بسم الله الرحمن الرحيم

Sudan University of Science & Technology

College of Graduate Studies

Evaluation of Minimum Fluidized Air Flow in Circulation Fluidized Bed Boiler at Garri (4) Power Plant

حساب معدل نفخ الهواء في المراجل ذات الطبقة المميعة الدوارة في محطة قري (4)

A thesis submitted in partial fulfillment to the College of Graduate Studies; Sudan University of Science & Technology for the requirement of the degree of Master of Science in Mechanical Engineering (Power)

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قال الله تعالى:

{ إِنَّ فِي خَلْقِ السَّمَاوَاتِ وَالأَرْضِ وَاخْتِلافِ اللَّيْلِ وَالنَّهَارِ وَالْفُلْكِ الَّتِي تَجْرِي فِي الْبَحْرِ بِمَا يَنْفَعُ النَّاسَ وَمَا أَنْزَلَ اللَّهُ مِنَ السَّمَاءِ مِنْ مَاءٍ فَأَحْيَا بِهِ الأَرْضَ بَعْدَ مَوْتِهَا وَبَثَّ فِيهَا مِنْ كُلِّ دَابَّةٍ وَتَصْرِيفِ الرِّيَاحِ وَالسَّحَابِ الْمُسَخَّرِ بَيْنَ السَّمَاءِ وَالأَرْضِ لَآيَاتٍ لِقَوْمٍ يَعْقِلُونَ }

صدق الله العظيم

سورة البقرة (164)

DEDICATION

Dedicated to:

My mother

My father

My wife

My sons (Ahmed and Elbraa)

With my love and respect

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Thanks to my supervisor:

Dr. Ali Seory

For his assistance, guidance and endless help throughout the stepofthis research works.

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Thanks for any one helped me to make this work, thanks for my

Mother for her stand with me side by side during my studies.

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ABSTRACT

Steam power plants are the most common electric power in the world. To reduce the cost of generation, Sudanese Thermal Power Generation Company (STPG) former National Electricity Corporation NEC has been built.

Garri (4) steam plant has been used Circulation Fluidized Bed boiler (CFB) technology by burning sponge coke which is produced at Khartoum Refinery Company as byproduct.

CFB technology depends on fluidization not only to increase the efficiency of heat transfer from sponge coke to water tube of stream but also to avoid over heating malting and phenomena pulsation.

Sand is added to sponge coke to keep a certain temperature homogenizes spread in all Furnace surfaces.

The focus of the research is to calculate the minimum fluidization velocity (the velocity at which all particles being to float) and bed particle size at corresponding to temperatures at different operation status.

In this research study the minimum fluidization velocity by using applied equation method, practice method and then comparison between the two methods .

Because these two methods are so difficult and complicated a computer program was built, and verified known data give immediately a good result of minimum fluidization flow corresponding bed particle size and temperatures compared between them and the manufactured values.

مستخلص البحث

تعتبر محطات القدرة البخارية من أكثر المحطات انتاجاً للطاقة الكهربائية في العالم. ولتقليل تكلفة التشغيل فقد قامت الشركة السودانية للتوليد الحراري (الهيئة القومية للكهرباء) بناء محطة قري (4) البخارية مستفيدة من الفحم البترولي الذي ينتج في مصفاة الخرطوم كوقود ثانوي ورخيص.

المرجل البخاري الدوار يعتمد على تكنولوجيا النفخ والتدوير ليس فقط لزيادة كفاءة انتقال الحرارة من الوقود للماء وانتاج البخار بل ايضاً لتجنب زيادة التسخين، وتحجر الفحم والاهتزازات الكاملة للمرجل.

تم اضافة الرمل للمحافظة على درجات الحرارة داخل المرجل متجانسة ولانها تمتص الحرارة.

في هذا البحث تمت دراسة المرجل الدوار بالتفصيل ومن ثم تم حساب اقل سرعة هواء لازمة للنفخ والتدوير.

تم حساب هذه السرعة عن طريق المعادلات الرياضية ثم بالطريقة العملية وتم مقارنة القيمة المتحصل عليها بالقيمة الموصى بها من قبل المصنع ووجد إنه مناسبة.

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List of symbols

symbols	Means	Unit
ρb	bulk density of fixed bed	[kg/m3]
mb	mass of the bed (fixed or fluidized)	[Kg]
Vb	bed volume (fixed, fluidized)	[m3]
ε	void fraction	
ρ_p	particle density	[kg/m3]
d_p	mean equivalent particle diameter	[mm]
d_i	is the smallest opening size of the sieve through which the particle has passed	[mm]
d_{i+1}	is the largest opening size through which the particle fails to pass in the course of the sieving process.	[mm]
$\emptyset_s$	particle shape factor.	
As	surface area of spherical particle of the volume V_p,	[m2]
V_p	volume of the particle	[m3]
A_p	particle surface area	[m2]
Fg	gravity force	[N]
g	acceleration of gravity	[m/s2]
F_A	buoyancy force	[N]
ρ_f	fluid (gas) density	[kg/m3]
F_D	resistance force	[N]
CD	particle drag coefficient	
u_p	particle velocity	[m/s]
Re_t	Reynolds number for particle based on terminal velocity	
Ar	Archimedes number	

λ	friction factor	
H_b	bed height	[m]
μf	dynamic viscosity of fluid	[kg/ms]
vf	superficial velocity of fluidizing gas	[m/s]
D_h	hydraulic diameter	[m]
ε_{mf}	void fraction at incipient fluidization	
$\mathrm{Re}_{\mathrm{mf}}$	Reynolds number for particle based on minimum fluidization velocity	

ESP	Electro static precipitator
FBC	Fluidized bed combustion boiler
CFB	Circulation fluidized boiler
LDO	Liquid diesel oil
MCR	Maximum continuous rated
PA	Primary air fan
HP	High pressure
SA	Secondary air fan
ID	Induced draft fan
MW	Mega, a million watt
MWh	means mega, a million watt in one hour

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CHAPTER ONE

INTRODUCTION

CHAPTER ONE

1.1Circulation fluidized Introduction:

Circulation fluidized bed boiler consists of furnace, solid separator (cyclone), and back-pass. The furnace is generally made of water tube in pulverized coal. A fraction of the generated heat is absorbed by these heat transferring tubes. The remaining heat is absorbed at duct –pass by the pre heater super heater, economizer and air pre heater surfaces..

Sponge coke is generally injected into the lower section of the furnace .Coke burns when mixed with hot bed solids.

The primary combustion air enters the furnace through an air distributor the secondary air is injected at some height above the grate to complete the combustion. Bed solids are well mixed throughout the height of the furnace .Thus ,the bed temperature is nearly uniform in the range 800_900 0^{c}.Relative coarse particles of sorbent(limestone and sand)and un burned char ,larger than cyclone cut-off size ,are captured in the cyclone and recycled back near the base of the furnace .

Finer solid residues (ash) are generated during combustion leave the furnace escaping through the cyclones, but they are collected by electrostatic precipitator (ESP) located further downstream.

1.2The objective of this research are to:

- Calculate the minimum air fluidization velocity of circulation fluidized boiler at Garri (4) sponge coke fired power plant.
- Estimate the optimum cut off size of the sand to reduce sand consumption which carry over to ESP and also reduce furnace tube failure in water wall and super heater wall.

CHAPTER TWO

DEVELOPMENT OF FLUIDIZED BED COMBUSTION BOILERS

CHAPTER TWO

DEVELOPMENT OF FLUIDIZED BED COMBUSTION BOILERS (FBC)

2.1 Introduction:

Fluidized bed combustion in both of its major forms—bubbling and circulating FBC—is an important and rapidly maturing technology, employed throughout the world.

Bubbling FBC technology has become the standard technology for drying, heat and steam production and power generation applications, and is widely used in Europe, North America, and China among other places to burn an enormous range of fuels, from various grades of coal and biomass.

The energy crisis at the beginning of the seventies, caused by an abrupt rise of liquid and gaseous fuel prices, has forced all of the leading countries in the world to reconsider their energy policy irrespective of their economic power and energy sources.

The following principles have been generally accepted

- Use domestic energy resources as much as possible.
- Reintroduce coal in all areas of energy production.
- Diversify the energy market by relying uniformly on several different energy sources and fuel suppliers.

The high technological level of equipment for combustion of liquid and gaseous fuels, as well as the necessity for rational and efficient use of nonrenewable energy resources, has resulted in very demanding requirements that must be fulfilled by equipment for energy production via coal combustion.

These requirements can be summarized as follows:[1]

- Combust low-grade coals.
- Achieve high combustion efficiency.
- Achieve boiler flexibility to type and quality of coal.

- Provide effective environmental protection from SO2, NOx and solid Particles.
- Achieve a wide range of load turndown ratio.
- Enable automatic start-up and control of operational parameters of the plant.

2.2 A short review of FBC history:

Long before the onset of the energy crisis in the seventies, when intensive research and development on FBC technology was initiated, the fluidized bed had been used as a suitable technology for different physical and chemical processes.

In chemical engineering, the fluidization process as well as chemical and physical reactions in fluidized beds had been extensively investigated and used immediately after the Second World War.

A few plants using the fluidized bed in the chemical and oil industries were even built before the war [1].

At the end of the fifties and the beginning of the sixties, the National Coal Board in Great Britain initiated studies on coal combustion in fluidized beds in order to increase coal consumption and regain the markets lost in competition with liquid fuels.

In 1970 in Houston, Texas (U.S.A.) the Second International Conference on Fluidized Bed Combustion was held [1]. Douglas Elliott described his expectations as follows:

- Industry will be increasingly interested in FBC.
- Design of the air distribution plate will be improved.
- Start-up systems will be developed which will not require auxiliary high power oil burners.
- Systems for control and operation of the process will be highly sensitive to a very narrow range of temperature changes of the bed.

And also Dr. John Bishop predicted the following:

- It will become possible to reach high specific heat generation.
- Steam boilers will be developed with parameters corresponding to those needed for electric energy production.

In 1985 the development of FBC boilers had reached the commercial phase for electric energy production [1].

Boilers of 1 to 500 t/h steam capacity, steam temperatures up to 540°C and steam pressure of up to 180 bars were marketed. These boilers were recommended for combustion of the following fuels: coal, wood waste, biomass, liquid waste fuels, mud, coal slurry, coal washing residue, coke, petroleum coke, lignite.

By 1987 the largest individual unit had a steam capacity of 420 t/h. [1].

In 1990 the largest was 397 MW with steam parameters of 135 bars and 540°C.

2.3 BUBBLING FLUIDIZEDBOILERCOMBUSION:

First generation FBC boilers are in the bubbling fluidization mode and are, therefore, called stationary bubbling FBC boilers. In the lower part of the furnace, on the distribution plate, there is a fluidized bed of inert particulate material. Air needed for combustion enters the furnace through the distribution plate and fluidizes the particles of inert bed material. Air velocity is lower than transport velocity of the particles, and the bed has a clearly defined, horizontal, although irregular free surface. Fuel burning(that is heat generation) mostly takes place in this fluidized bed of inert material.

Two ways of feeding the fuel are possible: over-bed or below the bed surface. For coarse, reactive coals, with or without only a small amount of fine particles (separated and washed coals), over-bed feeding and spreading on the bed surface are used. Thus, distribution of fuel over a larger area of the furnace cross-section is possible. For coal particles of

3–6 mm or less, fuel feeding below the bed surface is commonly used. Limestone for desulphurization is introduced in the same manner as the coal, and sometimes even with the coal.

Above the bed there is a freeboard with very low concentration of solid particles, where combustion of fine coal particles and volatiles is continued..

A first generation FBC boiler is comprised of:

- A system for preparation, transport, mass flow rate control and feeding of coal and limestone.
- Start-up system.
- A system for air distribution.
- A fluidized bed furnace.
- A system for recirculation of unburned particles.
- A water circulation system.
- A system for flue gas cleaning.

2.3.1THE ADVANTAGE OF THE BUBBLING FLUIDIZED BOILERS:

- Combustion of low grade fuels (moisture content up to 60%, ash up to 70%).
- High fuel flexibility.
- Low combustion temperature—possible combustion of coals with low ash.
- High heat transfer coefficients.
- Expensive pretreatment and preparation of fuels is not needed (drying, grinding).
- Effective emission control of SO2 in the furnace through removal by reaction with CaO.
- Burning of biomass and waste fuels,
- High combustion efficiency.

2.3.2THE DISADVANTAGE OF THE BUBBLING FLUIDIZED BOILERS:

- Relatively small amount of heat generated per unit area of furnace cross section.
- Difficulties associated with design of high capacity units because of a large number of fuel feeding points that are required.
- Small turndown ratio.
- Relatively high SO2 and NOx emission levels.
- Relatively insufficient fuel flexibility.
- Relatively low combustion efficiency.

2.4 CIRCUILATION FLUIDIZED BOILER (CFB)

The shortcomings of first generation FBC boilers have been the subject of much research and development in order to improve combustion efficiency the system for fly ash recirculation has been introduced to allow reinjection of the unburned fuel particles into the furnace for reburying. The problems of combustion efficiency and desulphurization efficiency have also been dealt with by the introduction of two or more fluidized beds placed one above the other.

Burn-up of unburned particles elutriated from the first (lower) bed is completed in the second (upper) bed together with desulphurization

A series of technical improvements has been tested in practice and on pilot plants in order to extend the range of turndown ratio for bubbling fluidized combustion.

Change of the bed temperature, change of the bed height (by changing fluidization velocity or by removing the inert material from the bed) the poorest results have been achieved in managing erosion of in-bed heat transfer surfaces. Protection of the tube surfaces with different coatings, refractory lining of the water-tube furnace walls and welding of protective vertical ribs or thickly placed cylindrical studs have all been used protected from erosion by fire bricks.

Combustion takes place at 800–900°C, similar to temperatures in bubbling fluidized combustion.

The inert bed particles are smaller than in bubbling fluidized combustionboilers, while the velocity of the combustion products, that is fluidization velocity, is higher than the transport velocity of the inert particles.

The inert particles are in fast fluidization regime and are, together with the fine unburned fuel particles, removed from the combustion chamber.

In one or more cyclones the solid material is separated from the gaseous

Combustion products and reintroduced into the furnace. Thus, recirculation of the solid particles (inert material and fuel particles) is realized in a closed circuit. Regulation of solids recirculation rate is achieved at the cyclone outlet by controlling the solid particle mass flow rate in the stand-pipe or through a special device called a pneumatic valve (loop seal) or, according to the design of the J-valve.

Gaseous combustion products leave the cyclone to enter the convective part of the boiler (second pass). They exchange heat with convective heat transfer surfaces (pre heater, super heater, economizer, and air heater), passing subsequently through bag filters or electrostatic precipitators to the chimney.

Circulating Fluidized bed boilers have the following basic components and systems:

- A system for handling, preparation and feeding of coal and limestone into the furnace.
- Combustion chamber with water-tube or partially refractory lined walls.
- A system for distribution of the primary and secondary air.

- A start-up system.
- Cyclones for separation and recirculation of solid material.
- Pneumatic valves, L-valves or J-valves.
- Convective heat-transfer surfaces (second pass).
- A system for flue gas cleaning.
- A water-steam circulation system.

2.4.1 THE ADVANTAGE OF CIRCULATION FLUIDIZED BOILER

Advantages of circulation fluidized boilers compared to bubbling fluidized boiler:

- Higher combustion efficiency.
- Higher sulphur retention degree.
- Better limestone utilization.
- Lower emission levels of NOx and SO2.
- Wider range of load turndown ratio.
- Design and construction of large units are feasible.
- A small number of fuel feeding points is needed.

2.4.2 THE DISADVANTAGE OF CIRCULATION FLUIDIZED BOILER:

- An very long start-up procedure.
- More expensive fuel and limestone preparation.
- Higher self-consumption of electric energy.

CHAPTER THREE

GARRI-4 THERMAL POWER PLANT

CHAPTER THREE

GARRI-4 THERMAL POWER PLANT

3.1 Introduction:

Garri4 is a sponge coke fired power plant. It is a first power plant in the Middle East which used a solid fuel.

Khartoum refinery produces 256 tone/year of sponge coke as a byproduct. This coke can be used to generate electric power. So NEC decided to build Garri4 power plant which used this coke as a solid fuel.

Garri4 is a steam power plant, it works with regeneration cycle. It consists of two steam turbines each one generate 55 MW. Each turbine has a boiler to supply superheated steam to the turbine which is known as a Circulating Fluidized Bed Boilers (CFB Boilers).

3.2 Location of Garri-4:

Garri-4 located at the east from garri-2 near phase II of Khartoum Refinery which produces sponge coke. This location has the following advantages:

- It is near Khartoum refinery to supply sponge cock.
- It is near garri2 to connect garri-4 substations with garri-2 and national grid, also supply garri-4 with liquid diesel oil (LDO) and water from garri2.

3.3 Layout of Garri-4 Power Station:

- Two CFB boilers
- Main power building which contain two steam turbines with generators and auxiliary equipment.
- Substation
- Clarified water tank
- Composite pump house.

- Demineralization plant.
- Waste water treatment plant.
- Cooling towers.
- Circulating water pumps house.
- LDO storage tank and pump house.
- Sponge coke shed.
- Convey system.
- Auxiliary boiler and emergency generator house.
- Administration building.
- Workshop.

3.4 The Specifications and Size of Boiler:[4

Table (3.1)

Maximum continuous Rating (B-MCR)	240t/h
Rated steam pressure	9.4Mpa
Rated steam temperature	5400 o_C
Feed water temperature	234o_C
Furnace width (distance between the central lines of the pipes on the water wall at the two sides)	9906 mm
Furnace depth (the distance between the central line of front and back water wall)	5638.8 mm
Elevation of central line of the drum	46380 mm

3.4.1 Circulation fluidized boiler component:

The function of CFB boiler is to generate superheated steam with proper pressure, temperature and flow rate to operate steam turbine and generate electric power.

The boiler has two fans which supply air for combustion to six burners to make initial combustion and help the coke to be burned when it is feed to the boiler. Combusted gases with heat energy heat the boiler feed water and generate steam and send it to the turbine. Exhaust gases filtered from ash before it flows to the atmosphere through stack [2].

CFB boiler circulating solids is dependent on energyprovided by Primary air (PA) fan, secondary air (SA) fan and induced draft (ID) fan.

3.4.2 The primary air system:

The air from PA fan is divided into three ways to enter furnace: in the first way, after heated by air pre heater, hot air enters wind box plenum at the bottom of furnace to fluidized bed material through the bubbling cap and form gas-solid two-phase flow upward through furnace; in the second way, hot air passes through booster fan for sponge coke pneumatic distribution before furnace; in the third way, a part of cold primary air without passing through air heater provides HP seal air for sponge coke feeding belts. In-duct burners are configured around wind box plenum. Combustion/cooling air of in-bed burners is also hot primary air.

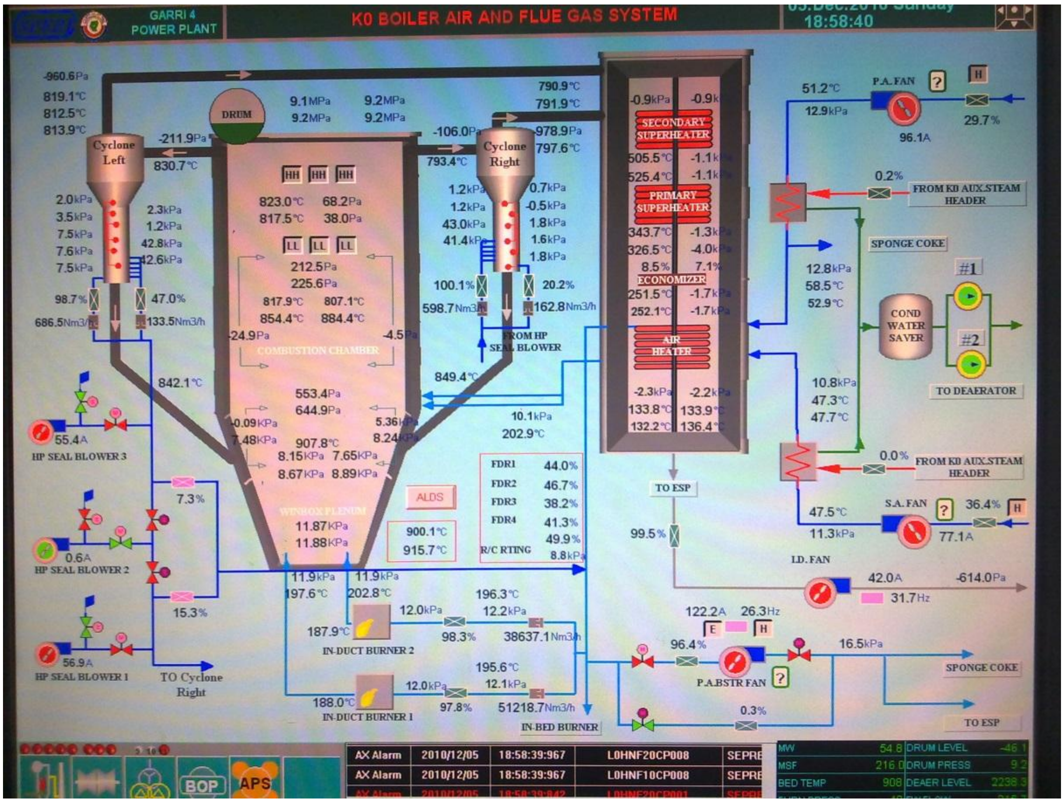
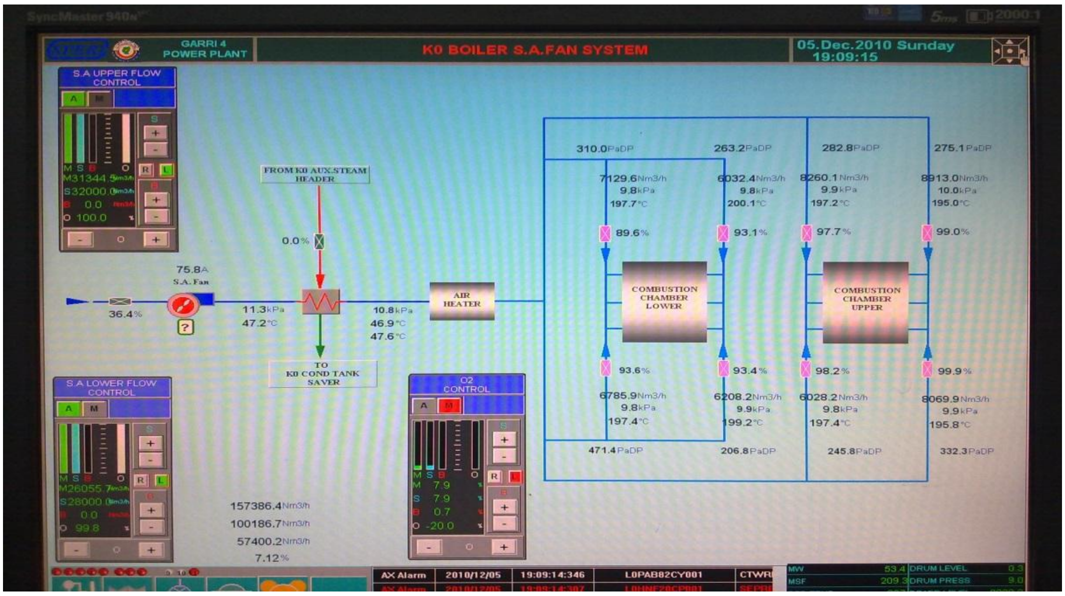


Fig (3.1) Primary air diagram

3.4.3 The secondary air system:

The secondary air from SA fan directly passes through the air preheated into secondary air box of upper furnace and is divided into two levels to enter the furnace.



Fig(3.2) Secondary air diagram

3.4.4 High pressure seal blowers system

Solids return leg (J-valves) is furnished with three HP seal blowers (contribution for each blower is 50%, with two operating and one standby in the normal state). The blower is fixed-capacity, so solid return air regulation is dependent on the bypass which delivers the redundant air to the primary air duct.

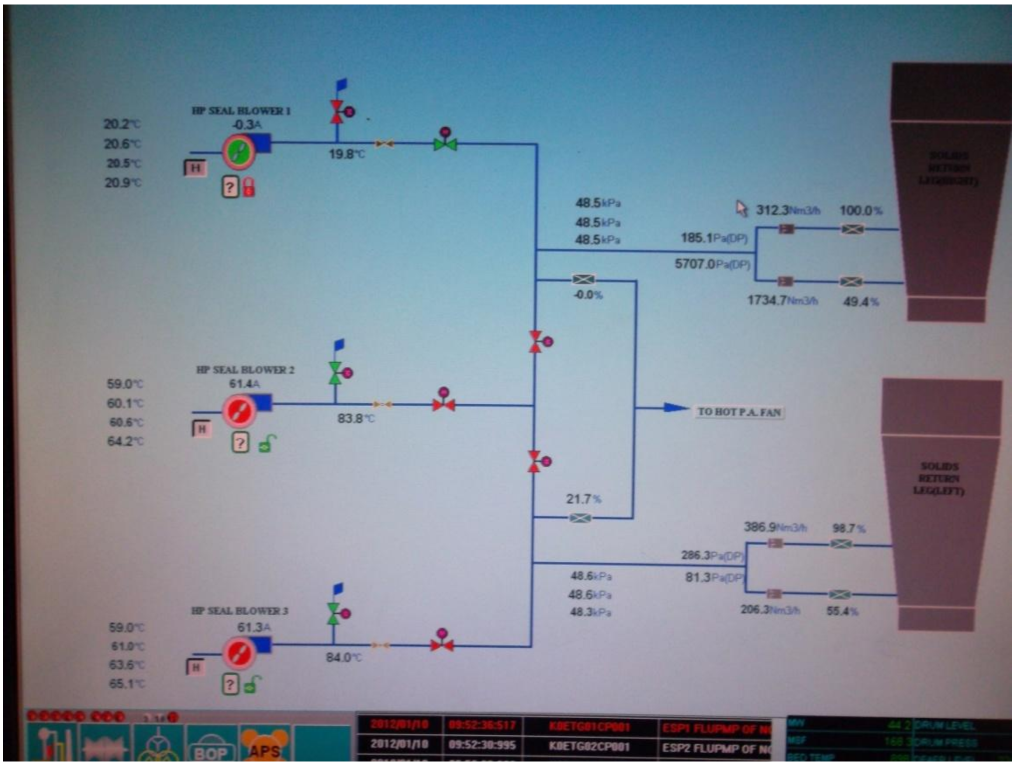


Fig (3.3) High pressure seal blowers diagram

3.4.5 Air and material circulation:

Combustion mainly concentrates at the lower combustion chamber that is water wall lower subassembly (Here bed material is densest and motion is most furious), by which all of the air & fuel is delivered into combustion chamber. The side walls of lower furnace are furnished with several interfaces between ash cooler and combustion chamber. Four sponge coke feed inlets and two limestone feed inlets are configured at furnace front wall.

Middle and upper of combustion chamber are made up of membrane walls, where the heat is passed to water through flue gas and bed material so that the water can be vaporized partly. Three pieces of furnace platen walls and four pieces of platen super heater tubeplatens are configured inside the furnace with uniformity to **mines** heat deviation. This area is also main desulfurized reaction zone.

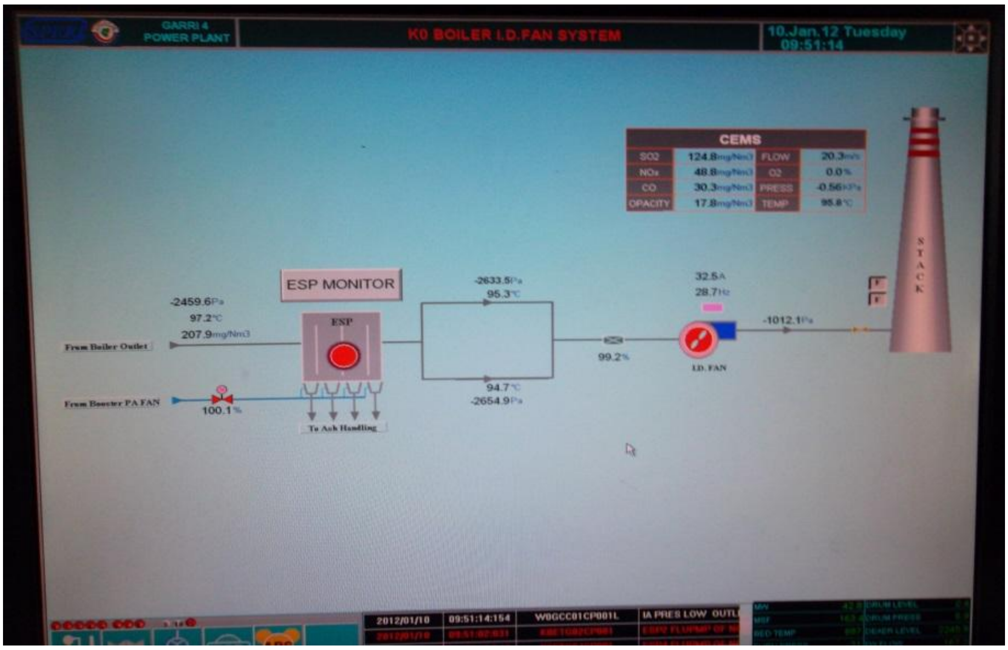


Fig (3.4) Air flue gases diagram

3.4.6 Induct burner system:

Two in-duct burners are configured at primary air (PA) induct before wind box plenum of the furnace. Each in-duct burner system consists of fixed oil lance, push ignition lance (with ignition transformer), oil inlet valve, oil inlet purge valve, oil return valve, oil return regulating valve, oil return purge valve. Atomization in mechanical method is adopted by the burner. There are two cooling air fans for flame detector (standby for each other). Oil that comes from oil pump outlet header is allocated to each in-duct burner after inflows through a motor-operated fast shutoff valve. Oil inlet valves and return valves shall keep open when the burners run. Two burners’ return oil congregates to oil return header.

The oil returns to oil storage tank after it flows through oil return header motor-operated regulating valve. The primary air that flow in-duct burner has combustion-supporting and cooling function. After heated, the primary air enters furnace through wind box plenum.

Purge air comes from service air system and has many branches, which is used for blowing oil lances and pipes when burners are out of operation

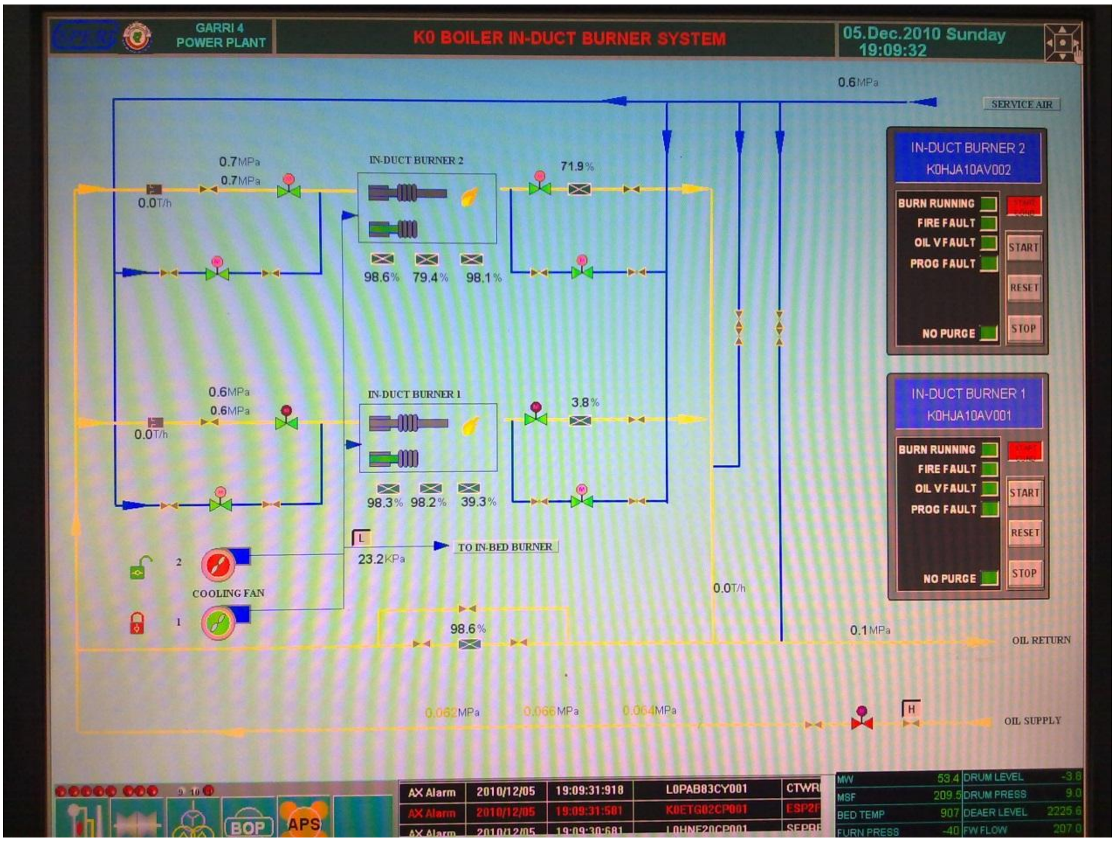


Fig (3.5) Oil induct burners diagram

3.4.7 Inbed burner system:

Besides, the boiler is furnished with four auxiliary in-bed burners. Each in-bed burner system consists of push oil lance, push ignition lance (with ignition transformer), oil inlet valve, oil inlet purge valve, oil return valve, oil return regulating valve, oil return purge valve. Atomization in mechanical method is adopted by the burner.

Oil that comes from oil pump outlet header is allocated to each in-duct burner after it flows through a motor-operated fast shutoff valve. Oil inlet valves and return valves shall keep open when the burners run. Four burners' return oil congregates to oil return header.

The oil returns to oil storage tank after it flows through oil return header motor-operated regulating valve. In-bed burner's combustion air is from hot primary air. In-bed burner's cooling air is from cold primary air. Purge air comes from service air system and has many branches, which is used for blowing oil guns and pipes when burners are out of operation.

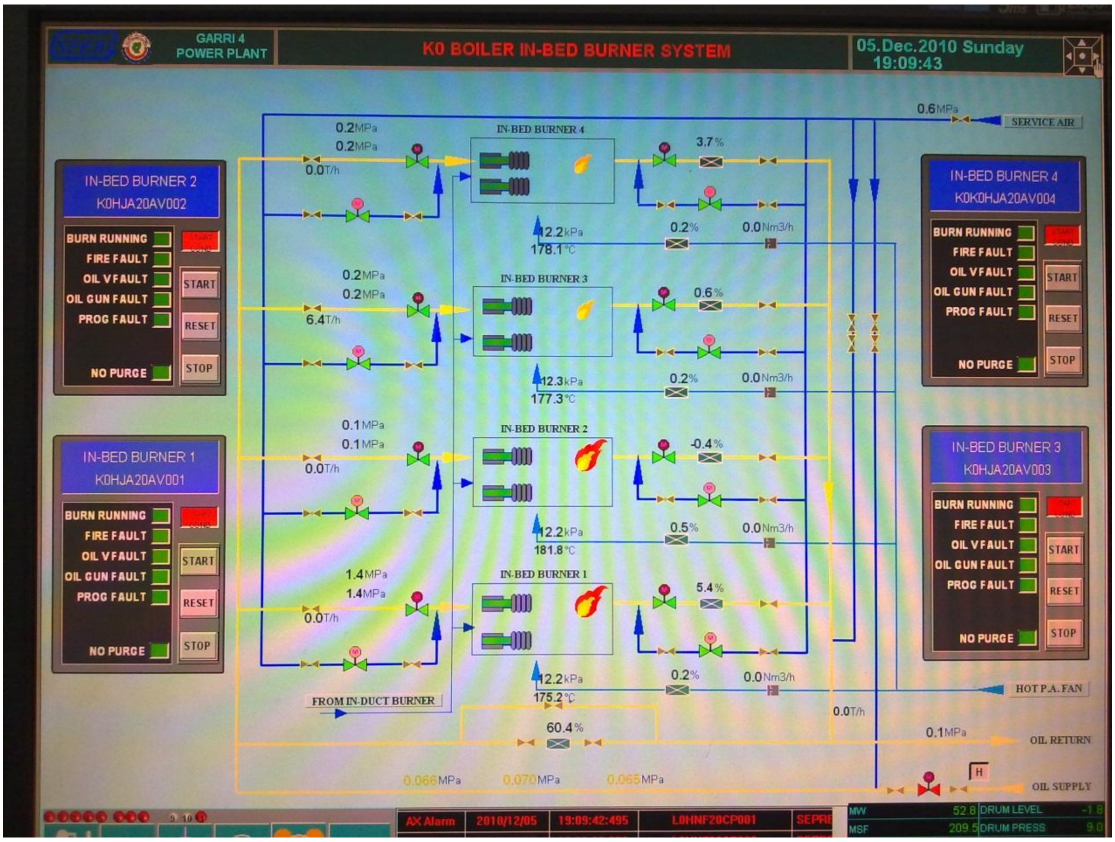


Fig (3.6) Oil inbed burners diagram

3.4.8 The sponge coke system

The boiler is furnished with four sponge coke feeding inlets (corresponding to four set of sponge coke feeder system) at the furnace front wall. Each set of sponge coke feeder system consists of sponge coke silo, sponge coke silo outlet valve, gravimetric belt feeder, sponge coke feeder outlet valve, sponge coke feeder outlet fast shutoff valve, pneumatic sponge coke distributed device and connecting pipe.

Sponge coke feeders adopt frequency conversion device to regulate sponge coke feed flow.

The sponge coke distributed air comes from hot primary air out of P.A booster fan.

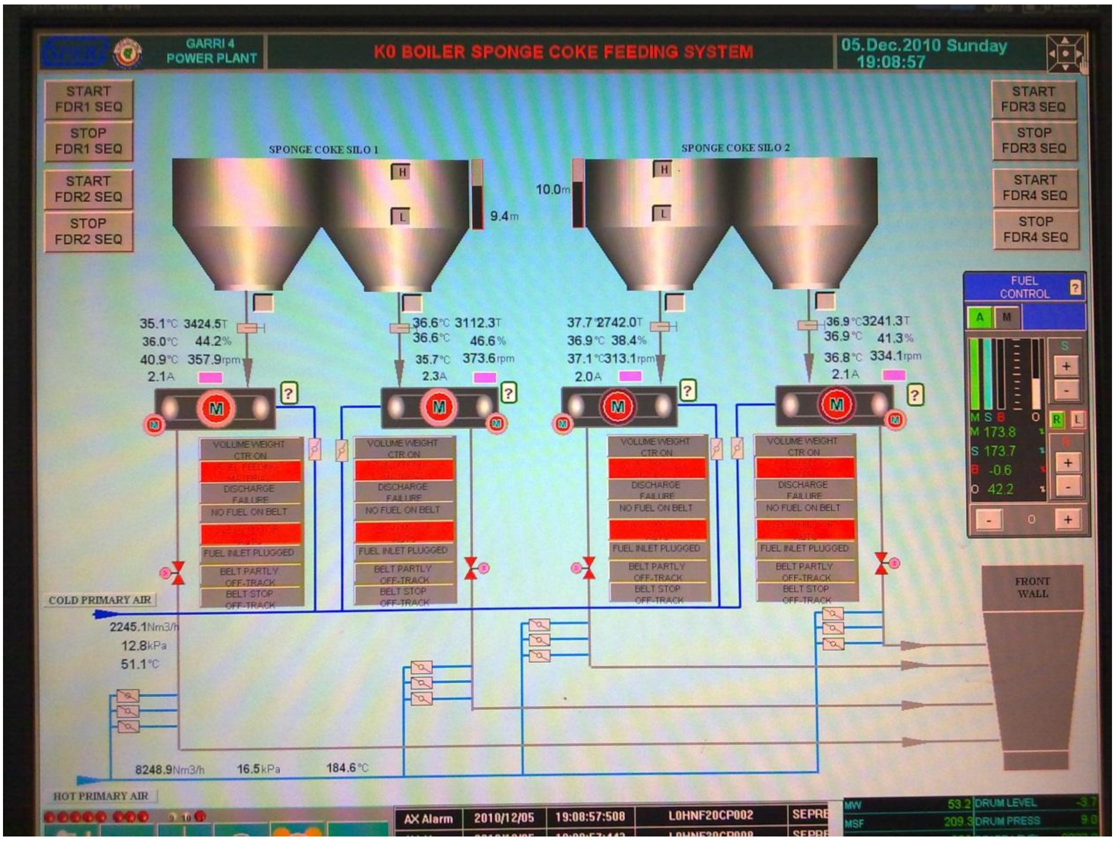


Fig (3.7) Sponge coke feeding diagram

3.4.9 Bottom ash system

Bottom ash enters two cylindrical ash coolers from ash discharge outlet at the bottom of furnace. Ash moves forward with the rotating of ash cooler. Condensate water will be used for cooling the ash. When the cooling water temperature or cooler outlet temperature goes beyond the reference value, the corresponding temperature controller in the local control cabinet will give an alarm. The cooled ash is discharged by slag removal system

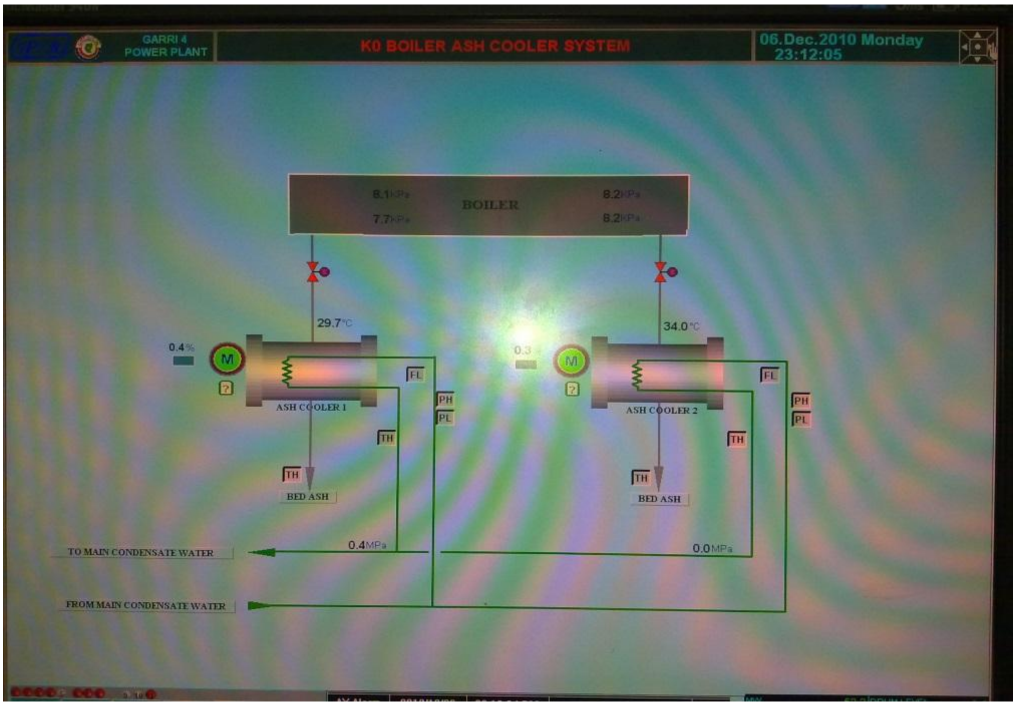


Fig (3.8) Bottom ash diagram

3.4.10 Sand feeding system

The two cyclones have their own sand feeding device. Bed material comes out of sand silo, passes the rotary valve, gets to bed material complementary inlets of solid return legs and drop into furnace by gravity

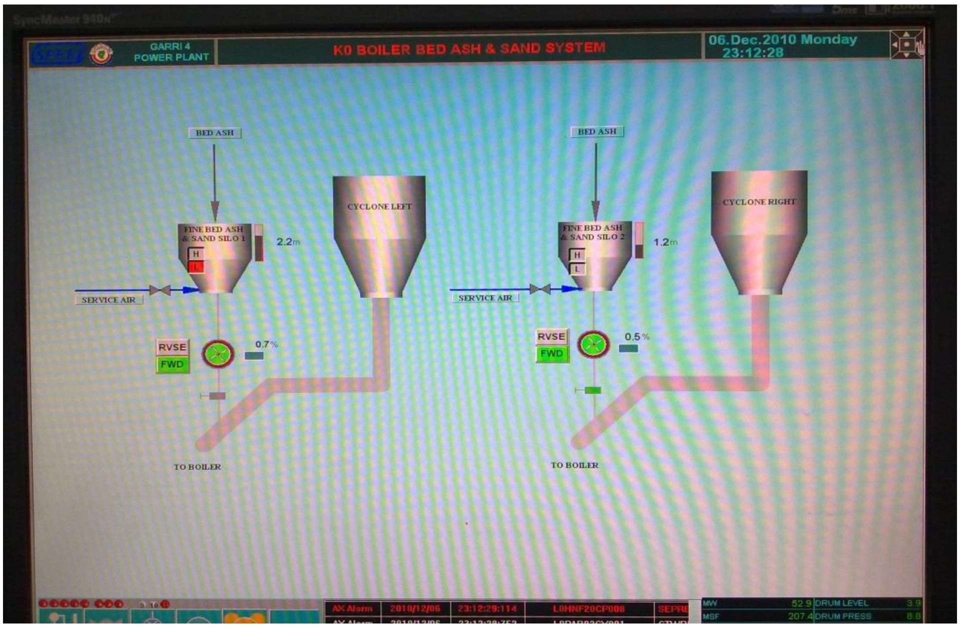


Fig (3.9) Sand feeding diagram

3.4.11Recirculation ash system

Recirculation ash system has one silo and one discharging/feed line. Recirculation ash is first moved from silo to ash hopper via a discharging rotary feeder. From hopper ash goes to feeding rotary feeder and then enters into recirculation ash blower outlet header. System has one recirculation ash blower, and ash is blowing to furnace from Side wall.

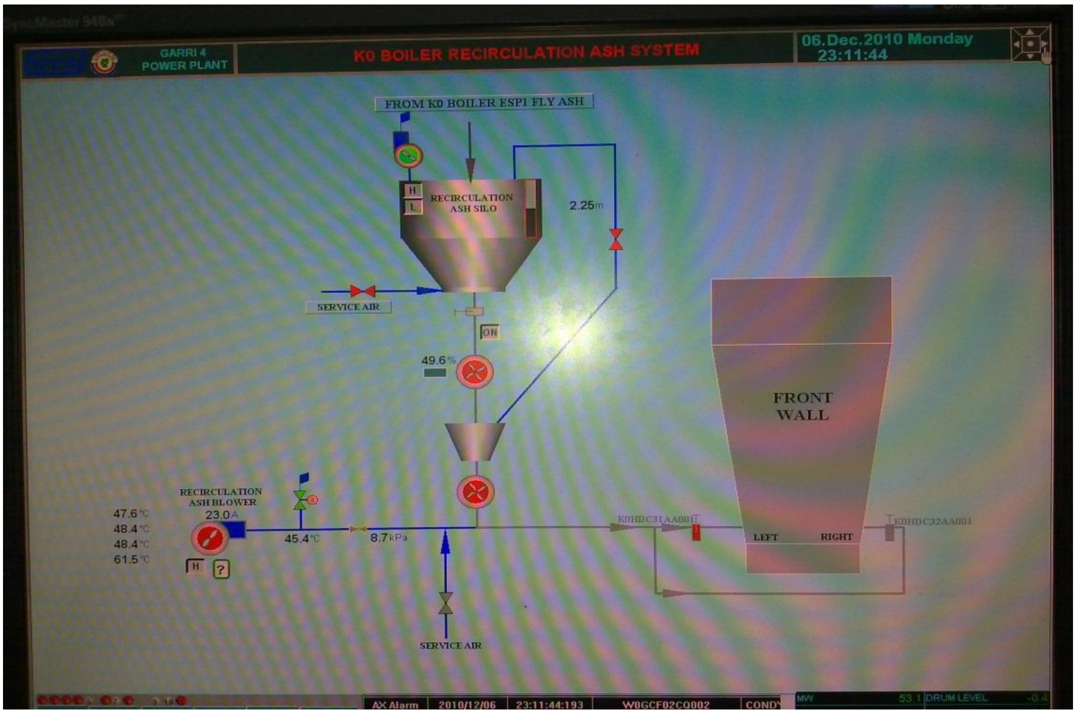


Fig (3.10) Recirculation ash feeding diagram

3.4.12The flying ash removal system

The flying ash removal system for two boilers consists of storage pump subsystem (Each boiler is furnished with six storage pumps. Two of them are used to deliver ash from air preheated and the rest storage pumps are used to deliver the ash from ESPs), pulse storage top dust cleaner subsystem, electric air heater subsystem, double shaft mixer subsystem, bulk loader subsystem.

Storage pump subsystem mainly consists of feeding device, pneumatic discharger valve, pumps body, and gasifies pipeline system and valves. The working process can be divided into four steps: Material feeding, Fluidization and pressurization, Delivery, Blowing and cleaning. Besides, Each storage pump is equipped with a set of manual anti-blocking device, which will be put into operation when the pipe is blocked.

The compressed air from air compressor is used as the driving power for ash removal system.

Through the closed duct of storage pumps, the sponge coke ash from air pre heater, ESP1,

ESP2, ESP3, ESP4 is delivered to the Fly Ash Silo, then passing through the storage bottom unloaded, bulk loader and double shaft mixer the ash is discharged to outside, and zero pollution ash discharge is realized. Besides by storage pumps, the sponge coke ash fromESP1 can be delivered to ash silo of each boiler for recirculation if the corresponding valve is open.

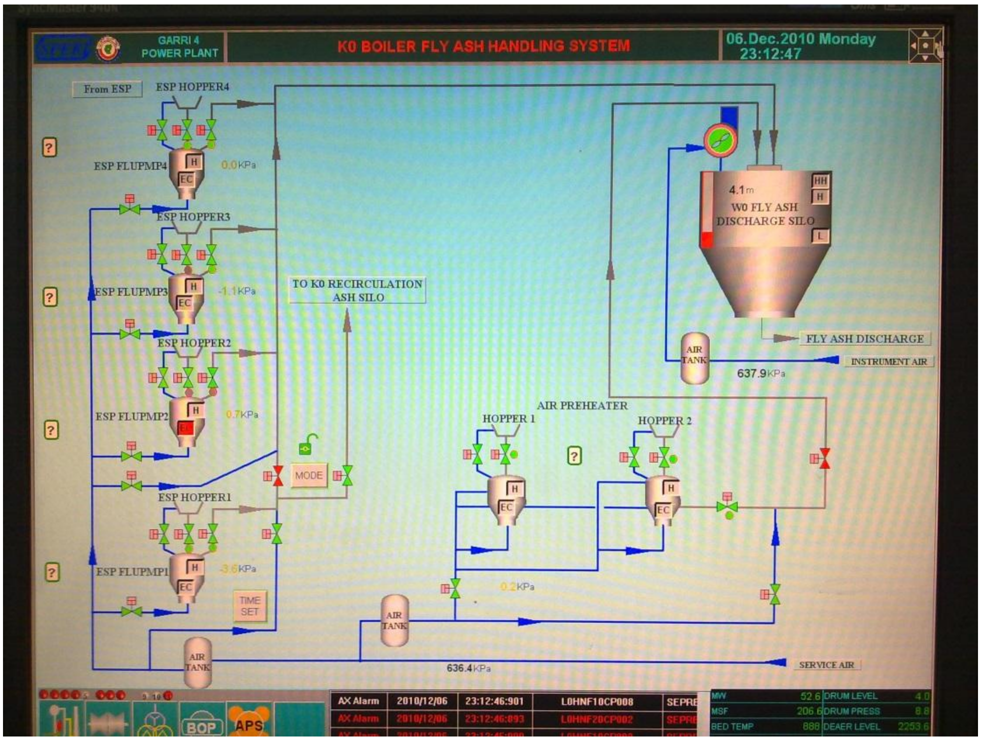


Fig (3.11) ESP removal ash diagram

3.4.12 The soot blowing

The purpose of soot blowing is to keep the heat surface area clean and this is done by steam which comes from inlet header of low temp. Super heater. The steam passes through a pressure reduction station and then is divided into two ways, HRA left and HRA right. 16 soot blowers totally (each way has 8 soot blowers) are divided for three groups: Superheated, Economizer and Air pre heater. In the end of each way there is a drain valve for soot blowing line warming. Soot blowers can be controlled locally or by soot blowing sequence.

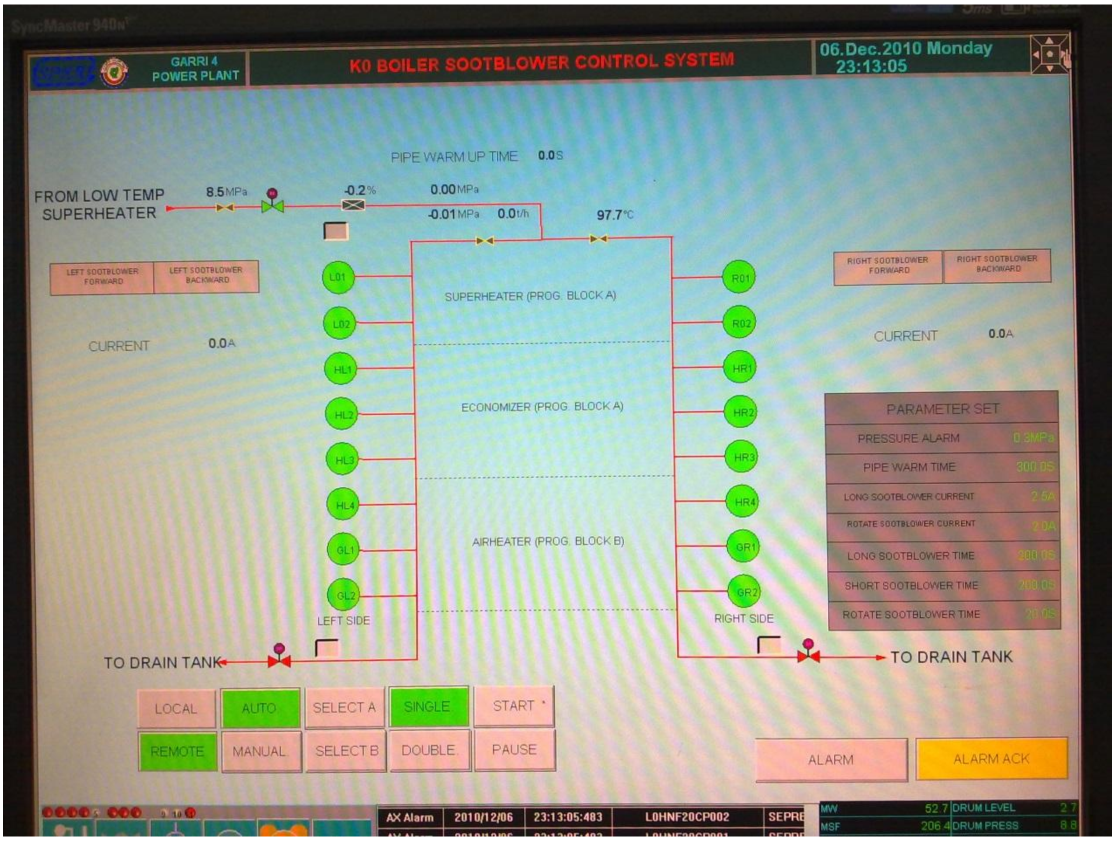


Fig (3.12) Soot blowing diagram

CHAPTER FOUR

CIRCULATION FLUDIZED BOILER ANALYSIS

CHAPTER FOUR

CIRCULATION FLUDIZED BOILER ANALYSIS

4.1 Basic definitions and properties of the particulate solids:

The materials participating in the processes in FBC boilers (sand, coal, Limestone, ash) belong to a class of materials called loose (particulate) solids.

The hydrodynamics of fluidized beds, heat transfer in fluidized beds, coal combustion, motion of particles in the bunkers, feeders, cyclones and separators, stand pipes and other pipelines for transport of sand, limestone, coal and ash, all crucially depend on the physical properties of solid particles

In most cases, particulate solids are composed of numerous solid particles of different shapes and very variable sizes. Most inorganic particulate solids appear in nature in a wide spectrum of particle sizes. These substances are called polydisperse materials. Loose materials resulting from technological operations are usually polydisperse. Some technological processes enable the production of particles that are similar in size and shape

Physical and chemical characteristics of loose material and hydrodynamic properties of solid particles are incorporated into formulae for the calculation of numerous processes in FBC boilers. It is, therefore, indispensable to know them in great detail

4.2 Physical properties of the particulate solids:

Bulk density of particulate solids is the mass of particles per unit of bed volume. Bulk density is always smaller than the true density of a solid particle, since the bed volume includes the volume of voids between the particles. Bulk density depends on the size and shape of the particles

$$\rho_b = \frac{m_b}{V_b} = \rho_p(1 - \varepsilon) \qquad (4.1)$$

Where

ρb bulk density of fixed bed, [kg/m3]

mb mass of the bed (fixed or fluidized), [kg]

Vb bed volume (fixed, fluidized), [m3]

ε void fraction

ρ_p particle density, [kg/m3]

Rough classification of particulate solids may be accomplished according to their bulk density:

– Light materials ρb<600 kg/m3,

– Medium heavy materials 600 kg/m3<ρb<2000 kg/m3, and

– Heavy materials ρb>2000 kg/m3.

Table (4.1) bulk density [1]

Material	ρ_b p[kg/m^3]
Sand	1200-1400
Limestone	1200-1400
Coal	600-800
Ash	1200-1500

It has generally been accepted that the particle size should be defined by a mean equivalent diameter, and that irregular particles should be considered spheres with the diameter equal to the mean equivalent particle diameter

In practice, the sieve analysis is most commonly used for determination of the particle size of particulate solids used in FBC boilers. The mean equivalent particle diameter is calculated then as the geometrical mean of the size of orifices on adjacent sieves

$$d_p = \sqrt{d_i d_{i+1}} \qquad (4.2)$$

Where

d_p mean equivalent particle diameter, [mm]

d_i is the smallest opening size of the sieve through which the particle has passed, [mm]

d_{i+1} is the largest opening size through which the particle fails to pass in the course of the sieving process.

It is customary to define the particle shape factor as the ratio of surface area of a sphere and surface of the particle having identical volumes

$$\emptyset_s = \frac{A_s}{A_p} = \frac{V_p^{\frac{2}{3}}}{0.205\ A_p}, \text{Where } 0 \leq |\emptyset_s| \leq 1 \quad (4.3)$$

Where

$\emptyset_s$ Particle shape factor

As surface area of spherical particle of the volume V_p, [m2]

V_p volume of the particle, [m3]

A_p particule surface area, [m2]

Table (4.2) shape factor for some particle[1]

Particle shape material		$\emptyset_s$
Sand	spherical	0.83
Sand	angled	0.73
Sand	Sharp angled	0.60
Sand	Mean for all kinds	0.75
Metallurgical coke	d_p=6-11.5mm	0.403

In the literature, different classifications of particulate materials are provided, according to the particle size [2]. One of the most commonly used classifications is the following: lumps (d max>10 mm), coarse grained (d_{max}=2–10 mm), fine grained (d_{max}=0.5–2 mm), powders (d_{max}=0.05–0.5 mm) and pulverized material (dust) (d_{max}<0.05 mm).

4.3 Hydrodynamic properties of solid particles:

In different modes of fluidization, particles move randomly and chaotically, either alone or in smaller or larger groups (clusters). The clusters disintegrate and reintegrate alternately, and/or randomly. The presence and motion of the surrounding particles significantly affect the interaction of particles and fluid.

For investigation of fluidization and for description of the phenomenon, it is important to know one of the basic hydrodynamic properties of a single particle– the free fall (or terminal) velocity. Knowing the free fall velocity and its physical implications is of utmost importance in understanding the fluidization process.

The physical interpretation of the free fall velocity and fluidization is practically identical. In both cases it is a question of achieving a balance of the forces acting on a particle-gravity, buoyancy force and hydrodynamic resistance of a particle during motion. Free fall velocity of a particle and the minimum velocity for the fluidized state share the same physical essence, although the pertinent values for the same particles are quite different.

The free fall velocity, as a characteristic magnitude, is incorporated into many formulae which describe fluidized state and other possible states of a mixture of solid particles and fluids (for example, pneumatic transport). When the upward velocity of a fluid passing through the fluidized bed of particulate material (fluidization velocity) reaches the free fall velocity of a single, isolated particle, further increase of velocity will result in removal of that particle from the fluidized bed, followed by the larger ones, as well. Therefore, the free fall velocity determines the upper limit of the velocity range in which it is possible to maintain a fluidized state of a bed of particulate solids

The following forces act upon a single spherical particle within the gravity field during free fall in an infinite space of stagnant fluid:

- Gravity force

$$F_g = \rho_p g V_p \qquad (4.3)$$

Where

F_g gravity force, [N]

g acceleration of gravity, [m/s2]

- Buoyancy force (Archimedes' force)

$$F_A = \rho_f g V_p \qquad (4.4)$$

Where

F_A buoyancy force, [N]

ρ_f fluid (gas) density, [kg/m3]

And

-resistance force

$$F_D = C_D \frac{d_p^2 \pi}{4} \frac{u_p}{2} \rho_f \qquad (4.5)$$

Where

C_D particle drag coefficient

u_p particle velocity, [m/s]

The gravity force and buoyancy force do not depend on the particle velocity, and they remain constant during the free fall if the fluid is incompressible (ρf= const.). At zero time, if the free fall started from rest, the resistances forceFD equals zero and the motion of the particle has started due to an imbalance of forces:

$$F_g > F_A \quad \text{for} \quad \rho_p > \rho_f \qquad (4.6)$$

Free fall is a uniformly accelerated motion, and FD increases during the fall, until the balance of forces is achieved:

$$F_g = F_A + F_D \qquad (4.7)$$

From this moment, the particles continue to move only due to inertia. The resultant force has become and remains zero. The particle continues to fall with a uniform velocity that is called the free fall (terminal) velocity.

The free fall velocity can be explained with a reversed sequence of events, also. If a particle is initially at rest on a porous barrier, and the fluid is moving vertically upwards, the particle will start floating when the fluid velocity reaches the free fall velocity. Thus, all the forces acting on the particle (Fg, FA and FD)will be balanced.

When expressions for the appropriate forces are introduced into the eq. (4.7), and the equation is reduced to a dimensionless form [2], the following expression is obtained:

$$C_D Re_t^2 = \frac{4}{3} Ar \qquad (4.8)$$

Where $$Ar = (\rho p - \rho f)\frac{g * dp^3 * \rho f}{\mu_f{}^2} \quad (4.9)$$

Re_t Reynolds number for particle based on terminal velocity.

Ar Archimedes number

In the eq. (4.8) the right hand side depends only on the properties of particle and fluid. Therefore, it is possible to express the free fall velocity only by using particle and fluid properties (dp, ρp, ρf, μf). The problems arise from the fact that the drag coefficient CD is a complex function of Reynolds number (that is, velocity), which cannot be expressed in a simple formula for a wide range of Reynolds numbers. The drag coefficient will also depend on the particle shape [2].

$$C_D = f(Re) \qquad (4.10)$$

The general interpolating formula is commonly used and recommended for calculations of free fall velocity in the whole range of Re numbers [6]:

$$Re_t = \frac{Ar}{18 + 0.61\ Ar^{0.5}} \qquad (4.11)$$

Stokes law<Re<0.4:

$$\frac{Ar}{18} = \frac{dp\,U_t\rho_f}{\mu} (4.12)$$

Intermediate law, 0.4<Re<500

$$(\frac{Ar}{7.5})^{0.666} = \frac{dp\,U_t\rho_f}{\mu} \quad (4.13)$$

4.4 Minimum fluidization velocity:

The minimum fluidization velocity, vmf, of a particulate solid is the velocity at which all particles begin to float when fluidization is established; the pressure drop will remain constant if gas velocity continues to increase (Fig. 4.1). Thus, the minimum fluidization velocity can be simply determined by using a diagram of the measured pressure drop as a function of' fluidization velocity.

For a bed of ideal monodisperse particulate material with insignificantly small antiparticle forces, the line presenting pressure drop across the fixed bed breaks abruptly when the minimum fluidization velocity is achieved (Fig.4.1). Determination of the minimum fluidization velocity of a polydisperse material, with irregularly shaped particles and rough particle surface, or with strong cohesive forces, and for the materials of the Geldart's groupC, is

Somehatmore complex. Intense cohesive forces among the particles will result in significantly higher pressure drop before the minimum fluidization velocity has been attained. When fluidization has been established, the pressure drop will assume a normal value ("b" curve). During velocity decrease hysteresis will occur "c" curve).

When polydisperse materials are fluidized, the transition is gradual.

Smaller particles begin to float at lower velocities. The pressure drop curve is similar to "c" curve ("d" curve). Minimum fluidization velocity is generally determined in these cases at the crossing point of the extrapolated left and right branches of the pressure drop curve. During fluidization of polydisperse materials at velocities substantially above the minimum fluidization velocity, the pressure drop diminishes ("e" curve), due to elutriation of fine particles. In case of no uniform fluidization, or if bed channeling takes place, the pressure drop plot will be similar to the "c" and "d" curves.

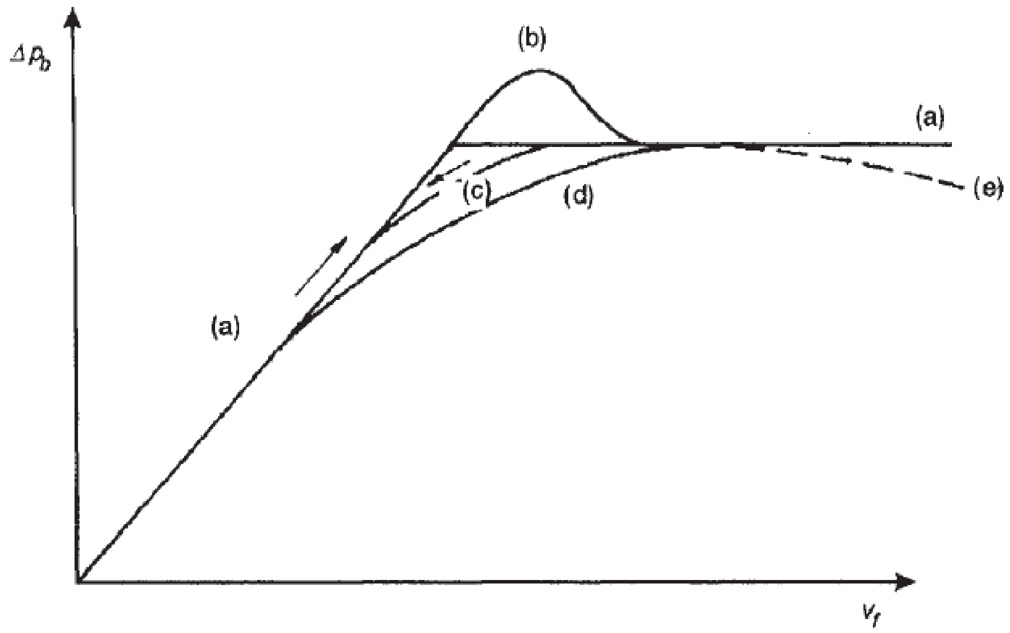


Fig (4.1) Fluidized velocity, pressure curve

Some characteristic curves of the bed pressure drop dependence on the fluidization velocity

The shape of the fluidization diagram (pressure drop versus fluidization velocity) provides a great deal of information on the nature and character of the fluidized bed and features of loose material in the fluidized state. Therefore, it is quite useful if FBC boilers are equipped with pressure drop measurement across the bed of inert material. Monitoring of the pressure drop is particularly important during the boiler start-up period.

The minimum fluidization velocity of a wide range of diverse materials has been determined since the inception of fluidization studies, and the literature offers a wide range of correlations for determination of the minimum fluidization velocity (e.g., references [2]). Originally, all such correlations were empirical, but the functional form proposed by Wen and Yu [2]is now widely accepted. These workers obtained this form by equating the correlations for the pressure drop of fixed and fluidized bed.

If assumed that the pressure drop through complex, irregular interspaces among the particles of a fixed bed can be expressed using the commonly employed Darcy formula:

$$\Delta p = \lambda \frac{L}{D}\frac{v^2}{2}\rho_f \qquad (4.14)$$

Where

λ friction factor

Which applies for a streamline flow through a pipe with circular (or almost circular) cross section, the Carman-Kozeny equation is obtained for the pressure drop across a fixed bed

$$\Delta p_b = H_b \frac{180(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu_f v_f}{(\emptyset_s d_p)^2} \qquad (4.15)$$

Where

H_b bed height, [m]

μf dynamic viscosity of fluid, [kg/ms]

vf superficial velocity of fluidizing gas, [m/s]

Where the following relations have been used:

- The total volume of interspaces between the particles

- The mean hydraulic diameter

$$D_h = \frac{6V_\varepsilon}{\sum A_p} = \frac{\varepsilon d_p}{\emptyset_s(1-\varepsilon)} \qquad (4.16)$$

Where D_h hydraulic diameter, [m]

And

- The total surface of particles in the bed

$$\sum A_p = \sum \emptyset_s d_p^2 \pi \qquad (4.17)$$

The numeric coefficient in the Carman-Kozeny equation(4.15) was obtained mainly based on experiments carried on with fine powders, Geldart's group A, for laminar flow. Therefore, it does not provide a satisfactory result when used for pressure drop measurements across a bed of particles with size >150 µm.

Here, Ergun's equation is used to cover practically all materials, since the second term accounts for inertia forces that become important in the turbulent flow regime:

$$\Delta p_b = H_b \frac{150(1-\varepsilon)^2}{\varepsilon^3} \frac{\mu_f v_f}{(\emptyset_s d_p)^2} + H_b \frac{1.75(1-\varepsilon)}{\varepsilon^3} \frac{\rho_f v_f^2}{\emptyset_s d_p} \qquad (4.18)$$

Gas velocity vf is based on the total cross section of the vessel (or a tube), as if there were no particles in it, as it has become customary in fluidization practice.

The pressure drop across a fluidized bed of particulate solids equals the weight of the bed material, reduced by the buoyancy forces, per unit of bed surface:

$$\Delta p_b = (1-\varepsilon)\left(\rho_p - \rho_f\right) g H_b \qquad (4.19)$$

By sub (4.15) & (4.16)

$$150\frac{(1-\varepsilon_{mf})^2}{\varepsilon_{mf}^3}\frac{\mu_f v_{mf}}{(\emptyset_s d_p)^2}+1.75\frac{1-\varepsilon_{mf}}{\varepsilon_{mf}^3}\frac{\rho_f v_{mf}^2}{\emptyset_s d_p}$$
$$=(1-\varepsilon_{mf})\left(\rho_p-\rho_f\right)g \qquad (4.20)$$

Where

ε_{mf} void fraction at incipient fluidization

Wen and Yu [1] have shown that for widely different loose materials thefollowing holds:

$$\frac{1}{\emptyset_s \varepsilon_{mf}^3}\approx 14 \text{ and } \frac{1-\varepsilon_{mf}}{\emptyset_s^2 \varepsilon_{mf}^3}\approx 11 \qquad (4.21)$$

According to which, with slight rearrangements, eq. (4.20) can be written as:

$$Re_{mf}=\frac{d_p v_{mf} \rho_f}{\mu_f}=(33.7^2+0.0408Ar)^{0.5}-33.7 \qquad (4.22)$$

$$Re_{mf}=(24^2+0.049Ar)^{0.5}-24 \; =\frac{v_{mf} * d_p * \rho_f}{\mu} \qquad (4.23)$$

Where

Re_{mf} Reynolds number for particle based on minimum fluidization velocity

$$A=\pi d^2 * n.1 * n.\frac{2}{4} \qquad (4.24)$$

Where d is orifice diameter

n.1 is number of nozzles

n.2 is number of orifice in each nozzle

Continuity equation:

$$Q=A*V \qquad (4.25)$$

4.5 Determination of minimum fluidization velocity by practice method: [3]

A fluidized bed is a packed bed through which fluid flows at such a high velocity that the bed is loosened and the particle-fluid mixture behaves as though it is a fluid. Thus, when a bed of particles is fluidized, the entire bed can be transported like a fluid, if desired. Both gas and liquid flows can be used to fluidize a bed of particles.

First, we consider the behavior of a bed of particles when the upward superficial fluid velocity is gradually increased from zero past the point of fluidization, and back down to zero. Reference is made to the figure (4.2).

At first, when there is no flow, the pressure drop zero, and the bed has a certain height. As we proceed along the left arrow in the direction of increasing superficial velocity, tracing the path ABCD, at first, the pressure drop gradually increases while the bed height remains fixed. This is a region where the Ergun equation for a packed bed can be used to relate the pressure drop to the velocity. When the point B is reached, the bed starts expanding in height while the pressure drop levels off and no longer increases as the superficial velocity is increased. This is when the upward force exerted by the fluid on the particles is sufficient to balance the net weight of the bed and the particles begin to separate from each other and float in the fluid. As the velocity is increased further, the bed continues to expand in height, but the pressure drop stays constant. It is possible to reach large superficial velocities without having the particles carried out with the fluid at the exit. This is because the settling velocities of the particles are typically much larger than the largest superficial velocities used.

Now, if we trace our path backward, gradually decreasing the superficial velocity, in the direction of the reverse arrows in the figure, we find that the behavior of the bed follows the curves DCE. At first, the pressure drop stays fixed while the bed settles back down, and then begins to decrease when the point C is reached. The bed height no longer decreases while the pressure drop follows the curve CEO. A bed of particles, left alone for a sufficient length of time, becomes consolidated, but it is loosened when it is fluidized. After fluidization, it settles back into a more loosely packed state; this is why the constant bed height on the return loop is larger than the bed height in the initial state. If we now repeat the experiment by increasing the superficial velocity from zero, we'll follow the set of curves ECD in both directions. Because of this reason, we define the velocity at the point C in the figure (4.2)as the minimum fluidization velocity

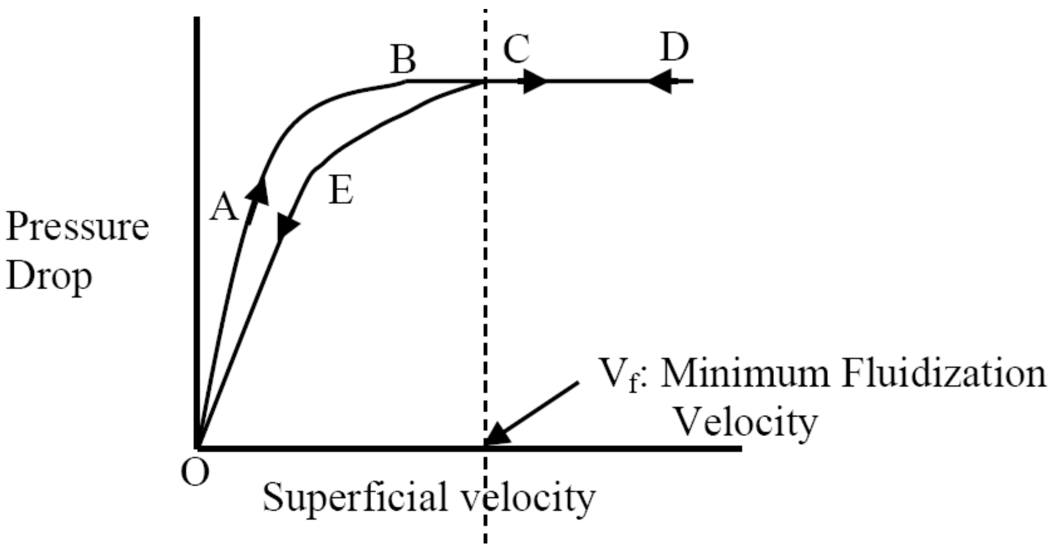


Fig (4.2) Minimum Fluidization Velocity and Pressure Drop Curve

4.6 CALCULATIONS:

METHOD (A):

Using equation method :

From equation (4.9) above,

$$\boldsymbol{Ar} = \frac{\mathbf{9.81 * (0.002)^3 * 0.316}}{\mathbf{0.0000444^2}}$$

Ar =18136

From equation (4.11)

$$\mathrm{Re_t} = \frac{18136}{18 + 0.61\ (18136)^{0.5}}$$

$$\mathrm{Re_t} = 181.093$$

From (4.12&4.13)

$$\mathrm{U_t} = \frac{0.0000444}{0.002 * 1} \left(\frac{18136.364}{7.5}\right)^{0.666}$$

$$\mathrm{U_t} = 13 m/s$$

By using equation (4.23)

$$\mathrm{Re_{mf}} = (24^2 + 0.049 * 18136)^{0.5} - 24$$

$$\mathrm{Re_{mf}} = 2.610766834$$

$$v_{mf} = \frac{2.610766834 * 0.000444}{0.002 * 0.316}$$

$$v_{mf} = 12m/s$$

Applied in equation (4.24)

$$A = \pi * 0.015^2 * 914 * 8/4$$

$$A = 1.29m^2$$

Sub in equation (4.25)

Q $_{fluidized} = 1.3 * 12 * 3600$

Q $_{fluidized}$=60000m^3/h

Similarly

Q $_{terminal}$ = 60000m^3/h

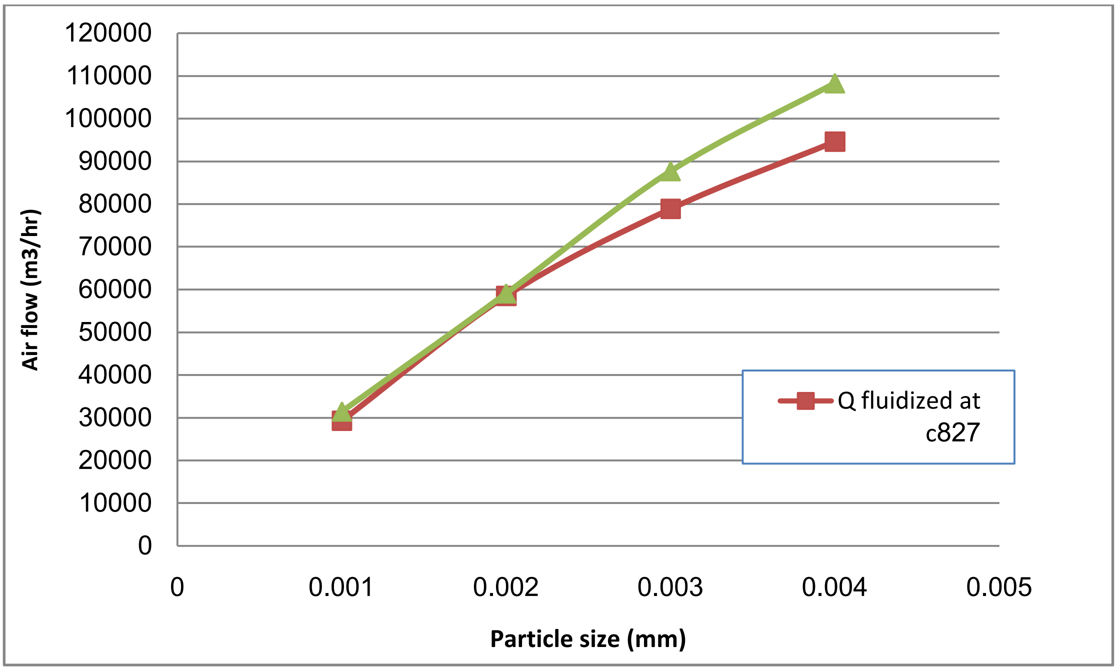
Similarly

Table (5.1) has designed as shown below also diagram (5.1)and (5.2) was drawn

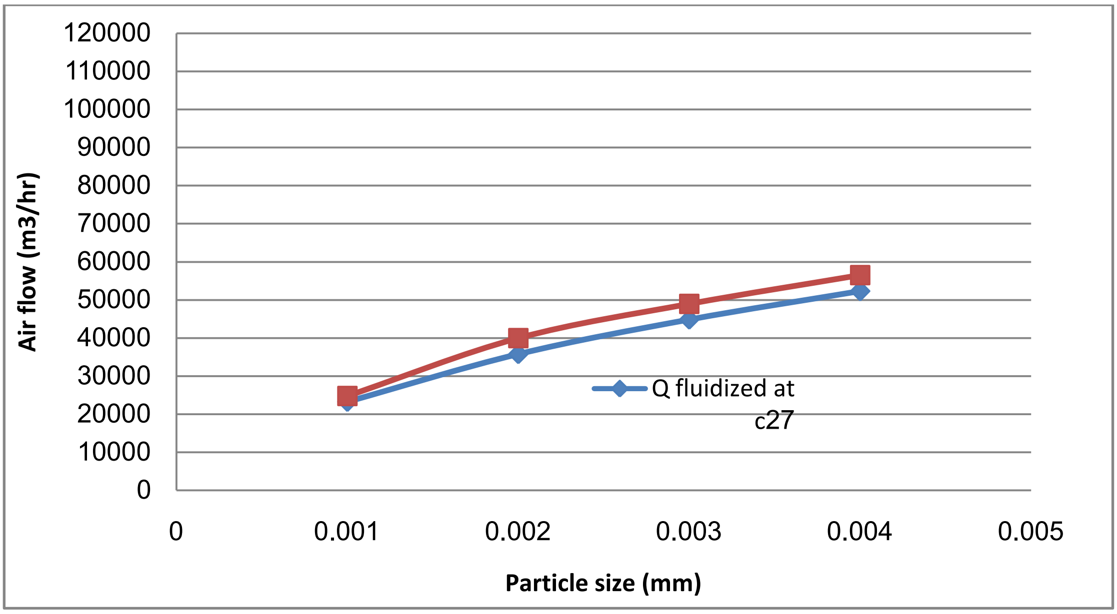
SYMPOLES	INPUT DATA	SYMPOLES	OUTPUT
g	9.81	Ar	18136.36366
dp	0.002	Ret	181.0928965
ρf	0.316	ut(m/s)	12.59126991
ρp	1442	Remf	2.610766834
μf	0.0000444	vmf(m/s)	12.72234905
C.1	27.2	A	1.291482
C.2	0.049	Q fludized	59150.46529
pi	3.14	Q termina;	58541.03443
n.1	914		
dia	0.015		
n.2	8		

dp	0.001	0.002	0.003	0.004
Q fluidized at 27c	23246.37882	35797.18425	44835.48768	52267.23
Q terminal at 27c	24799.88119	39954.18477	48933.68288	56503.75

dp	0.001	0.002	0.003	0.004
Q fluidized at 827c	29311.12291	58541.03443	78906.51217	94648.26
Q terminal at 827c	31480.42298	59150.46529	87740.37147	108290.4



120000
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Air flow (m3/hr)
0
0.001
0.002
0.003
0.004
0.005
Particle size (mm)
Q fluidized at c827



120000
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Air flow (m3/hr)
0
0.001
0.002
0.003
0.004
0.005
Particle size (mm)
Q fluidized at c27

METHOD (B):

Practice method

Determination of minimum fluidization velocity.[3]

1) Note the weight of glass beads, and their average diameter.
   Diameter =1_3 mm
2) Supply gas with a low flow rate (the lowest measurable) to the bed and note the flow rate using the Rota meter and the gas pressure at the bottom of the bed. Also note the bed height.
   Lowest air flow rate =15000$\frac{m^3}{h}$
   Gas pressure 5Kpa

   Bed high 630mm

3) Increase the gas flow slightly and again note the flow rate, pressure and the bed height.

Air flow rate =25000m^3/h

Gas pressure 7Kpa

Bed high 630mm

4) Repeat (3) until the maximum flow rate is reached. Observe the top surface and sides of the bed and note the flow rate when the bed just becomes fluidized.(Particles begin to vibrate)
   The maximum flow rate is reached120000m^3/h
   The flow rate when the bed just becomes fluidized 55000m^3/h

5) Repeat (3) starting from a high flow rate and decrease the flow rate slightly insteps. Note the flow rate when the bed is just defluidized.

The flow rate when the bed is just de fluidized is $60000m^3/h$

CHAPTER FIVE

RESULTS AND DISCUSSION

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Results:

- According to the calculation and practice result the minimum fluidization flow in circulation fluidized boiler at Garri (4) power plant at normal condition is 60000m^3/h
- According to measurement calculation result are tabled (5.1) the distribution change of sand particle size caused a change of the air fluidized velocity and fluidized air flow.
- Fluidized velocity and air terminal velocity are proposal to each other and the difference between their values is not much.
- Change in the bed temperature leads to air properties such as viscosity and density which lead to change of fluidized velocity.
- The air velocity in one region could drop below the minimum fluidizing velocity of the coarser fraction of the bed materials. The air will thus fail to fluidize the coarser particles making that section partially de fluidized. Fuel particles burning in that de fluidized section will fail to dissipate their heat and lead to overheating spot and even serious and very dangerous result such as molting.

5.2 DISCUSSION:

- In theoretical method friction was neglected and assumed nozzle efficiency 100% and there is no nozzle blocked or nozzle damaged and this gave smaller fluidized velocity value .
- In actual method fluidized velocity could not calculate accurate value and could not calculate at high temperature
- No uniform distribution of air may result; reduced performance of the combustor or gasifies to complete collapse of the bed due to agglomeration.
- The most common problems with fluidized bed boilers have been with fluidizing nozzles which such as high maintenance due to erosion, plugging, and back-sifting.
- Serious grid nozzle plugging could result in frequent cleaning, high bed temperatures, excessive limestone and ammonia consumption, and/or high excess air requirements.
- If velocity is less than the minimum fluidizing velocity of the coarser fraction of the bed materials, The air will fail to fluidize the coarser particles making that section partially de fluidized. Fuel particles burning in that defluidized section will fail to dissipate their heat and lead to a local hot spot.

CHAPTER SIX

CONCLUSION & RECOMMENDATIONS

6.1 Conclusion:

- In this research Circulation Fluidized Bed boiler in Garri (4) has studied in details, and calculated the minimum fluidized flow required for safe operation by theoretical method and practical method and then were compared with manufacture operation and maintenance manuals and it has founded about 60000m^3/h

6.2 RECOMMENDATIONS:

- In any operation cases and situations especially in low load running ,the CFB operator not allowed to let the primary air less than minimum fluidized air flow to avoid de fluidized ,overheating, even sponge coke accumulated and malting .
- Screen is recommended to use for selection the sand particle size, before feeding sand to boiler.
- Bed nozzle should clean to avoid blockage, change damaged and bad one to assure good fluidization.
- Before startup cold fluidization test should carry carefully .if fluidization test fail discharge bed material, double check re clean nozzle sand feeding good material.
- More studies of air flue gases inside furnace including combustion and coke particle behavior are recommended.

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