PART II
THERMO-ELECTRIC POWER PLANTS

5

Introduction to Thermal Power Plant

5.1. INTRODUCTION

The development of power in any country depends upon the available resources in that country. The hydel power totally depends upon the natural sites available and hydrological cycle in that country. New sites cannot be humanly created for hydel power plants. The development of nuclear power in a country requires advanced technological developments and fuel resources. This source of power generation is not much desirable for the developing countries as it is dependent on high technology and they are highly capital-based systems.

Many times, hydel power suffers if draught comes even once during a decade and the complete progress of the nation stops. The calamity of rain draught on power industry has been experienced by many states in this country. To overcome this difficulty, it is absolutely necessary to develop thermal plants in the country which are very much suitable for base load plants. Hydel power plants are much better for peak load requirements, therefore, the development of the thermal plants becomes a necessity for economic generation of the power. The development of all three sources should be made simultaneously if possible to assure sound supply of power in the country. The mix of three depends upon the availability in that particular area but it is always economical and desirable to develop all sources of power for steady and sure progress of the country.

5.2. GENERAL LAYOUT OF MODERN THERMAL POWER PLANT

The general layout of the thermal power plant consists of mainly 4 circuits as shown in Fig. (5.1). The four main circuits are :

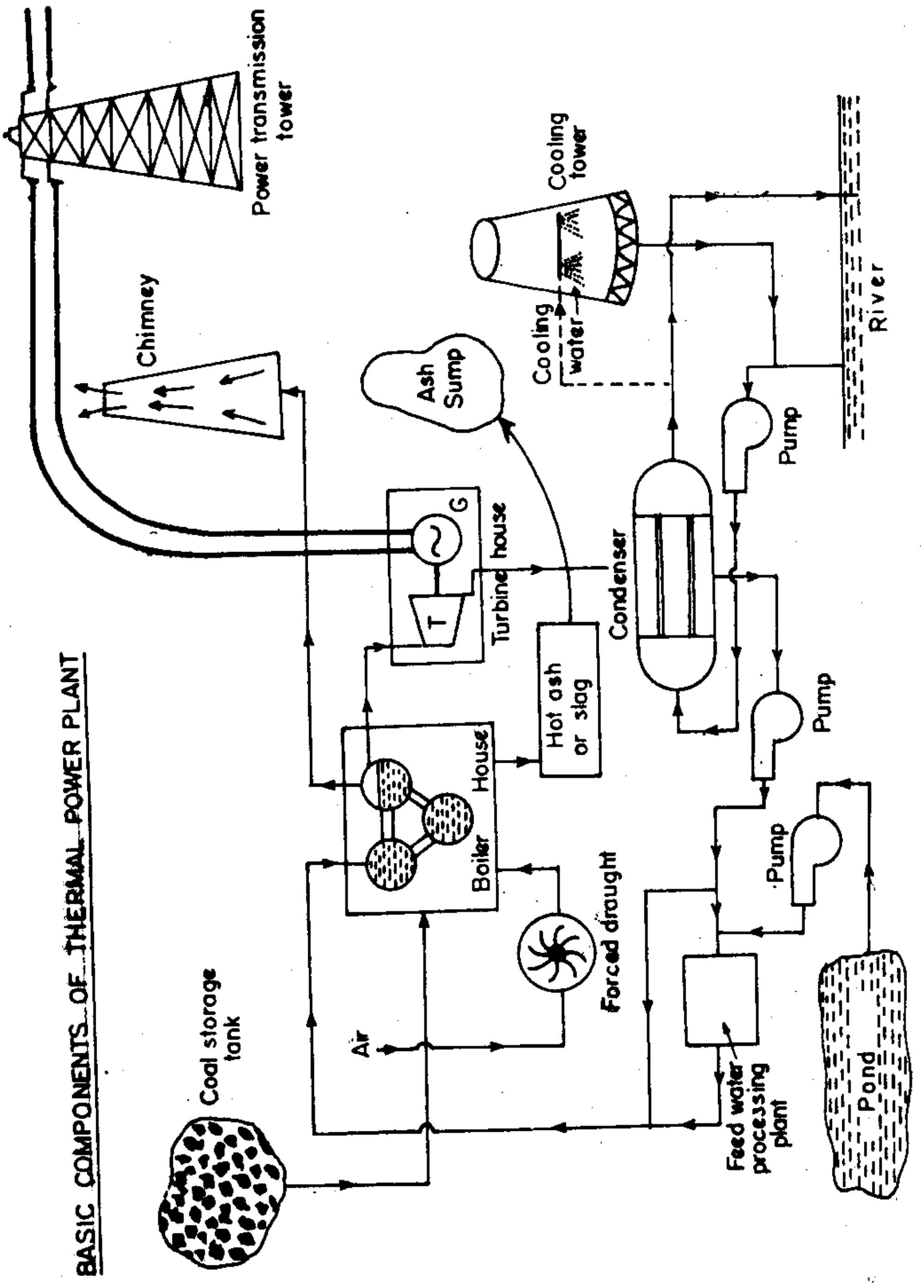
1. Coal and ash circuit. 2. Air and gas circuit. 3. Feed water and steam flow circuit. 4. Cooling water circuit.

A thermal power station using steam as working fluid works basically on the Rankine cycle. Steam is generated in a boiler, expanded in the prime mover and condensed in condenser and fed into the boiler again with the help of pump. However, in practice, there are numerous modifications and improvements in this cycle with the aim of affecting heat economy and to increase the thermal efficiency of the plant.

1. **Coal and Ash Circuit.** In this circuit, the coal from the storage is fed to the boiler through coal handling equipment for the generation of steam. Ash produced due to the combustion of coal is removed to ash storage through ash-handling system.

2. **Air and Gas Circuit.** Air is supplied to the combustion chamber of the boiler either through F.D. or I.D. fan or by using both. The dust from the air is removed before supplying to the combustion chamber. The exhaust gases carrying sufficient quantity of heat and ash are passed through the air-heater where the exhaust heat of the gases is given to the air and then it is passed through the dust collectors where most of the dust is removed before exhausting the gases to the atmosphere through chimney.

3. **Feed Water and Steam Circuit.** The steam generated in the boiler is fed to the steam prime mover to develop the power. The steam coming out of prime mover is condensed in the condenser and then fed



to the boiler with the help of pump. The condensate is heated in the feed-heaters using the steam tapped from different points of the turbine. The feed heaters may be of mixed type or indirect heating type

Fig. 5.1. General layout of thermal power plant.

Some of the steam and water is lost passing through different components of the system, therefore, feed water is supplied from external source to compensate this loss. The feed water supplied from external source is passed through the purifying plant to reduce the dissolved salts to an acceptable level. The purification is necessary to avoid the scaling of the boiler tubes.

4. **Cooling Water Circuit.** The quantity of cooling water required to condense the steam is considerably large and it is taken either from lake, river or sea. The cooling water is taken from the upper side of the river, it is passed through the condenser and heated water is discharged to the lower side of the river. Such system of cooling water supply is possible if adequate cooling water is available throughout the year. This system is known as open system. When the adequate water is not available, then the water coming out from the condenser is cooled either in cooling pond or cooling tower. The cooling is effected by partly evaporating the water. This evaporative loss (this includes evaporation and carryover) is nearly 2 to 5% of the cooling water circulated in the system. To compensate the evaporative loss, the water from the river is continuously supplied. When the cooling water coming out of the condenser is cooled again and supplied to the condenser, then the system is known as closed system. When the water coming out from the condenser is discharged to river downward side directly, the system is known as open system. Open system is economical than closed system provided adequate water is available throughout the year.

The different types of systems and components which are used in thermal power plants are listed below :

1. Coal handling system. 2. Ash and dust handling system. 3. Draught. 4. High pressure boiler. 5. Prime-mover. 6. Condensers and cooling towers. 7. Feed water purification plant. 8. Different components used as economiser, superheater, feed heaters, etc., to increase the thermal efficiency of the plant.

The details of each system will be given in succeeding chapters.

5.3. WORKING OF THE THERMAL POWER PLANT

Steam is generated in the boiler of the thermal power plant using the heat of the fuel burned in the combustion chamber. The steam generated is passed through steam turbine where part of its thermal energy is converted into mechanical energy which is further used for generating electric power. The steam coming out of the steam-turbine is condensed in the condenser and the condensate is supplied back to the boiler with the help of the feed pump and the cycle is repeated.

The function of the boiler is to generate the steam. The function of condenser is to condense the steam coming out of steam turbine at low pressure. The function of the steam turbien is to convert part of heat energy of steam into mechanical energy. The function of the pump is to raise the pressure of the condensate from the condenser pressure (0.015 bar) to boiler pressure (200 bar). The other components like economiser, superheater and steam feed heaters (steam from different points of turbine is fed to the heaters to heat the condensate to a higher temperature) are used in the primary circuit to increase the overall efficiency of the thermal power plant.

5.4. SITE SELECTION FOR THERMAL POWER STATIONS

The selection of site for thermal power plant compared with hydro-plant is more difficult as it involves number of factors to be considered for its economic justification. The following considerations should be examined in detail before selecting the site for the plant.

The location of the thermal power stations should be made with full considerations not only of the trends in the development and location of demand but also of the availability and location of the cheapest sources of primary energy.

A few important factors to be considered for the selection of site for thermal plants are discussed below.

1. **Availability of Coal.** The question of using diesel or gas for thermal power plant in India does not arise as these sources are limited. The major source of energy which is available in India for thermal power plants is coal. Therefore, it is necessary to concentrate for the best use of coal for power generation.

The huge quantity of coal is required for large thermal power stations. A thermal power plant of 400 MW capacity requires 5000 to 6000 tons of coal per day. Therefore, it is necessary to instal the power station near the coal mines. In this case, the power generation must be transported to the long distances.

therefore, it is necessary to find the location which will give the lowest cost considering the coal transport and power transmission charges.

Energy Survey Committee of India has suggested the use of by-products of coal for power generation which are a commercially unusable products resulting from the process of washing coal where washed coal is essential for metallurgical industry. The committee further pointed out that with increased washing of coal with the development of steel production, vast amounts of middlings would accumulate at the coking coal fields resulting the problem of disposal of such waste. The estimate made by the committee of such by-product of coal (middlings) is about 4.86 million tonns in 1973-74 and about 9 million tons in 1980-81. If this quantum of middlings is given to the power stations in Bengal and Bihar at zero cost, the power generation at washery-oriented power stations would be much cheaper (50 N.P./kW. hr) and it would save 14 crores with the use of 4.86 million tonnes of middlings in 1973-74 and about 25 crores in 1980-81.

2. Ash Disposal Facilities. The ash removal problem has become more serious particularly in India because the coal used for power generation contains large percentages of ash (20 to 40%). The quantity of ash to be handled is as large as 1500 to 2000 tons per day. The ash handling problem is more serious than coal handling because it comes out in hot condition and it is highly corrosive. Its effects on atmospheric pollution are more serious as the human health is concerned. Therefore, there must be sufficient space to dispose of large quantity of ash. A 400 MW power station requires nearly 10 hectares area per year if the ash is dumped to a height of 6.5 metres.

The disposal of large quantities of ash from the power station if the site for its disposal at the plant is not available also becomes a serious problem. In addition to the mounting problem of ash disposal at these power stations in the large cities like Delhi, Bombay, and Madras there is also a serious problem of pollution arising from fly ash. This has already become a problem attracting much attention in respect of thermal power station at Delhi to the extent that the Govt. of India has set up a committee to study the measures to be taken for mitigating this problem of health hazard to the city dwellers.

The ash can be easily disposed off to river, sea or lake economically if such facilities are available at plant site. Presently the ash from the power plants is used for many industrial processes, therefore, the question of its disposal to sea or river does not arise.

3. Space Requirement. The space and building requirements by the power station is another point to be considered. The average land requirement is 3 to 5 acres per MW capacity which includes the space required for coal storage, ash disposal, staff-colony, market facilities and the sapce required for whole machinery. Generally the space occupied in 10% for buildings, 33% for coal storage, 27% for cooling towers (if any,) 7% for switch yard and remaining 23% for other purposes. The percentages may also change slightly according to the surrounding conditions. The cost of the land adds in the final cost of the plant therefore it should be available at cheap rates. The large plants in the heart of big cities and near the centre of load are not economical as the cost of land is very high.

4. Nature of Land. The selected site for the power plant should have good bearing capacity as it has to withstand the dead load of the plant and forces transmitted to the foundation due to the machine operations. There are number of cases where the plants have failed due to weak foundations. The minimum bearing capacity of the land should be 10 bar.

5. Availability of Water. Large quantities of water are required for condenser, for disposal of ash and as feed water to the boiler and drinking water for the working staff.

The quantity of cooling water required in the condenser condensing the steam coming out from the turbines of 60 MW capacity plant is of the order of 20 to 30 thousand tons per hour if it is discharged to the lower side of the river. If the cooling towers are used, then the make up water required is also 500 to 600 tons per hour. The water required to feed the boiler owing to the losses in the system is also as large as 6 to 10 tons per hour for 60 MW capacity power plant. This water must be as pure as possible to avoid the scaling in the boiler tubes.

The large quantity of water is also required for disposing of the ash if hydraulic system is used.

It is, therefore, necessary to locate the power plant near the water source which will be able to supply the required quantity of water throughout the year.

The availability of drinking water is also equally important as 1000 MW capacity plant requires one million gallons of fresh water per day.

6. Transport Facilities. This is another important consideration in locating the thermal power station. It is always necessary to have a railway line available near the power station for bringing in heavy machinery for installation and for bringing the coal.

It is always thought that the site of thermal plant near the coal pit-head is more economical than selecting the site near the load centre. In this respect, it would be of interest to know the statement made by Late Dr. Bhabha in Geneva Conference in 1959 as given below in his own words.

"It will be seen that atleast 75% of the country is devoid of coal while some 55% of the coal reserves and 80% of the present production are in the states of Bengal and Bihar. This has the consequence that coal is often hauled over a distance of 1500 miles to the areas of the north, west and south. Even when the Central India coal fields are fully developed, coal will still have to be hauled over a distance of 700 miles to areas of South and West such as Bombay, Ahmedabad and Punjab and Western U.P. in North. Thus a million kilowatts of capacity in coal fired stations at a distance of 700 miles from the nearest coalfields would invoke transport of 3.6 million tons of coal over this distance and this will lock up some 10,000 wagons and 165 locomotives representing a capital investment of about 175 millions."

Another reason in locating the thermal station at pit-heads is, there is every possibility of danger arising from dislocation of coal through lock-outs and strikes in the railways. Also in the event of any war emergency, the transport capacity is unavoidably tied up in moving coal for power generation. As against, the modern transmission lines are so constructed that the maintenance required is very less. Therefore, the operating costs of the transmission line can be stated to be practically unaffected by rise in wages and material cost while the same is not true for transport as evident from the frequent increase in freight rates.

The U.K. Electricity Board has reached to a conclusion that it was more economical to locate the thermal power stations at or near pit-head rather than at load centres. The transport of electric energy is more economical for loads above 200 MW at 220 kV and 475 MW at 404 kV when the distances are of the order of 700 kilometres.

The problem of access during construction is also equally important. The transport of a 130 tonnes transformer from a New Castle factory to a Yorkshire power station in U.K. is a best example to understand the importance of access during construction. The direct distance from the factory to the station was about 100 miles. The transformer could not be carried by rail as it was too large for the loading gauge and it was also not feasible to send it by road owing to the number of weak bridges. Lastly it was carried to the site by shipping round the North of Scotland to Liverpool and then it was delivered to the site by another road route. The distance covered was about 900 miles.

7. Availability of Labour. Cheap labour should be available at the proposed site as enough labour is required during construction of the plant.

8. Public Problems. The proposed site should be far away from the towns to avoid the nuisance from smoke, fly ash and heat discharged from the power plant.

9. Size of the Plant. In small capacity plants, the cost of getting fuel into the plant and ease of water supply are relatively insignificant factors and the problem of plant location reduces almost entirely to an electric transmission problem. Other things being equal, the plant must be located at such a point that the investment in electric cables for transmitting the power together with the annual operating costs should be minimum. If such location takes the plant away from the point of fuel supply or water supply or both, the only saving in the electric transmission may be more than offset by extra costs in the fuel and water supply. Therefore, it is necessary to determine the relative significance of these items before selecting the site for the power plant. The expenses involved in electric transmission from a small plant are relatively severe owing to the impracticability of using high voltages, so that the electric transmission feature alone becomes dominant in the plant location.

In case of large capacity plants, the costs of transporting enormous quantities of coal and water are considerably high. Therefore, the plant must be located near the pit-head provided the required water quantity must be available as near as possible. A very slight difference in temperature of the available condensing water makes so marked a difference in the performance of the steam turbine that a change of location of few kilometres may easily justify the greater electric transmission expenses involved.

The large power plant must be located close to the rail road offering adequate services. Because, the cost of railroad track construction is so great in comparison with the cost of electric conduits or overhead lines as to overshadow any expense involved in electric transmission as against coal handling.

The economic significance of the large plant compared with small one is much greater than the mere ratio of size. Because, the large station will be likely to supply a community whose interests are so involved and so dependent or continuity of service that the coal supply must be absolutely continuous. It would be fatal to have a coal strike or railway strike even for one day. Therefore, the plant location must be adjacent to an ample space for the storage of coal. The storage can be one month's supply or half year as the judgement of the engineers and commercial policy of the business.

5.5. DIFFERENT MATERIALS REQUIRED FOR THERMAL POWER PLANTS

The thermal power plants presently are designed for 200 MW capacity of a single unit. The quantities of coal, air, water are considered the basic needs of the thermal power plant. The quantities required are so large that the availability of these materials mostly dictates the site of the power plant as discussed earlier.

(1) Feed Water. The feed water is the water circulated through a closed circuit of the power plant which is converted into steam in the boiler. Generally, the steam consumption in such big power plant is 5 kg/kWh. Therefore, a plant of 100 MW capacity requires nearly (5 × 100 × 1000/1000) 500 tons of water per hour to be circulated through the system. As this passes through the boiler, turbine, condender, pump and piping, there is always 2% loss of this water, therefore 10 ton of pure water/hr (2% of 500) must be fed in pure form from outside to a plant of 100 MW capacity.

(2) Coal. The quantity of coal required must be sufficient to generate the steam in the boiler for the power plant.

Considering 5 kg/kWh of steam generation and 500 kcal of heat per kg of steam supplied in the boiler, the quantity of coal required for 100 MW capacity plant is given by

$$W_c = \frac{(100 \times 1000) \times 5 \times 500}{5000 \times 0.8 \times 1000} \approx 60 \text{ tons/hr} \approx 1500 \text{ tons/day}$$

where the calorific value of the Indian coals containing 30% ash is taken as 20,000 kJ/kg and overall boiler efficiency as 80%. Generally the power plant located away from the coal pit-heads needs to store the coal at least for one month. The quantity of coal to be stored for a plant of 100 MW capacity requires a storage space for 50,000 tons of coal, a huge coalyard and all required facilities for the coal storage, transport, fire protection and many others.

(3) Cooling Water. The quantity of cooling water required for condensing the steam is nearly 50 kg/kg of steam. Therefore, the quantity of cooling water requirement even for a 100 MW plant

$$= \frac{5 \times 100 \times 1000 \times 50}{1000} = 25{,}000 \text{ tons/hr.}$$

Such a huge quantity of water must be available throughout the year which is very uncommon at most of the places. If hydroplant dams, big lakes or rivers (flowing with required quantities) are available, then the required quantity is assured throughout the year. But when such source of cooling water is not available, the water used once is used again and again by cooling the water coming out of condenser in the cooling tower with the help of air. This is effected by the evaporative cooling, so nearly 2% of the cooling water circulated is evaporated in the cooling water. The quantity of water carried by air

$$= \frac{2}{100} \times 25{,}000 = 500 \text{ tons/hr.}$$

for a 100 MW plant. At least this much quantity of cooling water must be available at the site throughout the year as it is directly a loss. As huge quantity of water carried with the air in the form of vapour, it forms fog around the plant and can create the air-transport difficulties as the surrounding transparency is very much reduced.

(4) **Ash.** The ash formed with the Indian coal is also considerably large as it contains 20 to 30% ash or even 40%.

The quantity of ash formed per hour

$$= \frac{3.4}{100} \times 50 \approx 20 \text{ tons/hr.}$$

Out of this, nearly 2 tons (10%) comes out as hot ash at 500 – 600°C from the bottom and 18 tons (90%) comes out in the form of fly ash. As the ash contains many harmful contents, it is necessary to dispose off far away from the power station and for a considerable time. A 100 MW plant can collect 5 million tons of ash during its life time of 20 years. There must be provision of the space to collect such huge amount of corrosive ash.

The quantity of water required to carry out this ash away from the plant in the form of slurry is also 100 tons/hr as nearly 5 kg of water is needed per kg of ash formed.

(5) **SO_2.** We are fortunate to have coal with low sulphur content (1 to 1.5%) but even then the emission of SO_2 formed in the combustion chamber during the burning of the coal should be prevented as it is highly poisonous to the human and animal health as well as for the crops. The amount of SO_2 coming out with the burned gases

$$= 60 \times \frac{1.5}{100} \times 2 \approx 1.8 \text{ ton/hr.}$$

for a plant of 100 MW plant requires 60 tons of coal which contains 1.5% sulphur and 1 kg of sulphur forms two kg of SO_2. A 100 MW plant will emit 50 tons of SO_2 into atmosphere per day if not removed from the exhaust gases.

(6) **Air.** A very large quantity of air is required for the combustion of the fuel. A 100 MW plant requires nearly = 60 × 20 = 1200 tons of air per hour as 20 kg of air is required per kg of coal burned. In addition to this, the quantity of air to be circulated in the cooling tower is 25000 tons/hr as one kg of water requires one kg of air for effective cooling.

These calculations will give an idea to the students about the huge quantities required for thermal power plants.

100 MWe Power Plant

Required Quantities per hour

Coal	*Feed water*	*Air for combustion*	*Cooling water*		*Ash Produced*	*SO_2 formed*	*Air in cooling tower*
			a	*b*			
60 tons	10 tons	1200 tons	25000 tons	500 tons	20 tons	2 tons	25000 tons

a – Once through system, *b* – with cooling tower

5.6. DEVELOPMENT OF THERMAL POWER IN INDIA

The coal resources in India account for about 5.7% of the proven reserves in the world. The geological reserves of coal in India are 193.8 billion tons as on January 1993 whereas mineable reserves are estimated at 142 billion tons likely to last for 280 years at the present rate of consumption. The states of Bihar, Orissa, M.P. and West Bengal account for 90% of coal reserves and Bihar alone has about 30% of the total reserves.

The reserves of crude oil in India are about 779 million tons (April 1993) and may last for 29 years. Out of this, onshore and offshore are 313 million tons (40%) and 466 mt (60%) respectively. The major onshore reserves are found in Gujerat and Assam and off-shore at Bombay High. The natural gas reserves are 717950 million-m^3 (1993) and would sustain a production of 80 million-m^3 per day for 15 years. The major onshore reserve, 252820 million-m^3 (35%) are found in Gujarat, Assam and Rajasthan and off-shore reserves 4,65,130 million-m^3 (65%) in Bombay High. The reserves of oil also include reserves in Nagaland, Tripura, Arunachal, Tamil Nadu and A.P.

Coal-Oil & Gas Production during two Decades in India

	Coal (million tons)	*Oil (million tons)*	*Gas (million-m^3)*
1974 – 75	88.49	07.68	2041
1984 – 85	147.41	28.99	7241
1993 – 94	246.03	27.02	20370

The production of coal increased at the rate of 4.6% during seventies and 6.4% during eighties. The crude oil production increased at 5.8% and 12.5% for the corresponding periods. The natural gas increased at the rate of 21.2% during eighties mainly because of Bombay High.

The indigenous production and consumption of coal, oil and natural gas is shown below :

	Coal (million tons)		*Oil (million tons)*		*Gas (million-m^3)*	
	1991 – 92	*1996 – 97*	*1991 – 92*	*1996 – 97*	*1991 – 92*	*1996 – 97*
Production	229.26	308.00	30.34	50.00	18645	30180
Consumption	228.83	310.0	51.42	63.32	14441	—

The consumption of three fuels for power industry compared with other sectors is shown below (1991 – 92)

	Coal (million tons)	*Oil (million tons)*	*Natural gas (million-m^3)*
Power	134.76	2.655	4.774
Transport	84.42	20.727	–
Steel	25.57	0.659	–
Total Production	223.21	59.603	18.645

The installed power generating capacity in the country was 76718 MW (March 1994). This includes hydel 20366 MW (26.5%), thermal 54347 MW (70.8%) and nuclear 2005 MW (2.7%). The installed thermal capacity increased by 10%, power generation by 11.8% and coal consumption by 13% per year during eighties. The increase in coal consumption is not only due to addition of new capacity but also due to deterioration in coal quality. The specific coal consumption 0.74 kg/kWh against projected figure 0.68 kg/kWh for eighth plan period.

Gas turbine generating power (open and combined cycle) based on natural gas has 3060 MW capacity (this is included in thermal capacity given above). The gas turbine generation is promoted because it works better peak plant, low gestation period and low pollution. About 28 to 42% of the natural gas was flared into atmosphere during eighties. In late eighties, the Govt. allowed use of natural gas for power generation and due to this, the flaring of gas declined to 10%. Presently, oil is used in coal based plants to support the flame. Over the years, there is gradual reduction in specific oil consumption from 18.5 ml/kWh in 1981-82 to 7.25 ml/kWh in 1990-91.

The quality of coal for power generation is deteriorating. The average calorific value of coals supplied to the power plant comes down from 5000 to 3500 kcal/kg during last two decades. The ash content went upto 45%. The Plant Load Factor (PLF) which indicates the extent of utilization of existing capacity is 61% now. It is reported that every 1% improvement in PLF of State Board plants makes available additional capacity of 390 MW. Similarly for every 1% increase in efficiency, about 800 MW can be increased from existing capacity.

The renovation and modernisation of thermal power plants totalling to a capacity of 13585 MW during VII plan has enabled to increase the PLF from 50% at the end of VI plan to 56.5% at the end of VII plan. This programme is also continued in VIII plan. In order to overcome the problem of poor quality coal, one approach is to beneficiate the coals, which improves efficiency, reduces forced outages and thus improves PLF. Other approach is to introduce advanced power generation systems which can utilise the poor quality coal with least pollution using integrated gasification combined cycle and pressurised fludised bed combustion. The Govt. has also planned to introduce advanced power generation systems.

India has vast hydel potential of 84044 MW, out of which only 20366 MW is used. The existing mix of power generation of hydel, thermal and nuclear is 26.5%, 70.8% and 2.7%. By increasing hydel power, coal can be conserved, while it reduces the pollution and can attain optimum mix of 40 : 60 for hydel-thermal.

The present non-conventional energy sources as per estimates of Indian ministry include 20000 MW wind, 10,000 MW small hydro, 80,000 MW from ocean and 492 billion kWh per year from solar energy. The Ministry has launched a number of programmes to promote and develop and generate energy from renewable energy sources. The programmes completed so far include electrification of villages through photovoltaics, wind energy farms of 114 MW capacity in Gujarat and Tamil Nadu and small hydro power of 110 MW. The Ministry has given high priority to develop these power sources in future.

The per capita income is increased from Rs. 2226 in 1992-93 to Rs. 2362 in 1994-95 which is equivalent to one week income of developed countries. This keeps India last in the list of undeveloped countries. This can be increased by increasing industry and indirectly power generation. The power capacity of the country was 1362 MW in 1947 which went to 76713 MW in 1994 which generated 323.53×10^9 units. The average growth of power remained 10% during last 40 years. The power demand is continuously increasing in India. Nearly 5 lakh villages are electrified and one crore pumps are running on electricity. The uses of electrical power are 40.6% industry, 28.9% for agriculture and 17.9% for domestic purposes. There is large deficit in demand and supply of power. In 1993-94, this deficit was 25×10^9 units. The present demand is increasing by 9% per year and therefore 65000 MW will be required extra by 2002. The Govt. will be able to build only 40,000 MW in public sector and remaining 25000 MW are to be built in private sector because of limited finances. By modernising the existing plants, it is estimated that 10,000 MW extra power can be made available. In addition to this, PLF has to be increased from 0.59 to 0.75. There is no national grid so even excess power available in one region cannot be transported in other regions. Therefore, priority should be given immediately to develop national grid which will partly reduce the scarcity of power in the country in future.

5.7. FOSSIL FUEL RESOURCES AND PROSPECTS OF THERMAL POWER IN INDIA

Coal occupies the most important position in the energy spectrum of India meeting 60% of the total commercial energy consumption. From the resource angle as well, coal is the most abundant of all the primary sources of energy in India. It is an important resource and could be an important substitute for scarce and fast depleting oil and atomic minerals. Coal has to bear the main burden of power needs of the country particularly in the present day context of shortage of oil, atomic minerals and lack of huge capital required to develop hydel projects. Fortunately, India has adequate reserves of coal and Govt. has already taken necessary steps to make it available for power generation.

The present coal reserves of India would be adequate to last for 100 years from now assuming that the annual coal production would reach 417 million tons (Mt) per year by the year 2000.

The main deposits of coal in India are concentrated in North-East part, in the states of West Bengal, Bihar, Assam, Orissa, central part of M.P. and Maharashtra and in the South Andhra Pradesh. The major coal fields in India are shown in Fig. 5.2. Major coal fields with their reserve distribution are listed in following table.

Table 1. Major Coalfields with their Reserve Distribution
(In thousand million tonnes)

Name of coalfield	*Location (State)*	*Coking*	*Non-coking*	*Total*
Raniganj	West Bengal/Bihar	2	25	27
Jharia	Bihar	8	11	19
Karanpura	Bihar	3	12	15
Bokaro	Bihar	8	–	8
Singrauli	Uttar Predesh/ Madhya Pradesh	–	10	10
Talcher Valley	Orissa	–	6	6
Ardha Valley	Maharashtra	–	2	2
Korba	Madhya Pradesh	–	1	1
Godavari Valley	Andhra Pradesh	–	8	8

The estimates of total reserves of non-coking coal are 47889 million tons while proved and indicated are 45021 and 71360 million tons respectively. The total reserve of coking coal is 27811 million tons whereas non-coking coal is 16426 million tons. The biggest deposit is in Jharia in Bihar while the Raniganj occupies second position. Together these two fields contribute about 40% of the total coal deposits in India.

The demand of coal has increased in India during the last 45 years and this increase is shown in the following table. The total output of coal increased from 38 Mt in I plan to about 203 Mt at the end of VII plan. As per perspective on energy demand and supply in India, in 2005, the demand for coal could be 450 to 540 Mt, non-coking constituting 380 to 472 Mt, out of this 302 Mt would be for power generation.

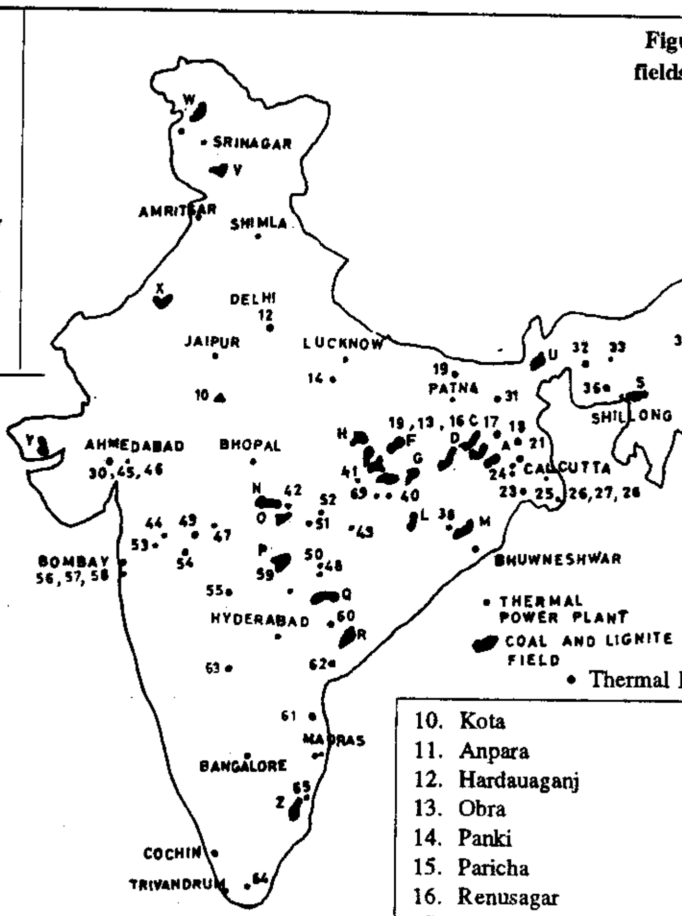
The power generating capacity in 1991 and after completion of VIII plan in the country by coal, hydro and nuclear are shown below :

Table 2. Demand and Production of Coal (In Million Tonnes)

Period	*Target*	*Production*	*Demand*
1. 1955 – 56 I Plan	39.00	38.30	41.60
2. 1960 – 61 II plan	60.00	55.67	–
3. 1965 – 66 III Plan	97.30	67.73	60.10
4. 1973 – 74 IV Plan	93.50	78.17	90.00
5. 1978 – 79 V Plan	135.00	101.95	165.00 +
6. 1984 – 85 VI Plan	165.00	147.41	143.00@
7. 1989 – 90 VII Plan	220.00	202.71	246.00 241.00*
8. 1994 – 95 VIII Plan	318.00	–	326.00* 325.00**
9. 1999 – 2000 IX Plan	410.00	–	417.00**
10. 2004 – 05 X Plan	520 – 512	–	450 – 500 & 520.00**

Delhi
Badarpur
Indraprastha
Rajghat Gas
Punjab
Ropar
Gurunanakdev
Bhatinda
Haryana
Faridabad
Panipat

Figure showing coal and lignite fields and thermal power plants.



• Thermal Power Plant

Lignite
X. Palana
Y. Kutch
Z. Neyveli

Coal and Lignite Fields—

A. Raniganj
B. Jharia
C. Giridih
D. Karanpura
E. Bokaro
F. Singarauli
G. Bisrampur
H. Umaria
I. Sohagpur
J. Chirimiri
K. Korba
L. Hingir-Rampur
M. Talchar

N. Pench-Kanhan
O. Kamptee
P. Wardha Valley
Q. Tandur
R. Pranhita-Godavari
S. Khasi Hill
T. Upper Assam
U. Derjeeling
Lignite
V. Kashmir
W. Baramula

10. Kota
11. Anpara
12. Hardauaganj
13. Obra
14. Panki
15. Paricha
16. Renusagar
17. Patratu
18. Bokaro
19. Mujaffarpur
20. Durgapur
21. Santhaldih
22. Chandrapura
23. Kalaghat
24. Bandel
25. Gauripur
26. Mulazore
27. Sou. Gen. Uni.
28. New-Cossipore
29. Titagarh
30. Nanakbori
32. Bongaigaon
33. Chandrapur
34. Lakwa
35. Namrup W. Uni.
36. Gailiki
37. Kathaguri
38. Talcher
40. Korba

41. Amarkantak
42. Satpura
43. Bhilai
44. Dhuvaran
45. Gandhinagar
46. Sabarmati
47. Ukai
48. Ballarshah
49. Bhusawal
50. Chandrapur
51. Khaperkheda
52. Koradih
53. Nashik
54. Paras
55. Purli
56. Trombay
57. Tata Elc. Gen.
58. Uran Gas
59. Ramagundem
60. Kothagudem
61. Nellore
62. Vijaywada
63. Raichur
64. Tuticorin
65. Neyveli
66. Ennore
67. Kalakot
69. Korba (NTPC)

Table 3.

	Installed capacity today in MW (1991)	*To be added in 8th Plan*	*Total at the end of 8th Plan*
1. Thermal (incl. gas)	39,245	32,000	71,245
2. Hydro	17,300	9,369	26,669
3. Nuclear	1,300	705	2,005
Total	57,845	42,074	99,919

New Thermal Plants. There is large non-availability of power in West Bengal and Bihar. To improve the power supply to this region, three plants (2 × 10 MW each) have been proposed to be set up on emergency basis at Moonidih, Chinakuri and Kathara. As a long-term major, there is a proposal to instal 800 MW and 1000 MW plants at Mukunda in Jharia coalfield of Bihar. NTPC has also proposed a 1000 MW thermal plant at North-Karanpura in Bihar.

With a minable reserve of over 2200 Mt of lignite in and around Neyveli of Tamilnadu, Neyveli Lignite Corporation (NLC) has decided to raise its present capacity of 1020 MW to 5990 MW by 2005 A.D. This is the only lignite fired power station in the country whose PLF is over 70% in the last ten years. The details of the new power plants are shown in table 4.

With increasing power capacity in the country, the coal production also increased. The demand of coal in 1994-95 was 181 Mt for power generation and it would be 217 Mt by 2000 A.D. The forecast of coal requirements in 450 to 540 Mt in the year 2004-5 of which power generation would account for between 216 to 302 Mt. The details of coal demands during the last 15 years and future 5 years are shown in table 3 A.

Table 3 A. Demand and Consumption of Coal for Power Generation (In Million Tonnes)

Year	*Installed capacity (MW)*	*Electricity generation (billion kWh)*	*Coal for power*	*Overall coals*
1974 – 75*	9,753	39.50	22.00	86.00
1979 – 80*	15,991	55.70	–	–
1984 – 85*	26,311	96.60	64.00	140.00
1987 – 88	–	–	83.90 (incl. middlings)	–
1989 – 90**	48.366	173.00	132.00	241.00
1994 – 95**	68.036	240.00	181.00 215.00@ 205.00b 210.13c	326.00
1999 – 2000			310.00@ 250 – 270b	–
2004 – 05**	76,925	319.60	216 – 302b	450
	1,07,270	445.50	270 – 330b	540

Table 4. Thermal Power Projects (Under Construction and Proposed)

Project	State	Total ult. cap. MW	Total appr. cap. MW	Source of coal/gas supply	Source of water	States under benefits	Units com-missioned	Units to be commissioned	Exec. agency	Remarks *
1	2	3	4	5	6	7	8	9	10	11
1. Farakka stage I, II	W.B.	2,100	2,100	Rajmahal coalfield	Farakka feeder canal	W.B., Bihar Sikkim, Orissa, DVC	3 × 200	1 × 500 = 91 – 92 1 × 500 = 92 – 93 1 × 500 = 95 – 96	NTPC	
2. Kahalgaon	Bihar	1,840	840	Rajmahal coalfield	Ganga river	States of eastern region	–	1 × 210 = 91 – 92 2 × 210 = 92 – 93 1 × 210 = 93 – 94	NTPC	
3. Dadri NCTPP	U.P.	1,840	840	North-Karanpura coalfield	Mat branch canal	National capital region	–	1 × 210 = 91 – 92 2 × 210 = 92 – 93 1 × 210 = 93 – 94	NTPC	
4. Talcher	Orissa	3,000	1,000	Talcher coalfield	Sanal Barrage	States of eastern region	–	2 × 500 = 94 – 95	NTPC	
5. Kawas gas	Gujerat	844	844	South basin gas field/ HBJ pipeline	Hazira branch canal	States in western region	–	4 × 106 = 91 – 92 2 × 210 = 92 – 93	NTPC	
6. Dadri gas I	U.P.	1,225	817	HBJ pipeline	Mat branch canal	States of northern region	–	4 × 131 = 91 – 92 2 × 146 = 92 – 93	NTPC	
7. Kayamkulam I	Kerala	2 × 210	–	Bombay High	–	States of southern region	–	–	NTPC	*
8. Mangalore I	Karnataka	2 × 210	–	Bombay High	–	"	–	–	NTPC	*
9. Yamunanagar I	Haryana	4 × 210	–	North-Karanpura coalfield	Yamuna river	Delhi, U.P. Haryana, H.P., Punjab, Rajasthan	–	–	NTPC	*
10. Vindhyachal II	M.P.	3,000	1,260	Singrauli coalfield	Discharge canal of Sing STPP	M.P., Guj. Mah., Daman, Nagar Haveli	Stage I 6 × 210	2 × 500	NTPC	*
11. Gandhar gas I	Gujerat	650	–	Bombay High	–	Gujarat, Raj., Mah.	–	–	NTPC	*
12. Rihand II	U.P.	3,000	1,000	Singrauli coalfield	Rihand reservoir	U.P., Raj. H.P., H.P., Delhi, JK, Punjab	Stage I 2 × 500	2 × 500	NTPC	**
13. Chandrapur I	MS	2 × 500	–	Wardha Valley coalfield	Wardha river	Maharashtra	–	–	NTPC	**

(*Contd.*)

1	2	3	4	5	6	7	8	9	10	11
14. Manuguru I	A.P.	2 × 500	–	South Godavari coalfield	Godavari river	A.P., Tamil Nadu Karnataka	–	–	NTPC	**
15. North Karanpura	Bihar	2 × 500	–	North Karanpura coalfield	Ganga river	Bihar and States of eastern region	–	–	NTPC	**
16. Anta Gas II	Raj.	843	413	South basin gas field/ HBJ pipeline	Kota right main canal	U.P., Raj., H.P., Delhi JK, Punjab Haryana	Stage I 3 × 88 GT + 149ST	–	NTPC	**
17. Dadri Gas II	U.P.	408	–	"	Mat Branch canal	States of northern region	–	–	NTPC	**
18. Faridabad Gas I	Har.	800	–	Bombay High	Yamuna river	Haryana, U.P., Delhi Punjab	–	–	NTPC	**
19. Godavari Gas I	A.P.	400	–	Godavari basin gasfield	Godavari river	A.P., Tamil Nadu, Orissa Karnataka	–	–	NTPC	**
20. Tripura	Tri.	500	–	Assam gas field	Tributary of Meghna river	States of eastern region	–	–	NTPC	**
21. Farrukhabad	U.P.	800	–	Bombay High	Ganga river	U.P., Delhi	–		DVC	
22. Mejia	Bihar	630	3 × 210	Jharia coalfield	Damodar river	Damodar Valley Corp.	–	1 × 210 = 91 1 × 210 = 92 1 × 210 = 93		
23. Birsinghpur	M.P.	2 × 210	–	Sohagpur coalfield	Son river	M.P.	Proposed		MPEB	
24. Mukunda	Bihar	2 × 500	–	Jharia coalfield	Damodar river	Bihar, W.B. and States of eastern region	–		BEB	
25. Neyveli	Tamilandu	2,700	2,700	Neyveli lignite field	Cauveri river	Tamilnadu, Kerala, A.P. Karnataka	1,020	8 × 210 = 94	NLC	

The above projections bring into sharp focus the rapidly increasing trend in the demands for lower grades of coal used predominantly in the power sector and likely to take an even upward turn with a fast rate of growth in the power sector. It is not unlikely that such a rapid rise in demand might create unexpected scarcity in the availability of coal for power generation.

A tentative assessment made up to 1999–2000 indicates additional capacity of the order of 72000 MW. The coal demand assessed by Central Electricity Authority (CEA) is given below.

Table 5.

		Coal in million tonnes	
	MW	*1994 – 95*	*1999 – 2000*
Existing Cap. (up to 90 – 94)	39,245	140.82	140.82
Ongoing schemes	7,700	26.21	26.97
CEA cleared	5,130	13.48	17.36
New schemes	51,530	34.49	132.23
Total	1,03,605	215.00	317.00

The CEA has not made out any forecast of the demand by 2004-05. By extrapolation of growth rate of 8.1% in the coal demand between 1994-95 and 1999-2000, the coal demand would be 468 Mt by 2004-05 in contrast to the figure of 270-330 Mt indicated by the Department of Coal. It is clear from this, that the gap between these two estimates is very wide (140 Mt) and unless these are properly reconciled it could lead to a situation of heavy surplus or serious deficit, neither of which is desirable.

SOLVED PROBLEMS

Problem 1. *A steam power station of 100 MW capacity uses coal of calorific value of 25600 kJ/kg. The thermal efficiency of the station is 30% and electrical generation efficiency is 92%. Determine the coal required per hour when the plant is working at full load.*

Solution. Assume W is the weight of coal supplied per hour

∴ Mechanical energy available

$$= W \times 25600 \times 0.3 \text{ kJ/hr.}$$

Electrical energy available

$$= W \times 25600 \times 0.3 \times 0.92 \text{ kJ/hr.}$$

100 MW plant if operated for one hr then its heat equivalent is

$$= 100 \times 1000 \times 3600 \text{ kJ/hr.}$$

$$\therefore \quad W \times 25600 \times 0.3 \times 0.92 = 100 \times 1000 \times 3600$$

$$\therefore \quad W = \frac{100 \times 1000 \times 3600}{25600 \times 0.3 \times 0.92} = 50950 \text{ kg/hr} = 50.95 \text{ tons/hr.}$$

Problem 2. *A coal having a calorific value of 28900 kJ/kg is supplied to a power station. The boiler, turbine and generator efficiencies are 83%, 32% and 97% respectively. If the coal consumption of the station is 30 tons/hr, determine the capacity of the power plant in MWe.*

Solution. Assume $$P = \frac{(W \times C.V) \times \eta_b \times \eta_t \times \eta_g}{3600 \times 1000}$$

where P is power in MWe, W is the weight of coal in kg used per hour and η_b, η_t *and* η_g *are boiler, turbine and generator efficiencies.*

$$\therefore \quad P = \frac{30 \times 1000 \times 28900 \times 0.83 \times 0.32 \times 0.97}{3600 \times 1000} = \mathbf{62\ MW}$$

Problem 3. *A small generating plant of 100 kW capacity uses gas of a calorific value of 4000 kJ/m^3. The overall efficiency of the plant is 20%, determine the volume of gas required per hour when the plant is running at full load condition.*

Solution.

$$P = \frac{V \times C.V. \times \eta}{3600}$$

where P is power in kW and V is the volume of the gas supplied in m^3 per hour and η is the overall efficiency of the plant.

$$\therefore \quad 100 = \frac{V \times 4000 \times 0.2}{3600}$$

$$\therefore \quad V = \frac{3600 \times 100}{4000 \times 0.2} = 450 \text{ m}^3\text{/hr}$$

EXERCISES

1. Draw a general layout of a thermal power plant and explain the working of different circuits.
2. What factors are considered in selecting a site for a big thermal power plant ?
3. How much coal, cooling water and combustion air are required for a super thermal power station of 500 MW capacity per hour ?
4. How much ash and SO_2 are produced per day from a plant of Koradi size 400 MW capacity if Indian low grade coal is used ?
5. What is the importance of thermal power plants in the national power grid ?

□□□

6

Fuels, Properties & Their Storage

6.1. INTRODUCTION

Coal is the oldest fuel and still used on large scale throughout the world for power generation. It is a fuel which brought about an industrial revolution and made a dramatic change in the life style of people. It has sustained most of our combustion activity until oil was struck and even now continues to be a major source of energy.

After the first and second shocks of oil prices, the power industry in the western countries moved from oil to coal. Mankind has realised that the future lies in establishing an energy economy at the earliest possible time, based on sun, wind, ocean tides and thermal gradients, bioman etc. All efforts are going on throughout the world to develop such non-conventional ever-lasting sources of energy. But it will take time, a couple of decades or more to develop these sources and in the present condition of soaring oil prices, the coal is going to play a vital role in the power generation industry, at least for 20 to 30 years.

Keeping this in mind, all oil based power plants are shifting to coal based plants in USA and Europe. In India, coal is the only source of power generation, and it will play very important role in coming years.

6.2. COAL A MAJOR SOURCE OF POWER IN INDIA AND WORLD

The rising prices of oil have hit India hard. India produces 12 million metric tons of oil per year but has to import another 20 million tons to meet the nation's requirements. This costs Rs. 54000 crores – 45% of the country's total import bill. This indicates the crippling economy in the years to come for India. Realizing this, India has drawn number of ambitious plants to develop alternative sources and coal is most important among all. Coal provides 60% of the total commercial energy consumption. From resource angle as well, coal is the most abundant of all the sources of energy in India. Ranking VI in the world in coal production – USA, USSR, China, Poland and UK – India is estimated to have coal reserves, of 111600 million tons. More important, the rate of finding new coal reserves in the country is one of the highest in the world. By using latest exploration technology, India is adding 1000 million tons a year to its geologically proven reserves.

The future feature of coal supply in India (1980-90) would be a major shift from underground mines to open cast mines. Out of targeted 260 million tons, 133 million tons (51%) would come from open cast mines and rest from the underground. Another feature of the coal reserve is the large variation in seam thickness, which varies from 2.5 m to 25 m. The thickest coal seam has been found in the Singrauli coalfield where it attains a thickness of 150 m. Another notable feature is the occurrence of a number of seams in the same coal field. Jharia coal-field in Bihar contains 30 coal seams. The union coal ministry (1999) has decided to reduce the production of coal by 20 million tons/year. The Govt. has reduced import duty from 100% to 4%, has made imported coal cheaper than Indian coal. Because of this, the power sector has reduced its generation target which is one of the factors of dumping coal stock. This Govt. Policy will throw lakhs of coal employees out of job.

The trend of using coal for power generation instead of oil is very common in all the countries. The Carter's goal for coal was to boost output to 1.2 billion tons in 1985, an increase of 75% over 685 million tons mined in 1977. Appalachia and Ohio valley contain coal seams rich enough to meet the country's need for centuries, no matter how much energy consumption may grow.

The most basic problem is the development of confidence between major coal consuming and coal producing countries. USA and Australia, the potentially largest coal exporters, secure access to coal markets in western Europe and Japan. The emergence of coal as a key commodity in world trade would have wider consequences beyond the scope of energy considerations, encompassing economic and political factors. The specific energy policy strategies may enhance nation's freedom in economic and foreign relations. The Western industrial nations have a common interest in ensuring that energy issues do not constrain world economic growth or cause conflict in political relations.

The development of world coal market would facilitate the efforts of developing countries to include it as a credible energy alternative in their own planning and thus contribute to the reduced tension in the world oil market.

Coal impact on world trade would be considerable. Even at 1980's price, a volume of 700 million tons moving in international trade would represent about $300 million. The evolution of much large world coal market would simulate world economic integration. Linking the major industrialized and industrializing areas of the world through substantial trade in a key energy commodity would reduce the present instability due to unbalanced world oil market.

The coal as fuel will have still long lasting impact if the coal under sea is used in future. Oil explorations have shown that there are coal seams upto 15 m thick between 600 and 3000 m below the North Sea. A team has been formed to consider the problems and the techniques that would be needed to mine coal from beneath the seabed in the 21st century.

6.3. ANALYSIS OF COAL

The classification of coal is based upon the physical and chemical composition of the coal and it is therefore necessary to study about the chemical composition of the coal.

The common tests which are used to find the commercial value of the coal are proximate analysis and ultimate analysis of the coal.

Proximate Analysis. The proximate analysis of the coal gives the composition of coal in respect of moisture, volatile matter, ash and carbon. The proximate analysis of most coals indicates the following ranges of various constituents :

Constituents	Moisture	Volatile matter	Ash	Fixed carbon
Percentage	3 to 30%	3 to 50%	2 to 30%	16 to 92%

The constituents given by the proximate analysis mostly decide the adoption of coal and design of power plant (handling, combustion and ash removal and dust removal system). The role played by each constituent in adopting coal for power plant is discussed below :

1. Moisture. All coal contains some percentage of moisture and it generally varies from 1 to 40%. The moisture in the coal exists in two forms as inherent and free moisture. The inherent moisture is the combined moisture and that is held in the pores of the coal. The percentage of inherent moisture is determined by heating the coal to 110°C in the current of nitrogen. The inherent moisture is never removed from the coal used for power plants as it is costly procedure. The free moisture is defined as moisture present in the coal which can be removed just by exposing the coal to the natural air flow or by drying with the help of air at 50°C.

Here we are mostly interested in free moisture in the coal as it has important effects on the plant working. The presence of moisture in the coal is objectionable as it adds to the transporting, handling and storing cost of coal and does not play any useful role. Moreover, it decreases the heating value of the fuel and part of heat generated is also carried away as it goes as vapour with the exhaust gases. The another added disadvantage of moisture is, it quenches the fire in the furnace of the boiler. Therefore, the coal which is used in power plants is generally dried and the free moisture is removed from the coal.

2. Volatile Matter. The volatile matter present in the coal may be as high as 50%. The volatile matter present in the coal may be combustible gases such as methane, hydrogen, carbon-mono-oxide and other hydrocarbons or incombustible gases like CO_2 and N_2. The presence of incombustible gases is always undesirable as they do not add in heat value but increase the volume of furnace required. Overall, the volatile matters (combustible or non-combustible) affect the furnace volume, and arrangement of heating surfaces.

3. Ash. Ash is another most undesirable constituent of coal. The ash present in the coal is of two forms as fixed ash and free ash. The fixed ash present in the coal comes from the original vegetable matter and it cannot be removed from coal before burning the coal.

The free ash comes with the coal in the form of clay, shale and pyrites. The free ash can be reduced or removed by mechanical processing of coal such as washing and screening, but the presence of fixed ash is more or less unavoidable.

The presence of ash like moisture also increases transporting, handling and storage costs. It also decreases the heat value of the fuel and involves additional cost in ash disposal. The presence of ash with coal also causes early ware of the furnace walls, burning apparatus and feeding mechanism.

Another disadvantage of ash is the formation of clinker (clinker is material formed by the fusion of ash at high temperature 1000°C). The clinker formation on the grate of the furnace may choke air passages and remain attached with the unburned fuel. This also causes the loss of fuel. The percentage of fixed ash in coal mostly decides the type of the combusion chamber, burners and feeding system used in power plant. It is always economical to use high ash (fixed) content coal in the form of powdered coal as it eliminates the clinkering difficulties and reduces the loss of fuel and helps for efficient burning.

Ultimate analysis. The proximate analysis of coal does not give any idea about the suitability of coal for the purpose of heating. It is also not possible to find out the calorific value of coal with the help of proximate analysis.

To find out the chemical analysis of coal, like carbon, hydrogen, oxygen, nitrogen, sulphur and ash, ultimate analysis of coal is generally used.

The chemical analysis of coal alone is not enough to find out the suitability of coal for heating purposes, however, it is very useful to find out composition of flue gases.

The ultimate analysis of most coals indicates the following ranges of various constituents :

Constituents	Carbon	Hydrogen	Oxygen	Sulphur	Nitrogen	Ash
Percentage	50 – 95%	1 – 5.5%	2 – 40%	0.5 – 3%	0.5 – 7%	2 – 30%

The role played by each constituent calculated by ultimate analysis in adopting coal for power plant is discussed below :

1. Carbon. The percentage of carbon plays most important role in the selection of coal for thermal power plant. Higher percentage of carbon gives high heat value and reduces the size of combustion chamber required.

2. Hydrogen. It is always assumed that part of the hydrogen exists in the coal in combined form with oxygen known as inherent moisture. This inherent moisture is objectionable as it carries heat with flue gases without playing any part in combustion. High percentage of hydrogen (free) is always desirable as it increases the heating value of the coal.

3. Oxygen. The oxygen which is present in coal is always in combined form with hydrogen. Low percentages of oxygen is always desirable as it reduces the percentage of hydrogen available for free heating.

4. Nitrogen. The percentage of nitrogen in coal does not play any importance in the combustion calculations as it has no heating value.

5. Sulphur. The percentage of sulphur in coal varies from 0.5% to 7%. It adds a little heating value, but furnishes many undesirable characteristics. It occurs in coal as pyrites, sulphates, iron sulphides and organic sulphur compounds. The high percentage of sulphur is highly objectionable because the sulphur is responsible for clinkering, slagging, corrosion of air-preheaters, economisers and stacks, spontaneous combustion during storage, and air pollution. In spite of these disadvantages, it sometimes happens that the low price of high sulphur coal outweighs the difficulties.

6. Ash. Ash is a residue from combustion, while clinker is caused by the melting of this ash. The ash contains silica, alumina, ferric oxide, calcium oxide, magnesium oxide and alkalies. It also contains 1 to 2% sulphur. The percentage of sulphur left in ash depends upon the grate temperature. The formation of clinker on the grate depends upon the percentages of constituents in ash and the temperature over the grate. The temperature of the clinker formation lies between 1000 to 1500°C according to the percentages of ash constituents. The bad effects of clinker are mentioned earlier.

The coal with highest ash fusing temperature would be most desirable (other things being equal) as it would give stable solid ash particle in the presence of high furnace temperature. The ash fusion temperature, many times, imposes a limitation upon the capacity at which the equipment can be operated. It is always difficult to switch a unit to use low fusion coal which was previously using high fusion coal, as it would invite troubles from slagging and clogging of the gas passages.

Another important desirable property of coals is *"grindability index" as it helps in evaluating the firing characteristics of coal and cost of pulverization. The grindability index is an important characteristic in pulverized coal plants, as it is a measure of the relative case of pulverizing different kinds of coal.

6.4. BASIC COAL INGREDIENTS AND THEIR EFFECTS ON FURNACE DESIGN

The basic ingredients of coal as mentioned in the previous article are carbon, volatiles, ash, sulphur and bound water. Their percentages and nature control the boiler design to adopt a particular type of coal and effect of available coal on the performance of existing boiler. The effects of each components are discussed below.

1. Volatiles and Carbon. The percentages of volatiles and nature of carbon are mostly responsible for the furnace design. When the coal starts burning on the grate, all the moisture is removed from the coal by the time temperature increases to 300°C. At 400°C only, some type of coal mass melts and acquires plastic form. This peculiar behaviour of coal is called *Caking.* At 500 – 600°C, the plastic mass gets solidified again, forming a mass with holes within the coal. At this juncture, the rich hydrocarbon gases (volatiles) get released from the mass. The volatiles which are released need additional air to burn as the primary air leaving the bed is used in coal burning. This is generally done by supplying secondary air over the bed through a number of passages located above fire bed.

The caked coal (plastic form) engulfs the non-caking coal and forms very hard clinker and hence the consequent troubles like reduced oxidation of volatiles and unburnt carbon are generally started. Highly caking coal normally has high calorific value which intensifies caking effect and further clinker formation. Caking coal is never used for boilers and it is used to convert coal to coke fuel.

2. Fines. Fines is not the property of coal but in the process of handling and transportation, the fines are generated. The percentage of fines in coal is also increased by grading and crushing. The use of coal with fines is limited. The coal size of 6 mm is limited to ram type stoker. Other stokers can tolerate coal size upto 3 mm. The coal dust cannot be used in any of the furnaces except in pulverised firing.

The fines dropping below grate into the ash pit may burn further. The fire bars may get overheated, burn or bent as they are left below for sufficient time. This difficulty can be reduced by constantly removing the ash from ash pit. The loss due to fine may cost Rs. 10 lakhs per year for a boiler burning hardly 50 Tons of coal per day. The gravity of the problem can be mitigated by adopting the following measures.

* Sprinkling water over coal before feeding to the boiler. The water rate is limited at 5% which is converted into steam during combustion. The formed steam helps to burn CO further to CO_2 and releases heat.

* The collected fines can be thinly spread over coal layer.

* The bricketts of 2.5 cm size can be prepared if economically viable.

3. Ash. The ash consists of shales and clays (oxides of silicon and aluminium), calcium and magnesium carbonates and organic pyrites. The constituents of ash are not combustible and do not contribute to heat release. The major troubles caused by the ash during combustion are listed below.

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*A definite amount of coal is passed through a miniature pulverizer when definite amount of energy is supplied to it. The weight of the ground product that will pass a 200 mesh sieve is used to calculate a grindability index number, known as *Hardgrove Grindability*. The typical values of index are 50 to 60 for good bituminous coal.

* It reduces the calorific value per kg of the coal.

* The ash being finely distributed with combustible constituents, they keep on interfering in combustion of combustibles. More the ash content, slower the rate of burning (kJ/m^2-hr) in the furnace. Slow rate of burning tends to develop lower furnace temperature and induces a good amount of air, through coal bed, without taking part in combustion. Therefore, slower rate of burning of high ash coal needs much larger excess air to be supplied and thereby further reduces the furnace temperature.

* The lower furnace temperature of high ash coal induces lingering of combustion of volatiles (particularly heavier hydro-carbon gases) and some volatiles may escape without complete combustion. The overall effect of all these parameters is to reduce the actual heat generated per kg of coal burned in furnace.

* The ash constituents are chemical compounds having some fixed fusion temperature. These are 8 to 10 different ash constituents, each having its own fusion temperature. The chemical reaction between the constituents forms new compounds, with some different temperature. It has been observed that the resultant fusion temperature is lower than the lowest fusion temperature of one of the constituents.

If the temperature developed by coal burning is higher than the fusion temperature of ash, the ash melts. The melting ash engulfs the unburned coal particles and forms a solidified mass which is known as **clinker.** Clinkering generally occurs when coal contains ash of low fusion temperature.

Additional danger of fouling and corrosion of boiler tubes exists when the ash in the coal contains alkaline compounds (Na_2O, K_2O, NaCl) of low volatile temperature. When the furnace temperature exceeds the volatile temperature of these compounds, they form vapours and these vapours condense on refractory walls and reduce their thermal and mechanical strength. The vapours condensing on heating surfaces (water tubes) buildup deposits and retard heat transfer. The flyash is deposited on these sticky vapour layer and builds up high thermal resistance to heat flow. The effect will be to overheat the tubes or may burn or bend or puncture the tubes. In addition to this, molten alkaline ash on the walls form a hard mass, difficult to remove.

The major problems faced by the boiler are clinker formation, molten ash on refractory walls, slagging down of refractory, ash and clinker deposits on the tube surfaces. All these problems are due to low fusion temperature of ash and presence of larger quantities of alkaline constituents. This trouble is aggravated further with coals having higher calorific value. Generally coals of high calorific value have lower ash content. *A good coal having low ash content and hence high calorific value but having low fusion temperature (lower than the furnace temperature) is wholly responsible for all these problems. A high ash content coal, having high fusion temperature is more acceptable than low ash content, having lower ash fusion temperature.*

Low ash content with high calorific value coal (so called good coal) with low fusion temperature coal will have initially an intensely hot furnace bed due to high calorific valve of the coal. As the ash in the fuel starts fusing, it forms a plastic mass and engulfs the unburned coal and thus forms the clinker. The formed clinker obstructs the passage of primary air. With such condition of starved air, it is impossible to burn the coal further supplied by the operator. The operater has to stop coal feed and he has to remove the sticky mass from the grate bars to enable primary air to flow. The entire furnace gets cooled during this period and the coal fed after this will go through the same cycle described above. The boiler thus fails to give the rated output and in addition suffers from the trouble of burntout grate bars.

The boiler working on high ash and high calorific value coal but having high fusion temperature also suffers from low output but there will not be breakdown of boiler and refractory components as would happen with high calorific value and low ash fusion temperature coal (a bad coal). Hence a *bad coal* is more suited to the boiler compared with good coal.

4. Quantum of Ash. The ash content interferes with the combustion of coal and reduces the temperature of combustion zone. Higher ash content coal burns slow compared with low ash content coal under identical conditions of feed rate and excess air supplied. Therefore, a given ash content coal can burn at different rates (kg/m^2-hr) depending on how fast and how effectively surrounded by the air. This phenomena can be observed by more intensified glow of coal burning.

High ash content coal burns slowly and reduces the steam-output of a boiler. It can increase the rate of burning and consequently steam generation rate by increasing air feed rate within limits. This method is effective as long as the ash content does not exceed 35% and the calorific value is not below 20,000 kJ per kg of coal. The coal with higher ash content ($> 35\%$) and lower calorific value ($<$ 20000 kJ per 1 kg) does not respond to the increased air flow rate.

A boiler is always designed to give specific steam output using coal having definite ash content, ash fusion temperature and calorific value of coal.

Since the available coal could be of any ash content, any ash fusion temperature and any calorific value, the questions that arise to the designers and users are :

(*a*) For what coal specifications, the boiler be designed and what output rating be given to such boilers.

(*b*) The users may get any type of coal for their boiler. What will be the steam output from the boiler ?

(*c*) It is necessary for the users to get some minimum output from their boilers irrespective of the type of the coal they get. If it is so, what measures need be incorporated in design.

(*d*) How to counteract the evils of high calorific value, and low fusion temperature coals and how rated output be managed even with such bad coals.

(*e*) What optimum performance can be expected from a boiler when using coal of different ash content and calorific value but having safe ash fusion temperature.

Prof. T.R. Sarkari, Director Technical Thermax Pune, has developed charts for solving the above mentioned problems.

6.5. CLASSIFICATION OF COAL

The coals are classified in the following manner in the increasing order of their heat value.

1. Peat. The peat is the first stage in the progress of transformation of buried vegetation into coal. It contains high percentage of moisture (90%) and small percentages of volatile matter and carbon. It is not suitable for power plants as it contains high percentage of moisture. It is used for domestic and other purposes. It is sun dried to remove the greater part of moisture and converted into briquettes before being transported.

2. Lignite. Lignite is the next stage in the development of coal. It also contains high percentage of moisture (30 to 45%) but can be dried just by exposing to air. It is brown in colour and exhibits a woody structure. It hardly contains 6% moisture when dried. Therefore, it can be used as fuel in pulverised form. Considerable deposits of lignites exist in India, Germany, Russia and Australia.

Neyveli power station in Tamilnadu is the first power plant in the country which uses lignite as fuel. Another super thermal station is proposed at Neyveli using lignite as fuel. India will have two more thermal plants based on lignite. One in Bikaner (Rajasthan) and another in Kutch (Gujarat). Government has also sanctioned Palna lignite thermal plant in Rajasthan of 120 MW capacity which will be developed by using lignite. The proved lignite deposits in Bikaner district are estimated to be 24 million tonnes which can sustain a power station of 120 MW capacity for its life time (25 years). The detail contents of lignite are listed below.

Lignite (Dried)

Ash content —— 10 to 15%
Volatile —— 36 to 42%
Moisture —— 12 to 15%
Carbon —— 68 – 74% (H_2 – 5 to 5.4%)
C.V. —— 4450 to 5450 kcal/kg
Phosphorus —— 0.002 to 0.006%
Chlorine —— 0.03 to 0.16%
Sulphur —— 1.4 to 6.7%

Ash Composition

SiO_2 —— 11.1 to 20.8%
Al_2O_3 —— 6.5 to 10.3%
Fe_2O_3 —— 14.7 to 17.4%
LiO_2 —— 0.9 to 1%
P_2O_3 —— 0.08 to 0.12%
SO_3 —— 23 to 25.5%
CaO —— 15.4 to 22.7%
MgO —— 7.9 to 11.4%
Alkali & thens —— 1.2 to 5.2%

Ash Fusion Temp.

Mild reducing atmosphere —— 1030 to 1160°
Oxidising atmosphere —— 1060 to 1180°C

3. Bituminous Coal. It is most popular form of coal used for all purposes. It has low moisture content. It has high *caking power. The ash content may vary from 6 to 12% and fusion temperature of ash is usually 1093°C. Low volatile matter and high caking coals are prepared for metallurgical industries while high volatile matter and low caking bituminous coals have great utilities for gas making purposes.

Sub-bituminous coal is similar to lignite. It contains 50% less moisture than lignite. It also contains less ash than lignite but it has no caking power. It is also used either in the form of briquettes or pulverised state.

Semi-bituminous coal is intermediate between anthracite and bituminous coals in properties and is used widely in thermal power plants. It has low percentages of moisture, ash, sulphur, and volatile matter and has high percentage of available hydrogen. Its C.V. is high and it has usually caking properties. It contains 90 to 93% carbon, 10 to 20% volatile matter and 2 to 4% oxygen. It is used on moving grates as well as in pulverised form.

4. Anthracite Coal. Anthracite is the last stage in the process of transformation of buried vegetation into coal and it contains highest percentage of carbon and the percentage of volatile matter is below 8%. It has zero caking power. It burns only at high temperature and does not fuse or soften. The pulverisation of anthracite is very difficult and costly, therefore, it is used only on the grate with forced draft.

The properties of semi-anthracite coal lie between anthracite and bituminous coal. These are found in small quantities and are costly for power generation.

Fuel Characteristics and Its Suitability for Boiler

Coal is composed of carbon, hydrogen, oxygen, nitrogen, sulphur and ash. The coal is classified into four types based on fuelsage : anthracite, bituminous, sub-bituminous and lignite.

Anthracite, the oldest coal, is clean, dense, hard, noncaking and hard to ignite. It burns freely, uniformly and smokelessly.

Bituminous coals cover a large range with drastically different composition and burning characteristics. These coals are the most common industrial fuel and ignite easily and burn freely.

Sub-bituminous coals also have a wide range of features. Generally, they are high in moisture, break when dried and ignite easily and quickly and noncaking and free burning.

Lignite is a very young coal with a high moisture content and low heating value.

The most important coal properties are heating value, volatile matter, fixed carbon, moisture and sulphur content and mineral characteristics of ash. These factors vary widely. For example, heating value is between 12000 to 30000 kJ/kg, ash is between 3 to 15%, volatile matter content which affects ignition and flammability is between 20 and 38% and suphur content which determines pollution control requirements, is between a trace to 10%.

Proximate analysis identifies coal suitability to a particular boiler, utimate analysis is more detailed and used for heat balance purposes. Fig. 6.1 graphically illustrates a proximate analysis of four coal types. Analysis information should be supplied to the boiler manufacturer to ensure proper equipment design.

Pulverised coal is burned in suspension, burned in chunks on a grate, Pulverised coal is blown into furnace, chunks are introduced by a travelling grate, overfeed or underfeed stoker and combination fired coal is flung onto a travelling grate stoker by a spreader.

Stoker feeding is selected for less than 50 tons/hr of steam capacity and pulverised firing is used for over 120 tons/hr steam generating capacity.

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*The volatile matter is driven off from the coal when heated leaving behind practically pure carbon. The process is known as caking and formed product is known as coke.

Primary advantages usually associated with pulverisers over stokers include higher operating efficiencies (5 – 10% higher), rapid response to load swings and the ability to use a wide range of coal. The boiler must burn enough fuel at higher η to justify the greater cost of the pulveriser system.

6.6. COAL BENEFICATION

Coal benefication is the primary preparation of coal or cleaning of coal prior to its use. The purpose of preparation is to make acceptable coal to the consumers. Preparation includes sizing, removal of rock originating from mine roof, removal of ash and sulphur bearing minerals, drying to remove excessive surface moisture and blending of different coals to achieve desired physical and chemical properties.

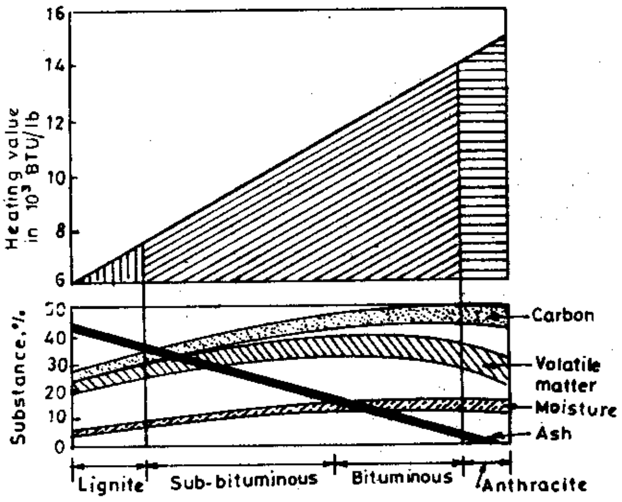


Fig. 6.1. Graphical representation of proximate analysis of different coals.

The coal cleaning at mine is becoming more important as it offers many advantages. About 35% of coal (200 million tons) is cleaned in USA every year to remove ash and sulfur impurities and increase the coal heating valve.

Fig. 6.1(*a*) represents a simplified flow diagram of coal preparation plant.

The adverse effect of ash and sulphur on the boiler of thermal plants are well known and methods to reduce the level of these impurities by mechanical means are available on commercial basis.

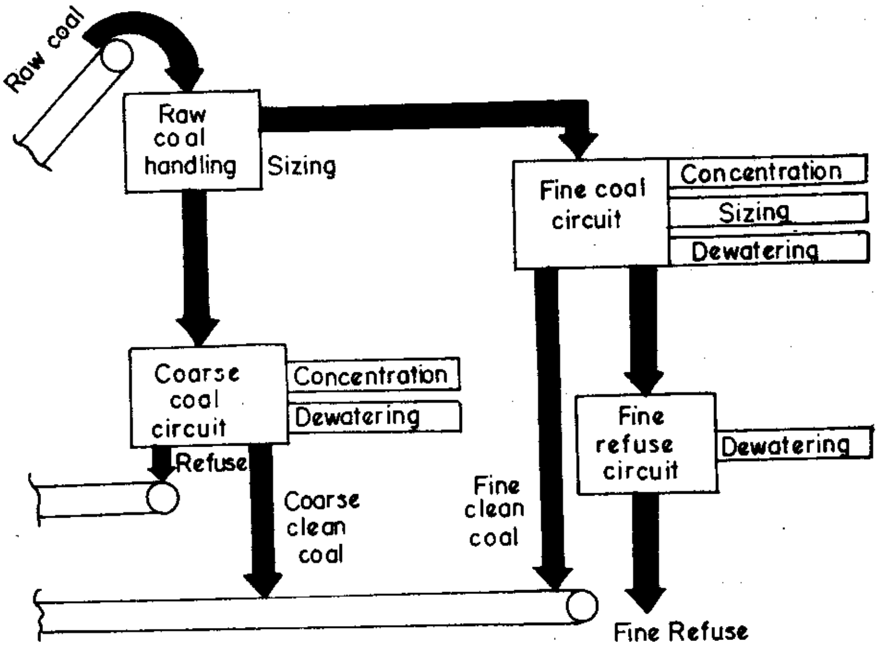


Fig. 6.1. (*a*) Simplified diagram of coal preparation plant.

To design a coal cleaning process, information regarding an accurate physical and chemical characteristics of the coal to be cleaned and the cleaned coal requirements are specified by end user.

Most of the cleaning processes rely on the relative differences in specific gravity. Specific gravity separation is most widely used method for coal cleaning. Impurities usually have a specific gravity greater than 2 while coal ranges from 1.3 to 1.5. When a coal of such composition is placed in a medium whose specific gravity is between the two, impurities will tend to sink while coal will float. The specific gravities of coal and impurities are listed below.

Specific Gravities of Coal and Impurities

Bituminous Coal	*Bone Coal*	*Shale*	*Clay*	*Pyrites*
1.12 – 1.35	1.35 – 1.70	2.0 – 2.6	1.8 – 2.2	4.8 – 5.2

The different media which are used to separate coal from impurities are discussed below.

1. Water. It is most commonly used as easy to separate the coals. The common equipments used are coal Jigs, concentrating tables and hydrocyclones.

2. Air. It is used only where water is scare. Air Jigs and tables are generally used for the purpose.

3. Magnetite in water. The cyclone separators use liquids of specific gravity between coal and impurities for removing impurities. The fluid commonly selected is finely ground magnetite in water. The gravity of separation can be adjusted by varying the concentration of magnetite and provides greater flexibility than water.

Coal Cleaning Equipments. The equipments required are coal sizing equipments, size classification equipments (screens), coal drying equipments, concentrating equipments (washing) and dewatering systems.

(*a*) **Removal of dirt.** On being brought to the surface, the coal is passed through primary screening to separate the large coal above 8 cm in size from the small coal. After that, the large coal is cleanedd by hand. The coal below 8 cm in size is cleaned by washing or dry cleaning plants.

Dry screening is a purely mechanical operation of separating the various sizes of coal but no foreign matter is being removed. During screening, the fine dirt associated with coal is automatically removed. The final conditioning of the coal size is governed by the amount of vibration imparted to the screen.

The dry cleaning can be used when the coal to be cleaned has less than 3% free moisture. But unfortunately, the coal which is brought to the surface is too wet to clean by dry cleaning. The main advantage of dry cleaning is that the coal is kept at the same moisture content as when mined.

(*b*) **Coal drying.** The moist coal is undersirable as a fuel for power plant because of the following reasons :

(1) A proportion of heat of combustion (about 0.12% for every 1% of moisture) is utilised in evaporating the moisture in the furnace.

(2) The capacity of pulverised fuel mills reduces with an increase in moisture content of the fuel (reduction of 2.5% per 1% increase in moisture content). Thus a power plant of 2000 MW capacity requires one additional ball mill with an increase in moisture by 20%.

(3) The power consumption of auxiliary plant (mills, I.D. and F.D. fans, etc.) increases with an increase in coal moisture.

(4) The transportation cost of coal from mine to power station increases with an increase in moisture content.

Therefore the drying of coal before transportation is essential due to the high moisture content in raw coal. The common methods used for drying are steam drying ; oil dehydration and fuel gas drying. The moisture content in the coal can be reduced to 10% by steam heating for lump sizes and flash drying using flue gas heating for dust.

The thermal drying is used for reducing the losses associated with the milling, feeding and burning of wet coal. The steam drying system of 200 tons/hr capacity (hourly consumption of 500 MW plant) can reduce the moisture content from 12% to 4%. The pressure of steam generally used is 30 bar and is bled from I.P. turbine.

(*c*) **Coal sizing.** The uniformity of the coal size is essential for higher efficiency of utilization. Even exact relationship between size of fuel and efficiency of utilization is not known.

The combustion of coal is a surface reaction and as the size of the lump is reduced, the ratio of surface to weight is increased. Therefore, the rate of combustion depends upon the rate of mixing which also depends upon the size of the coal.

The different sizes of coal are recommended for different types of grates. A consideration must be given for installation of both stokers fired and pulverised coal plant. If the coal screening plant is included in coal handling plant, a screening plant would be adjusted so that the fine coal could be fed to the pulverised fuel plant while the screened product would be ideal fuel for the strokers. Such an arrangement is only useful for dry coal as no screens would separate finer if the coals were dump.

(*d*) **Sulphur Removal.** The sulphur content in the coal may be as high as 5 to 6%. The use of coal containing more than 2.5% of sulphur is restricted due to fouling and corrosion action on the plants and equipments and objectionable air pollution.

The sulphur may occur in any of the following forms as pyritic in combination with iron, organic and sulphates in combination with calcium and iron. Pyritic contains 50 to 80% of total sulphur, organic up to 40% and sulphate sulphur rarely exceeds 3%.

Methods of practically removing the sulphur depends upon the form in which it is present. The pyritic sulphur can be removed easily by hand-picking depending upon the size of the lumps but organic sulphur which forms the part of the coal cannot be removed by any of the well-known processes.

(*e*) **Washing.** This is the process where coal impurities are actually separated. The equipment used is largely dependent on the coal size and washability.

The common equipments used for washing are discussed below.

1. **Water Jigs.** Water jigs are the oldest types of coal cleaning devices and most widely used for coarse size coal.

A jig operates by means of the stratification that takes place as fluid pulsates through a bed of coal particles as shown in (Fig. 6.2). Heavier particles tend to sink toward the bottom of the bed while the lighter particles move toward the top. Particles with a specific gravity higher than a predetermined cut-off point

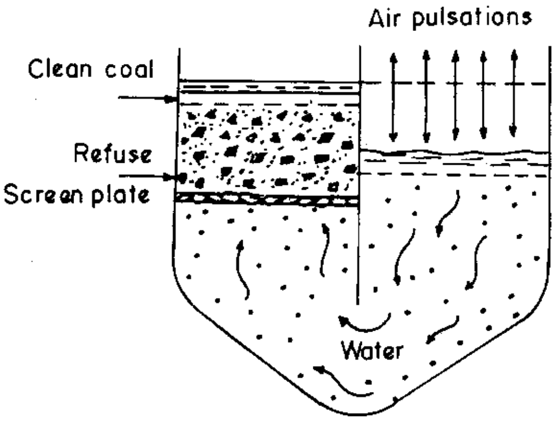


Fig. 6.2. Beum-type jig is used for cleaning coarse coal, with water as the medium.

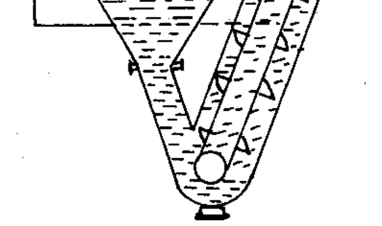


Fig. 6.3. Feldspar-bed jig is used for fine coal. Bucket conveyor is used to carry out refuse.

are continuously removed from the bottom of stratified bed and carried out of the jig by bucket elevators. Pulsations of water through the bed can be effected either by air pressure or by a plunger.

When a wide size range of coal is cleaned, the efficiency of separation decreases when the particle size decreases. Jigs used to clean intermediate size coal are equiped with feldspar beds (stone beds) as shown in (Fig. 6.3) to improve stratification of the finer sizes and to prevent the loss of recoverable fines with the refuse.

Nandan Washery (using Chhindwara based coal) constructed by Western Coal Field Ltd., is of this type and working from 1982 onwards giving 1.2 million tons of washed coal per year reducing 17% ash. Its cost is 24 crores.

2. Concentrating Table. It is widely used for fine coal cleaning because of its efficiency. A concentrating table consists of a flat, rhomboid shaped wooden deck, covered with a rubber surface with tapered riffles as shown in (Fig. 6.4). The table is reciprocated horizontally and as the feed particles spread out across the surface they become arranged so the finest and heaviest particles move to the bottom and the coarsest and lightest move to the top.

Concentrating tables make separations according to particle size as well as particle density.

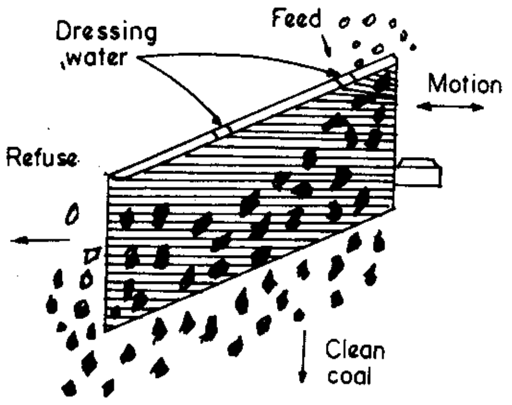


Fig. 6.4. Concentrating Table.

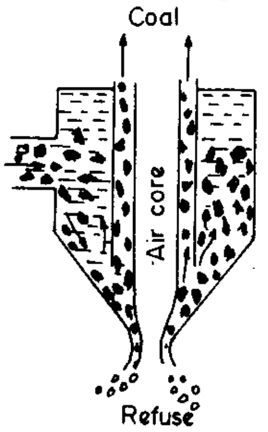


Fig. 6.5. Hydrocyclone.

3. Hydrocyclone. It consists of a cylindrical and a conical section as shown in (Fig. 6.5). Raw feed slurry flows tangentially under pressure into the cyclindrical section and moves into the conical section, where the particles in it are subjected to extremely high centrifugal forces. High density particles (refuse) move outwards and downward and discharge as underflow from the cyclone apex. Low-specific gravity particles (coal) tend to be trapped in the ascending vortex within the cyclone and are carried out in the cyclone overflow. Hydrocyclones are relatively inefficient devices and are not generally used to clean coals.

To avoid this difficulty, a two-stage recirculation of the overflow material is often recommended as shown in (Fig. 6.6). In this arrangement, first stage is adjusted to produce an acceptable clean coal and second stage is adjusted to produce a refuse that is essentially free of misplaced material. The overflow of the secondary cyclone containing misplaced coal from primary cyclone is returned to the primary for reprocessing.

4. Heavy Medium. Heavy medium is used to clean coal in heavy medium vessels and heavy medium cyclones. Heavy medium vessels as shown in Fig. 6.7 (*a*) are used to clean coarse coal (> 6 mm). 30% of the US coal is cleaned by this method presently. It consists of drum containing dense liquid that could be an organic fluid dissolved salts or most commonly magnetite which is an iron oxide finely ground to 325 mesh.

In this equipment, raw coal is continually introduced at one end of the vessel, particles with a specific gravity greater than that of the medium sink to the bottom and are removed as refuse. Low density particles float to the surface and are discharged from the vessel as clean coal.

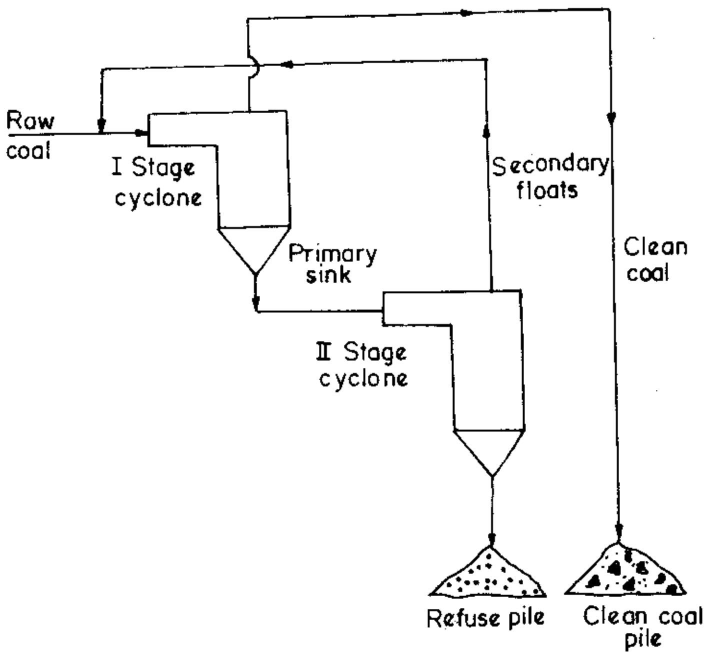
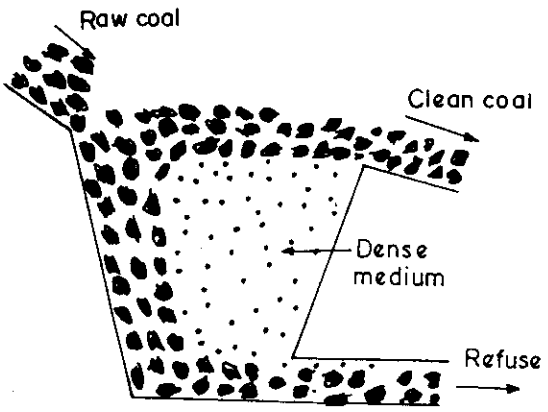


Fig. 6.6. Two stage cyclone.

The advantages of this method are, specific gravity of separation can be altered simply by addition of water and magnetite and therefore sharp separations over a wide range of specific gravities and sizes are possible.



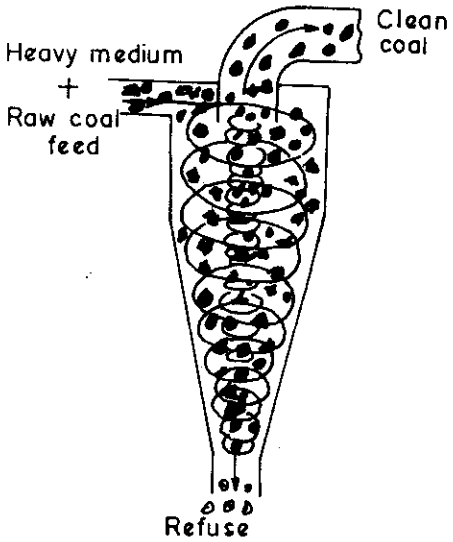


Fig. 6.7. (*a*) Heavy medium vessel. Fig. 6.7. (*b*) Heavy medium cyclone.

Heavy medium cyclone is used to clean coal finer than 6 mm. In this device, centrifugal forces complement the action of the heavy medium. This cyclone as shown in Fig. 6.7 (*b*) is similar to hydrocyclone except for the cone angle. Hydro-cyclone has a large cone angle (120°) while heavy medium cyclone cone angle is limited to 20°. Feed to heavy medium cyclone is introduced tangentially near the top of the cylindrical section and heavy particles move downward and discharge as refuse through the apex. Low density particles (coal) move towards the longitudinal axis, where they are tapped in the ascending vortex and carried up to the overflow chamber.

When heavy medium cleaning devices are used, they must be supplemented with well design system for the recovery of the medium. Magnetic separators are generally used for the recovery of magnetite.

Dewatering. Excessive surface moisture on the coal reduces the heating value of coal, increases transportation costs and creates handling and shipping problems. Therefore, dewatering is necessary after washing to produce clean coal. Vibrating screens are used to dewater coal-water mixtures. Centrifugal driers are used to dewater coarse to medium size coal. Centrifugal force upto 600 g pulls moisture from coal particles.

Advantages of Coal Preparation. The cleaning of coal costs very much. Therefore, a decision to use cleaned coal must weigh the reduced power plant capital and operating costs. Many times, the savings and benefits compensate more than the cost of cleaning the coal. Utilities are burning more cleaned coal each year because they find that the saving it offers in fuel handling, plant efficiency availability and environmental controls compensate for the added costs. The benefits are listed below.

1. Reduced Transportation. The cleaning can eliminate waste that accounts for 15 – 20%. A significant long term saving can be realised where the hauls are long and volume handled is large.

2. Improved Coal Quality. Washing eliminates non-combustibles and produce fuel of uniform size. This creates high quality fuel which costs less to transport, handle, crush and pulverise. This increases the ability of boiler to meet peak load. Washed coal reduces the outages caused by excessive wear of crushers and pulverisers as pyrites, rock, tramp iron and other abrasive constituents are removed.

3. Reduces Pulveriser Operation and maintenance costs because there will be less hard mineral matter to pulverise.

4. Improved Boiler Performance. The boiler efficiency increases due to higher quality feed stock. The cleaning of coal further reduces slagging, fouling and corrosion and increases boiler life expectancy.

5. Less Ash to Handle. Cleaner coal can reduce upto 70% of the ash in the coal, reducing ash handling and ash disposal costs. The load on electrostatic precipitator and fabric filter is also reduced. Cleaner coal means less sensible heat loss in bottom ash and gives improved overall heat transfer.

6. Removal of sulphur. Physical cleaning cannot remove all sulphur associated with coal because a significant amount of sulphur is chemically bound with the coal. Much of the unbound sulphur (pyrites) can be removed by simple washing (50%). For further removal of sulphur, chemical cleaning is necessary.

Higher surface moisture of washed coal may partially negate the benefits gained out of ash reduction and may also aggravate a freeze control problem in winter. Therefore, before going to adopt clean coal, a cost benefit analysis must be made.

6.7. COAL BLENDING OR MIXING

Coal properties vary from region to region, mine to mine and even seam to seam. Parameters such as heating value, moisture, sulphur content, ash and its composition, and quality are important in maintaining boiler rating and reliability. As utilities are faced with growing needs to use different coals from a variety of sources, they are increasingly turning to coal blending to meet the often conflicting demands of environmental requirements and reliable boiler operations.

1. Bed Blending. Bed blending is used when coal supplies have variable properties. In this system, bulk material is layered in long narrow piles to form a layer cake with 100 to 400 layers. An reclaimer slices the cake to obtain a product which is representative of the blended coal cake.

2. Belt Blending. Classified coal is reclaimed from several piles at once via belt feeders and layered on to tunnel belt conveyor. The coal supplied to Georgia power station is an example of this system. Such blending is used generally to meet SO_2 requirements.

3. Automatic Blending. A programmable controller is used now-a-days for blending. In this system, the operator can merely dial or key the desired coals and blend ratios and then system will automatically start and stop, monitor and control all functions.

The main advantages of blending are listed below :

The blending is generally adopted for uniform performance of boiler, less fouling troubles and to meet environmental regulations, particularly for SO_2 emissions.

1. A variety of coals from different sources can be blended in different proportions to meet the boiler performance and emission criteria.
2. Blending can provide widest latitude in selecting coal.
3. It allows the operater to better control the plant performance parameters.

When blending for boiler performance, different parameters may be minimized, maximized or balanced. These can include ash content, grindability, percentage sodium, acid/base ratio and heat value. The sodium is prime culprit in the fouling problems and blending for condium content would be beneficial.

Many times, coals having very low sulphur is not suitable as power plant fuel because it affects the performance of electrostatic precipitator very much. Under such conditions, it becomes necessary to blend the existing coal with high sulphur content coal. Sometimes it is also not desirable to use coal with high sulphur content as it emits more SO_2 and cannot fulfil environmental requirements. Under this circumstances, it becomes necessary to blend the existing coal with low sulphur content coal.

To solve the ash clinkering problems, Central Illinois Light Co, is using blended coal for Edwards power station. Montana and Calorado coals, sulphur contents are well within emission requirements but their ash characteristics are quite different. One has a sub-bituminous ash (where $Fe_2O_2 > CaO + MgO$) and the other is lignite (where $Fe_2O_2 < CaO + MgO$). The lignitic ash was more troublesome and this problem was solved by blending lignite coal with sub-bituminous coal.

6.8. COAL DESULPHURIZATION

Some of the pyritic sulphur can be removed by mechanical means. It is done first by crushing the coal and then processing it to separate the heavier masses which are mostly rock and pyrites. 5 to 15% coal is rejected as waste along with undesired rocks and pyrites.

Deep cleaning is used to separate the pyrites using a density difference method as mentioned earlier. Coal cleaned by this method contains very less sulphur but nearly 35 to 40% of the coal is lost as waste along with unwanted components.

A Chemical-TRW-Meyers Process. The chemical separation of sulphur is the only solution to remove sulphur from coal economically. In this method, a chemical reaction is used which yields a compound that can be removed easily. This is done either by oxidising the sulphur or the sulphur is dissociated from the iron and incorporated in another compound.

Finding suitable chemical reaction cannot solve the problem. It must also lend itself to an economically competitive process that does not create new pollutants. The process adopted must fulfil the following requirements.

(1) It must react only with pyrites and should not attack coal.

(2) The temperature of reaction should not exceed 400°C where coal starts to decompose.

(3) The reagent must be regenerable.

(4) The reagent should be either soluble or volatile both before it enters into the reaction and afterwards, so that it can be easily recovered from the coal.

(5) The reagent must be inexpensive because it is used in large quantities and even though it is regenerated, some of it will be lost in the process.

The only process developed on commercial basis is Meyer process (in 1977). The components of the process are shown in Fig. 6.8 and operations involved in the system are listed below.

(*a*) The coal is crushed and sent to mixing tank.

(*b*) The crushed coal is mixed with a water solution of ferric sulphate [$Fe_2(SO_4)_3$] to make a slurry.

(*c*) The resulting slurry is heated to 100°C – 130°C using steam in a reactor vessel. This causes the ferric sulphate to react with pyrites to yield ferrous sulphate ($FeSO_4$) which is soluble in the solution. Oxygen is introducd to regenerate ferrous sulphate back to ferric sulphate.

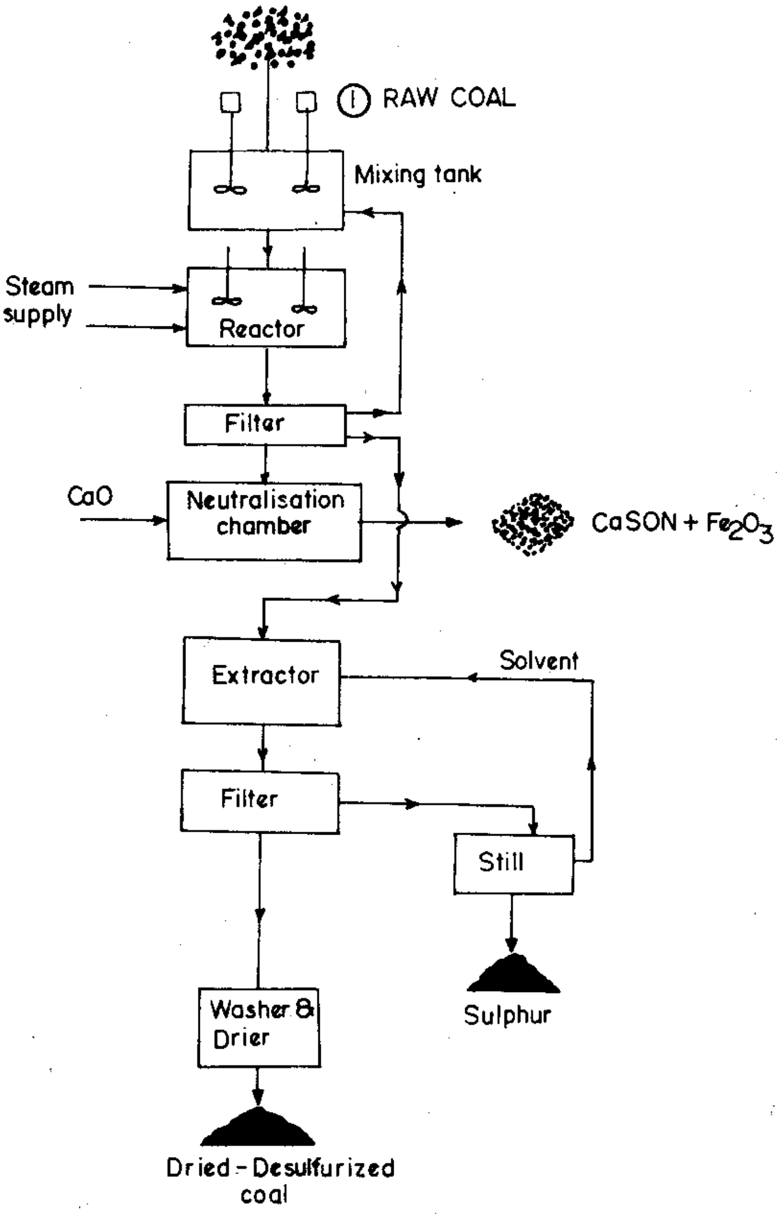


Fig. 6.8. Flow diagram of TRW Meyers Desulphurization process.

(*d*) The coal-leach solution is pumped to a filter where the solution is strained out and the coal is sent to an extractor.

(*e*) The leach solution is neutralized by the addition of CaO to remove the excess ferrous/ferric sulphates and bring the concentration back to its original value. The reaction of the lime and iron sulphate yields calcium sulphate which is gypsum. This inert insoluble byproduct is removed and leach solution is recycled back to start the process.

(*f*) In the extractor, the coal is mixed with warm acetone and water which dissolves the elemental sulphur left in the coal.

(*g*) The acetone—water and coal slurry goes to a filter that removes the acetone. The coal is then fed to a washer and drier where the remaining acetone and leach solution are washed out and coal is dried to cake form.

(*h*) The acetone from the filter flows to a still where the acetone is evaporated, leaving the elemental sulphur. The sulphur is removed and the acetone is condensed and sent back to the extractor again.

The process takes in coal plus pyrites and produces coal without pyrites and rusty gypsum. The gypsum being chemically inert, can be disposed off since it does not leach into the soil.

The cost of the system is $ 12 per ton of coal treated. This process is cost effective only for a plant more than 200 MW capacity and working as a base load plant.

The chemical reactions in different components are listed below.

(1) **Leaching**

$FeS_2 + 4.6\ Fe_2(SO_4)_3 + 4.8\ H_2O = 10.2\ FeSO_4 + 4.8\ H_2SO_4 + 0.85\ H_2O$

(2) **Regeneration**

$9.6\ FeSO_4 + 4.8\ H_2SO_4 + 2.4\ O_2 = 4.8\ Fe_2(SO_4)_3 + 4.8\ H_2O$

(3) **Neutralization**

$$Fe_2(SO_4)_3 + CaO = 3\ CaSO_4 + Fe_2O_3$$
$$Fe.SO_4 + CaO = CaSO_4 + FeO.$$

6.9. INDIAN COALS

Most of the Indian coals contain high ash and the ash is finely disseminated through the coal. Therefore the cleaning of coal to reduce the ash content is difficult and costly process.

The large deposits of coal in the country exist in Bengal, Bihar, and M.P. The main coal fields in India are Raniganj, Jharia, Bokaro, South Karanpura and Neyveli.

The washing of coal to reduce the ash content is necessary to obtain low ash metallurgical coal. The washing process creates large proportion of middlings which can be used as fuel for thermal power plants. The middlings is successfully used as fuel in France for power generation. Nearly 15% of the total raw coal supplied to washery can be recovered in the form of middlings.

The average ash content in Indian coal is as high as 20% to 30% and ash content of middlings at coal washeries lies between 30 to 40%. Therefore, it is necessary to design the plant to burn the coal of high ash content. The high ash content of coal reduces thermal efficiency of the boiler as loss of heat through unburnt carbon, excessive clinker formation and heat in ashes is considerably high. It further supplements the difficulty of hot ash disposal. Therefore, use of high ash content coal increases the size of the plant, increases the transportation cost of fuel per unit of heat produced and reduces the thermal efficiency. Besides all these difficulties, it makes the control difficult due to irregular combustion.

Such high ash content fuels can be used more economically in pulverised form. Because it increases the thermal efficiency as high as 90% and controls can be simplified just by adjusting the position of burners in pulverised fuel boilers. The recent thermal power plants in India are generally designed to use the pulverised coal.

6.10. SELECTION OF COAL FOR THERMAL POWER PLANTS

It is not so simple to suggest the general trend of suitability of coals for steam generation. The firing qualities of coal are very important when combustion equipment is being considered.

The slower burning coal of low volatile content generates high fuel-bed temperature and therefore requires forced draught. The high fuel bed temperature may damage the grate unless it is protected by adequate ash.

The fast burning coals of high volatile content require large combustion chambers for the combustion of the volatiles. Such coals are more suitable for meeting sudden demand for steam because the liberation of combustible volatile gas burns rapidly than the solid fuel on the grate.

The most important factors which are considered for the selection of coal are the sizing, caking, swelling properties and ash fusion temperature. The sulphur content in the coal also carries considerable importance in most of the cases.

Electro-static Precipitator (ESP) works better with high sulphur coal because of improved resistivity of the flue gases. However, for other systems, a little SO_2 can raise the acid DPT dramatically and this raise can retard the corrosive effect on the equipments. For example, as little as 100 ppm of SO_2 in the gases can raise DPT to 155°C. Therefore sulphur content in the coal is a critical factor for selecting a right system of dust removal.

The larger sizes of coal should be used when the draught is low and some moisture percentage must be essentially maintained if the percentage of fineness of coal is high.

The use of anthracite coal as fuel requires forced draught furnaces incorporating means for admitting steam to cool the fire bars and hardened clinker. The supply of steam is not necessary when high ash fuels such as anthracite duff or unwashed coals are used as fuels. The use of anthracite duff alone as fuel requires special design and therefore the installations are usually confined to the producing area or to places where transport costs are reasonably low.

Duff can be added to higher volatile caking coal of a similar size. The blending practically enables anthracite duff to be used practically in any installation at higher combustion rates than is possible with the duff alone.

The characteristics which control the selection of coal for a particular combustion equipment are sizes of coal, ultimate and proximate analysis, resistance to degradation, grindability, deterioration during storage, caking characteristics, slagging characteristics, corrosive characteristics and many others.

6.11. LIQUID FUELS

The liquid fuel is used in thermal power plants to generate the steam instead of coal as it offers many advantages over coal as listed below :

(1) Excess air required for complete combustion is less as uniform mixing of fuel and air is possible.
(2) The storage and handling is much more easy compared with coal.
(3) The changes in load can be met easily and rapidly.
(4) There is no problem of ash disposal.
(5) The system is very clean.
(6) The operational labour required is less and therefore overheads are considerably less.

All the commercially used liquid fuels are furnished by petroleum and its by-products. The petroleum or the crude oil consists of 83-87% carbon. 10.14% hydrogen and various percentages of sulphur, nitrogen, oxygen and metallic derivatives of venedium.

The fuel oils used for industrial or domestic purposes are obtained by refining the crude oil. The refining process separates and recombines the hydro-carbons into specialised products like gasoline, fuel oil, etc. The distillation process is generally used to separate into different groups of fuel. The typical fractions from light to heavy oil are naptha, gasoline, kerosene and gas oil and the remainder is heavy fuel oil which is commonly used for steam generation. The typical fuel oil analysis is given below :

Constituent	Carbon	Hydrogen	Sulphur	Oxygen	Nitrogen	Moisture
Percentage	84	22	2	1	0.5	3.5

The important properties of liquid fuel considered are specific heat, viscosity, pour points, flash point, volatility, carbon residue, heating value, ash, moisture, sediment and sulphur.

The pour point indicates the case of handling the oil and it is defined as the lowest temperature at which the oil will flow under specified conditions.

The viscosity is the measure of resistance to the oil flow through the pipes and nozzles. This affects the cost of pumping the fuel. The viscosity of the fuel oil is generally determined by standard viscometer.

The flash point of fuel oil decides the safety of fuel and it is also an indication of ease of ignition.

The percentage of sulphur should be as minimum as possible as it results in the corrosion of different parts in the plant and reduces the life.

For better combustion of fuel, the moisture and sediment must be as small as possible. The ash content in the fuel oil is not very important in steam power plants.

As the fuel oil contains more percentage of hydrogen as compared to coal, therefore, the moisture carried by the gas per kg on fuel burned is considerably more. This results in overall lower combustion efficiency of the plant as compared to the coal burning.

The use of oil for steam generation has no scope in India due to limited resources of oil which are badly needed for industrial and transport purposes.

6.12. GASEOUS FUELS

The gaseous fuel may be either natural or manufactured. The manufactured gas is costly, therefore, only natural gas is used for steam generation.

The natural gas generally comes out of gas wells and petroleum wells. It contains 60.95% of methane with small amounts of other hydrocarbons such as ethane, napthene and aromatic, CO_2 and nitrogen. The natural gas is carried through pipes to distances which are hundreds of kilometres from the source. Many power plants in Canada and U.S.A. use the natural gas for steam power plants.

The natural gas is colourless, odourless and is non-poisonous. Its C.V. lies between 25000 kJ to 50,000 kJ/m^3 according to the percentage of methane in gas.

The various manufactured gases are coal gas, coke oven gas, blast furnace gas, water gas and producer gas. The coal gas and coke oven gas are produced by carbonizing high volatile bituminous coal. The blast furnace gas is produced as byproduct from blast furnaces used in steel industry. The water gas is produced by passing steam and air through a bed of incandescent carbon. The details of manufactured gases are not given as they do not play much important role for steam generation purposes.

The gaseous fuels have all advantages of oil fuels except ease of storage. The major disadvantage of using natural gas as fuel is that the power plant must be located near the natural gas field otherwise transporation and cost of transportation play an important part in selecting the fuel for thermal power plant.

6.13. COAL FINES AS FUEL

Middlings constitute a significant proportion of raw coal washed in Indian Coal Washeries. The significant proportion of these can be recovered by conventional processes like heavy media separation and flotation.

The Indian coal mining industry is progressively adopting mechanization in mining. This had led to a large quantum of fines being generated. In addition, these fines are of high ash necessitating their benefication. This has led to all washeries incorporating flotation section in their washing circuit.

One of the leading methods of fine coal benefication universally accepted by the coal washing industry is *Froth Flotation.* From the time of its introduction to the coal washing industry, froth flotation has come a long way and has established itself as a technologically sound and efficient method of processing coal fines. The first froth flotation washery established in India is Sudamdih coal washery of BCCL.

Froth Flotation. This system uses chemical reagents to make coal adhere to air bubbles and rise to the surface. It is used for the recovery of ultrafine coal particles and does not depend on a difference in density between coal and refuse. Flotation depends on the surface characteristics of the particles in the feed. Chemical reagents are used to produce hydrophobic surface characteristics on the solids to be floated and hydrophilic characteristics on the other solids. As very fine air bubbles pass through the slurry, the hydrophobic particles adhere to the bubbles and rise to the surface where they are removed as clean coal concentrate.

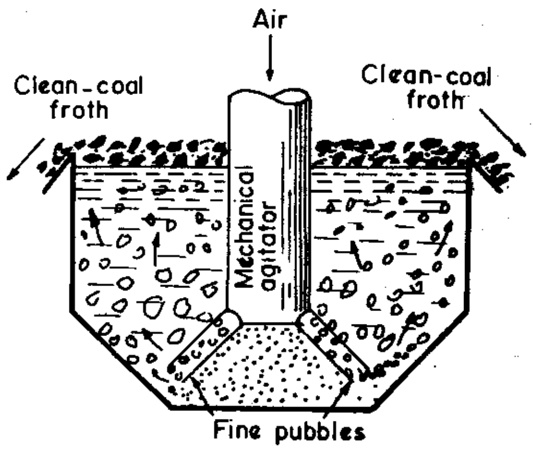


Fig. 6.9.

Dewatering of the fine coal slurries is one of the major problems faced by coal industry. Thickeners get frequently jammed and on each occasion, the plant may shut down for several days. If the thickener is bled to avoid jamming, it results in loss of good quality coal fines as also process water. To overcome this problem, a research project has been assigned to Indian School of Mines for research studies on dewatering of coal slurries.

6.14. OIL SHALE AND TAR SANDS—NEW FUEL SOURCES

The oil which has been the major energy suppliers all over the world is now fast depleting and has created widespread alarm. Experts have already started advising the consumers with phrases like "*Save every drop of oil or in 20 years, you will walk the distance.*" In fact, it is much likely that before 2000 A.D. world oil supply may fail to meet the demand. Therefore, scientists and technologists all over the world are searching for alternative sources of energy.

Oil shales and tar sands are two promising sources known to the technologists. These sources are also large compared with conventional oil. The current production of these sources is 0.2 MBDOE* and expected to go to 3 MBDOE by 2000 A.D.

Oil Shales. Oil shales are carbonaceous rocks that produce oil when heated to pyrolysis of cracking temperatures (800 – 1000°F). The oil precursor in the rock is a high molecular weight polymer called "Kerogen". Kerogen has the following average constituents C – 80.5%, H_2 – 10.3%, N_2 – 2.4%, S – 1% and O_2 – 5.8%.

The largest known oil shale reserves are found in USA, Brazil, Runia, Canada, Burma and China. One difficulty with shale oil production is the disposal of spent shale and water (1.4 m^3 of water per m^3 of oil produced). Presently, this source is not tapped very much on commercial basis.

Tar Sands. Bituminous sands and oil sands are rapidly gaining favour. The largest tar sand reserves are in Canada holding about 300 billion barrels of oil. In Canada, oil sands lie in beds of 15 to 30 metre thick under an area of 12000 square miles near the Mickenzie River in northern Alberta.

Like oil shale, in-situ and surface mining are possible in case of tar sands. 90% of the oil sand lie too deep for surface mining and must be recovered by in-situ methods. In the in-situ method, the capital cost is lower and the environmental problems of land reclamation involving very large quantities of sand would be avoided.

Surface mining and processing of oil sands have been demonstrated by Grate Canadian oil sands which produces about 50,000 BBL/day of oil. Problems associated with oil sands mining are excavating and transporting the sticky mass of sands and disposing of very large quantities of sand tailings.

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*Million Barrels per day of oil equivalent.

6.15. INTRODUCTION TO SLURRY OR EMULSATION TYPE FUELS

The present change over from oil to coal for the thermal power plants requires lot of capital as major changes are necessary in the original components of the power plant. In addition to this, storage space for coal is not available at the plant site. Coal handling and coal preparation are the major requirements which must be included during the change-over from oil to coal.

Under these circumstances, the slurry fuels (coal and oil, coal and water coal and methanol) are economically attractive for boilers not designed to burn coal and for boilers capable of firing coal when conversion from oil to coal is not practical.

The slurry type fuels offer the following advantages.

(1) It helps to shift oil fired stations to coal fired stations without major changes is the system.

(2) It improves the quality of burn.

(3) It also keeps the boiler clean.

(4) It reduces unwanted pollutants and increases efficiency.

(5) The slurry being in liquid form, the existing pumps and pipelines with oil fired station can be used to unload from ships as is the case with oil. This simplifies loading and unloading problems.

There are mainly three types of slurries, coal-oil, coal-water and coal-methanol which are considered as substitute to the oil.

1. Coal Oil Mixtures (COM). The technology of COM is essentially aimed at utilising coal in existing oil-fired units, where coal cannot be substituted completely. COM is thus emerging as one of the oil displacement technologies that is ready for commerical use at competitive prices without involving large capital outlays. The common interest in COM technology results from the fact that many countries of the world are dependent on imported oils.

Virtually all the development work on slurry fuels focuses on the preparation, handling, storage and combustion of mixture. The arrangement of the system for supplying coal-oil mixture is shown in Fig. (6.10).

The three major aspects of COM preparation are coal grinding, mixing of coal and oil and stabilization. The coal is first pulverised by ball and race mill to approximately 100 mesh in order to prevent the rapid settling of coal from oil.

Since coal-oil mixture is intended to replace a liquid fuel, it is important that the properties of the COM are compatible with the system in which it is to be used. Among the major physical properties to be considered in evaluating a coal-oil mixture are its stability, the aggregation of the coal in the oil and the rheological properties of the COM.

The stability of COM is the ability of the coal to remain suspended uniformly throughout a COM mixture when COM is stagnant. Stability can be achieved either by adding a chemical additive to the mixture

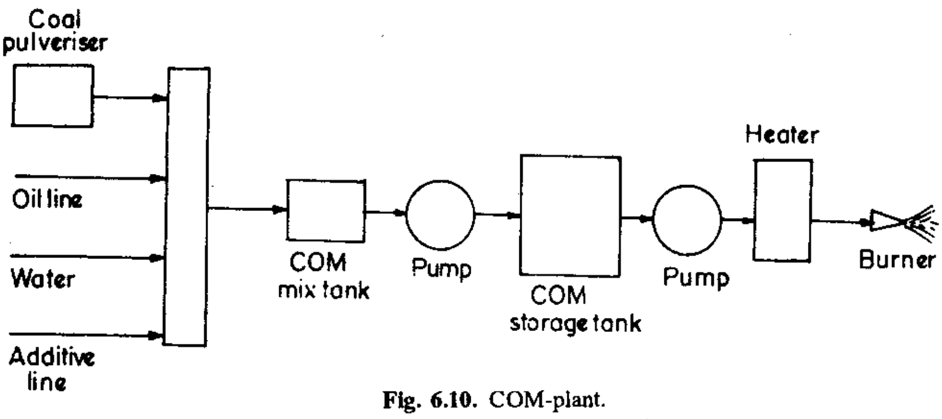


Fig. 6.10. COM-plant.

or by using ultrafine coal. The stability depends upon oil viscocity, operating temperature, coal concentration and percentage of chemical additives. The optimum storage temperature for COM lies between 50-80°C but recirculation in the tank is essential. In most cases, the presence of some water in COM is essential to enhance the COM stability.

A major problem of COM combustion in existing oil fired units is boiler derating. The primary reason being the ash erosion of boiler tubes. The most important impact on the design and operation of COM fired boiler is the quantity of ash contained in the COM, in addition to its chemical and physical characteristics.

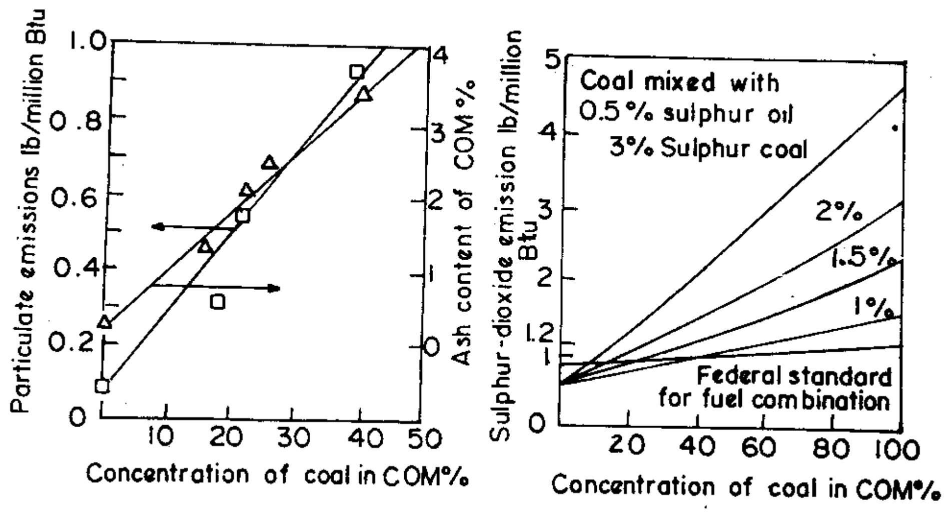
The performance of COM depends upon percentage concentration of coal in COM and ash content in the coal.

The maximum concentration of coal that can be achieved in slurry fuels influences plant performance significantly. A high coal concentration in the mixture results in cheaper fuel, relative to oil, and a quicker payoff of capital costs, than a lower concentration. But too much coal also influences the system operation adversely in general respects as reduced pumpability (for example, the viscosity may increase by tenfold as the coal percentages increase from 40 to 50%), increased erosion of fuel system components, greater emissions of flyash and other components and increased corrosion and erosion of boiler components. The optimum value of coal content in COM is 40-45% as per the experiments conducted.

The effects of coal concentration on particulate emissions and SO_2 are shown in Fig. 6.11 (*a*) and Fig. 6.11 (*b*).

Another important point with COM fuel, is a non-Newtonian fluid that falls into pseudoplastic classification. This means its viscocity decreases with increasing velocity gradient or viscosity increases rapidly as the velocity increases (known as Thixotropic material).

This property of COM causes problems to move COM overland by a pipeline and has caused some difficulty in determining the valving and metering needed to assure proper flow control.



(*a*) Relationship between the amount of coal in the slurry and particulate emissions.

(*b*) SO_2 emission from COM combustion for coals of varying sulphur content. Oil contains 0.5% sulphur.

Fig. 6.11.

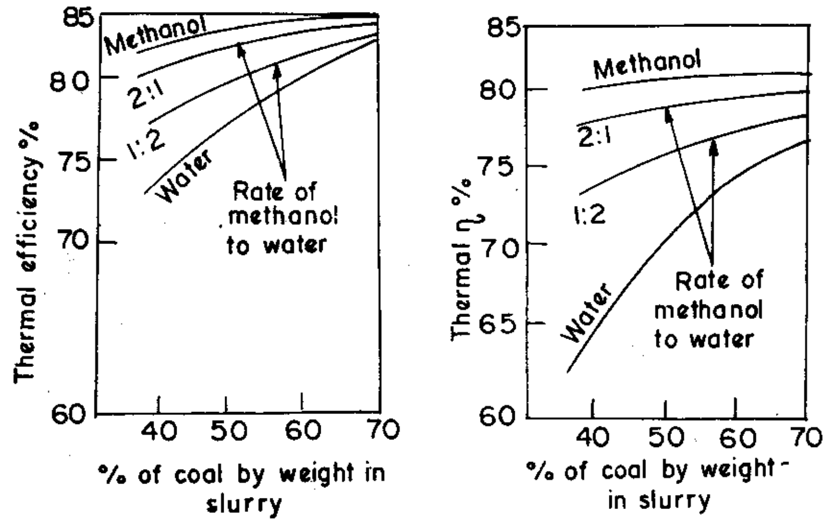
Therefore, to convert an oil-fired boiler to COM firing ; the boiler may be modified to include burners, root blowers, a bottom ash removal system and flyash collection device. In addition to this, there must be arrangements for storage, grinding and handling the COM fuels.

2. Coal-Water Mixtures (CWM). The CWM is similar to COM in many respects and draws upon COM technology base for its development. The distinct feature of CWM is that, it contains mostly coal but can be handled like fuel oil. The water in the CWM will decrease the boiler thermal efficiency and the high coal loading will derate the boiler thermal efficiency in varying degrees depending on fuel characteristics (ash-content). Such systems are not common like COM systems but they are in the stage of introducing in the power plants where fuel oil supplies are uncertain and are very costly. Presently CWM has been successfully demonstrated on a commercial scale at three coal designed plants where water percentage varies from 30 to 50%. 40 tons of slurry was supplied per hour generating 170 tons of steam per hour.

3. Coal-Methanol Mixture (CMM). CMM offers a method of completely replacing oil retaining many beneficial properties of fuel. CMM has good rheological properties and can be easily transported by pipeline containing 50% coal. CMM offers the greatest promise for low cost transportation since a given volume of this slurry contains 60% more energy than a similar CWM. The coal loading in CMM is much higher than COM system.

CMM is excellent compared with CWM but quite expensive compared with CWM. In practice, a coal slurry with blend of water and methanol appears to provide the best compromise of performance and economy. When methanol replaces some of the water, which requires 2200 kJ per kg for vaporization, extra amount of heat 20,000 kJ per kg is added. Air required for slurry combustion is also reduced as methanol is an oxygenated compound. The adiabatic flame temperature also increases for this reason.

Methanol vaporises rapidly and mixes easily with air. This helps for efficient combustion. Moreover, methanol is known to penetrate and to swell coal particles. Such coal particles, either puffed or porous, burn more efficiently than conventional coal particles. If the coal water slurry containing 60% coal is burned in a preheated air at 300°C, 85% carbon burns, but if the slurry contains water and methanol in 2 : 3 ratio, no air preheat is required and carbon utilization, goes to 90%. The effect of methanol percentage in water-methanol-coal slurry on the thermal efficiency is shown in Fig. 6.12.



(*a*) Bituminous coal. (*b*) Sub-bituminous coal.

Fig. 6.12.

EXERCISES

6.1. Why coal is considered most promising source of energy upto the end of 20th century ?

6.2. What do you understand by proximate and ultimate analysis of coal ? What are the uses of these analysis when coal is to be used as fuel in power plant ?

6.3. What are the basic coal ingredients and how they affect the furnace design ?

6.4. High ash content coals with high fusion temperature are preferred than coals having low ash percentage but with low flusion temperature. Discuss.

6.5. Alkaline contents in the coal are more troublesome than any other undesirable contents when coal is used as power plant fuel. Discuss.

6.6. The effective burning of volatiles is essential for better performance of boiler because its ineffective burning increases unburnt carbon loss also. Discuss.

6.7. What are the major advantages of coal benefication ?

6.8. Explain the working of different water washing systems used to clean coals with neat sketches.

6.9. What is the principle of heavy medium separation of coal ? Explain two methods used for coal separation.

6.10. What is the necessity of coal desulphurization ? Explain Meyer's Process of Desulphurization with a neat sketch.

6.11. Fine coal is considered as a promising future fuel. Discuss. Discuss the principle and operation of Froth flotation method of fine coal separation.

6.12. What are the advantages of using slurry fuel ? Discuss COM is considered the most promising fuel for coming decade, why ? List out the major difficulties to be faced for using COM system.

6.13. Coal methanol mixture is considered most promising than COM and CWM, why ? Discuss in detail.

□□□

7

Coal Handling, Storage, Preparation & Feeding

7.1. INTRODUCTION

Coal handling and storage systems are experiencing many changes as coal gradually plays a dominant role as a fuel. The predicted growth in coal fired plants is 90% in the next five years, as 250 new power stations are expected by 2000 only in USA.

Continuously increasing power demand even in developing countries calls for setting up of higher capacity power stations. Rise in capacity of plant poses problems in coal handling systems. A good coal handling plant must perform two duties as unloading the coal from railways wagons as fast as possible and then transferring the unloaded coal either to coal bunkers or in the stock pile for storage and then feeding the coal from the stock pile to the bunkers when railway wagons are not available.

Today, most of the world's coal production is still consumed in the countries where it is mined. Only about 10% of the total production are traded internationally. Coal used for power plants accounts for only 30% of the total coal traded internationally, and much of this goes only short distances, such as from Poland to Russia and Western Europe and from USA to Canada. In contrast, 65% of the world's oil is traded internationally.

The future of the world coal trade will require construction of greatly enlarged transportation system and this in turn will involve massive investment and long lead times. Much progress has been already made by improving operating procedures and by scaling up conventional equipment. Even with present technology, there are still considerable opportunities for increasing the capacity of the present infrastructure by improving existing ports to take larger ships and adding more large ships to the dry bulk fleet.

Main sources of exported coal are likely to be the USA, Australia, Southern Africa, Canada, Poland, USSR and possibly China. In due course, Columbia and Botswana are likely to emerge as significant exporters of coal.

7.2. OUT-PLANT HANDLING OF COAL

Continuously increasing demand for power at lowest cost calls for setting up of higher capacity power stations. Rise in capacity of the plant poses a problem in coal supply system from the coal mines to the power station.

With an increase in power plant capacity, the coal requirements per day are considerably large. An annual consumption of a 2000 MW station amounts to approximately 5 million tons per year or 20,000 tons daily over 250 days.

The coal from the coal mines to the power station is transported by sea or river or rail or road. The supply of coal by road is limited to a small capacity power plant and this mode of handling the coal does not play much important part in modern capacity power plants.

(*a*) **Transportation by Sea or River.** Pithead generation is the answer to the bottlenecks of coal transport by rail from the mines to power station. The concept of seaboard stations recognises the immediately realiable potential of sea transport along the country's coast line. If the power plant is situated on the bank of river or near the sea shore, it is often economical to transport the coal by ships or barges. The coal brought by the ship is unloaded mechanically by cranes or grabbuckets at the site of the power plant. The unloaded coal from the ship is either sent to storage yard or directly to the conveyor system which carries coal directly to the combustion chamber hopper. Many power stations located on the banks of the large river in U.S.A. receive coal by barge as it is more economical than other modes of transport. This mode of transport is on the upsurge because of better equipments and improved navigation. Barge transport terminals on Mississippi and Ohio rivers are increasing.

Coal is generally transported in the largest possible vessel because the freight savings obtained depend on the length of the haul and availability of shore facilities for loading and unloading at adequate rate. An average saving of 25% can be achieved using a 150 × 10^3 dwt instead of 60000 dwt ship. Until recently, the largest ships, carrying coal were in the *Panamax* class (50 to 80 thousand dwt). The growth of trade and improved port facilities have allowed an increased use of ships in the 120 to 175 × 10^3 dwt class.

The future of Ocean transport in India is also bright. With the current development of the Bengal-Bihar coalfields and Haldia port loading facilities, 56.5 miles downstream of Calcutta, coal supplies can be made to the coastal stations to synchronise with their commissioning. Coal unloading from ships at the receiving ends would be alongside piers where suitable docking facilities are constructed in time. Haldia's rail connection with main Howrah-Kharagpur line is at Panchkura railway station about 71 kilometres from Howrah. This will provide the rail communication between Haldia and Raniganj coalfield 325 km from Haldia. Haldia port is currently being developed for handling two million tonnes of coal per year. The loading of 1500 tons of coal per hour is also provided at the station and the capacity of the storage yard is of 350 × 10^3 tons of coal. The Haldia port facility will be capable of loading the ships of 60,000 dwt class.

The coal from the coal field to the sea port is usually transported by rail or conveyor. The unit train is the most economical transportation system for inland transport of coal. These operate on dedicated routes and avoid extra delays and costs of marshalling. The number of wagons per train and amount of coal per train lie between 50-130 wagons and 4000-13000 tons of coal.

The loading and unloading of huge amount of coal to the ships are the major problems with ship transport. High speed loading and unloading facilities are developed so that each operation can be performed within 3 to 4 hours.

A huge ship loader shown in Fig. 7.1 established at the Alabama port has tripled its coal handling capacity. The machine moves on the rails and handles 50,000 tons of coal per hour. Its 30 m long boom rises to clear ship masts and chute and controls the direction.

(*b*) **Transportation by Rail.** The transportation of coal by rail is the most important means of transportation in common use. The coal supply to Indian power plants is mainly by rail as unfortunately river transportation is not available. This mode of transport plays very important role for power stations which are located interior. A railway siding line is taken to the power station and coal is either delivered to the storage yard or close to the point of consumption.

The ordinary rail tracks available (like in India) will not be able to supply the required coal to large power stations.

To overcome this difficulty, a "unit train" system has come into existence both in Europe and U.S.A. The "unit train" system consists of 130 to 150 wagons and each wagon can be titled individually. The couplings are so designed that they remain intact even though the next wagon is being titled. There is no necessity to remove the coupling during unloading the coal from one wagon after another. A circular route is arranged for the train linking the coalfields to the power station. The trains move continuously round the clock along the circular track of train. The train track being in continuous form, is known as 'Merry Go Round' (MGR) in U.K.

Fig. 7.1. Shiploader at Alabama port.

A 3200 MW Monros power station (64 km from Detroit) in U.S.A. uses a unit train system to get coal from coal fields 576 km away from the power station. The coal is loaded at the rate of 3000 tons per hour. Unloading at the rate of 17400 tons is done for each trip. Each train is pulled by 5 locomotives of 3000 H.P. at a speed of 64 km per hour.

Another unit train system used in U.S.A. is at River Rouge power station of 933 MW capacity. No driver is required for the engine during unloading for this system. The engine is started every time by remote control and one wagon is unloaded and that moves one car length and stops again. This results in saving in man power and time during unloading. The first MGR system will be installed in India to carry coal from Kusmunda mines to Kobra plant of 1100 MW capacity.

Rapid Train Loading System for Gevra Project.

A British firm, in collaboration with a firm in Calcutta, will supply a rapid train loading system for Western Coalfields Ltd., Gevra, Madhya Pradesh, at a value of Rs. 45 million.

The Gevra opencast mining project, when completed, will have a production capacity of five million tonnes (Mt) a year in the first phase. This capacity will be extended to 10 Mt a year in the second phase. The mine is linked to the Korba super thermal power station, which will have an ultimate capacity of 2100 MW.

The rapid train loading system will be of the merry-go-round type, that is, the train will operate on a closed circuit track without any shunting operation at either loading or unloading point, and will be used to deliver coal from the mine to the Korba power station. Trains consisting of up to 35 wagons will be loaded automatically by a sophisticated electronically controlled, integrated loading, and weighing system capable of feeding 60 tons of coal into each wagon in one minute, with the train moving at up to 1.2 km/hr.

The system will be suitable for round the clock operation, seven days a week, and will despatch 10 Mt of coal a year from mine to power station, that is, 18 to 20 trains a day.

(*c*) **Transportation by Ropeways.** This is very efficient method of transporting the coal from the mine to the power station. This is particularly used when the distance between the mine and power station is less than 10 kilometres. The major advantage of this system is, it supplies the coal continuously and free from workers' strike which is common with rail transport.

(*d*) **Transportation by Road.** The transportation of coal by road is used only for small capacity plants. The major advantage of road transport is that the coal can be carried directly into the power house upto the point of consumption. This is better system for small capacity plant as traffic restrictions are comparatively less.

The lorries used for coal transport are self-tripping, their containers have usually one or two hydraulic cylinders which are actuated by the engine itself. The lorries are emptied after weighing is carried out on weighing platform by end tripping either into ground hoppers with belt conveyors underneath or on to the open coal storage.

The selection of proper method of coal supply from the coal mines to the power stations depends upon the system capacity in tons per hour, location of the plant with respect to rail or water facilities available and location of available outside storage and overhead coal bunkers.

The coal handling system used at Koradi power station in Maharashtra is a typical one as ropeways, railways and road transport are used simultaneously to supply the coal to the power plant.

(*e*) **Transportation of coal by pipeline.** The power demand throughout the world is increasing quite faster and coal is going to be the only fuel to run the thermal plants as liquid fuel prices are escalating day by day. In most of the countries, the power generating stations are far away from the coal mines and the existing railway facilities are not sufficient to cope up with the increasing demands. In India, it is expected that the power demand will be doubled by the end of the century and it is physically impossible for the railways to haul the required coal to the coming-up power plants.

Transportation of coal by pipeline is considered most speedy method among all available. Pipe lining of coal slurries from remote mines to strategically located generating plants shows great promise for future development.

The pipeline coal transport system offers many advantages as listed below :

(1) It is a continuous transport system unaffected by the climate and weather.

(2) It is capable of transporting very large quantities of coal (25 million tons per year with a single pipeline).

(3) It has high degree of reliability and safety as the moving machines are limited to the stationary pumping and boosting stations.

(4) It is easy to carry the pipeline through difficult terrain like hills, valleys and swamps compared with other modes of transport.

(5) Man-power requirement is low and maintenance charges are also low.

(6) Loss of coal during transport due to theft is totally eliminated.

(7) Requirement of large areas as in the case of railway system for site dumping and storage is eliminated.

(8) The system is amenable to automation, increasing its reliability and smooth operation. 99% reliability has been already proved with the operation of Black Mesa system in USA from last 20 years.

(9) It produces the least environmental disturbance as noise and dust problem and traffic congestion is drastically reduced.

(10) It provides simplicity in installation and increased safety in operation.

(11) It is more economical than other modes of transport when dealing with large volume of coal over long distances (50 – 75% of rail cost).

(12) The impact of inflation on the operating cost is less than other modes of transport.

Some of the disadvantages of the system are listed below :

(1) It requires large quantity of water as 1 kg of coal requires one kg of water.

(2) Preparation of coal at the pumping terminal as well as dewatering and recovery of the coal at the delivery terminal requires high capital and operating cost.

(3) Consumers must be able to use coal with added surface moisture (10%). This also results in some loss in the useful heat of coal.

The System. The pipeline transport system can be divided into three main sub-systems as described below :

(*a*) *Coal Preparation and Pumping Terminal.* The washed coal is crushed to a suitable size (14 mesh) and fed into storage bunker. The crushed coal and water is mixed to form a homogeneous slurry in the slurry preparation plant. The formed slurry is then pumped into the pipeline system. The pressure at which the slurry is pumped lies between 50 bar to 300 bar depending upon the distance and the type of the terrain.