A REVIEW ON ASH AGGLOMERATION PHENOMENON IN FLUIDISED BED COMBUSTION BOILER

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ABSTRACT

Most of the Indian coal has high percentage of ash by using this coal boiler face the problem of ash agglomeration or ash sintering which affect the bed height, refractory material and primary air supply. In Current study we will evaluate and then reduction will be made by different techniques in CFBC boiler and effect of agglomeration in boiler. A survey of ash agglomeration and deposit formation in industrial boiler found that all the boiler facing some form of bed ash agglomeration. In combustion using Indian coal having high percentage of sulphur ash becomes deposited on the bed particles. After certain temperature (about 800^{O}C to 1000^{O}C) ash showing the sticky behaviour tend to stick ash and form agglomerates. Large agglomeration decreases the bed mixing and result of this activity de-fluidisation take place in the boiler.

For utilising high ash coal circulating fluidised Bed Combustion (CFBC) boiler is favourable choice. Problem of ash agglomeration occurred also in CFBC boiler result of this choking loop seal which affect the circulation of fuel or ash particles. Finally concentration of the study given to de-fluidisation and loop seal blocking, A CFD based model prepare to analyze the problem of ash agglomeration or ash sintering in CFBC boiler. This CFD model will help to find out the optimum solution of the ash agglomeration problem.

Keywords: *CFBC, Cyclone separator, Fluent 14.5, Agglomeration, CFD etc.*

1. INTRODUCTION

Circulating fluidized bed combustors (CFBCs) are considered in some respects to be an improvement over the traditional methods of coal combustion. Operation of industrial CFBCs has confirmed many advantages including fuel flexibility, broad turn-down ratio, high combustion efficiency, low NOx emissions and high sulphur capture efficiency. These characteristics assure increasing commercialization of CFBC in power generation applications. Although CFBC technology is becoming more common, there are some significant uncertainties in predicting performance in large-scale systems. Technical knowledge about design and operation of CFBC is widely available, but little has been done in the field of mathematical modeling and simulation of combustion in CFBCs. This might be attributed to the fact that the combustion process occurring in a CFBC involves complex phenomena including chemical reaction, heat and mass transfer, particle size reduction due to combustion, fragmentation and other mechanisms, and gas and solid flow structure. Using a lumped modelling approach.

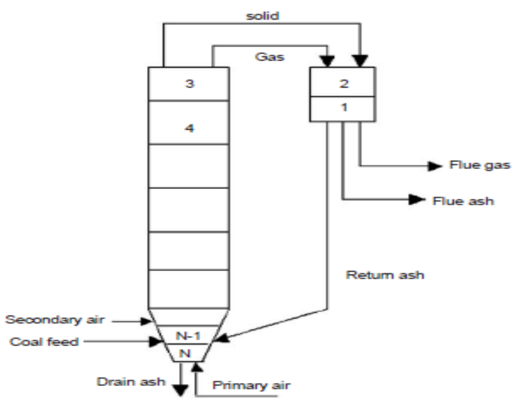

Fig. 1. Cell structure of the 1D CFB model.

Fig. 1 shows the cell structure of the model; the cyclone and boiler furnace are divided into 17 cells. In each cell, the ash particles are specified with size and residence time or age. There are 14 size groups and 5 age groups in this 1D mass balance model.

Cyclone Separators

Cyclone separators have been a decisive factor in the development of coal combustion technologies. Among diverse possibilities for hot gas cleaning, these devices have demonstrated the most favorable balance of separation efficiency and cost of investment, operation and maintenance.

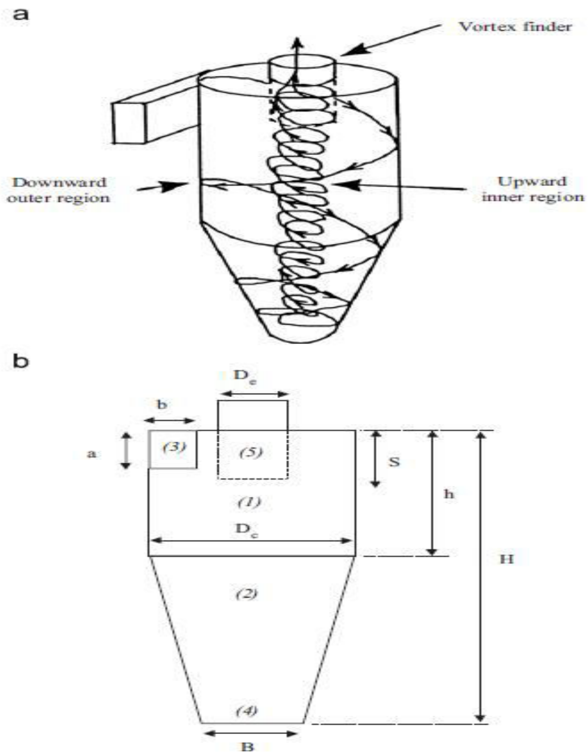

Fig. 2. (a) Qualitative drawing of the principle of operation and flow patterns in cyclones. (b) Main parts and dimensions of an inverse-flow cyclone: (1) cyclone body, (2) conical part, (3) inlet duct, (4) exit duct, (5) vortex finder.

Able to handle any combination of gas pressure, temperature and very high solids loading, their performance is tolerable as compared with more efficient separation equipment (i.e., ceramic filters), being at once much more simple, robust and reliable. Presently, cyclones are a key component in most advanced coal utilization concepts, such as pressurized and circulating fluidized bed combustion (PFBC and CFBC). In PFBC, cyclones are essential to maintain the integrity of the gas turbine, and thus the advantages of the concept itself. In CFBC, the scaling-up of the equipment to sizes compared to conventional coal firing is being developed partly based on new designs of integrated, compact cyclonic separators.

In this device, the fluid enters tangentially into the cylindrical chamber with a high rotational component. The flow descends rotating near the wall, until a certain axial location where the axial velocity component reverses itself, thus making the flow to ascend. This is referred to as the vortex end position. The ascension proceeds near the cyclone axis and, since the flow rotation continues, a double vortex structure is formed, as indicated in the figure. The inner vortex finally leads the flow to exit through a central duct, called the vortex finder. The vortex finder protrudes within the cyclone body, which serves both to shield the inner vortex from the high inlet velocity and to stabilize it. It is also worth to mention that the inversion leading to this peculiar flow structure is apparently originated by the pressure field inside the cyclone, and not directly influenced by the conical shape or the geometrical length.

Fluidized bed conversion of solid fuels

Fluidized beds are used for a variety of applications in the process industry, such as fluidized catalytic cracking (FCC) including catalyst generation and other strongly exothermal processes, drying, solid fuel conversion and gas-phase polymer production. This review focuses on high-temperature processes, especially thermo-chemical solid fuel conversion carried out in fluidized beds. For an overview of the different thermo chemical conversion routes (combustion, gasification, liquefaction) as well as bio chemical conversion routes (fermentation, anaerobic digestion). Fluidized bed conversion of carbonaceous solid material (e.g. coal, biomass, etc.) at high temperatures is industrial practice to generate steam, electricity and hydrogen. The solid fuel is added to a fluidized bed of inert solid material, which acts as a heat reservoir. Silica sand is most commonly used as bed material.

Ash formation

Accurate prediction of mass balance in CFB boiler requires knowledge of PAPSD of the burned coal. PAPSD is the size distribution of ash particles after the char fragments and fast attrition process. The method to get the PAPSD of the burned coal will be described in detail in Section 3.2. In the calculation in ash balance model, the PAPSD will be converted into ash formation matrix, $A_{18\times7}$; the column means the sieve size cuts of coal and the row means the ash sieve size cuts, respectively.

Residence time model

In CFB system, the different size particles may have different residence times; even the same size particles may have different residence times, i.e., different ages. The residence time for multi-size particles will greatly influence the attrition of coal ash particles in the CFB boiler. Based on such fact, ash particles are classified into size group as well as age group. The size dispersed ash particles are fed into the furnace at feed rate, ˙min (di, t0). In the t0 age group, the di size group particles experience attrition process and the mother particles experience continuous size reduction. The produced fine particles fall into the smallest size group and some mother particles fall into the next size group.

Agglomeration in fluidized beds

Despite its broad application, solid fuel conversion in fluidized bed processes still has some technical difficulties. Agglomeration is a major operational problem. Usually, the conversion of the solid fuel is carried out with silica sand and ash as bed material. Inorganic alkali components from the fuel, mainly potassium (K) and sodium (Na),1 can be a source for agglomeration by the formation of low-melting silicates with the silica from the sand. The content of this critical inorganic material can vary much between fuels; especially in the case of certain types of biomass as well as some low-rank coal types the content is often rather high. When both alkalis and silica are present in the bed they can form low-melting silicates, characterized by a lower melting point than the individual components. As a consequence, the sand particles become coated with an adhesive layer. Sand particles with a sticky surface then grow towards larger agglomerates due to the formation of permanent bonds upon collisions. If this process is not recognized, it eventually propagates to partial or total de-fluidization of the reactor, which in turn results in a lengthy and expensive unscheduled shutdown.

2. LITERATURE

E.J. Anthony, L. Jia-Fluidized bed combustor (FBC) ashes from high-sulfur, low-ash fuels, can agglomerate if subjected to sulfating conditions for long enough (days to weeks). The degree of sulphation increases with both temperature and time under these conditions, and at a conversion equivalent to the production of 50–60% or more of $CaSO_4$ in the deposit the ashes agglomerate. Fly ash agglomerates less readily than does bed and loop seal ash and produces weaker deposits, although all of these materials will agglomerate if sufficient time is allowed. The potential for agglomeration increases if the temperature is increased from 850 to 9508C. Agglomeration also occurs at lower temperatures (down to at least 7508C), but the mechanism may be via carbonation and then sulphating of the ash. Although experiments reported here suggest that if pure $CaSO_4$ is compressed to the 140kPa range it does show some tendency to agglomerate, the agglomeration of FBC ash is not produced simply by the formation of $CaSO_4$. Finally, the agglomeration process is only weakly influenced by the partial pressure of SO_2 in the flue gas. Attempts to identify physical parameters to differentiate the tendency of various bed materials to agglomerate have been only partially successful. Two bed materials with strong and weak agglomerating tendencies were studied. These were shown to have very similar particle shapes and only slightly different angles of repose, but quite different bulk densities. Residues with a greater bulk density appear to have a stronger tendency to agglomerate, and this may provide a method of ranking the agglomeration potential of different bed materials. **L. Huilin et.al**-A steady state model of a coal-fired circulating fluidized-bed boiler, based on hydrodynamics, heat transfer and combustion, is presented This model predicts the flue gas temperature, the chemical gas species (O_2, H_2O, CO, CO_2 and SO_2) and char concentration distributions in both the axial and radial locations along the furnace including the bottom and upper portion. The model was validated against experimental data generated in a 35 t/h commercial boiler with low circulation ratio. A numerical model to simulate two regions with combustion in the furnace of a circulating fluidized bed boiler of low circulating ratio with wide size distribution was implemented. This model was coupled a model for the dense region derived from turbulent bubbling bed theory with a model for dilute region which was a core-annular flow structure. Radiative heat transfer in the dilute region was modeled by using zone method. The model allows for the calculation of gas concentration, chemical species, temperature and heat flux along the furnace. A model for SO_2 retention was also included. The model can now be used to represent a CFBC unit in various applications but more experimental data are still required to confirm the proposed CFBC model in order to make it more comprehensive and reliable. **Lothar Reh-**First a report about present status of circulating fluidized bed reactors for coal and multi-fuel combustion in power plants is given. Thereafter the development potentials and research needs for further improvement of CFB combustors operating with finely grained bed materials are discussed and recommendations for direction of further research and development work are presented. In a little over 20 years following its introduction as a coal firing system, though not without teething troubles, and as result of not unusual learning, the young ACFBC system has found worldwide acceptance in many power plants up to medium utility size, e.g., projected for 600 MWel with supercritical steam generation, and burning a wide variety of coals.

In Germany and some other Western-European countries due to reduced combustion of coal in smaller communal and industrial co-generation power plants, the application of the ACFBC in its present design has turned towards multi-fuel combustion. An increasing number of ACFBC orders in China, East Asia and increasingly in the Eastern European countries despite difficult financing conditions has emerged as a clear signal. Further intensive and interdisciplinary co-operation of plant constructors, operators and scientists of all disciplines will lead to further increase in net power efficiency and decrease in emissions of CFBC units. Even in a world troubled by increasing CO_2 emissions and decreasing fossil primary energy resources, CFB combustion and gasification will play an increasingly important role. The most important demands to be considered for future efforts in research, design and operation of CFBC are: improve performance by adjusting and control of fine bed material grain size by adequate solid feed preparation, increased recovery of fines in recycling separation system avoiding bimodal ash grain size distributions, utilizing ashes in cement and building industry investigate and control macro-scale mixing patterns of solid-solid, gas-solid, gas-gas impact of jets and wall layers study reaction requirements for pollution control coupled with above mixing processes feed points location for air and solids to control local atmosphere chemical composition of bed improve multi-scale two-phase modeling in direction of gas/cluster interaction predicting solid concentrations and real wall layer temperatures improvement of validation using CFB data bases **J.G. Mbabazi et.al-** Fly ash particles entrained in the flue gas from boiler furnaces in coal-fired power stations can cause serious erosive wear on steel surfaces along the flow path. Such erosion can, as a particular example, reduce significantly the operational life of the mild steel heat transfer plates that are used in rotary regenerative heat exchangers ('air heaters') that extract heat from the flue gas and transfer it to the incoming boiler combustion air. This paper describes research into fly ash impingement erosion on such surfaces. The effect of the ash particle impact velocity and impact angle on the erosive wear of mild steel surfaces, using three different power station ash types, was determined through experimental investigations. The experimental data were used to calibrate a fundamentally-derived model for the prediction of erosion rates. The model incorporates the properties of the ash particles and the target metal surface, as well as the characteristics of the ash particle motion in the form of the impingement velocity and the impingement angle. When tested using the three different types of ash, the experimentally-calibrated general model yielded results that generally differed by less than 15% from the values that had been measured experimentally. **HairuiYang et.al-**An 1D model of the circulating fluidized bed (CFB) boiler is developed specifically to predict the material balance in CFB boiler. This model emphasizes on the important factors that influence the ash balance in CFB boilers, such as ash formation, attrition and size reduction, residence time and segregation in dense bed. The corresponding sub-models are discussed in detail. In the simulation of a 135MWe CFB boiler in Zibo power plant, China, the parameters in mass balance model under full load operation, such as segregation parameters and axial decay constant, are optimized. The model can predict the mass balances at different operating loads in the same boiler. An 1D model has been developed for predicting the mass balance of CFB boiler. This 1D model considered the influence of ash formation, attrition and size reduction, residence time and segregation on the size changes and mass balance in CFB boilers. Some parameters such as segregation parameters and the exponential decay constant were optimized from the data measured in field at full load operation for a 135MWe CFB boiler in Zibo power plant. The mass balance of other full or partial load for the 135MWe CFB boiler was predicted; the comparisons of the model prediction and field data validate the 1D mass balance model. **Cristo´ bal Corte´s et.al-**This paper reviews the models developed for the flow field inside inverse-flow cyclone separators. In a first part, traditional algebraic models and their foundations are summarized in a unified manner, including the formulae for tangential velocity and pressure drop. The immediate application to the prediction of collection efficiency is also reviewed. The approach is the classical, treating first the dilute limit (clean-gas correlations), and afterwards correcting for "mass loading" effects. Although all these methods have had a remarkable success, more advanced ideas are needed to model cyclones. This is put forward by exploring the work done on the so-called "natural" length of the cyclone, that has led to the discovery of instability and secondary flows. The resort to computational fluid dynamics (CFD) in this case is difficult, however, due to the very nature of the flow structure. A closing section on the subject reviews past and recent CFD simulations of cyclones, both single- and two-phase, steady and unsteady, aiming at delineating the state-of-the-art, present limitations and perspectives of this field of research. Cyclones are robust devices, widely used in the chemical and process industries, as well as for heavy-duty hot gas-cleaning service in several applications of combustion of solid particles. Much ingenuity has been devoted to the prediction of their performance parameters, collection efficiency and pressure drop, which has required a previous knowledge of their basic flow patterns. The classical view of a steady flow, that can be calculated as a clean gas, single-phase flow corrected by mass loading effects has been relatively successful. Many algebraic models and semi-empirical formulas have been developed throughout the years; among them, the more complex models of Muschelknautz for pressure drop, and Trefz and Muschelknautz for collection efficiency give most accurate results as compared to experimental data. However, the complexity of the flow in cyclones is due to instability, as modern experimental and numerical techniques have demonstrated. Specifically, the double-vortex structure that makes up the basic flow is essentially unstable, and develops a phenomenon of quasi-periodic oscillations known as a "processing vortex core". This instability can be a threat to the cyclone objective of solids' separation, but also affects a basic flow feature, formerly thought of as stationary, called the cyclone natural length. This is in turn a major influence in cyclone velocity patterns, pressure drop and collection efficiency. As a result, it can be said that the flow in cyclones is not yet completely understood. Given the kind of phenomena involved, classic, algebraic models are positively not well suited to a proper account; modern progress should evidently resort to CFD calculations. However, the very nature of the problem makes the task difficult. Unusual high precision in the numerical discretization and unsteady simulation methods (LES or URANS) are needed to possibly capture the whole complexity of the unsteady flow of gas inside a cyclone. The simplest of these methods is computationally very costly, much more than the usual steady-state simulation of industrial equipment. Perhaps this has prevented up to now a closed account of several related design aspects, such as a precise methodology to reasonably estimate the cyclone natural length, and thus the advisable geometric length, the circumstances for and the effects of a loss of coherence of the vortex and the ensuing chaotic flow patterns, the effect of swirl-stabilization devices, y . More systematic research is obviously needed in this direction. On the other hand, more work should be devoted to ascertain if, and under what circumstances, a URANS solver with advanced turbulence models (differential RSTMs) can supplant a more rigorous, but more costly, LES or its variants. Finally, two-phase flow simulation of cyclones is certainly at its very beginning and demands several advances. On the one hand, factors like inter particle phenomena and conditions at the wall have not received yet the attention they surely deserve. But most importantly, modern two-phase flow simulations of cyclones have turned out to be too costly, due to the necessity of reproducing unsteadiness of the gas flow and combine it with the simulation of a poly-disperse particulate system. Even for dilute flow, even for one-way coupling, present computer capabilities are insufficient, at best making the CFD calculation a costly expedient. Simplified schemes are obviously needed. To the possibilities explored in the literature of using "abridged" LES data to this end, we may add the necessity of directly testing URANS methods, not yet realized. A development of the PSI-Cell techniques is the sense of coping more efficiently with time-variable problems seems also, obviously, very convenient. As for the calculation of highly-loaded cyclones, the experience to date is so meager that we can only hope for simplified, algebraic-slip models that can compete in simulating dilute flows and then can be applied to the dense regime. In any case, the incipient experience with two phase flow simulations seems to be in the verge of another revolution, in the sense that classical, well established theories on cyclone particle flow might be compromised. This would be of course stimulating, and surely a great step forward in our understanding of cyclone operation. **Li Dengxin et.al -** The fly ash (high carbon content and high reacted CaO) recirculation in CFB is a typical method to improve the carbon burnout efficiency and the calcium utilization ratio. While the effectiveness of it is limited by the resident time and the reactivity of the re-injected fly ash particles. In the present research, an improved fly ash recirculation method is suggested in which the CFB fly ash is mixed with water or the mixtures of additives (such as waste water of paper mill, cement, sodium silicate, and carbide slag) and water in a blender. Then, this mixture is re-injected into the combustion chamber of CFB by a sludge pump. Because the temperature in CFB is higher, the fly ash was flash hydrated. At the same time, it was dehydrated and agglomerated. The size of agglomerates is bigger than that of original particle and their attrition rate is lower. Therefore the resident time of agglomerates is much longer than that of fine fly ash particles. The absorption of SO2 is higher than that of original particles, too. This results in high carbon burnout efficiency. The hydrated lime also improves the calcium utilization.

3. ÒBJECTIVE OF THE STUDY

Agglomeration is a major operational problem. Usually, the conversion of the solid fuel is carried out with silica sand and ash as bed material.

In Present study we will use Indian coal as a fuel and setup the Mathematical Model of CFBC Boiler with Cyclone separator then using Actual Boundary condition by Ansys (Fluent) Software tools. In our Research we will evaluate mass fraction of Agglomeration and then Reduction will be made by using different technique like Operating conditions (Controlling temperature of compact separators, Controlling primary air supplied to stripper cooler chamber) and using various Additives (Al-Si , P-Ca and Sulphur containing additives).

4. PROBLEM FORMULATION

The process parameters for the CFBC operation are listed here taken as a reference from 1X120 T/H, 64 kg/cm2 (g), 485± 5° C to conduct CFD study. The flue gas of 1.3128 Kg/Nm3density flows with rate of 113350 Nm3/hr along with maximum size of coal is 6mm. The weather condition where the operation conducted is as ambient temperature 30^0C with 80% relative humidity.

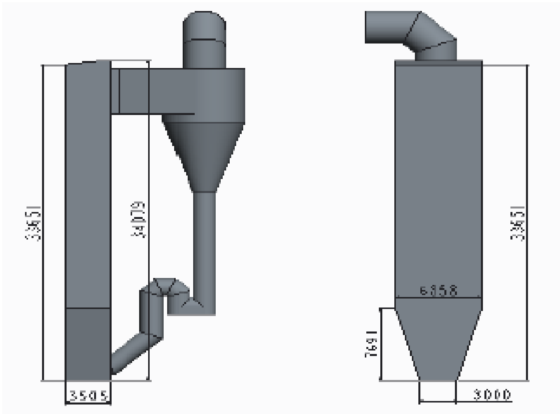

Figure 3: 3D CAD Model of Setup

5. PROPOSED METHOD

Most uncertain & unplanned activity due to failure of refractory is the shutdown of boiler operation. To bring back boiler into operation is cumbersome activity. So it is always advisable to avoid the unplanned shutdowns. Aim & objective is to understand the cause of failure & serve the solution with technical aspects. This can be only achieved by using advance CAD/CAE/CFD tools available to demonstrate the actual boiler operation phenomenon virtually in to computers. Steps followed to achieve the simulation are

1. Prepare individual equipments into CAD software
2. Prepare the general arrangement of equipments of CFBC boiler
3. To simulate the flow of flue gas inside the loop of CFBC boiler by using CFD software to understand & address the failures.

6. PROPOSED RESULTS

Proposed outcomes of the study by Simulation of the Mathematical Model of CFBC Boiler with Cyclone Separator using ANSYS (Fluent14.5) Software tools are:

1. Temperature Variation
2. Pressure variation profile
3. Velocity contour
4. Streamline Velocity contour
5. Mass fraction of Agglomeration or precipitants
6. Turbulent kinetic energy
7. Total energy

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