Thermal Power Projects: Past, Present and Future

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ABSTRACT

The commercial electric power generation started from coal based thermal and hydro in the 1880s. Today, not only the coal fired but diesel and gas based power generation technologies are well proven. However, emission of polluting green house gases emitted due to the burning of fossil fuels has become a matter of serious concern. This challenge is well accepted by the researchers which haveresulted in the development of green power generation technologies. These technologiesburn the fossil fuels more efficiently with lower emissions. This paper will discuss conventional as well as green power generation from coal in addition to the carbon capture technologies.

Keywords: Subcritical boiler, supercritical boiler, IGCC, carbon capture

I INTRODUCTION

A coal based thermal power plant converts the chemicalenergy of the coal into electrical energy. In 1884 Sir Charles Parsons built the first coal fired boiler (with a thermal efficiency of just 1.6%). The efficiency was improved by introducing the first condensing turbine coupled to the AC generator. The efforts continued and by the early 1900s, the capacity reached in the range of 1 MW to 10 MW by providing an economizer, evaporator, and a superheater in the boiler. By the 1910s, the coal-fired power plant cycle was improved even more by introducing turbines with steam extractions for feed water heating and boilers with air preheaters which resulted in the increase in net boiler efficiency to about 15%.

In India, on 17 April 1899, the first thermal power plant of The Calcutta Electric Supply Corporation Limited was commissioned at Emambagh Lane. In 1902, the Calcutta Tramways Company switched to electric driven from horse-drawn carriages.

In 1947, the year of India's independence, total installedpower capacity was 1363 MW with 855 MW share of thermal power. The installed thermal power capacity as on December 2020 is given in Table 1.

Table 1
Installed thermal power capacity in India [1]

Fuel	Capacity, MW
Coal	199864.5
Lignite	6260.0
Gas	24956.5
Diesel	509.7
Total	231590.7

The installed thermal power capacity given in Table 1 was 61.7% of the total capacity of 3,75,323 MW from all the sources of energy including renewables.

The performance of the boiler depends on the combustion of coal which depends on 3Ts i.e. temperature, time and turbulence. Ideally there should be complete combustion. The combustion improves with the increase intemperature, travel time of the fuel particles and turbulence inside the boiler. Hence, the trend is to achieve complete combustion by operating at higher temperature. This has led to the development of supercritical boilers i.e. the boilers operating at a temperature and pressure above the critical point of water (221 bar and 374° C) as shown in Figure 1.

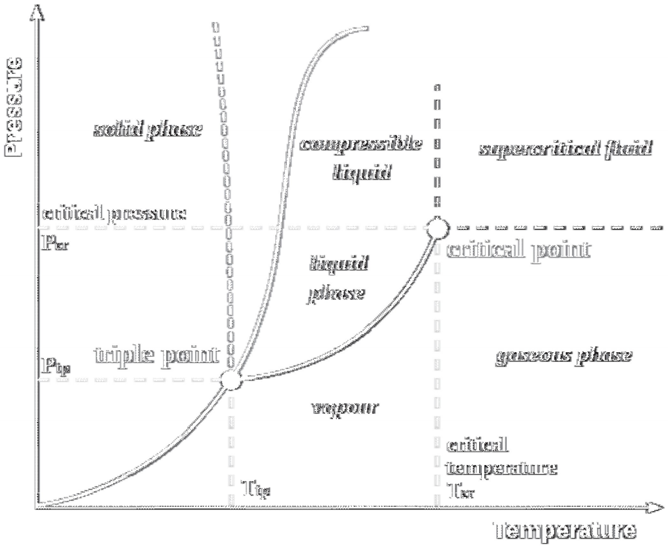
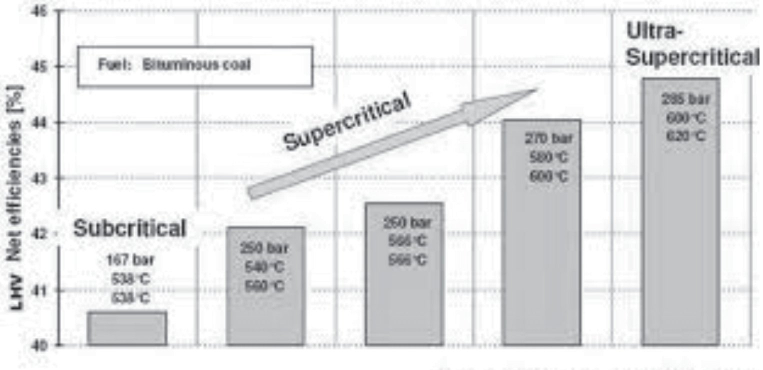


Fig. 1 Change of water phases with temperature and pressure [2]

Above critical point of water, the phase boundaries disappear. The classification of the boilers and increase in efficiency with pressure and temperature are shown in Figure 2.



Source: siteresources.worldbank.org

Fig. 2 Rise in efficiency thermal power plant with evolution of technologies [3]

(a) Largest unit capacity in India - In supercritical boilers, the emission of gases is reduced and the efficiency is increased. In supercritical boilers 660 MW and 800 MW units are installed in several power plants. The first highest capacity 800 MW coal fired thermal power generating unit based on supercritical technology was commissioned in Mundra Power Plant, Gujarat by Tata Power in 2012.

(b) Largest unit capacity in the world -The 6000 MW Dangjin Thermal Power Plant in South Korea has 10 × 500 MW + 2×1020 MW. The 1020 MW units are probably the largest unit capacity. The generation form this plant was 32,000 GWh in 2016.

(c) Generator capacity-In India, the nominal frequency of the power grid is 50 Hz. The generating units in thermal power plants mostly have 2 poles synchronous generators which operate in synchronism with the grid at a nominal speed of 3000 rpm. However, actual speed of rotation at any instant depends on the grid frequency. In some countries including USA, Brazil etc., the power grid frequency is 60 Hz and hence power plant generated operate at a speed of 3600 rpm.

The output of a synchronous generator P is given by:
$P = K \times D^2 \times L \times N$
where

K	Output coefficient (electric loading, magnetic loading, etc.)
D	Internal diameter of the stator core
L	Stator core length
N	Speed of rotation

If the rotating speed N is constant, an increase of generator capacity can be attained by increasing the output coefficient K or the generator size ($D^2 \times L$).

The capacity of generator can be increased up to 20% by improving the cooling of generator windings. However, while doing so, it will be necessary to take care of temperature and vibration level of each part to be within the permissible limits. The basis of design would be to increase the output coefficient by about 15% and restrict the sizeto about 3%. [4]

(d) **Cooling of generator winding -** During operation, the generators emit heat which has to be dissipated to enable the generators to operate at maximum efficiency. The higher temperatures of the windings reduce the life of insulation. The air is used as the cooling medium in smaller units, although, the technical advancements have resulted in the development of air-cooled generators up to 500 MVA. The large generators typically use hydrogen whereas very large capacity generators resort to water/hydrogen cooling of generator windings. [5]

In hydrogen cooled generator, the stator winding is indirectly cooled whereas the rotor winding is exposed and hence is directly cooled. Hydrogen has several advantages over air including high specific heat, very low viscosity, lower windage losses than air-cooled generators. The windage loss due to friction between the hydrogen and the rotor may account for 30-40% of the total generator losses.

Water-hydrogen is another variant of cooling in which stator winding is directly cooled by water flowing through the hollow conductors whereas the exposed surfaces of rotor winding are directly cooled by hydrogen.

Figure 3 shows the transition in generator capacity achieved mainly by cooling media.

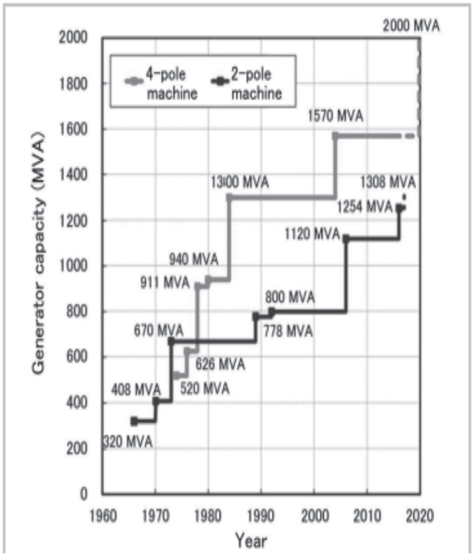


Fig.3 Transition of unit capacity of turbine-generator [4]

II CONVENTIONAL POWER GENERATION

The fossil fuels are available in solid (coal), liquid (furnace oil, light diesel oil, Low sulphur heavy stock) and gaseous (natural gas, propane and butane) forms. Figure 4 shows a process diagram of a sub-critical coal fired power plant having conventional sub-critical boiler which operate at a temperature and pressure below critical point as explained earlier. In sub-critical, there is a non-homogenous mixture of water and steam. Thus, two phases viz. liquid and gaseous phases co-exist.

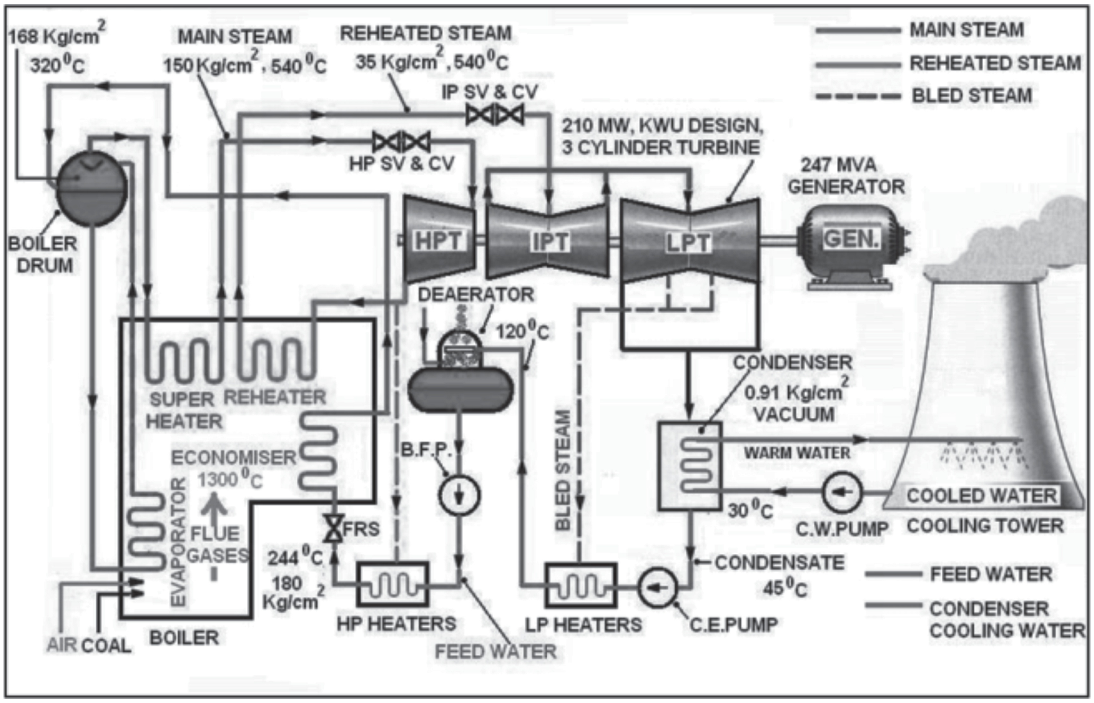


Fig.4 Process diagram of a sub-critical coal fired power plant [6]

(a) **Working of a power plant -** Coal management: In a thermal power plant, coal is transported from coal mines to the power plant by railwagons or in a merry-go-round system. Coal is unloaded from the wagons to a moving underground conveyor belt. The coal from the mines is of non-uniform size. Weighing of coal is done and recorded at sending and receiving ends. Coal samples are taken from each wagon as per agreed procedure.The samples are tested for calorific value and ash content whose values determine the billing. This is main dispute between coal supplier and power stations. Continuous followup of coal goods racks is required to ensure timely supply.

The coal from mines carries stones also. The stones are removed manually by deploying dedicated labourers. The stones if get crushed with the coal, it damages coal mill balls and also reduces efficiency of boiler. It also harms boiler. The percentage of stones in coal is a major dispute between mine owners and power stations.

Crusher: The coal is taken to the Crusher and crushed to a size of say, 20 mm. The crushed coal is stored as below:
Dead storage generally 40 days coal supply

Live storage 8 hours coal supply in the coal bunker in the boiler house

Coal pulverization: The coal from the bunker is powdered (pulverized)to 200 mesh size.

Coal combustion in boiler: The powdered coal is blown into the boiler by pressurized hot air to create turbulence in the combustion zone of boiler. The coal-air mixture is burnt in the modern boilers by tangential firing system i.e. the burner nozzles form tangent to a circle. The burning zone is called fire ball where the temperature isof the order of 1300° C.

Water to steam: The boiler consists of tubes hanging from the top. A closed cylindrical chamber is created by welding the adjacent tubes. Water pumped to the boiler tubes is converted into steam and supplied to the boiler drum.

Boiler drum: A boiler drum is provided for separating the steamfrom water before it is superheated for feeding into the H.P. turbine.

Superheating: The saturated steam from the boiler drum passes through the superheaterfor superheating.

HP steam turbine: The superheatedsteam from the superheater is supplied to the High Pressure Steam Turbine. The steam pressure is utilized to rotate the turbine.

Re heater: The steam from the outlet of HP turbine is wet. The wet steam is taken to the reheater installed inside of the boiler to dry and raise its temperature.

Intermediate Pressure (IP) turbine: After reheating, the steam is supplied to the IP turbine. In some designs, there is no IP turbine and the steam from reheater is supplied directly to the low pressure (LP) turbine.

Low pressure turbine: The steam from the LP turbine is sent to the condenser.

In a 500 MW turbine set, the sharing of power by HP, IP and LP turbines were found as below:[7]
HP = 27.3%IP = 35.1% LP = 37.6%

Condenser: The steam is condensed back to water. The condensed water is collected in a hot well.

Water for boiler tubes: The water used for making steam is generally drawn from a river and is demineralized by chemical treatment to prolong the life of boiler tubes.It is quite costly and hence same water is reused in a closed loop. The steam from LP turbine flows to the condenserfor cooling andthen fed to the boiler. The lost water is compensated from demineralized water plant.

Feed water to the boiler: The water from condenser is again circulated in the boiler in a closed loop by a boiler feed pump.

Generator: The shafts of turbine and generator are coupled. The mechanical energy imparted by the turbine to generator. The generator converts mechanical energy into electrical energy.

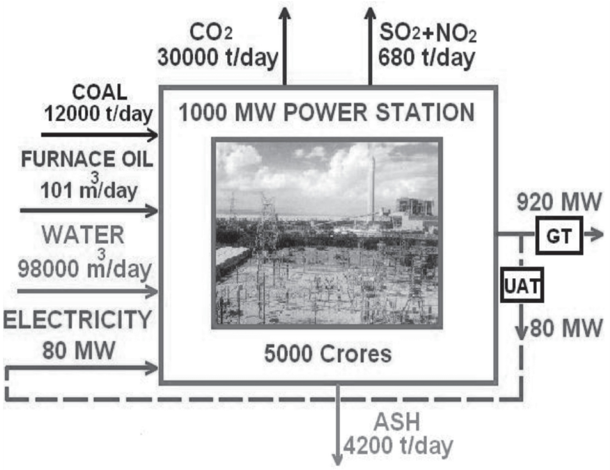


Fig.5 Inputs, outputs and byproducts of a 1000 MW coal power plant [6]

(b) Cooling water system - Due to environmental rules and regulations, majority of power plants adopt 'closed-cycle' cooling water system to conserve water. A typical recirculating cooling water system is shown in Figure 6. In this system, a separate stream of water is used to cool and condense the steam coming out of the L.P. turbine. In this process, the cooling water coming out of condenser gets heated-up. The hot water is then sprayed into a cooling tower. Some of the hot water droplets evaporate out of the cooling tower into the atmosphere.

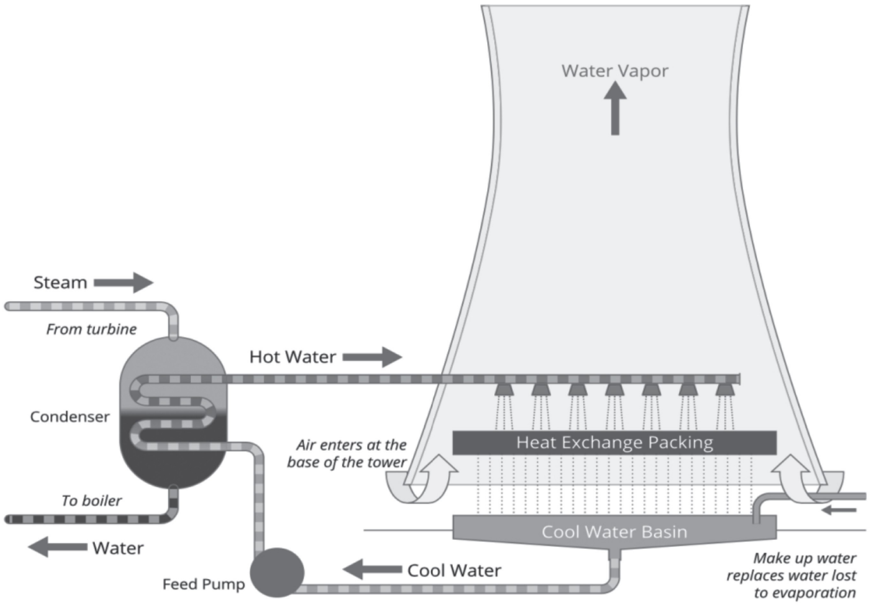


Fig.6 Typical cooling water system in a thermal power plant [8]

(c) Ash handling system - The ash handling system of a thermal power plant collects the ash and residues from select points, transport it to storage bins or silos, and prepare the ash for transport or disposal. The characteristicsof ashes vary from the boiler to the environmental equipment, the collection, transport and storage systems. Hence, separate systems are provided to suit the boiler and collection points. The bottom ash collection is done mostly in wet form whereas fly ash is invariably collected in dry form.

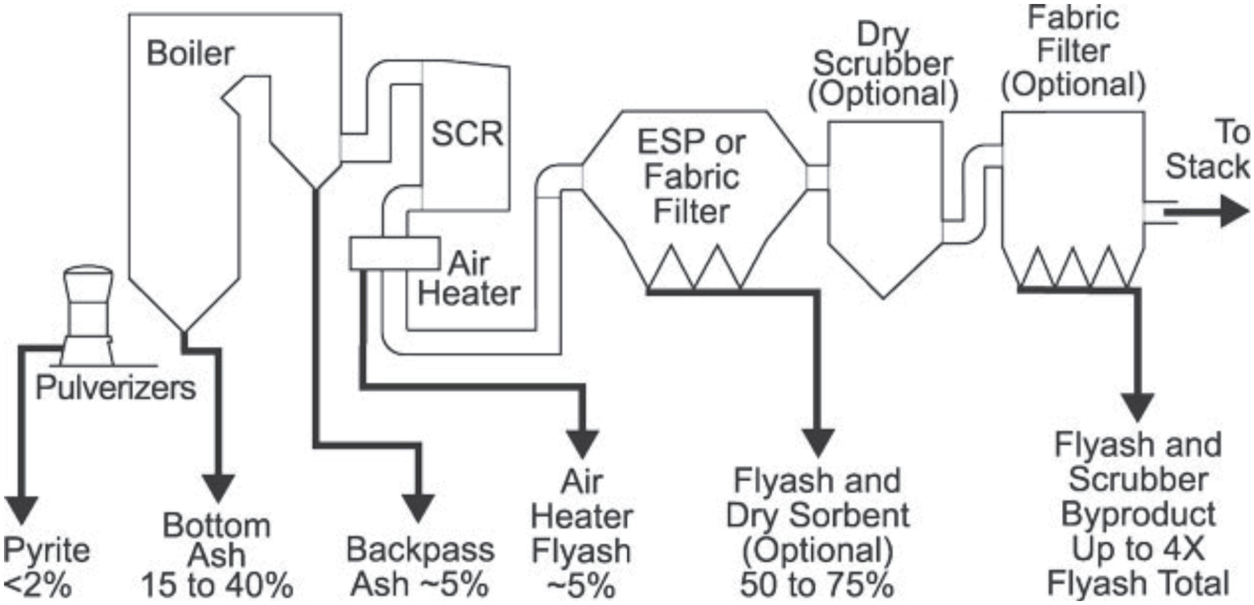


Fig. 7 Process flow diagram of ash handling system [9]

(d) **Bottom ash-**Bottom ash is generally conveyed in the form of wet slurry in which it flows and is delivered to either an ash pond or to a remote dewatering device. Alternatively, mechanical drag systems are used to convey bottom ash to the dewatering storage bin because they need less water and usually have a lower initial cost. Both systems are designed to handle ashat high temperatures of say 1300° C, requiring each system to have a quenching by water at the bottom ash hopper.

A recent development, the ash conveyor system handles the ash in dry condition. It means that this system operates without water for quenchingand delivers a dry, lower carbon content material to the discharge end of conveyor. The rejects from the pulverizer are transported generally via bottom ash conveyance system.

(e) **Fly ash -** The fly ash consists of low density fine particles. Most of the ash from a pulverized coal-fired boiler is carried through the boiler and air heater by the flue gases. The **particulate control** device, such as a fabric filter or ESP carry 50% to 70% of the total ash generated by the combustion of pulverized coal. These devices have rows of collection hoppers that are emptied regularly by the **fly ash transportation system**. The temperature of fly ash is much lower than the bottom ash and it is mostly transported pneumatically as dry ash only. The pneumatic transport systems are vacuum, pressure, combination of vacuum/pressure or dense phase type.

In view of the environmental concerns associated with the huge amount of ash, it has been made mandatory for thermal power plants to have tie-up with the cement industry, Further, it has been made mandatory for the cement industries to blend ash with the cement.

Fly ash can be used as prime material in Portland cement concrete pavement (PCC), road construction, concrete block, brick etc. which provides significant financial gains.

III ENERGY EFFICIENT TECHNOLOGIES

The supercritical thermal power plants andIntegrated coal gasification combined cycle operate at higher efficiencies with reduced emission of gases.

(a) **Supercritical boilers -** The supercritical boilers operate at a temperature and pressure above the critical point i.e. above 221 bars and 374° C (Refer Figure 1). Above critical point, there is no distinction between steam and water phases i.e. water and steam loose their individual identity and behave like a fluid as a single entity. Figure 8 shows a process diagram of a generating unit equipped with supercritical boiler along with its correlation with Rankine cycle.

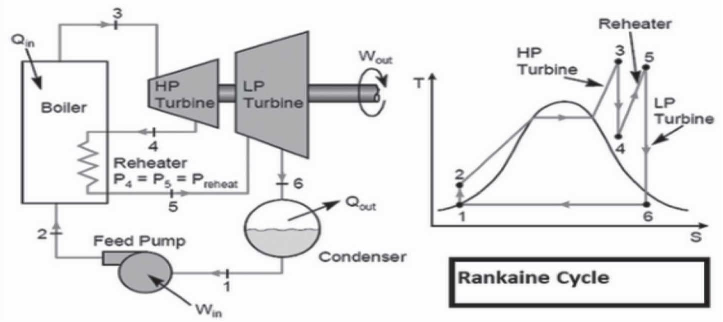


Fig.8 Process diagram of generating unit equipped with supercritical boiler [10]

The main differences between subcritical and supercritical technologies are summarized below:

(i) **Output:** Due to higher temperature difference between the entry of steam at turbine and exit of steam, more is the output. The fuel needed is less for the same output. Since the fuel is less, the emissions are also reduced.

(ii) **Part load operation:** Lower the pressure would be lower (because then efficiency is higher because steam throttling is avoided in the turbine) the operation becomes subcritical.

(iii) **Boiler drum:**Due to same liquid phase, no bubbles and no dry-out and hence, drum is not needed. This is why supercritical operation is also known as once through technology

(iv) **Efficiency:** Increase in the thermodynamic efficiency of the Rankine cycle with 170 bar and 540 / 540° C (SH / RH) the efficiency of 38 %. Supercritical boiler units operating at 250 bar and 600/615 ° C and can have efficiencies of about 42 %. Ultra supercritical boiler units at 300 bar and 615 / 630 °C will may achieve efficiency up to 44 %.

(v) **Water purity:** The water in the boiler has to be of extremely pure, otherwise f impurities may result in deposits on turbine blade.

(vi) **Materials:** Supercritical power plants use special high grade materials for the boiler tubes with the turbine blades of improved design and materials. In fact, the very increase in higher pressure and temperature designs is an metallurgical issue and depends on the development of newer and newer alloys and tube materials.

(b) **Integrated coal gasification combined cycle plant -** Integrated coal gasification combined cycle (IGCC) power plants are a next-generation thermal power system. They enhance power generation efficiency by coal gasification and the Gas Turbine Combined Cycle (GTCC) system. Large-type IGCC systems can improve power generation efficiency by about 15% and reduce CO_2 emissions compared to conventional coal-fired thermal power generation. A block diagram of IGCC is shown in Figure 8.

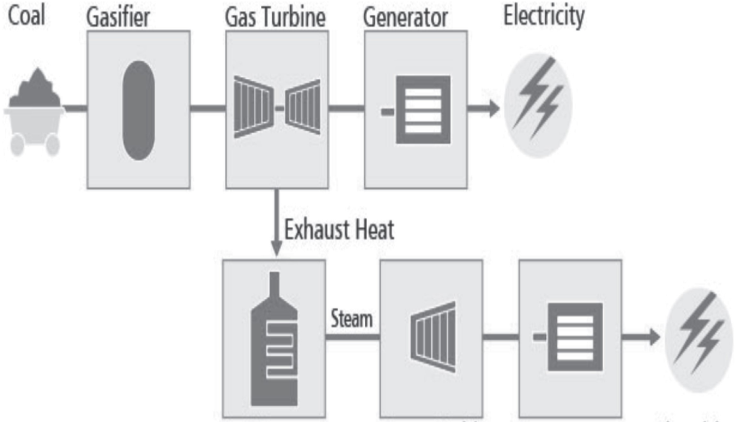


Fig. 8 Schematic of IGCC plant [11]

BHEL set-up a 6.2 MW IGCC plantin 1989 at a cost of Rs. 15 crore at its Tiruchirapalli unit. It was the first coal-based IGCC plant in Asia and the second in the whole world. IGCC is the ideal technology for India as it will help utilise the country's abundant quantities of low grade coal without much serious health and environmental implications. BHELhas demonstrated the capability to scale up the technology to 100 MW.

IV CARBON CAPTURE TECHNOLOGIES

Atmospheric carbon dioxide comes from two primary sources—natural and human activities. Natural sources of carbon dioxide include mostly the animals which exhale carbon dioxide. Human activities responsible for emission of carbon dioxide is the burning of fossil fuels in thermal power plants. Carbon dioxide is the most commonly produced greenhouse gas.

The three common technologies viz. pre-combustion, post-combustion, and oxy-fuel are for CO_2 capture.In post-combustion capture technology, CO_2 is separated from the flue gases before releasing into the atmosphere through chimney. The most common technology uses amine gas to remove CO_2 by aqueous solutions of amines. After removing the CO_2 from the amine solvent, it is dried and compressed to reduce its volume before storage.

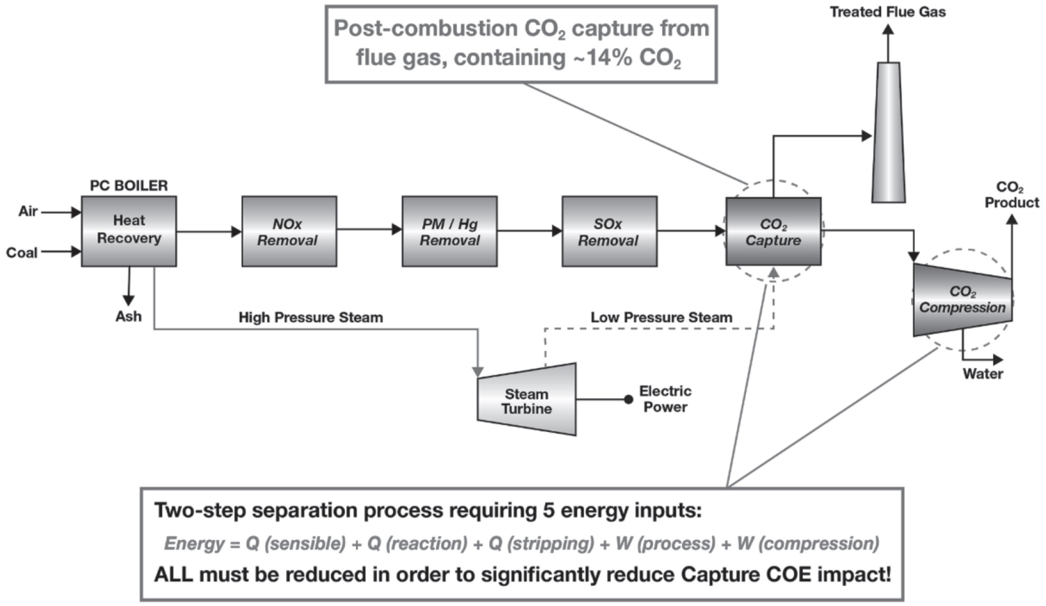


Fig. 9 Process diagram of post-combustion carbon capture and compression [12]

In a pre-combustion capture technology, fossil fuels are gasified to produce a syngas (synthesis gas) or fuel gas composed of carbon monoxide and hydrogen. Additional water (steam) is then added and the mixture is passed through a series of catalyst beds for the water–gas shift reaction to approach equilibrium, after which CO_2 can be separated to leave a hydrogen-rich fuel gas. The energy needed in pre-combustion capture may be about 50% of that required in post-combustion capture. However, the water requirement in pre-combustion process is more.

In the oxy-fuel capture, pure oxygen is used for combustion. It gives a flue gas mixture mainly of CO_2 and condensable water vapour, which can be separated and cleaned relatively easily during the compression process.

Post-combustion capture is useful for separating CO_2 from exhaust gases released by burning of fossil fuel. The exhaust gases, a mixture of CO_2, nitrogen and some oxygenated compounds (SO_2, NO_2 and O_2) are first treated to remove particulate matter and the oxides of nitrogen and sulphur. Generally, they are in contact with a liquid solvent, typically an aqueous amine solution. The amine selectively absorbs the CO_2, capturing more than 85% of the CO_2 and enabling nitrogen and oxygen to be released into the atmosphere. A CO_2-rich amine is regenerated by stripping the CO_2 out of the liquid with steam, allowing the lean amine to be recycled to the absorber while producing a concentrated CO_2. The CO_2 is compressed and cooled in liquid form.

V CONCLUSION

The climate change has emerged as one of the biggest challenges of the 21^{st} century. The main cause of which is the emission of green house gases from the power plant generation based on burning of fossil fuels. It has thrown a challenge on the well establishedcoal fired thermal power plant technologies. A new era has started to deal with such challenges by developing green power generation technologies. Supercritical boilers which operate at higher temperature and pressure at higher efficiencies and emit less gas. Similarly, IGCC, and carbon capture technologies have emerged and are briefly presented in this paper.

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