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Design Aspects of Bubbling Fluidised Bed Boiler for Municipal Solid Waste

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***Abstract:* Continuous growth in global municipal waste, increasing legislation and an acute shortage of suitable landfill sites are a serious concern for a sustainable environment. The generation of municipal solid waste (MSW) is found to increase with increasing population. Fluidized bed combustion technology gives solutions to the municipal waste disposal. Bubbling fluidized bed combustion technology is emerging as a potential technology for incineration of all solid wastes and have advantages over other types in concern of emissions of gases which affect environment.**

The present work deals with the design of furnace with heat load estimations for optimal conditions to recover energy from municipal solid waste. The geometrical dimensions are estimated taking few constraints into consideration to handle the requisite amount of waste and generating steam out of waste.

Keywords: Types of solid waste combustors, Municipal solid waste, Fluidization,Bubbling fluidised bed, furnace load calculations

I. INTRODUCTION

Rapid urbanization and municipal refuse is rapidly increasing with rate of population growth especially in a few decades has led to increase in MSW (Municipal Solid Waste) generation in India.MSW has always a great challenge to Urban Local Bodies in India. It is estimated that a typical urban area in India disposes 0.6kg/man-day and it is increasing at a rate of 1.3% per year due to rise in per capita purchase potential. It is also estimated that the waste production will go up to 1.5 kg/man-day. This is low compared with developed countries where refused generation is of order of 3kg/man-day. But due to high density of population in India the refuse produced is quite larger.

Processing of waste and final disposal is in unscientific dump sites, posing problems of ground water contamination and air pollution. This is refuse is disposed in the form of land filling or incineration. This method is commonly used in India. Land filling contributes least to air pollution problem but requires large and suitable land sites,. Recently, attention has been given in India to incineration as a medium for refuse disposal.

In the incineration process, hydro carbon compounds of the combustible refuse combines with O_2 to form CO_2 and water and leave the minerals and the metals as solid residue.

The oxidation releases high energy which can sterilize the residue, destroy odorous compounds and convert the waste into vapor which together with CO_2 becomes an acceptable exhaust. Combustion of municipal refuse produces a significant amount of heat. This heat can be easily recovered in FBC system by the gas which can be further used for power generation. In addition to power, the materials like metals, ash and glass are recovered in FBC system.

The metals are sold as scrap; glass is sold to glass manufacturers. The ash is collected is used for cement production or stabilizer for road or fill materials. Our city Visakhapatnam has made some efforts in the few years to improve the MSW. There is still a need to make substantial improvement in MSW system of the city. An effort has been made to solve the above problem of a handling MSW using FBC.

A. Waste Characterization

To evaluate the feasibility of destroying a hazardous waste material by incineration, one must know the physical form, elemental composition, heat content, water content and ash and organic compounds of the waste. The necessary equipment can be determined and regularity concern can better be addressed with such a complete knowledge of waste.

Increased regulation of hazardous waste disposal also makes selection of the correct equipment even more critical, state and local standards are requiring hazardous waste to be incinerated with the best state of the art equipment. The relevant waste characteristics needed to select design and evaluate an effective incineration system.

B. Msw processing techniques

There are several MSW processing technologies which are being followed in various parts of the world. Further, it is to mention that out of the various processing technologies, the technologies which are being used considered for use in Indian conditions are:
(i) Composting, (ii) Anaerobic digestion to recover biogas and electricity, (iii) Refuse Derived Fuel and (iv) Pyrolysis, as below under different technical groups
For now we are following thermal processing technologies especially to convert waste to useful form of energy efficiently by burning them in different forms by considering the environment norms. There are different types of solid fuel combustors are available to burn solid fuel in different mechanism and classified according to way of combustion and type of fuel determine processes occurring inside combustion chamber. Combustion technology has a strong influence on a mechanism of heat transfer to surfaces and overall thermal efficiency of the process.There are types of solid fuel combustor are a) Grate firing b) fluidizing technology.

C. Fluidization

Fluidization is a process similar to liquefaction whereby a granular material is converted from a static solid like state to a dynamic fluid like state. This process occurs when a fluid (liquid or gas) is passed up through the granular material. When a gas flow is introduced through the bottom of a bed of solid particles, it will move upwards through the bed via the empty spaces between the particles.
At low gas velocities, aerodynamic drag on each particle is also low, and thus the bed remains in a fixed state. Increasing the velocity, the aerodynamic drag forces will begin to counteract the gravitational forces, causing the bed to expand in volume as the particles move away from each other. Further increasing the velocity, it will reach a critical value at which the upward drag forces will exactly equal the downward gravitational forces, causing the particles to become suspended within the fluid. At this critical value, the bed is said to be fluidized and will exhibit fluidic behavior. By further increasing gas velocity, the bulk density of the bed will continue to decrease, and its fluidization becomes more violent, until the particles no longer form a bed and are “conveyed” upwards by the gas flow.

When fluidized, a bed of solid particles will behave as a fluid, like a liquid or gas. Like water in a bucket the bed will conform to the volume of the chamber, its surface remaining perpendicular to gravity objects with a lower density than the bed density will float on its surface, bobbing up and down if pushed downwards, while objects with a higher density sink to the bottom of the bed.

D. Mechanism Of Fluidized Bed Combustion

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream the bed is called “fluidized”. With further increase in air velocity, there is bubble formation, vigorous turbulence, rapid mixing and formation of dense defined bed surface. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid “bubbling fluidized bed”.
At higher velocities, bubbles disappear, and particles are blown out of the bed. Therefore, some amounts of particles have to be recirculated to maintain a stable system "circulating fluidized bed".

E. Features Of Bed Mechanics

Fluidization of most materials entails bubbles formation in the bed volume. But the moment when bed starts “bubble” and mechanics of the process depend strongly on a type of bed material. Classification suggested by D. Geldart based on density and size of particles (fig.3.6). It divides particulate material into four groups. *Group A* includes materials consist on particles of small size and low density (less than 1400 kg/m^3). Fluidization of such materials is achieved before the moment when bed starts to bubble. In bubbling fluidized bed gas velocity in particulate phase is lower than in bubbles. *Group B* is formed by materials of medium particle size and density. Most of inert bed materials (river sand, olivine) belong to this category. Bubbles occur in the bed of such materials right in the moment when minimum fluidization velocity is achieved. Gas in bubbles has velocity higher than in the particulate phase. Materials of *C group* are finepowders with predeposition to formation of channels hindering fluidization. *Group D* consists on materials from high-density coarse particles. During the fluidization of such materials air velocity in particulate phase is much higher than velocity of rising bubbles. Bubbling fluidized bed boilers use mainly materials of the group B (closer to the boundary with D group).

II. DESCRIPTION OF BUBBLING FLUDIZED BED

A bubbling fluidized bed boiler comprises a fluidizing grate through which primary combustion air passes and a containing vessel, which is either made of (lined with) refractory or heat-absorbing tubes. The vessel would generally hold bed materials with or without heat absorbing tubes buried in it. The open space above this bed, known as freeboard, is enclosed by heat-absorbing tubes.

The boiler can be divided into three sections, (1) Bed, (2) Freeboard,(3). Back-pass or convective section.

Including that above three main parts BFB boiler system may be divided into several subsystems, which are elucidated in the following sections with reference to (Figure):

Feedstock preparation, transport, and flow-rate control

Combustion

Air and flue gas handling

Ash handling system and emission control

Steam generation

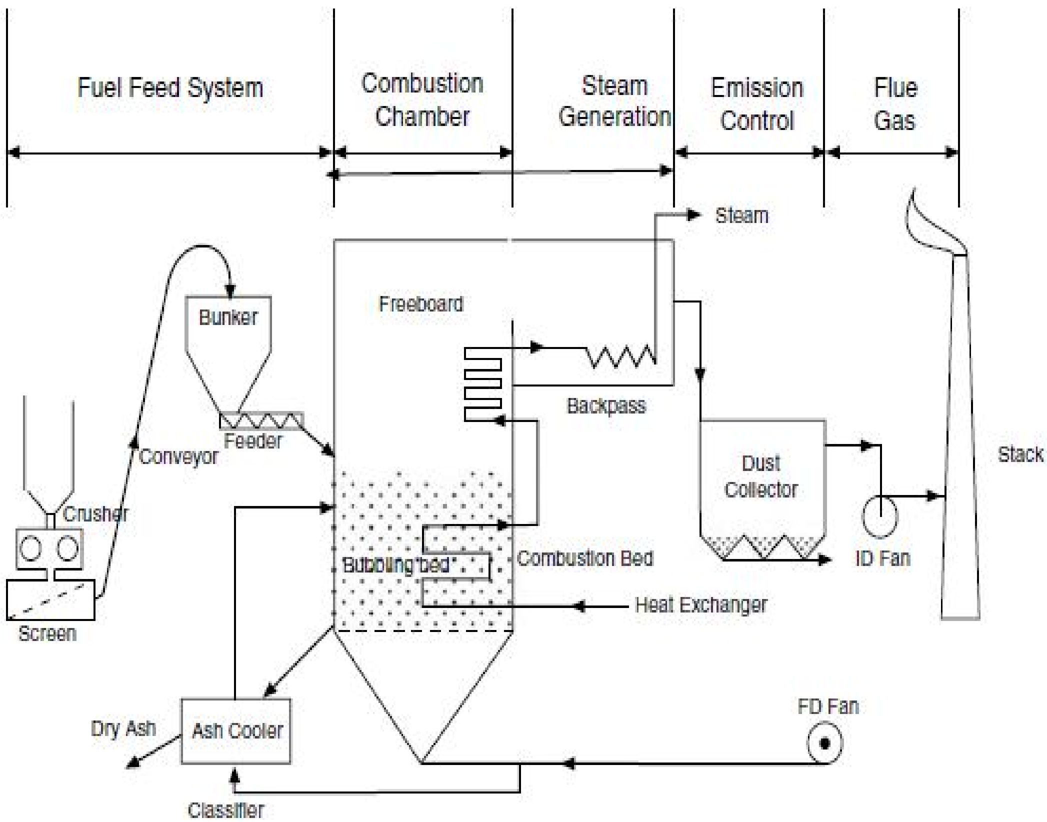


Fig.4.1. Schematic of a bubbling fluidized boiler system

A. Feeding System

The feed system of a bubbling fluidized bed (BFB) boiler performs the following tasks:

1) Crush coarse or lump fuel particles into desired sizes (0 to 12 mm).

2) Feed the crushed particles into the bed evenly.

Feed system should be designed simple for easy maintenance in such a way that it should perform the above tasks effectively and also to achieve high combustion efficiency, reduce unburned carbon loss, to increase the residence time of feed particles in the combustion zone.

B. Bubbling fluidized bed boilers use two types of feed systems:

1) Over-bed system

2) Under-bed system

C. Sorbent Feeding System

Boilers requiring sulfur capture must have a limestone crushing, conveying, and feeding facility. The sorbents are generally ground to finer sizes (6 mm) and then conveyed pneumatically and injected into the bed.

D. Air Distribution

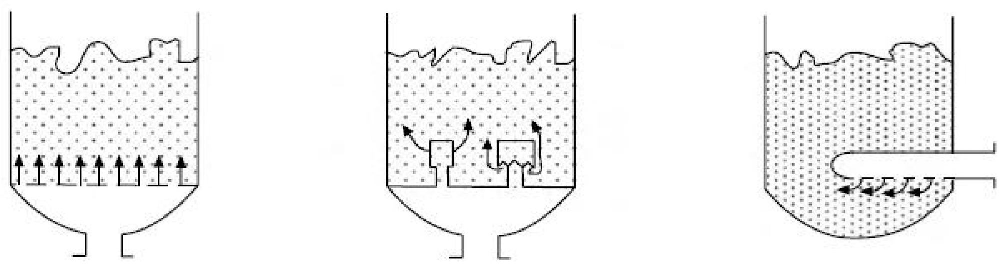
The combustion air is sometimes preheated in the air heater. The primary air enters the bed through a grate called a distributor, which helps distribute the air uniformly across the bed and prevent solids from dropping into the air plenum below. Design of this component is more critical to the operation of BFB boilers than that for CFB boiler.

Distributor plates can be broadly classified into three groups:

1) Porous and straight-hole orifice type plates generally use punched or drilled verticalholes through a plate or sintered plates. It is also called a plate-type distributor.(fig a)

2) Nozzle-type or bubble cap-type uses nozzles, which distribute air into the bed through horizontal vertically, or downward holes. (Fig b)

3) Sparge pipe-type which comprises of air-carrying tubes with holes. These are introduced directly into the fluidizing bed without a grid plate or a plenum box below it (Fig c)



(a) Plate (b) Tuyere (c) Sparge

E. Combustion Chamber

The furnace of a BFB boiler typically comprises a dense bubbling bed and a lean freeboard above it. These two parts constitute the furnace or combustion chamber. The energy released from the combustion of fuels is split between the fluidized bed and the freeboard approximately in the percentage ratio of 88:12. The temperature of the bubbling bed (also called dense bed) is generally maintained between 800 and 900^{0}C by extracting appropriate amounts of heat.

The lower bed of a biomass-fired boiler is generally refractory-lined while that of a fossil fuel fired boiler may be made of evaporator tubes. The latter type of boiler often has additional evaporator or Superheater tubes immersed in the bed for effective heat absorption. The height of the dense bed typically varies between 0.5 and 1.5 m and the average size of the solid particles (bed material) is around 1 mm and they may be sand, limestone, or ash. The large mass of well-mixed hot solids allows BFB boilers to efficiently burn even hard-to burn fuels. Thus a wide range of fuels like coal, paper sludge, anthracite, paddystraw and fluid coke etc., can burn in a BFBboiler with minimum air pollution

F. Ash Handling System

1) Bottom Ash Removal: In the FBC boilers, the bottom ash constitutes roughly 30 – 40 % of the total ash, the rest being the fly ash. The bed ash is removed by continuous over flow to maintain bed height and also by intermittent flow from the bottom to remove over size particles, avoid accumulation and consequent defluidization. While firing high ash coal such as washery rejects, the bed ash overflow drain quantity is considerable so special care has to be taken.

2) Fly Ash Removal:

The amount of fly ash to be handled in FBC boiler is relatively very high, when compared to conventional boilers. This is due to elutriation of particles at high velocities. Fly ash carried away by the flue gas is removed in number of stages; firstly in convection section, then from the bottom of air preheater/economizer and finally a major portion is removed in dust collectors.
The types of dust collectors used are cyclone, bagfilters, electrostatic precipitators (ESP's) or some combination of all of these. To increase the combustion efficiency, recycling of fly ash is practiced in some of the units.

G. Emission Control System

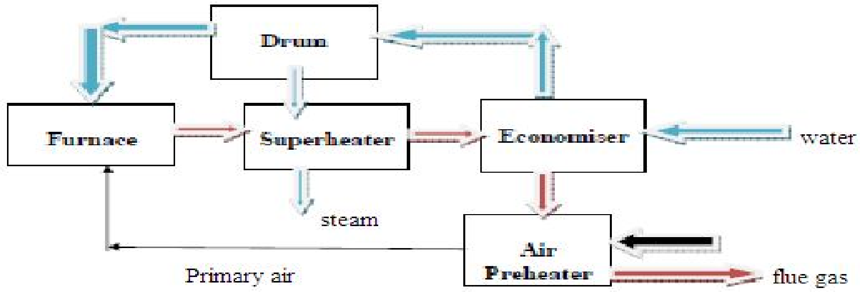
The low combustion temperature (800 to 900^{0}C) creates favorable conditions for reductions in the emissions of NO_x and sulfur dioxide in a BFB boiler. Thus, the flue gas, leaving a BFB boiler with limestone injection, is relatively free from harmful gases like SO_2 and NO_x. As a result, a well-operated fluidized bed boiler does not need post-combustion units like SCR for reduction of harmful gas emissions. However, for the control of mercury or for meeting exceptionally low SO_x emission standards some plants use a scrubber followed by a bag filter or ESP.
:Amount of Fuel-bound nitrogen, a high nitrogen proportion in the fuel increases formation of nitrogen oxides.
Excess air ratio and combustion temperature, NOx formation increases with combustion temperature and with excess air ratio.

H. Flue Gas Path

Flue gas, generated in the bed, rises into the freeboard and then exits the furnace from the top. The gas leaves the bed at bed temperature (800 to 900^{0}C) and cools down to 500^{0}C after losing heat to the Superheater (SH) or reheater. After leaving the freeboard, the gas passes through the convective section, which may accommodate the bank tubes, super heater, reheater, economizer, and air heater as the design demands. Finally, the gas is discharged to the atmosphere through the stack. The flue path shown in figure

I. Circulation And Steam Generation System

The steam/water mixture is inside the tubes in water tube boilers, and is heated by external combustion flames and flue gases. The water tube boilers are classified by the way of the water/steam circulation: natural circulationforced or assisted circulation, once-through and combined circulation type boilers. The water/steam circulation begins from the feed water tank, from where feed water is pumped. The feed water pump raises the pressure of the feed water to the wanted boiler pressure. In practice, the final steam pressure must be under 170 bar in order for the natural circulation to work properly. The feed water is then preheated in the economizer almost up to the boiling point of the water at the current pressure. To prevent the feed water from boiling in the economizer pipes, the water temperature out of the economizer temperature is on purpose kept about 20-30 degrees under the boiling temperature. From the economizer the feed water flows to the steam drum of the boiler. In the steam drum the water is well mixed with the existing water in the steam drum. This reduces thermal stresses within the steam drum. The saturated water flows next from the steam drum through down comer tubes to a mud drum (header). There are usually a couple of down comer tubes, which are unheated and situated outside the boiler.
The name "mud drum" is based on the fact that a part of the impurities in the water will settle and this 'mud' can then be collected and removed from the drum. The saturated water continues from the header to the riser tubes and partially evaporates. The riser tubes are situated on the walls of the boiler for efficient furnace wall cooling. The rises tubes are sometimes also called generating tubes because they absorb heat efficiently to the water/steam mixture (steam being generated). The riser tubes forms the evaporator unit in the boiler.After risers, the water/steam mixture goes back to the steam drum. In the steam drum water and steam are separated the saturated water will return to the downcomer tubes and the saturated steam will continue to the superheater tubes. Thus also salts, minerals and other impurities are separated from the steam. The purpose of this separation is to protect the inside of the superheater tubes and turbine for impurity deposition. The steam from the steam drum continues to the superheater, where it is heated beyond its saturation point. After the last superheater stage the steam exits the boiler. This type of circulation is called natural circulation, since there is no water circulation pump in the circuit. The circulation happens by itself due to the water/steam density differences between the downcomers and risers.



Schematic flue gas path and steam generation path in boiler

J. Factors Affecting Combustion Efficiency

The combustion efficiency of a bubbling fluidized bed (BFB) boiler is typically up to 90% without fly-ash recirculation and could increase to 98–99% with recirculation (Oka, 2004). The efficiency of a circulating fluidized bed (CFB) boiler is generally higher due to its tall furnace and large internal solid recirculation.

The efficiency depends to a great extent on the physical and chemical characteristics of the fuel as well as on the operating condition of the furnace. The following section discusses different factors that could influence the combustion efficiency.

Factors affecting the combustion efficiency can be classified into three categories:

1) Fuel characteristics

a) *Feed Stock:* In conventional boilers, the fuel is characterized by a number of parameters including heating value and grindability. These characteristics are not adequate or even entirely relevant for fluidized bed (FB) boilers, because the combustion mechanism in these systems is different.

b) *Fuel Ratio:* The fuel ratio of a fuel is the ratio of fixed carbon (FC) and VM contents of the fuel. This ratio has an important effect on the combustion efficiency in a CFB boiler with higher ratios possibly leading to lower combustion efficiencies coals. A high rank fuel like anthracite has a higher fuel ratio than a low rank fuel like lignite. For this reason one can see that low-rank fuels (or low fuel ratio) like lignite and Bituminous have higher efficiencies than anthracite.

c) *Ignition and Agglomeration:* The ignition temperature influences the bed start-up condition. The lower the ignition temperature, the shorter the start-up time and the lower the auxiliary fuel consumption. Bed agglomeration, leading to clinkering, could be a problem in bubbling bed boilers. Clinker formation leads to particle growth and hence alters the size distribution of particles in the beds.

2) Operating Conditions

a) *Fluidizing Velocity:* The combustion efficiency generally decreases with increasing fluidizing velocity due to higher entrainment of the unburnt fines and oxygen by-passing. However, lower velocities run the risk of defluidization and therefore clinkering. The fluidization velocity is specified taking these things into account.

b) *Excess Air:* The mixing between fuel and air is never perfect. Some areas will be oxygen-deficient and some areas even oxygen-starved. Ultimately, all fuel particles must have the necessary oxygen to complete their burning; thus, extra oxygen is always provided in FB boilers in the form of excessair. The combustion efficiency improves with excess air, but this improvement is less significant above an excess air of 20%. Bubbling bed boilers may need a slightly higher amount of excess air than CFB boilers.

c) *Combustion Temperature:* The combustion efficiency generally increases with bed temperature because the carbon fines burn faster at high temperatures. The effect of temperature is especially important for less reactive particles, which burn under kinetic-controlled regimes. This effect is more prominent in the 700–850^{0}C range than above it. The less reactive the coal, the higher the combustion temperature should be, from a combustion efficiency.

3) Design Parameters Affecting Combustion Efficiency

a) *Bed Height:* A deeper bubbling bed would give higher combustion efficiency as it provides longer residence time for combustion, but it increases the fan power requirement and entrainment rate of solids.

b) *Freeboard Height:* The freeboard height increases the combustion efficiency as it allows longer time for combustion. A heavily cooled freeboard, however, may not be as effective

c) Fuel-Feeding: The fuel ratio, defined earlier, is an important parameter affecting the combustion efficiency. A low fuel-ratio is often responsible for low combustion efficiency especially in a BFB furnace, but under bed feeding gives higher efficiency for low fuel-ratio. Over-bed feeding is more effective for higher fuel ratio feed stock.

K. Stoichiometric Calculations

As municipal waste generation is increasing with increasing urbanization, a suitable technique namely incineration could be a possible solution to dispose municipal waste. A combustor is to be designed taking in view of the constituents of municipal waste. The ultimate analysis considered for the estimation of physical dimensions of the combustor is presented in Table.

Element	Carbon	Hydrogen	Sulphur	Nitrogen	Oxygen	Moisture	Ash
Percentage	37.14	5.41	0.9	2.2	24.93	25	32.21

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L. Calculation Of Combustion Air Supply

Stoichiometric calculations are carried out to estimate theoretically the quantum of air required for complete combustion in the subsequent sections

Considering theoretical combustion reaction for the elemental analysis of MSW

1) *Carbon (C):*

$C + O_2 \rightarrow CO_2$

$12kgC + 32kgO_2 \rightarrow 44kgCO_2$

$\text{Oxygen required} = 0.3714 * (32/12) = 0.9904/\text{kg MSW}$

$\text{Carbon dioxide produced} = 0.3714 * (44/12) = 1.3618/\text{kg MSW}$

2) *Hydrogen (H):*

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

$2Kg\ H_2 + 16kg\ O_2 \rightarrow 18kg\ H_2O$

$1Kg\ H_2 + 8kg\ O_2 \rightarrow 9kg\ H_2O$

$\text{Oxygen required} = 0.0541 \times 8 = 0.4328\ \text{kg/kg MSW}$

$\text{Steam produced} = 0.0541 \times 9 = 0.4869\ \text{kg/kg MSW}$

3) *Sulphur (S):*

$S + O_2 \rightarrow SO_2$

$32Kg\ S + 32kgO_2 \rightarrow 64kgSO_2$

$1Kg\ S + 1kgO_2 \rightarrow 2kgSO_2$

$\text{Oxygen required} = 0.009\ \text{kg/kg MSW}$

$\text{Sulphur dioxide produced} = 2 \times 0.009 = 0.018\ \text{kg/kgMSW}$

Total oxygen required per Kilogram of MSW = 0.9904 + 0.4328+0.009 – 0.2493 =1.1829 kg

Air required per Kilogram of MSW = $\frac{1.1829}{0.233}$ =5.07 kg

Where air is assumed to contain 23.3% O_2 by mass

I.e. Stoichiometric air/fuel ratio = 5.07:1

To burn one kilogram MSW 5.07 kg of air is required

4) *Calculation of heating value (HHV) of MSW:* The approximate higher heating value, HHV of a solid fuel may be calculated from the Dulong and Petit formula:

HHV = 33, 823C + 144, 249(H –$O/8$) + 9418S [kJ/kg]

HHV = $33823(0.374) + 144249$(0.541-0.249/8)$+9418(0.009)$ = 15.196 MJ/kg

M. Basic Design Of Furnace

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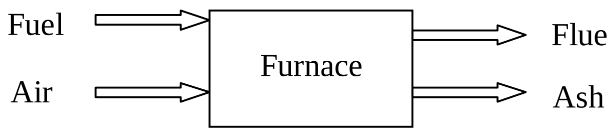
The furnace of a BFB boiler serves as both combustion chamber and heat exchanger. The furnace ensures generation of the required amount of energy with a minimum loss. It also ensures that the required thermal energy is transferred to water or steam to meet the specified furnace exit temperature. The typical furnace will determine the following the following:

1) Basic dimensions of the furnace such as height, width, and breadth
2) Height of bed and freeboard
3) Sizes of surface area for water wall

The furnace cross section is chosen primarily from combustion considerations. The air velocity across the combustion chamber is generally considered as 2.5 m/s with an excess air of 20 %. The bed temperature inside the combustor generally doesn't exceed 850°C limiting the generation of SO_2 and NO_x emission with appreciable combustor efficiency.

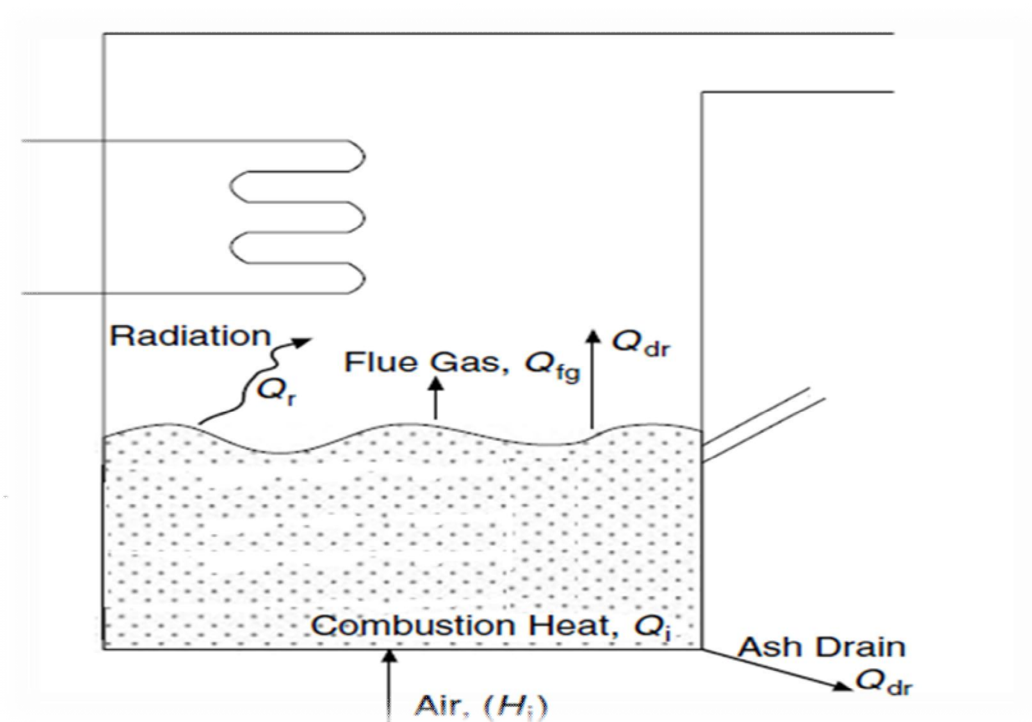
Mass balance: Selecting the entire bed in the combustor as the system of control volume, mass balance across the control volume be assume,



Mass flow rate of air into the system be:*x* kg/h
Mass flow rate of flue gas out of system be: *y* kg/h
Mass flow rate of fuel into system be: 500 kg/h
Mass flow rate of ash drain from the system be: 160 kg/h
Thus material balance for the system can be written as
Material into the system = material out of the system
500+*x* =*y*+160

4) *Energy balance in the bed:*The total energy liberated by virtue of combustion is accounted for the total energy balance across the combustor. The total heat lost in the form of flue gas (Q_{fg}), ash drain (Q_{dr}) and the radiation loss component (Q_r) must be equal to the heat released by combustion (Q_i) and enthalpy of primary air used for combustion (H_i), which is shown in Eq. 5.2. The energy balance for the control volume is shown in fig

$$Q_{fg} + Q_{dr} + Q_r = Q_i + H_i$$



Heat balance in a bubbling bed

Let fuel fed into bed (m_f) be 500kg/hr, HHV of fuel as calculated using Dulong formula is 15.2MJ/kg. The combustion of fuel is assumed to complete within the dense bubbling bed. Thus the heat released in the bed Q_i)

$$Q_i = m_f \times HHV$$

The enthalpy brought into the bed by the primary air H_i depends on the mass of primary air (m_a) and it is preheated to temperature

$$H_i = m_a \times C_{pair} \times (T_i - T_a)$$

Quantity of air into the system (m_a) = $x$kg/h
Temperature of air after preheating (T_i) = 250^{0}C
Temperature of ambient air (T_a) = 30^{0}C
Specific heat of air (C_{pair}) @250^0 =1.038 kJ/kgK
Heat into system with air (H_i) =$x \times 1.038 \times (250 - 30) = 228.36x\ kJ/h$
Therefore total heat into the system is heat by combustion and heat with air
Total heat input = $Q_i + H_i$

Heat radiated from bed surface (Q_r), is a major source of heat loss from the bed exposed to freeboard, it should between 1% - 5 % of combustion heat, let us consider average of range 3% of combustion heat.

$$Q_r = 3\%(Q_i)$$

Heat loss by radiation from the system (Q_r) = 3% of combustion heat
The flue gas carries the fly ash. Temperature of flue gas produced is equal to the temperature of bed. Thus the total heat loss in flue gas Q_{fg} ,

$$Q_{fg} = m_{fl} C_f T_b$$

Quantity of flue gas produced (m_{fl}) = $y$kg/h
Temperature of flue gas (T_b) = 850^{0}C
Specific heat of flue gas at 850^{0}C (C_{pfl}) = 1.277 kJ/kgK
Heat loss through the bed drain

$$Q_{dr} = m_f X_{ash} x_d C_{pdr} T_b$$

Where, X_{ash} is the ash content in the fuel as mentioned in ultimate analysis *Table 5.1*, generally residual ash after combustion acts as bed material for certain duration after which around 40%of bed material is drained off from the bottom to maintain the required temperature and fresh bed material is topped up to maintain the requisite bed height.

Fraction of ash in the fuel (X_{ash}) = 32.2%
Total fraction of ash in the bed (x_d)= 40%
Ash content in feed = $m_f X_{ash}$= 500$\times$ 0.32 = 160 kg/h
Specific heat of ash (C_p ash) = 0.920 kJ/kgK
Temperature of ash (T_b) = 850^{0}C
Heat loss through bed drain
Sensible heat loss due to ash (Q_{dr}) = $(160 \times 0.40 \times .920 \times 850)$ = 54740kJ/h
Total heat energy leaving the bed along with flue gas which carries away partial radiation loss from the bed to freeboard and heat loss through bed drain.
F,Total heat leaving the bed = $Q_{fg} + Q_{dr} + Q_r$
=225720 + 54740 +1085.45y

$$225720 + 54740 + (1085.45y) = (7600 \times 10^3) + (228.36x)$$

By solving mass balance and heat balance of the dense bed We can determine air flow rate and flue gas flow rate.
Mass flow rate of air (x) = 8106 kg/h

Mass flow rate of flue gas (*y*) = 8446 kg/h
By using flow rate of flue gas generated in the bed at 850^{0}C, the dimensions of the furnace can be estimated as follows

N. Furnace Sizing

Quantity of flue gas produced = 8446 kg/h
Flue gas temperature = 850^{0}C
Density of flue gas at 850^{0}C = 0.315 kg/m^3
Volumetric flow rate of flue gas = 8446/ (0.315*3600)
= 7.4479 m^3/s
Assume the flue gas velocity is2.5m/s, generally for bubbling fluidized bed operates in ranges of 1.5 -3 m/s, select the operating velocity within the range.
Cross –sectional area (A_b) = (volumetric flow rate)/velocity = 7.4479/2.5
= 2.979 m^2

Assume to be square bed
(side)^2= (2.979)
Side of bed = 1726 mm
Hence, Cross –sectional area of furnace, which is to be square in shape be 1726mm ×1726mm
Height of the furnace comprises of bed height and free board height. The freeboard height is an important design parameter, especially in a bubbling fluidized bed boiler. In a boiler with water-walls but without in-bed tubes, the freeboard height is generally dictated by the heating-surface area requirement for the evaporator. When in-bed tubes are used, the freeboard height may be chosen for other considerations. An important consideration is to minimize the entrainment of unburnt carbon by choosing a freeboard exceeding or close to the transport disengaging height (TDH).
There are a lot of empirical correlations for determination of TDH, but most of them are derived from experiments with fine particles and beds of a small diameter, so they have high accuracy usually in a narrow range. For calculation of TDH for boiler furnaces the equation of Chan and Knowlton [12] can be used:
$TDH = 0.85\, U_f^{1.2}\, (7.33 – 1.2\log U_f)$ Eq. 5.8
Where, U_f is fluidization velocity m/s
Height of bedThe height of the bed generally ranges from 0.8 to 1.2m (deep bed). The choice depends mainly on desulphurization requirements. The combustion of fuels with high sulphur content requires a deep bed with a high proportion of sorbent. The sorbent selected is limestone due to its high sulphur retention property at low pressures. The combustion process takes place at a pressure slightly lower than the atmospheric (around - 40 mbar). Height of bed of 1.2m at full load is selected, by considering desulphurization and pressure drop. Pressure in the bed operates at atmospheric pressure (i.e.) 1.01 bar.
Total disengagement height is calculated from Eq. 5.8
$TDH = 0.85\, U_f^{1.2}\, (7.33 – 1.2\log U_f)$, $U_f$be fluidizing velocity = 2.5 m/s
$=0.85(2.5)^{1.2}\, (7.33 – 1.2 \log(2.5)) =9.20$m
From Eq. 5.8, total disengagement height is estimated as 9.20m. So, height of furnace should be greater than total disengagement in order to prevent combustion loss. Selection of furnace height depends on another factor namely gas residence time. As sulfation reaction is slow, longer gas residence is favorable for sulfur capture. The gas in a fluidized bed is generally in plug flow. The gas residence time may therefore be taken as h_f/U_f; where h_f is the furnace height and U_f is the fluidization velocity. Thus, h_f and U_f affect sulfur emission from the furnace. In a bubbling fluidized bed, a higher fluidizing velocity reduces the residence time and increases the sorbent entrainment. Assuming residence time (t_s) fluidizing velocity is equal to height of furnace /residence time. The residence time is estimated so that height of furnace should above disengagement height. Sulfur capture decreases quickly with increasing gas residence time, but for a longer residence time this improvement is much less. In commercial BFB furnaces, where the gas residence time is already quite high (in the range of 6 to 8 sec), a further increase in furnace height would only marginally improve the sulfur capture efficiency, Oka, S 1991 [13]
Residence time of gas is 6sec, which is optimum time to attain maximum Sulphur capture, selected MSW fuel has less percent of Sulphur content, which was mentioned in ultimate analysis of fuel in previous section.
Height of furnace (h_f) is equal to residence time of gas multiplied by fluidizing gas velocity
$h_f = 6 \times 2.5 = 15$m

O. Bed Selection

The fluidized bed boiler is a type of steam generator where fuel is burnt in a fluidized state. The furnace of a fluidized bed boiler contains a mass of granular solids, generally in the size range of 0.1 to 0.3 mm or 0.25 to 1.0 mm depending on the type of fluidized boiler.

These solids are called bed materials, which could be made of the following:

1) Sand or gravel (for boilers burning low-ash fuels, such as woodchips)
2) Fresh or spent limestone (for boilers burning high-sulfur coal requiring control of sulfur emissions)
3) Ash from coal (for boilers firing high- or medium-ash coal requiring no sulfur retention)

Biomass-fired boilers may use special bed materials including synthetics to avoid agglomeration in the bed. Sometimes a combination of several types of bed materials is used. The size of fuel particles, especially for the low-ash variety do not necessarily have a major bearing on the size of bed materials, because fuel constitutes only a minor fraction (1 to 3%) of the total bed materials in the fluidized bed furnace. However, for high-ash fuels the characteristic of the fuel exerts an important influence on both size and composition of the bed materials.

The combustion temperature of a fluidized bed boiler is maintained in the range of 800 to 900^{0}C through the extraction of heat from the combustion zone by flue gas. Most bubbling fluidized bed boilers use Group B or D particles, which results in large bubbles and get fluidized fast. Hence the bed material is sand of Group B type and selection of particle size, density of sand particles is based on availability conditions is discussed in section 3.5

$$\text{Size of particle} = 300\mu m$$

$$\text{Density of sand } (\rho_p) = 2500 \text{ kg/m}^3$$

$$\text{Bulk density of bed for sand } (\rho_b) = 1200 \text{ kg/m}^3$$

$$\text{Voidage } (\varepsilon) = 0.52$$

$$\text{Depth of the bed } (H_b) = 1.2 \text{ m}$$

$$\text{Pressure drop of bed } (\Delta P_b) = \rho_p \; gH(1-\varepsilon)$$

$$= 2500 \times 9.81 \times 1.2 \times (1-0.52)$$

$$\Delta P_b = 11772 \text{ Pa} = 1200 \text{ mm of } H_2O$$

P. Design Of Distributor Plate

For the design of the nozzle standpipe type distributor the dimensions and certain other parameters must be determined. The following factors should be considered.

1) *Nozzle density:* Excellent fluidization and high combustion efficiencies can be obtained with nozzles spaced on a square pitch of 75 to 100 mm. The choice of the pitch will be influenced by the operating bed depth. A 75 mm pitch is recommended when the static bed depth is 150 mm or less, while a 100 mm pitch is more suitable for general use and when the static bed depth is greater than 200 mm.
2) Nozzle diameter:The nozzle internal diameter should be sufficient to ensure that the pressure drop for flow through the nozzle body is insignificant compared with that through the holes at the upper end. Nozzles made from tubing having an internal diameter in the range 12 - 25 mm should be suitable for most applications. There is no undue restriction on the outside diameter and a nozzle wall thickness of 1.5 - 3 mm (0.06 - 0.12 in.) has been commonly used

To determine the distributor pressure drop, following conditions must satisfy for even fluidization throughout the bed. Most practical designs of bubbling beds keep the distributor pressure drop within 15 to 30% of the bed pressure drop. Kunii and Levenspiel (1991)

$$\Delta P_d = (0.15)\Delta P_b$$

Minimum Pressure drop of distributor plate = 0.15$\times \Delta P_b$

= 0.15$\times$11772

= 1765.8 Pa = 180 mm of H_2O

Where, ΔP_d is distributor pressure drop, ΔP_b is bed pressure drop.

Design of distributor plate, diameter of the nozzle can be determined using total amount of primary air through the plate, selecting the suitable pitch between the nozzles, select the number of nozzles according area available to maintain uniform distribution and pressure drop of distributor plate.

Let the diameter of nozzle be: d (mm)

Total air mass flow rate (m_a) = 8106 kg/hr

= 2.251 kg/sec

Air entering temperature (T_i) = 250^0C

Density of air at 250^0C (ρ_a) = 0.674 kg/m^3

Air flow rate = $\frac{2.251}{0.674}$ = 3.3394 m^3/sec

Total number of nozzles in the distributor plate = 284

Velocity through each nozzle (U_n) = $0.8 \times [(2\Delta P_d)/\rho_g]^{0.5}$

Total air flow rate (m^3/s) = [Total no. of nozzles] × [area of each nozzle] × [velocity through each Nozzle]

= $n \times \pi/4 \times d^2 \times U_n$

Area of nozzle (A)

Where, area of nozzle = $[(\pi \times d_n^2)/4]$

Diameter of nozzle = $[(4 \times 2.0273 \times 10^{-4})/\pi]^{0.5}$

d_n = 16 mm

Diameter of each nozzle (d_n) = 16 mm

Q. Water – Steam Circuit System

The working of a BFB has been illustrated in FIG.5.1 where conversion of water into steam had been discussed earlier. The geometrical dimensions of the water walls are evaluated by determining the mass flow rate of steam, mass flow rate of feed water. Initially, the mass flow rate of steam is estimated by assuming the boiler efficiency in the range of 85-98%.

Mass balance of water and steam flows allows to define unknown components:

$$\mathbf{m_s = m_{fw} - m_{bd}} \quad \text{Eq. 5.10}$$

Where, m_s is main steam flow, m_{fw} is feed water rate and m_{bd} is blow down value. Typically, blow down is generally 1 – 5% of feed water rate. When water and steam flows are defined,

Mass flow rate of steam (m_s) = $Q_{combustion}/H_{fg}$ @14 bar × combustion efficiency (kg/h)

= $0.85 \times (2111/1957.6) = 3300$ kg/h

Mass flow rate of steam (m_s) = m_{fw} - m_{bd}

Mass flow rate of feed water (m_{fw}) = 3300/ (1-(5/100)) = 3666.6kg/h

Economiser is a heat recovery equipment to recover heat from flue gas to utilize to increase feed water temperature enhancing efficiency of the system. The heat load on the economizer is evaluated as follows

$$Q_{Eco} = m_{fw}(H_{Eco\ outlet} - H_{Eco\ inlet})$$

Where $H_{Eco\ outlet}$ is enthalpy at economizer outlet which is usually 20^0-30^0C lower than the saturation temperature in order to prevent boiling of feed water in economizer tubes. Pressure at outlet of economizer is almost equal to drum pressure. The inlet temperature of feed water to the economizer varies according to size of the plant, quality of water and processes to remove impurities in water.

Feed water inlet temperature at economizer = 110℃

Enthalpy inlet to Economiser ($H_{(Eco\ inlet)}$ @ 110℃) = 461.315 kJ/kg

Enthalpy at Economiser outlet ($H_{(Eco\ outlet)}$ @ 175℃ = 741.18 kJ/kg

Economiser heat load (Q_{Eco}) = [1.0185× (741.18- 461.315)] = 285.04 kW

walls in a boiler can be estimated by using

$$Q_{Eva} = m_s(H_{outeva} - H_{in})$$

Where, Q_{Eva} is heat demand on evaporator, H_{in} is the enthalpy at evaporator inlet, it is equal to enthalpy outlet of economizer, H_{outeva} is enthalpy at outlet of evaporator ,it is usually saturated mixture of steam and water .

Pressure in Evaporator = 14 bar

Enthalpy at Evaporator inlet = Enthalpy at Economiser outlet = 741.18 kJ/kg

Superheater The heat gained by the working fluid as it flows across the superheater can be evaluated using

$$Q_{sh} = m_g(H_{sh\,outlet} - H_{shinlet})$$

Where, Q_{sh} is Super heater heat load, the steam enthalpy at the outlet of the super heater is estimated with existing pressure and temperature of steam at the exit of the super heater. During the initial thermal design, when the type of super heater has not been decided, the pressure drop (ΔP_{sh}) is estimated as 10% of the steam pressure at the outlet of super heater or obtained from experience or from the manufacturer of the super heater. Steam at the inlet of the super heater is at saturated pressure P_{sh} inlet.

The total heat load of the boiler can be estimated from Eqs. 5.11, 5.12 $ 5.14 respectively.

$$Q_{Steam} = Q_{Economiser} + Q_{evaporator} + Q_{superheater}$$

$$Q_{superheater} = 1794.35 - 872.26 - 285.04 = 637.05 \text{ kW}$$

From Eq. 5.14, we can estimate superheated steam temperature

637.05 = 0.916 ($H_{sh\ outlet}$- 2788)

$H_{sh\ outlet}$ = 3483.46 kJ/kg

From steam tables at $H_{sh\ outlet}$ = 3483.46 kJ/kg in superheated table, Steam temperature approaches to 400^0C (approximately)

R. Construction Of Water Wall Tubes

Evaporation phase occurs in water wall tubes. Evaporation is the process to convert water into steam. Therefore water wall tubes should be designed and constructed to provide high heat absorption, minimum excess air level and highest boiler efficiency. Water wall tubes should be constructed to prevent air leakage into steam boiler, eliminate amount of heat losses and permit high heat release and combustion rate in the furnace. Construction of water wall tubes must provide high quality of the supporting component such as tubes, casing, refractory, lagging, tile, fin and so on. Best construction will reduce heat loss and maintenance. Construction of water wall tubes can be classified into four types such as:

Among the above types, Membrane or fin tube water wall is considered as available best design and construction because this type can give more protection in the insulation and yield highest efficiency with available heat transfer surface.

*1) Size of Water wall Tube: N*Tube dimensions are calculated considering velocity of the fluid flowing past and recommended velocity for steam falls in the ranges of 20m/s – 40m/s, If the designed velocity exceeds the given range then the tubes are highly prone for erosion.

Diameter of tube d_g = $\left(\frac{\text{mass flow rate of steam} \times 4 \times \text{specific volume of steam @14bar}}{\text{velocity of steam} \times \pi}\right)^{0.5}$

d_g $=\left(\frac{3300\times4\times0.1409}{40\times\pi\times3600}\right)^{0.5}$ = 64.11mm …… it is not commercially available

The size tube is modified to nearest size according to commercial availability in the tube size chart.

III.CONCLUSIONS

Design aspects of small size low pressure bubbling fluidized bed boiler furnace is designed for disposing municipal solid waste and there by generating steam for productive purpose. The dimensions of bubbling bed combustors are been estimated using stoichiometric calculations and energy balance by fixing bed temperature at 850^0C and gas velocity at 2.5m/s. The dimensions of the bed are estimated as 1726mmx1726mm with a bed height of 1.2m. The total furnace height is estimated as 15m. The pressure drop across the distributor plate is estimated as 180 mm of H_2O. A total of 284 nozzles are required to handle the duty of disposing municipal solid waste with nozzle dimensions are estimated as 16mm.

The heat loads across transfer surfaces like economizer, water walls and super heater have been estimated. The heat transfer across the economizer is estimated as 285 kW ie., 15% of total heat load, 872.26 kW ie 51.8% and super heater 637 kW ie., 36% of the total heat load respectively. The required pipe dimensions are also estimated as 71mm OD with 5 mm thickness is required to handle the requisite heat load.

REFERENCES

[1] Kelleher BP, Leahy JJ, Henihan AM, O'Dwyer, Sutton D, Leahy MJ, "Advances in poultry litter disposal", Biosource Technology 2002;83:27–36.
[2] Permchart., "Emission performance and combustion efficiency of a conical fluidized-bed combustor firing various biomass fuel", Bioresource Technology 92 (2004): 83–91.
[3] Basu.P, Cen.K.F, Jestin.L, 2000, "Boilers and Burners", Springer, New York.
[4] M. Rozainee, S.P. Ngo, A.A. Salema, K.G. Tan, M. Ariffin, Z.N. Zainura, "Effect of fluidising velocity on the combustion of rice husk in a bench-scale fluidized bed combustor for the production of amorphous rice husk ash", Bioresource Technology 99 (2008) 703–713.
[5] L. Armesto, A. Bahilloa, K. Veijonenb, A. Cabanillasa, J. Oteroa, "Combustion behaviour of rice husk in a bubbling fluidised bed", Biomass and Bioenergy 23 (2002) 171 – 179.
[6] Niemela, Westerlund, "Experience of fluidized bed technology for biomass plants in different applications and development towards new applications in RDF burning".
[7] Ragnar G.Lundqvis, "Fluidized Bed Combustion of Unconventional Fuels", a few studies from operating boilers.
[8] Dimpal Vij, "Urbanization and solid waste management in India: Present practices and future challenges", International Conference on Emerging aspects and Challenges. International Journal of Geology, Earth and Environmental Sciences ISSN: 2277-2081.
[9] D.O. Hall, F. Rosillo-Calle, R.H. Williams, J. Woods, "Biomass for Energy: Supply Prospects", Washington DC, 1993.
[10] J. Goldemberg, T.B. Johanson, "World Energy Assessment", Overview 2004 Update, United Nation Development Programme, New York, USA, 2004.
[11] L. Cheng, Fang, Luo, "Design and Performance Verification of a 62-MWt CFB Boiler", ASME J. Eng. Gas Turbines Power, 116, pp. 462–467.
[12] Basu. P, and Fraser, S. A., 1991, ''Design Considerations,'' Circulating Fluidized Bed Boiler Design and Operations", Butterworth-Heinemann, Boston, pp. 174–184.
[13] Yang, Wen-Ching, "Handbook of fluidization and fluid-particle systems", Taylor & Francis Group LLC, 2003.
[14] Arsic, B., Oka, S., and Radovanovic, M., "Characterization of limestones for SO_2 absorption in fluidized bed combustion", Presented at Fifth International Conference on Fluidized Bed Combustion, London, pp. 171–177, 1991.
[15] Basu, Prabir. 2006. Combustion and gasification in fluidized beds. Boca Raton, FL: CRC Press/Taylor & Francis Group, 2006.
[16] Oka, Simeon; Anthony, E. J.. 2004. Fluidized bed combustion. New York: M. Dekker, 2004