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Studies on Particulate Matter Emission in CFB Boiler- A Review

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Abstract

The particulate matter (PM) emissions involve solids or liquid particles suspended in a gas, most found in the earth's atmosphere. One of the major sources of PM emissions is the Circulating Fluidized Bed (CFB) and Pulverized Fuel fired (PF) boilers, IC engines, etc. The PM generated from CFB boilers usually consists of harmful substrates like Cu, Rb, Pb, Hg, As, and Se, which largely contribute to PM 2.5 emissions. PM emissions are the most common form of air pollutants that cause a wide variety of health problems, including lung cancers and cardiovascular diseases, so it is very important to regulate the PM emissions to a safe level, and with the advent of stricter norms like BS-VI, it has become a necessity to invent new methods of reducing and controlling PM emissions. In this article, we will focus on the new technologies and some currently available to keep the PM emissions in check.

Keywords: *Particulate Matter, Circulating Fluidized Bed, Pulverized Fuel, Emission, Filters.*

1. INTRODUCTION

With the advent of more stringent norms, it has become very essential to control the particulate matter emitted from CFB boilers, which are the most common in operation worldwide. Boilers from power plants are the major contributor to the generation and dissipation of PM 2.5 in the atmosphere. The most common fuels for industrial boilers include Coal, oil, and natural gas, all of which contain hydrocarbons. Fossil fuel burning produces a variety of harmful air pollutants, including primary particulate matter, gaseous pollutants, water-soluble ions, and different trace metals. Various trace metals released, such as Pb, As, Se, Cu, and Rb, can have substantial carcinogenic and mutagenic impacts on human and animal health.

Particulate matter emissions emanating from biomass combustion in CFB boilers can generally be divided into mainly two categories PM2.5 and PM10. PM2.5 means that the particle size or diameter of PM is less than 2.5 µm, and PM10 has a particle size of fewer than 10 µm. The primary air pollutant of concern is PM2.5 as PM10 can largely be removed using advanced techniques like Electrostatic Precipitator (ESP), Cyclone separator, Gravitational Separator, Bag Filters, and other experimental technologies like Particle Agglomeration. PM2.5 can further be categorized into two types, viz, Filterable Particulate Matter (FPM) and Condensable Particulate Matter (CPM). FPM gets released automatically in the form of solid or liquid state from the chimney outlet, while CPM exists in the vapor phase inside the chimney, but it can condense or react after cooling in the air to form a solid or liquid PM immediately after emission from the vent. Studies have found that CPM is the main contributor to PM2.5 emissions.

In another study by Ngo et al. [1]Polyaromatic hydrocarbons (PAH) with 5-6 aromatic rings emitted from industrial boilers tend to attach to particulate matter in the atmosphere and form Benzo[a]pyrene (BAP's), Benz[a]anthracene (BAA's) which are found to be carcinogenic, were the main constituents in the PM2.5 emissions from CFB boilers, where the CPM percentage was 10-30 times higher than FPM and was the leading cause behind ECR (Excess Inhalation Cancer Risk) in the atmosphere.

Numerous experimental techniques have been invented to reduce the PM 2.5 and PM10 emissions, which are briefly discussed in this paper; as the world is yet to completely transition from fossil fuel-based energy sources, it becomes imperative to implement these techniques in CFB boilers.

2. EXPERIMENTAL STUDIES ON PM EMISSIONS IN CFB BOILERS

Tong et al. [2] calculated the emissions of CO, CO_2, NO_x, SO_2, PM2.5, and PM10 from around 105,000 Boilers across various places in China and deduced that due to the major contribution of coal among all fossil fuels to combustion, Coal-fired boilers contributed the most to air pollution (77.6–94.0%) with second place earned by Biomass-fired Boilers.

Yang et al. [3] observed the PM emissions from five different fuel-based boilers and came to the conclusion boilers using natural gas as fuel exhibited lesser PM2.5 emissions than all those CFB boilers which used solid or liquid fuel for combustion owing to the reason that natural gas burns cleaner than coal, biomass, wood, diesel or any other type of solid or liquid type fuel and leaves almost negligible ash content when compared with the latter. He also deduced that due to the higher temperature of combustion in CFB boilers when compared with PF boilers, the FPM content is much lesser when compared with the CPM content simply because the low temperature is favorable for FPM emission. The trace metal emissions in FPM consisted of more than 10% of total metals for the CFB boilers (Fe, Zn, Na, Cu, and K) and three metal elements (Ca, Na, and K) accounted for more than 60% of CPM emissions.

In another study, Xu et al. [4] performed an experiment on the biomass as fuel which, is cheaper and more easily available than fossil fuels but the main challenge in the biomass-based boilers is that the volatile mineral matter concentration of biomass fuels is high e.g. (Cl, K, etc.) which results in large quantities of ash particles being released. So, a study was performed on two different types of combustion, both using the same fuel i.e., biomass viz CFB and Grate type (Fixed Bed type), and found that the mass fractions of PM10 and PM1 in the fly ash content of CFB boilers were less than 10% when compared to fixed bed type boilers (40-80%), suggesting that there were coarser PM in the total fly ash content in the former when compared to latter, which can then easily be collected using ESP resulting in lesser FPM emissions.

Reinik et al. [5] analyzed the ash samples from oil shale fired CFB boilers and found that the fly ash from the ash hopper of ESP in CFB boilers were coarser in size compared to that PF boilers because there is a lower temperature in the furnace of the former due to which the metals have less tendency to vaporize and condense onto the fly ash matter surface and remain in solid phase resulting in lesser toxic metal emissions than the latter.

Zhou et al. [6] performed an investigation on the Cd emission from PF and CFB boilers equipped with De-NOx, De-SO2, and De-dust devices and found that most of the Cd input came from feed coal (81-90%), while the Cd output in fly ash content was significantly less in CFB boilers (67.6%) when compared with PF boilers (78.9-95.8%), indicating that CFBs have lower Cd release ratio than PFs.

Li et al. [7] experimentally investigated the Hg Emission factor (MEF) of two different CFB boilers equipped with ESP and De-SO2 devices and concluded that Hg inputs primarily came from feed coal (98.3-99.9%) and escaped mostly in the form of fly ash (97.4-99.5%).Cui et al. [8] further found that CFB boilers with combinations of ESP & WFGD (Wet Flue gas desulphurization) or WFGD plus Fabric Filters (FF) seem to reduce the Hg emissions to a great extent in the atmosphere.

Huang et al [9] investigated the Arsenic and Selenium emissions from CFB and PF boilers and concluded that As/Se mainly constituted the PM1 in PF boilers as compared to the major contribution to PM2.5-PM10 emissions in CFB boilers, making the latter emissions easier to reduce using Particle agglomeration techniques. Further, it was found that on adding limestone (Calcium Oxide) to CFBs FPM bound As and Se formation was suppressed since limestone addition causes the As/Se to be adsorbed by Ca increasing the size and making it easier to remove.

For achieving minimal NOx emissions from CFBs without the use of De-NOx equipment, Li et al. [10] developed a method of retrofitting the oxidizing/reducing environment in the furnace by raising the solid circulation rate and lowering the bed content along with the mean size of bed material, all while maintaining adequate air supply and bed temperature.

Yue et al. [11] found that weak gas mixing and improving bed quality in CFB are essential to creating an ultra-low NOx emission behavior.Duan et al. [12] analyzed a CFB boiler using a mixture of coal and coal sludge for combustion, fitted with Fly Ash Recirculation by Bottom-Feeding (FARBF) technology. It was found that the emissions of NO and CO drop as the recirculation rate rises, but PM emissions increase. Pal et al. [13] performed a study on the optimization of the shape of ESPs available and found that in comparison to the flat plate, the charge density for W-type collecting surface is more uniform and Cup-shaped electrodes produce more ions or electric fields than regular circular-shaped electrodes. Using both these designs together greatly increases the collection efficiency of ESP.

Zhou et al. [14] proposed an optimal energy from waste technology that uses Shoe manufacturing waste (SMW) as fuel in a CFB boiler and analyzed the emissions to conclude that superfine particles with sizes lesser than 0.1 μm mainly consist of chlorides of alkalies. Calcium makes up most of the super micron particles. In addition, heavy metals like Cr and Pb primarily exist in the superfine form.

Finally, Zhang et al. [15] performed a numerical analysis on GAMBIT and FLUENT to look into the impact of using ionic wind and magnetic field in conjunction with a wire plate ESP to catch FPM and found that both of these modifications give promising results and subsequently improve the collection efficiency for PM2.5, and with decrease in particle sizes, the results of these modifications can be seen more clearly. The collection effectiveness of PM2.5 decreases nonlinearly as gas velocity rises, whereas a sharp rise is seen in the involvement from ionic wind or magnetic field in the efficiency of collection.

3. CONCLUSION

Based on our study, we can draw several conclusions from this literature review, which are illustrated below as follows:

- Natural gas based CFBs produce less emission than all other solid/liquid fuel CFBs
- Biomass as fuel can be used in CFB boilers producing lesser emissions than PF boilers.
- CFB process produces coarser fly ash than PF.
- Toxic trace metal emissions like As and Se can be reduced to a great extent by limestone addition and particle agglomeration techniques.
- By improving the bed quality and employing weak gas mixing, it is possible to reach extremely low NOx emissions in CFB boilers.
- By optimizing the design of ESPs and employing other technologies like WFGD, and FF along with ESP, the collection efficiency can be greatly increased leading to lesser PM emissions.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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