An Insight into Advanced Technology in Circulating Fluidised Bed Combustion Steam Generators

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Abstract

Indian economy is growing at a fast pace and to cater to the economic growth, there is need to augment the power generation rapidly. Coal will continue to remain as the main fuel for power generation. However the gap between demand and availability of domestic coal in the terminal year of the 11th five year plan is about 74 MT necessitating import of coal. The shortfall will further increase to about 120 MT when all the 11th plan projects are commissioned and expected to stabilize in the beginning of the 12th five year plan. Domestic coal appears to be unavailable to meet the 12th five year plan requirements unless a significant increase in domestic coal production is achieved. In this scenario it is imperative that an aggressive thrust to identify new lignite deposits is made. This would to a limited extent make up for the shortfall in capacity addition due to inadequate coal linkage. Considering the requirement of high efficiency in power generation and environmental considerations, installation of power plants with Circulating Fluidized Bed Combustion (CFBC) technology with lignite as main fuel would be a techno economically viable option. This paper outlines the present status of CFBC technology and details of existing installations in India and abroad.

Introduction

Within the past three decades, fluidised bed combustion (FBC) technologies have emerged as a commercially viable alternative, and becoming a technology of choice in many situations. These technologies have been applied to all solid fuels including bio-fuels, peat, lignite, coal, anthracite culm, coal washery wastes, petroleum coke, oil shale, municipal waste based fuels and an array of hazardous wastes. Many have been designed to co-combust several dissimilar solid fuels and wastes simultaneously.

Fluidised bed combustion systems introduce the concept of solids turbulence into the combustion process, and dramatically impact the processes of heat and mass transfer and mechanisms associated with combustion. Fluidised bed combustion technologies also provide methods for making combustion temperature an independent variable, rather than a consequence of stoichiometry and combustion air temperature. During the combustion process, acid gas control within the furnace by means of direct introduction of sorbent materials into the combustor. These technical advances have caused fluidised bed combustion to become the technology of choice among system designers. The very first commercial bubbling FBC steam generators (SG) were commissioned in the early 1970s. By 1980 the bubbling bed SGs dominated the market accounting for about 80% of installed capacity. The first commercial Circulating Fluidised Bed (CFB) SG has been commissioned in the late 1970s. . Fig. - 1 indicates the major milestones in CFB SG technology.

CFBC PROCESS

Velocities in CFB SG

CFB conditions are achieved at velocities greater than 3 m/s with mean bed particle size smaller than 500 microns. A large fraction of bed mass is small enough to be entrained in the gas stream. This material must be collected and recycled to maintain bed inventory. The clear distinction between bed and free board noticed in bubbling bed systems fades and bubbles are no longer apparent in CFB SG. The pressure drop from the bottom to the top of combustor follows a smoothly declining gradient, as shown in Fig. - 2.

Recycle ratios

Even though the gas velocity is above the entrainment velocity of most particles in the bed, the entire bed is not entrained out of the combustor. This is because the particles tend to form “clusters” which break-up, move up and down within the combustor. The gas velocity is below the entrainment velocity of these clusters. These clusters thus ensure considerable bed inventory at usual CFB velocities, and also account for considerable internal bed recirculation. The entrained material is of a large enough size to be captured by a cyclone for transport back to the bed. This process results in substantial external recycle which leads to excellent mixing and gas solids contact with high performance in terms of combustion efficiency and sorbent utilisation. Recycle ratios of 10 to 100 : 1 and greater are typical and are required to maintain the desired high solids concentration in the combustor. Fig. - 3 indicates a typical process schematic.

Heat transfer co-efficient

In CFB design, the heat transfer co-efficient in the furnace is proportional to bulk density. Therefore, in case of CFB boilers, the furnace heat absorption depends on the total furnace surface and external recycle rate. The furnace heat balance is also influenced by the way a particular fuel burns. When fuel is introduced into a fluidised bed, majority of it burns in the dense bed. The actual split between dense bed and above dense bed depends on fuel properties such as type, volatility, size and feed system. Because of the large amount of recirculated solids, the heat release pattern in a CFB furnace does not have a strong influence on temperature distribution. For this reason, CFB furnaces are more tolerant of fuel changes than bubbling beds.

Fuel feed size

Proper fuel feed size is extremely important to operation and performance. If the feed is too coarse, there will be insufficient material in circulation which in turn will reduce burnout, sorbent utilisation and combustor heat transfer. In the extreme, the solid circulation rate will be low enough to cause large temperature gradients in combustor. This condition can lead to clinkering and defluidisation. Further the coarse material which resides in lower combustor adds unwanted pressure drop. If feed is too fine, excessive material will be entrained from the combustor, thereby producing insufficient material in circulation and a resultant negative impact on performance. In general, high ash fuels must be crushed finer than low ash fuels. This is because smaller feed size is required to produce optimum bed particle size and carbon will tend to get encapsulated by ash leading to higher carbon loss.

Combustor surface to volume ratio

As CFB SGs get larger in size, the combustor surface to volume ratio decreases and it is not possible to perform the required evaporator duty in the furnace water walls enclosure. For example, the CFB SG furnace heights of a 125 MW and 250 MW unit are 33 and 37 metres respectively. The additional duty requirements must be carried out using either in-furnace surfaces or external heat exchanger surfaces. In-furnace surfaces consist of either Omega Panels or Wing walls. Omega Panels are normally used as first superheater pass. Major considerations while locating in-furnace surfaces are:

a. Location in zone effective for heat transfer

b. Arrangement should be such that no major change in the gas-solids flow will occur and result in erosion

c. These surfaces should be at a reasonable distance away from denser and coarser solids in the furnace
d. Should not be affected by firing of auxiliary fuel during low loads

e. Surface should not be affected by any localised fuel combustion which may occur at low loads

f. Physical arrangement should provide enough flexibility for cyclic duty requirement of typical utility units

g. Should require minimum inspection and maintenance

Details of external heat exchangers are furnished in the subsequent sections.

LARGE CAPACITY CFBC STEAM GENERATOR DESIGN CONCEPTS

The application of circulating fluidised bed combustion technology in steam generating plants has seen a rapid growth in the United States and in Europe in the past few years. Even in India many of these technologies are now available. The major process licensors and SG manufacturers have developed several concepts which differ mainly in the method of solid circulation and heat exchange. The main characteristics of major circulating fluidised bed technologies are as follows:

Ahlstrom Pyropower

Fig. - 4 shows the Ahlstrom Pyropower system. Ahlstrom was one of the pioneers in the field. The circulating fluidised bed division is now a part of the Foster Wheeler group. In the combustion chamber heat is transferred to the membrane water tube walls through the internal circulation of solid material. There is no in-bed heat exchanger. External recirculation of hot solid material is carried out via. cyclone. No external heat exchanger is provided in the external recirculation path. Concentration of solid particles in the combustion chamber is between 3 and 5 kg/m^3.

Austrian Energy (Formerly Lurgi Lentjes AG, Germany)

The Austrian Energy system.is shown in Figure -5 and is similar to Ahlstrom system. Unique to this system is the external heat exchanger which is a fluidised bed with a low fluidising velocity (0.30 to 0.50 m/s). The concentration of solid particles in the combustion chamber is between 6 and 10 kg/m^3.

Foster Wheeler

Fig. - 6 shows a typical Foster Wheeler type unit prior to their taking over of Ahlstrom Pyropower. It is similar to the other two above in basic design except for the following distinguishing features. Foster Wheeler uses an air swept coal feeder design. The cyclone is steam cooled and it is the first pass of superheater. The major advantage is that it is now a part of the furnace system. Thickness of refractory is reduced, reducing start-up times. Another distinguishing feature is the use of an unfired fluidised bed heat exchanger called Integrated Recycle Heat Exchanger (INTREX^{TM}). The INTREX^{TM} is integrated with the furnace system and normally has superheater tubes. The INTREX^{TM} discharges into a solid return channel. The solids return channel acts as a buffer between the INTREX^{TM} and the furnace.

Circofluid bed combustion system

The Circofluid bed combustion system is shown in Fig -7. It is characterised by a circulating fluidised bed with relatively low solids concentration in the freeboard above the bed (1.8 kg/m^3). The elutriated solid particles are transported by the flue gas through the heating surfaces in the combustion chamber and reach the cyclone separators with a temperature between 300 and 400^{0}C. For this low temperature there is no need for thick refractory lining of the cyclones. The collected material in the cyclones is returned back to the combustion chamber. The start-up and shutdown times are relatively lower compared to the previous systems. The cooling of elutriated solid particles in the combustion chamber can cause unburned coal particles to produce carbon monoxide. The system was developed by Deutsche Babcock.

Babcock & Wilcock

Babcock & Wilcock type is shown in Fig. - 8. It is called the internal recirculation type CFB. This type employs a patented two stage separation system. The primary stage consists of U beam impact separators and the secondary stage consists of multi cyclone dust collector (250 mm small diameter cyclones) which work together to provide a particle collection efficiency in excess of 99.8%. The U beam separator system forms a part of the furnace water wall enclosure reducing the amount of refractory required. This also reduces the start-up time.

Multi-Solid Fluidised Bed

Fig. – 9 shows the Multi-Solid Fluidised Bed offered by Riley Stoker Corporation, USA. The technology is licensed from Battelle Memorial Institute. The multisolid fluidised bed is a coarse dense bed in which fuel and sorbent are fed. The bed operates at a high fluidising velocity in which a fast recycled bed of fine material is superimposed. The combustion reactions are largely confined to the dense bed. The fine solids are cooled by heat transfer surface in an external heat exchanger before being recycled to the dense bed. The combustion temperature is controlled by the rate of circulation of the fine material.

Steinmueller system

The Steinmueller system is shown in Fig -10. It uses a labyrinth separator for recirculating solids instead of the hot cyclone. This type is used for capacities less than 100 t/h.

Pyrocompact

Pyrocompact as shown in Fig. - 11 was developed by Ahlstrom Pyropower. Essential features of the compact design are its straight panels walls in both hot separator and solids return channel. Gas and solids flow into separator from combustor through an inlet channel and gas flows out through the cylindrical vortex finder. Flow structure inside the separator is a swirling vortex despite the square walls of the separator enclosure. In the return channel, the normal loop seal system is replaced by a patented gill seal system that allows the solids to return to the furnace and effectively seals the furnace.

Cymic

Fig. - 12 shows Tampella's cylindrical multi-inlet cyclone (CYMIC) design, which is unique water cooled cyclone internal to and concentric with CFB combustor.

DESIGN AND CONSTRUCTION FEATURES

Turndown

Turndown is accomplished by reducing both fuel and air to the unit. In the process, grate and combustor velocity should be kept above a minimum level in order to produce adequate mixing and solids recirculation for reasonable fuel combustion and to avoid severe temperature maldistribution and back sifting of bed material into the air plenum. This usually implies excess air levels holding constant as load is decreased until the minimum velocity is reached, after which excess air percentage increases to maintain fluidisation velocity. Further load reduction causes the combustor temperature to drop. When the solid fuel permissive temperature is reached the lances and subsequently started burners must be switched on.

With a Fluidised Bed Heat Exchangers (FBHE), combustor temperature can be maintained at its normal value through a wide load range. As load is reduced, solids flow to FBHE is reduced by the ash valve, which adjusts the primary loop heat absorption to the required level without affecting combustor temperature. The combustor performance is maximised at part load. On further load reduction, the solids flow to FBHEs are also stopped and below this point however the combustor temperature will drop with further decreasing load.

Start-up

Start-up is accomplished by means of start-up burners located in lower combustor walls and / or in primary air duct. Once minimum primary air flow is established, start-up burners are light-up to heat the bed material slowly, at a rate dictated by refractory heat-up limits of 55 to 100^0C/hour. When solid fuel permissive temperature is reached, typically between 500^0C to 700^0C, solid fuel addition is started. Temperature is further increased by adding solid fuel and backing down start-up/support fuel. At about 30% MCR, the boiler will be on solid fuel alone.

Fuel feeding system

The solid fuel feed system usually consists of a pressurised belt feeder followed by a rotary air lock valve and fuel pipe leading to the side of the lower combustor. Fuel from the feeder falls by gravity through the air lock valve into the combustor. The feeder is pressurised. At least one completely redundant feed system is recommended.

Alternatively, the fuel can be dropped into an air stream and injected pneumatically into the combustor. This approach will help fuel dispersion in the combustor and offers possibility of using secondary air ports for fuel feed, thereby reducing the total number of openings required in the walls of the combustor.

High moisture fuels, such as lignite, are generally fed to the combustor through the discharge side of the seal pot to mix the fuel with hot solids, thereby partially pre-drying the fuel. This feed location also has the advantage of eliminating a separate opening in the combustor for fuel feed.

Number of fuel feed points

Fuel heating value can also influence the number of feed points. Liquid and gaseous fuels for load carrying are fired in lances. Lances are located in lower combustor. The lance is intended to disperse the fuel within the bed, where it is combusted in the fluidising air stream. Full load can be obtained on liquid or gaseous fuels if adequate lance capacity is provided. It must be noted that these gaseous and liquid fuels would have a much lower residence time than solid fuels, and hence require more feed points for proper fuel distribution and performance. Lances are either stationary or retractable. If a substantial load is to be carried by liquid or gaseous fuel, bed material make-up would be required.Typically the feed lignite particle size would be in the range of 0 to 15 mm with d50 = 0.8 -1 mm.

Sorbent feed

Sorbent will be transferred typically to the combustion process via variable speed rotary valves from the storage silo as required by the combustion process and is flowing by gravity to the seal pot. The rotary valve is controlled proportional to the fuel feed and adjusted depending on sulphur dioxide level in the stack flue gas. For limestone the feed size would be typically 100% less than 1 mm with d50 = 0.16 mm.

Bed make-up material feed

Bed make-up material such as sand or bottom ash from the bed ash bin can be added to the ash inventory in case the ash derived from the burned fuel is insufficient to be retained for any length of time with the CFB system. Mean particle size of bed make up material is typically in the range of 50 - 300 microns. Bed material is fluidised by typically preheated primary air introduced through the nozzle gate and by the combustion gases generated by upward flowing combustibles with a relatively high fluidising velocity.

Combustion air supply

Typically the primary air and secondary air are supplied to the combustor by separate centrifugal fans generally arranged in parallel. These streams are preheated in air heater.The combustion air is introduced in the combustor at multiple levels. About 40 - 50% of the combustion air, is passed as primary fluidising air through the nozzle grate on the bottom of the combustor. Primary air fans are designed to fluidise the bed ash and start of the boiler with only one fan.

The total combustion air flow is automatically controlled as a function of the load to ensure that the pre-set air to fuel ratio is maintained keeping emission limits. On increasing the load, the air rate is the load parameter with coal feed rate being controlled as a function of the air feed rate. On decreasing load, the coal feed rate controller takes the lead and the air feed rate is controlled as a function of the coal feed rate. The delivery head generated by all fans and blowers is sufficient to overcome the pressure losses across the system and the backpressure in the CFB combustor.

Balance combustion air is admitted as secondary air, typically in two levels through multiple ports in sidewalls of the combustor. The pressure levels of secondary air are much lower than primary air by injecting the air at a higher level. In addition combustion air is supplied by various blowers, which are operated also during part load providing a constant quantity of combustion air. Fluidising air for seal pot, FBHE, ash coolers etc. as the case may be are supplied either by positive displacement blowers or by centrifugal blowers. Depending on the flow rates, it may be economical to preheat these air streams in an air heater.

Fluidising air nozzles are provided in the bottom of the combustor, seal pot, FBHE, ash cooler etc. as case may be, for proper distribution of fluidising air. These nozzles are designed to avoid back sifting of solids into air supply system.

Combustor

The combustor corresponds to the furnace in a pulverised fuel or stoker fired SG. The combustor consists of two zones: lower combustor and upper combustor.

Lower combustor

The lower combustor is the portion containing primary-air distributor, secondary air ports, fuel feed ports and solids-recycle ports. The density of the bed in this region is relatively high on average, being highest at the elevation of the air distributor and dropping off rather rapidly with increasing height. Due to staged air feed, this region is sub-stoichiometric. Physically, this section is usually rectangular, tapered, formed from finned or fusion welded water wall tubing and lined with refractory to protect the tubing from erosion by dense bed and corrosion in sub-stoichiometric atmosphere. The optimum refractory lining is hard (to minimise erosion), thin (to minimise weight) and reasonably conductive to maximise combustor heat absorption.

Upper combustor

The upper combustor, section above the refractory lined lower combustor, contains the gas outlets or outlets to cyclones. The density of the bed is relatively low and drops off with increasing combustor height. Because all air has been fed in lower combustor, the upper combustor region operates under excess air (oxidising) conditions. Physically this section is usually rectangular, straight walled, and formed from finned or fusion welded water wall tubing to maximise heat absorption.

Cooling of air distributor (grate)

The air distributor (grate) containing the air nozzles in the lower combustor can be uncooled or water cooled as can the air plenum below the grate. Water cooling of the grate and plenum provide a seal-welded, gas tight combustor and minimises the size of expansion joints connecting the primary-air ducts to combustor.

Pant leg configuration

If necessary on large units, two tapered lower combustors can be used with a single upper combustor, forming a so-called “pantleg” configuration. This configuration improves fuel and air distribution within large combustors.

Combustor support

The combustor can be top-supported or bottom supported. Top supporting is the more traditional approach.

Solids separator

Solids separation is a key element of any CFB SG design influencing both capital and operating costs of the unit. Depending on the SG manufacturer, these could be an impact separator or a cyclone separator.

U- beam separator (impact separator)

The U-beam separator (impact separator) system technically consists of few rows of in-furnace U-beam separators, typically two rows and external U-beam separators typically four rows. The internal U-beams are able to collect more than 75 percent of the solids entering the separators. The external U-beams are generally installed behind the furnace rear wall plane to collect most of the solids passing the infurnace U-beams. A particle storage hopper is located at the bottom of external U-beams. The separated solids are recycled internally into furnace via. discharge port from transfer hopper. The U-beams are made of stainless steel 309 H. It must be noted that the flue gas side pressure drop in U beam separators is about 25 mm water column compared to the 100 - 150 mm water column pressure drop in cyclones.

Cyclones

Cyclones can also be used to collect solids entrained in the gas leaving the combustor. The cyclone is designed to collect essentially all particles with a diameter greater than 100 microns. Given the relatively large particle sizing entering the cyclone, the separation efficiency is typically over 99 percent. When needed, a vortex finder can be added to the cyclone gas to improve collection efficiency.Hot cyclone is typically constructed of steel plate with a multiple layer refractory lining. The hot face of the lining is a dense erosion resistant material, backed by lighter weight insulating material. Alternate construction using water cooling or steam cooling is also feasible.

Solids reinjection system

A solids reinjection system called as L valve, J valve, loop seal or seal pot is a simple non-mechanical hydraulic barometric seal against combustor shell pressure. Most of them are large diameter steel pipe with refractory lining. Inside there are no internals, but there are nozzles for admitting compressed air that keeps the material fluid like.

The seal pot is a non-mechanical valve which moves the solids collected by the cyclone back into the combustor against combustor back pressure. Solids flow down on the inlet side, up on the outlet side, then back to combustor. The bottom portion of the seal is fluidised so that material can seek different levels on each side of the seal with the difference in level corresponding to the pressure difference across the seal. Then, solids entering the seal inlet displace solids out of seal on the outlet side.

Fluidised bed heat exchangers

The FBHE is an alternate means used by some of the manufacturers to remove heat from hot solids in the primary solid recirculation loop and reduce combustor size.The FBHE is a bubbling bed heat exchanger consisting of one or more compartments separated by weirs and containing immersed tube bundles. Hot solids from the seal pot enter the FBHE, where they are fluidised and transfer heat to the heating surface within and then flow back to the combustor. The tube bundles immersed in the FBHE compartments can be evaporator, superheater or reheater surface.

Fluidising velocity

Fluidising velocity is low (0.3 to 0.6m/s). The fluidising medium is air. Particle size is small and carbon content of material in circulation is negligible. All these conditions lead to essentially no erosion or corrosion of in-bed tube bundles. Also because of the high bed density, heat transfer rates are very high. Containment can be either refractory lined steel plate or water cooled construction.

Convective pass

The convective pass is of the same design as in a conventional pulverised fuel SG. The convective pass can contain super heater, reheater, boiler bank and economiser surface. Gas velocities are kept low to avoid erosion. Initial designs never used soot blowers. Current designs use retractable or rotary soot blowers to keep heat transfer surfaces clean.

Air preheater

A prime consideration in selecting an air preheater type for CFB applications is the high air to gas pressure differential resulting from high primary air pressure required. This has led to use of low leakage designs like tubular air preheaters or heat pipe air preheaters.

Generally air preheaters are provided for primary air and secondary air circuits. For CFB units with FBHEs, which require large amounts of fluidising air, it is sometimes economical to provide air preheating for fluidising air also. With tubular air preheaters, the most common design for CFB applications is gas over tube / air through design. The dust laden gas passes over the tubes and because the tubes are arranged in line, they can be easily be cleaned with soot blowers. Gas through / air-over designs, though somewhat difficult to clean, have also been successfully used.

Ash removal system

The ash removal system includes both the bottom ash and fly ash systems.

Bed Ash system

The main function of the bed ash system is to control bed inventory. Bed pressure drop is a measure of inventory and bottom ash flow is adjusted to maintain the desired bed pressure drop. Bed ash system can also help in controlling accumulation of oversize material. In CFB, such an accumulation can produce an unfavourable pressure profile with most material in the lower combustor and little in the upper combustor resulting in poor performance. However the best and most direct way to control oversize accumulation is with proper design of fuel sizing equipment to avoid oversize. Two ash drains per combustor are usually sufficient.

Ash classifiers

Ash classifiers are used by some manufacturers (refer Fig - 13) to remove oversize and adjust pressure profile without excessive bottom ash flow rates. Such classifiers can operate continuously or in batch mode and can also cool the ash. Bottom ash must be cooled from combustor temperature to around 120 - 150 deg C, before entering bottom ash conveying system. On high-ash fuels, the heat from the bottom ash stream may represent a significant percentage of heat. In such cases, fluidised bed ash coolers (FBACs) can be used for these purposes. The FBAC is a bubbling bed fluidised bed heat exchanger identical in design to FBHE. Cooling coils immersed in the bed cool the ash. Ash flow from combustor to the FBAC is controlled by cone valve, as with FBHE. The FBAC design must accommodate the accumulation of coarse material which can lead to sintering and / or defluidisation. Cooled ash from ash cooler passes to bottom ash handling system.

Safety margin for bed ash removal system

Normally, the design of bed ash removal system includes a large safety margin because of the uncertainty as to where the solids will exit the system and to handle changes in fuel. Operating results indicate bed drain flow can range from 0 to more than 50 percent of the total solids output. In the case of fuels with a high alkali content in the ash, it may be necessary to drain the bed material from the boiler at a rate higher than the solids build up rate to prevent a concentration build up of alkali in the bed. Typically if the concentration of alkali exceeds 5 to 6% of bed weight, the probability of forming agglomerates increases significantly.

Fly ash system

The fly ash system will be similar to conventional pulverised fuel SG.

Refractory

CFB SGs use extensive amounts of refractories to withstand harsh temperatures, frequent cycling and continuous attack by erosive high velocity particles. Specific areas requiring protective refractories include the combustor, cyclones, FBHE, ducts, transfer lines etc. Correct selection and installation of materials is critical. Refractory selection is complicated by reciprocal physical properties. For example, good insulating materials often have poor erosion resistance. To make-up for same, refractory systems are made of several materials applied in layers.

Liner design

Three general types of liner designs are used in advanced CFBs. Erosion protection linings are provided for membrane walls and steam cooled walls where required. These use short studs to hold a thin layer (1 - 5 cm) of dense refractory to flue gas side of boiler assemblies. Conventional insulation is affixed outside. Another type of refractory lining is typically 15 cm or less in total thickness and usually has both dense and insulating layers. This type of refractory is usually supported by Y studs. Thick refractory linings usually consist of two or three layers totalling 30 - 45 cm. A dense “hot face” of abrasion resistant brick or castable protects against the erosive actions of hot, high velocity particles. Back-up layers of insulating material reduce heat loss, decrease shell temperatures and improve overall efficiency.

Material composition of refractories

Refractories consist of mineral combination - usually oxides - formed into rigid shapes with the aid of a binder. They are classified as preformed or unformed. Performed refractory materials such as brick and tile are usually fired before installation. Unformed materials are applied after erection of SG and are fired after installation to form seamless monoliths.

OPERATION EXPERIENCE OF CFB SGs

Sub-critical CFB SG

One of the largest capacity CFB SG is the 250 MW Soprolif Power Plant at Gardanne, France [commissioned in (1995)]. The CFB boiler technology supplied at Provence was developed through a joint collaboration between Alsthom Stein Industrie, Velizy - Villacoublay, France and LLB Germany. It features four cyclones, each with its own pair of external heat exchangers housing superheater and reheater elements of the steam circuit. Four independent coal feed systems two per leg - supply the fuel. Fluidisation velocity in the combustion chamber is 5.5m/s. This natural circulation SG delivers 700 t/h of 169 bar / 567^{0}C steam with reheat at 566^{0}C. Main steam temperature is controlled by water injection. Reheat steam temperature is adjusted by the solids flow through the FBHEs. Water-cooled surfaces of furnace include pant-leg system, fluidisation grids and wind boxes. Evaporation occurs in the furnace water wall tubes and in common backpass. Some superheat and reheat also occur in backpass.

Super critical CFB SG

The largest capacity super critical CFB SG is the recently commissioned 460 MW Lagisza Power Plant at Katowice, Poland [commissioned in (June 2009)]. The CFB boiler technology supplied at Lagisza was developed by Foster Wheeler USA. The CFB SG incorporates for the first time ever in any CFB SG “Benson Vertical once through technology” licensed and developed by Siemens Germany. The general arrangement of Lagisza Boiler is shown in Fig.14.

Presently, there are more than 250 CFB steam generators operating in the world. Some of the other large CFB units in operation are as listed in Table - 1 below.

Table - 1

Large CFB SG Units in the World

	Location	Unit capacity MW	Steam flow t / hr	Steam conditions (PRESS. & TEMP.) Kg/cm.sq. (a) / deg. C	Commissioning Year / fuel
1)	Robertson Texas, New Mexico Plant, U.S.A.	2 x 175	500	140; 540 / 540	1990 / Lignite
2)	St. Nicholas, U.S.A.	1 x 103	375	108; 530	1989 / Anthracite
3)	RWE Goldenberg, Germany	Cogen	400	117; 505	1992 / Lignite
4)	NISCO Cogen, West Lake, U.S.A.	2 x 110	375	114; 540 / 540	1994 / Pet. Coke
5)	Nova Scotia Power Co., Point Aconi, Canada	1 x 165	526	130; 540 / 540	1994 / Coal
6)	Vaskiluodon, Voina Oy, Finland	1 x 125	400	159; 540 / 540	1990 / Coal, Peat
7)	Colorado - Ute Electric, Nucla, U.S.A.	1 x 110	420	107; 541	1987 / Coal
8)	Soprolif Power Plant,Gardanne, France	1 x 250	700	169; 565/565	1995/ Lignite
9)	Warrior run,Mayland ,(Applied Energy Services)	1 x 210	633	130 540/540	1999/ Bituminous Coal
10)	Jacksonville Electricity Auhority (Northside Station No 2).,USA	1 x 300	904	165; 540 / 540	2001/ Coal,Petcoke
11)	Lagisza, Poland	1x 460	1300	275; 560 / 580	2009 / Coal

Location	Unit capacity MW	Steam flow t / hr	Steam conditions (PRESS. & TEMP.) Kg/cm.sq. (a) / deg. C	Commissioning Year / fuel
12) Novocherkasskaya,Russia	1 x 330	1000	248; 565 / 565	Under execution
13) Turrow Power Station,Poland	2 x 235,Unit No1 and 2	667	132; 540 / 540	1998
14) Turrow Power Station,Poland, Unit Nos.4,5,6	2 x 235,	704	170; 568 / 568	2002/03/04

In India some of the largest CFBC units in operation are as given in Table - 2 below

Table - 2

Large CFB SG Units in India

Location	Unit Capacity MW	Steam flow T / hr	Steam conditions (Press. & Temp.) Ata / deg. C	Commissioning Year / Fuel
a) Indian Aluminium Hirakud, India	60	2 x 145	91/ 515	1992 / Coal
b) Tata Chemicals Ltd., Mithapur, India	16.5 (Cogen)	200	113/ 565	1995 / Coal
c) Kanoria Chemicals & Industries Ltd., Renukoot, India	25	1 x 105	64/ 485	1996 / Coal
d) Sinarmas Pulp & Paper (I) Ltd., Pune		1 x 175	105/ 525	1998
e) Gujarat Industries Power Co. Ltd., India ,Surat Lignite Power Plant (SLPP)-Phase -I	2 x 125	2 x 390	132/ 540 / 540	1999/2000/ Lignite
f) Gujarat Industries Power Co. Ltd., India ,Surat Lignite Power Plant (SLPP)-Phase -II	2 x 125	2 x 390	132/ 540 / 540	2010/ Lignite

	Location	Unit Capacity MW	Steam flow T / hr	Steam conditions (Press. & Temp.) Ata / deg. C	Commissioning Year / Fuel
g)	Barsingsar Thermal Power Project(BTPP) of Neyveli Lignite Corporation, Barsingsar Rajasthan	2 x 125	2 x 390	132/ 540 / 540	2010 [Unit -1]/ Unit -2 [under execution] Lignite
h)	RRUVNL, Giral Thermal Power Station,Rajasthan,India	2 x 125	2 x 390	132/ 540 / 540	2009/ Lignite
i)	RRUVNL, Giral Thermal Power Station,Rajasthan,India	2 x 125	2 x 390	132/ 540 / 540	Under execution/ Lignite
j)	Neyveli Lignite Corporation, TPS –II Expansion at Neyveli,Tamilnadu	2 x250	2 x 845	170/ 540/540	Lignite/ Under advanced stage of execution
k)	Bhavnagar Energy Company Limited,	2 x250	2 x 845	170/ 540/540	Lignite/ Under execution

It can be seen from the above that CFB technology for large units of 400 t/h i.e. 120 MW units is a proven technology..

In India the largest utility CFB SG is under erection at Neyveli Lignite Corporation Limited. The details of the same are as indicated below in Table -3.

Table - 3

Details of Neyveli – 2 X250 MW TPS –II Expansion CFB SG

Sl no	Description	Details
a)	Boiler Manufacturer	BHEL, India
b)	CFBC Technology Supplier	Austrian Energy (Formerly Lurgi Lentjes Babcock Energietechnik GmbH)
c)	Boiler Parameters Flow	845 t/h
d)	Steam parameters	176 ata/540^{0}C/ 540^{0}C
e)	Feedwater Temp.	256^{0}C
f)	Flue Gas Temp.	140^{0}C (Air Pre-heater Outlet)

Sl no	Description	Details
g)	Boiler Efficiency	78.62 % (Based on GCV)
h)	Lignite Consumption	262 t/h (Guarantee)
i)	Limestone Consumption	16.0 t/h (Guarantee) 29.0 t/h (Worst Lignite)
j)	Sulphur Capture Efficiency	95 %
k)	Ca:S Molar Ratio	1.8 (Guarantee)
l)	Ultimate Analysis of Guarantee **Lignite**	
	Moisture	50.50 %
	Ash	8.50 %
	Carbon	27.50 %
	Hydrogen	2.20 %
	Sulphur	0.70 %
	Nitrogen	0.20 %
	Oxygen	10.40 %
	Gross Calorific Value for Guarantee	2650 Kcal/Kg

TCE Experience in CFBC

TCE has been providing consulting engineering services for a large number of CFBC SG units installed in the country. Details of the same are furnished in the Table-4 below

Table - 4

Details of TCE Experience in CFBC SG

	Location	Unit Capacity MW	Steam Flow t / hr	Steam Conditions (Press. & Temp.) Ata / deg. C	Commissioning Year / Fuel
a)	Gujarat Industries Power Co. Ltd., India ,Surat Lignite Power Plant (SLPP)-Phase -I	2 x 125	2 x 390	132/ 540 / 540	1999/2000/ Lignite
b)	Gujarat Industries Power Co. Ltd., India ,Surat Lignite Power Plant (SLPP)-Phase -II	2 x 125	2 x 390	132/ 540 / 540	2010/ Lignite
c)	Barsingsar Thermal Power	2 x 125	2 x 390	132/	2010 [Unit -1]/ Unit -2

	Location	Unit Capacity	Steam Flow	Steam Conditions (Press. & Temp.)	Commissioning Year / Fuel
		MW	t / hr	Ata / deg. C	
	Project(BTPP) of Neyveli Lignite Corporation, Barsingsar Rajasthan			540 / 540	[under execution] Lignite
d)	Neyveli Lignite Corporation, TPS –II Expansion at Neyveli,Tamilnadu	2 x250	2 x 845	170/ 540/540	Lignite/ Under advanced stage of execution
e)	Bhavnagar Energy Company Limited,	2 x250	2 x 845	170/ 540/540	Lignite/ Under execution

Besides the above, TCE was also associated with design and engineering related to FBC and CFBC steam generators at several industrial installations.

Acknowledgment

The authors would like to thank the Management of Tata Consulting Engineers Ltd., for their encouragement and help in preparation of this paper.

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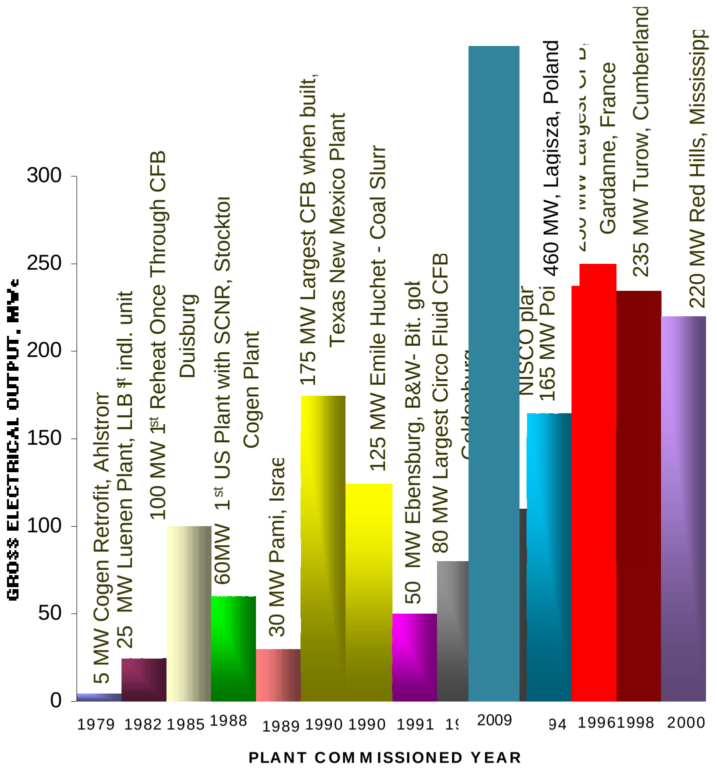

Fig -1 Milestones in CFB Technology

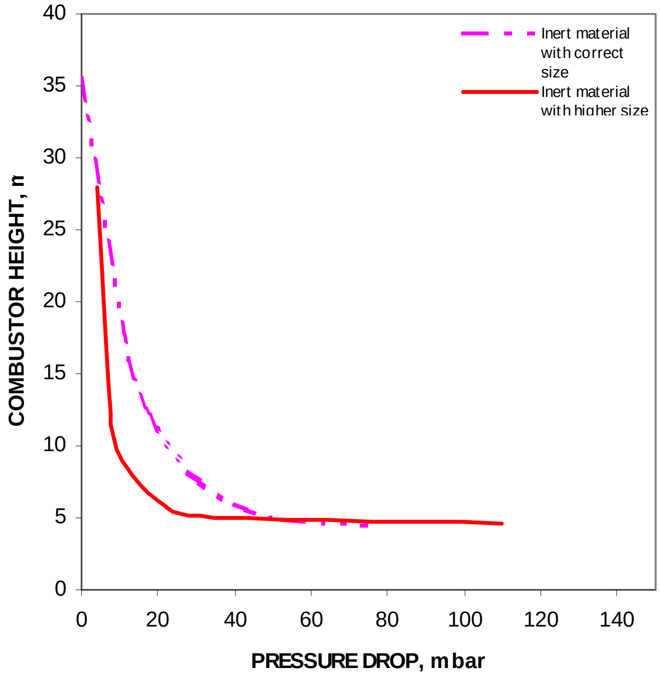

Fig -2 Pressure Gradient in Combustor

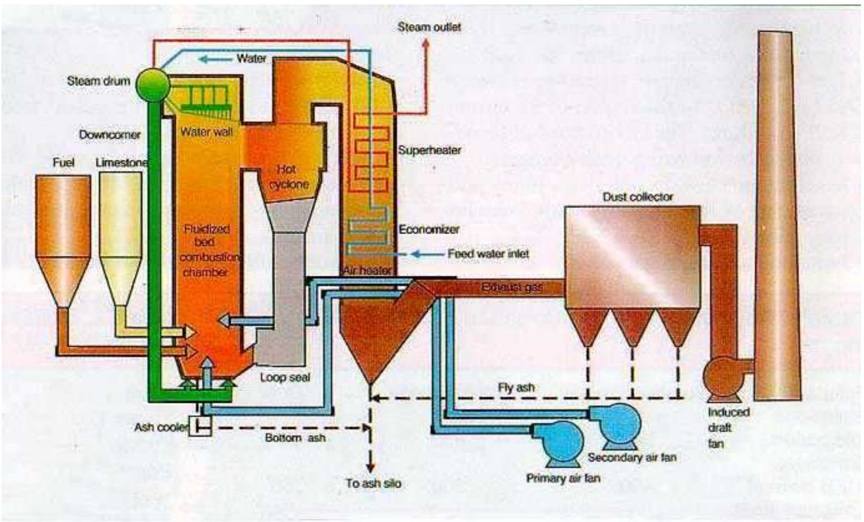

Fig -3 Typical Process Schematic

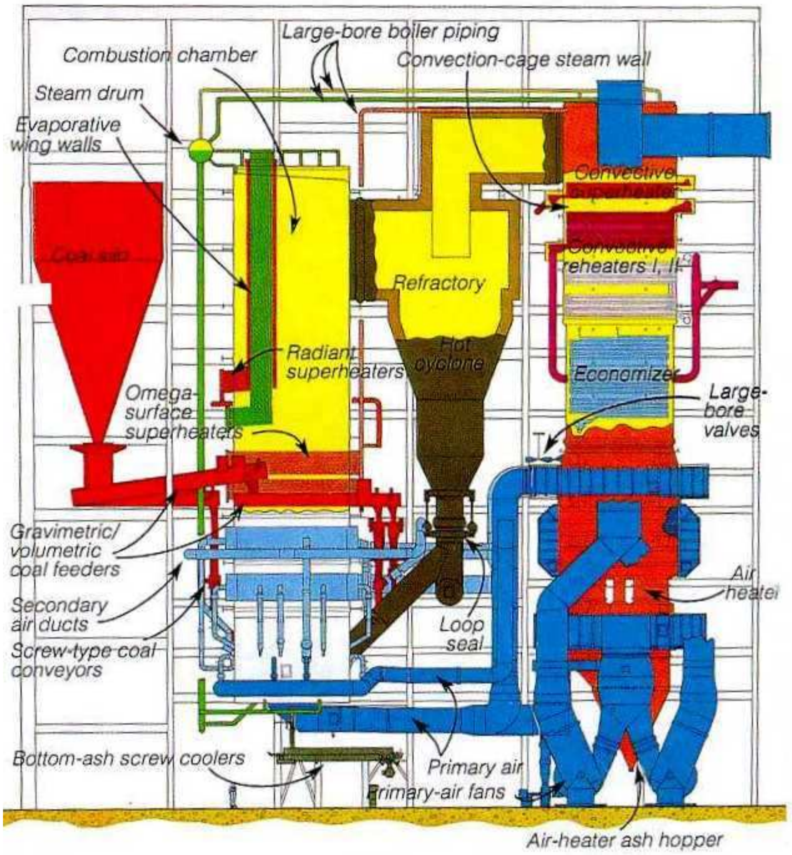

Fig. - 4 Ahlstrom Pyropower SG

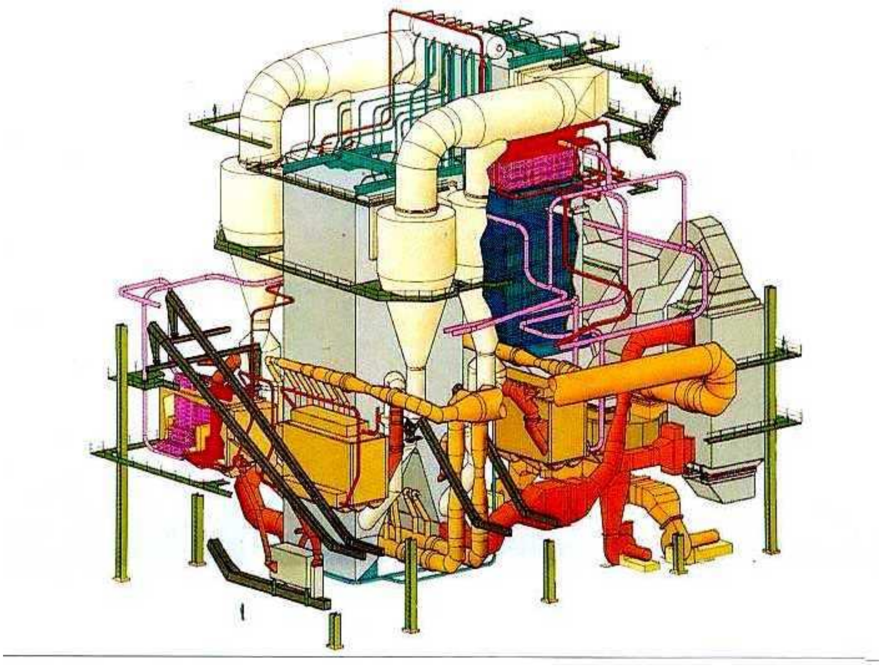

Fig -5 LLB Design SG Gardanne France

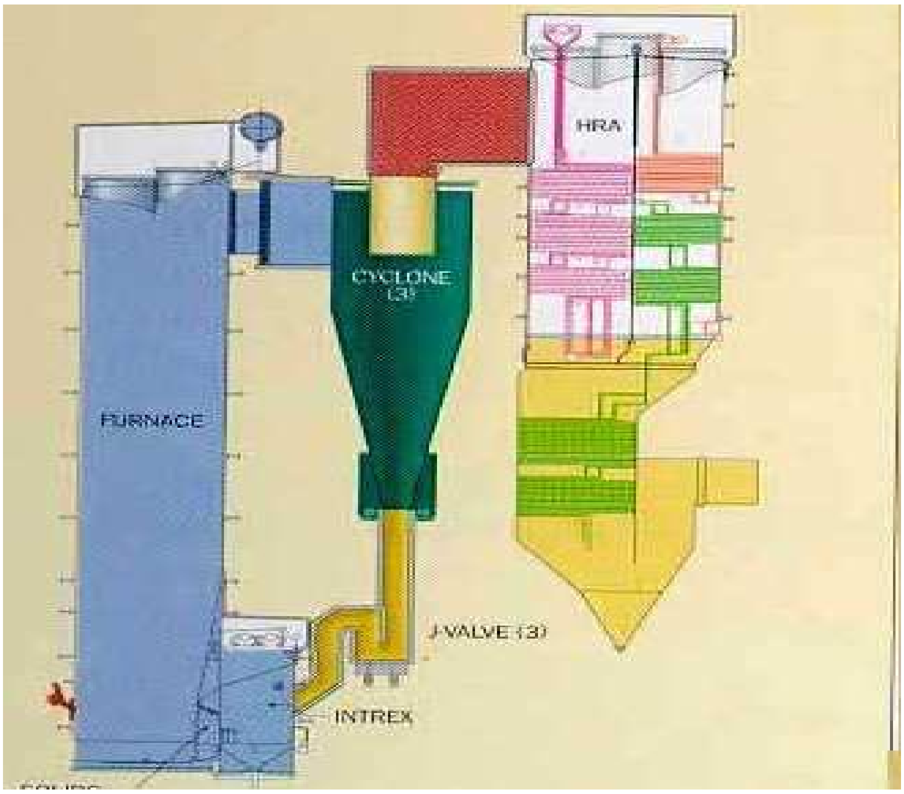

Fig. - 6 Foster Wheeler SG

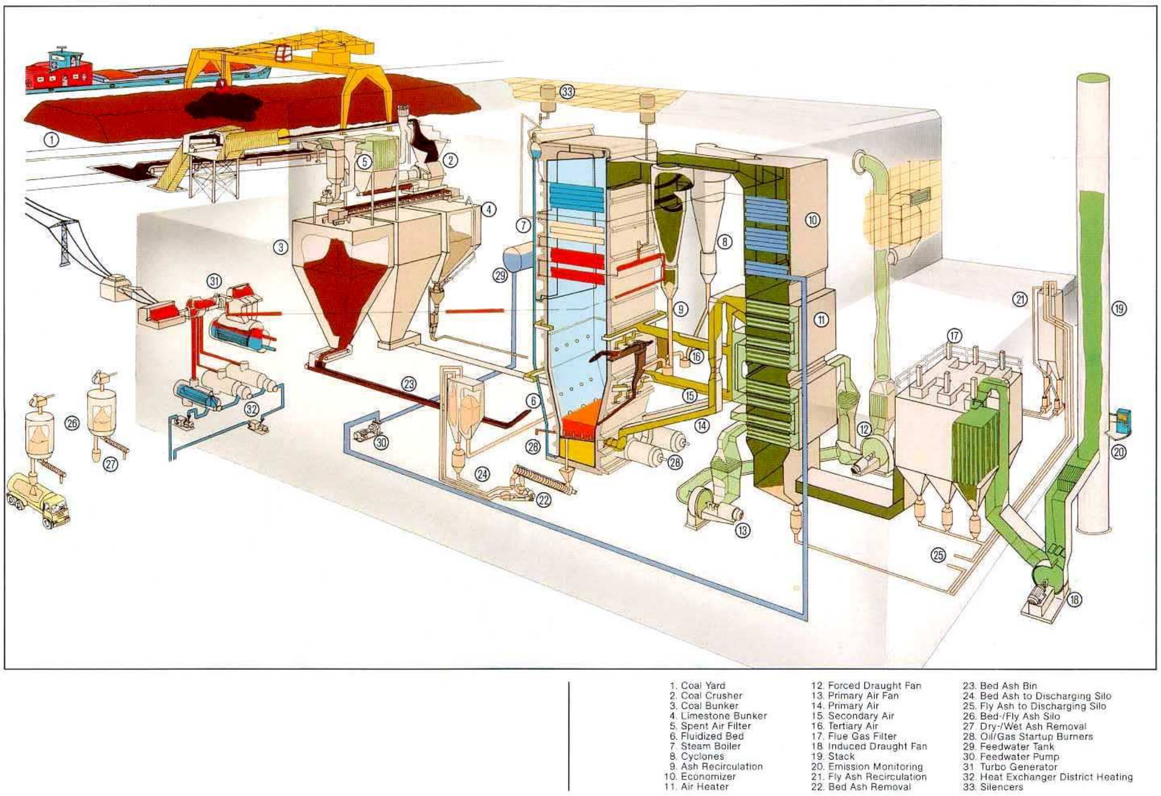

Fig. - 7 Circo Fluid SG

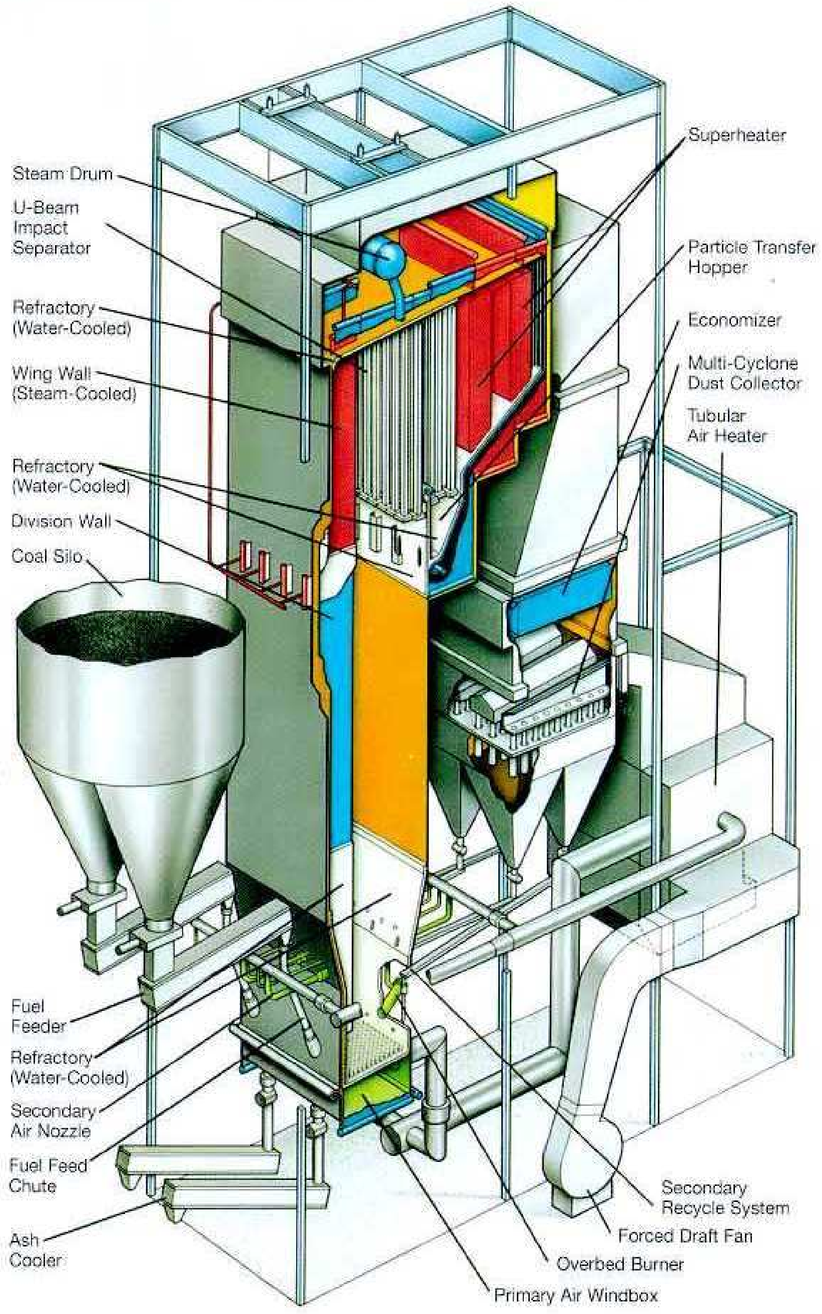

Fig. - 8 Babcock & Wilcock SG

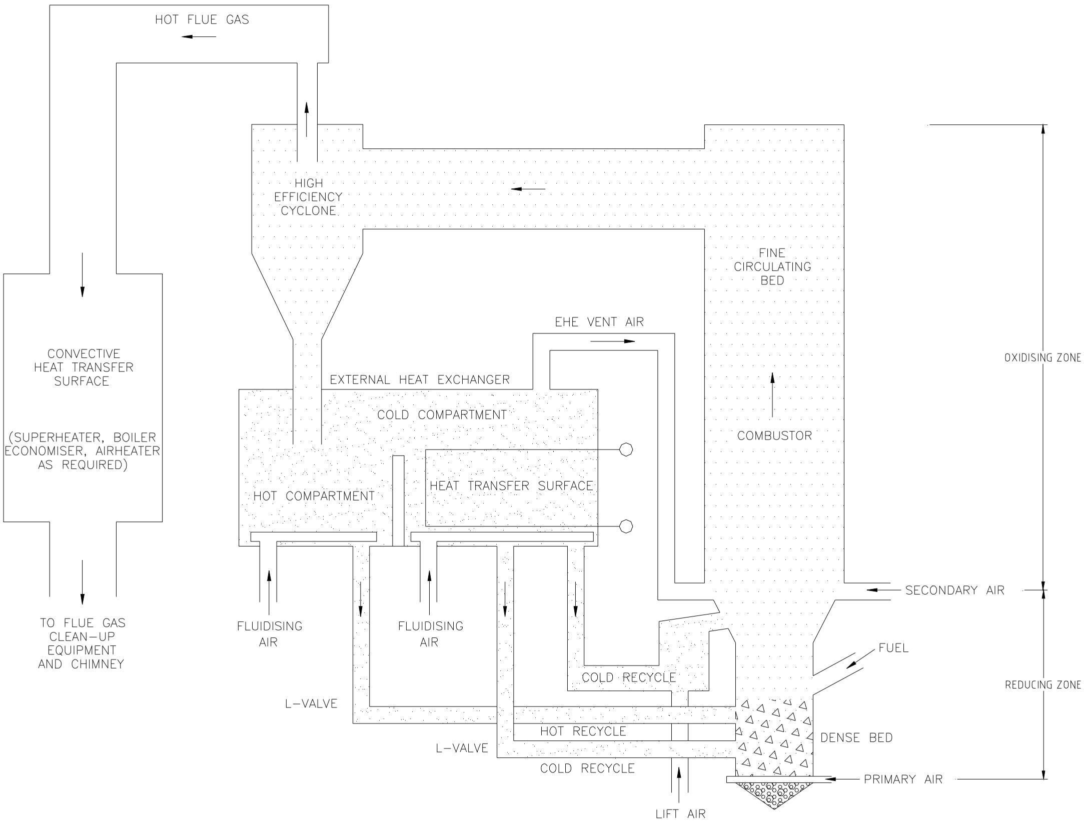

Fig. - 9 Multi Solid Fluidised Bed

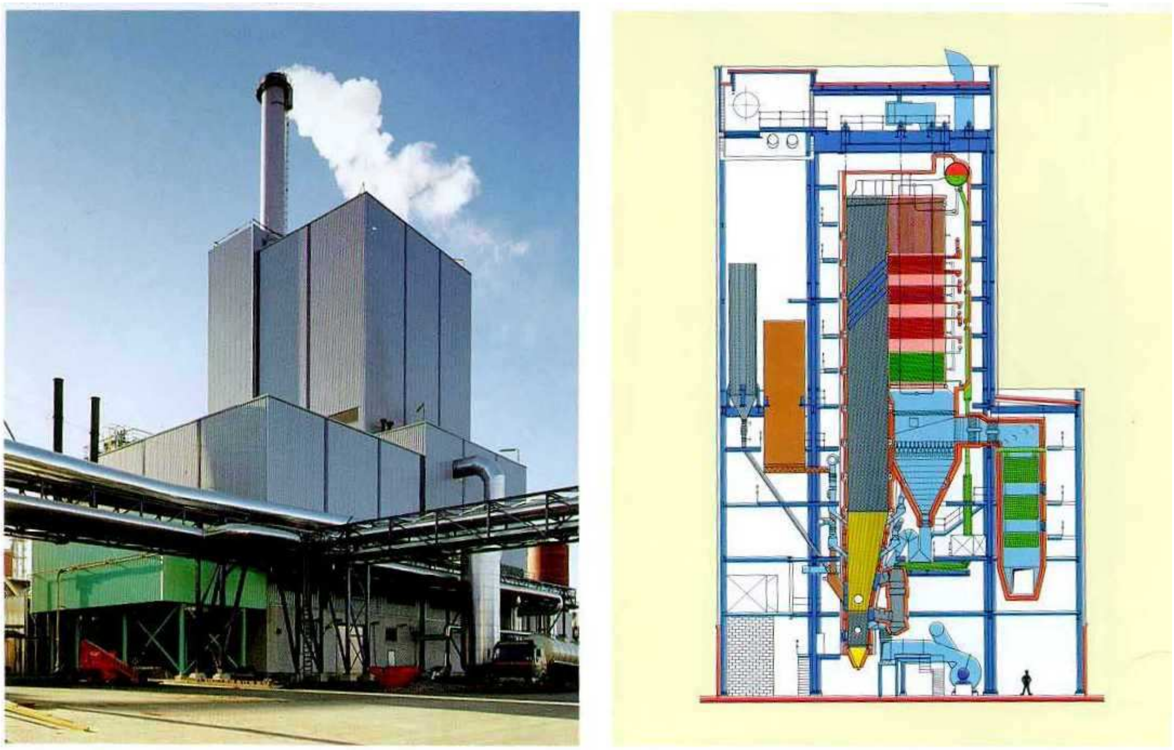

Fig. - 10 Steinmuller SG

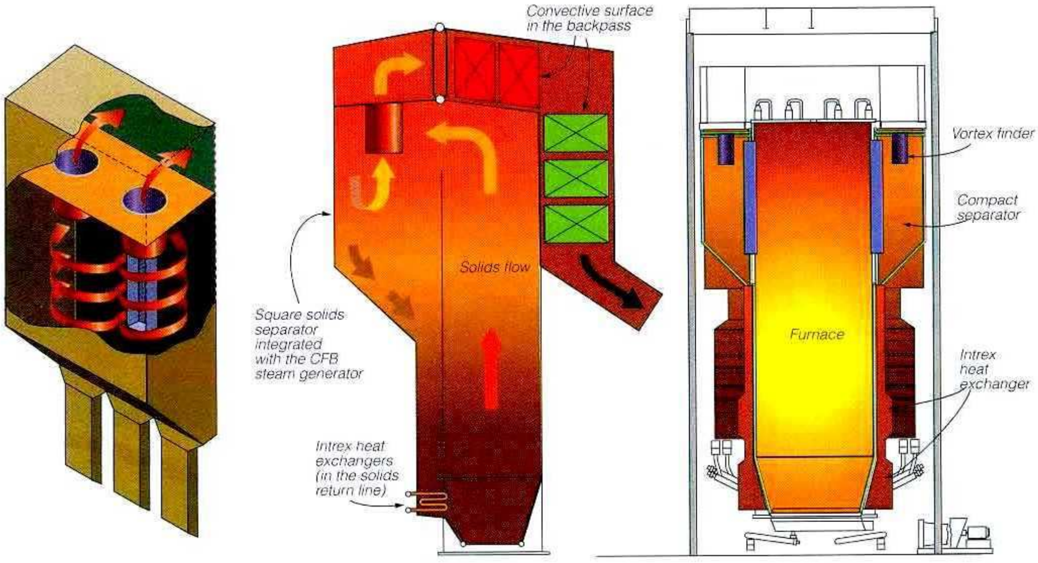

Fig. - 11 Pyrocompact SG

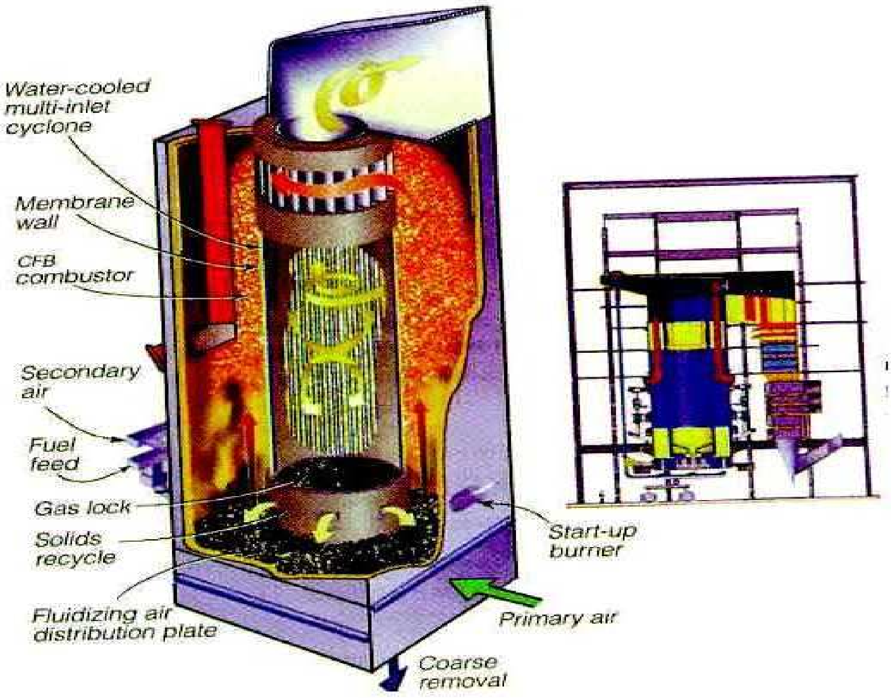

Fig. - 12 CYMIC SG

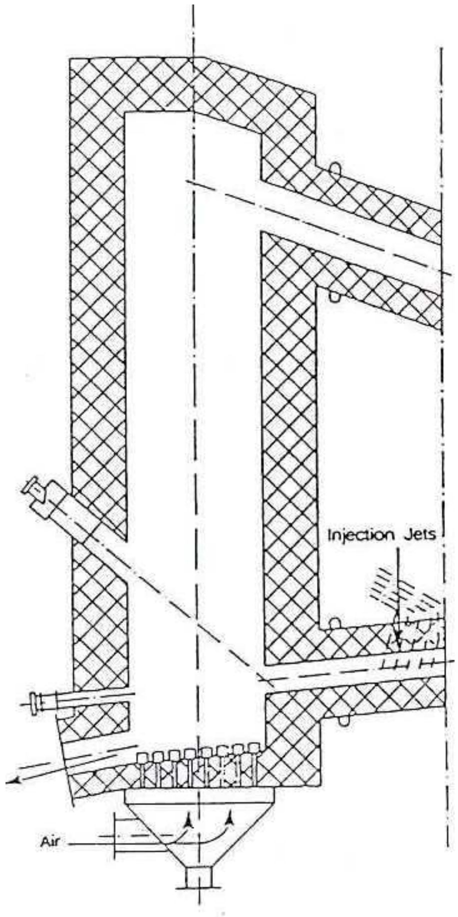

Fig. - 13 Ash Classifier

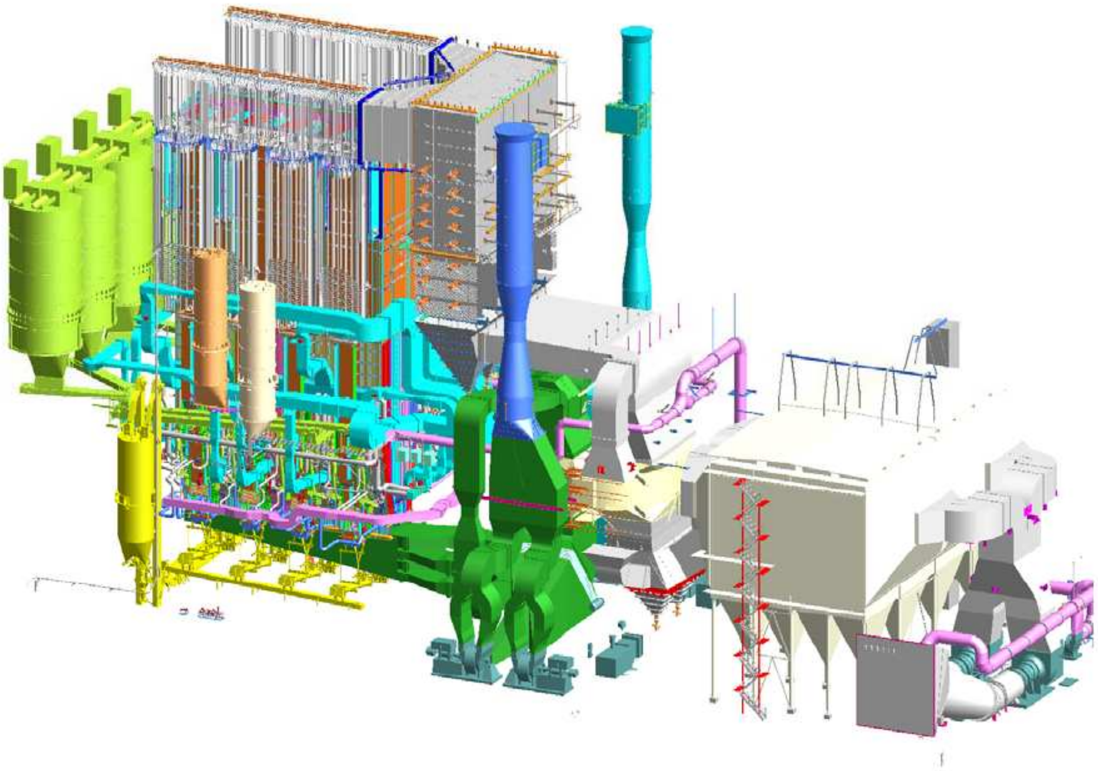

Fig - 14 Lagisza Boiler General Arrangement