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FLUIDIZED BED COMBUSTION (FBC)IN COAL BASED THERMAL POWER PLANTS

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ABSTRACT

Energyhas become a sign to global prosperity and economic growth for a country. It plays a major role in development and economic growth of people. Industries and other sectors are more dependable on energy to run their machines. But there is a necessity to equalize the economic growth as well as environment protection by decreasing the use of unsustainable energy resource which play a crucial role in the emission of greenhouse gases and other pollutant product which are majorly responsible for the global warming and climate change.

In India, most of energy comes from coal thermal power plant as it has abundant amount of coal and it is cheaper for industries to produce electricity from it. However, it is also an important source of harmful gases such as CO2, NOx etc. We can adopt other source of renewable energy like hydro, solar, wind etc.to reduce the emission of greenhouse gases, but coal will still remain a major source of energy due easy availability and better energy predictability. Hence, clean coal technology is an appropriate way to accomplish both energy production and environment protection.

Key Words: Fluidized Bed Combustor, Power Plants, Coal Power, Bubbling Bed etc.

I. INTRODUCTION

The International Energy Agency (IEA) predicts that world energy demand will grow approximately 60% over the next 30 years [1], most of it in developing countries such as India which has substantial quantities of coal reserves. India ranks third in the world both in terms of coal production (407 million tons) and coal consumption (around 425 million tonnes). In India, almost 70 percent of the growth in coal consumption is expected to be in the electric power sector and most of the remainder in the industrial sector [1]. There is lack interest in producing renewable energy particularly in solar and wind due to its high cost and non- availability of appropriate technology.

There are many minor and major sustainable technologies available by which we can manage the problem of global warming gas emission. Some of the technologies include washing of coal to reduce emission of ash and sulphur dioxide, use of electrostatic precipitators and some fabric filters which can remove 99% of the fly ash from the flue gases. We can reduce nitrogen oxide emission by up to 40% by the use of low NOx burner and another technologieswhich reduce it by 70%.

II. COAL TECHNOLOGY

Fluidised Bed Combustion (FBC) uses fine coal particles suspended in air. Solid coal behaves as a fluid at high pressures and allows rapid transfer of heatwhich increases the efficiency of the burning process because the movement of coal carries a steady supply of hot particles to the surface. The heat is take out and consume in a conventional power generation cycle. It operates at inferior temperatures than the Pulverized Fuel (PF) process, and hence, reduces NOx release in the atmosphere.

2.1 Types of Fluidised Bed Combustion Boilers

There are three basic types of fluidised bed combustion boilers:

2.1.1 Atmospheric classic Fluidised Bed Combustion System (AFBC)

2.1.2 Atmospheric circulating (fast) Fluidised Bed Combustion system (CFBC)

2.1.3 Pressurised Fluidised Bed Combustion System (PFBC).

2.1.1 AFBC / Bubbling Bed

In AFBC, coal is meshed to a size of 1 – 10 mm depends upon the recycled quality of coal, type of fuel feed and fed into the combustion chamber. In this atmospheric air use as fluidization air and combustion air which delivered at a pressure which preheated by the discharge flue gases and pass through the bed. The velocity of fluidising air is in the range of 1.2 to 3.7 m /sec. The velocity of air which is blown through the bed decides the quantity of fuel that can be reached. Almost all AFBC/ bubbling bed boilers use evaporator tubes in the bed of sand, limestone and fuel for removing the heat from the bed to maintain the bed temperature. The depth of bed is generally 0.9 m to 1.5 m deep and the pressure fall averages around 1 inch of water per inch of bed depth. Around 2 to 4 kg of solids of material leaving bubbling bed is reused per ton of fuel burned. The main advantage of atmospheric fluidised bed combustion is working of within the relatively narrow temperature range. With coal, there is risk of clinker development in the bed if the temperature exceeds 950°C and loss of combustion efficiency if the temperature falls below 800°C. For efficient sulphur retention, the temperature should be in the range of 800°C to 850°C.

- **General Arrangements of AFBC Boiler**

AFBC boilers comprise of following systems:

- Fuel feeding system
- Air Distributor
- Bed & In-bed heat transfer surface
- Ash handling system.

2.1.2 Circulating Fluidized Bed Combustion (CFBC)

In Circulating Fluidized Bed Combustion the size of coal particle is reduced to 0.07–0.3 mm and the velocity is kept at 5–10 m/sec, so that the particles are took away in the steam gas. Due to compactness of gasifier, the release of heat at higher rate per unit area can be achieved. Circulation gives efficient heat exchange to the furnace walls and longer residence time for carbon and limestone utilisation. Heat transfer outside the combustion zone – convection section, water walls, and at the exit of the riser the circulating bed is developed to move more solids out of the furnace area. For large units, the taller furnace characteristics of CFBC boiler offers better space utilisation, greater fuel particle and sorbent residence time for efficient combustion and SO2

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capture, and easier application of staged combustion techniques for NOx control than AFBC generators. CFBC boilers are said to achieve better calcium to sulphur utilisation – 1.5 to 1 vs. 3.2 to 1 for the AFBC boilers, although the furnace temperatures are almost the same. CFBC boilers are generally claimed to be more economical than AFBC boilers for industrial application requiring more than 75 - 100 T/hr of steam.

The CFBC can make use of low grade coal having high ash, or even lignite, and has been adopted in India.

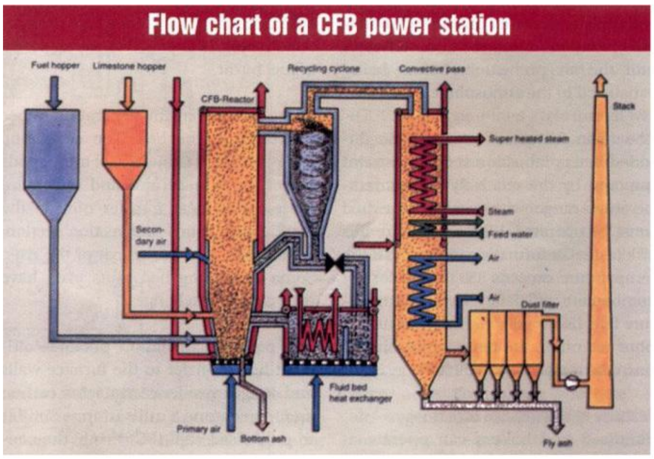

Fig.1.Flow Chart [1]

Major performance features of the circulating bed system are as follows:

- It has a high processing capacity because of the high gas velocity through the system.
- The temperature of about 870 °C is reasonably constant throughout the process because of the high turbulence and circulation of solids. The low combustion temperature also results in minimal NOx formation.
- Sulphur present in the fuel is retained in the circulating solids in the form of calcium sulphate and removed in solid form. The use of limestone or dolomite sorbents allows a higher sulphur retention rate, and limestone requirements have been demonstrated to be substantially less than with bubbling bed combustor.
- The combustion air is supplied at 1.5 to 2 psig rather than 3–5 psig as required by bubbling bed combustors.
- It has high combustion efficiency.
- It has a better turndown ratio than bubbling bed systems.
- Erosion of the heat transfer surface in the combustion chamber is reduced, since the surface is parallel to the flow. In a bubbling bed system, the surface generally is perpendicular to the flow.

2.1.3 Pressurized Fluidized Bed Combustion (PFBC)

Pressurized Fluidized Bed Combustion meant for large-scale coal burning applications uses crushed coal with a limestone suspension as a sorbent (to absorb the sulphur content in the coal) .The interior boiler air pressure is increased to 16 to 20 bars at a temperature about 850°C, the limestone sorbent take over the sulphur in the coal and make a dry paste, which gets gather at the base of the boiler and can be separate. The off-gas from the fluidised bed combustor drives the gas turbine. The steam turbine is driven by steam raised in tubes immersed in the fluidised bed. The condensate from the steam turbine is pre-heated using waste heat from gas turbine exhaust and is then taken as feed water for steam generation.

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The PFBC system can be used for cogeneration or combined cycle power generation. By combining the gas and steam turbines in this way, electricity is generated more efficiently than in conventional system. The overall conversion efficiency is higher by 5% to 8%.

At elevated pressure, the potential reduction in boiler size is considerable due to increased amount of combustion in pressurized mode and high heat flux through in-bed tubes. A comparison of size of a typical 250 MW PFBC boiler versus conventional pulverized fuel-fired boiler. This technique is particularly suitable for high sulphur coals.

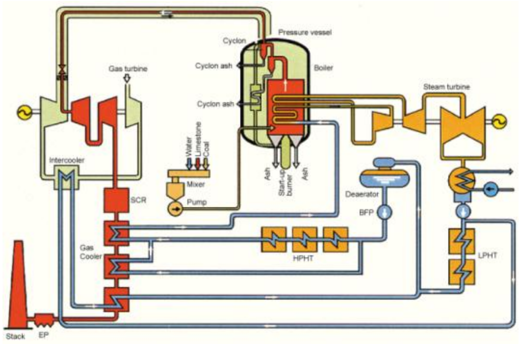

Fig.2. Flow Diagram [2]

Advantages of Fluidised Bed Combustion Boilers

- **High Efficiency**
- FBC boilers can burn fuel with a combustion efficiency of over 95% irrespective of ash content. FBC boilers can operate with overall efficiency of 84% (plus or minus 2%).
- **Reduction in Boiler Size**
- High heat transfer rate over a small heat transfer area immersed in the bed result in overall size reduction of the boiler
- **Fuel Flexibility**
- FBC boilers can be operated efficiently with a variety of fuels. Even fuels like flotation slimes, washer rejects, agro waste can be burnt efficiently. These can be fed either independently or in combination with coal into the same furnace.
- **Ability to Burn Low Grade Fuel**
- FBC boilers would give the rated output even with inferior quality fuel. The boilers can fire coals with ashcontent as high as 62% and having calorific value as low as 2,500 kraal/kg.
- Even carbon content of only 1% by weight can sustain the fluidised bed combustion.
- **Ability to Burn Fines**
- Coal containing fines below 6 mm can be burnt efficiently in FBC boiler, which is very difficult to achieve in conventional firing system.
- **Pollution Control**

- SO_2 formation can be greatly minimised by addition of limestone or dolomite for high sulphur coals. 3% limestone is required for every 1% sulphur in the coal feed. Low combustion temperature eliminates NOx formation.
- **Low Corrosion and Erosion**
- The corrosion and erosion effects are less due to lower combustion temperature, softness of ash and low particle velocity (of the order of 1 m/sec).
- **Easier Ash Removal – No Clinker Formation**
- Since the temperature of the furnace is in the range of 750 – 900 °C in FBC boilers, even coal of low ash fusion temperature can be burnt without clinker formation. Ash removal is easier as the ash flows like liquid from the combustion chamber. Hence less manpower is required for ash handling.
- **Less Excess Air – Higher CO2 in Flue Gas**
- The CO_2 in the flue gases will be of the order of 14 – 15% at full load. Hence, the FBC - boiler can operate at low excess air - only 20 - 25%.
- **Simple Operation, Quick Start-Up**
- High turbulence of the bed facilitates quick start up and shut down. Full automation of start-up and operation using reliable equipment is possible.
- **Fast Response to Load Fluctuations**
- Inherent high thermal storage characteristics can easily absorb fluctuation in fuel feed rates.
- Response to changing load is comparable to that of oil fired boilers.
- **No Slagging in the Furnace–No Soot Blowing**
- In FBC boilers, volatilisation of alkali components in ash does not take place and the ash is non sticky. This means that there is no slagging or soot blowing.
- **Provisions of Automatic Coal and Ash Handling System**
- Automatic systems for coal and ash handling can be incorporated, making the plant easy to operate comparable to oil or gas fired installation.
- **Provision of Automatic Ignition System**
- Control systems using micro-processors and automatic ignition equipment give excellent control with minimum manual supervision.
- **High Reliability**

The absence of moving parts in the combustion zone results in a high degree of reliability and low maintenance costs.

- **Reduced Maintenance**

Routine overhauls are infrequent and high efficiency is maintained for long periods.

- **Quick Responses to Changing Demand**

A fluidised bed combustor can respond to changing heat demands more easily than stoker fired systems. This makes it very suitable for applications such as thermal fluid heaters, which require rapid responses.

- **High Efficiency of Power Generation**

By operating the fluidised bed at elevated pressure, it can be used to generate hot pressurized gases to power a gas turbine. This can be combined with a conventional steam turbine to improve the efficiency of electricity generation and give a potential fuel savings of at least 4%.

III. LITERATURE REVIEW

Toni Pikkarainenet. al. [3] get the worst sulphur capture in oxygen combustion was measured in direct sulphur capture conditions, where high CO2 partial pressure in low temperature prevents the calcinations of CaCO3. Therefore the design of the furnace heat transfer and temperature levels has significant effect on in-furnace sulphur capture in CFB combustor, especially in oxygen combustion conditions. At comparable conditions in oxygen combustion the feed gas oxygen content or oxygen staging (to primary and secondary feed gases) had no remarkable effect on SO2 capture or emissions of nitrogen oxides.

G. Hofbaueraet. al. [4] Experiments for oxy-fuel combustion of bituminous coal in a circulating fluidized bed were carried out. A mixture of oxygen and recirculated flue gases was used as the fluidizing agent. No constraints regarding the stability of the facility and the combustion process could be found.

PichetNinduangdeeet. al. [5] conducted an experimental investigation in which he successfully test the burning oil palm shells at fuel feed rates of 45 kg/h and 30 kg/h, while ranging excess air from 20% to 80% for fixed combustor load and concluded that operating conditions (fuel feed rate and excess air) have effects on the behavior of major gaseous pollutants (CO, CxHy and NO) inside the combustor, as well as on its emissions and combustion efficiency; at the rated combustion load, high (about 99%) combustion efficiency can be achieved when burning oil palm shells at excess air of 60% ensuring acceptable levels of CO and NO emissions from the combustor; no bed agglomeration occur in the combustor when using dolomite as the bed material, as has been shown by 30-h combustion testing; compared to original dolomite, the reused bed material shows a decrease of mean diameter size in the course of the time; fine powder formed during dolomite calcination adhere to the large particles of the bed material.

Jan Skvarilet. al. [6] conducted an experimental measurement (i.e. combustion flue gas temperature and concentration of O2, CO2, CO, and NOX) at different points in the full-scale biomass-fired bubbling fluidized bed boiler. Results of the constructed profiles from the furnace indicate the intermediate stage of thermo chemical reactions and show that the thermo chemical reactions peak at the center of the furnace and combustion intensity decrease towards the wall. Furthermore, increased levels of CO concentration close to the wall have been found in the vicinity of port SHE.

Pankaj Kalitaet. al. [7] conducted experiments at four different percentages blending of biomass such as 2.5 %, 7.5 %, 15 % and 20 % in sand with two different weight composition ratios and at a superficial velocity of 5 m/s. Operating pressure is varied from 1 to 5 bar in a step of 2 bar. He have conclude that the suspension density increases with the increases in operating pressures and the axial heat transfer coefficient increases with an increase in operating pressure at all the % blending with the radial heat transfer coefficient decreases from the wall (about 480 W/m2-K) to the core (93 W/m2-K) of the riser in all the operating conditions.

Hanfei Zhang et. al. [8] studied on solid waste mixtures combustion in a circulating fluidized bed: emission properties of NOx, Dioxin, and Heavy Metals in which fuels were combusted in a circulating fluidized bed

(CFB) reactor and resulted the furnace temperature can be reached at approximately 850 ºC when combusting all mixed fuels, which could effectively improve the combustion performances of the waste fuels, benefiting the thermal processes of sludge and domestic garbage and thus realizing the purpose of waste-to-fuel and the dioxin emissions were much lower than the emission standards, and NOx emissions could be reduced significantly by adjusting the ratio of waste fuels.

PriatnaSuheriet. al. [9] studied co-firing of oil palm empty fruit bunch and kernel shell in a fluidized-bed combustor and optimization of operating variables in a fluidized-bed combustor using alumina sand as bed material to prevent bed agglomeration and found that the effects of excess air on co-combustion of palm kernel shell (primary fuel) and empty fruit bunch (secondary fuel) had been investigated on a conical fluidized-bed combustor at different energy fractions of the secondary fuel. With increasing the heat contribution by secondary fuel and lowering excess air, the CO and CxHy emissions increased, while the NO emission showed the opposite trends. The cocombustion at the optimal energy fraction of empty fruit bunch (about 0.15) and optimal excess air (some 50%) ensures high, about 99%, combustion efficiency, the minimum "external" (emission) costs of the combustor, and resulted in the 35% NO emission reduction compared to firing pure palm kernel shell.

Simone Lombardi et. al. [10] worked on effect of coupling parameters on the performance of fluidized bed combustor - stirling engine for a microCHP system by placing the hot side heat exchanger of a stirling engine (SE) immersed in a fluidized bed combustor (FBC) and concluded that the effect of the geometric parameters of the SE heater on the performance (power and efficiency) of a microCHP system, starting from the optimal values the diameter of the heater tubes was an important design parameter in view of the performance and appropriate choice of the length of the heater tubes allows to obtain a higher flexibility on the other design parameters, which could be sized to obey design constraints, given by the specific application, without high losses of efficiency and power.

Eman Tora et. al. [11] analysed on CFD Ansys - Fluent simulation of prevention of dioxins formation via controlling homogeneous mass and heat transfer within circulated fluidized bed combustor by CFD Ansys – Fluent simulation as to help the plant operator attain uniform heat and mass transfer via enabling the plant operator to adjust the operating conditions to fit well the used fuel and concluded that the fuel distribution between the ports should be adjusted to make the temperature and velocity profiles in the corners more equal, especially when the fuel had higher moisture content. When the fuel was very wet and also content of PVC was significant it should be compensated by mixing in dryer fuel.

AhmmadShukrieet. al. [12] studied on heat transfer of alumina sand in fluidized bed combustor with novel circular edge segments air distributor and concluded the value of maximum heat transfer coefficient decreases with increase in particle diameter due to increase in gas conduction path and decreases in particle surface area per unit volume for heat exchange with the heater surface.

Jan Hrdlickaet. al. [13] worked on oxyfuel combustion in a bubbling fluidized bed combustor by the help of experiments with various semi-oxyfuel and full oxyfuel modes in fluidized bed combustor and points out results that CO2 concentration that agrees within less than 10 % relative difference. Air-only mode to full oxyfuel mode the adiabatic flame temperature drops by about 250°C.

Miccioet. al. [14] worked on the integration between fluidized bed and Stirling engine for micro-generation by an experimental study which was carried out, proving the ability of the bed to exchange heat at high rate with an immersed coil that realistically emulates the heat exchanger of a small Stirling engine and concluded that the heat transfer coefficient attains values up to 280 W m^{-2} K^{-1}. No dirtying of the immersed surface occurred during a combustion test of biomass.

IV. OPPORTUNITIES IN INDIA

Nearly 63 percent of the India's total energy requirements are met from coal. The available coal reserves in India are sufficient to meet our needs for at least another 100 years. India now ranks 3rd amongst the coal producing countries in the world. Taking the above facts into consideration, it is obvious that coal is one of the potential energy substitutes in India and consumption of coal in our country is about 339,000,000 [14].Total installed power generation capacity in June 2014 by coal is148,478.39MW which is 59.51% of totalenergy [15].Government is planning to electrify rural area which generates more demand of electricity and they need more power plants to meet the demand. Private sector taking interest in opening new power plant which is a sign of achieving goal rapidly but it comes with a worry of environment problem. To solve the problem of environment concern as well as power plant efficiency we have to adopt new coal technology which is appropriate for our power plant and other thermal industry. The electrical energy demand for 2016–17 is expected to be at least 1,392 Tera Watt Hours, with a peak electric demand of 218 GW [16].

A large part of Indian coal reserve is similar to Gondwana coal. It is of low calorific value and high ash content. The carbon content is low in India's coal, and toxic trace element concentrations are negligible. The natural fuel value of Indian coal is poor. On average, the Indian power plants using India's coal supply consume about 0.7 kg of coal to generate a kWh [17], whereas United States thermal power plants consume about 0.45 kg of coal per kWh. This is because of the difference in the quality of the coal, as measured by the Gross Calorific Value (GCV). On average, Indian coal has a GCV of about 4500 kcal/kg[17], whereas the quality elsewhere in the world is much better. The high ash content in India's coal affects the thermal power plant's potential emissions. Therefore, India's Ministry of Environment & Forests has mandated the use of beneficiated coals whose ash content has been reduced to 34% (or lower)[17] in power plants in urban, ecologically sensitive and other critically polluted areas, and ecologically sensitive areas.

India has nearly 50 GWs of installed capacity represented by units 11-30 years old which have reduced reliability, output and efficiency relative to design conditions. Some of these plants should retire, others be rehabilitated and other be replaced with new state-of-the-art units. The Government has identified the units which belong in each of these three categories and is implementing its strategy.Considering the requirement of high efficiency in power generation and environmental considerations, installation of power plants with Circulating Fluidized Bed Combustion (CFBC) technology with lignite as main fuel would be a techno economically viable option for available coal in present which have high ash content and low calorific value., fluidised bed combustion (FBC) technologies have emerged as a commercially viable alternative, and becoming a technology of choice in many situations. These technologies have been applied to all solid fuels including biofuels, peat, lignite, coal, anthracite culm, coal washery wastes, petroleum coke, oil shale, municipal waste based fuels and an array of hazardous wastes. CFB technology is already used in India burning lignite and other low qualityfuels. If SO2 emission regulations are introduced in the future, it is likely that thistechnology will be used more.Atmospheric Fluidised Bed Combustion uses many industry of India like Bhushan Ltd., Nava Bharat Ferro Alloys Ltd., Usha Martin, Jamshedpur, Shree Cement,,AmbujaCements,JKCement,,Madras Cement,,Nestle,JSW Energy Ltd.,GraceIndustries,Waste Coast Paper Mills Ltd.,DCW, Khanna Papers Mills Ltd., Chemplast[18].High-ash fuels, such as lignite, brown coals and Indian coals, are particularly suitable for CFB technology. CFB is considered commercially available up to 300 MW, as demonstrated by hundreds of such boilers operating throughout the world (e.g., Australia, China, Czech Republic, Finland, France, Germany, India, Japan, Poland, Republic of Korea, Sweden, Thailand and the United States). CFB technology has been used in India. Low rank coal such as India's is a most suitable fuel for CFB boilers. India has started using the technology successfully. Reportedly, there are more than 36 CFB units in operation representing 1,200 MW of installed capacity; most of them are relatively small (2-40 MW) with the largest unit being 136 MW. Also, two 250 MW lignite-fired CFB units are under construction by BHEL.

V. CONCLUSION

In the present study, we have analysed the importance of coal based power plants in countries like India where coal is cheap and easily available. Although coal based power plants are often liked to environmental issues but the use of fluid bed technology provides both process benefits as well as commercial benefits.Process benefits includes small amount of unburned components in residues and flue gas,low NOx production, wide range for calorific value and water content, wide range for superheating power due to low combustion temperature and high recirculation gas flow. Commercial benefits includes reduced space requirement, reduced cost for boiler plus combustion chamber, low fouling and corrosion risks, high availability and high electrical efficiency. Hence, it can be concluded that coal based thermal power plants can be effectively used with degrading the environment to some extent.

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