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Effect of fuel particle size on the process of fluidization in a fluidized bed combustion boiler

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ABSTRACT

Today, Fluidized bed combustion is considered as the future of Thermal Power Plant. In the study of Fluidized bed combustion, the fluidization process is very critical & behavior of fuel & air mix as a fluid is very significant for the combustion performance. A lot of research work has been conducted in order to investigate the fluidization process &heat transfer characteristics of a typical fluidized bed furnace, which provides a useful starting point for understanding the furnace behavior in FBC boilers. This paper describes fuel particle relations to fluidization process based on a simple experiment. Starting with a brief review of the combustion process inside a fluidized bed boiler, the paper elaborates on the concept of fluidization & its controlling parameters. Impact of these parameters on heat exchange process in furnace &In-bed Heat exchanger used in fluidized bed combustion is explained. Also the aspects such as corrosion, erosion are elaborated. With the help of a this simple experimental set-up the paper focuses light on the relations between fluidizing air velocity & particle size which contribute as a major factor in FBC furnace design.

Keywords— **Fluidized bed combustion, Heat transfer, In-bed heat exchanger.**

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I. INTRODUCTION

Fluidization is a very interesting yet a very complicate process involving a mix of solid fuel particles along with combustion air. Unlike other combustion technologies, combustion inside FBC furnace is very sensitive & changes with many parameters. Parameters such as fuel ingredients, air velocity, bed dynamics and furnace heat transfer etc. control combustion process in their own ways.

It is very difficult to predict the boiler performance without using professional tools such as CFD (Computational Fluid Dynamics). Also the simulation results obtained through CFD are tested with some experimental set-up or a test bed. CFD simulations are used to simulate two phase problems & predict heat transfer characteristics such as temperature, heat transfer coefficient & hydrodynamic characteristics such as pressure, velocity, volume fraction etc.

Until 1987, main focus of FBC experiments was on particle velocities & particle concentrations. Since then numerical modellers are able to compare & evaluate their theoretical models with experimental studies. Study reports tell that the lower furnace portion is very sensitive to erosion during operation of a FBC boiler, as this lower region is exposed to dense hot stream of fuel, limestone (as applicable) and sand etc. To design FBC boiler, the study on lower furnace portion is equally important.

The present study considers proven literature as a basis & refers to the available CFD simulations for hydrodynamic characteristics of two phase flow. A simple experimental set-up is used to conduct few trials, helps to develop relations between the fluidizing air velocity & fuel particle size in process of fluidization.

II. FLUIDIZED BED COMBUSTION

A FBC boiler uses pressurized furnace & circulates un-burnt particles again into the furnace (in case of CFBC. This improves combustion efficiency considerably.) In general for all Fluidized Bed Boilers, furnace is a bed of hot sand, ash & fuel. The bed is maintained in a turbulent fluidized state by the primary air which is introduced through nozzles located at the bottom of the combustor. The large quantity of heat held by the bed functions as a thermal "flywheel", keeping the temperature constant throughout the furnace & leveling out variations in fuel quality and moisture content. Low combustion temperature, low excess air & staged combustion provide means for minimizing the NOx generation in the flue gases. The operation characteristics of FBC ensure total fuel flexibility. Also SOx formation can be controlled by adding limestone in furnace to capture sulfur & hence requirement of FGDs. (Flue Gas Desulfurization) is eliminated.

III. FLUIDIZATION PROCESS

If to be defined, fluidization is a two-phase process which induces an upward flow of a gas through a stacked height of solid particles. At high enough gas velocities, the gas / solids mass exhibits liquid like properties & hence termed as fluidized bed. On fluidizing, a bed of solid particles gets converted into an expanded, suspended mass which possess many properties of a liquid. For example, zero angle of repose, it seeks its own level, and assumes the shape of the containing vessel. Generally particle size distribution is between 8 mm to 15 mm give best results with least formation of large bubbles. Large particles cause instability and result in slugging or massive surges & Small particles frequently, even though dry, act as if damp, forming agglomerates or fissures in the bed, or spouting. Adding finer sized particles to a coarse bed or coarser-sized particles to a bed of fines usually results in better fluidization. If we go on increasing air flow rate continuously, the drag forces on the particles counterbalance the gravitational force. Due to this the solid particles remain suspended in air. The upward velocity of the gas is usually between 0.5 m/s to 6 m/s. This velocity is based upon the flow through the empty vessel and is referred to as the superficial velocity (Us). As the gas velocity is increased, pressure drop increases until it equals the weight of the bed divided by the cross-sectional area. This velocity is called minimum fluidizing velocity, (Umf). When this point is reached, the bed particles will expand uniformly until at some higher velocity gas bubbles will form (minimum bubbling velocity, Umb). Minimum fluidizing velocity is a vital term used in fluid-bed calculations. It quantifies one of the particle properties. This gives a particle size that takes into account effects of size distribution and sphericity. The flow required to maintain a complete homogeneous bed of solids in which coarse or heavy particles will not segregate from the fluidized portion is very different from the minimum fluidizing velocity.

If the gas velocity is increased further, bed density will reduce & turbulence will increase. If bed is smaller is cross section, slugging will be observed due to increase in bubbles size greater than half of the bed cross-section. The increase is by vertical and lateral merging. Size increase is also due to the gas velocity increase. On further increase in gas velocity, bubbles start to disappear and streamers of solids and gas prevail, pressure fluctuations in the bed are greatly reduced. Further increase on velocity results in dilute-phase.

IV. FLUIDIZED –BED DESIGN

The fluidized bed is comprised of various parts such as Fluidized furnace, fuel feed & control system, fuel discharge & distribution system, air supply system & required amount of instrumentation.

The fluidization furnace consists of Fluidized-bed, bed height & Gas distributor or wind-box assembly. The volume above the bed is called the disengaging space. In boiler terms it is also called as bed height. Bed cross-sectional area is determined by the volumetric flow of air and the allowable or required air fluidizing velocity at operating conditions. Dimensions of the bed (cross-sectional area and height) decide maximum air flow required. It also depend up-on carry-over of solids. Bed height is worked based on various factors, like Air-contact time, L/D ratio constraints for air staging, Space required for In-Bed Heat exchangers & fuel particles retention time in furnace.

FBC boilers operate at elevated temperatures of the range 800 - 1000˚C. Of course due to high temperature operation furnace is refractory-lined. The refractory serves two main purposes; it insulates the pressure parts from the elevated temperatures, and it protects the pressure parts from abrasion by the bed and particularly splashing fuel particles at bed top resulting from bursting bubbles.

Bed height is the distance between the top of the fluid bed and the end level of dense phase of fluidized mix. Two actions take place within the bed height: Mixing of fuel particles with air & burning of the fuel particles in the same suspended position after the start of combustion. During process of combustion, fuel particle burns & losses its mass. Due to loss of mass it moves vertically up. Bed temperature increases and it also expands vertically up. The wind-box assembly provides stage-wise progressive combustion & has a considerable effect on proper operation of the fluidized bed.

Bed temperature and heat transfer coefficient increases with increase in bed inventory and particle size.

Fluidized bed furnace can be distinguished into two zones as dense zone at bottom & dilute zone at top. The dense zone is the zone the fuel particles are fluidized by the primary air supply whereas the dilute zone is the region with decaying suspension density especially the upper portion of the furnace.

V. EXPERIMENTAL SETUP

Following figure shows a simple set-up for the experiment of fluidization. This involves a large volume to represent furnace made from a simple 20 litre mineral water tank (made up of PVC). This tank is transparent such that it will be easy to observe the fluidization process while trial. The volume at the bottom is attached with a air distribution plate. This plate is made up of thermo-coal & is drilled with 140 holes of diameter 4 mm equi-spaced all over the tank cross section. An opening symbolizing chimney is available for air exit. Below air distribution plate, a small tank resembling wind-box is provided for air supply into the furnace & is supplied with a positive displacement blower & inlet duct (made up of a simple PVC pipe). The set-up is equipped with required instruments such as flow-measurement & draft gauges such that we can conduct number of trials & note down required parameters. Required size mesh-screens are used to ensure k fuel particle size as required & a weighbridge to get only required weight of the fuel.

Steady state experiments were conducted to examine relations between particle size, density, distribution area & fluidization air velocity. These experiments were conducted with variety of material such as coal, coffee beans & corn so that variation in density also can be taken into consideration.

VI. EQUATATION USED

1. Calculations for Viodage (ε)

$$\epsilon = \frac{\boldsymbol{M}}{(\boldsymbol{\rho P} * \boldsymbol{\rho A} * \boldsymbol{A} * \boldsymbol{H})}$$

Where
ε = Bed Voidage Fraction
M = Mass of fuel particles (in Kg)
ρp = Density of fuel (Kg/m3)
ρA = Density of air (Kg/m3)
A = Cross sectional area of furnace (m²)
H = Bed height (m)

2. Minimum fluidisation velocity (Umf)

$$\square\square\square = \frac{[(\square\square - \square\square)^{\square.\square\square\square}] * [\square^{\square.\square\square\square}] * \square\square^{\square.\square}}{[\square\square\square\square * \square^{\square.\square\square}\square\square^{\square.\square\square\square}]}$$

Where
Umf = Minimum fluidization velocity (m/sec)
g = Gravitational acceleration (m/sec²)
Dp = Average Particle size (in m)
μ = Viscosity of air (cp)

3. Superficial Velocity (Us)

$$\square\square = \frac{\square}{\square * \square\square\square\square}$$

Where
Us = Superficial velocity (m/sec)
Q = Theoretical Air flow required (m3/hr)

4. Pressure drop thru bed plate

$$\Delta \boldsymbol{Pb} = \frac{\boldsymbol{Vb^2} * \boldsymbol{\rho A}}{\boldsymbol{0.64} * \boldsymbol{2g}}$$

Where
ΔPb = Pressure drop across bed plate (in mwc.....converted from Kg/cm²)
Vb = Velocity thru bed nozzle (m/sec)

5. Total Pressure drop (ΔPt)

$$\Delta\square\square = \square * (\square - \epsilon) * (\square\square - \square\square) * \square$$

Where
ΔPt = Total Pressure drop (in mmwc.....converted from Kg/cm²)

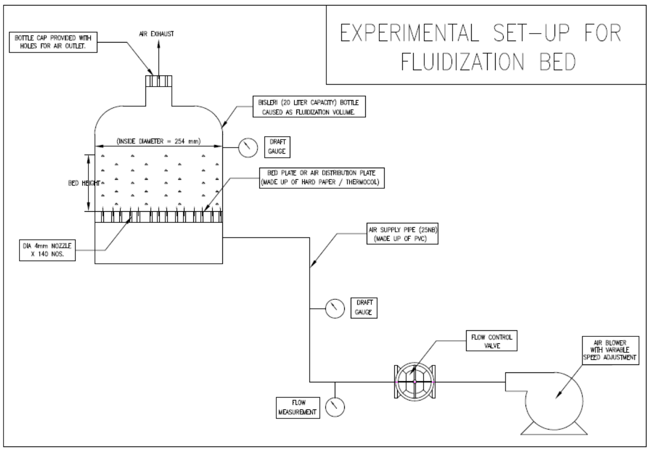

Figure 1: Experimental Set-up

VII. EXPERIMENTAL SETTINGS

A READINGS OF TRIALS CONDUCTED FOR VARIOUS CASES WITH VARIATION IN FUEL DENSITY AND / OR FUEL PARTICLE SIZE

Case	**1**	**2**	**3**	**4**	**5**
Specimen	Coal				
Density (kg/m3)	800	800	800	800	800
Particle size (mm)	6	8	10	12	15
Bed height (mm)	150	150	150	150	150
Flow rate (Q)	15	24	21	24	25.6
Velocity thru bed plate hole (m/sec)	2.4	3.8	3.3	3.8	4.04
Pressure drop (Δp) thru bed plate When bed is fluidised @ given flow rate (MMWC)	7	11	14	18	20.3
Total Pressure drop (Δp) When bed is fluidised @ given flow rate. (MMWC)	75	78	81	83	85.8
Actual Flow rate (m3/hr)	21	32	28	33	38
Actual Total Pressure drop (Δp) (MMWC)	115	120	135	138	142

Case	**6**	**7**	**8**
Specimen	Green Coffee-bean		
Density (kg/m3)	721	721	721
Particle size (mm)	8	10	12
Bed height (mm)	160	160	160
Flow rate (Q)	20	21.4	23.8
Velocity thru bed plate hole (m/sec)	3.16	3.38	3.76
Pressure drop (Δp) thru bed plate When bed is fluidised @ given flow rate (MMWC)	12.39	14.19	17.55
Total Pressure drop (Δp) When bed is fluidised @ given flow rate. (MMWC)	73.55	76.90	78.88
Actual Flow rate (m3/hr)	24	26	31
Actual Total Pressure drop (Δp) (MMWC)	98	104	111

Case	**9**	**10**	**11**	**12**	**13**
Specimen	Corn				
Density (kg/m3)	641	641	641	641	641
Particle size (mm)	8	10	12	15	18
Bed height (mm)	160	160	160	160	160
Flow rate (Q)	20	22	24.3	30	32
Velocity thru bed plate hole (m/sec)	3.16	3.47	3.84	4.7	5.05
Pressure drop (Δp) thru bed plate When bed is fluidised @ given flow rate (MMWC)	12.4	15	18.3	28	31.7
Total Pressure drop (Δp) When bed is fluidised @ given flow rate. (MMWC)	68.4	71.4	73.5	75	77.3
Actual Flow rate (m3/hr)	24	29	32	38	43
Actual Total Pressure drop (Δp) (MMWC)	91	99	110	138	142

Case	**14**	**15**	**16**
Specimen	Roasted Coffee-bean		
Density (kg/m3)	481	481	481
Particle size (mm)	8	10	12
Bed height (mm)	160	160	160
Flow rate (Q)	11.5	14	17.1
Velocity thru bed plate hole (m/sec)	1.82	2.21	2.7
Pressure drop (Δp) thru bed plate When bed is fluidised @ given flow rate (MMWC)	4.1	6.07	9.06
Total Pressure drop (Δp) When bed is fluidised @ given flow rate. (MMWC)	56.2	57.7	58.7
Actual Flow rate (m3/hr)	16	19	23
Actual Total Pressure drop (Δp) (MMWC)	98	104	111

VIII. Graphs Based on Actual Trials

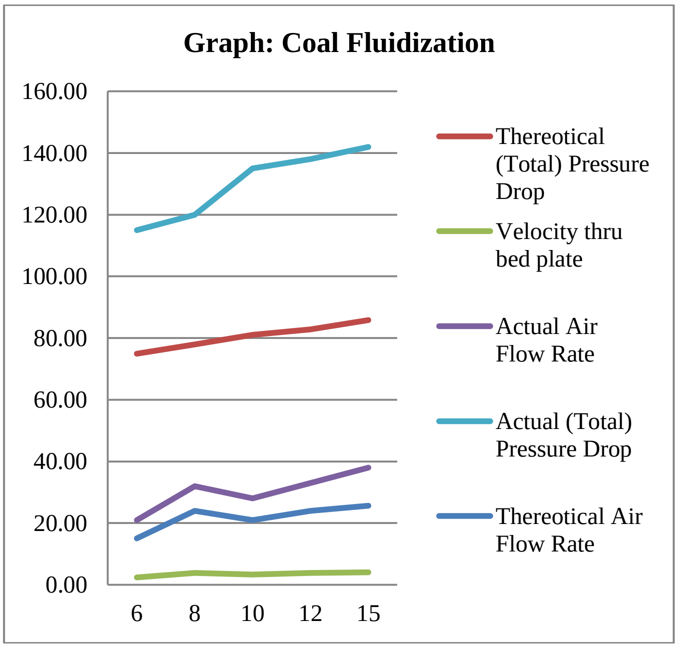

Figure 2: Graph showing variation in fluidization due to change in size of fuel particles.

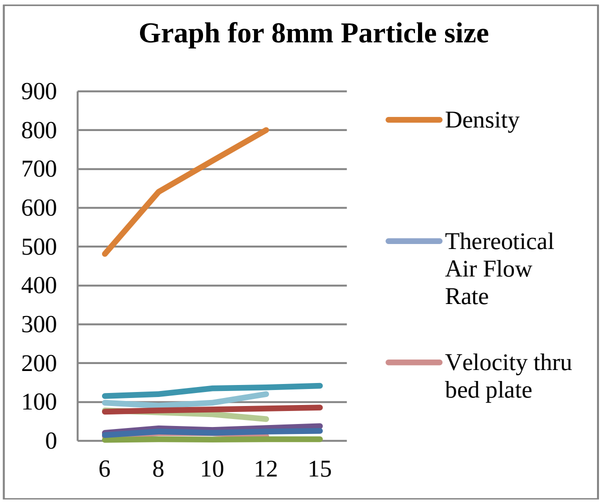

Figure 3: Graph showing variation in fluidization due to change in fuel density

IX.OBSERVATION

1. Due to few system leakages there is an increase in actual air flow requirement compared to the theoretical.
2. Due to the manual feeding of the fuel particles from the top of the tank, there is slight trouble in the initial phase & due to this there is an increase in actual air requirement for fluidization.
3. Due to limited layout of blade plate holes the air distribution is limited & it calls for extra fluidization air required. The similar experiment can be carried out by changing the number & size of bed plate holes to check the effect.
4. As the particle size is increased for the same density, required air flow rate increases, with effective increase of fuel mass allowed. The ratios of increase are almost same.
5. Actual pressure drop is more due to few leakages, limitation of experimental set-up & due to limited accuracy of the measurement.
6. Pressure drop increase is more dependent on air flow than the particle size. Due to this actual pressure drop is higher compared to the theoretical as air flow required in actual case is high.
7. Other parameter such as L/D ratio for the tank also has impact on pressure drop & air flow requirement which is not considered in the experiment.
8. The experimental results match with the theoretical with accuracy level of + 10 % which is even though not a very good accuracy but is sufficient to confirm the theoretical basis.

X.CONCLUSION

Thrugh the experiment simulating fluidization, we can summarize few facts such as, fluidizing, converts the bed of fuel particles into an expanded, suspended mass having many properties of a liquid. Compared to the smaller size particles, large particles cause more instability. If the variation in the particle size is too high, fluidization becomes difficult as we cannot predict the exact fluidization air requirement.

There is a slight variation (5 – 10%) in Bed height w.r.t. (similar) change in density however for the same density variation; change in air requirement is about 25%. Similarly pressure drop reduction with reduction in fuel density is almost 20%.

If for the same Fuel density, particle size is changed, then the change in fair flow requirement is significant & it can be upto say 50% for increase of 2 mm in particle size. Increase in pressure drop is minimal for the above increase in particle size.

The results of the simulations match with theoretical values within accepted level of accuracy limits & guides toward an exercise to check the effect of variation in number of holes & hole diameter on bed plate on the fluidization process.

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