ART OF BED MANAGEMENT IN AFBC BOILERS

Fluidization had been extensively researched and brought out in many papers. The fluidization which as originally used for chemical reactors was extended to combustion technology. It had been nearly 30 years since the fluidization had been commercially applied for combustion. Many manufacturers design and supply boilers with Bubbling fluidized bed combustion technology. Many fluidized beds are operating successfully. There are some installations wherein the fluidization misbehaves leading to poor combustion and bed coil failures. The subject of fluidization is reviewed here for the benefit of operating engineers.

The behaviour of a fluidized bed is difficult to predict since the parameters such as the particle size, shape and density are not simply some numbers. These parameters in real world fall in to wider range. There are many Fluidization regimes which have been well explained in Fluidization engineering by Kunii & Levenspiel.

REVIEW OF FLUIDIZATION BASICS

What is Fluidized Bed?

When air or gas is passed through an inert bed of solid particles such as sand supported on a perforated plate, the air, initially, will seek a path of least resistance and pass upward through the sand. With further increase in the velocity, the air starts bubbling through the bed and the particles attain a state of high turbulence. Under such conditions, the bed assumes the appearance of a fluid and exhibits the properties associated with a fluid and hence the name 'Fluidized Bed'. If velocity is too low, Fluidization will not occur, and if the gas velocity becomes too high, the particles will be entrained in the gas stream and lost. Hence, to sustain stable operation of the bed, it must be ensured that gas velocity is maintained between minimum Fluidization velocity and particle entrainment velocity. Fluidization is widely used for many commercial operations, such as transportation, heat treatment, absorption, mixing, combustion, chemical reactions.

Regimes of Fluidized bed combustion (*source: Fluidization engineering-Kunni & Levenspiel)*

When the solid particles are fluidized, the fluidized bed behaves differently as velocity, densities of gas & solid particles are varied. It has become evident that are number of regimes as shown in figure 1.

- Regime A- Fixed bed- the particles are at rest.
- Regime B- Minimally fluidized bed: The upward moving gas is able to overcome the gravitational force on the particles. The voidage increases slightly.
- Regime C- As the velocity is increased further, the bubbles are generated. The bubbles coalesce and grow as they rise to the top of bed.
- Regime D- If the ratio of the height /diameter of the bed is high; the size of the bubbles becomes equal to the diameter of the bed. This is called slugging.
- Regime E- When the particles are fluidized at a high enough rate, the upper surface of the bed disappears. Instead of bubbles one observes turbulent motion of solid clusters and voids of various sizes and shapes.
- Regime F- With further increase in gas velocity, eventually the fluidized bed becomes an entrained

bed in which the pneumatic transport of solids take place.

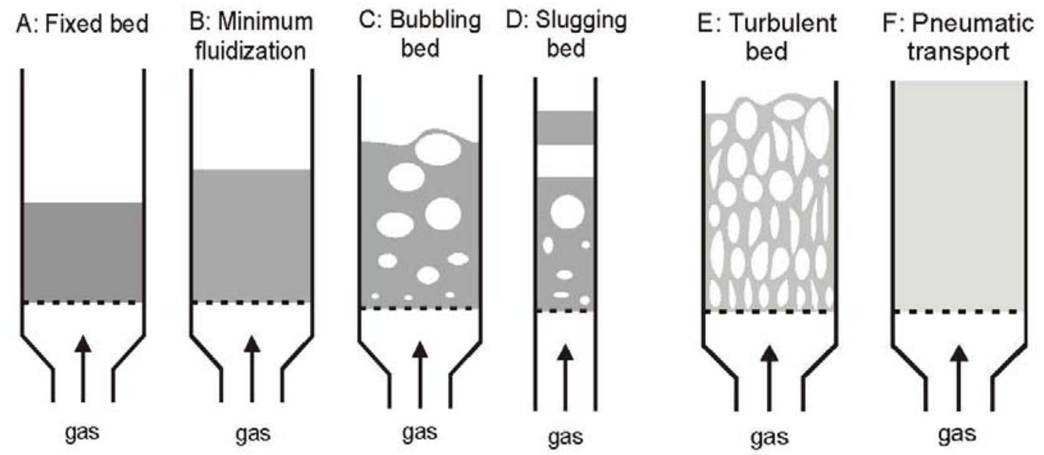

Figure 1: Different regimes of fluidisation

As you might have guessed we are supposed to operate in regime C. But invariably we may land in regime E, where the particles have become coarser. Even coarser particles are seen getting out of the bed.

GELDART CLASSIC CLASSIFICATION OF PARTICLES

Not every particle can be fluidized. The behaviour of solid particles in fluidized bed depends mostly on their size and density. A careful observation by Geldart (1973) is shown in figure 2. There are four different types of materials categorized.

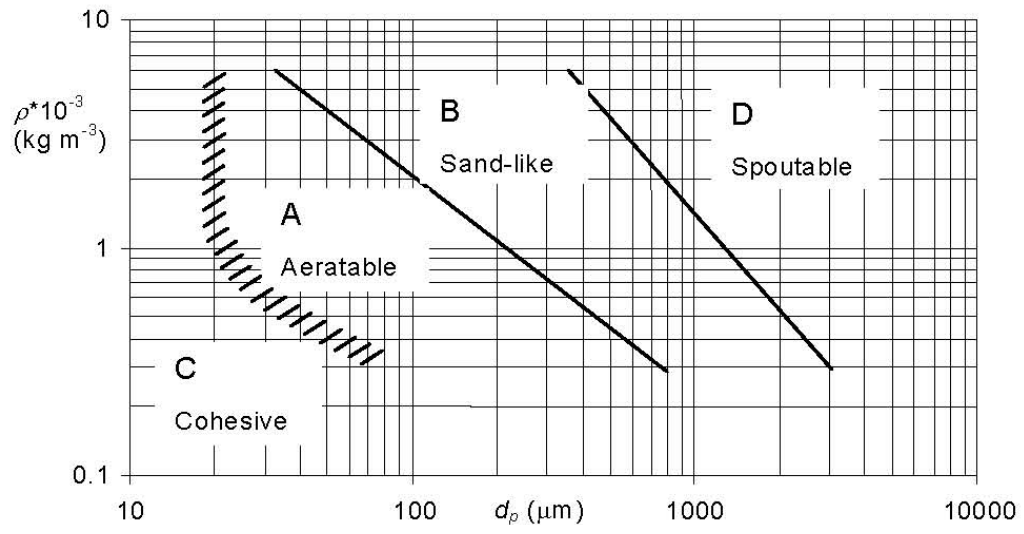

Figure 2: Geldart classification of particles (Geldart-1973)

- Group A- these are designated as '***aeratable'*** particles. The particles have small mean particle size (d_p<30μm) and or low particle density (<1.4g/cm^3). Fluid cracking catalysts are in this category. These solids fluidize easily, with smooth Fluidization at low gas velocities without the formation of bubbles. At higher gas velocity, a point is reached when bubbles start to form and the minimum bubbling velocity, U_{mb} is greater than $U_{mf.}$

- Group B –these are called '*sand like'* particles. Most particles of this group have size range of 150μm to 500μm and particle density is from 1.4 to 4 g/cm^3.
- Group C-these particles are cohesive or very fine powders. Their sizes are less than 30μm. They are extremely '*difficult to fluidize'* because inter particle forces are relatively large. Examples of group C materials are talc, flour and starch.
- Group D –these materials are called, '*Spoutable*' and the materials are either very large or very dense. They are difficult to fluidize in deep beds. As the gas flow is increased, a jet is formed in the bed and material may then be blown out with the jet in a spouting motion. Roasting metal ores are examples of group D materials.

Geldart's classification is clear and easy to use as displayed in figure 2 for Fluidization at ambient conditions and for U less than about $10*U_{mf}$. For any solid of known density and mean particle size this graph shows the type of fluidization to be expected.

FLUIDISATION VELOCITY

Many fluidization velocity correlations are available in text books. A typical correlation found in fluidization engineering by Kunii & Levenspiel is presented below.

$$V_m \approx \frac{g(\rho_s-\rho_g)}{150\mu}\cdot\frac{\varepsilon_m^3}{1-\varepsilon_m}\phi_s^2 D_p^2$$

$$when, \frac{D_p V_m \rho_g}{\mu} \lhd 20$$

The above equation is usable for smaller particle system

$$\frac{1.75}{\varepsilon_m^3\phi_s}\left(\frac{D_p V_m \rho_g}{\mu}\right)^2 + \frac{150(1-\varepsilon_m)}{\varepsilon_m^3\phi_s^2}\left(\frac{D_p V_m \rho_g}{\mu}\right) = \frac{D_p^3\rho_g(\rho_s-\rho_g)g}{\mu^2}$$

$$when, \frac{D_p V_m \rho_g}{\mu} \rhd 20$$

The above equation is usable for coarser particle system

Legend in above equations is as below:

V_m = Minimum Fluidization velocity
ε_m = Void fraction
$Ø_S$ = Sphericity
μ = viscosity of gas
g = acceleration
ρ_p = density of particles
D_p = Diameter of the particle
ρ_g = density of gas

We need to notice the following in the above equations-

**Min Fluidization velocity is proportional to Dp^2 or Dp^3 – depending on the particle size.
**Min Fluidization velocity is proportional to particle density.

The above equations are based in narrow particle distribution. In real life fluidized bed system, we have wider particle size distribution. For example in coal preparation plant from one plant to another we may not have same particle size distribution. From mines to mines the coal ash will be different in terms of composition and thus particle density is going to be different. In some case, we may have complete segregation of particles in to a region of predominantly small particles and a region of predominantly larger particles. The segregation is characterized by the abrupt change in porosity. The picture is same in case the bed has two different particle densities. The picture is shown in figure 3. When the particle sizes fall into a relatively narrow group we would have an intermediate case, as shown in figure 4. The larger size particles (or denser particles) are found grouping at bottom. There is zone where we have a mix of particles. The above theoretical exposure would now help in analyzing our problems in fluidized bed combustion boilers.

REAL LIFE FLUIDIZED BED COMBUSTION SYSTEM

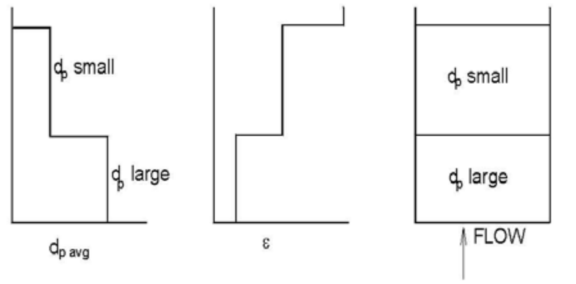

Figure 3: Fluidisation with wider particle distribution / wider particle density difference

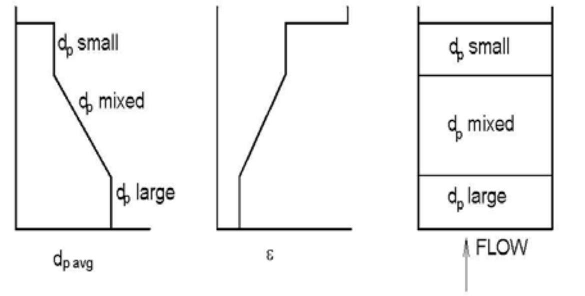

Figure 4: Fluidisation with wider (not too wide) particle distribution / wider particle density difference

In a fluidized bed combustion system, the fuel / bed material is a source of the particles. In the case of coal, the burning particles & and the burnt particles are the main contributors which decide the fluidization behaviour in the bed. The bed material which is used for start up of a bed may be particles which have been sieved from the ash obtained from Fluid bed combustor or it is generally sieved river sand / sieved crushed refractory bricks...

ABOUT SAND

When sand is used as bed material, particles less than 1.5 mm should be used. These particles are generally round in shape. When the sand particle happens to be on the higher size, we can notice that the sand is sharp in nature. Such sand particles are found to be erosive when the bed is not properly fluidized. It is not necessary to remove the finer portion of sand. The sand size range of 0-1.5 mm gets the best combustion of fuels in many installations. Sand is practically a crystallized material and does not have pores.

ABOUT CRUSHED REFRACTORY

The refractory bricks are made from recycled bricks & fresh refractory clay. The old refractory bricks dismantled from ore melting furnaces and many other refractory furnaces are crushed to minus 3mm as part of raw material preparation in refractory manufacturing industry. The refractory grog prepared in this way is screened in 20 & 8 mesh and the material that is lying in between is used as bed material for FBC. This bed material is found to be less erosive. As the density of this material is lesser as compared to sand, the size range is 2.35 to 0.85 (corresponding to mesh numbers 20 & 8). Higher size has been permitted here as the particle density is lower due to presence of pores.

ABOUT FUEL PARTICLE SIZE- COAL FIRED BOILERS

Even if the sand / refractory bed material conforms to required size range, over a period of FBC operation, the entire particles are going to be replaced with the ash particles generated from fuel.

Thus the fuel sizing is very critical for trouble free FBC operation. Ignorance to maintain screen system at coal handling plant can lead to accumulation of oversize particles. Once the over size particles are accumulated, the bed goes for spouting. Even the heavier particles get thrown out of the bed. The loss on ignition would go up if the furnace residence time is less. Otherwise we may not notice it. Again if the coal is reactive with high volatile matter, the unburnt in ash may not go high. In the case of under bed firing, the erosion of bed coils is accelerated due to violent turbulence at fuel feed points. The generation would come down as the particle size increases. This is due to the fact that smaller particles have more surface area to conduct the heat to bed heat transfer surfaces.

ABOUT FUEL PARTICLE SIZE- AGRO FUEL FIRED BOILERS

In the case of agro fuels such as rice husk, de-oiled bran (DOB), ground nut shell the ash from fuel does not contribute to bed particle size. Whatever the bed material used gradually disintegrates and the fines go out of bed. Regular addition of bed material is required in order to maintain the bed height. DOB fired boilers experience peculiar problem of heavier particle generation due to melting of ash. DOB ash melts and agglomerates to over the sand / bed material. More sand will be required to offset the bed particles becoming heavier. In general agro fuels are having lesser density as compared to bed material and they try to leave the bed earlier. Using finer material helps to achieve a good bed expansion and binds the fuel particles better.

Stone ingress in husk fired boilers is well known among old installations. More drains had been added in some cases to bring out the stones. The stone removal by mechanical screen system is not effective. Only way to get the best from these combustors is to resort to frequent draining and recharging screened bed material. Fine sand is the right option for husk fired boilers as the disintegration of the refractory type bed material could increase the operational cost.

ABOUT FUEL PARTICLE DOLACHAR FIRED BOILERS

Dolachar & coal are fired together in boilers used in sponge iron industries. The Dolochar contains iron particles which are heavier. As one can expect the bed can have segregation of particles to bottom of bed. In many cases, the operators ignore this. Once a bed lands in to segregation of particles, there is no way out in the case of flat distributor plate designs. Only open bottom design can pull out the oversize particles which settle at bottom. Alternately sloped distributor plate / DP with many drains can help to control the particle separation. Particles separation when takes place preferential erosion of bed coils is seen.

In these combustors, the generation of bed ash is also more. We may not find a requirement to add bed material. Except for a fresh start up we may not use iron free bed material. Bed coils in these boilers call for early replacement and the availability of the boiler is greatly disturbed due to unscheduled shut downs. In under bed feed system, the erosion of bed coils is localized whereas in overbed the erosion is not so, provided we keep removing heavier lot. If heavier lot is allowed to accumulate, the bed coil erosion is of different kind. The coil is seen eroded in between studs to as in photograph 4. There is a gross erosion of bed coil. All these troubles are related to iron accumulation. They solution could be a continuous bed ash iron removal system. The bed ash must be cooled and discharged to an automated magnetic separator system & over size screen system. The screened bed material should be recharged to bed through a bed material silo and feeder system. In a case where I had visited, the plant in charge had resorted to magnetic plate for removal of iron from bed ash. See photograph 5. Yet the rate of accumulation was so high the iron % in bed ash did not come down. The customer was advised to resort to continuous bed ash removal and recharge system. More bed drains have been advised so that the removal is effective.

CASE STUDY 1- RELATED TO FLUIDIZATION

This is a 90 TPH coal fired AFBC boiler with over bed feed arrangement. The customer was restarting the boiler after a shut down from cold condition after 5 days shut period. The bed material was not changed. Whatever remained before the shut had been used as such. Naturally we can expect that particle range will be right from fly ash dust to coarser ash. As this boiler was provided with over bed start up burners, the height of the bed material had to be kept to 600-700 mm in order to cover up the bed coil. The burner was put on for 3 hrs to raise the boiler pressure slowly and to promote circulation in bed coils & other evaporative circuits. In over bed burner start up system, the bed never gets heated up beyond 150 deg C. The airbox pressure was raised to 800 mmWC and the coal feed was done. The powder content in bed material got separated to the top and gave a picture as if the bed was fluidizing. The bed plate design was checked for MCR pressure drop. It worked out to be 300 mmWC. That means nearly 900 mmWC air nozzle pressure drop will be required to set a cold Fluidization. When the FD fan can not give 1500 mmWC, the question of thorough fluidization can not be achieved. There were temperature differences between bed thermocouples even after 12hrs after start up. In this situation whatever fluidization which was observed was clearly a regime of fluidization with two sets of particle groups. Now to correct the situation I simply drained the bed material from several drain points simultaneously to bring out the coarser fraction of material at the bottom. After 4 hrs, we had seen that all the bed temperatures read the same value. Further, the customer was advised to use finer bed material. I recommended minus 1.5 mm sand. I advised not to discard the finer fraction of bed material that is less than 0.5 mm.

CASE STUDY 2- RELATED TO FLUIDIZATION

This is a coal fired AFBC boiler with under bed feed arrangement. Within 2 months of changing over to new lot of imported coal, the plant suffered bed coil erosion. The unit experienced severe iron accumulations in bed ash. It was as high as 33%. The source was found to be the high iron content in coal ash itself. A model calculation done proved that we need to increase the fresh bed material feed rate to 25% of fuel feed in order to limit the iron in bed ash to 5.6%. Incidentally more the iron content in coal, the ash fusion temperatures could be lower. The bed may begin to generate clinkers as well (see photo).

Table 1- Ash analysis summary – Fe_2O_3 has increased in recent coal supply.

Ash constituents	Bed ash at present	Bed material	Coal used before Failure		Coal –used of late
			Coal 1	Coal 2	
SiO_2	27.11	53	48.27	56.79	35.09
Al_2O_3	15	34.5	26.31	27.36	19.46
Fe_2O_3	33.4	0.8	6.12	6.19	29.88
CaO	0.234	3.5	9.65	3.19	5.28
MgO	0.56	2.1	1.4	0.53	1.91
Na_2O	2.898	-	1.2	0.81	1.34
K_2O	0.31	-	0.87	1.41	2.2
SO_3	-	-	0.244	0.2	0.49

CASE STUDY 3- RELATED TO FLUIDIZATION

This was a rice husk fired boiler. The customer experienced severe polishing of bed tubes. The steam generation had come down drastically. Rice husk fired boilers need regular make up of bed material. When I visited I found the bed ash drained from the bed was heavier. When checked up with a magnet we noticed that the bed ash contained 40% iron. The source of iron was found to be the bed material itself. The crushed refractory as explained earlier is made from crushing used bricks removed iron melting furnaces. Naturally the iron content in the crushed material has to be more. The vendor did not separate the iron which was the normal process used for making refractory bricks to meet the IS 8 specification bricks. The customer was advised to change over to fine river sand.

CASE STUDY 4- RELATED TO FLUIDIZATION

This case is a 100 TPH Boiler which was designed for high DP drop operation by design. The cold Fluidization was checked by me in person. With a bed height of 300 mm and with air box pressure of

1000 mmWC, the bed did not fluidize. I requested the customer to change over to finer bed material for start up. I explained that the bed would not fully fluidize. I have enclosed photo 5, which proved that the bed did not fluidize even after 12 hrs after the coal feeding was commenced. I recommended that fresh fine bed material had to be added to large extent simultaneously drain the bed that did not fluidize initially. Cold fluidization is being ignored by many in the recent boilers which were provided with overbed start up burners. When the bed is designed with hot air generator this would not be a problem. Had the boiler been provided with charcoal start up burner lances, the boiler would have never started. It would have experienced clinkering every time. In fact I had attended a case where the client got the entire set of air nozzles replaced with higher diameter holes to have the cold fluidization.

FINAL WORD

Boiler operators need to realize the importance of the right size of bed material with the right particle density is important for a thorough Fluidization. Use of mechanized bed ash / bed material screen system, regular sieve & ash analysis of fuel, regular measurement of sieve analysis bed ash, frequent check in iron content of bed ash & bed material would help to improve get the best from the AFBC boilers. Manufacturers need to realize that the additional drains are a must for smooth operation of FBC boilers. High DP drop in bed would give problems in setting the cold Fluidization. Cold Fluidization inspection should be part of start up process and can not be compromised.

Photo 1-heavier particles are thrown in bed

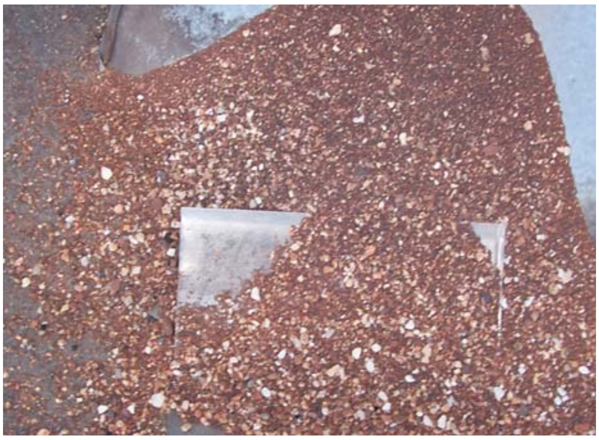

Photo 2- heavier particles collected at inspection door.

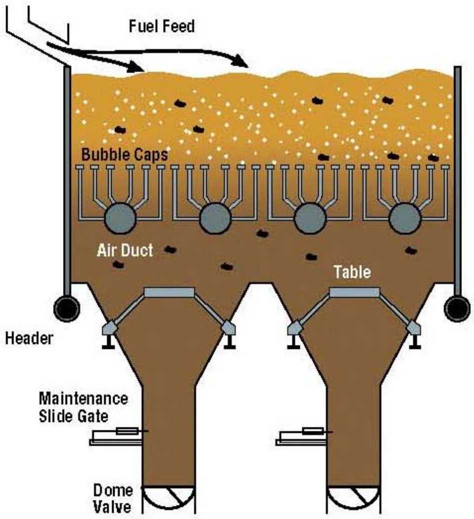

Photo 3-Open bottom furnace originally designed by B&W

Photo 4- bed coil erosion in overbed fed boiler. The heavier particles settling at bottom of the bed has caused erosion.

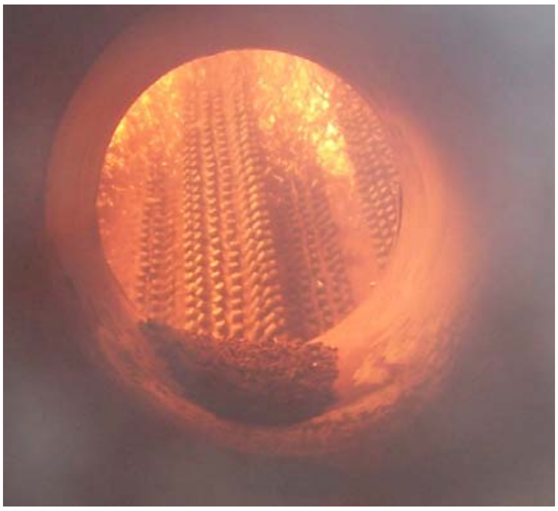

Photo 5-Improper fluidization –High DP drop

Photo 6- Fusion of ash in case of high iron.

Photo 7: A sample of bed ash was checked in a boiler where the total bed defluidized due to iron containing bed ash particles. The weight % of iron containing particles is found to be 51.9%.

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