# CHAPTER IV

# FLUIDIZED BED COMBUSTION

Although fluidized bed combustion (FBC) has received increasing importance as a national objective in the area of energy development during the past few years in many countries, no significant work have been done in Thailand. The need for full understanding of the FBC systems is without question and the development of FBC technology in this oountry is also essential for the full and efficient utilization of two of the country important natural resources, ie. lignite and oil shale.

## 4.1 Basic Technical Terms

For clear understanding in the oncoming sections, the following terminologies must be understood[13]:

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|---|---|
| Bed | A place where an action or reaction take place. |
| Elutriation | The lifting out of the small elements in a mixture of solid particles by a stream of high speed gas. |
| Fluidization | The state of suspending particles in a rapidly moving stream of gas or vapor, the particles are close enough together and interact in such a manner that they give the impression of a boiling liquid. |
| Fluidized | A gathering of small solid particles |

| | |
|---|---|
| Bed | maintained in balanced suspension against gravity by the upward motion of a gas or liquid. |
| Fluidized Bed Combustion | The burning of fuels in a fluidized bed. |
| Residence Time | The period of time spent by a typical particle in a particular zone of a fluidized bed. |

## 4.2 Basic Principles of Fluidization

In FBC the packed bed consists of solid materials confined in a vessel, usually cylindrical in shape. The force of gravity causes the solid materials to pack together inside the vessel. The relative position of the packed material remains constant without the application of additional forces. The packing material rests on a distributor which, as the name implies, is employed to keep upflowing fluids (gases or liquids) evenly distributed inside the packed bed, and which supports the gravitational weight of the packed materials.

If a stream of air is introduced at the bottom through the distributor, the pressure drop across the packed bed, $\Delta P$, which is monitored by a manometer, increases as the velocity of gas, V, through the packed bed increases. At the beginning, the pressure drop varies linearly with the gas velocity, but, as the velocity increases, the pressure remains steady. At this point the surface of the packed bed is absolutely level as if it were a liquid. This is the transition point at which the packed bed has become a fluidized bed.

If the gas velocity is further increased, sufficient air is introduced to "fluidize" the packed bed by causing the packing material to be suspended, and to behave like a fluid. The gravitational force acting on the solid is balanced by the action of the frictional force exerted by the upflowing air.

Minimum fluidization is generally not a clear-cut point. It possesses the following characteristics:

- The top bed surface becomes level, which is indicative of fluid behavior.
- The interparticulate contact is no longer continuous. Unlike the packed bed it cannot transmit a force along the direction of application.
- There are no visible gas or air bubbles. The movement of air inside an incipient or minimum fluidized bed is in a dynamic steady state, no accumulation of gas which forms bubbles is observed.

There is no clear-cut minimum or incipient fluidization velocity for bed materials with appreciable interparticle attractive forces or with a wide range of particle sizes. The minimum fluidization velocity can be measured or observed by an indirect method from a pilot of bed pressure drop versus the fluidization or superficial gas velocity (the actual gas volumetric flow rate divided by the cross sectional area of the empty vessel which will contain the fluidized bed).

For most bed material of uniform size, the classical plot of bed pressure drop versus velocity exhibits a hysteresis effect. This is shown in Figure 4.1. The plot differs for increasing and decreasing velocities. A bump in the curve is observed for increasing gas velocity which is attributed to the interparticle attractive forces against which extra force is required to disperse the particles.

For particles of wide size distribution, the pressure drop versus velocity plot exhibits a smooth increase; this is shown in Figure 4.2. The gas velocity at which fluidization begins is hard to determine by visual observation. The lack of the clear-cut inflection in the curve for minimum fluidization is probable due to the localized fluidization of fine particles which gradually fluidizes the entire packed bed. Fines may fluidize in the interparticle space, and the fluidization process then gradually spreads throughout the packed bed. Consequently, the sudden transition of packed bed into a fluidized bed is not clearly demonstrated.

As the gas fluidization velocity is further increased, the gas can no longer pass through the interstices between the bed particles without the formation of gas bubbles. The gas bubbles inside a fluidized bed will cause the volume of the bed to expand. The upward movement of the gas bubbles promotes in-bed solid-solid mixing, though a bubble will retard gas-solid contact for the gas trapped inside the bubble.

If the velocity of fluidization air continues to increase, the bed materials become entrained. Instead of remaining inside the confines of the vessel, the bed

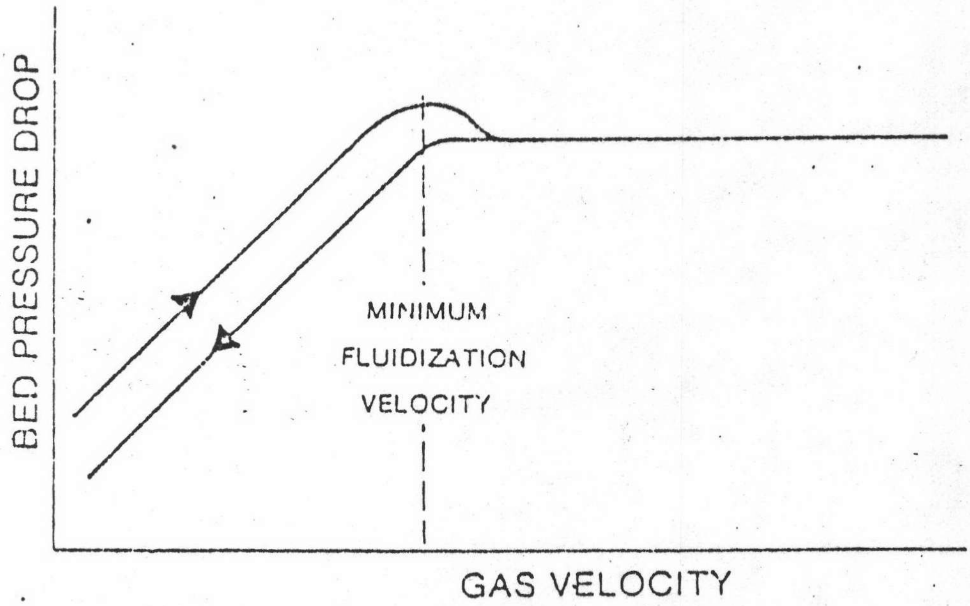


Figure 4.1

Bed Pressure Drop Versus Gas Velocity

Showing Hysteresis Effect[14]

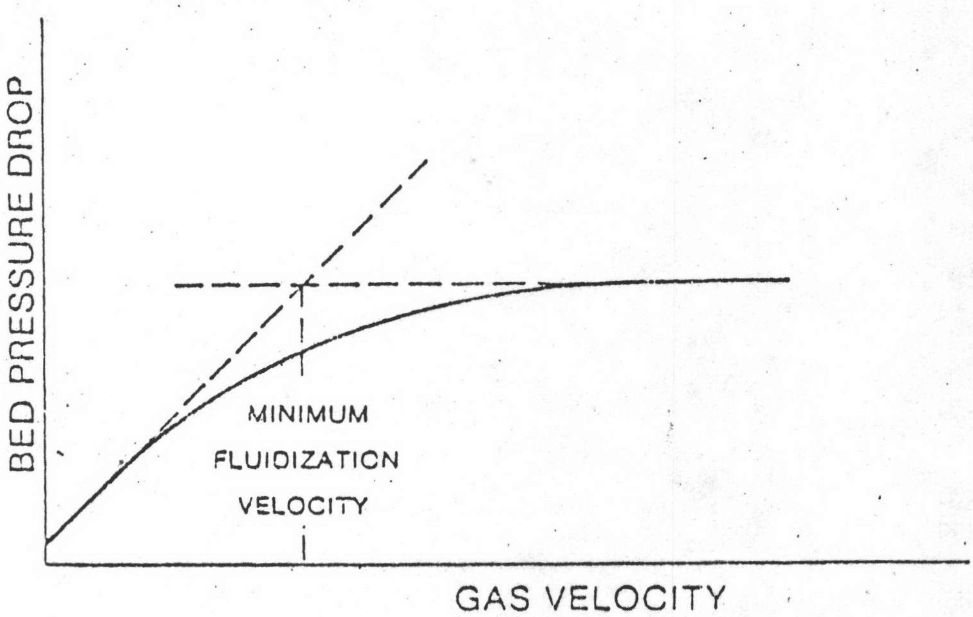


Figure 4.2

Bed Pressure Drop Versus Gas Velocity

for Particles of Wide Size Distribution[14] materials are blown out of the bed in a manner almost identical to pneumatic air conveying. No bubbles are formed. If the bed materials are not continuously replenished, no bed material will remain inside the vessel. This phenomenon is known as bed entrainment.

To this end, we deem that all fluidized bed operations are bracketed by the incipient/ minimum fluidization and entrainment/ dilute phase flows[14].

## 4.3 Basic Components of a Fluidized Bed Combustion Boiler

In Figure 4.3, a schematic diagram depicts the basic components of an FBC boiler. Air is supplied from a blower or compressor. This air may be preheated by exhaust flue gas (gaseous products of combustion) from the fluidized bed combustor. The preheated air enters the plenum, an air chamber under the air distributor. The plenum serves as a surge tank which tempers air surges and pressure pulses from the piping system and the air mover. The air distributor's main function is to evenly distribute the air which enters the fluidized bed.

Solids, such as oil shales or coal, and limestone or other sulfur adsorbents are fed into the fluidized bed by pneumatic air conveyers, screw feeders, or stoker spreaders. Because of vigorous mixing, the temperature profile is uniformly distributed. This is one of the reasons the fluidized bed is considered to be among the best chemical reactors when back-mixing and a high rate of heat release are required.

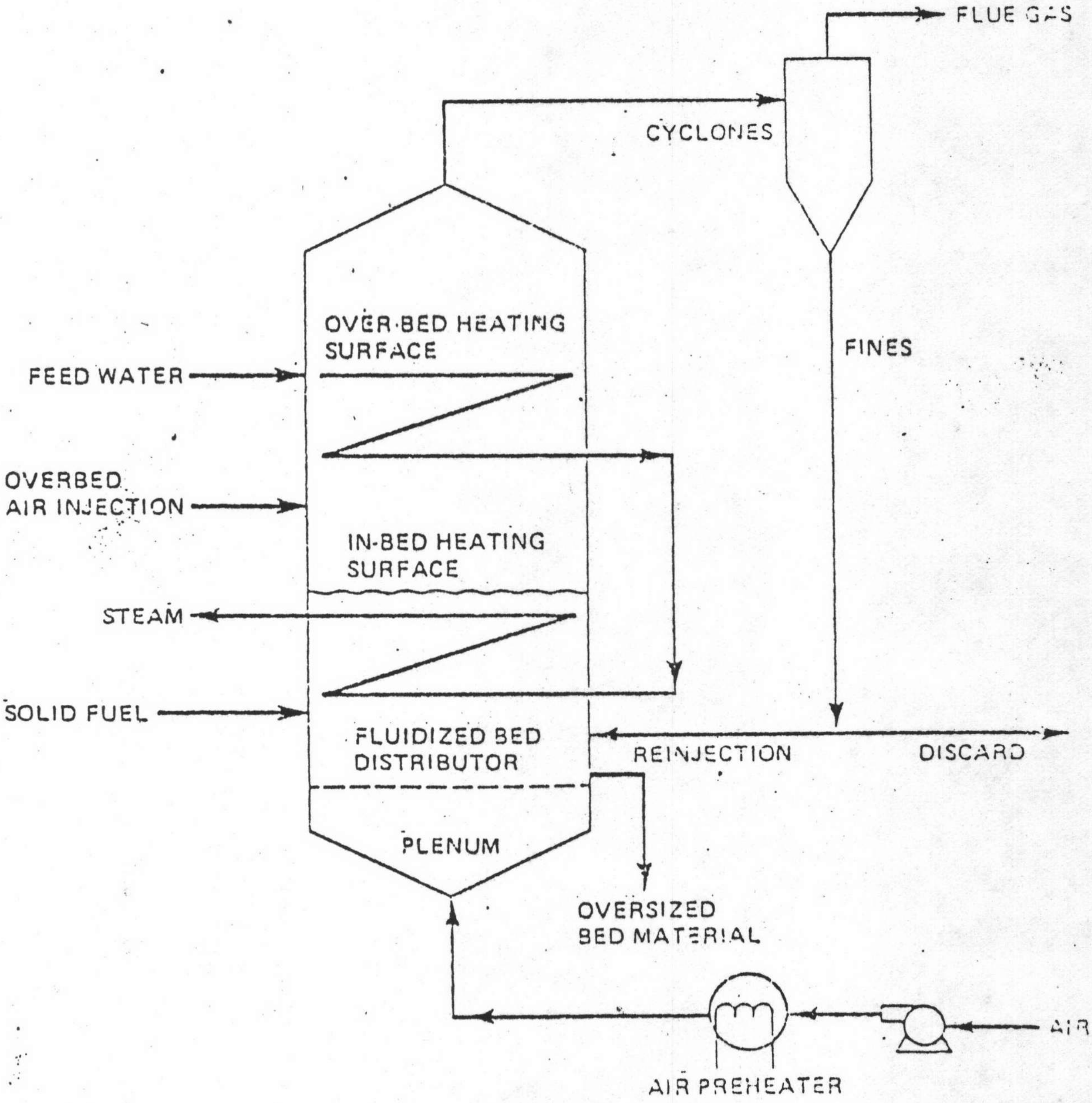


Figure 4.3

Basic Components of Fluidized Bed Combustion Boiler[14]

Bed material is constantly withdrawn from the fluidized bed through or along the distributor. In deep-bed fluidized beds, sufficient residence time is allowed for uniform mixing. In shallow fluidized beds, lateral mixing may not be as uniform as in deep fluidized beds. This is the reason why more than one feeder is required for large FBCs.

Heat transfer surfaces in the form of water wall and tube bundles are immersed in the fluidized bed. Over-bed heat transfer surfaces can also be provided to recover heat energy in the over-bed (freeboard) space. The over-bed heat transfer mechanism is not drastically different from that of a conventional boiler.

Because of the considerable solid entrainment caused by high fluidization velocities, some unburned carbon fines may be carried over into the over-bed space. These carbon fines may react with oxygen or with carbon dioxide and form carbon monoxide in the freeboard region. To insure complete combustion, maximum thermal energy recovery, and to expedite the relaxation of nitrogen oxides, two remedial provisions are made: fly ash reinjection and over-bed secondary air injection. The fines are collected in a cyclone train placed above the fluidized bed to collect the carried-over particles.

The flue gas effluent from the cyclone goes to the secondary particulate recovery system, which could either be a bag filter house, an electrostatic precipitator, or some combination of both. In some cases, a final high-energy water scrubbing system is used to control particulate emission[14].

## 4.4 Performance of a Fluidized Bed Combustion Boiler

A fluidized bed combines the physical characteristics of both a solid and a liquid. The combination has found many uses in the chemical industry and elsewhere. In a fluidized bed combustor the bottom of the firebox is filled with granular inert particles of sand, limestone or ash. Air is blown up through holes or pores in the floor of the firebox, making the particles into a fluidized bed. Fuel is fed into this bed. The fuel may constitute less than one percent of the material in the bed. But, as fuel burns; it makes all the inert particles red hot. The surface of the bed looks like bubbling molten lava. The turbulence of the churning bed keeps the temperature stable, so that the bed does not get rapidly hotter or cooler. Heat is transferred within the bed, and from the bed to the surrounding walls or boiler tubes, by the direct impact of the glowing particles. This direct impact allows a much higher rate of heat transfer than there is in a conventional boiler. The magnitude of the heat transfer coefficient is 200 to above 500 $w/m^2/^\circ c$ compared with 70 $w/m^2/^\circ c$ in conventional boilers[15].

As fresh fuel is added, even though it may be much cooler initially, its temperature rises rapidly to that of the whole hot bed. Accordingly, even very low-quality fuel can be burned, e.g., low-grade coal, urban refuse, even wet sludge, materials which could not be burned in any conventional firebox.

Because the heat is deliveried by the direct impact of particles, a fluidized bed combustor can be operated at a temperature much lower than that in the firebox of a conventional combustor. The low operating temperature makes it possible to reduce dramatically the formation of nitrogen oxides. Furthermore, at such a temperature, any product of burned fuels does not melt. This avoids the problems caused by molten ash, including corrosion of boiler tubes.

The fluidized bed transfers the heat out of the bed comparatively rapidly. It is therefore possible to produce more heat output per unit time in a given volume of firebox. Accordingly, a fluidized bed combustor can be physically much smaller than a conventional combustor of the same heat output. This in turn means that the fluidized bed combustor is likely to cost less, may be built more rapidly, and transported more easily.

## 4.5 Classification of FBC

FBC may be classified according to combustion pressure into atmospheric (AFBC) and pressurized fluidized bed combustion (PFBC). Volume reduction, smoother fluidization characteristics, and potential topping power generation cycle applications have led to the use of higher than atmospheric pressure in FBC systems in the process of PFBC. PFBC is currently in the developmental stage. Its success hinges on the satisfactory development of hot gas cleaning system. Moreover, sticky matter, alkali metal concentrations, and particulate size distribution and concentration should be reduced to a sufficiently low level for gas turbine applications.

## 4.6 Advantages and Disadvantages of FBC Boiler[14-18]

The FBC boiler has both desirable and undesirable characteristics. These are brought out by comparing its behaviour with that of other boilers and may be summarized as follows:

### 4.6.1 Advantages

- The FBC boilers are basically simple since no mechanical moving parts are involved in the fluidization, and therefore are simply constructed; they can be manufactured and operated easily and cheaply without sophisticated control instrumentation or highly trained operators.

- The rapid mixing of solids leads to nearly isothermal conditions throughout the bed, ie. a very high effective internal thermal conductivity.

- Heat and mass transfer rates between gas and particles are high.

- The rate of heat transfer between a fluidized bed and an immersed object is high, hence it permits a high degree of heat recovery to be tapped directly from the bed, therefore resulting a lower combustion temperature for a given steam condition which, in turn, the fouling and corrosion of tubes by volatilized alkali compounds can be substantially reduced.

- The state of fluidization and the presence of a thermally stable bed material inside an FBC boiler allows for the controlled combustion of a wide variety of fuels, including those with high ash content (up to 70 %), low heating value (2,000 Btu/lb or less), and high water content (in excess of 120 % moisture content). It is not sensitive to the volatile and the ash content of the fuel burned and also the nature of the latter.

- The low combustion temperatures prevent vitrification of the ash particles, causing them to be less abrasive than ash from other boiler types.

- FBC is not hindered by a wide range of fuel sizes. The costs of fuel crushing should be reduced, since fine grinding would be unnecessary.

- The major pollutants resulting from the combustion of solid fuels are $SO_x$, $NO_x$, particulates, and trace elements. FBC is far superior in handling all these pollutants, with the exception of particulates.

- FBC boilers have a high heat load per unit grate (distributor) area which is about 3 or 4 times larger than that of a conventional boiler. The combustion volume, where the fluidized combustion takes place, can be made more compact; therefore, the initial investment for an FBC boiler can be much less than for conventional boilers of comparable heat duty. The relative heat load per unit boiler volume for an FBC boiler is 10 times larger than that of a pulverized coal-fired boiler, and 4 to 5 times larger than that of a stoker-fired boiler. Moreover, the heat transfer coefficient inside an FBC boiler is about 5 to 10 times higher than in a conventional boiler. Consequently, the iron and steel requirements for an FBC boiler are much lower than for a conventional boiler.

4.6.2 Disadvantages

- When burning fuel with low reactivity, like anthracite, anthracite culm, or oil shales, the elutriated fly ash contains a considerable amount of unburned carbon. Burning the carbon in the fuel requires a finite amount of time at sufficiently high temperatures. When fine particles are fed to the bed, the lower temperature in the freeboard, the short residence time in the combustion zone, and carbon elutriation all take their toll on carbon burning efficiency. When burning anthracite about 70 % of the anthracite ash is elutriated as fly ash with up to 30 % unburned carbon. The high elutriation rates requires attention to discover means to improve carbon combustion efficiency and to provide an adequate dust recovery system. Current endeavors include using a carbon burnup cell and/or a fly ash reinjection system.

- FBC boilers require a blower to provide the fluidization pressure head, which can be substantial. A substantial pressure drop across the distributor is necessary to maintain the desired flow uniformity.

- The vigorous and continuous contact of the bed material with FBC boiler components may result in erosion of the contact surfaces.