Design, Feasibility study and Utilisation of Fluidised Bed Combustion Technique for Sewage Sludge

A Dissertation submitted

in partial fulfillment of the requirements for the award of degree of

Master of Engineering

In

Thermal Engineering

Submitted by

Gaganpreet Singh
(Registration No. 851383002)

Under the supervision of
Dr S.K.Mohapatra
Sr. Professor and H.O.D (MED)

Department of Mechanical Engineering
Thapar University, Patiala
July 2017

Certificate

I, Gaganpreet Singh, hereby declare that the thesis entitled" **Design, Feasibility Study and Utilisation of Fluidised bed Combustion Technique for Sewage Sludge** " is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **Thermal Engineering** at **Thapar University, Patiala** under the supervision of **Dr.S.K.Mohapatra**,Sr.Professor and H.O.D , Department of Mechanical Engineering , Thapar University, Patiala during July, 2015 to July, 2017.No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

Date: 30-7-2017

G.Singh
Gaganpreet Singh

It is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.

Dr.S.K.Mohapatra, Sr. Professor
Department of Mechanical Engineering
Thapar University, Patiala - 147004

Acknowledgement

Foremost, I would like to express my deepest appreciation and sincere gratitude to my supervisor **Dr.S.K.Mohapatra** for his valuable guidance, excellent supervision and timely suggestions during whole project that has helped me in exploring this topic. His immense knowledge and constant encouragement has helped me in completing my project in time.

I would like to thank **Dr Satish kumar and Dr Vikrant Khullar**, Assistant Professors of Mechanical Engineering Department for providing me an opportunity to work on this project .The facilities provided in laboratories has helped me working on this topic and carrying out experimental work for my thesis.

I also express my indebtedness for my family members specially my elder sister Shikha Bahl for their continuous support and encouragement throughout my project work that has lead to timely completion of this research oriented venture.

Gaganpreet Singh

List of Figures

List of Tables

List of Graphs

Nomenclature

A Ash content in fuel (%)

A_c Cross-sectional area of the particle (cm^2)

A_i Cross-sectional area at inner surface (cm^2)

A_o Cross-sectional area at outer surface (cm^2)

At Cross-sectional area of the bed (cm^2)

C_D Co-efficient of discharge through orifice

CD Drag coefficient, a function of the particle shape and Reynolds number

D_B Bubble diameter (cm)

D_{BM} Maximum bubble diameter (cm)

D_{BO} Initial bubble diameter (cm)

d_{or} Diameter of orifice (cm)

d_P Fuel particle diameter (cm)

d_{PAVG} Average diameter of fuel particles (cm)

E_{XAIR} Fractional excess air

F_{ME} Actual molar feed rate (g.mol/s)

F_{MTH} Stoichiometric air feed rate (g.mol/s)

g Acceleration due to gravity (cm/s^2)

g_C Conversion factor $g/(dyne.s^2)$

H Height of the bed in fluidised state (cm)

h Heat transfer coefficient A(W/m^2K)

K Constant (dimensionless)

k Thermal conductivity (W/m/K)

N_D Number of orifice openings

N_{OR} No. of orifices per unit area of distributor

Nu Nusselt number (dimensionless)

P_{AV} Average pressure in the combustor (atm)

P_R Prandtl number (dimensionless)

r Radius of the particle (cm)

Re Reynolds number (dimensionless)

R_g Gas constant ($atm.cm^3/g.mol.K$)

t Wall thickness (cm)

T_B Bed Temperature (K)

U Overall coefficient of heat transfer (W/m^2K)

U_{minf} Minimum fluidisation velocity (cm/s)

U_o Fluidisation velocity (cm/s)

U_{or} Velocity of fluid through orifice (cm/s)

V Volume of the fluid (cm^3)

V_s Velocity of the fluid (cm/s)

W_{FUELl} Fuel feed rate into the combustor (g/s)

C_X Carbon content in fuel (%)

H_X Hydrogen content in fuel (%)

O_X Oxygen content in fuel (%)

S_X Sulphur content in fuel (%)

W_X Moisture content in fuel (%)

ΔP_D Pressure drop across the bed (atm.)

ΔP_F Pressure drop due to static weight (hydrostatic head) of fluid in bed (atm.)

ΔP_S Pressure drop due to static weight of the solid in bed (atm.)

ΔP_W Pressure drop due to friction at the wall (atm.)

Greek Symbols

α Average porosity or void fraction of bed in fluidized state

θ_1 Temperature of hot fluid (K)

θ_2 Temperature of hot fluid (K)

θ_m Logarithmic mean temperature difference (K)

μ_g Viscosity of fluidizing gas (g/cm.s)

ρ_f Density of the fluid (g/cm^3)

ρ_g Density of fluidizing gas (g/cm^3)

ρ_p Density of fuel particles (g/cm^3)

Chapter 1

Introduction

Introduction

Now-a-days, a lot of attention is drawn for waste to energy conversion .With increase in urbanization and population, the generation of sewage sludge has increased exponentially. In India, the use of sewage is mainly in landfill or mainly in agriculture but sometimes even dumped in rivers. This type of use of sewage sludge has serious environment concern due to highly contagious pathogens and coliform bacteria. Hence the future of these disposal methods is in dark and can be banned. Sewage sludge is gaining ground for its use as alternative fuel because of its calorific value reaching as high as 18000 kJ/kg. But the main drawback to use it as fuel is because of its moisture content.

Nearly thirty four years after independence i.e. during the census of 1981, a survey was conducted on sanitation of rural households in India and it was found that only one percent of rural households have access to toilets i.e. having sanitation while others defecate in open. After that different programs were being led by government to cover households under sanitation coverage .The programs are listed as below:

Year	Name of Progamme	Objective
1986	Central Rural Sanitation Programme	Improving quality of life of rural people
1999	Total Sanitation Campaign	Making people aware of sanitation i.e. Information, Education and communication
2012	Nirmal Bharart Abhiyan	Accelerating sanitation coverage in rural areas
2014	Swachh Bharart Abhiyan	Toilets for all

Table 1: List of programs run by Indian Govt.

The Swachh Bharat Abhiyan is flagship programme of central government and is targeted to achieve toilets for all. The next move would be to connect these IHHL's to sewage plant either at block level or at village level. Since the inception of S.B.M,199.05 lakh toilets are built under programme.

Fig 1.1: Overall Coverage Vs Financial years (source: http://sbm.gov.in/sbmreport/home.aspx)

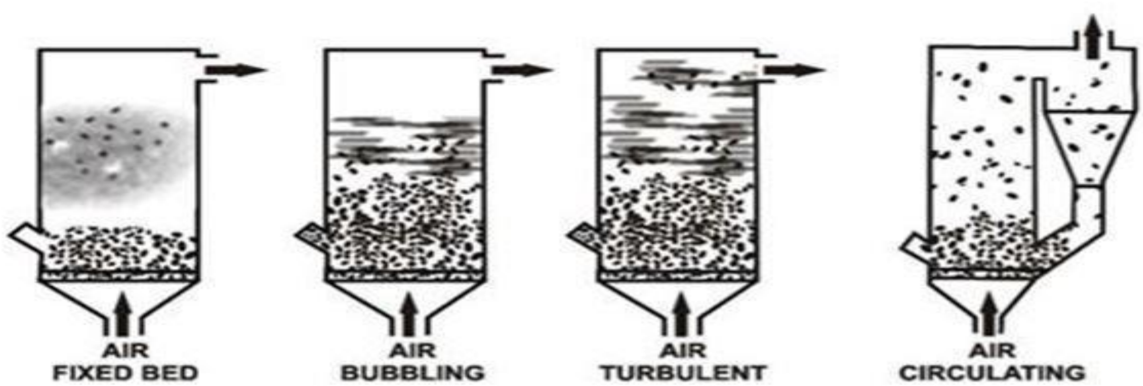
1.1 Fluidized Bed Combustion System

In India most coal availability is in the south eastern part which has the quality of coal regarded as low grade coal because of high content of ash and low calorific value. The traditional fuel firing systems have technical as well as economic limitations and are not viable to meet the needs of future generations. On the other hand fluidized bed combustors prove technology of viable future use because of their compact design, ability to burn low grade fuels, reduced emission of SO_x and NO_x and ability to burn high ash fuels. Different fuels that can be burnt are rice husk, rice straw, bagasse, coal and now a days sewage sludge too. They can operate over wide range of capacity of 0.5 t/hr to over 100 t/hr.

1.2 Mechanism of Fluidized Bed Combustion

It consists of two type of media, one called suspended media and other called flowing media. When gas or air is passed upward through suspended media, it first passes freely through voids of suspended media. When the upward velocity of fluid is increased ,the solid media gets suspended in air stream and the bed is known to be fluidized. It is illustrated in Figure 1.2.

With further increase in gas velocity, the bed starts to appear as boiling liquid and looks like a fluid, hence it is called bubbling fluidized bed. When the air velocity is further increased then turbulence, rapid mixing and defined bed formation can be observed.



Fixed, bubbling and fast fluidized bed

When the bubble formation starts in bed of particles, it is called to be fluidized but when the velocity of gas is further increased, solid media can blow out and hence must be recycled in order to maintain a stable system. The above diagram shows different types of fluidized bed combustor.

Fixed, bubbling and fast fluidized bed

The flowing media can be air or gas or any liquid but suspended media generally chosed is sand or dolomite for combustion in fluidized bed.

As the velocity of bed of particles increases, a value is reached when the bed fluidises and bubbles form as in a boiling liquid. At higher velocities the bubbles disappear and the solids are rapidly blown out of the bed and must be recycled to maintain a stable system

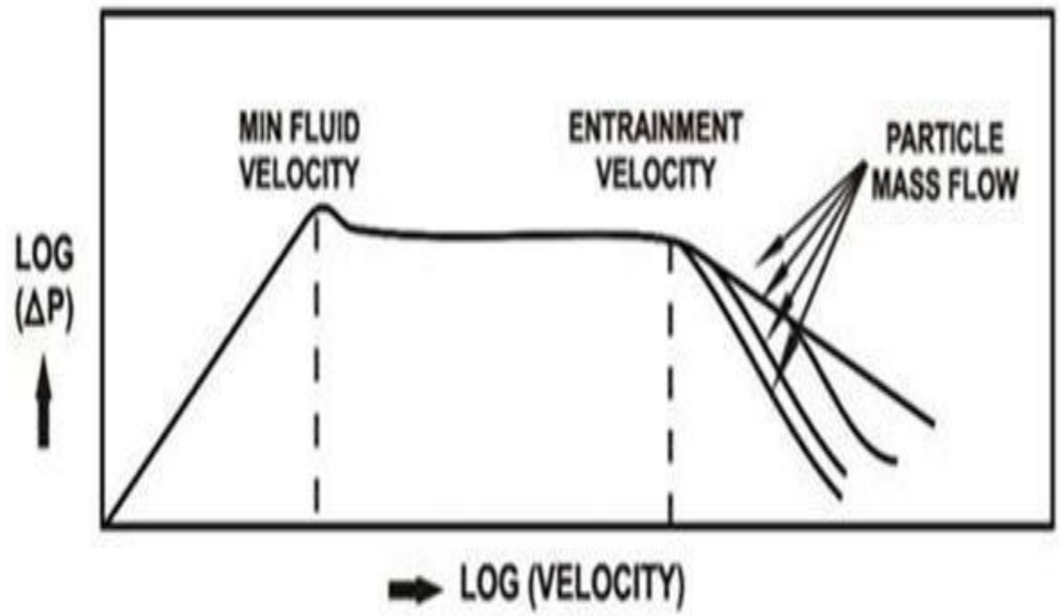


Fig 1.2: Pressure drop Vs Velocity (Source: From Kunii and Levenspiel, 1977)

Bubbles are blown out of bed when gas velocities are increased beyond certain limit. There is always some particles which get blown out of combustor and in order to maintain certain fluidized media, circulation of particles is followed, therefore they are called fluidized bed boilers.

Fluidization phenomenon is mainly the function of particle size and air velocity. As shown in figure 1.3, that gas velocity increases at higher rate than solid velocity, then a new term arises called slip velocity which is known as difference between mean solid velocity and mean gas velocity. For good heat transfer maximum slip velocity and intimate contact is required.

If sand particles of bed are heated to ignition temperature of sludge and sludge pellets are injected into bed from side window, the sludge will burn rapidly attaining uniform temperature. The fluidized bed combustion takes place generally below 950℃ which is below ash fusion temperature, hence melting of ash and other associated problems can be averted.

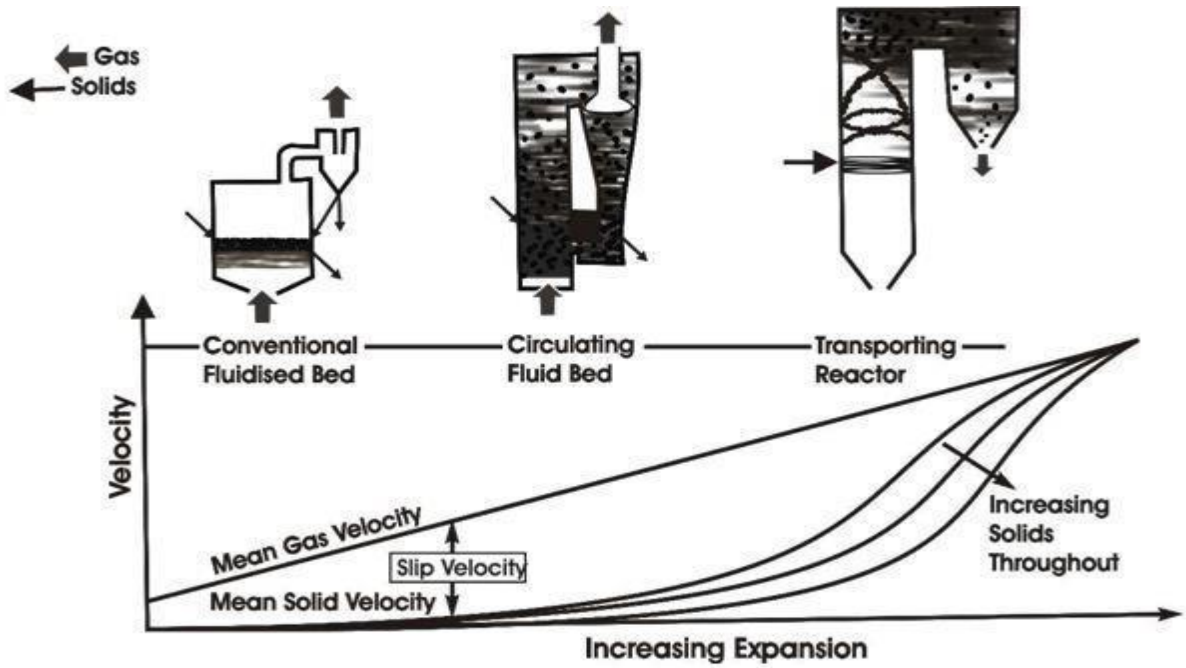


Fig 1.3:Relation Between Gas Velocity and Solid Velocity
(Source: Bureau of energy efficiency, 2005)

It has low combustion temperature because of high heat transfer coefficient due to rapid mixing in bed. It is therefore required to insert the tubes in bed and wall for effective extraction of heat. For avoiding the carrying away of particles in the gas stream, fluidization velocity is selected in between the range of minimum fluidization velocity and particle entrainment velocity.

For achieving NO_x and SO_X control without the help of additional equipment, limestone as bed particle media is used. It is the main advantage of FBC over earlier boilers.

1.3 Advantages of Fluidized Bed Combustion Boilers:

- Continuous and automatically controlled operation is possible because of smooth and liquid like flow of particles in combustor.
- Rapid mixing of solids makes the whole bed of isothermal nature.
- It is suitable for operations of large scale.
- The rate of heat and mass transfer is high over other contacting modes.
- Heat exchanger of small surface area is efficient here because of high heat transfer rate.
- Due to low temperature of combustion, NO_x formation is very less.
- Low grade fuels having high ash content can be used in the system

1.4 Chronological Development of FBC:

Innovation and refinement have always been generic terms of those creative activities of humanity that, in modern times we classify as technology. Each innovation is followed by a sequence of refinements, the motivation for which comes from several factors such as utility, economy, reliability, and performance etc. The area of circulating fluidized bed combustion of agriwaste for power production has evolved as a consequence of these motivations.

India is possibly one of the small number of countries in the world to have drawn up a complete strategy and action plan. It sets precise medium term goals for renewable energy based capacity count in the energy sector of the country. Increasing population and the rapid speed of industrialization have resulted in elevated growth rates in energy demand. Now-a-days, around 98 million tones of oil, around 400 million tones of coal and around 450 billion units of electricity are consumed in our country. In calculation, a huge amount of non-commercial forms of energy is also used which some estimates set at approximately 40% of overall energy use. The non-commercial form of energy consists of animal wastes, agriwaste and draught animal power.

In current years, utilization of some agriwaste, in general rice husk, in industries like boiler fuel has also taken root because of the following reasons:

- Conservation of coal
- Conservation of other non-renewable natural resource.
- Mitigating the emission of green house gas (GHG) i.e. CO_2 as rice husk is a carbon neutral fuel.
- Help in reducing pollution
- Help in proper utilization of by products in various fields
- Contributing to a little enhancement in the local employment by employing skilled and un-skilled personnel for action and repairs of the equipment.
- Adopting an advanced and sustainable technology for long term benefits.
- Helping to bridge the gap of electricity demand and supply at local level

A fluidized bed combustor consists of a set of combustible particles suspended in an upward flowing gas stream at such a velocity that the particles are not carried out of the vessel but cavities, usually called 'bubbles' move through the suspended mass which help the vigorous circulation of the bed material. Since the bed offers resistance to flow, the drag forces, as given by pressure drop across the bed, are sufficient to support the weight of the bed. Thus the bed has a pseudo-density and has many attributes of a liquid (Davidson et al., 1977).

The main reasons for major development of fluidized bed combustion technology during 1970's are as follows :

- Due to political crisis of gulf, there was increase in prices of oil and at that time supply was also not certain.
- Technical and economical problems faced by pulverized fuel fired conventional boilers.

- Use of low grade fuels
- Due to strict environment control regulations of different countries,there was need to move to less polluting one technology.

1.5 Types of Fluidized Bed Combustion Boilers

There are three basic types of fluidized bed combustion boilers:

1) Atmospheric Classic Fluidized Bed Combustion System (AFBC).
2) Atmospheric Circulating(fast) Fluidised Bed Combustion System (CFBC)
3) Pressurized Fluidized Bed Combustion System (PFBC).

1.5.1 Atmospheric Fluidized Bed Combustion System (AFBC)

In AFBC, wide range of fuel particles having different size distribution is fed to combustion chamber of combustor. Atmospheric air act as fluidizing as well as combustion air. After getting heated by exhaust gases, combustion air passes through bed at pressure. Fluidizing velocity ranges from 1.2m/s -3.7m/s.The mass flow rate of air decides the mass flow rate of fuel.

The evaporator tubes are used in bed of limestone, sand and fuel in all atmospheric fluidized bed combustors to maintain the bed temperatures by extracting heat from it. In commercial fluidized bed boiler, the height of non fluidized bed vary from 90 cm to 150 cm and there is variation of pressure of 25mm of water for each mm depth of bed. Only 0.2 to 0.4% solids needs to be recycled i.e. two to four kilogram in case of solids used net weight of one tonne. Fig 1.4 and 1.5 shows bubbling bed boiler of different types:-

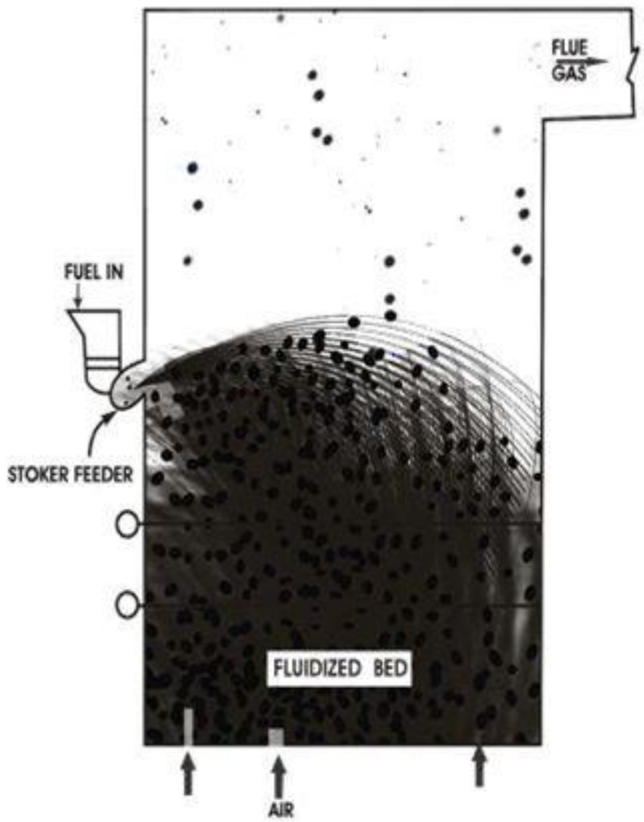


Fig 1.4: Bubbling Bed Boiler -1 (Source Oka, 2004)

Fluidized bed boilers can operate at near atmospheric or elevated pressure and have these essential features:

- Distribution plate: It is the plate having fine holes through which air is blown.
- Immersed water heating tubes: These tubes are immersed in bed of particles of combustor.
- Water heating tubes above bed: Tubes above the bed which extract heat from hot combustion gas before it exits the combustor.

The combustion gases originates from the bed, passes over superheater section, then to economizer, dust collector and at last air preheater before they are being exhausted to atmosphere.

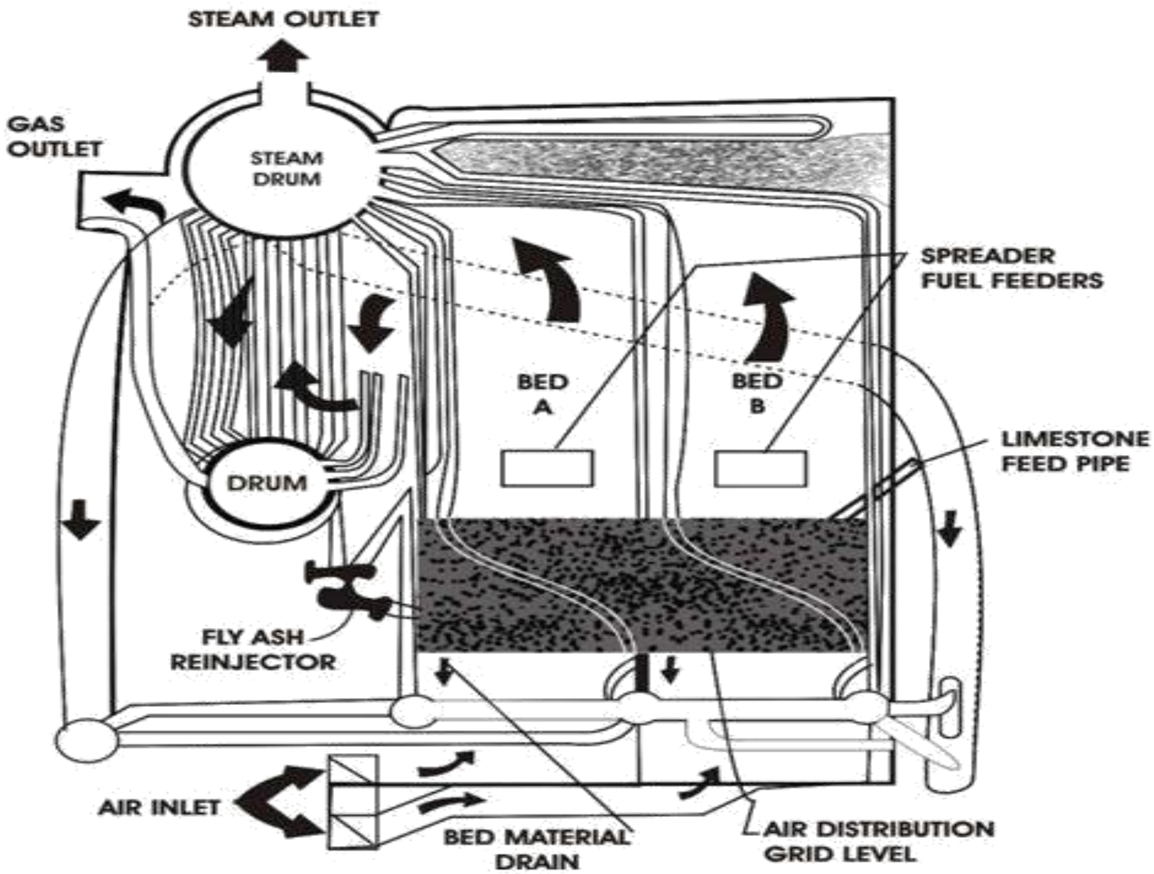


Figure 1.5: Bubbling Bed Boiler 2 (Source: F.B.C Boilers by BEE)

For coal to be used in atmospheric fluidized bed combustor, one constraint is proposed i.e. the working temperature range .Many processes such as clinker formation, combustion efficiency and sulphur retention are directly or indirectly related to it. Above 900 ℃ clinker formation starts and below 800℃ combustion efficiency falls sharply. Hence keeping in view all above factors and efficient sulphur retention, working temperature range is selected as 800-850 ℃ for coal.

1.5.2 Circulating Fluidized Bed Combustion System (CFBC)

In order to overcome the drawbacks of atmospheric fluidized bed combustion, circulating fluidized bed combustors are evolved. Circulating fluidized bed combustion as shown in Figure 1.4.

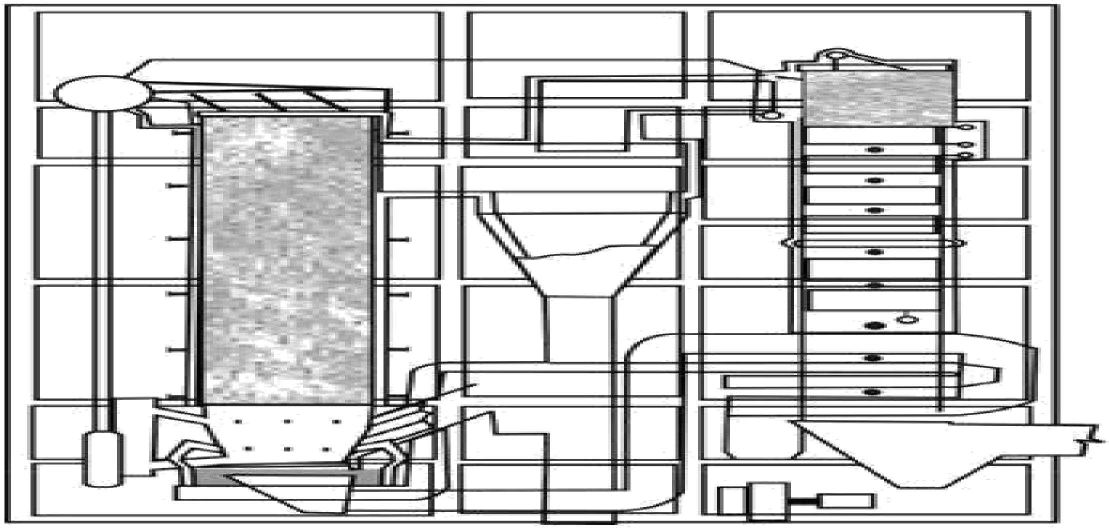


Fig 1.6:Circulating Bed Boiler Design

In circulating fluidized bed combustor, fuel and limestone of size 6 to 12 mm are injected in furnace. Air enters the furnace from bottom through distributer plate and suspends the solid particle making particle in fluidized state. The working range of fluidization velocity is from 3.7 to 9 m/s. Secondary air here is the balance of combustion air which is passed above furnace i.e. All particles are not of same size, those particles whose size is less than 450 microns gets elutriated by the air with a fluidizing gas velocity of 4-7 m/s. The working range of temperature in these boilers is 840 -900℃. Solid separators are used to collect particles that are elutriated out and circulated back to the furnace.

Unlike the atmospheric fluidized bed combustors, the steam generation tubes are not immersed in bed here. Since a lot of solids get circulated out of furnace area therefore more heat transfer is achieved outside the combustion zone i.e. in water walls, exit of risers and convection wall. Sometimes external heat exchangers can be used. Here longer time is available for carbon and limestone utilization i.e. due to longer residence time, particle provide efficient heat transfer. The controlling parameters in circulating fluidized bed combustion are turbulence, temperature and residence time.

Rate of recycling of fine particles decide the combustion temperature for high fluidizing velocities where fast recycling of bed particles is superimposed on bubbling bed of large particles. Cyclone is used to separate hot fine particles. The fine particles are further cooled in heat exchanger. It is again then recycled to combustion bed.

When using on commercial scale, taller furnace of CFBC are preferred because of more fuel particle and sorbent residence time in furnace for efficient combustion. Moreover they offer better space utilization, SO_2 capture, NO_X control and eases staged combustion techniques than atmospheric fluidized bed combustors.

They are more economical over atmospheric fluidized bed combustors and are preferred in industrial applications where requirement is more than 75-100 tonnes of steam per hour.They require huge cyclones in order to capture elutriated particles, hence requires a tall boiler.

A circulating bed combustor boiler could be a better choice if the following criteria are met:

- Boiler of capacity large to medium is required.
- NO_X controll and sulphur emission is important.
- Low grade fuel is available for firing in boiler or the fuel is having high fluctuation quality.

Major performance features of the circulating bed system are as follows:

a. Its processing capacity is high because gas velocity fluidizing the media is high here.
b. A constant temperature i.e. nearly isothermal temperature is attained because of high turbulence and solid circulation in bed. Because of low combustion temperature i.e. 870 ℃ NO_X formation is also minimum.
c. Sulphur present in the fuel is retained in the circulating solids in the form of calcium sulphate. It is removed in solid form. The use of limestone or dolomite sorbents allows a

higher sulphur retention rate.

d. Bubbling bed requires combustion at 3-5 psi but here combustion air is supplied at 1.5-2 psi.

e. It has higher combustion efficiency over atmospheric boiler.

f. It has a better turn down ratio than BFBC systems.

g. Here heat exchanger tubes are arranged in parallel to the flow of fluidizing gas, no heat exchanger tubes is used in bed Hence the erosion of heat transfer area is reduced. AFBC have surface perpendicular but CFBC have parallel heat transfer surface area.

Pressurized Fluid Bed Combustion System (PFBC):

When large scale coal burning operation is required pressurized fluidized bed combustors are preferred over CFBC. The operating pressure in PFBC is 16 atm nearly. The feed water for steam generation is preheated by heat from gas turbine exhaust. The gas turbine is driven by off gas from combustion in combustor. The tubes in combustor generate steam which is used to run the steam turbine. A pressurized fluid bed combustion boiler is shown in Figure 1.7.

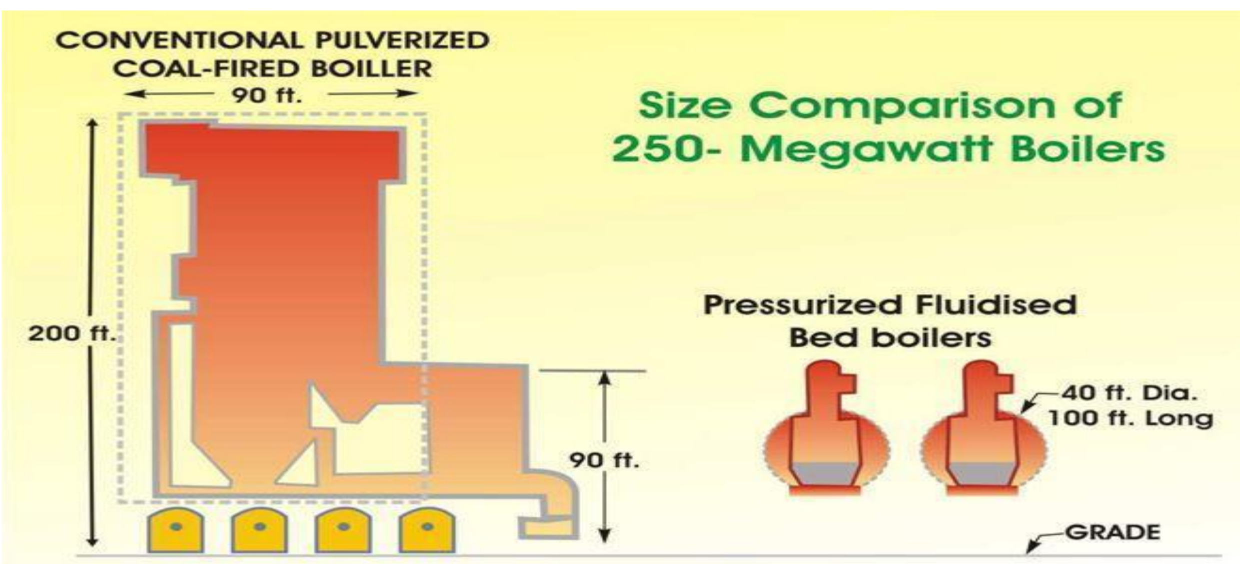


Figure 1.7: PFBC boiler for cogeneration

Cogeneration cycles are preferred with PFBC systems. Electricity can be generated in efficient way by joining gas and steam turbine in PFBC systems. By using cogeneration, the overall efficiency increases by 5-8%. A comparison of size of a typical 250 MW PFBC boiler versus conventional pulverized fuel-fired boiler is shown in the Figure 1.7.

Chapter 2

Literature Review

The literature review is always required for strong problem formulation.In this chapter,the literature review has been presented on topics such as sewage sludge drying, combustion,copelletisation and flammability properties of sewage sludge.Different papers were found on combustion of rice husk or its co combustion with biofuels in fluidized bed combusters.But very less research is done on sewage sludge's combustion in fluidized bed .Therefore in order to study fluidized bed combustion of sewage sludge sewage, we first have to design the combuster for sewage sludge.

J.J.Ramirez et.al[1] developed a fluidized bed combuster for rice husk on pilot scale .The parameters used by him in designing combuster are mean particle size,porosity,apparent density and sphericity.Using above he calculated fluidization velocity and over all height of combustion chamber.

Takahiro Murakami[3] studied about thermal potential of sewage sludge and found that higher heating value of sewage sludge ranges from 16-21 MJ/kg k.He found that as organic substance breaksdown further and further,its calorific value decreases.In order to find weather this calorific value is achievable or not in different sewage sewage treatment plants,test will be performed.

Sen [10] studied the fluidization behaviour of rice husk in perplex column of 76 mm diameter and 900 mm height using multiorifice distributer plate.Minimum fluidization velocity and bed pressure drop depends on fuel also as he found that it is different for whole rice husk and ground husk.

Natrajan[11]. He found that agglomeration tendency of rise husk and found that temperature for agglomeration is more than 1000℃. When using lime as bed material instead of quartz the agglomeration temperature further improves. He concluded that high agglomeration temperature (> 1000℃) fuel can be used in fluidized combusters. Salour[13] found that there was a decline in bed pressure drop just before agglomeration which may be due to channeling of air through bed.

For studying the sewage sludge's combustion characterstics, first we need to have a thorough study on the working of sewerage treatment plant in Punjab. Then different stages needs to be study in these plants inorder to get maximum calorific value. During a literature review, it was that if we choose dewatered sludge i.e. at the end after anaerobic and aerobic reaction it has lower calorific values. But if we choose sludge in the starting of treatment plant then its dewatering will pose problems.

2.1 Literature review of some papers on Fluidised Bed Combustion sytems

S.NO	Author(s)	Description of work	Remarks
1	Sebastian	He studied the physiochemical properties of dried sewage sludge produced from two polish plants and compare it.	He found that there is no significant difference in carbon hydrogen chlorine and fluorine and low percentage of sulphur presence makes it good alternative fuel.
2	M.S.Zakaria	He studied the characterization of Malaysian sewage sludge dried using Thermal Drier.	He developed a disc Thermal Drier Which reduces the final moisture content to 17.8% as having heater heating value 16MJ/kg.
3	Takahiro Murakani	He studied the combustion characteristics of sewage sludge in an incineration plant for energy recovery.	He found that higher heating value of dried sewage sludge is 16-21MJ/kg and heating value of digested sewage sludge is low as organic substance got breakdown during digestion.
4	Hui li	He studied the co-pelletization of sewage sludge and biomass in terms of energy input and properties of pellets.	He found that compression energy is function of applied pressure, die temperature and water content sample. He first dried the sample in oven at 40*c for 48 hours and then sieved in the size of 0.45mm and then converted into pellet.
5	Malgorzata Wzorek	He studied the co combustion of sewage sludge.	He recommended the utilization of sewage sludge by mixing it together with other waste like under grade sized coal, wood waste and waste from animal sewage. He found calorific value of fuel between 13-19MJ is for mixture.

6	Nieves	He studied the flammability properties of thermally dried sewage sludge.	He studied ignition sensitivity, explosion severity, thermal sensibility and thermal stability. He found that it is possible to decrease the risk in thermal drying of sewage sludge by increasing the inert part of dust.
7	Ljiljana	He studied the self ignition tendency of thermally dried sewage sludge during storage and transportation.	He adopted methods such as Thermo gravimetric technique, self ignition temp analysis and UN Division 4.
8	Flangian	He studied the fluidized bed gasification of rice hulls.	He found that multi solid system is favorable for fluidization of rice husk, minimum fluidization velocity and terminal velocity is 16 m/s and 80 m/s respectively. He also found that mixture of ash and rice husk is better for fluidization.
9	Nguyen	He studied fluidization characteristics of rice husk and wood pellets.	He found that fluidization behavior of mixture of two different material will depend on percentage of biomass mixture.
10	Sen	He studied the combustion characteristic and fluidization behavior of rice husk on pilot scale.	He found broken husk has smoother fluidization, less minimum fluidization velocity and less minimum bed pressure when compared to whole husk.
11	Natarajan	He studied the tendency of some common agricultural such as rice husk ,bagasse etc residues to form agglomerates.	He found that the fuels having higher agglomeration value can be used in FBC's.He experimentally found that rice husk and bagesse can be used in FBC because of high agglomeration temperatures. .
12	Mansaray	He studied the agglomeration tendency of sand rice husk mixture having alumina at various temperature level and ash content.	He found that at all temperature levels i.e. 750 to 1000°C, there was no indication of melting but weak agglomerates were observed between 950 to 1000°C.
13	Singh	He studied the agglomeration chacerstics in plant based on rice	He found that magnesium sodium and potassium are the

		husk.	main reasons causing agglomeration due to regular use of sand in fluidized bed, there is increase in size of sand particle hence required periodic refreshment.
14	Rajram	He studied rice straw's fluidized bed combustion.	He found that due to high bulk density of rice husk bales, it sank in bed thus increases residence time hence promote more complete combustion.
15	K.H.Helwa	He studied the drying ability of wood in green house.	He experimentally found that drying ability of wood depends upon air availability to evaporate.As air scavenges the moisture from the surface continuously and hence increases evaporation rate.
16	S.Janjai	He studied the performance of greenhouse drying over natural drying.	He experimentally found that greenhouse drying is 1.6 times more efficient than natural drying.
17	Kaseem	He studied the effect of three different types of architectural forms on drying of onions.	He experimentally found that hemispherical dome is preferred over other shapes for drying.
18	K.Bauerfeld	He studied drying aspect of sewage sludge on pilot scale solar drier.	He experimentally found that drying depends on parameters such as heat input, aeration rate, scaling present and under floor heating.He also found that underfloor heating proved to have 25 % higher evaporation rate.
19	Anuradha	He studied the incomplete combustion of carbon in rice husk for combustion.	He found that incomplete carbon conversion is favorable at temperature above 700 ℃.
20	Swasdisevi	He studied the design, construction and testing of FBC for paddy drying.	He achieved thermal efficiency of 59 % and carbon conversion efficiency of 90 %.
21	Armestoa	He studied the combustion efficiencies of atmospheric fluidized bed boiler of 30 Kw capacity using fuel such as rice husk.	He found that during all test runs the combustion efficiency was found to be more than 97 %.

22.	Kuprainov	He studied the experimental study on combustion of three different biomass fuels in FBC.	He found that maximum efficiency was obtained for excess air percentage of 60 %.
23	Chungsangunist	He studied the impact of fossil fuels causing environmental problems.	He found that except photo oxidation formation capacity of CO,rice husk is having lesser harming potential than fosil fuels for environment.
24	Osaka	He studied the staged combustion of bubbling fluilidized bed combustor using rice straw.	He used the combustor having 300mm inner diameter and 3300mm its height. Cylindrical pellets of nearly 15mm length and 12mm diameter were used. He found as secondary air is increased, combustion efficiency first increases but then decreases because entrained fixed carbon and carbon monoxide starts to increase.
25	Bhatacharya	He studied many aspects of fluilidized bed combustion using rice husk such as combustion intensity increase n bed height, air flow rate.	Combustion intensity is as high as 530 $kg/h/m^2$ can be achieved. As we increase the bed height the combustion efficiency also increases as air flow rate increases. There was increase in combustion efficiency but upto certain limit after which appreciable change was observed.
26	Flanigan	He studied the fluidized be gasification of rice hulls. He found that multi solid system is favourable for fluilidization.	He found that mixture of ash and rice husk is better for fluilidization and found U_{MIN} =16 cm/s and U_{term} =80cm/s.

2.2 Limitations from literature review

During the literature review, following observations were noticed:

1) A lot of work has been done in field of fluidized bed combustion of rice husk but no work has been done in combustion of sewage sludge in fluidized bed combustor.
2) It has been found that different type of pilot scale set up were developed for rice husk or other fuels, but no setup was developed for testing of sewage sludge in fluidized bed combustors even on pilot scale.
3) Feasibility study for combustion such as calorific value, proximate analysis and ultimate analysis were done for other fuels but no such testing was done for sewage sludge in its different stages.

2.3 Objectives

1) Designing fluidized bed combustor for sewage sludge.
2) Feasibility study for sewage sludge in terms of proximate analysis,ultimate analysis and calorific value calculation.
3) Utilizing sewage sludge for combustion in fluidized bed combustor on pilot scale to study factors such as:
    i. minimum fluidization velocity,
    ii. superficial velocity,
    iii. bed temperature ash content
    iv. moisture .

2.4 Scope of study and problem formulation:

With the population of more than one twenty five crore and growing industrialization, the rate of sewage sludge generation weather industrial or domestic has increased drastically and the present way of disposing them possess environment threat. The present way of disposing sewage sludge in fields, land fill or drains still pose danger because it has coeliform bacteria which can only be destroyed by heat.

The present study focus on different stages of sewage sludge generation and to study whether we can utilize sewage sludge generated at different stages for combustion in fluidized bed combustors or not. For different sewage sludge, first feasibility study was done in terms of proximate analysis, ultimate analysis and calorific value testing was done. Then on basis of density and sphericity, fluidized bed combustor was designed ,after which utilization study was done on pilot scale combustor which was developed based on above data.

Chapter 3

Sewage Treatment Technologies used in Punjab

3.1 Types of Sewage Sludge Treatment Technologies commonly used in Punjab:

1) Waste Stabilization Pond Technology.

2) S.B.R Technology.

3.1.1 Waste Stabilization Pond Technology:

The W.S.P. Technology is the one method of treating the grey water by passing it through large but shallow ponds, giving time for both bacteria and algae to play their roles in waste stabilization.

3.1.1.1 Stages of Treatment:

First step towards treatment of waste water is removal of large floating particles. Secondly, there should be a mechanism to measure incoming discharge, which here is measured by V-Notch.

Pond Name	Depth(in mtrs)	Purpose	Quantity
1)Anaerobic Pond	2-5	B.O.D.Removal	1
2)Facultative Pond	1-2	B.O.D.Removal	1
3)Maturation Pond	1-1.5	Faecal Bacteria Removal	2

Table3.1: Specifications of Ponds

Grey water first enters the anaerobic pond and undergo anaerobic reactions in absence of fresh air which leads to B.O.D. removal. It is then pumped to facultative pond where further B.O.D. reduction takes place. Then it enters maturation pond which are shallow than anaerobic and facultative pond which allows sunlight to enter and due to high temperature, pH and solar disinfection, pathogens and faecal bacteria die out.

Fig.3.1 Waste Stabilization Pond for Grey Water

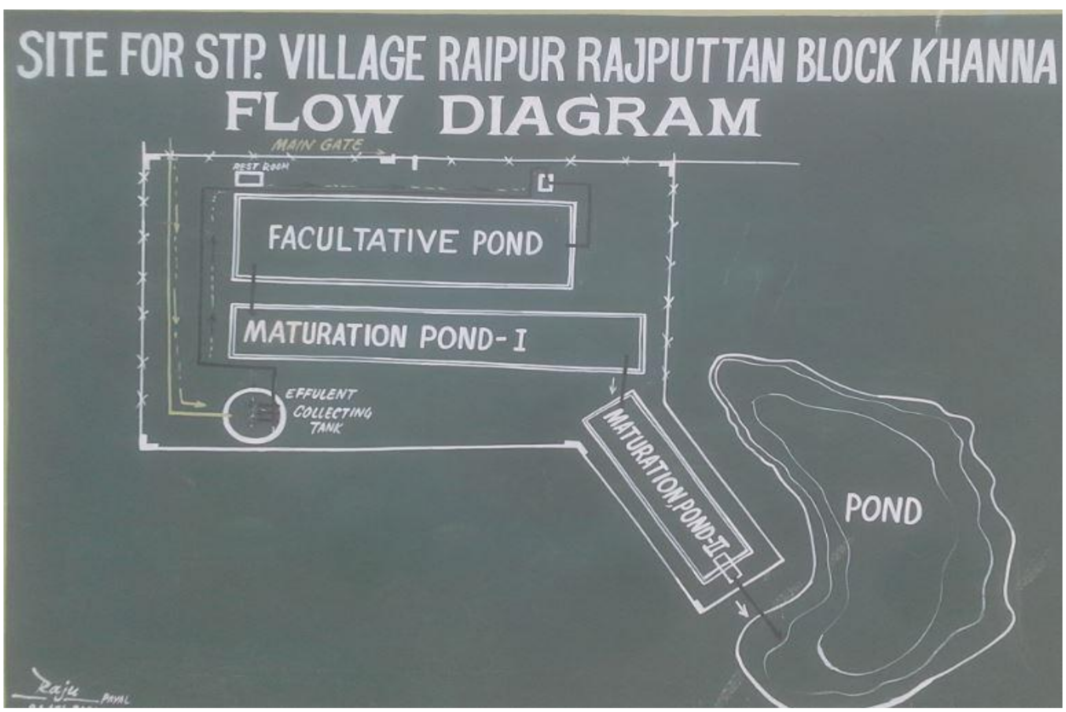


Fig 3.2:Site layout of DWSS STP Raipur Rajputtan

Site Visit: DWSS STP Village Raipur Rajputtan Block Khanna.The waste stabilization technology is followed since many decades but since development in research of this technology as led us to greater efficient mechanism with defined design criteria, organic loading, detention period etc.

Untreated waste water not only pollutes the air by its foul smell but also to the aquatic biota. Hence untreated waste water pose danger to human health and needs to be treated. After treatment of waste water, the sludge will be generated and our prime focus in the coming chapters is to study whether we can use sludge for heating purpose or not. Waste stabilizations ponds are easy to construct as it include only civil structure in form of pits.

It includes no use of electrical and mechanical energy and waste water flows only by gravity. The main requirement is land but generally existing ponds are converted to waste stabilization plant.

WSP are very helpful in removing suspended solids up to more than 90%, ammonia, lessen the BOD, pathogens and require chlorine to achieve destruction of bacteria. They are resilient as well as robust to hydraulic and organic shock loads other than waste treatment process. Due to warm climate and availability of sufficient land they are best suited for sewerage treatment in Punjab.

Fig 3.3 V-Notch

This technology include shallow ponds having earthen embankments. Since here oxidation is slow, hence retention period is heavy. Venturimeter measures the inflow of black water to measure the efficiency of plant. BOD removal is done in anaerobic and facultative ponds while bacteria removal takes place in maturation ponds. The main driving factor in working of these ponds is sunlight. Facultative and maturation ponds are also called photosynthetic ponds because oxygen required by pond bacteria to oxidize waste water is given by algae which grow in these ponds. CO_2 required by algae is given by pond bacteria as end product.

ANAEROBIC POND

Fig. 3.4 Anaerobic Pond

The depth of anaerobic pond vary from 2-5 m .It has organic loading capacity of hundred grams BOD per cubic meter or 300 kg/hr day. It contains no algae or no dissolved oxygen. The prime function of this pond is BOD removal from sewage water. The design aspect of this pond includes 60% or more BOD removal at 20℃. Sedimentation of settling solids and anaerobic digestion develops a sludge layer which hides the sunlight to go inside the pond. Desludging of anaerobic tank is required once in three years.

Fig 3.5 Facultative Pond

The depth of facultative pond varies from 1-1.8 m. It has the organic loading capacity of 100-400kg /hr day. Oxygen for BOD removal is mostly produced by algal photosynthesis. It is to be noted that the depth of facultative pond should not be less than 1 meter as it will act as breading ground for mosquitoes. The location of this pond is decided in such a way that it has ample wind to circulate over it and ample sunlight for photosynthesis.

Fig 3.6 Maturation Pond

The main purpose of maturation pond is pathogen reduction that is fecal bacteria and virus decomposition. It is aerobic throughout its depth. Therefore normally its depth is kept up to 1m so that sunlight can penetrate. It has the only drawback that due to less depth macrophytes i.e. root plants can grow and their shaded area can become shelter for mosquito breading.

Fig 3.7 Drying bed

3.1.2 Sequential Batch Reactor Technology:

It employs physiochemical as well as biological process for sewage treatment. It has different units working in sequence written as follows:

1. Raw Sewage Pumping Station: It comprises of generators and pumps to feed water to primary unit for treatment.
2. Primary Unit: It is the inlet chamber in which raw sewage after grit removal is fed.
3. Treatment Unit: In this unit sewage is made to pass through aeration ponds and then allowed to settle and then by decanting, the upper part of treated water is send to chlorinator and lower part after keeping some amount as activated sludge, other part is fed to centrifuge units for water removal.

   Steps in Treatment:

   I. Aeration,
   II. Settling,
   III. Decantation.

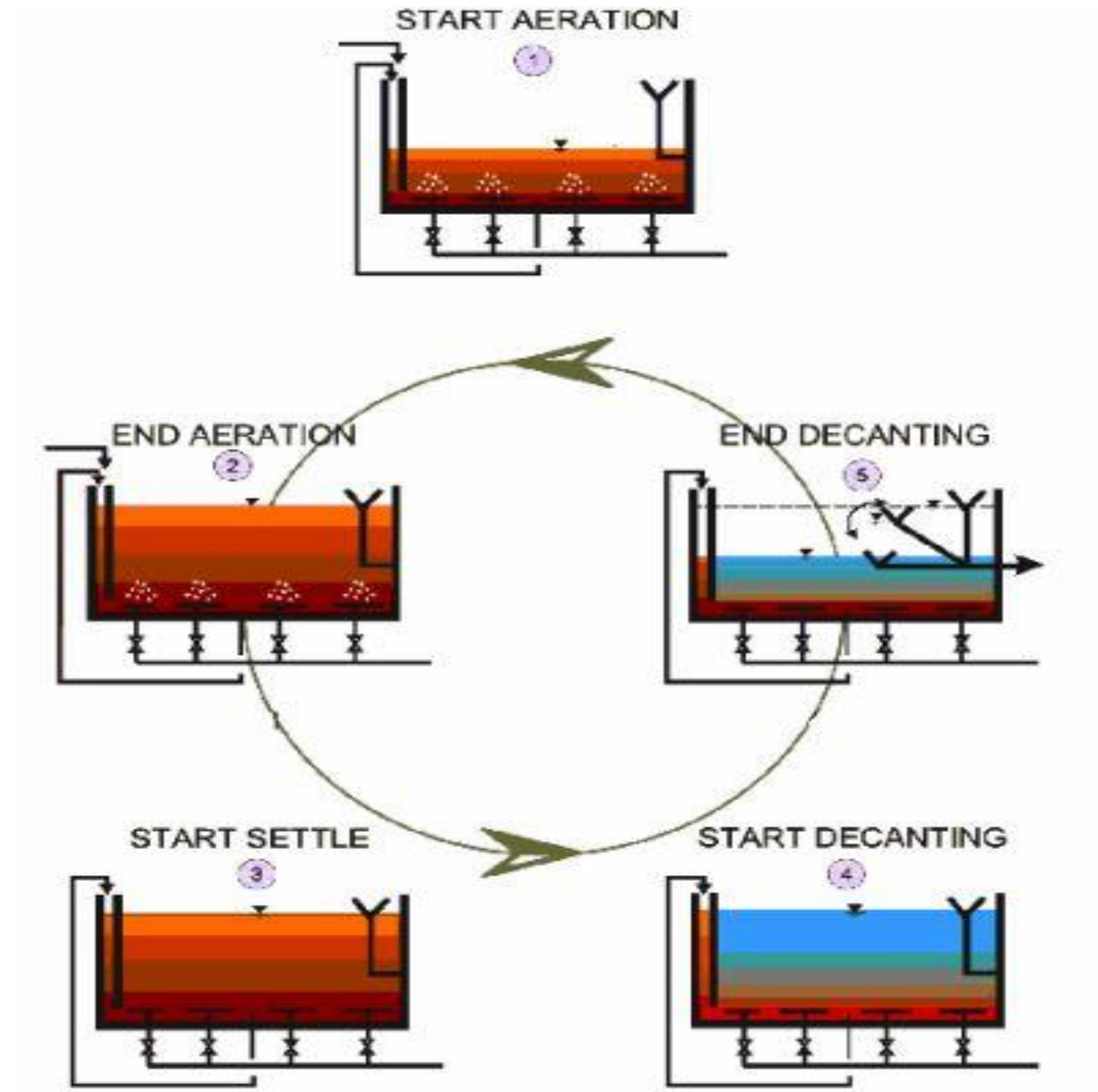


Fig 3.8: Sequencing Batch Reactor

3.2 Site Visit: 10 MLD ABLOWAL

1. **Collecting Tank**

Fig 3.9: Collecting Tank

It is used to collect the sewage water from city to sewer plant. It has a dimension of 30ft × 35ft × 30ft having depth, width, height respectively.

2. **Pumping Machinery**

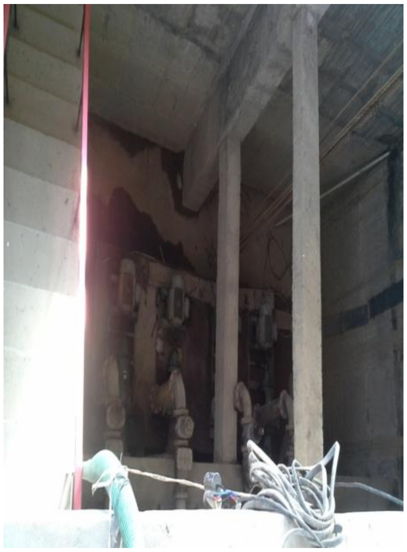


Fig 3.10: Pumping Machinery

Pumping machinery is consists of four motors having the capacity forty horsepower each. They are used to pump sewage sludge from collecting tank to primary unit.

3. **Grit Removal Unit**

Fig 3.11 : Grit Removal Unit

It consists of two parts one automatic and other stationary. They are used to grit of 6mm or above .the automatic grit removal unit makes to and fro motion for once in every 10sec in order to avoid clogging of sewage water.

Fig 3.12 Grit Removal Machinery

Fig 3.13Grit Collection Point

4. **Primary Unit**

Fig 3.14 Primary Unit

Sewage water comes from pumping machinery to primary unit to aeration ponds through primary unit. It is made in such a way that slope is provided at the base of unit and slow rotating motion is provided to sludge for proper mixing and in order to avoid settling sludge at the base.

5. **Reactivated Sludge Mixing**

Sludge generated in plant is classified into two types reactivated sludge, and surplus activated sludge. Surplus sludge supplied to centrifuge whereas reactivated sludge is again supplied to aeration ponds through reactivated sludge mixing chamber.

Fig 3.15 Reactivated Sludge Mixing

6.Aeration Pond

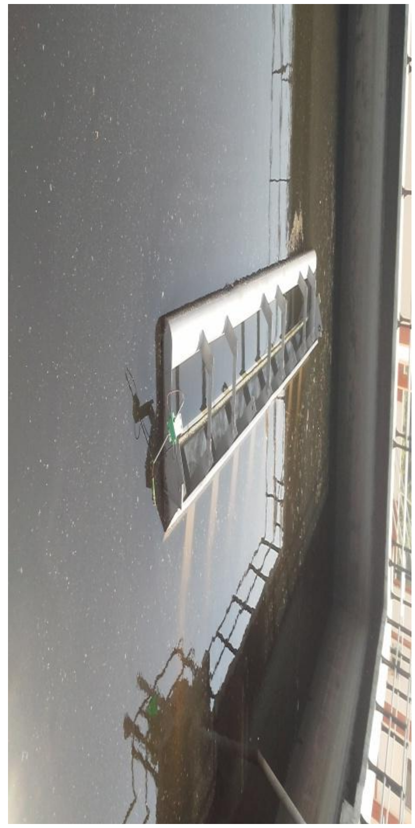


Fig 3.16 Aeration Pond Fig 3.17 Settling of Sludge In Aeration Pond

In aeration ponds nozzles are provided at the base in order to increase oxidation. Aeration is done with the help of three motors having the capacity of hundred horsepower each. They are fixed with VFD in order to motor in case of overheating. One process cycle is completed in 244 mins which includes filling of aeration tanks, gate closing aeration settling and decanting. Filling of aeration tanks takes 52 mins, aeration is done for 72mins, settling is done for 52 mins whereas decanting is done for 72 mins.

Fig 3.18 Decanting

7.Sludge Sump

Fig 3.19 Sludge Sump

It is used to collect sludge i.e. surplus activated sludge from aeration tank. Sludge is given bubbling motion in order to avoid its settling and thoroughly mixed with water. Sludge from here is sent to centrifuge to dewatering by thoroughly mixing it with polyelectrolyte

8. Dewatering of Sewage Sludge

In order to lessen the volume and increase the solid concentration, dewatering of sewage sludge is done. Sludge thickening can be obtained by gravity ,air floccation or with the help of centrifuge.Here sludge is introduced in centrifuge and mixed with polyelectrolyte, increasing the solid capture from sewage sludge.

Fig 3.20 Polyelectrolyte mixing in centrifuge Unit

Fig 3.21 Centrifuge Outlet Unit

Fig 3.22 Motor Rotating Centrifuge Unit

Fig 3.23 Collection Point under Centrifuge Unit (at STP Ablowal)

Fig 3.24 Sewage Sludge Dumping Unit

Types of Grit :

Fig 3.25 Coarse grit

Fig 3.26 Fine Grit

Chapter 4

Preparation of Sewage Sludge Pellets

4.1 Experiment

Sewage sludge and mixing substitutes.

4.1.1 Apparatus

Pelletizer

4.1.2 Procedure

1. Black water from inlet pond is collected in two five liter containers.
2. Polyelectrolyte is mixed in these containers used five gram for five liters.
3. It is thoroughly mixed and stirred so that solid solvents got settled either at base or suspended at surface.
4. It is then filtered and the coagulate are allowed to separate out from the solution.
5. 15-20 gram of wet coagulate sample is taken and allowed to dry in oven at 90 °C for 24 hours .
6. Sample is then kept in dessicator in order to cool it down to room temperature .
7. 1-2 gram of sample is taken and weighted on weight balance machine.
8. Sample is then put in hand pelletizer machine and pellets are made.

Fig 4.1 Wet Sludge Derived Pellet Unit

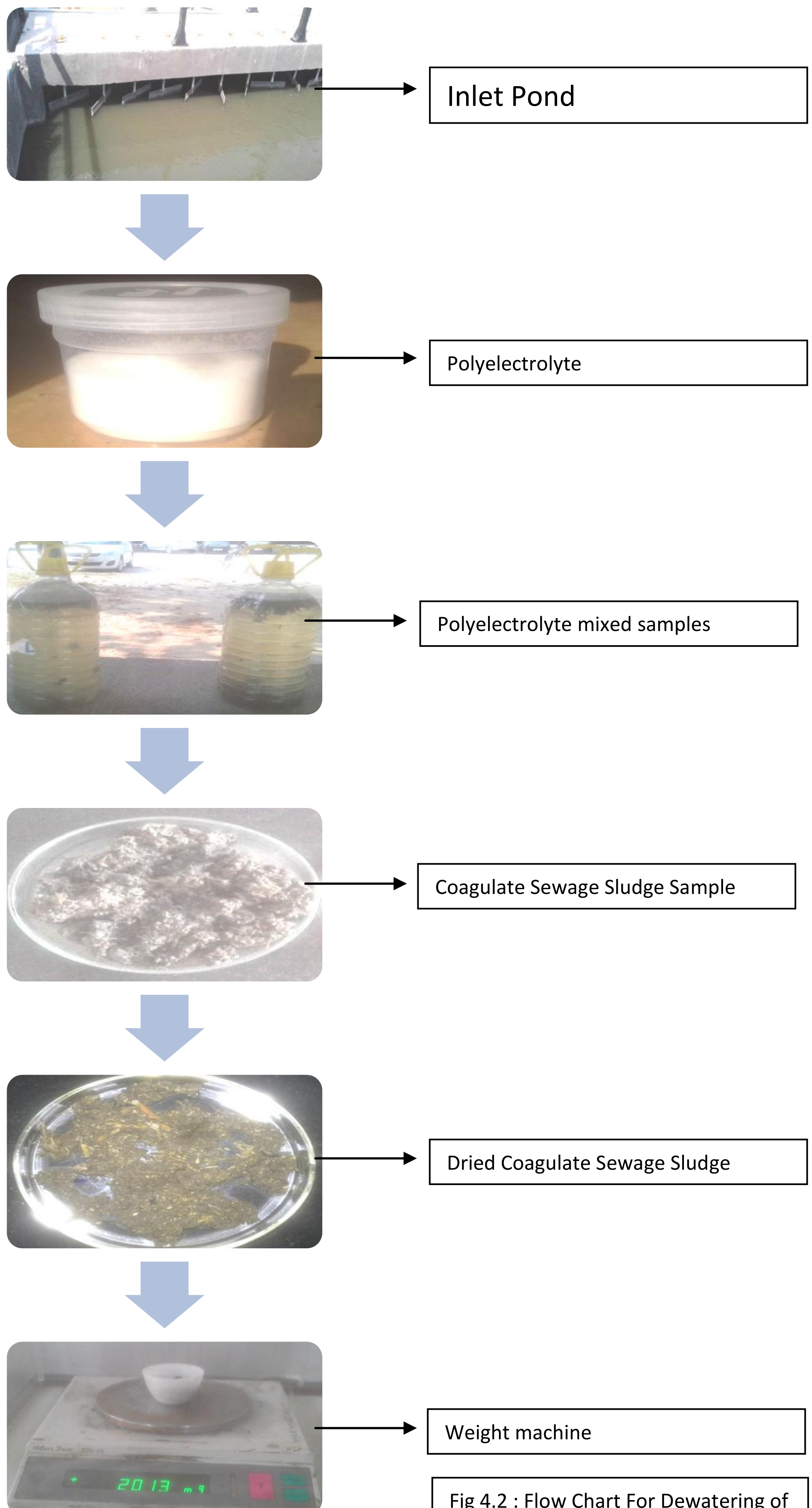


Fig 4.2 : Flow Chart For Dewatering of Sewage Sludge

4.2 Procedure for finding of T.S.S. value of black water in inlet tank:

4.2.1 Apparatus Required

1. Vacuum Pump.
2. Whatman filter.
3. Conical Flask.
4. Suction Pump.

4.2.2 Procedure

1. Black water is taken from inlet pond in a beaker.
2. 500 ml of black water is taken in conical flask with the help of suction pump.
3. Whatman paper is taken after keeping it for some time in dessicator and weighted.
4. It is then kept in flat cup type glass container black water is poured on it and suction effect is made with the help vacuum pump.
5. After full 500 ml is sucked through filter paper, it is kept in oven for 2hrs time and at 105℃ temperature.
6. Now it is kept in dessicator for 20 minute time and again weighted.
7. The change in weight of paper tells the total solid solvents in black water.

4.3 Testing of Pellets in FBC System

For testing of Pellets in FBC system the following set procedure has to be followed.

1. Blower is started and made to run for nearly 5 minutes. Burnt and unburnt particles are removed from combustion chamber with the help of some tool.
2. After cleaning first layer of sand having definite particle size is put in combustion chamber bed. Dry sand is gently added into combustion chamber from side window in such a way avoiding as much as possible that sand does not enter plenum through nozzles.
3. Then a layer of dolomite is put in combustion chamber just to cover the sand area.
4. Charcoal is then put in before kerosene sprinkling in order to start the fire.
5. Then the sludge pellets are put in combustion chamber and ignited.

6. Now the pump is started so that a constant rate of flow of water is maintained in pipes of heat exchanger during combustion.
7. Pressure reading after every five minutes should be noted.

The apparatus for testing consists of following:

QUANTITY	Component
1 meter	Glass tube
1 No	Blower
1 No	Electric Motor
	Manometer
	Metal Frame
	Distributer Plate
	Valves

Table 4.1 Apparatus required for testing of pellet in F.B.C system

Chapter 5

Design Aspects of Fluidized Bed Combustion Technique

It has the following main parameters to be studied:

1) Design of Distributer plate.
2) Design of Heat Exchanger Coil.
3) Design of Bed.
4) Design of Blower.

5.1 Design of distributer plate

Distributer plate is used for introducing the fluidizing medium through cross section of the bed. It keeps the particle in continuous motion and thus prevents the zones causing defluidisation. The structure of distributer plate consists of geometric patterns in definite shape made perforations in metal plate. The perforation can be of many types such as single perforated plate,perforated plate with bubble caps ,pipe grid etc. Every distributer has its own pro's and con's.Wired mesh /perforated flat plate or two staggered perforis commonly used for laboratory operation, staggered perforated plate is used for industrial operations because good design coupled with good distribution of gas.

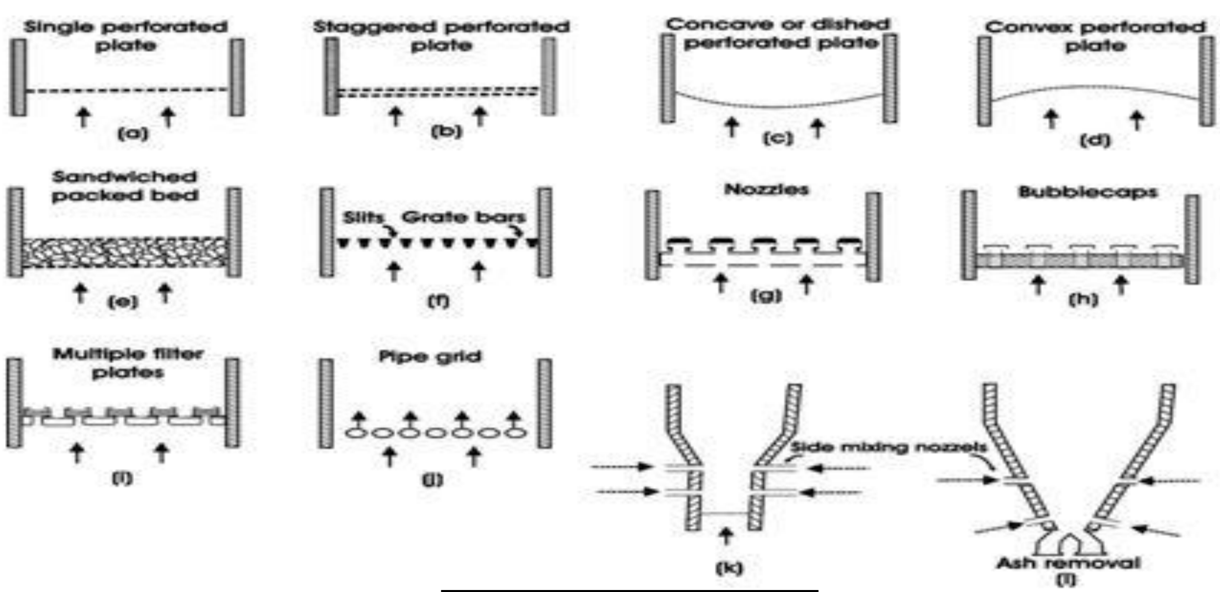


Fig .5.1Fluidised Bed Distributer plates

Curved plates are preferred over flat plates because under haevy loads,flat plates deflect and are also good to overcome thermal stresses.Bubbling should be evenly distributed over the entire cross section of bed but have the tendency to occur near the central axis .Hence more orifice near the circumference of bed hepls to this disadvantage.Sandwiched packed bed is used when fluidising medium is solid free type and when low temperatureinlet gases are to be proctected from hot bed. Nozzle type and bubble cap type beds are used to prevent entry of particles down through the distrubuter.Multiple filter plate distributer has better distribution of gas than nozzle type or bubble cap type but special precaution is needed to ensure that fluidising medium is clogging free otherwise it will clog the filter and and restrict the entry of gas in combustor.In order to improve the flow characterstics some times side mixing nozles are also provided as shown in figure (k).

Because of many possibilities in designing of distributers and only good exoerience and judgement will tell us that what modification is required for given application. Hence the first step for useful and successful application of fluidised bed process is good design and selection of distributer.

5.2 Design of Bed:

The fluidising medium exerts a drag force on solid particles of bed in upward direction and the bed weight exerts the weight force in downward direction.When the total drag on particles just equal to the weight of particles they will begin to lift and barely fluidise.It can be expressed as :

$$W_s = \rho_S A_S h(1-\varepsilon) \qquad (01)$$

Where,

W_s=Solid's mass in bed

ρ_S =Density of Solid

A_S =Area of Cross section of solid

h=Height of bed before particles start to lift

ε=Void Fraction of the Bed

Mathematically:

Void Fraction of Bed is defined as follows:-

$$\varepsilon = 1 - \frac{\text{Mass of Particles}}{\rho_S \times Total\ bed\ volume} \quad (02)$$

For low fluid velocities ,the pressure drop because of Drag can be represented by Eurgen Equation given by Kunii and Levenspiel.

$$F_P = \frac{150}{Re_p} + 1.75 \quad (03)$$

$$F_P = \frac{\Delta P}{h} \frac{D_P}{\rho {V_S}^2} \left(\frac{\epsilon^2}{1-\epsilon}\right) \quad (04)$$

$$Re_p = \frac{D_P\, V_S\, \rho}{(1-\varepsilon)\mu} \quad (05)$$

Substituting the values of F_P and Re_p from above equation 2 and 3 respectively and substituting in equation 1 gives:

$$\frac{\Delta P}{h} = 150 \frac{(1-\epsilon)^2}{\epsilon^3} \frac{\mu V_S}{D_P^2} + 1.75 \frac{(1-\varepsilon)}{\varepsilon^3} \frac{\mu \rho_f}{D_P} \quad (06)$$

Where

ΔP=Pressure Drop.

Through orifice,determination of velocity of fluid can be done as:

$$U_{or} = C_d \left(\frac{2g\Delta P_d}{\rho_g}\right)^{0.5} \quad (07)$$

$$U_o = 3.14 \times d_{or} \times U_{or} \times N_{or} \quad (08)$$

h=Height of sand bed partics before it starts to lift.

μ = Fluid Viscosity.

ρ_f=Fluid Density.

V_S=Velocity of solid particles.

D_P =Diameter of solid particle.

Incipient Fluidisation:When the downward gravitational force and upward drag force became equal ,the solid particles start to move up and the condition is called as incipient fluidisation.

5.3 Design of Reactor :

Let us assume the following:

Height of Glass tube =1m

Diameter of glass tube=40mm

Bed Material = Sand particle Dia 1800μm

Weight:0.6 N

Density of sand:2.6129g/ cm^3

Bed Void=1-$\frac{60}{2.6129\times\pi\times4^2\times{}^{2.5}/_4}$

=0.269

Pressure Drop=0.025× $9.81(2612.9-1.25)(1-0.269)$

=468.031N/m^2

Minimum Fluidisation velocity= $\left(\frac{9.81(2612.9-1.25)\times0.269^3\times0.0018}{1.75\times1.25}\right)^{0.5}$

=0.64 m/s

Fluidisation velocity= $\frac{(2612.9-1.25)\times9.81\times\left(1.8\times10^{-3}\right)^2\times(0.269)^3}{150\times18.75\times10^6\times(1-0.269)}$

=0.79m/s

Terminal Velocity:=$\frac{9.81(2612.9-1.25)\times\left(1.8\times10^{-3}\right)^2}{18\times18.75\times10^{-6}}$

=245.86m/s

Therefore X-sectional area of bed:

A=$\pi d^2/4$

= $\frac{\pi\times16\times10^{-4}}{4}$

=1.257× 10^{-3} m^2

At various velocities,Flow rate was calculated as

$\emptyset = A\times\mu$

Velocities	Calculation	Flow rates	Units
Minimum Velocity	$1.257\times 10^{-3}\times 0.64$	8.04×10^{-4}	m^3/s
Fluidised Velocity	$1.257\times 10^{-3}\times 0.79$	9.93×10^{-4}	m^3/s
Terminal Velocity	$1.257\times 10^{-3}\times 245.86$	0.309	m^3/s

5.4 Power requirement of bed is calculated as follows:

$Q_{min}=\Delta P_{min}\times \emptyset_{min}$ (09)

$=1111.505\times 0.000804$

=8.94W

$Q_{max}=\Delta P_{max}\times \emptyset_{max}$ (10)

$=1372.014\times 0.000993$

=13.62W

$Q_{max}=\Delta P_{max}\times \emptyset_{max}$ (11)

$=42691.66\times 0.309$

=13191.72W

Heat Exchanger Coil Design:

The device through which heat is conducted from one medium to another by a good conducting wall is called heat exchanger. Heat exchanger is designed for effective heat energy transfer between two fluids. Because of high thermal conductivity ,copper is preferred in tubing.

Same fluidising velocity has different effect on two ends i.e.upper part and lower part of fluidising bed .i.e.it behaves differently.For shallow bed this variation is small and for deep bed this variation is more.In shallow bed less pressure gradient is created and thus requiring less blower power consumption .i.e. but in deep bed more power consumption is there because of more pressure gradient.A no of parameters decides the heat transfer through coil such as:

1. Design of Heat Exchanger
2. Distributer Plate Design.

3. Temperatue of Bed.
4. Size of Particle.
5. Pressure of Bed.
6. Superficial Velocity of Gases.

Depending on the Fluid flow direction, the heat exchanger coil can be classified into two types.i.e.

1. Counter Flow Heat Exchanger.
2. Parallel Flow Heat Exchanger.

Counter Flow H.E. : When fluid enters from opposite sides and and leaves from other opposite ends,the exchanger is called counter flow.

Parallel Flow H.E. : Both fluids i.e. Hot fluid and cold fluid enters on same side and leaves on same side i.e. the flow is unidirectional and parallel to each other is called parallel flow heat exchanger.

Counter Flow H.E. are preferred over parallel flow heat exchangers because over a given surface area ,counter flow heat exchangers gives maximum heat transfer rate i.e. if heat transfer rate per unit surface area is considered,counterflow heat exchangers have heighest efficiency.

In fluidised bed, transfer of heat batween bed and immersed surface is necessary which could be that of coil or bundle of tubes.Heat exchanger can be vertical,inclined or horizontal. In terms of pressure drop, vertical type of heat exchanger in deep bed is less preferred over horizontal type in shallow bed.

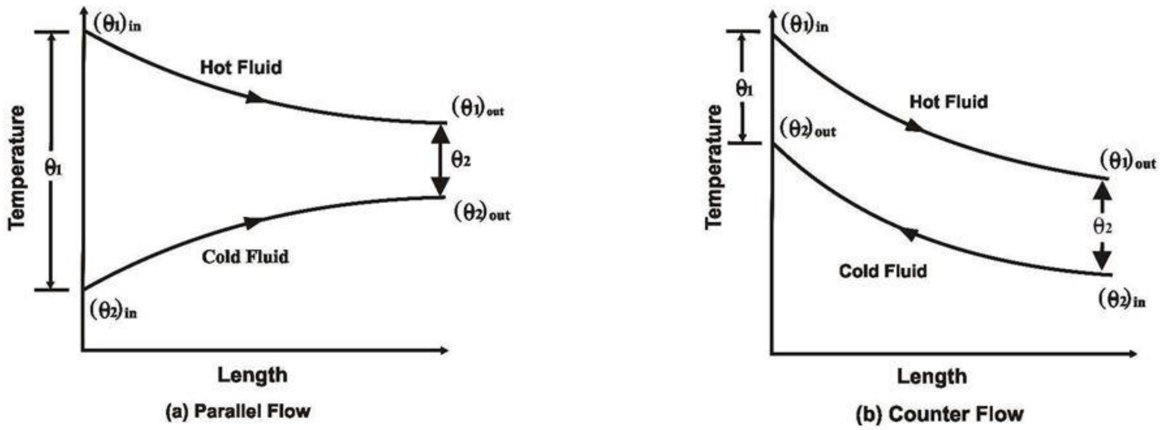


Fig 5.2 : Parallel flow and counter flow heat exchanger

The log mean temperature difference (LMTD) of counter flow heat exchanger is heigher than parallel flow heat exchanger.Hence has heigher efficiency than parallel flow H.E.

Parameters details assumed for pipe length calculation of H.E :

Minimum Fluidising Velocity at 200 °C	0.25 m/s
Parameters	Value
Mass flow rate of gases,m	0.5 kg/s
Inlet Temperature of air, $(\theta_1)_{in}$	50 °C
Outlet Temperature of air, $(\theta_1)_{out}$	200°C
Inlet Temperature of Water, $(\theta_2)_{in}$	20°C
Outlet Temperature of Water, $(\theta_2)_{out}$	80°C
Tube Material	Copper
Tube Bore Inner (inner dia .i.e. d_i)	12 mm
Outer Diameter of Tube (outer dia .i.e. d_o)	15 mm
Particle Type	Silica sand
Diameter Of Particle	427 μm

Table5.2: Parameters assumed for Pipe Length

Table 5.3:Physical Properties Assumed for Pipe Length Calculation:

Density of Particle, ρ_p	2612.9 kg/ m^3
Mean Specific Heat of Air , S_{air}	1.04 kJ/kgK
Thermal Conductivity of Air (at 200°C) K^A	3.87×10^{-2}
Density of air at 1 atm(at 200°C) ρ_G	0.746kg/m^3
Viscosity of air at 200 °C μ_G	2.58×10^{-5} kg/ms
Viscosity of water at 50 °C μ_W	544×10^{-6} kg/ms

Prandtl no of water at 50℃ Pr	3.542
Specific Heat of water, S_W	4.186 kJ/kgK
Thermal Conductivity of Water K_W	64×10^{-6} kw/mk
Thermal Conductivity of Copper K_{CU}	380 W/mk

Duty rquired from heat exchanger:

$$D = m \times S_{air} \times ((\theta_1)_{out} - (\theta_1)_{in}) \quad (12)$$

$=0.5\times 1.04 \times 150$

=78.0 kW

Flow rate of water:

$$\theta_W = \frac{D}{((\theta_2)_{out} - (\theta_2)_{in}) \times S_W} \quad (1\ 3)$$

=0.3110 kg/s

Water velocity when this flow rate of water is passed through double coiled tube:

Velocity of water i.e

$$U_W = \frac{\theta_W}{Cross\ sectional\ area\ of\ tube} \quad (14)$$

$$= \frac{0.3110}{1.57\times 144\times 10^{-3}}$$

=1.37 m/s

Now by using the emperical relation, we will now find heat transfer coefficients at inner surface and outer surface of heat exchanger tubes i.e.

$$Nu=0.023(Re)^{0.8}(Pr)^{0.4} \quad (15)$$

Here,

Nu is Nusselt number

Re is Reynolds number

Pr is Prandtl number

$$\text{Re}=\frac{\rho_w \times \mu_w \times d_i}{\mu_w} \tag{16}$$

$=\frac{1000\times 2.740\times 12\times 10^{-3}}{0.000544}$=60441.17

We have assumed heat exchanger with twin tubes .Hence Reynolds no becomes

Re=60441.17$\times$ 2

=120880

Nu=0.023$\times$ $(120880)^{0.8} \times (3.540)^{0.4}$

=443.83

Now Finding heat transfer coefficient at inner surface of tubes,

$$h= \frac{\text{Nu}\times \text{K}_\text{W}}{\text{d}_\text{i}} \tag{17}$$

$=\frac{443.83\times 6430\times 10^{-6}}{0.012 \times 2}$

=11.89 kW/m^2K

Checking applicability

Archimedes no:

$$\text{Ar}= {d_p}^3 \times \rho_{g\times} \rho_p \times g/{\mu_g}^2 \tag{18}$$

=$(427 \times 10^{-6})^3 \times 0.745 \times 2612.9/(2.58 \times 10^{-5})^2$

=2233.53

At minimum Fluidisation Velocity, Reynolds no calculated as:

$$\text{Re}_{\text{min}}=\rho_{g\times} U_{min} \times d_p \tag{19}$$

=0.745$\times$ $0.64 \times 427 \times 10^{-6}/(2.58 \times 10^{-5})$

=7.89

Using equation

$h_{max} = 35.8 \times \rho_p^{0.2} \times K_a^{0.6} \times d_p^{-0.36}$

$= 35.8 \times (2612.9)^{0.2} \times (0.00387)^{0.6} \times (427\times 10^{-6})^{-0.36}$

= 400 W/m^{2}K

To find heat transfer rate, taking the 70 percent of above value

$=0.7\times400$

$= 280 W/m^2K$

Overall heat transfer coefficient can be given as:

$1/ h_o A_o$: Convection resistance due to fluid film at outside surface (W/m^2K)

$1/ h_i A_i$: Convection resistance due to fluid film at inside surface (W/m^2K)

$t/k A_m$: Wall conduction resistance(W/m^2K)

$$\frac{1}{UA}=\frac{1}{h_oA_o}+\frac{1}{h_iA_i}+\frac{1}{KA}$$

$= 245.39/3.14L\ W/m^2K$

$A_o = \pi d_o L$

$A_i = \pi d_i L$

$A_m = 0.5\ \pi\ (d_o+d_i)\ L$

LMTD is based on assumption that the fluidized bed has the same temperature as that of outlet gas temperature

Hence,

$$\text{LMTD}, \theta_M=[(\theta_1)_{out}-(\theta_2)_{out}]-[(\theta_1)_{out}-(\theta_1)_{in}]/\ \ln\frac{(\theta_1)_{out}-(\theta_2)_{out}}{(\theta_1)_{out}-(\theta_1)_{in}} \quad (20)$$

$=148K$

Hence length of pipe required$=\frac{245.39\times78}{148\times\pi}$

$= 41.1\ m$

Chapter 6

Development of The Model

6.1 Physicical and Chemical Parameters

To study physical and chemical parameters, a mathematical model has been developed. The parameters considered are such as superficial velocity of fluid, minimum fluidization velocity and bubble diameter of fluidized bed combustor.

6.1.1 Superficial Velocity

The fuel composition determines the stochiometric rate of air feed and it can be expressed as :

$$F_{mth} = W_f(1 - M_X)\frac{\left[\frac{C_X}{12}+\frac{H_X}{4}+\frac{S_X}{32}-\frac{O_X}{32}\right]}{0.21}\text{g.mol/s} \quad (21)$$

Where for fuel, the nomenclature can be given as

W_{fuel} = rate of feeding fuel to combustor (g/s),

$C_X = Carbon\ content.$

$O_{X=}$Oxygen content.

S_X=Sulphur content.

H_X=Hydrogen content.

M_X=Mositure content.

The actual rate of feeding the fluidizing medium can be calculated as follows :

$$F_{me} = F_{mth}(1 + E_{air})\ g.mol/s \quad (22)$$

Where,

F_{me}: Actual molar feed rate

E_{air} : Fractional of excess air

The calculation of superficial velocity can be done as:

$$U_{\circ}=\frac{F_{me}\, R_g\, T_b}{A_t\, P_{avg}} \qquad (23)$$

F_{me} =Actual molar feed rate(g.mol.K).

R_g = Gas conatant(atm)

T_b = Absolute Temperature of Bed(K)

A_t = Area of cross section of bed(cm^2)

P_{avg}=Average Pressure in combustor(atm)

Minimum Fluidization Velocity

Because of particle size greater than 100 μm,Wen and Yu-1966 correlation is used to calculate minimum fluidization velocity:

$$U_m=\frac{\mu_g}{d_p\, \rho_g}\left[\frac{0.0408\,(d_{pav})^3\, \rho_g\, (\rho_p-\rho_p)g}{\{\mu_g{}^2+1135.7\}^{0.5}-33.7}\right] \text{cm/s} \qquad (24)$$

Where,

U_m=Minimum Fluidisation Velocity(cm/s).

μ_g =Fluidisaing Gas Viscosity(g/cm.s).

d_p =Diameter of fuel Particle(cm).

d_{pav} =Fuel particles average Diameter(cm).

ρ_g =Density of fuel particles(g/cm^3).

Tb=Temperature of bed (K).

Fluidising Gas Viscosity:

The final expression of viscosity as a function of temperature of bed is as follows:

$$\mu_g=\frac{1.4\sqrt{(T_b)}}{10^5} \text{ g/cm.s} \qquad (25)$$

Avegare Equivalent Bubble Diameter:

There are many no of correlation used in literature for finding the bubble diameter but the most widely used is by Mori & Wen-1975 .The model by Mori & Wen not only takes into account distributer type but also the dia of bed:

$$D_b = D_{bm} - (D_{bm} - D_{bo})e^{-0.15/D_R} \quad (26)$$

Where,

D_{bm}=1.6377$\left[A_t\left(U_\circ - U_{minf}\right)\right]^{0.4}$ and

$$D_{bo}=0.8716\left[A_t\left(U_\circ - U_{minf}\right)/N_D\right]^{0.4} \quad (27)$$

N_D=No of orifice openings in perforated plate.

D_b	:	Diameter of Bubble in cm.
Dbm	:	Maximum diameter of bubble in cm.
Dbo	:	Initial diameter of bubble in cm.
N_D	:	Orifice openings number.

In case of Mori and Wen -1975, the correlations are used with perforated type distributer plates for laboratory type FBC.For industrial type combustors, where wall friction no longer deserve much concentration ,Rowe-1976 expression can be used,which is given below:

$$D_b = (U_\circ - U_{minf})Z^{0.75}g^{-0.25} \quad (28)$$

Here

Z = bed height in cm

Heating Value Model:

On basis or regression analysis of samples tested for proximate and ultimate analysis,the following empirical relation can be derived:

6.2 For Proximate Analysis:

$$H.H.V=(60.3211\times FC)-(83.7832\times Ash)+(206.6153\times VM)-(142.532\times M)+5999.8670$$

Here,

% Absolute error = 7.266

% bias error = -1.17684E-14

For Ultimate analysis:

$$\boldsymbol{HHV} = -4765.356465*(C/0) + 4116.991725*(C/H) + 32.40536825*O + 4202.581324*S + 2260.700539*N + 516.657751*H - 145.3645966*C - 20793.85696$$

Here,

% Absolute error = 6.156

% bias error = -3.29181E-14

Chapter 7

Operation of 5MW FBC At Village Khusropur

7.1 Introduction of Plant

The boiler at Vishal paper industries has been installed were established in 1995. It is located in village Khusropur on outskrits of historic village main in district Patiala of Punjab. The fluidized bed boiler was installed in the plant in year 2007.

The furnace arrangement of boiler is shown below:

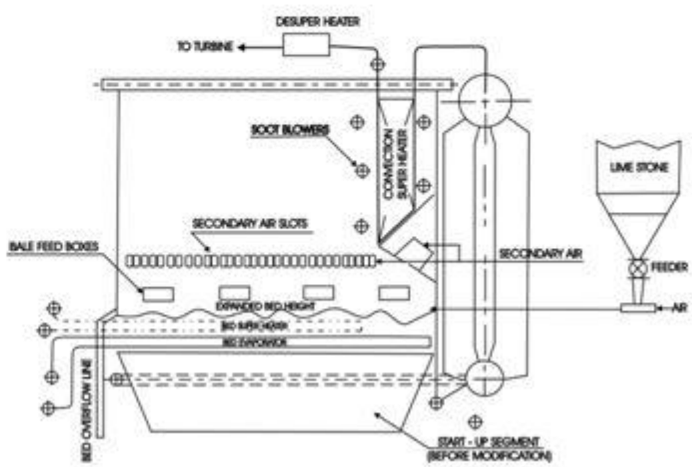


Fig 7.1 Furnace of 5 MW Pet Coke and Rice Straw Fired Fluidized Bed Combustor Boiler

Table 7.1

Design parameters of FBC Boiler

Type of boiler	: Fluidized bed type
Fuel	: Rice straw and Pet Coke. Pet coke is in form of granules and rice straw in form of small bundles called bales.

Size of unit	: 5 MW
Maximum continuous rating of steam flow	: 30 T/hr
Outlet pressure of steam	: 64 bar
Temperature of main steam line	: 485 ℃
Economiser inlet feed water temperature	: 105 ℃
Maximum continuous rating of fuel	: 3 T/hr

7.2 Observation Regarding Operation of Plant

There were two types of air provided i.e. primary air and secondary air. It was noticed that there was dull upward flame. Hence it is suggested that if secondary air is provided near the base, it will enhance the complete combustion of volatile matter and char. The complete combustion will take place at base and reduces the temperature of flue gases which enter convection super heater.

Deposition of ash was observed on tubes of convection super heater which may be due to close location of light off segment. Due to very high temperature at inlet i.e.1173 k or more, ash get melted and deposited on tubes. Hence the light off segment and tubes of convection super heater should be located at farthest point within the bed segment.

Some modifications after analysis of observations were suggested to enhance the performance are as under:

Bed Material size:

For proper fluidization at low velocities, bed particle diameter has to be reduced from 3 mm to 1.5 mm.

7.3 Brief Description of Boiler:

The boiler is bottom supported, natural circulation having bi drum configuration. The cross sectional area of the bed is twenty two meter square. As small bundle of rice straw called bales is fed along with pet coke from side walls, the tubes are hence arranged in horizontal pattern.

Forced circulation is followed for in bed evaporator tubes. Fluidizing pet coke should submerge the coils during fluidization. Hence a bed height of 300 mm is maintained.

The superheated steam is divided into two sections, one in the bed of furnace and other at the exit of furnace outlet section. A super heater is provided between super heater outlet and at base for controlling final temperature of steam.

Boiler bank tubes are arranged after super heater. Hence after passing through super heater, gas passes to boiler bank tubes. After boiler bank tubes, economizer is provided which is followed by tubular air heater.

In order to reduce the particulate emissions, bag filter is located. Two no induced fans of radial type are also provided for collection of dust. Fly ash hopper works in intermittent way with the help of hydrovac system.

Soot blowers are provided at economizer areas, convection superheated outlet and in boiler banks. Soot blowers are provided because of presence of alkalis in rice straw.

Fuel Feeding Arrangement:

The fuel is fed with the help of conveyer belts and is in pulverized form having size varying from 1.5 to 3 mm.

Table 7.2: Proximate and Ultimate Analysis of Rice Straw, Sewage Sludge sample and Pet coke

Proximate Analysis	Percentage	Rice Straw Sample	Sewage Sludge Sample
Moisture	%	6.1	6.20
Volatile	%	62.1	55.9
Ash	%	15.7	38.5
Fixed Carbon	%	16.1	8.50
H.H.V.	MJ/kg	14.53	13.90
Ultimate Analysis			
Carbon	%	37.39	31.81
Hydrogen	%	5.34	4.34
Sulphur	%	2.57	1.20
Nitrogen	%	1.27	3.03
O_2 diff.	%	31.53	25.79

Table 7.3 Physical and Chemical Parameters of Plant:

Parameters	Symbol	Value	Units
Fuel Feed Rate	w_{fuel}	3	T/hr
Moisture content	W_X	1.41	%
Carbon content	C_X	37.40	%
Hydrogen content	H_X	5.35	%
Sulphur content	S_X	2.55	%
Oxygen content	O_X	31.53	%
Fractional Excess Air	E_{XAIR}	0.10	------
Bed Temperature	T_b	1100	℃
Pressure in the Combustor	P_{AV}	1.02	Atm
Cross-sectional area of bed	A_T	219400	cm^2
Fuel Particle Diameter	d_p	1.5	Mm
Bed Height	Z	300	Mm

Chapter 8

Design of Experimental Setup of Pilot Scale Atmospheric Fluidized Bed Combustor

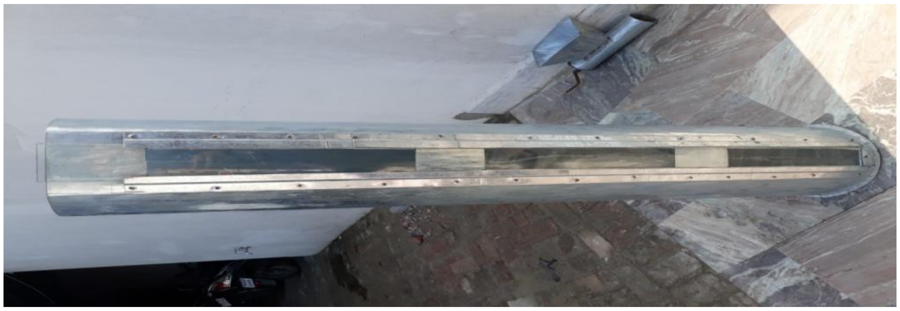
After design of heat transfer coil and distributer plate ,the other components of CFBC needs to be designed so that the experimental set up can be assembled. Some components to be designed are given as below:

- Blower
- Setup stand
- Conduit cloth
- Cubical plenum
- Furnace
- Fuel feeding system

8.1 Component specification:

Components	Specification
Furnace	Steel 0.5 mm thick
Nozzles	G.I. Pipes Welded and drilled
Tubing	Copper
Base plate	Cast Iron
Piping	Plastic
Insulation	Fine Clay
Bed	Silica Sand
Manometer	U Tube Manometer
Thermometer	Mercury Glass
Blower	3 H.P, Air Velocity of 45m/s

Furnace :



It is made up of Rourkela steel plant's sheet having thickness 0.50 mm of 26 gauge steel. The inner diameter of rolled steel is 278 mm. The height of one rolled cylinder is 1260 mm. It contains 3 windows of dimension 33.5×10mm.The windows are separated from each other by 10 mm space .The windows are covered with 8 mm glass. At base of furnace a window of 110 mm is provided for slag removal.

Plenum

The plenum is cubical box 0.5 mm gauge thickness having height of 300 mm, width of 195 mm and length of 255 mm.

Air is fed into the plenum from side AB i.e. bottom .The plenum is bolted to the base of plate .Air is collected from blower and then passed to the nozzles through distributer plate with the help of plenum.

The given picture shows the detail of plenum:

Nozzles: The nozzles used to inject air are made up of GI pipe 10 mm dia. The nozzles has diameter of inlet port and outlet port of 8 mm and 3 mm respectively. Four exit ports are provided at each nozzle having height of 25 mm.

Diffuser plate :

The diffuser plate is square in shape having dimension 300 mm × 300 mm .There are nine nozzles welded on the plate .

Tubing :

The given picture shows the detail of tubing:

For heating water,copper made tube is used having internal and external diameter of 4mm and 6 mm respectively.Length of tube taken is 7.92 m. Out of 7.92 m, 1630 mm is used for inlet and outlet port for water flow, rest is converted in helical coil of 125 mm diameter.

Blower:

The blower used here is BRI make of 3 hp motor capable of delivering air at maximum air flow rate of 45 m/s.

The given picture shows the detail of blower:

8.2 Fluidised bed combuster setup

(Front view)

(Back view)

Chapter 9

Results and Discussion

1) As the literature survey tells us that calorific value of sewage sludge ranges from 16-21 MJ/kg k .Ten different samples from three different sewage treatment plants were taken. The calorific value of sludge from these plants taken varies from 3.9 MJ/kg k to 13.9 MJ/kg k. There is wide variation of calorific value ,hence it becomes important to choose from where to take sludge sample and from which stage also. The sewage sludge sample S11 is best to use taking in consideration of calorific value.
2) The diameter of combustion chamber used is 278 mm and height is 1260 mm. The pressure drop in bed varies from 0 to 170 mm of water .
3) During utilization of sewage sludge in combustor, different parameters such as minimum fluidization velocity, superficial velocity, ash content and moisture content were studied. The graphs were found similar to literature as found my Ravinder Kumar and K.M.Panday.

1.Graph between Minimum Fluidisation velocity and ash content(S11)

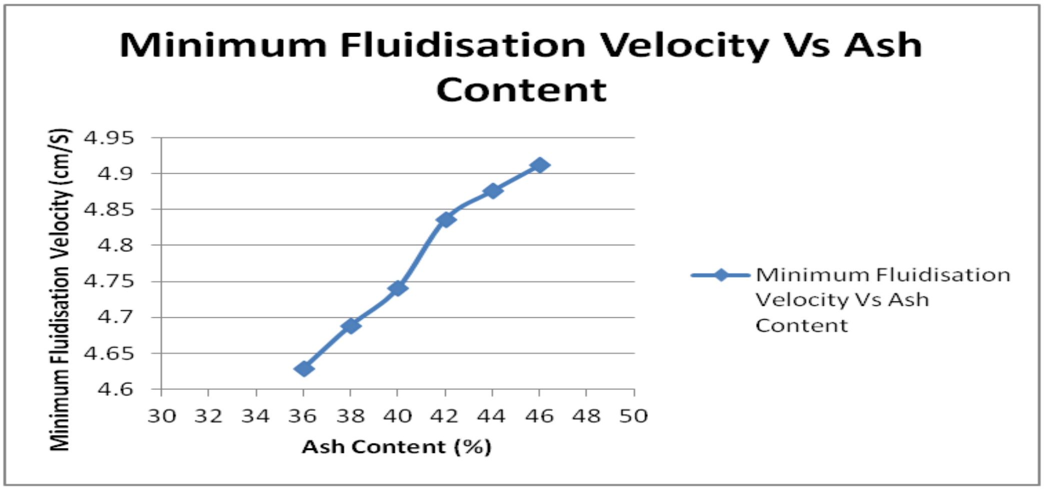


Figure 9.1: Minimum Fluidisation Velocity Vs Ash Content

From the graph it is clear that minimum fluidization velocity increases with increase in ash content. In graph we can see the fluidization velocity varies from 4.62-4.91 when ash content of sample taken from shermajra varies from 36-46(air dried basis-In percent).

2.Graph between Superficial Velocity and Temperature(S11)

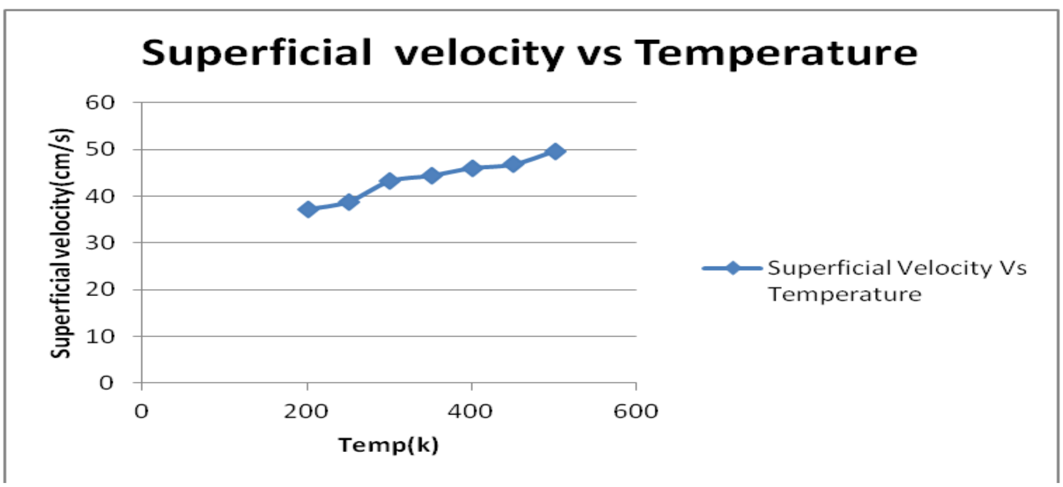


Figure 9.2: Superficial Velocity Vs Temperature

From the graph it is clear that superficial velocity increases with increase in temperature. In graph we can see the fluidization velocity varies from 37.2-49.6 when temperature varies from 200 to 500 K.

3.Graph between Superficial Velocity and Moisture(S11)

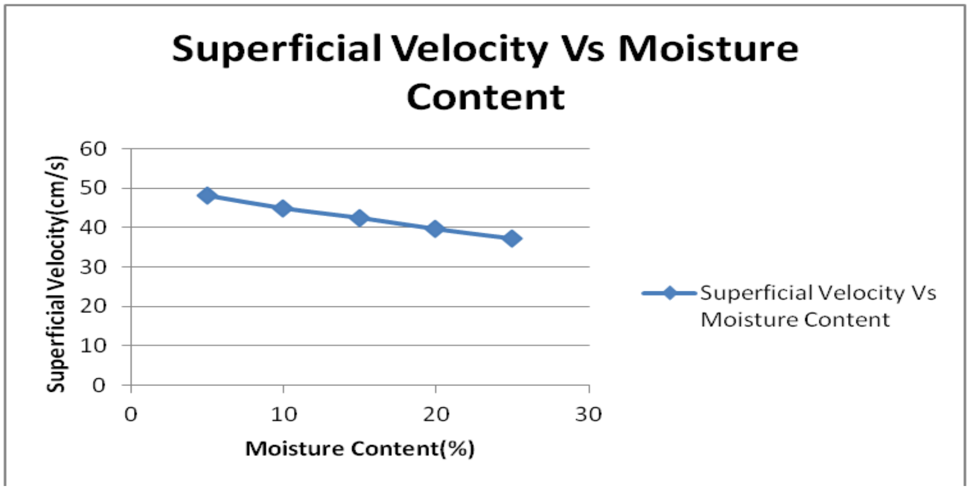


Figure 9.3: Superficial Velocity Vs Moisture

From the graph it is clear that superficial velocity increases with increase in moisture content. In graph we can see the superficial velocity varies from 37.2-48 when moisture varies from 5to 25 (air dried basis-In percentage).

4.Graph between Minimum Fluidisation velocity and Bed Temperature(S11)

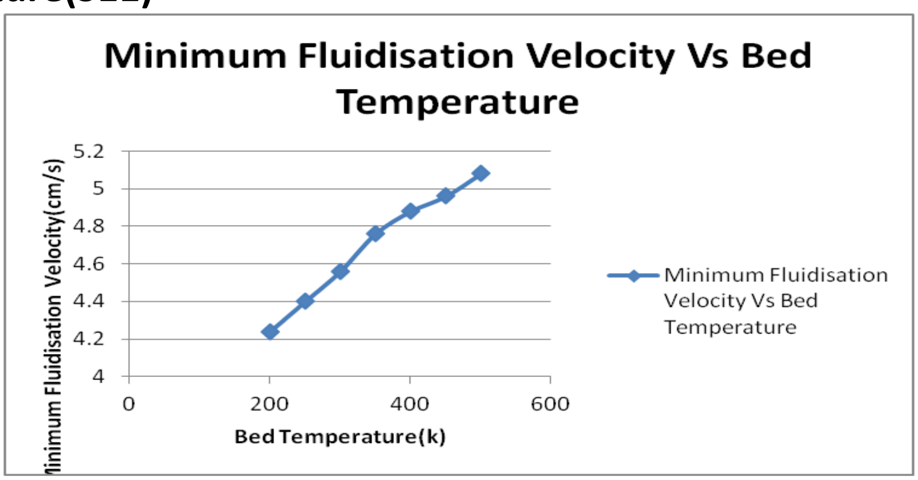


Figure 9.4: Minimum Fluidisation Velocity Vs Bed Temperature

From the graph it is clear that minimum fluidization velocity increases with increase in bed temperature. In graph we can see the fluidization velocity varies from 4.24-5.08 when bed temperature of combustor varies from 200-500 K.

5.Graph between Minimum Fluidisation velocity and ash content(S12)

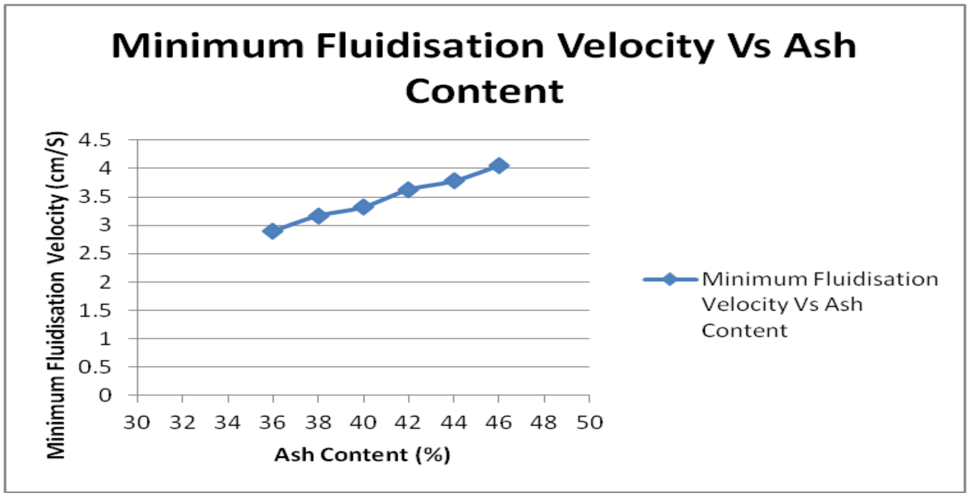


Figure 9.5: Minimum Fluidisation Velocity Vs Ash Content

From the graph it is clear that minimum fluidization velocity increases with increase in ash content.In graph we can see the fluidization velocity varies from 2.89-4.05 when ash content of sample taken from shermajra varies from 36-46(air dried basis-In percent).

6.Graph between Superficial Velocity and Temperature(S12)

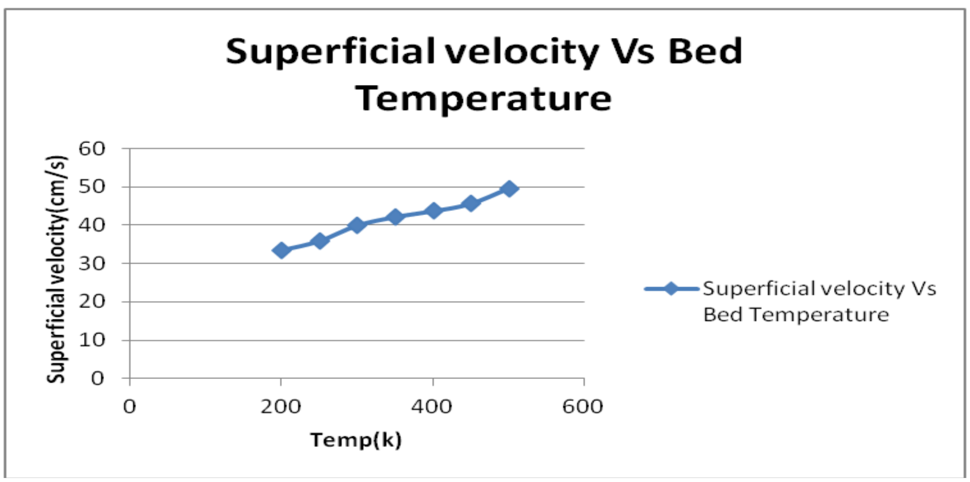


Figure 9.6: Superficial Velocity Vs Temperature

From the graph it is clear that superficial velocity increases with increase in temperature.In graph we can see the fluidization velocity varies from 33.48-49.6 when temperature varies from 200 to 500 K.

7.Graph between Superficial Velocity and Moisture(S12)

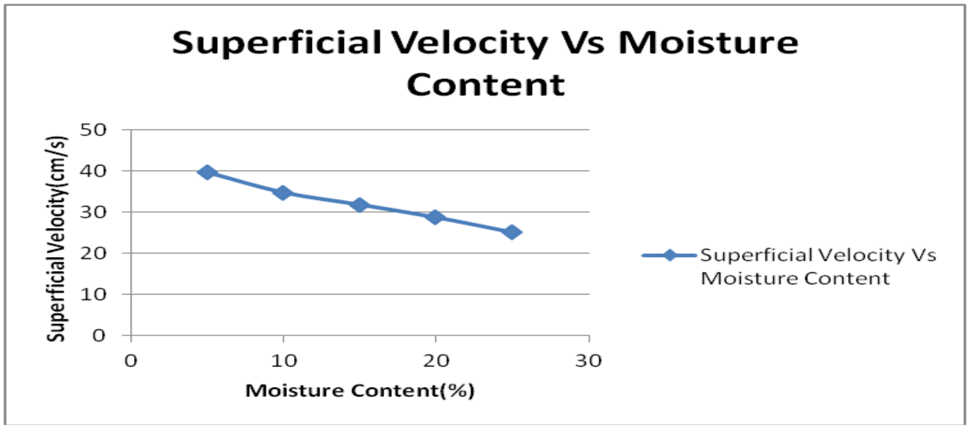


Figure 9.7: Superficial Velocity Vs Moisture

From the graph it is clear that superficial velocity increases with increase in moisture content. In graph we can see the superficial velocity varies from 25.11-39.6 when moisture varies from 5to 25 (air dried basis-In percentage).

8.Graph between Minimum Fluidisation velocity and Bed Temperature(S12)

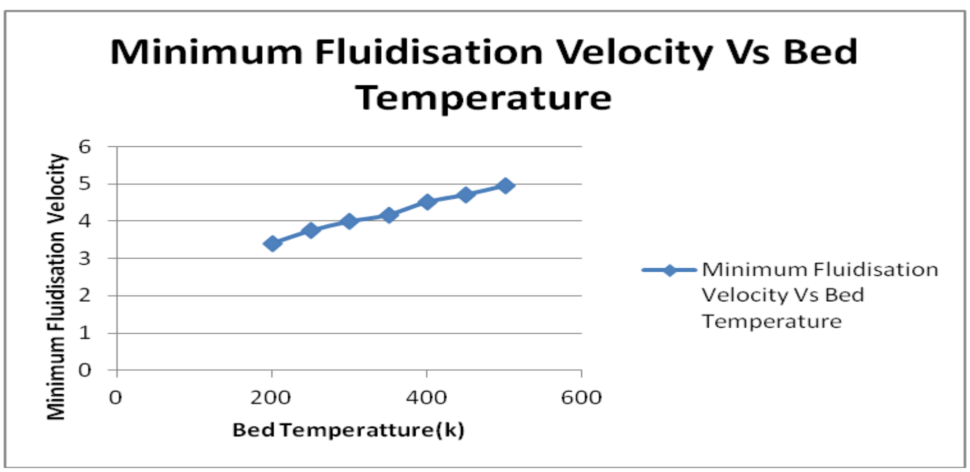


Figure 9.8: Minimum Fluidization Velocity Vs Bed Temperature

From the graph it is clear that minimum fluidization velocity increases with increase in bed temperature. In graph we can see the fluidization velocity varies from 3.39-4.95 when bed temperature of combustor varies from 200-500 K.

9.Graph between Minimum Fluidisation velocity and ash content(S11)

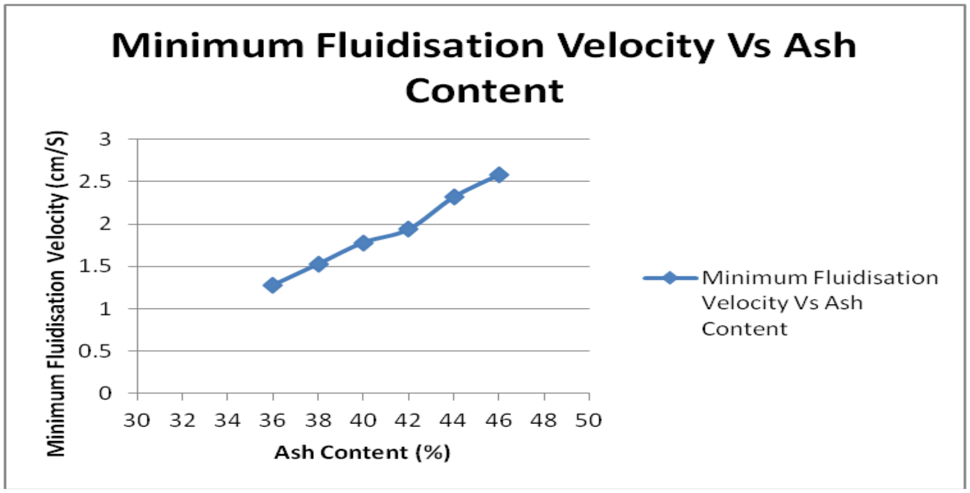


Figure 9.9: Minimum Fluidisation Velocity Vs Ash Content

From the graph it is clear that minimum fluidization velocity increases with increase in ash content.In graph we can see the fluidization velocity varies from 1.27-2.57 when ash content of sample taken from shermajra varies from 36-46(air dried basis-In percent).

10.Graph between Superficial Velocity and Temperature(DWSS)

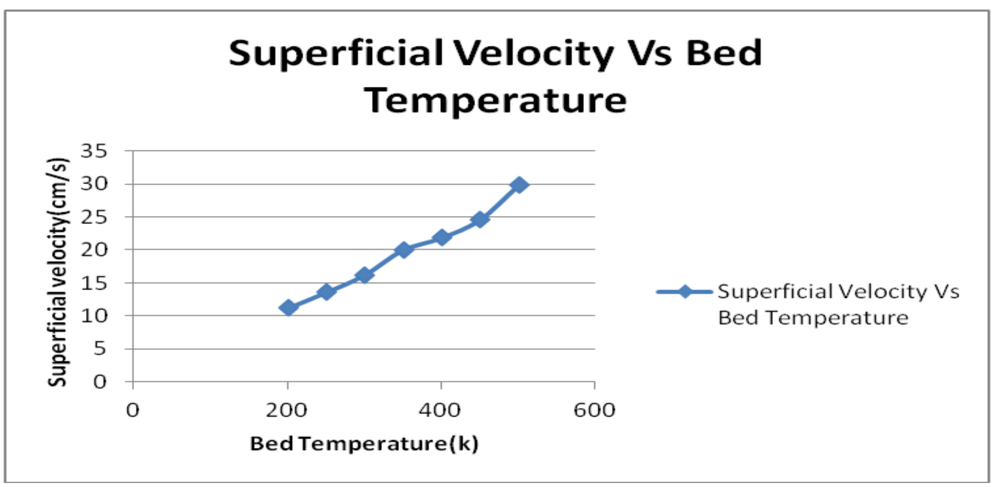


Figure 9.10: Superficial Velocity Vs Temperature

From the graph it is clear that superficial velocity increases with increase in temperature. In graph we can see the fluidization velocity varies from 11.16-29.76 when temperature varies from 200 to 500 K.

11.Graph between Superficial Velocity and Moisture(DWSS)

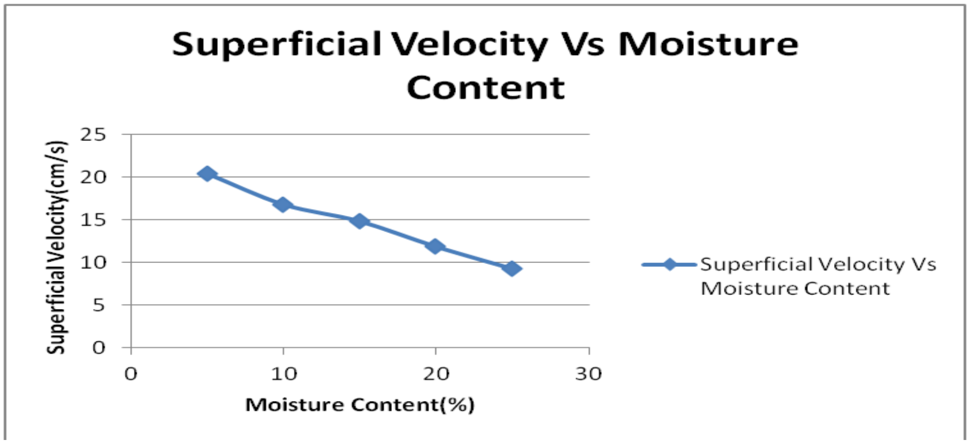


Figure 9.11: Superficial Velocity Vs Moisture

From the graph it is clear that superficial velocity increases with increase in moisture content. In graph we can see the superficial velocity varies from 9.3-20.4 when moisture varies from 5 to 25 (air dried basis-In percentage).

12.Graph between Minimum Fluidisation velocity and Bed Temperature(DWSS)

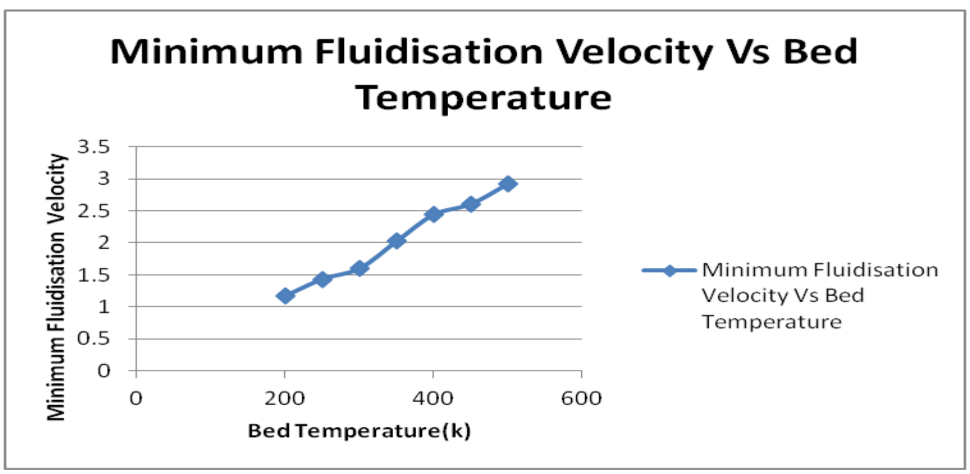


Figure 9.12: Minimum Fluidization Velocity Vs Bed Temperature

From the graph it is clear that minimum fluidization velocity increases with increase in bed temperature. In graph we can see the fluidization velocity varies from 1.16-2.92 when bed temperature of combustor varies from 200-500 K.

13.Graph between Minimum Fluidisation velocity and ash content(Comparison)

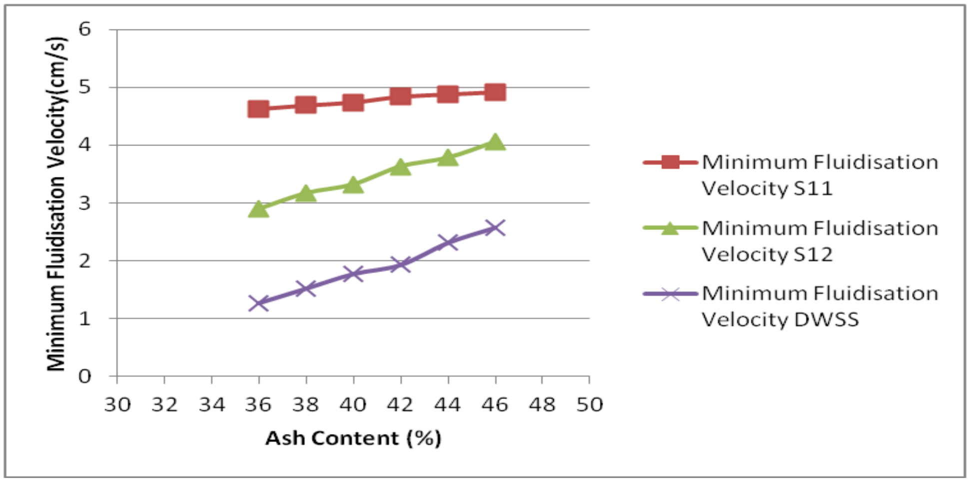


Figure 9.13: Minimum Fluidization Velocity Vs Ash Content

From the graph it is clear that minimum fluidization velocity increases with increase in ash content.In graph we can see that minimum fluidization velocity is least for sludge taken from DWSS plant and maximum for the sludge taken from plant at Shermajra.

14.Graph between Superficial Velocity and Temperature(comparison)

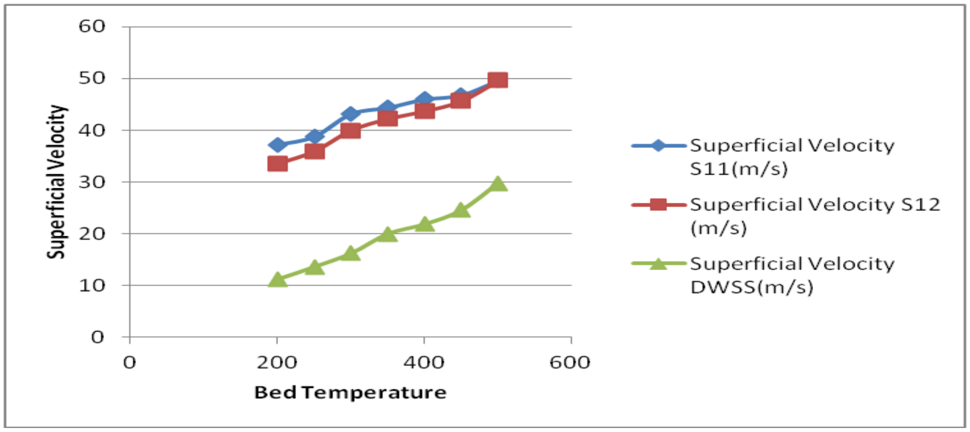


Figure 9.14: Superficial Velocity Vs Temperature

From the graph it is clear that superficial velocity increases with increase in temperature. In graph we can see that superficial velocity is least for sludge taken from DWSS plant is less and more for the sludge taken from plant at Shermajra over the given temperature range .

15.Graph between Superficial Velocity and Moisture(Comparison)

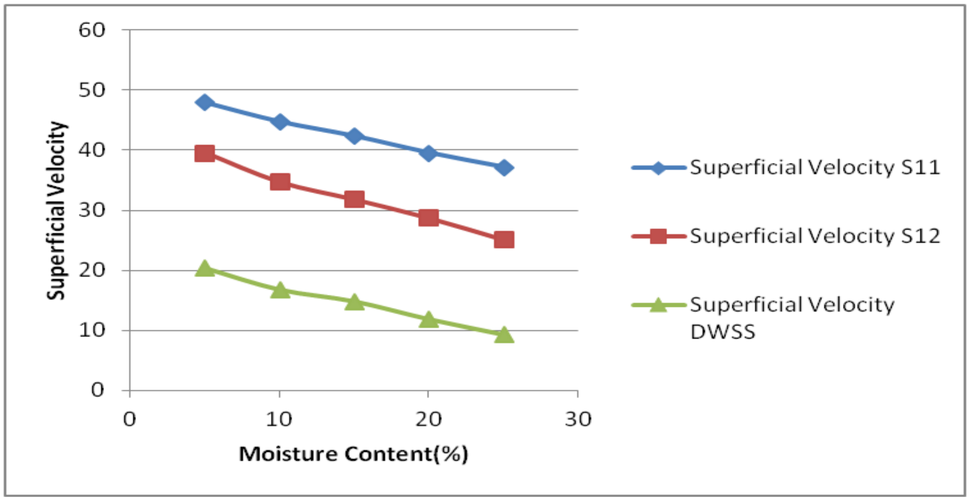


Figure 9.15: Superficial Velocity Vs Moisture

From the graph it is clear that superficial velocity decreases with increase in moisture content. In graph we can see that for a higher moisture content less will be the superficial velocity.

16.Graph between Minimum Fluidisation velocity and Bed Temperature(Comparison)

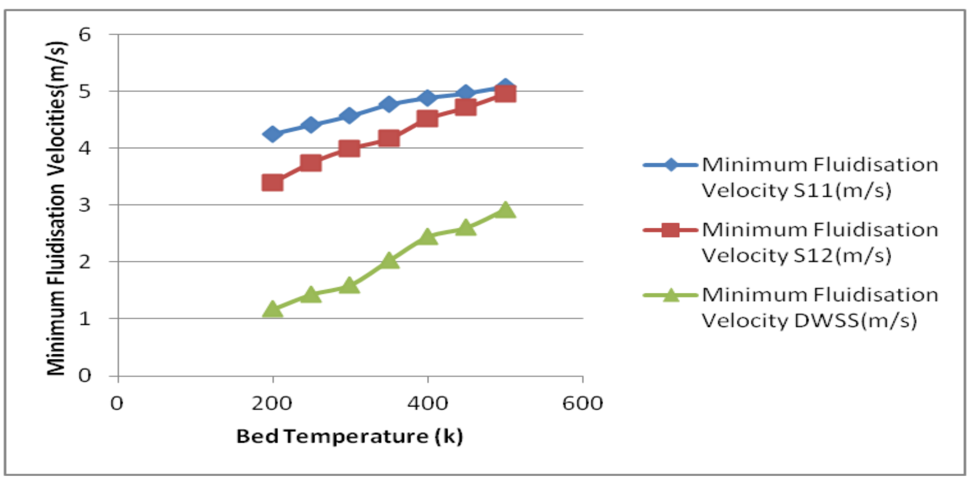


Figure 9.16: Minimum Fluidization Velocity Vs Bed Temperature

From the graph it is clear that minimum fluidization velocity increases with increase in bed temperature. In graph we can see that minimum fluidization velocity is higher for sludge taken from Shermajra than the sludge taken from DWSS plant.

CHAPTER 10

CONCLUSIONS AND SCOPE OF FUTURE WORK

Conclusions

1. As the moisture content of sample fuel increases, superficial velocity decreases.
2. As the fluidized bed temperature increases, superficial velocity increases.
3. With increase the temperature of bed, size of particle and ash content of sample fuel, min fluidization velocity V_{min} increases.

Scope of Future Work

1. Sewage sludge contains a large amount of moisture in it. In present work it is removed in air dried oven but when using on commercial scale ,Green House technology can be used for reducing its moisture content.
2. Centrifuge Mixtures can be used for proper mixing of polyelectrolyte in black water so that maximum T.S.S can be separated out.

APPENDIX

Fuel Analysis

Fuel samples of sewage sludge collected from Sewage Treatment Plant of Dept of Water Supply and Sanitation at Ludhiana and two S.T.P of Sewage Board i.e.10 MLD Ablowal and 46 MLD Shermajra were collected and proximate analysis was done in lab.

A.1 Proximate Analysis of Fuel

Determination of Moisture, Volatile Matter, Ash and Fixed Carbon by heating the sample for different time and temperatures is called proximate analysis of fuel .When under specified conditions, the sample is heated for 1 hour at 110 ℃ ,the moisture in the sample gets evaporated and the difference in weight tells the moisture content of sample.

Setup Required

1) **Air oven:** It is oven capable of maintaining uniform and constant temperature of 110 ℃ in a ventilated area.
2) **Melting pot** : One melting pot made of silica is required.
3) **Weighing Machine:** Weight measuring machine weighing up to milligrams is needed for measuring mass of sample.

Procedure

1. Clean the melting pot & dry it in oven at 110 ℃ for 1 hour.
2. Take out the silica crucible with pair of tongue from oven cooled it for fifteen minutes in dessicator.
3. Accurately weighted one gram of silica sample is taken and put in crucible.
4. Crucible having sample in it is kept in ventilated air dried oven for 1 hour at 110 ℃.
5. Crucible was taken out from oven with the help of tongue.
6. It is cooled in dessicator and weighted accurately.

Calculations

Weight of crucible (dried & empty)	=a gm
Combined weight of crucible & sample	=b gm
After heating weight of crucible & sample	=c gm
Hence after heating weight of sample	=(b-a) gm.
Weight of moisture	=(b-c) gm.
Moisture percentage	={(b-c)/(b-a)}×100

Determination of Volatile Matter

When in absence of air,the sample is heated for nine minutes at nine hundred degree Celsius, there is loss in weight of sample called volatile matter.

Apparatus Required

1) **Muffle Furnace**

   A furnace capable of giving temperature upto 1200 ℃ is called muffle furnace .

2) **Silica Crucible**

   It is crucible made up of silica and capable of withstanding temperature upto 1200℃ without getting deformed.

Procedure

1. Take a clean silica crucible and weigh it accurately.
2. One gram of sample of sewage sludge is taken and spread in crucible by tapping it .
3. Furnace is allowed to reach temp of 900℃ .
4. Crucible having sample is now transferred to furnace with the help of tonge.
5. After 9 minutes,sample crucible is taken out and cooled in dessicator for 15 minutes.
6. It is then weighted accurately.

Calculations

Mass of crucible (dried & empty)	=a gm
Combined mass of crucible & sample	=b gm

After heating mass of crucible & sample	=c gm
Hence after heating mass of sample	=(b-a) gm.
Mass loss	=(b-c) gm.
Volatile Matter(% age)	={(b-c)/(b-a)}×100

Determination of ash

When under specified conditions, the sewage sludge sample is burned for 1 hour at 800℃ ,the amount of residue left is called ash.

Setup Required

1. **Muffle furnace**

   It is a furnace which is capable of giving temperature upto 1200 ℃.

2. **Melting pot**

   It is crucible made up of silica and capable of withstanding temperature upto 1200℃ without getting deformed.

Procedure

1. Take a clean silica crucible and heat it for 1 hour at 800℃.
2. Take silica crucible out and spread the sewage sludge sample evenly in it.
3. Set the temperature 450℃ and place the crucible having sample in it in furnace .
4. Raise the temp to 800℃ and keep the crucible in it for one hour.
5. The residue left is ash ,weigh it accurately.

Calculations

Mass of crucible (dried & empty)	=a gm
Combined mass of crucible & sample	=b gm
After heating mass of crucible & sample	=c gm
Hence after heating mass of sample	=(b-a) gm.
Ash mass	=(c-a) gm.

Ash(% age) ={(c-a)/(b-a)}×100

Proximate Analysis and Ultimate Analysis of Different Samples:

Sludge Sample	Proximate Analysis (air dried basis-In Percentage)				Ultimate Analysis (as received basis-In Percentage)							Heating value(kJ/kg)
	Moisture	Volatile Matter	Ash	Fixed carbon	C	H	N	S	O	C/H	C/O	
AS1	4.7	36.5	60.3	3.1	15.53	2.33	2.43	1.06	9.80	6.65	1.58	8300
AS2	3.5	37.9	56.1	4.9	19.4	3.3	3.1	0.9	19.5	5.87	0.99	8800
AI1	6.7	55.4	39.5	5.0	26.6	4.0	4.3	0.6	27.6	6.65	0.96	13300
AI2	5.7	52.5	40.7	6.7	29.5	4.6	5.0	0.9	21.6	6.41	1.36	12800
SS1	3.8	42.1	51.9	5.9	20.9	3.4	3.3	0.8	21.7	6.14	0.96	10100
SS2	4.2	43.4	61.9	3.6	18.1	2.8	2.4	0.7	16.8	6.71	1.07	9400
SI1	6.2	55.9	38.5	8.5	31.81	4.31	3.03	1.20	25.79	7.38	1.23	13900
SI2	5.2	51.2	42.1	6.6	27.6	4.2	3.9	1.0	23.4	6.57	1.17	13200
DWSS1	9.0	23.3	74.3	2.5	9.1	2.3	1.6	1.5	18.3	3.95	0.49	3500
DWSS2	4.5	24.7	73.0	2.1	10.7	1.9	1.7	0.3	15.8	5.63	0.67	4300

Here AS1.AS2, Al1, Al2, SS1, SS2, Sl1, Sl2, DWSS1, DWSS2 are samples samples taken from sewage treatment plants of Department of Water Supply and Sanitation and Sewage Board.

AS1: Centrifuge dried sludge sample 1 From 10 MLD Ablowal,

AS2: Centrifuge dried sludge sample 2 From 10 MLD Ablowal,

Al1: From Inlet Pond Polyelectrolyte mixed Air Dried sludge 1 From 10 MLD Ablowal,

Al2: From Inlet Pond Polyelectrolyte mixed Air Dried sludge 2 From 10 MLD Ablowal,

SS1: Centrifuge dried sludge sample 1 From 10 MLD Shermajra,

SS2: Centrifuge dried sludge sample 2 From 10 MLD Shermajra,

Sl1: From Inlet Pond Polyelectrolyte mixed Air Dried sludge 1 From 46 MLD Shermajra,

Sl2: From Inlet Pond Polyelectrolyte mixed Air Dried sludge 2 From 46 MLD Shermajra,

DWSS1: From Anaerobic Pond Air Dried sludge 1 From Village Raipur Rajputtan.

DWSS2: From Maturation pond Air Dried sludge 2 From Village Raipur Rajputtan.

REFERENCES

[1] A comparative study of sewage treatment plants with different technologies in the vicinity of

Chandigarh city. (2013). *Journal of Environment Science, Toxicology and Food technolgy*, 113-121.

[2] A Murray muspratt, T. N. (2014). Fuel potential of facecal sludge: Calorific value results from Uganda, Ghana and Senegal. *Journal of water sanitation and hyigeine for development*, 223-230.

[3] Barz, M. (2003). Sewage Sludge Combustion In a Spouted Bed Cascade System. *China Particuology*, 223-228.

[4] Bengt-Johan Skrifvars, R. B. (2000). Bed Agglomeration Characteristics during Fluidized Bed Combustion of Biomass Fuels. *Energy & Fuels*, 169-178.

[5] F. Kirzhner, V. S. (2014). Combustion of Sewage Sludge and Coal Powder. *International Journal on environmental science and development*, 561-565.

[6]Ha Na Jang, J. H. (2016). Combustion characteristics of waste sludge at air and oxy fuel combustion condiins in a circulating Fluidized bed reactor. *Fuel*, 92-99.

[7] K. Bauerfeld, R. D. (2014). Technology transfer-oriented research and development in the wastewater sector - validation at industrial-scale plants. 100-110.

[8] Letter by Ministry of Drinking Water supply and Sanitation to To The Principal Secretaries Incharge of Sanitation of All States, (2012).

[9] Longbo Jiang, J. L. (2014). Co pelletization of sewage sludge and biomass: The density and hardness of pellet. *Bioresource Technology*, 435-443.

[10] M. Rashid Khan, M. M. Sewage Sludge: A Fascinating Feedstock For Clean Energy, 22-38.

[11] M. S. Zakaria, S. H. (2015). Malaysian Sewage Sludge Dried Using Thermal Dryer. *Akademia Baru*, 24-29.

[12] Nieves Fernandez-Anez, J. G.-T.-P. (2014). Flammability properties of thermally dried sewage sludge, 165-170.

[13] Ning Yi wang, C. H. (2013). Envirnmental effects of sewage sludge carbonization and other treatment alternatives. *Enegries*, 871-883.

[14] Quiroga, F. J. (2004). Waste Stabilisation Ponds For Waste Water Treatment,Anaerobic Pond, 1-11.

Sludge management; NPTEL *Module 22; Lecture 36*,(2016).

[15] Srinath Suranani, V. R. (2011). Combustion Characteristics of Sawdust in a Bubbling Fluidized Bed. *IACSIT Press, Singapore*, 167-172.

[16] Takahiro Murakami, Y. H. (2009). Combustion Characteristics of sewage sludge in incineration plant for energy recovery. *Fuel Processing Technology* , 778-783.

[17] Werle, S. (2013). Potential and Properties of the Granular Sewage Sludge As a Renewable Energy Source. *Ecological Engineering* , 17-21.

[18] Young Ju Kim, H. o. (2004). Heating value characteristics of Sewage sludge: A comparative study of different Sludge types. *Jour. Chem. Soc. Pak* , 702-771.

[19] Melgorzeta Wzorek (2015) characterization of properties fuels containing sewage sludge, 80-89.

[20] Ljiljana (2014) Characterization of spontaneous combustion tendency of dried sewage sludge 1453-1462.

[21] Patal (2008). Tomographic diagnosis of gas maldistribution in gas-solid fluidized bed,149-164.

[22] Ravi Inder Singh (2011),Fluidised bed combustion and gasification of rice husk and rice straw-state of art review, 1022-1034.

[23] Sathi (1982),Heat transfer between vertical tube and air fluidized bed at moderate temperature (335-528 K), 172-181.

[24] Guo (2004),Agglomeration behavior in a bubbling fluidized bed at high tepmperature, 252-275.

[25] Zhu(2008) Catalytic gasification of char from co-pyrolysis of coal and biomass, 381-394.

[26] Jiang(2016) Co-pellezation of sewage sludge and biomass Thermogravimetric analysis and ash deposits, 1114-1132.

[27] Guardiola(1996),Influence of particle size fluidization velocity and relative humidity on fluidized bed electrostatics, 2215-2230.

[28] Vaux (1988),Wear on tubes by jet impingement in a fluidized bed, 572-593.

[29]Renga R.Rajan(1980),A comprehensive model for fluidized bed coal combusters, 676-673.

[30]Shiao Hung Chiang(2000),Coal conversion processes proceses, cleaning and desulfurization, 894-913.

[31]Ramesh C Borah(2011), A review on devolatisation of coal in fluidized bed, 445-472.

[32]Saidur (2011), A review on biomass as fuel for boilers, 2023-2035.

[33]Chien-Song Chyan(1989), Minimum fluidization velocity of binary mixtures, 213-240.

Design, Feasibility study and Utilisation of Fluidised Bed Combustion Technique for Sewage Sludge

ORIGINALITY REPORT

%17	%13	%7	%4
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	dspace.thapar.edu:8080 Internet Source	%10
2	Submitted to Thapar University, Patiala Student Paper	%1
3	Patel, A.K.. "Tomographic diagnosis of gas maldistribution in gas-solid fluidized beds", Powder Technology, 20080710 Publication	%1
4	www.procon.org Internet Source	<%1
5	ethesis.nitrkl.ac.in Internet Source	<%1
6	Ravi Inder Singh. "Fluidised bed combustion and gasification of rice husk and rice straw – a state of art review", International Journal of Renewable Energy Technology, 2011 Publication	<%1
7	www.engin.umich.edu Internet Source	