Central Power Research Institute
Vol. 14(2)/184-190, December 2018
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v14i2.144732
Power Research

Emerging Post Combustion Technologies for Coal Fired Thermal Power Plants

S. Mohan Krishna* and N. Krishnamurthy

Department of Electrical and Electronics Engineering, College of Engineering and Design, Alliance University, Anekal, Bengaluru – 562106, Karnataka, India; smk87.genx@gmail.com

Abstract

There have been technological advancements for reducing carbon emissions from coal based thermal power plants. The primary objective of the same is to ensure that the energy produced and consumed is sustainable and which does not affect the environment. There are primarily four main components of clean coal technology employed for power generation. As the primary fuel used for power generation is coal, the post coal combustion phase assumes significance in the way the carbon emissions are being captured and sequestered. This paper discusses the progress in the post combustion technologies used in coal fired thermal power plants. The paper also lays greater emphasis on the current status of the same in India.

Keywords: Carbon Emissions, Carbon Capture and Storage, Carbon Utilisation, Green Technology, Post combustion, Sustainability

1. Introduction

Part of the sun's radiation reaching the earth is reflected back into space and the other part is absorbed by earth's surface. The absorbed part heats up the earth which in turn radiates energy in the Infrared region. A steady state is reached where the earth is absorbing and radiating energy at the same rate resulting in a fairly constant average temperature. However, the Infrared radiation emitted by earth is absorbed by the gases in the troposphere and become trapped. The radiation is then re-emitted back towards the earth, which is known as the Greenhouse Effect. This leads to an increase in temperature on the surface of the earth to an average of about 14.6^0 C which is keeping the earth hospitable and helps to sustain life. If there were no greenhouse effect at all, then the surface temperature of earth would be about -300^0 C and at this temperature, life on earth would not be possible.

Gases produced by human activities can increase the natural greenhouse effect of the atmosphere. This is known as the enhanced greenhouse effect. The enhanced greenhouse effect is mainly due to emission of Greenhouse Gases (GHG), notable among them is Carbon dioxide (CO_2). Since the industrial revolution, utilisation of steam power and later additional usage of petroleum has resulted in the steady increase of greenhouse gases. There is an accelerated increase in emission of CO_2 since the Second world war and now, the concentration of CO_2 has surpassed 400 ppm and is increasing by about 0.5 % per year. This has resulted in global warming and the temperature of earth is increasing to an alarming level causing climate changes adversely, decrease in production of crops, and even possible submersion of the major cities in the near future. Increasing global warming has to be seriously and urgently addressed and steps have to be taken to reduce emission of greenhouse gases and thus, reverse the trend of global warming[1–3].

One of the major source of emission of greenhouse gases is power plants fuelled by fossil fuels such as coal, oil and natural gas. Among them, coal is abundantly available and is cheaper. So, thermal power plants in use all over the world are mostly fuelled by coal. Evidently, large amount of CO_2 is emitted by such plants. Technologies are being developed to reduce, restrict and to use CO_2 for some useful purpose and thus, greatly restrict the emission of CO_2. Thereby, reversal of global warming is achieved.

This paper reviews the technological advancements made in the post coal combustion stage which result in lesser emission of CO_2. It also presents the technological

*Author for correspondence

headway achieved and the current status of the same in India[4–8].

2. Features of Coal based Thermal Power Plant

Earlier, as coal was available in plenty and at a low cost, the need to restrict emission of carbon was not felt. Little attention was paid to efficient combustion and overall increase of efficient thermal plants so that amount of carbon burnt per kWh of power generated was minimum. There is improvement in combustion of coal, like burning pulverized coal in fluidized bed and also increasing the temperature of steam in super critical thermal plants leading to greater efficiency. Thus, the technology has been updated to increase efficiency from 15 % to 30 %. Thus, as the amount of carbon for producing unit kWh is reduced and to that extent CO_2 emission is also reduced. There is saturation to this approach and major reduction has to be achieved in preventing the CO_2 produced from emission to atmosphere. This is post combustion management of CO_2 by new and emerging technologies. The emerging technologies are in the field of CCS (Carbon Capture and Sequestration), transport of CO_2 to places of storage, finding possible use for CO_2 from flue gases. The 750 MW Lunen coal-fired thermal power plant commissioned in December 2013 in Germany is shown in Figure 1.

Figure 1. Lunen hard coal-fired power plant, Germany.

3. Post Combustion Handling of CO_2

Apart from CO_2, other greenhouse gases include water vapour, methane, nitrous oxide, hydro fluorocarbons, Perfluoro-carbons and Sulfur hexafluoride. It has been estimated that the global GHG emissions on account of human activities disproportionately increased by about 70 % between 1970 and 2004, to which CO_2 emissions contributed a whopping 80 %. Therefore, several post combustion management processes occupied considerable research space. They are illustrated in Figure 2.

3.1 Carbon Scrubbing and Capture

The sector wise CO_2 emissions of important nations (large emissions) are shown in Table 1. This reinforces the need for post combustion CO_2 capture and handling of the same. There exist three different types of technologies for capturing CO_2 as shown in Figure 3. This paper lays emphasis on the post combustion capture process. In order to prevent the CO_2 from escaping to the atmosphere, post combustion carbon capture works by isolating CO_2 from the flue gases after combustion. Once CO_2 has been removed or scrubbed from flue gas, it is then released to the atmosphere.

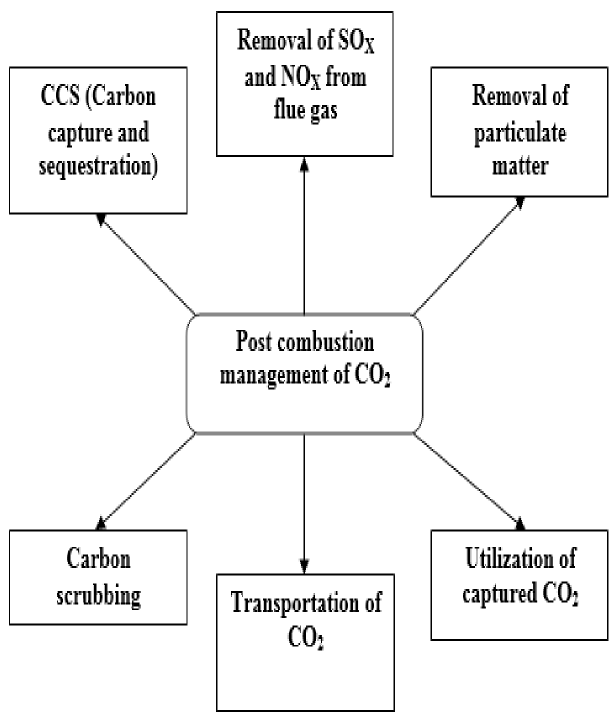

Figure 2. Post combustion management processes of CO_2.

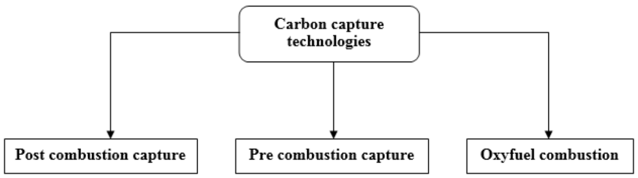

Figure 3. Carbon capture technologies in use.

Several methods have evolved to scrub CO_2 from flue gas. Using a liquid solvent to bind with CO_2 and separate it from the other gas components is the most popular method. Two solvents commonly used for this purpose are aqueous ammonia and monoethanolamine (MEA). After the fossil fuel is burned in the air, the resulting gases (flue gases) are collected and chilled. The solvent is then added which absorbs CO_2, forming a new compound in a reversible chemical reaction. This new compound separates out from the other gases by

entering a more solid state that gets pumped to a new chamber and reheated. The heat causes the CO_2 to come out of the solution so that it can be diverted for storage. The solvent is sent back to the beginning of the cycle to be reused and the cleaned flue gas is released to the atmosphere. One of the disadvantages of solvent process is that excess heat may decompose MEA releasing toxic substances to the atmosphere. Other methods for scrubbing CO_2 include:

- Polymer membrane gas separators, where the membrane prevents CO_2 from passing while other gases are allowed to pass.
- Photosynthesis ex. Algae based carbon sink.
- Cooling the flue gases to a temperature that forces CO_2 to condense out of the solution for separation.

3.2 Carbon Dioxide Sequestration

Various forms have been conceived for permanent storage of CO_2 [9–11]. They are shown in Figure 4. These forms include gaseous storage in various deep geological formations (including saline formations and exhausted gas fields) and solid storage by reaction of CO_2 with metal oxides to produce stable carbonates.

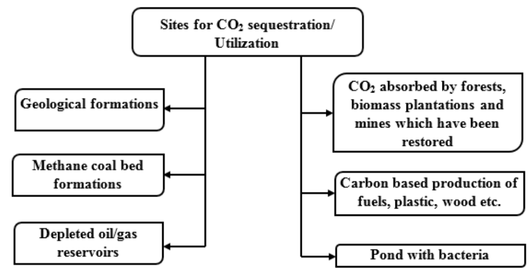

Figure 4. Sites for co_2 sequestration from a coal-fired thermal power plant.

Table 1. Sector specific carbon dioxide emissions (% of total fuel combustion)

	USA	Europe	Russia	China	India
Electricity/Heat production					
1990	43.9	36.8	55.9	32.2	43.4
2010	47.9	38	56.6	53	57.6
Manufacturing					
1990	14.4	21	13.2	40.9	29
2010	10.9	16.2	18.6	32.3	24.7
Residential/commercial					
1990	11.1	18.5	13.1	16.5	9.9
2010	10.1	17.8	8.6	6.1	5.5
Transport					
1990	29.2	21.4	13.6	5.3	14.3
2010	30.2	26	15.3	7	9.9
Other sectors					
1990	1.3	2.4	4.2	5.1	3.3
2010	0.9	1.9	0.9	1.6	2.3

3.2.1 Geological Storage

Also known as geo-sequestration, this method involves injecting CO_2, generally in supercritical form, directly into undergroundgeological formations, oil fields, gas fields, saline formations, unmineable coal seams have been suggested as storage sites. CO_2 is sometimes injected into declining oil fields to increase oil recovery. Approximately 30 to 50 million metric tonnes of CO_2 are injected annually in the US into declining oil fields. This option is attractive because the geology of hydrocarbon reservoirs is well understood and storage costs may be partly recovered by the sale of additional oil that is recovered. Disadvantages of old oil fields are their geographic distribution and their limited capacity, as well as the fact that subsequent burning of additional oil so recovered will offset much or all of the reduction in CO_2 emissions.

Unmineable coal seams can be used to store CO_2 because the CO_2 molecules attach to the surface of the coal. The technical feasibility, however, depends on the permeability of the coal bed. Saline formations contain highly mineralized brines and have so far no benefit to humans. Saline aquifers have been used for storage of chemical wastes in some cases. The main advantage of saline acquifers is their large potential storage volume and their common occurrence. The geology of saline acquifers is less known compared to oil fields and coal seams. The side effect or leakage has not been studied. There is no recovery of any saleable product to offset the cost of sequestration. Current research shows, however, that trapping mechanism such as structural trapping, residual trapping, solubility trapping and mineral trapping could immobilize the CO_2 underground and reduce the risk of leakage. For well-selected, designed and managed geological storage sites, it is estimated that CO_2 could be trapped for millions of years and the sites are likely to retain over 99 % of the injected CO_2 over 1000 years.

3.2.2 Ocean Storage

In the past, it was suggested that CO_2 could be stored in the oceans, but such practices have been made illegal under specific regulations and ocean storage is no longer considered feasible.

3.2.3 Mineral Storage

In this process, CO_2 is exothermically reacted with available metal oxides, which in turn produces stable carbonates. This process occurs naturally over many years and is responsible for a great amount limestone on the surface of the earth. It is suggested that mineral olivine is a proper material for this purpose. The reaction rate can be made much faster by reacting at higher temperature and/or pressure. This method requires additional energy. In 2009, it was reported that scientists had mapped 6000 sq miles (16000 km^2) of rock formations in the US, that could be used to store 500 years' worth of US CO_2 emissions.

3.2.4 Energy Requirements

The energy requirements of sequestration processes may be significant. It is quoted that sequestration consumed 25 % of the plant's rated 600 MW output capacity. After adding CO_2 capture and compression, the capacity of the 600 MW coal-fired power plant is effectively reduced to 457 MW. A major concern with CCS is whether leakage of stored CO_2 will compromise as a climate change mitigation option. Intergovernmental Panel on Climate Change (IPCC) estimates that risks are comparable to those associated with current hydro carbon activity. However, critics point out that lack of experience in this process is to be considered while estimating the risks. Leakage through the injection pipe is a greater risk.

Although the injection pipe is usually protected with non-return valves to prevent release on a power outage, there is still a risk that pipe itself could tear and leak due to pressure.

3.3 Flue Gas Desulfurization (FGD) for Removal of SO_X

It is a technology for the purpose of removal of sulfur dioxide (SO_2) from exhaust flue gases which are used for combustion in fossil fuel based power plants. Flue gas desulfurization consists of two stages: Fly ash removal stage and SO_2 removal stage. A FGD absorber is shown in Figure 5.

There are different types of scrubbers for removal of SO_2. In the wet scrubber, the flue gas is made to pass through a fly ash removal device, which can either be an electrostatic precipitator or a baghouse and then into the SO_2 absorber. In the dry scrubber, the SO_2 reacts with lime and then the flue gas is made to pass through a particulate control device.

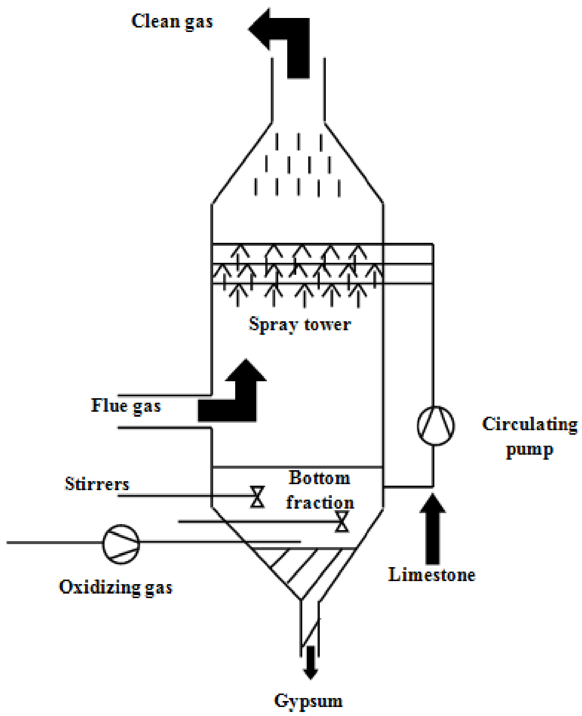

Figure 5. FGD absorber.

3.4 Selective Catalytic Reduction (SCR) for Removal of NO_X

The technology used for conversion of nitrogen oxides (NO_X) with ammonia (NH_3) as a catalyst into diatomic Nitrogen (N_2) and water (H_2O). Reductants like anhydrous ammonia, aqueous ammonia or urea, are added to the flue gas stream coming from boilers used in power generation. It is placed in between the economizer and air heater. There exists an ammonia injection grid to inject ammonia into the catalyst chamber. It is shown in Figure 6.

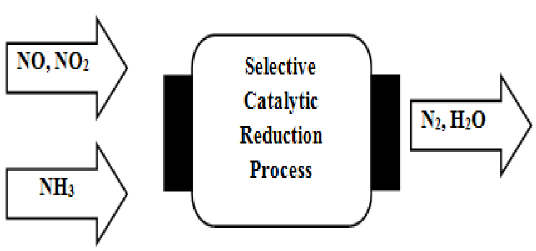

Figure 6. SCR for removal of NO_X.

By keeping, the temperature of combustion low, formation of NO_X can be avoided. Also, by oxyfuel combustion, i.e, burning coal in an atmosphere of oxygen than air, prevents formation of NO_X and the flue gas contains predominantly CO_2 and therefore CO_2 scrubbing will not be necessary.

3.5 Removal of Particulate Matter

In ash handling process, ash is removed, but still, the flue gases will contain particulate matter. This needs to be weeded out as it affects the operation of the power plant by forming unwanted deposits. The particulate matter in the flue gases are blown away by wind and can deposit even several hundred km's as it happened over the island of Kyushu of Japan, by the thermal power plant in China. The technology to remove particulate matter is by

3.5.1 Electrostatic Precipitator for Finer Particles

It is a filtration equipment employed for the removal of dust and smoke from the gas by using the effect of an induced electrostatic charge which in turn acts as an impediment to the flow of gases in the unit. Energy is applied only to the particulate matter. They are extensively used in thermal power plants for removing fly ash from the electricity utility boiler emissions. The setup is shown in Figure 7.

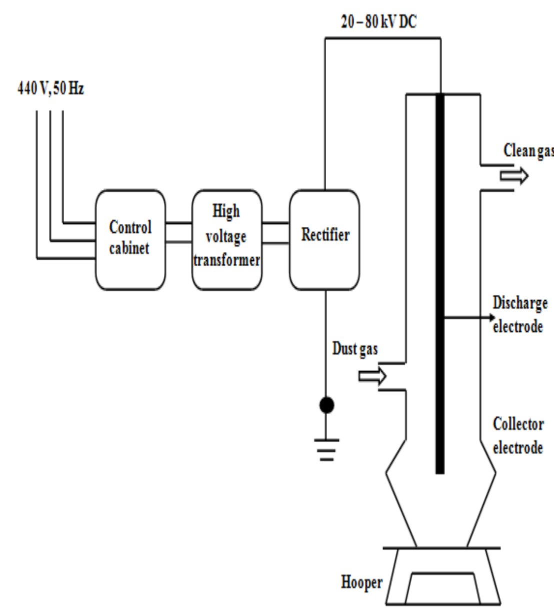

Figure 7. Electrostatic precipitator used for the removal of particulate matter.

3.5.2 Baghouse Filter for Larger Particles

It is a fabric filter used for the purpose of dust collection or removal of particulate matter from the air or any gas released due to combustion for power generation. They are also used for emission control of pollutants and find place in many industries. They have a very high particulate collection efficiency. A typical baghouse filter used in industrial process is shown in Figure 8.

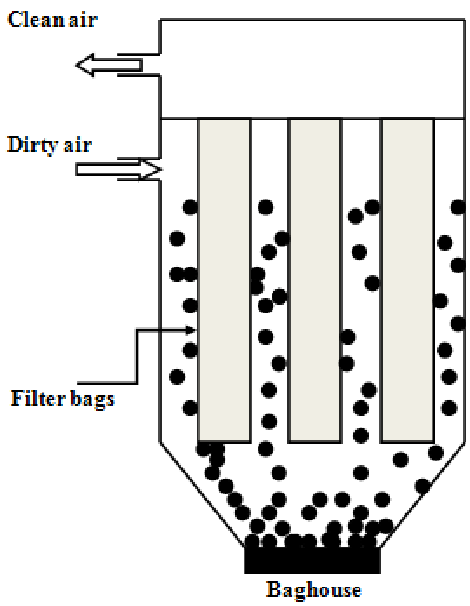

Figure 8. Baghouse fabric filter for the removal of larger particles.

3.6 Current Status of Post CO_2 Combustion Technologies – India

Based on an agreement of cooperation in Science and Technology between the Governments of India and Norway, the Department of Science and Technology (DST) and the Research Council of Norway (RCN) initiated a programme which requires joint funding joint research projects in CCS and climate research. The state owned Oil and Natural Gas Corporation (ONGC) also is setting up an Enhanced Oil Recovery (EOR) project in Gujarat with the captured CO_2 from the gas plant at Hazira which would be supplied to the oil field at Ankleswar. National Aluminium Company (NALCO) is the first public sector undertaking to have initiated a pilot project on Carbon sequestration for its captive power plant at Angul in Odisha. For this purpose, an area of 0.18 acres has been put aside to set up a technology by tieing up with M/s Indo-Can Technology Solutions (ICTS), which will provide technical consultancy, for project completion within 18 months. There are plans to grow algae in shallow ponds and the CO_2 emitted from the thermal power plant will be captured and sent into the pond. The algae can then be utilised for producing bio-fuel, poultry and cattle feed etc. Bharat Heavy Electricals Limited (BHEL) setup a 6.2 MW plant using Integrated Gasification Combined Cycle (IGCC) technology at Tiruchy which has higher efficiency, ease of capture of CO_2 and reduces the impact of fossil fuel combustion on environment. The technology employs a high pressure gasifier which is used to convert coal and other carbon based fuels into pressurized gas (synthesis gas - syngas). Impurities from the syngas before the power generation cycle can be eliminated in turn resulting in lower emissions of SO_X, particulates, mercury, and CO_2. The plant setup by BHEL is shown in Figure 9.

Figure 9. BHEL 6.2 mw IGCC plant at Trichy.

Research and Development on the same[12–16] is encouraged by the DST and BHEL. The DST is having an exclusive thrust area and funding under the clean coal research initiative to encourage cutting edge research on the same. BHEL has also set up a Process evaluation and demonstration unit at Hyderabad which has a coal throughput of 18 tonnes/day and a Pressurized Fluidized Bed Gasification (PFBC) pilot plant. It is setup for the purpose of assessment of performance of gasifier and subsystems shown in Figure 10.

Figure 10. BHEL 6.2 mw IGCC plant at Trichy.

4. Conclusions

The primary components of clean coal technology were discussed with special emphasis on the post coal combustion and the technological advancements being made. As the world still transits from the fossil fuel format to the renewable energy format, it is imperative to ensure that the existing coal fired thermal power plants are retrofitted with latest technology which ensure reduced greenhouse gas emissions. As the sector specific CO_2 emissions are very high in the power generation sector, it becomes all the more important to discuss and implement technological solutions to reduce the impact of the same. Although, in India, the status of clean coal technology is still at nascent stages, efforts have been taken to incorporate the same at pilot level and greater thrust is being provided by the Government by means of research funding and testing.

5. References

1. Available from: http://coal.nic.in/content/coal-reserves.
2. Available from: https://en.wikipedia.org/wiki/Electricity_sector_in_India.
3. Goel M. Implementing clean coal technology in India, India Infrastructure Report; 2010.
4. Singh BP. Need for coal beneficiation and use of washery rejects, Workshop on Coal Beneficiation Technology; 2007.
5. Kinjavdekar C. Green growth and clean coal technologies in India. The Energy and Resources Institute; 2015.
6. N Krishnamurthy and S Mohan Krishna, Recent Developments in Study of Carbon Footprint, its Measurement and Mitigation, Proceedings of International Conference on Energy, Environment And Eco-Friendly Buildings (ICEEEB), pp. 11, 2013.
7. Available from: https://pubs.usgs.gov/fs/2008/3097/pdf/CarbonFS.pdf
8. Krishnamurthy N, Krishna SM. Progress in the technology of coal fired thermal power plants for sustainable development. Proceedings of the National Conference on Waste to Energy, Carbon capture and Storage (NCWECCS); 2017. p. 419–26.
9. Available from: https://hub.globalccsinstitute.com/publications/india-ccs-scoping-study-final-report/4-current-ccs-activity-india.
10. Available from: https://www.c2es.org/content/carbon-capture/.
11. Kapila RV, Haszeldine RS. Opportunities in India for carbon capture and storage as a form of climate change mitigation. Energy Procedia. 2009; 4527–34. https://doi.org/10.1016/j.egypro.2009.02.271
12. Viebahn P, Vallentin D, Holler S. Prospects of Carbon Capture and Storage (CCS) in India's power sector - An integrated assessment. Applied Energy. 2014; p. 62–75, 2014. https://doi.org/10.1016/j.apenergy.2013.11.054
13. Akash AR, Rao AB, Chandel MK. Prospects of implementing CO2 Capture and Sequestration (CCS) in the proposed supercritical coal power plants in India. Energy Procedia. 2016; p. 604–12. https://doi.org/10.1016/j.egypro.2016.11.229
14. Viebahn P, Höller S, Vallentin D, Liptow H, Villar A. Future CCS implementation in India: A systemic and long-term analysis. Energy Procedia. 2011; p. 2708–15. https://doi.org/10.1016/j.egypro.2011.02.172
15. Singh U, Rao AB, Chandel MK. Economic implications of CO2 capture from the existing as well as proposed coal-fired power plants in india under various policy scenarios. Energy Procedia. 2017; p. 7638–50. https://doi.org/10.1016/j.egypro.2017.03.1896
16. Akash AR, Rao AB, Chandel MK. Relevance of carbon capture and sequestration in India's energy mix to achieve the reduction in emission intensity by 2030 as per INDCs. Energy Procedia. 2017; p. 7492–503. https://doi.org/10.1016/j.egypro.2017.03.1882