CLEAN COAL TECHNOLOGIES

8.1. INTRODUCTION

The demand for electrical power has been growing at the rate of 9% a year and is likely to be 385 GW by the year 2020. Of the total installed generating capacity, more than 50% is based on coal. Because of certain factors such as limited reserves of petroleum and natural gas, cost and technology factor of renewable energy etc., coal will continue to be the main source of energy. With the ever increasing use of coal, the emission from energy sector will increase five times by 2020.

The choice of technology to minimize emissions in power generation has to follow the given routes :

(*i*) Increasing the efficiency so that lesser fuel is burnt per unit of energy produced.

(*ii*) Using cleaner fuel.

(*iii*) Adopting a combustion process that removes pollution at the start.

Increasing environmental concerns and the necessity to improve efficiency of thermal power plants have led to the development of some new technologies called as "clean coal technologies".

Clean coal technologies are :

1. Coal treatment and benefication ;
2. Coal gasification and combined cycle power generation ;
3. Fluidized bed combustion ;
4. Flue gas cleaning and desulphurization.

The primary preparation and cleaning of coal is called "coal benefication". Coal benefication provides proper combustion, adequate furnace temperature, reduced stack gas and better thermal efficiency. The break down of coal or any other carbon based feedstock into its basic chemical constituents is known as coal gasification. Coal gasification offers one of the cleanest and most adaptable and efficient ways to convert the energy content of coal into electricity, hydrogen, and other forms of energy for future generation automobiles and power generation plants. In a conventional thermal power plant, heat from coal is used to produce steam and this steam drives a steam turbine and an alternator. Efficiency of such conventional thermal power plant is in the range of 35% to 39%. Whereas in a coal gasification power plant, the cleaned coal gases are fired in a gas turbine. The gas turbine is coupled to an alternator and electricity is produced. The hot exhaust of the gas turbine is then used to generate steam for the conventional steam turbine which powers an additional generator. A coal gasification power plant converts much of the inherent energy of coal into electricity thereby enhancing the overall efficiency to over 50 percent. Very efficient desulphurization and cleaning of coal gas reduces the environmental impact. Because of the low combustion temperature and long residence time the amount of CO and NO_x formed are very small. The amount of CO_2 emission per unit of fuel burnt is also less because of the high overall efficiency.

Fluidized bed combustion (FBC) has emerged as a viable alternative and has significant advantages over conventional firing systems. The fuels used in such a system are coal, rice husk, bagasse, agricultural waste, municipal waste, sewage plant sludge etc. Coals with high ash content and low calorific value can also be used. The benefits of FBC system are compact boiler design, fuel flexibility, higher efficiency of combustion and reduced emission of pollutants such as NO_x and SO_x.

Clean coal technology describes a new generation of energy processes that stridently reduce air emission and other pollutants compared to older coal burning systems. By opting for one or a combination of the above technologies, the emission from fossil fuel power plants can be reduced to the regulatory limits. Moreover, the efficiency of these systems is better than that of conventional steam plant. The emissions are reduced because of the capability of clean coal technology to purify as much as 99 percent of the pollutant and impurities from coal derived gases. For example, sulphur in coal emerges as hydrogen sulfide and can be confined by processes used in the chemical industry. Sulphur can also be extracted in a form that can be sold commercially. Similarly, nitrogen egress as ammonia and can be scrubbed from the coal gas by processes that produce fertilizers or other ammonia-based chemicals. Though expensive, such technologies may prove to be cost-effective in near future because of their higher efficiency.

8.2. COAL BENEFICATION

The primary preparation and cleaning of coal prior to its use is called "coal benefication". Preparation of coal includes sizing, removal of rock, removal of minerals with ash and sulphur, drying and blending of different quality coals etc. Preparation of coal is done to achieve desired physical and chemical properties. For example, removal of ash and sulphur impurities increase the heating values. Similarly, large and irregular lumps of coal may cause poor combustion, inadequate furnace temperature, higher excess air resulting in higher stack gas and low thermal efficiency. It is apparent that coal benefiction reduces the cost of power generation, predominately in terms of coal transportation, coal handling, ash handling, coal milling plant, main boiler including air heater, draft fans electrostatic precipitators, boiler bunker and structure, ducting etc. It is estimated that about eight percent reduction in power station cost can be easily made by coal beneficiation.

The processes done in coal preparation are as follows :

1. Removal of dirt
2. Drying
3. Sizing
4. Removal of sulphur
5. Washing of coal.

Proper coal sizing in accordance to the type of firing system helps in evenly burning, reduced ash losses and better combustion efficiency. Coal is reduced in size by crushing and pulverizing. Specific gravity separation is the most widely used method of coal cleaning. Specific gravity of impurities is more than that of coal and therefore impurities will tend to sink while the coal floats on the surface of the medium used. Water is the most commonly used and the easiest medium to separate coal from impurities. Air is used where water is not adequate. A cyclone separator use liquids of specific gravity between coal and impurities. The fluid generally 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.

8.2.1. Benefits of coal benefication. The various benefits of coal benefication are as follows :

1. Reduced transportation. Cleaning eliminates waste which accounts for nearly 15 to 20% of the total mass. So significant saving can be achieved in coal hauling and handling.

2. Improved quality. Coal preparation eliminates non-combustibles and produce coal of uniform size. The cleaning of coal increases the ability of boiler, reduces slagging, fouling and corrosion. It also increases boiler life.

3. Reduced operation of pulverizer. Washing of coal removes pyrites, rock, trapped iron and other abrasive constituents. This reduces the wear of crushers and pulverizer.

4. Reduced ash content. Cleaner coal contains nearly 70% less ash. Lesser ash content means reduced ash handling and disposal cost. The load on the electrostatic precipitator and fabric filter is also reduced. The sensible heat loss in bottom ash is reduced because of the use of cleaner coal and this improves over all heat transfer.

5. Removal of sulphur. Much of the unbound sulphur *i.e.*, pyrites can be removed by simple washing. For further removal of sulphur, chemical cleaning is required.

Use of cleaned coal results in reduced operating cost of power plant although cleaning of coal is a costly affair. Preparation of coal offers better fuel handling, better plant efficiency and availability, environmental benefits etc. In many cases, the savings and benefits outshine the cost of cleaning.

8.3. SYNTHETIC FUELS

Synthetic fuels are gaseous and liquid fuels produced mainly from coal in an economical and environmentally acceptable manner. These fuels are also called synfuels. These fuels can be used for steam generation in power plants and also in domestic, industrial and transportation sector.

Synthetic fuels are produced by

(*i*) Coal gasification

(*ii*) Coal liquefaction

8.3.1. Coal gasification. Earlier coal gas was produced by destructive distillation of coal. This gas was used for cooking and illumination purpose. Coal when heated in absence of air is carbonized into coke. The coke thus produced when burned with less quantity of air (less than the stoichiometric quantity) yields the producer gas.

$$\underset{\text{Coke}}{2C} + \underset{\text{Air}}{(O_2 + 3.76\,N_2)} \rightarrow \underset{\text{Producer gas}}{2CO + 3.76\,N_2}$$

When the temperature is increased to high value and the flow of air is replaced by a flow steam, water gas is produced.

$$C + H_2O \rightarrow \underset{\text{Water gas}}{CO + H_2}$$

Modern gasification techniques are based on the reaction of producer gas and water gas. The production processes are continuous and are more efficient. Coal is first ground into powder and then preheated and dried to reduce caking. Fig. 8.1 shows the basic steps in the gasification process.

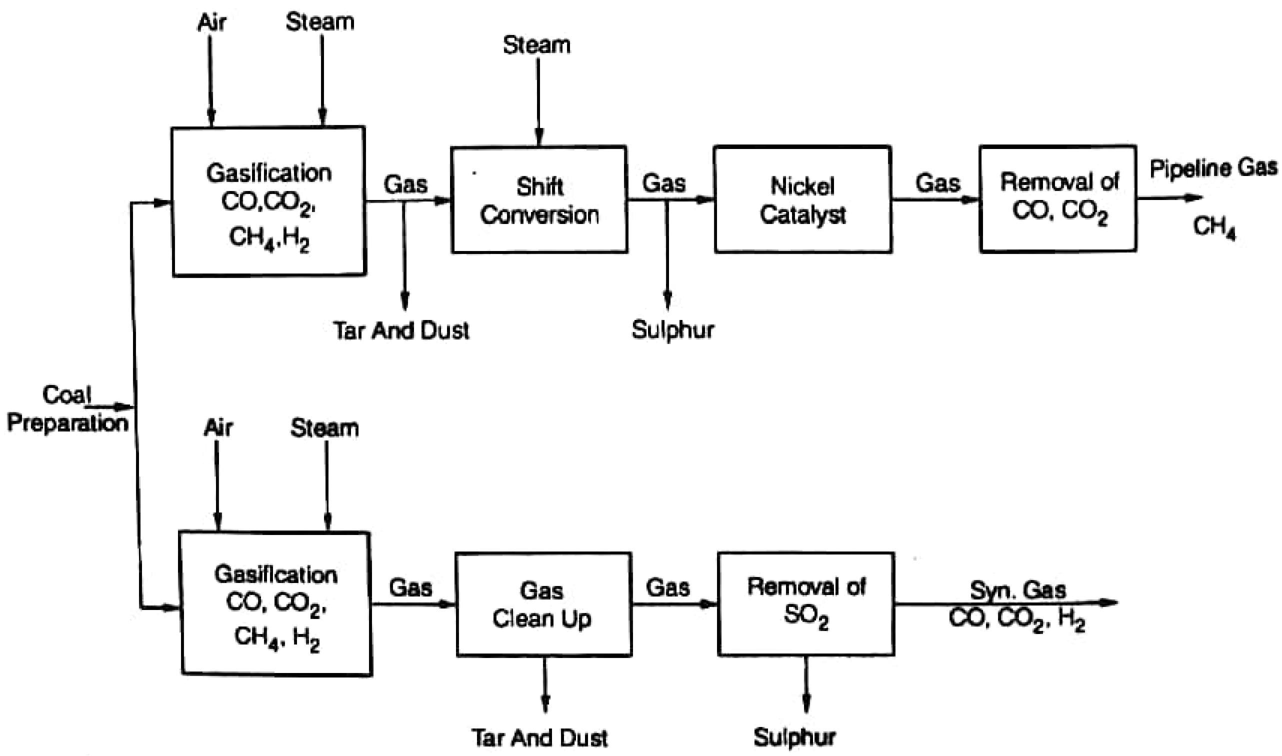

Fig. 8.1. Coal gasification process.

Gas mixtures of low, medium and high heating values are produced during coal gasification. The gas of low heating values which is a mixture of water gas and producer gas is the "synthetic gas". This low heating value gas can be used as fuel in combined cycle power plant. The gas with high heating value has properties nearly the same as that of natural gas and is called "pipeline gas".

There is another method of coal gasification called "hydrogasification" in which fluidized coal is directly gasified with hydrogen-rich steam. The overall efficiency of this method is higher than the earlier method. Some reserves of coal are inaccessible and can not be mined by conventional techniques. Such deposits of coal could be economically utilized by underground gasification. Coal is gasified in situ and the gas produced is conveyed to the surface and utilized to meet various needs. The advantages of underground coal gasification method are :

1. It can extract energy from inaccessible reserves of coal.
2. It reduces the requirement of mining personal and equipment.
3. Needs less coal handling and transportation.
4. The fuel gas thus produced is cheaper than other forms of energy.
5. Hydrogen sulphide, the predominant form of sulphur produced in this method, can be economically treated.

Coal gasification is of particular interest because of the better emission control. It is much easier to clean fuel gas and to have a very clean fuel rather than to clean the combustion gases from a conventional coal boiler because :

1. The volume flow rate of coal gas is less than 1% of the exhaust gases.
2. Removal of H_2S is much easier than that of SO_2.
3. Many other pollutants such as heavy metals, chlorides etc are also removed during the gasification process.
4. Elemental sulphur is obtained as by-product of the desulphurization process which can be further sold.
5. The waste disposal of slag produced by gasifier is easier.

8.3.2. Coal liquefaction. Coal liquefaction is the conversion of coal into a petroleum-like fuel that can be subsequently refined. Although burning of coal liquids releases CO_2, just like any other fossil fuel, but it produces more useful energy per tonne of coal. As a result, the CO_2 release per tonne of useful energy is also reduced. The ratio of hydrogen atoms to carbon atoms is only 0.8 to 1 in coal whereas in petroleum products this ratio is 1.75 to 1. So this conversion requires the addition of hydrogen to the coal. There are three processes of coal liquefaction. They are :

1. **Hydrogenation process**

2. Catalytic conversion, and
3. Hydropyrolysis.

In the hydrogenation process, coal and catalyst are suspended in slurry, which is reacted with hydrogen at high pressure and moderate temperature to form liquid hydrocarbons. In the catalyst conversion, a synthetic gas is produced from the coal. The hydrogen and carbon monoxide in the gas are then combined in the presence of a catalyst to form a liquid hydrocarbon fuel. Hydropyrolysis process involves heating of coal beyond 450°C. The fraction of coal volatilized greatly exceeds the volatile matter in the coal. The hydrogen entrained pulverized coal is flash pyrolyzed. Nearly half of the coal can be liquefied by this method. The Fischer-Tropsch process produces a mixture of CO and H_2 from coal and steam. This is followed by catalytic reactions at about 150°C and 150 bar, which yield a range of hydrocarbons from gaseous methane to higher liquid hydrocarbons. These are then separated with methane.

8.4. INTEGRATED GASIFICATION COMBINED CYCLE

Integrated Gasification Combined Cycle (IGCC) is rapidly emerging as one of the most promising technologies in power generation and utilizes low quality solid and liquid fuels. IGCC are extremely clean, fulfills the advanced stringent emission limits, and are much more efficient than the traditional coal fired systems. The emission from IGCC plant is very clean about 99% sulphur and 90% nitrogen pollutants can be removed.

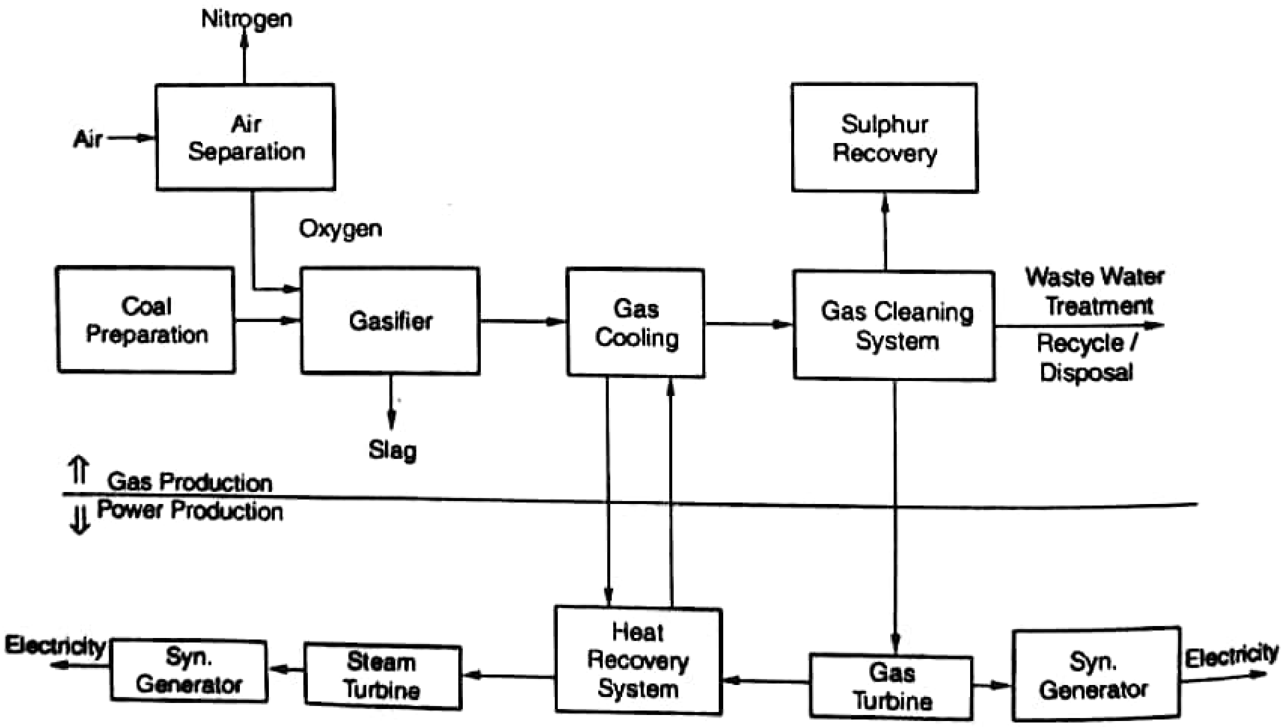

Fig. 8.2. Basic arrangement of IGCC power plant.

Fig. 8.2 shows the basic arrangements of an IGCC power plant. In the coal preparation block, coal is prepared according to the specification. The prepared fuel is converted into gas in an air/oxygen gasifier, operating at high pressure. Pure (95%) oxygen and gaseous nitrogen are produced in the air separation block. The oxygen is fed to the