + H_2$. A special feature of this gasifier is the very high through-put rate compared to the other two types of gasifiers. A variant of this is a gasifier wherein a liquid is used to "entrain" the particles in the gasifier leading to a "slurry feed" as opposed to the dry feed in the former case.

Based on the above three fundamentally different gas-solid contacting reactors a number of (possibly more than 50) gasifier schemes have been patented to date with a wide variety of design and operating characteristics to meet the requirements of specific types of coals to obtain desired product gas compositions. Table 2.3.2 is indicative of the operating parameters of the three types of gasification technologies.

It is pertinent to note here that most of these technologies have been developed with low ash and high sulphur coals in view and therefore one should be very careful in selecting any one of these for the Indian high ash and low sulphur coals.

3. COAL UTILISATION TECHNOLOGY

3A. Clean Coal Utilisation Technologies

The main objective of Clean Coal Utilisation Technologies (CCUT) is to enhance efficiency and environmental acceptability of the extraction of energy from coal for useful purposes. The visible impact of these technologies will be a clean environment, energy conservation and fuel saving.

A CCUT-based Power Plant, in general will have the following three stages :

(i) Coal Benefication Stage which would give de-ashed, purified clean coal as input to the energy extraction stage.

(ii) Energy Extraction Stage which may consist of coal combustion-steam generator-steam turbo-generator scheme OR gasification-combustion-gas turbo generator scheme.

(iii) Pollution Control Stage consisting of a DESOX system like Flue Gas Desulphurisation (FGD) equipment for removal of SO_2, a DENOX system for removal of NO_x, and a Particulate Control System for the removal of particulate matter.

However, it is also possible that the Energy Extraction Stage itself may be inherently pollution-controlling, as in Fluidised Bed Combustion and PC firing with combustion modification for NO_x control.

In order to extract energy from coal for power generation in an environmentally acceptable manner the aforementioned processes of coal combustion and coal gasification can be used individually or in tandem resulting in the following technology alternatives :

(A) Conventional PC Firing in a Rankine Cycle power plant with FGD and DENOX Systems

(B) Atmospheric Fluidised Bed (AFBC) Boiler in a Rankine Cycle power plant

(C) Circulating Fluidised Bed (CFBC) Boiler in a Rankine Cycle power plant

(D) Pressurised Fluidised Bed Boiler (PFBC) in a Combined Cycle (Rankine cycle plus Brayton Cycle) power plant

(E) (i) Integrated Gasifier Combined Cycle (IGCC) Power plant with a High Pressure Gasifier, Gas Turbine, followed by Heat Recovery Steam Generator (HRSG) and a Steam-Turbo-Generator

(ii) A modified IGCC Power Plant with a High Pressure Gasifier, Gas Turbine and a Fluidised Bed Combustor (atmospheric or high pressure) with a Steam Turbo-Generator (variously referred to as Hybrid Plant or Partial Gasifier Fluidised Bed Combustion (PGFBC or Topping Cycle plant)

(F) Fuel Cell based IGCC power plant

(G) Magento Hydro Dynamics (MHD) Combined Cycle Power Plant

Each one of the above design alternatives has its own overall plant efficiency, environmental performance , economics and reliability. Among the above, A, B and C are *commercial* and well proven, D is in the *initial stages of commercialization,* E is at an advanced *demonstration* stage. Technology F and G are in the pilot plant stage with great potential for long term application.

3.1 Technology A : PC Firing with FGD and DENOX Systems

The SO_2, NO_x and particulate matter concentrations in the flue gases must be within limits prescribed according to local conditions which vary from country to country. These limits are being gradually made more stringent to protect the environment. A typical set of limits would be 300 - 400 mg/ Nm^3 for SO_2, 200 - 300 mg/Nm^3 for NO_x and 50 - 100 mg/ Nm^3 for particulate matter. A number of techniques have been developed and / or under development to reduce the emissions of SO_2 and NO_x form the conventional PC fired power plants all over the world, Fig 3.1.1. The most important of these are outlined below :

3.1.1 FGD System

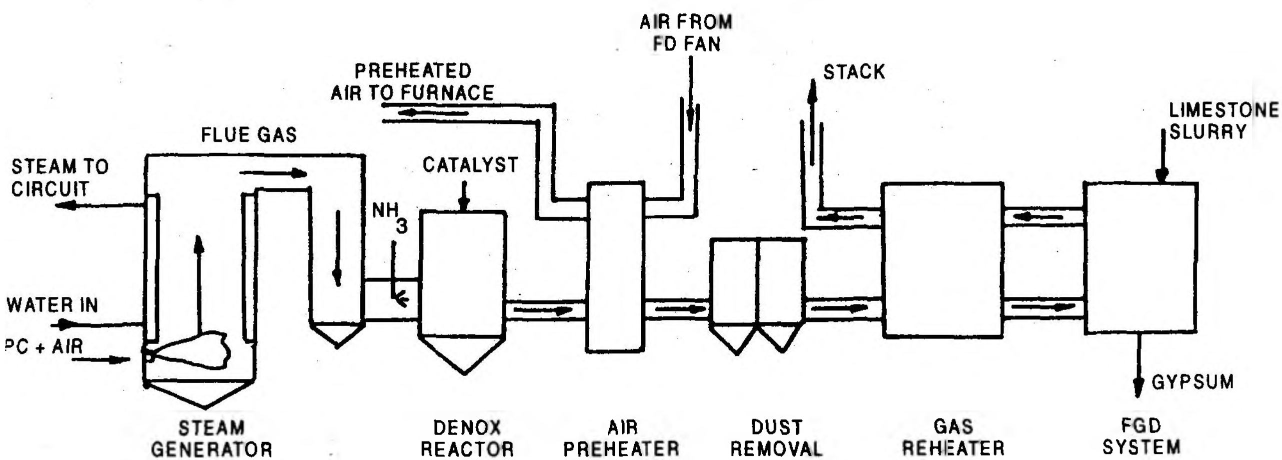
FGD Systems for SO_2 emissions control are based on one of the following three processes :

(i) Wet Limestone / Gypsum process
(ii) Spray Dry process
(iii) Sorbent Injection process
(iv) Circulating Fluidised Bed Process

3.1.1.1 Wet Limestone/Gypsum Process

In this process, flue gases from the boiler are cooled and then scrubbed in an absorber tower wherein the upward moving flue gases react with the downward moving limestone ($CaCO_3$) slurry in the form of sprays. The cleaned flue gases exit the

FIG. 3.1.1 PC FIRING WITH FGD & DENOX



absorber through a demister before being heated and sent out to the stack. Gypsum is the by-product of the process. In a non-regenerable limestone process, which is the most widely commercialised FGD process, the by-product gypsum is either in the form of a sludge or a solid, and disposal of this by-product (or its use) poses an environmental problem. In a regenerable system like the Welman -Lord Process which uses sodium sulphite solution as a sorbent, SO_2 is recovered for conversion to sulphuric acid (H_2SO_4) or to elemental sulphur which can be used in other industries. These are not very popular today because of the costs involved.

3.1.1.2 Spray Dry Process

In the spray dry process the flue gases at the air preheater outlet temperature are made to react with an atomised slurry of lime (CaOH). The water evaporates and the flue gases carry the spent sorbent to the paticlulate control system for disposal with the ash.

3.1.1.3 Sorbent Injection Process

In the "furnace" injection process finely pulverised limestone or slaked lime is injected into the upper zones of the PC furnace where the temperature is 1100-1200°C.About 35-40% sulphur retention occurs at a Ca to S ratio of 2 : 1 in the LIMB and LIFAC processes. Downstream humidification of the flue gases ahead of the precipitators raises the sorbent utilisation to about 70% sulphur retention. In "duct" injection process $Ca(OH)_2$ or sodium bicarbonate ($NaHCO_3$) is injected into the duct downstream from the furnace for a sulphur retention of about 70%.

3.1.2 Status of SO_2 Control

Among the several FGD processes mentioned earlier the most widely used is the wet limestone/ gypsum process with more than 70% of the installed FGD systems being of this type in UK and USA. Spray dry systems, sorbent injection systems, and other minor variations of the wet system are much less in use. The CFB process is at the stage of initial commercialisation in UK. It is very clear that adoption of any of these technologies very much depends upon the sulphur content of the coal, the type of combustion which controls the emission and finally the permissible SO_2 limits in a particular location, needing a thorough techno-economic analysis before final selection.

In India no FGD systems are in operation, neither are they required by law. The low sulphur content of Indian coal is deemed to result in very low SO_2 emission. While this assumption is generally acceptable, there have been situations in several power plants in the country wherein the SO_2 emissions were beyond acceptable limits. Considering the fact that Indian coal is of very low calorific value, high rates of coal consumption is necessary to meet the increased power plant capacity requirement in future and this might lead to excessive SO_2 emissions. Hence it becomes important to consider FGD systems in our power plants in the very near future. It is of course obvious that if high sulphur Assam coal is used, FGD systems become absolutely essential. Today's power plants (> 500 MWe capacity) are required to reserve enough space for a FGD system in case it becomes necessary in the future.

3.1.3 DENOX System

The NO_x emissions in a power plant originate mainly from two sources, namely, "thermal NO_x" which is the result of reaction between the nitrogen in the supply air and the available oxygen at the high temperatures of combustion, and "fuel NO_x" which is the product of the reaction between the nitrogen content of fuel and the available oxygen. The PC fired boiler gives the highest level of NO_x emission because of the very high temperature involved (1400°C-1600°C). This product NO_x emission has to be controlled to meet the local permissible limits, typically of the order of 200-300 mg/Nm^3.

The NO_x control techniques are basically of two types : combustion modification techniques and flue gas side techniques. The former, in general, suppress the formation of NO_x in the furnace itself, while the latter tend to remove the emitted NO_x from the flue gases.

3.1.3.1 Combustion Modification Techniques

There are several NO_x reduction techniques by combustion modification such as air staging, fuel staging (fuel reburn), and reduced flame temperature (by flue gas recirculation). Tangential firing (also known as corner firing) leads to very low NO_x formation compared to wall firing technique. Further it is claimed that cluster firing (alternate sets of coal and air nozzles in the furnace) reduces NO_x emission even compared to tangential firing.

Low NO_x burners designs which control the amount and location of inlet of primary and secondary air and in some cases the tertiary air have been developed to reduce NO_x formation and are in commercial use. Fuel reburning technique involves introducing and burning the fuel in stages so that the NO_x produced in the primary stage is cracked into nitrogen and carbon di oxide on reaction with the fuel in subsequent stages. Similarly air can be introduced at different points in the furnace with the ultimate aim of complete combustion in the uppermost zones of the furnace and NO_x break up. In Flue Gas Recirculation (FGR), a part of the exiting flue gases which are at relatively low temperature is introduced into the furnace at appropriate locations to reduce the flame temperature which directly controls NO_x formation, thus resulting in low NO_x levels within the furnace.

It would appear that a judicious integration of tangential firing, low NO_x burners, over fire air (OFA) introduced at the top of the furnace and FGR would result in NO_x emissions well within the limits presently prescribed. However if the permissible limits become too stringent for combustion modifications alone to satisfy, flue gas side techniques to control NO_x become essential.

3.1.3.2 Flue Gas Side Techniques

The two most widely used flue gas side measures to control NO_x are (i) SNCR (Selective Non Catalytic Reduction) and (ii) SCR (Selective Catalytic Reduction). In the SNCR process ammonia (NH_3) or urea (NH_2CONH_2) or any nitrogen bearing hydrocarbon compound is injected into the flue gases just at the exit from the furnace where the temperature is in the 800 -1100°C range called the "temperature window". The injectant reacts selectively in the form of intermediate radicals NH or NH_2 with NO_x to form molecular nitrogen (N_2) and water (H_2O). In this respect "selective" means that NO_x reacts faster as the oxidant and not the surplus amount of molecular oxygen. The reaction needs a reaction time between 0.2 and 0.4 seconds within the temperature window. There is no additional equipment needed downstream of the injection point except the usual air preheater, ESP and if required, FGD system for SO_2 removal

In the SCR process a selective reaction of NO_x with NH_3 (or urea) occurs at the surface of a catalyst to result in nitrogen and water. This technique needs a temperature range of 320-450°C and the active catalysts used are oxides of metals such as Vanadium and Tungsten. Depending upon the dust concentration in the flue gases the SCR reactor can be placed either before the dust removal system or after the FGD system.

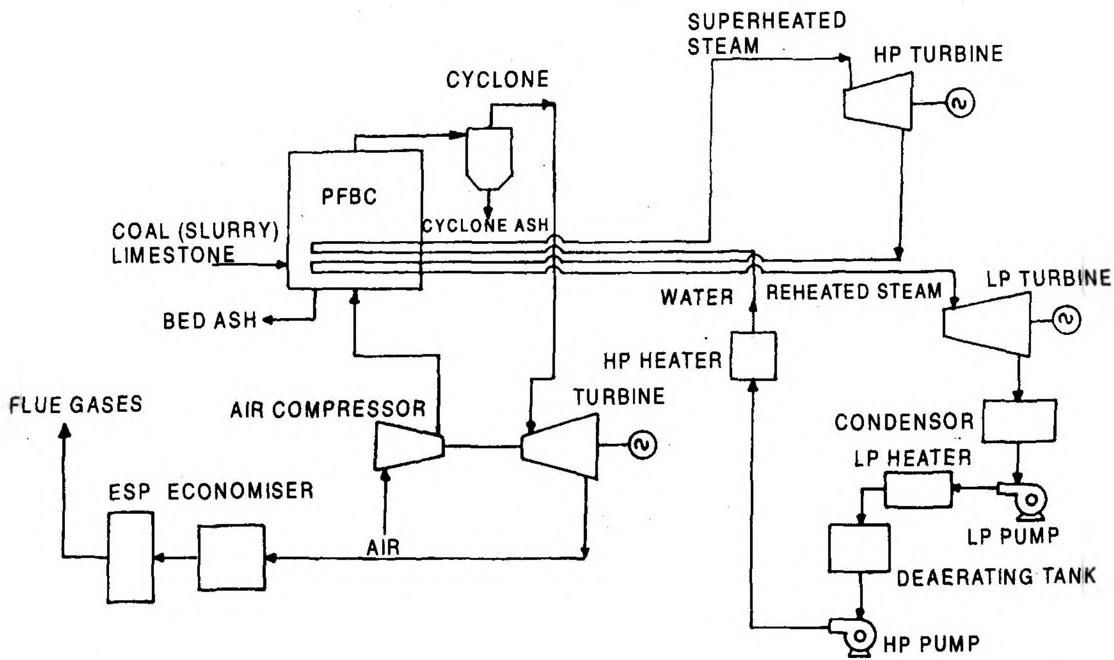
3.1.4 Status of NO_x Control

A number of different DENOX techniques have been used in various operating power plants in the world since 1985, especially in Europe and USA. Pressurized liquid ammonia injection is the most commonly used technique.

3.2 Technology B : AFBC Power Plant

An AFBC power plant, shown in Fig 3.2.1 consists of a bubbling fluidised bed boiler with limestone particles (upto 1mm) operating normally at 850°C with crushed coal (0 - 6mm) as the fuel and fluidising air velocities of the order 1.5 - 3 m/s. The fluidised bed height in actual application is less than 1m within which water carrying tubes are immersed to act as evaporators in which steam is generated at required pressure. Immersed tube bundles in the bed may also be used as super heaters if required. One of the main advantages of FBC boilers of this design is that the heat transfer coefficient from the hot bed to the surface of the tube is high leading to relatively small bundles resulting in compactness of the boiler. The SO_2 absorption is controlled by varying the Ca (in limestone) to S (in coal) ratio through control of limestone feed rate as and when the SO_2 concentration in the flue gases

FIG. 3.2.1 AFBC POWER PLANT



exceeds allowable limits. There is no additional equipment needed for NO_x control especially in boilers with multi-stage air supply. The thermal efficiency of these boilers is of the order of 85% while the combustion efficiency is in the range of 90-95% without recycle of the unburnt carbon escaping from the furnace. The particulate matter in the exhaust can be controlled as usual by ESP. AFBC boiler is the first generation in the FBC family and hundreds of such boilers today are in operation for industrial steam generation.

3.2.1 Status of AFBC Technology

Since its conceptualisation by Prof. Douglas Elliot in UK in the early 1960's, FBC has come a long way, thanks mainly to the co-ordinated efforts by the Department of Energy, the power industry, the Universities and Research Laboratories in USA with parallel R&D programmes in UK and Germany. AFBC boilers for steam generation today are available upto a capacity of 200 T/hr steam in several countries. A 165 MWe power plant is operating in the US for the past ten years, in addition to some smaller capacity plants.

In India industrial boilers for steam generation are in commercial use since 1980, the maximum capacity being 165 T/hr of steam. A 10 MWe AFBC power plant using coal washery rejects is operating in Jamadhoba, Bihar for TISCO while another similar unit using rice husk is in operation in Punjab. No large capacity power plant of this type is planned to be built in India in the near future. However it is expected that industrial boilers upto a capacity upto 100 T/hr steam will be of this type.

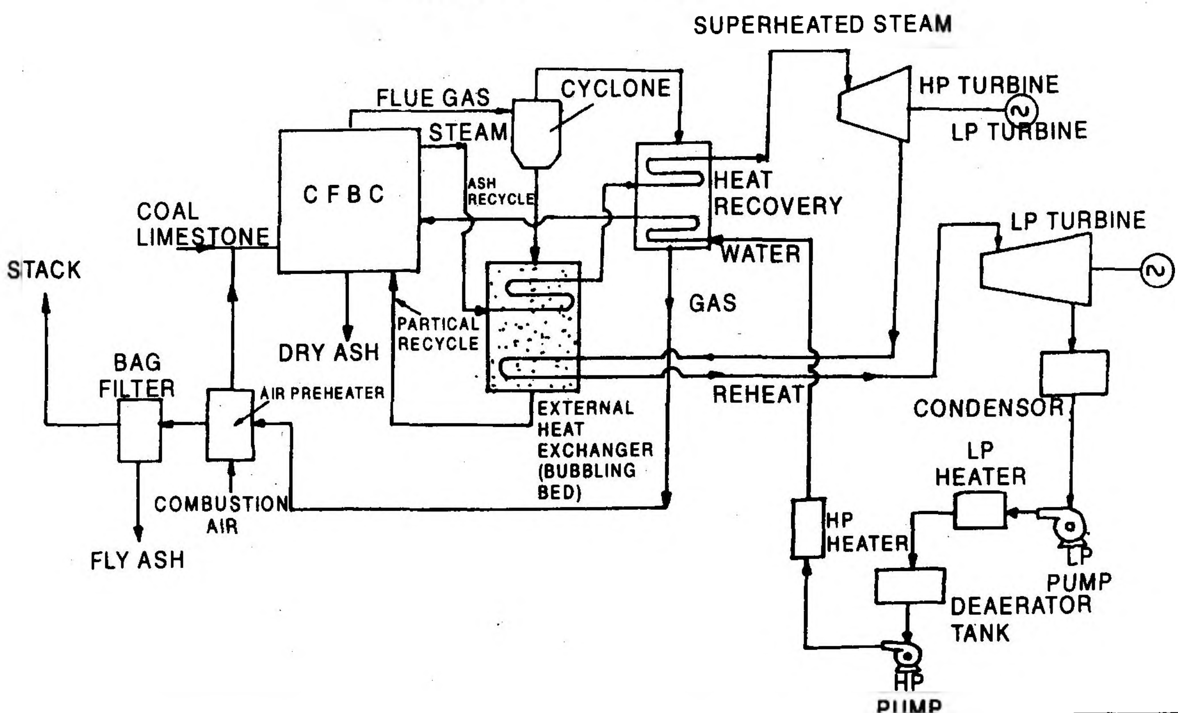
3.3 Technology C : CFBC Power Plant

This is also an atmospheric unit but with an entirely different nature of contact between the fluidising air and the coal and limestone particles. In classical terms the gas-solids motion is said to be in the "fast fluidisation regime" with no bubbles . The steam is generated in the water walls of the boiler and superheated if required in the upper zones by the exiting flue gases. The chief advantages of CFBC over AFBC are its better fuel flexibility, better sulphur di-oxide control and combustion efficiency approaching that of PF boilers. The flue gases are let out to the atmosphere after heat recovery by the economiser and the air pre-heater and removal of particulate matter by the ESP. Fig 3.3.1 shows a CFBC based power plant.

3.3.1 Status of CFBC Technology

Since the first CFBC boilers came into the market in the late 1970's and early 1980's in USA the industrial boiler industry has recognised the distinct advantages of CFBC in effectively suppressing SO_2 emission and the facility to burn coals of varying quality, and various kinds of biomass both individually and in the co-firing mode. This has led to the wide use of

FIG. 3.3.1 CFBC POWER PLANT



CFBC boilers in many countries and industrial boilers of 300T/hr steam are being offered in the market.

However a very significant development has been the acceptance of CFBC boilers for large scale power generation especially in the United States. The first CFBC power plant at Nucla, Colorado, USA with a capacity of 110 MWe has been operating since 1990. Several such CFBC power plants are operating in Germany, UK, Canada and Japan using various kinds of coal and biomass fuels. The largest CFBC power plant is the 250 MWe unit in France which was commissioned in 1996. Presently 350 MWe units are being constructed in Canada and Japan. Thus the CFBC technology has more than fulfilled the expectations of the boiler industry of the 1970's and has the unique claim to be the first commercialised technology based on a new concept after the first PC power plant of early 1920's.

In India, a 1m x 1m CFBC Pilot Plant is operating at BHEL - Trichy for the last eight years basically for fundamental research studies and component development. Based on this experience and in collaboration with LURGI of Germany, BHEL has commissioned a 30 MWe CFBC power plant using lignite as the fuel in Maharashtra in 1997. This is the largest capacity power plant of the FBC family operating in India today. Among all the new coal technologies, this has the greatest potential for immediate large scale adoption in India, from the environmental and fuel flexibility point of view. Ahmedabad Electrical Company has plans to establish a 125 MWe CFBC power plant in Gujarat.

3.4 Technology D : PFBC Power Plant

While AFBC and CFBC power plants referred to above are definitely an advancement over the PC power plant in terms of environmental performance and fuel flexibility, their over all plant efficiency is still the same as that of PC plant since they are based on the Rankine cycle for their operation. A PFBC power plant overcomes this deficiency by facilitating the high pressure combustion gases to run a gas turbine in a Brayton cycle and the high pressure steam to operate a steam turbine in a Rankine cycle. This combined cycle approach offers a overall plant efficiency in the range of 39-43%. In addition to this the PFBC offers better SO_2 control and smaller plant size because of the higher operating pressure. Fig 3.4.1 depicts a PFBC combined cycle power plant. It is to be noted that there is no additional equipment for control of SO_x and NO_x.

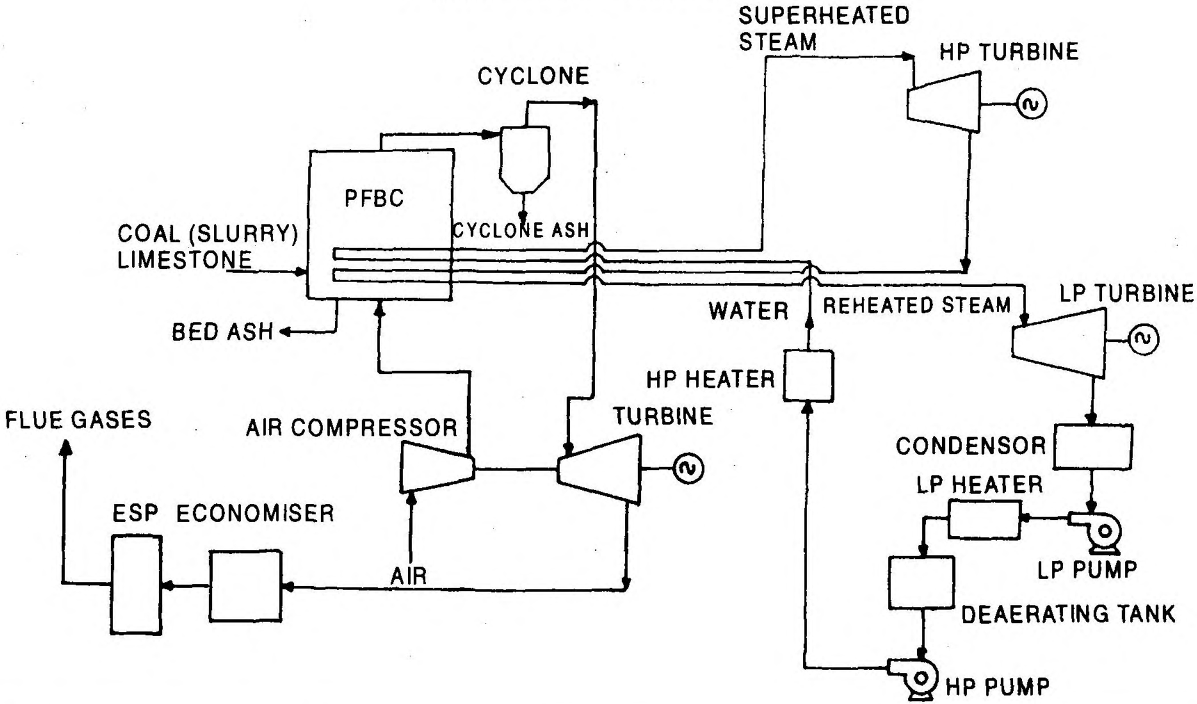
The PFBC operates like an AFBC in the range of 800-900°C, limestone or dolomite as the bed material at fluidising air velocities of 0.8 - 1.3 m/s. The bed is very deep allowing large amount of heat exchanger surface area to be immersed resulting in a very compact combustor. This gives an added advantage in the sense that PFBC power plants can be designed to be modular facilitating shop fabrication of major components, their transportation to the field, and field assembly.

The critical component of the PFBC power plant is the High Temperature High Pressure (HTHP) particulate control system sandwiched between the boiler exhaust and the gas turbine intake. This system should be efficient enough at the prevalent harsh conditions to remove entrained particulate matter to a very low value with the concentration limit dictated by the safety of the gas turbine blades. Presently in the three demonstration plants operating in the world the particulate control is effected by multi-stage cyclone system in addition to using a rugged gas turbine design. Yet another limitation on the PFBC technology is the inability to go beyond a combustion temperature of about 900°C which results in low gas turbine entry temperature (TET) which directly results in low gas turbine efficiency and therefore a correspondingly low overall plant efficiency. If the gas temperature just before the gas turbine inlet can be increased by additional heat input, the state of the art gas turbine which can tolerate inlet temperatures upto 1250°C can give substantially higher efficiencies.

3.4.1 Status of PFBC Technology

The first demonstration plant of capacity of 130 MWe (+ 224 MW_t co-generation) has been operating in Stockholm, Sweden since 1991 meeting all the stringent environmental conditions.

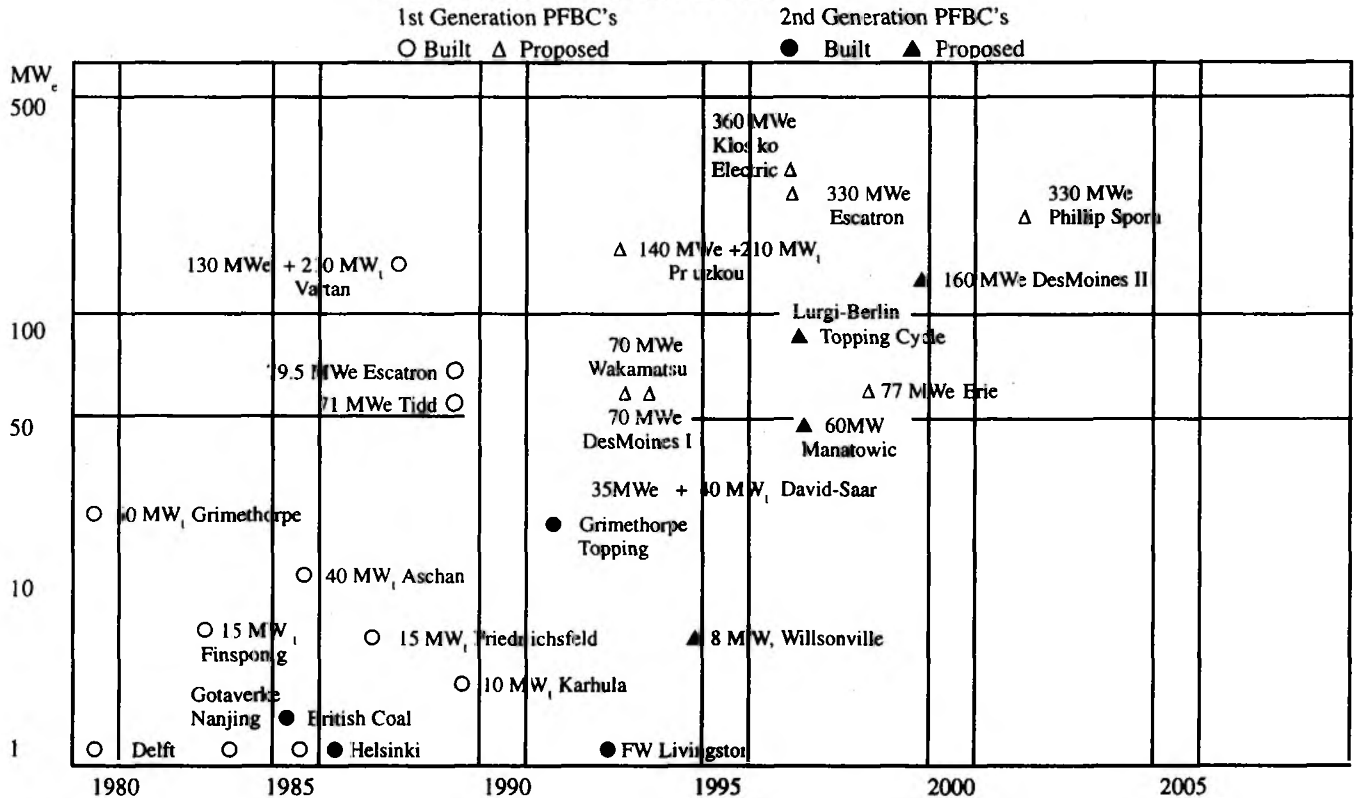
FIG. 3.4.1 PFBC POWER PLANT



Another demonstration plant of 80 MWe capacity is operating in Escatron, Spain using 36% ash black lignite. The third demonstration plant of 70 MWe at TIDD station, OHIO, USA was shut down in 1994 after a eight year demonstration period in which a large amount of useful data and experience were obtained. A 70 MWe demo plant operated at Wakamatsu from 1993 to 1996. Presently a 350 MWe PFBC power plant is planned in Japan and another is on order in USA (to be operated at SPORN). UK has gathered a large amount of data on a 80 MWe PFBC plant in Grimethrope during its operation from 1980-1992 and is now offering commercial PFBC plants and developing second generation PFBC. ABB-Sweden is the leading international manufacturer which has supplied the first three demonstration plants in the world and is now offering 300 MWe units plants. A number of pilot plants are also operating as shown in Table. 3.4.1.1.

In India BHEL-Hyderabad has been operating a 400 mm PFBC for the last eight years and has collected substantial amount of research data. IIT Madras has a 300 mm diameter research facility built with NSF (USA) grant. A proposal by BHEL for a 60 MWe PFBC plant is under consideration with the Government of India.

TABLE 3.4.1.1. LIST OF PFBC POJECTS IN THE WOLD

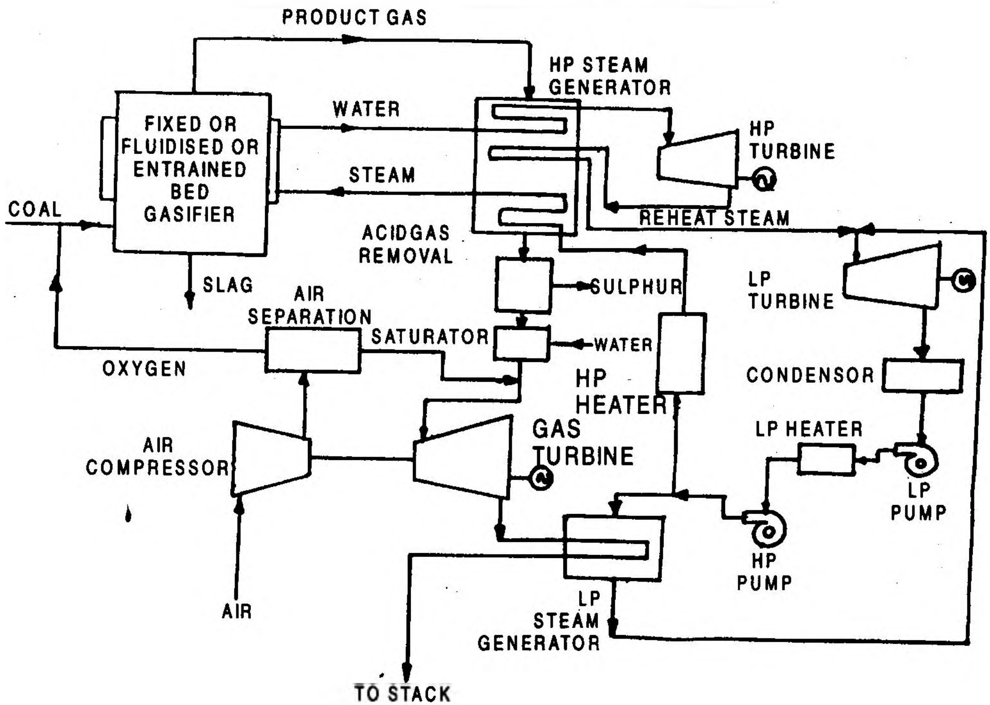


3.5 Technology E : Integrated Gasification Combined Cycle (IGCC) Power Plant

As the name implies this power plant consists of a coal gasifier whose product gas (CO +H2+CH_4) with a calorific value of 4 - 7 MJ/Nm^3 is cooled in the gas cooler and then cleaned (to remove H_2S, COS, and particulate matter) in a Gas Clean Up (GCU) system before being introduced into the combustor of a gas turbine. The hot gases from combustor at a temperature of upto 1250°C are expanded in the gas turbine to generate electrical energy. The exhaust gases from the gas turbine which are still at a considerably high temperature are made to generate steam in a Heat Recovery Steam Generator (HRSG). The high temperature high pressure steam is sent to turbo generator for production of electricity. The exhaust gases from HRSG are let out to the atmosphere with additional heat recovery in an economiser. The combined cycle operation of using the gas turbine and the steam turbine results in a overall plant efficiency between 39 - 45% and has the potential of achieving close to 50% in the future. Further as the gas is cleaned before it is combusted the amount of gaseous and particulate pollutants in the exhaust gases is very low. In fact it has been well established that presently this is the most environmental-friendly technology for coal utilisation. Fig 3.5.1 depicts an IGCC power plant.

The overall performance of this technology depends very much on the type of gasifier employed which further depends

FIG. 3.5.1 1ST GENERATION IGCC PLANT



essentially on the type of coal. A variety of gasifiers have been patented by various private industries in the West encompassing all the three types of gasifiers explained in section 2.3. These include fixed bed gasifiers like Lurgi Dry Ash, DGL Slagging, entrained bed gasifiers like the Shell, Texaco and Kopper-Tozek and finally, fluidised bed gasifiers like KRW, U-gas and high temperature Winkler. Accordingly there has been an accelerated development in the gas turbine technology to suit the characteristics of the product gas from the gasifier.

A Hybrid IGCC Plant is shown in Fig. 3.5.2. In the Hybrid Plant (Also called a Topping Cycle Plant or Partial Gasification Plant), coal is partially gasified in a pressurised fluidised bed gasifier (PFBG), the product gases are cleaned and burnt in the combustor of a Gas Turbine (GT) to generate electricity. The GT exhaust gases produce steam in a Heat Recovery Steam Generator (HRSG) to run a steam turbine for electricity generation. In addition, the unburnt char from the PFBG is burnt in an atmospheric circulating fluidised bed combustor (CFBC) to generate steam for electricity generation. Thus direct char combustion and indirect coal gas combustion is used to generate electricity in a combined cycle mode.

3.5.1 Status of IGCC Technology

The first IGCC power plant based on a fixed bed gasifier of 170 MWe capacity was operated in Lunen, Germany during

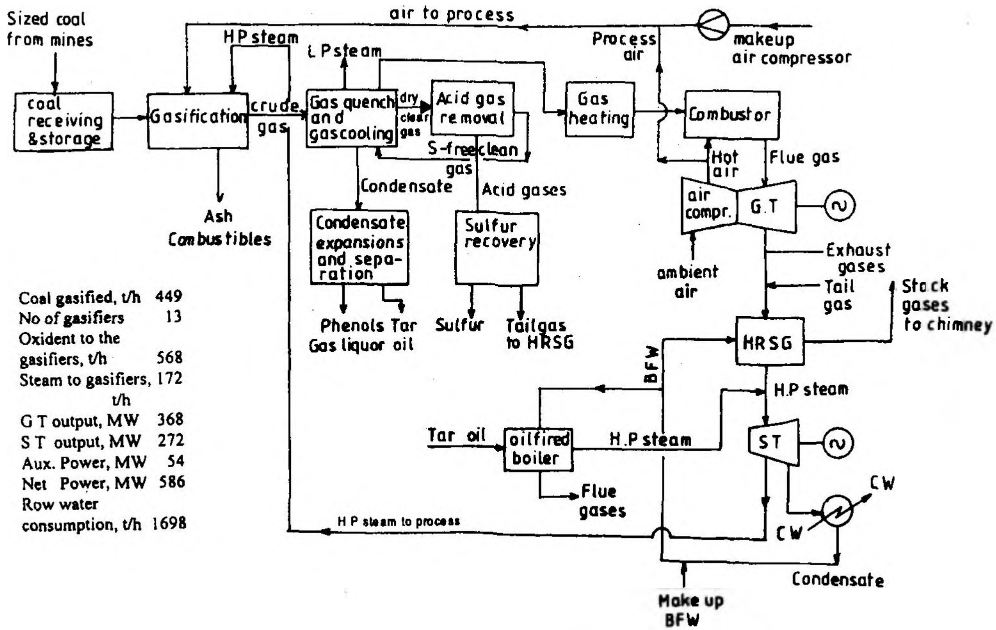
1972-1977. Also a 500 Tonnes/day coal IGCC plant based on BGL process was also operated in UK in the 1970's. The most publicised IGCC power plant has been the Cool Water demonstration plant of 110 MWe capacity based on the entrained bed Texaco gasifier technology. It was operated for four years between 1984-88 and has more than fulfilled the expectations of high availability and environmental acceptability but operated at a lower efficiency than expected. Another entrained bed gasifier bed IGCC plant of 250 MWe capacity is today in operation at Buggenum in Netherlands since 1993. The plant based on a Shell gasifier has had some problems with the hot gas clean up system. A third entrained bed gasifier based IGCC plant is the one at Plaqumine of 160 MWe capacity with a Dow gasifier which is operating since 1987. Table 3.5.1 shows the current IGCC projects world wide.

In India the Indian Institute of Chemical Technology, Hyderabad has been developing coal gasification technology since 1983. It has a 24 Tonnes/day pilot plant on which various Indian coals have been studied. Based on this experience IICT has developed a conceptual design of a 600 MWe IGCC plant (Fig 3.5.1.1) and a comparative study has been made of the performance and economics for four gasifier alternatives namely, Shell entrained bed, the Texaco entrained bed, the KRW fluidised bed and the Lurgi fixed bed processes. This analysis was done in collaboration with

TABLE 3.5.1 CURRENT IGCC PROJECTS

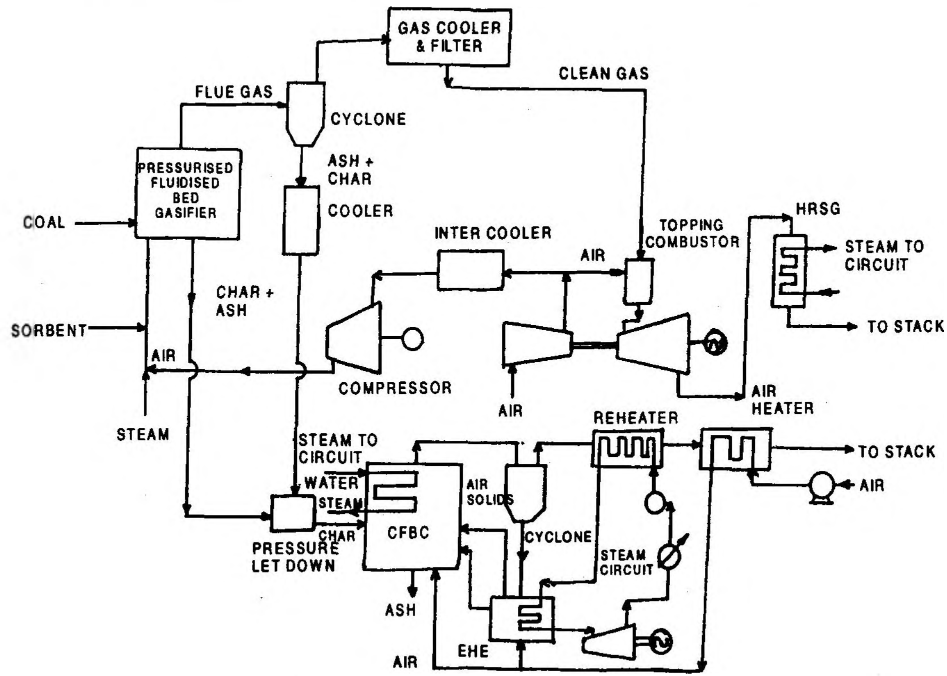
Project Customer	Date of Commissioning	MWe	Application	Gasifier	Status
SCE Cool Water -USA	1984	120	Power/Coal	Texaco	No Activity
PSI/Destec - USA	1995	260	Repower/Coal	Destec	GT start-up on fuel oil 6/95; Coal gas start-up in 8/95; 250-hour run completed in 7/96
Tampa Electric - USA	1996	250	Power/Coal	Texaco	Just began operation; ASU & GT delivery 3/95; Syngas cooler installation 7/95
Sierra Pacific - USA	1996	100	Power/Coal	KRW	Under construction
Texaco El Dorado - USA	1996	40	Cogen/Pet Coke	Texaco	No Activity
SUV/EGT - Czech.	1996	350	Cogen/Coal	ZUV	No Activity
Schwarze Pumpe - Germany	1996	40	Power/Methanol/Lignite	Noell	No Activity
Shell Pernis - Netherlands	1997	120	Cogen/H_2/Oil	Shell/Lurgi	No Activity
IBIL/Sanghi - India	1998	60	Power/Lignite	Tampella	Under negotiation
Sarlux/Enron - Italy	1999	550	Cogen/H_2/Oil	Texaco	No Activity

FIG. 3.5.1.1 FLOW DIAGRAM OF CONCEPTUAL 600 MW IGCC PLANT



Coal gasified, t/h	449
No of gasifiers	13
Oxident to the gasifiers, t/h	568
Steam to gasifiers, t/h	172
G T output, MW	368
S T output, MW	272
Aux. Power, MW	54
Net Power, MW	586
Row water consumption, t/h	1698

FIG. 3.5.2 IGCC PLANT (HYBRID) WITH TOPPING COMBUSTOR



Bechtel Corporation of US under a US AID programme in 1990. Tables 3.5.2 and 3.5.3 present certain relevant details of the 600 MWe conceptual design.

TABLE 3.5.2. PERFORMANCE OF MOVING BED GASIFICATION BASED IGCC PLANT USING HIGH ASH INDIAN COAL

No. of gasifiers	13
Gasifier coal feed, t/h	448.65
Calorific value of coal (HHV), kcal/kg	3282
Steam to the gasifier, t/h	172.29
Oxidant to the gasifier, t/h	567.95
Calorific value (LHV) of clean fuel gas (dry), kcal/nm^3	1304.04
Specific gas yield Nm^3/kg coal	1.71202
GT output, MW	368.3
ST output MW	271.8
Auxillary power, MW	54.4
Net power, MW	585.7
Net heat rate (HHV), kcal/kWh	2514
Net heat rate (LHV), kcal/kWh	2427
Cold gas efficiency %	74.1
Overall Thermal Efficiency (LHV)	35.2
(HHV)	34.2
Raw water consumption, t/h	16989
By products :	
Sulfur, t/h	1.313
Ammonium sulfate, t/h	2.708

BHEL - Tiruchirapalli has successfully demonstrated the operation of a 6 MWe IGCC power plant using a fixed bed gasifier. Presently a 150 Tonnes/day coal pressurised fluidised bed gasifier is under demonstration. On its successful completion it is expected that the PFBG will be integrated into the existing combined cycle system for an overall demonstration of the IGCC plant based on fluidised bed gasifier.

Several national level committees have looked at the various gasifier technologies that can be adopted for Indian coal, the pros and cons of the IGCC route to power generation and the techno-economics of IGCC. In 1988 one such committee recommended the setting up of 100 MWe IGCC power plant based on a fixed bed gasifier as a demonstration plant.

TABLE 3.5.3. PERFORMANCE OF THE MOVING BED BASED IGCC VIS-A-VIS CONVENTIONAL PC AND PC + FGD PLANT

	MB based IGCC	PC	PC + FGD
Coal (as received), MTPD	10,678	10,886	10,886
HHV, x 10^6 kcal	1495	1511	1511
LHV, x 10^6 kcal	1421	1437	1437
Limestone, MTPD	–	–	280
Raw water, m^3/h	1698	2754	3000
Plant output, MW			
Gross power generated,			
GT	368.3	–	–
ST	271.8	600	600
Total	640.1	600	600
Inplant power consumption	54.4	42.0	45.0
Net power to grid	585.7	558.0	555.0
Net specific power generated, kcal/kg coal	1.31	1.23	1.22
Net heat rate, kcal/kWh			
HHV basis	2514	2708	2723
LHV basis	2427	2575	2589
Overall thermal efficiency			
HHV basis	34.2	31.8	31.6
LHV basis	35.4	33.4	33.2
Sulfur byproduct, MTPD	32.0	–	–

However till very recently no further progress was made in terms of its implementation because of lack of sufficient funds. In the meantime several new IGCC demo plants have been operated in US and Netherlands. Very recently an inter-ministerial committee of the Government of India has been formed which has been seriously considering the establishment of a 250 MWe IGCC plant following the recommendations of a Task Force set up for the purpose. The IGCC technology development is now in a Mission mode and is a part of CSIR S&T Missions. Under this mission it is expected that the proposed 250 MWe IGCC facility will be set up in Dadri, U.P within the next few years, if the plan is approved and funds made available. The hybrid Power Plant is at a pilot stage in UK.

3.6 Technology F : Fuel Cell based IGCC Power Plant

A fuel cell is a device where a gaseous fuel and a gaseous oxidant are made to react electro chemically to generate electricity and heat. The fuel and the oxidant are fed to the anode and cathode of the cell with a suitable electrolyte which generates and promotes electrochemical reaction generating electricity. The heat given out in the process can be used for steam generation for a Rankine cycle power plant.

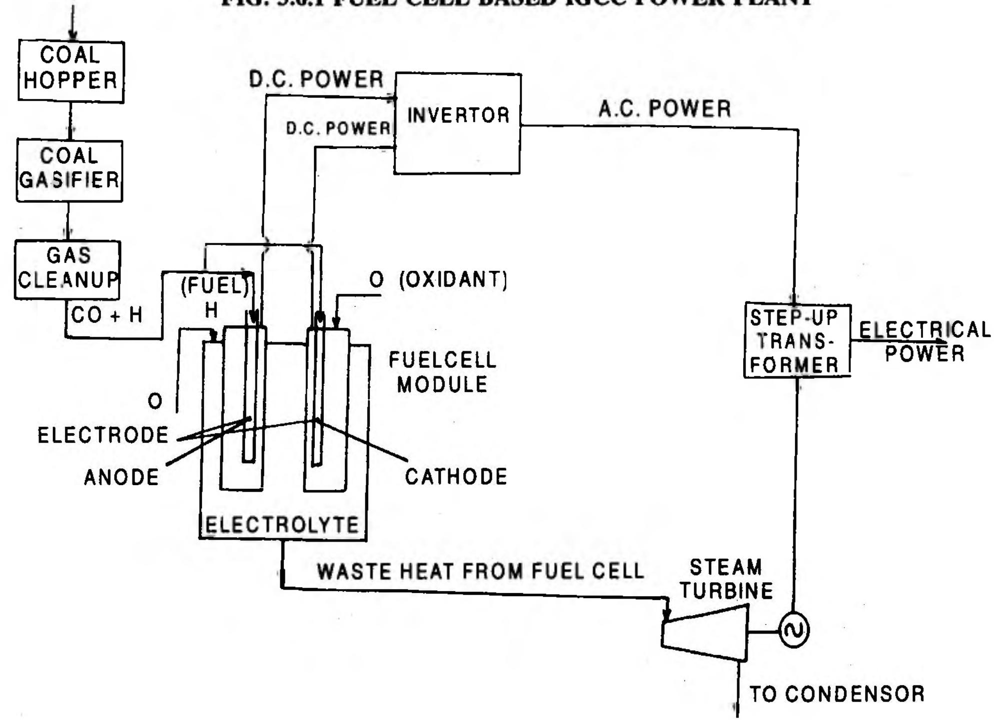
3.6.1 Status of Fuel Cell Technology

Fuel cells with phosphoric acid (PAFC) or molten carbonate (MCFC) are commercialised upto 100 kW capacity. 1 MWe fuel cells are in an advanced stage of demonstration. In India, BHEL has a fuel cell development programme with the aim of demonstrating a 1 MWe unit in the near future. IGCC plant using fuel cell is basically in a conceptual stage with futuristic applications in the very long term, Fig 3.6.1.

3.7. Technology G : Coal Fired MHD Power Plant

The concept of generation of electricity when an electrical conductor moves in a magnetic field is made use of in the MHD power generation. The moving conductors can be copper wires as in the case of conventional power generation or a flowing gas of very high electrical conductivity. In this kind of a power plant coal is burnt in a combustor to produce a very high temperature gas at about 2250°C at which temperature the gas becomes electrically conductive which is further sought to be enhanced by the addition of a seed material, potassium carbonate. This high temperature, high electrical conductivity coal gas is made to flow through at high velocities in a divergent channel around which a magnetic field of 5-12 tesla strength is applied. This results in direct energy conversion and electricity is tapped off at the terminals. The exiting gas from the channel is still at a very high temperature of the order 1500 -1800°C. Hence a series of heat exchangers and a heat recovery steam generator (HRSG) are provided to extract as much thermal energy as possible from the hot gases. The steam from the HRSG is used to generate

FIG. 3.6.1 FUEL CELL BASED IGCC POWER PLANT



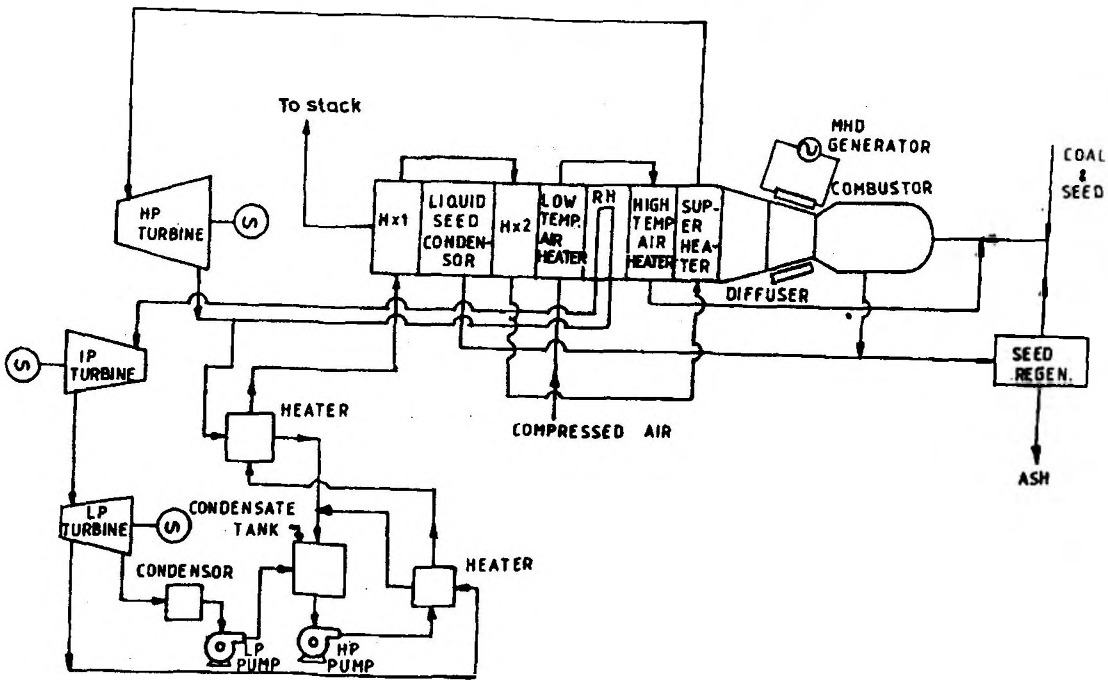
electrical power conventionally in a Rankine cycle based power plant. The seed material can be recycled to the combustor after due processing. Thus electricity is obtained at two points resulting, under ideal design and operating conditions in overall plant efficiency of the order of 50 -55%. Fig 3.7.1 depicts a power plant based on MHD.

3.7.1 Status of MHD Technology

The main impetus to MHD technology was given in Russia and USA in the 1970's and 80's. A 20 MWe power plant was designed, erected and operated in Russia for several years in the 70's. USA also operated a few small pilot plants. Both the countries jointly proposed a 500 MWe power plant in the early 1980's. However the project was abandoned due to the escalating cost of the project mainly due to the necessity of materials to withstand very high temperatures and the cooling required for the magnet. As of today, there is no activity in this area.

In India BHEL-Trichy set up a 6 MWe MHD plant in the late 1970's and 1980's. The feasibility of the technology was demonstrated. The complexity of the plant especially, the very high temperature equipment prompted the termination of the project. Presently there is no active interest in developing this technology.

FIG. 3.7.1 COAL FIRED MHD CYCLE POWER PLANT



3B. Other Advanced Technology

3.8 Technology H : PC Fired Supercritical Power Plants

The conventional sub-critical boiler based power plants operate at a maximum steam temperature of 560°C and pressures of upto 180 atm with an overall plant efficiency of 33-37%. It is very well established that the cycle efficiency can be increased if the temperature of heat addition is increased. This requires the steam temperature to be raised and accordingly, the pressure. This is accomplished in a super-critical boiler wherein the final steam conditions are above the critical pressure of 221 ata and temperatures going upto 620°C. Major requirements of this technology is water of very high purity as boiler feed water, and materials to withstand high temperature and high pressure. Availability and reliability of the plant are matters of some concern.

3.8.1 Status of Supercritical Technology

Several super-critical plants of upto 1000 MWe capacity are in operation in Europe and USA for the last 5-10 years with a maximum reported overall plant efficiency of 45%. Some problems associated with materials exposed to high temperature and pressure have been identified and overcome. Several major international boiler manufacturers routinely offer this technology.

3.9 Technology I : Slagging Cyclone Combustion Technology

In this technology which is in a state of advanced development, high ash coal is burned in an inclined cylindrical combustor at temperatures of the order of 1500-1700°C outside the main water walled boiler. More than 90% of the ash in the coal in a molten form flows down the cylindrical chamber and is tapped off. The hot flue gases with the rest of the ash flows up the boiler space to generate steam. The main advantage of this technology is the removal of ash as a molten slag with minimum fouling of the water walls of the boiler resulting in improved boiler performance.

3.9.1 Status of Slagging Combustion Technology

The technology has been demonstrated at the pilot plant scale by TRW systems in USA. Cyclone Combustors of advanced design are being demonstrated for ash removal combined with SO_2 and NO_x control .

In India, BHEL has conducted laboratory scale studies on a horizontal cyclone combustor. It was found that the molten slag did not have enough flowability for it to be easily removed from the combustor and recuperation of heat from the molten slag posed practical problems. Presently no serious activity is contemplated.

4. Coal Benefication Technology

Coal mining started in India almost over 200 years ago. In 1947 the coal production was about 30 million tonnes which rose to about 78 million tonnes by 1974. A large percentage of this production was by underground mining. Coal production since then has gradually increased to about 300 million tonnes in 1997-98 and a majority of this was through mechanised opencast mining. Very close to 90% of this coal has high ash (upto 45%) and low sulphur (less than 0.6%) content. The coal for power plants is graded from A to G in the decreasing order of the heating value, A being the best coal (> 6200 kcal/kg) and G being the worst coal (1300-2400 kCal/kg). More than 60% of the coal reserves are coals of Inferior Grades E, F and G whose calorific value varies from 1300 -3360 kcal/kg.

This low grade coal is today being supplied from the coal rich areas of the states of Bihar, West Bengal, Orissa, Andhra Pradesh and Madhya Pradesh to various power, steel and cement plants in the country for power generation and manufacturing. It is estimated that in 1996-97 Pithead power plants (power plants located at or close to the coal mines and using local transportation facilities only) used 74 million tonnes of coal, about 90 million tonnes of coal were transported upto a distance of 1000 km from the mines, and about 43 million tonnes of coal were transported over more than 1000 km distance. It is estimated that by 2004-2005 AD about 110 million tonnes of coal may have to be transported to power plants located more than 1000 km away from the mines. Tables 4.1 and 4.2 present the coal consumption pattern and the coal distance-wise transportation pattern as projected by the Ministry of Coal. Further it is also expected that the amount of ash in the coal would increase in the coming years, and combined with the stones and shales that are mixed with the coal, the cost of coal transportation will increase enormously per unit of useful energy transported. Table 4.3 presents the likely cost reduction in the transportation of "cleaned" coal over a distance of more than 1000 km, if coal were beneficiated.

The present day supply of coal to power plants is quite erratic in terms of quality with the supply ash content being substantially different from the design value and varying over the day by 5 - 10%. This directly affects the performance of the power plants, damages the various components of the power plants leading to frequent outages which finally result in a low Plant Load Factor (PLF). It therefore becomes very attractive and in fact essential to clean coal before its use in the power plants by removing as much of stones and shales as possible and reducing the ash content even by a few percentage points.

TABLE 4.1 PROJECTED CONSUMPTION OF COAL FOR THE NEXT 20 YEARS

(In million tonnes)				
	1996-97	1999-2000	20004-2005	2009-2010
Steel	41.50	43.20	45.00	45.00
Power	177.50	218.00	302.00	372.00
Cement	17.40	20.36	25.00	29.00
Others	78.60	104.44	143.00	184.00
	315.20	386.00	515.00	630.00

TABLE 4.2 DISTANCE-WISE COAL REQUIREMENT

Total distance(km)		Coal requirement (mt.)			
	1989-90	1996-97	1999-2000	2004-2005	2009-2010
Pit-head	46.18	79.21	85.30	110.32	123.75
Upto 500	78.26	112.16	132.21	162.66	187.54
501 - 1000	51.04	75.55	97.78	127.66	152.66
1001-1500	19.01	32.84	35.10	45.00	55.04
Above 1500	7.42	15.44	35.61	68.76	111.31
	201.91	315.20	386.00	515.00	630.00

TABLE 4.3 REDUCTION IN BULK OF COAL TO BE TRANSPORTED 1000 KM

(million tonnes)				
	1996-97	1999-2000	2004-05	2009-10
Power House	3.0	15.0	25.0	37.0
Other Sectors	-	3.0	5.01 1	10.01
	3.0	18.0	30.0	47.0
Savings freight (Rs. crs) at current average rate of Rs.0.41/t Km	166	995	1660	2600

The other impurity that is generally sought to be reduced in coal before its use is sulphur which can either be in organically bound or in pyritic form. There are several processes commercialized to remove a part of the pyritic sulphur. The very low sulphur content of Indian coal does not presently warrant adoption of pre-combustion sulphur removal from coal. However from the long term point of view it may be useful to consider its removal as well as of trace element impurities (like Hg, As, Va, Mb, Pb, Sb) from coal before its use.

4.1 Coal Beneficiation Technology

Indian coals have a high content of near gravity material (ngm, ± 0.1 specific gravity) and also unsatisfactory crushing characteristics, and therefore need "wet washing" method of cleaning. While the standard jig, moving screen jig (ROM jig), and modular barrel cum cyclone washers are the most common wet washing devices, the following is a typical washing process that is adopted in Indian washeries :

- Screening of raw coal at 100 mm or at 75 mm
- Crushing of oversize raw coal to - 100/-75 mm in a suitable type of crusher
- Mixing of natural and crushed -100/-75 mm coal and stocking and blending in a bunker of about one day capacity

- Screening of blended raw coal at 13 mm to produce two fractions i.e, +13 -75/100 mm and 0-13 mm
- Beneficiation of +13 mm fraction in a standard two product jig to produce clean coal and rejects
- Mixing of clean product with untreated - 13 mm. fraction
- Recovery of fines (-0.5mm) through thickner, solid bowl centrifuge and tailing pond

4.2 Status of Coal Beneficiation Plants

That coal cleaning is a must for the Indian power plants was recognised by various national level committees even by 1988 and therefore the establishment of coal washeries for the non-caking coal (power coal)was recommended. Three coal washeries with a total capacity of 19 million tonnes per annum were proposed at the following places :

(i) Piparwar (Central Coal Fields Ltd. Ranchi) : 6.50 million tpa (mtpa raw coal), 5.25 mtpa (clean coal) - To be supplied to Dadri and Yamunanagar Thermal Power Station (TPS);

(ii) Bina (Northern Coal Fields Ltd., Siagrauli) : 4.50 mtpa (raw coal), 3.29 mtpa (clean coal) - to be supplied to UPSEB stations at Obra and Anpara "A". and

(iii) Kalinga (Southern Eastern Coal Fields Ltd., Bilaspur) : 8.00 mtpa (raw coal), 5.92 mtpa (clean coal) - to be supplied to TNEB stations like N. Madras and Tuticorin Extn. and NTPC stations at Kayamkulam and Mangalore.

Presently the Piparwar coal washery is in operation. Further a coal washery of 2 mtpa capacity has been set up at DIPKA mine near Korba coal field by a consortium of US and Indian companies. Ministry of Environment and Forests, Government of India has enacted a law recently that power plants which are away from the coal mine by 1000 km and above and located near urban and sensitive areas shall use only washed coals with ash content of 32 ± 2% from June 2001 onwards. As per this, it is estimated that about 53 million tonnes of non caking coal will have to be washed, in coal beneficiation plants before despatch to power plants.

The implementation of this directive requires the establishment of 20 -25 more washeries for power coal and 15 - 20 more washeries for cleaning the caking coal for the steel sector (where the allowable ash content is 17 - 18%), in addition to more than 20 coking coal washeries operating today. This has led to the decision of inviting private sector investment for the construction and operation of coal washeries.

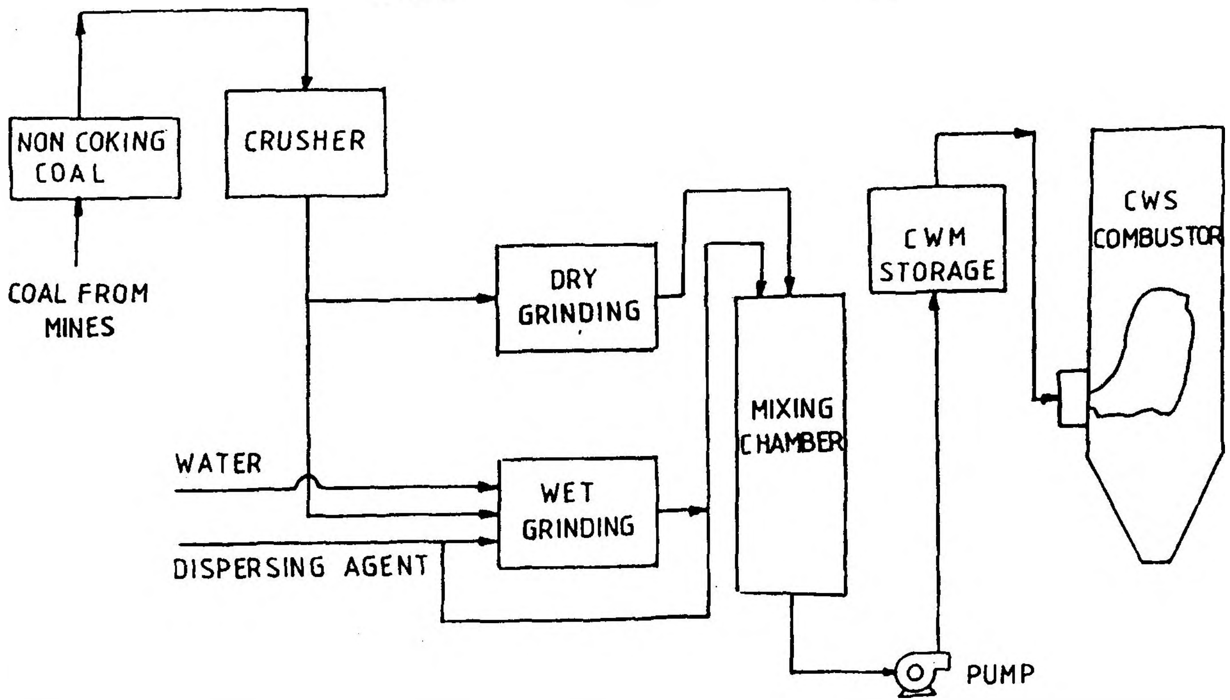
5. Coal Water Slurry (CWS) Combustion Technology

Coal- water slurry is, as the name implies, a mixture of coal and water in suitable proportions which can be transported through pipelines and burned directly, without dewatering, in a furnace. The driving force behind this concept is the substitution of expensive oil, especially for oil importing countries like India. All the boilers in a PC power plant resort to use of furnace oil for startup, low load flame stabilisation and / or load sharing, thus increasing the operating cost of the power plant. Coal being our major national resource for a long time to come, with our coal based thermal power plants contributing almost 70% of the total installed power capacity, there is tremendous need and scope for the development of CWS combustion with attendant energy security and economics. Fig 5.1 shows a conceptual system for CWS combustion.

CWS is prepared by adding suitably sized coal particles and a suitable additive to ordinary water under constant stirring conditions. The entire preparation procedure influences the three most important theological properties of CWS, namely, viscosity, stability, and atomisation. The viscosity of the slurry determines the pumping power required to transport the slurry as well as the ease with which it atomises. The stability of the slurry refers to its capability to maintain a homogenous mixture with uniform dispersal of solid particle through out the volume of the water with minimum or nil sedimentation. Atomisation is the propensity with which the slurry can form a spray of fine droplets as it comes out of the burner.

The controlling factors of input coal are : its surface characteristics, particle size distribution, and concentration (weight % of coal in the slurry). The most widely used

FIG. 5.1 COAL WATER SLURRY COMBUSTOR



concentration values are 50 - 60% while from a thermal point of view a high concentration of coal of the order of about 80% is desirable but not necessarily practical. While the CWS can be transported over long distances either as fine coal (< 1mm top size), medium coal (< 6mm top size) and coarse coal (> 6mm top size), about 100 micron top size is mostly widely adopted for combustion purposes. The combustion characteristics of CWS fuel ultimately depends upon the atomising characteristics and the relative mixing of the slurry droplets and the input air. A well designed air (primary and secondary) system will ensure high combustion efficiency and low NO_x emission.

5.1 Status of CWS Technology

The Coal Water Slurry technology originated in Germany and Russia in the 1960's. The Russian work emphasised the utilisation of rejects from coal beneficiation plants and fines produced during mining. Extensive work in the development of CWS preparation and combustion has been reported in Japan, USA, Canada and Italy. In USA a 60 : 40 CWS combustion was demonstrated in a commercial utility boiler as early as in 1961 involving pumping of the slurry through a distance of 170 km. In Japan the technology was demonstrated on a 75 MWe power plant in 1986. The CWS combustion technology was demonstrated by firing 1200 tonnes of CWM in an oil fired boiler in Italy in 1984. In Russia the Novosivirsk power plant was converted from PC firing to CWS firing in the 1980's.

However the CWS combustion technology use has come to a halt all over the world because of the low oil and gas prices. It was demonstrated in all these countries that the CWS technology while meeting all the technical requirements of combustion could not compete in price with the easily available oil and gas. This scenario will continue till CWS becomes competitive in the future.

It can be concluded that CWS technology for India is ideally suited for substituting oil in the power plants during either startup, low load flame stabilisation and load sharing. Developmental work on CWS combustion technology was initiated in CFRI Dhanbad and BHEL in the early 1980's. CFRI is involved in the preparation, characterisation and standardisation of the CWS and laboratory combustion studies. BHEL is engaged in the development of the CWS combustion system including the design of the atomiser and the burner suitable for high concentration CWS. CWS was tested in a Fuel Evaluation Test Facility (FETF) with a 1 million kcal/hr burner.

Presently NTPC, CFRI, BHEL (Trichy), IIT Madras are in the process of preparation of a proposal to demonstrate the CWS technology in the Farakka thermal power station. It is planned to replace four oil burners at one level of the furnace with four CWS burners of individual capacity of 15 million kcal/hr. The CWS will have a calorific value of 4520 kcal/kg and 13.2 tonnes of CWS will be fired per burner. The heat input of CWS firing will amount to 10% of the boiler MCR heat input. A 15 million kcal/hr prototype burner will be tested at BHEL Trichy in its FETF facility. CFRI and IIT Madras will jointly develop the CWS preparation technique with wet grinding circuit. The NTPC will retrofit the burner on the Farakka boiler and conduct a long duration test programme.

It is to be emphasised that the world wide development of CWS technology has been restricted only to very low ash coals. The main problems using CWS with high ash coal are basically operational problems like reduced burner turndown, severe wear of atomisers, and slagging and fouling problems during long duration operation. CWS is also not a substitute fuel for fully oil fired installation due to high derating. However the high sulphur-low ash Assam coal may be a good candidate for CWS application for oil substitution in power plants as a support fuel only. Obviously there is a substantial scope for focused R&D efforts in our country to find ways and means of using the abundant high ash coal reserves. Coal beneficiation plants can play a big role in providing improved coal as input to the coal water slurry. The development of a suitable burner with anti-erosive materials should accelerate the adoption of CWS technology for power generation, possibly for small capacities.

6. Repowering Technology

"Retrofit" technologies generally are pollution control devices that can be installed on older power plants without making major changes in the plant design. Some retrofit concepts do not reduce sulphur emissions by the 90% required for new plants (unless possibly used in combination with each other) but offer a means of reducing sulphur emissions by 50% to 70% (called for in most new legislation to reduce acid rain) at far less cost than a scrubber. Retrofit technologies include:

- Pre-combustion coal cleaning
- Limestone injection multistage burners
- In-duct sorbent injection
- Gas reburning
- Advanced slagging combustors
- Advanced scrubbers

"Repowering" technologies, in general replace a major portion of an existing plant (such as the boiler) with new power generating equipment while retaining other portions of the plant. Pollution control is inherent in the process, but it is not the only advantage. A repowered plant can produce more power, sometimes twice as much or more than the original plant, as well as extending a plant's lifetime by 20 to 30 years.

Repowering comes into play when existing coal-fired plants reach the end of their useful lives-typically around 25 to 40 years after they were built-and a utility must decide whether to retire or rebuild the facility. Repowering also becomes attractive when power generation needs have increased and a utility wants to avoid the problems of finding and obtaining approval for a new site. Many repowering concepts also rely on standardised, shop-fabricated components. This minimises the costly customised, onsite construction typical for conventional technologies. Several examples of repowering technologies are:

- Atmospheric fluidized bed combustors
- Pressurized fluidized bed combustor combined cycle
- Integrated gasification combined cycle
- Utility-scale fuel cells

A large number of power plants in India are more than 25 years old. These plants were designed for coal with 25-30% ash and calorific value 21 MJ/kg. However over the years the coal quality has been gradually deteriorating, and today these plants are being forced to operate on coal with 40-45% ash and calorific value 12-15 MJ/kg. This has resulted in severe operating and maintenance problems leading to low plant load factors (PLF). Renovation and Modernisation (R&M) of these old power plants is expected to extend their lives with improved PLF. Such a national program is already in place. National agencies have identified about 135 thermal sets with capacity of 18000 MWe for Renovation and Modernisation in the 9th plan period with a projected cost of Rs. 7500 Crores. R & M of old plants appears to be a very cost and time effective solution, partial though, for the problem of power shortage. The approach has a duel advantage of a shorter gestation period and comparatively lower investment.

Repowering of these old plants needs careful and immediate attention. A technology which can be seriously considered to replace the old PC boilers is the Fluidised Bed Combustion boiler, both bubbling and circulating type. In several parts of the world, and to an extent in India too, attempts have been made to repower small industrial boilers with AFBC boiler with considerable success. The initial capital cost of a new CFB boiler is generally higher than the cost of a PF boiler without FGD system. The cost of refurbishment for life extension of an existing PF boiler with CFB boiler is much less.

For a given energy output, the height of a large CFB boiler is similar to that of a PC boiler. Therefore, the existing boilers can be refurbished easily with major modification of some auxiliaries like FD fans of higher ratings. Power consumption by these fans may be much higher than the existing fans but a CFB does not require the degree of coal milling necessary for a PC boiler and hence auxiliary power consumption in both the cases are same. This option will also eliminate some potential source of breakdown and maintenance experienced in the existing PF firing system.

There is hardly any difference in combustion efficiency between the PC fired and CFBC technologies on fuels that both can fire. CFBC has a distinct advantage that high ash coals may be fired. Most of the boiler performance parameters are same in both PC firing and CFB firing. Like ash from PC plant, CFBC residues of the plant can also be used for land filling, brick manufacturing and other conventional purposes.

Repowering could also be thought in terms of converting conventional PC plant to coal Gasifier-based plants. A proven example of this is the demonstration of IGCC plant at Wabash Power Station in the US. This repowering upgraded a 100 MWe unit derated to 90 MWe with 30% efficiency into a 252 MWe unit with an efficiency of about 38%. Application of such technology to Indian coal fired plants would increase capacity by about 2.5 times with increased efficiency of operation.

6.1 Modular Repowering

Repowering concepts allow utilities to add new capacity in highly efficient modules. The modules can be brought into the rate base quickly and the most costly investment (the coal gasification plant) deferred until justified by fuel economics.

Phase I

In the first phase, peak demand is met by installing combustion turbines fuelled by natural gas.

Phase II

As demand for electricity increases, a steam cycle is added to create a combined cycle plant for intermediate and baseload service.

Phase III

A coal gasification plant is added when oil and natural gas prices rise.

Phase IV

Gasifier-turbine (or fuel cell) modules are added as warranted by growth in demand and fuel cost.

6.2 Status of Technology

Several medium-sized conventional boilers have been converted to CFB boiler in US. In India, similar work has been done for small scale boilers using AFBC boiler. A study was made by Damodar Valley Corporation (DVC) to retrofit one unit of the 45 year old Bokaro 'A' PC fired plant by a CFB boiler.

7. Plan of Action

7.1 Clean Coal Utilisation Technology

The ultimate objective of development of Advanced Coal Technologies in India is to optimally use the available abundantly high ash-low sulphur coal and high moisture lignite in the most efficient, environmentally acceptable, and economical manner possible for power generation. The identification, development and commercialization of any one technology is a formidable task involving time, funds and expertise. While it should be noted that the possible alternative technologies have now been identified, except for atmospheric CFBC technology (of which a 30 MWe power plant based on lignite has been commissioned in Maharashtra in 1997) no other technology boasts of a demonstration plant of a reasonable size. It may not be prudent to single out any one technology at this point in time as "the best" technology for Indian high ash coal. Instead, it may be advisable to consider a "possibly best available technology" scenario wherein the several technologies known today to have the potential should be taken to the demonstration stage and only later the appropriateness of the technology will be confirmed or otherwise. It is also quite possible that more than one technology will have to be commercialized in different slots of the power generation capacity range. This concept is quite relevant and valid especially in view of four specific points :

(i) There is an absolute urgency to commercialize these technologies in India at the earliest to meet the ever increasing energy requirements of the country.

(ii) While most of the technologies developed are basically for the abatement of the SO_2 problem because of high sulphur coals, the Indian coal has very low sulphur and SO_2 emission limits are not yet very stringent. This fortunate circumstance should permit us to look at technologies which are more efficient than at present but not necessarily those which are claimed (but not yet demonstrated) to have efficiencies beyond 50%.

(iii) Most of the technologies under development or developed are for low ash coals while the Indian coal has a minimum ash content of about 35% with an expected increase in the coming years. Even with new beneficiation plants coming on line, the ash content will be reduced at the most by about 10%. Therefore it is important to actually operate large scale plants on the demonstration size with Indian high ash coals for a proper judgement as to the suitability of any technology.

(iv) The plethora of technologies available, especially considering the second generation advanced technologies under development, makes it impossible to identify any one particular technology for commercialization. At the same time it may not be right to wait for the development of a "highest efficiency" technology, especially when it is not known if and when that will happen.

Based on the above, the following plan of action may be seriously considered :

7.1.1. Implementation of Advanced Technology

(i) Encourage the establishment of AFBC and CFBC power plants (for which proven technology is available) with a strong directive that all power plants in a certain capacity range should use CFBC technology in a given time frame (for example 2-4 years from now)

(ii) Establish immediately a first generation PFBC power plant of a suitable capacity (150-250 MWe) for demonstration purposes as well as to advance development of HTHP particulate control system

(iii) Establish in the very near future an IGCC power plant of suitable capacity (150 - 250 MWe) based on the Fluidised Bed Gasifier technology for demonstration purposes to prove the claim of overall plant efficiencies greater than 45% during long duration operation.

(iv) Initiate detailed design study of a large power plant (500 MWe – 1000 MWe) based on first generation PFBC and IGCC technologies for possible implementation 5 to 7 years from now.

(v) A large amount of washery middling and rejects will be available in the cone benficiation plants in future, almost to the tune of 15-30% of the input coal. The coal companies and power plant suppliers must be very strongly encouraged to set up pit-head FBC power plants to utilise these coal washery by-products with high ash content (more than 60%)

(vi) Adoption of super-critical boilers must be given a serious reconsideration. This is especially important in the light of the claim by several international manufacturers of supercritical plants with 45% overall plant efficiency operating trouble-free. This will necessitate adoption of commercially available DENOX systems.

7.1.2. Technology Development

(i) Establish a pilot scale Pressurised Circulating Fluidised Bed Combustion (PCFBC) facility to study its design and performance with Indian high ash coal

(ii) Establish a Pressurised Circulating Fluidised Bed Gasifier (PCFBG) pilot facility to study its appropriateness and adequacy for IGCC application for Indian high ash coal.

(iii) Encourage conceptual and design studies of second generation PFBC technologies and advanced IGCC technologies.

(iv) Support technology development in associated systems like DENOX, HTHP particulate control and other system components

7.1.3. Basic Research

All the advanced coal utilisation technologies are reasonably complex and in most cases are in the final stages of demonstration or initial stages of commercialization. A few of the technologies are under development. This scenario demands a concentrated research programme on a wide variety of fundamental problems associated with various components of the complex system. Accordingly basic research, with respect to Indian coal and lignite as fuels, should be encouraged in several areas of which the following are a few examples :

(i) Bed (gas-solid)dynamics and heat transfer in combustors and gasifiers;

(ii) Modelling of combustion and gasification processes;

(iii) NO_x formation and its control;

(iv) SO_2 emission and its control;

(v) Modelling of particulate control systems;

(vi) Erosion and Corrosion of material exposed to high temperature, high pressure, dust-laden, erosive and corrosive environment;

(vii) Ash formation and agglomeration studies;

(viii) Effects of alkali elements in fuel;

(ix) Studies on trace elements in fuel;

(x) System Optimisation studies;

7.2 Coal Beneficiation Technology

7.2.1 Implementation of Technology

The Ministry of Environment and Forest has already issued a notification that coal supplied to power plants more than 1000 km away from the mines must be washed to control the ash content at 32 ± 2% from 1st June 2001. To achieve this very desirable objective, coal mining companies and the coal users must be encouraged to arrive at a reasonable cost of the cleaned coal and agree to, if found necessary to share the cost of the beneficiation plants. The coal companies must be encouraged to use the best available technology to meet the requirement of about 50 million tonnes of clean coal per year by 2001.

7.2.2 Technology Development

Technology development efforts must be initiated to improve the cleaning efficiency in order to remove more than 10% of ash from the coal.

7.2.3 Basic Research

Research must be initiated in fine coal beneficiation, dry and wet grinding of coal, and transportation of coal-water slurry (CWS)

7.3 Coal Water Slurry Combustion Technology

7.3.1. Implementation of Technology

A demonstration project to prove the suitability of CWS combustion to substitute oil firing in an operating power plant must be implemented at the earliest.

7.3.2. Technology Development

The following technology development tasks must be initiated:

(i) Developmental efforts in CWS preparation, pumping, and transportation, especially including wet grinding circuit for coal.

(ii) Development of Atomisers for various CWS compositions

(iii) Development and optimisation of CWS burner for application in large capacity boilers

7.3.3 Basic Research

The following are some of the areas needing basic research efforts :

(i) Coal particle size distribution, coal to water loading ratio and their effect on the viscosity, stability and atomisation characteristics of CWS

(ii) Coal Water Slurry transportation characteristics in long pipelines

(iii) Various atomiser and burner designs for optimum combustion including pollution control

7.4 Repowering Technology

7.4.1 Implementation of Technology

(i) An old power plant of 100-220 MWe capacity must be repowered with a CFB boiler to demonstrate higher efficiency and pollution control

(ii) Encourage owners of old boilers/powerplants to go in for repowering with fluidised bed boilers by offering suitable incentives

7.4.2 Technology Development

(i) A comprehensive program to study suitable repowering technology for all the old plants in the country should be taken up. This will help in identifying technology gaps to initiate developmental projects on filling these gaps.

7.4.3 Basic Research

(i) Identification of limits/restrictions to repowering by known alternative technologies and study of suitable modifications to suit specific needs of an old power plant.

(ii) Other associated problems, especially repowering boiler technology.

7.5 Final Remarks

It should be recognised that basic and applied research, technology development, demonstration and implementation of the best available technology must progress simultaneously, with active collaboration and mutual support among the industry, academic institutions, R&D laboratories and the Government, in a well focused, well defined, and time bound manner for an optimal solution to the critical energy problem facing us today. Large scale funds are necessary to be provided. Most importantly the implementation of this programme must be based purely on technical and technological aspects and no extraneous elements should influence the thinking and the decision making process. The technological and managerial capabilities available must be utilised to their maximum capacities in the implementation if India desires to be a "global leader" in power technology. Otherwise we will be left behind, as has happened earlier, to continue to be "global followers" in the new scenario of Globalisation.

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