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"To Improve Thermal Efficiency of 27mw Coal Fired Power Plant"

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ABSTRACT: *Booming demand for electricity, especially in the developing countries, has raised power generation technologies in the headlines. At the same time the discussion about causes of global warming has focused on emissions originating from power generation and on CO2 reduction technologies such as:*

(1) Alternative primary energy sources,
(2) Capture and storage of CO_2*,*
(3) Increasing the efficiency of converting primary energy content into electricity.

In the dissertation, the thermal efficiency of the power plant is improved when Control of furnace draft (nearer to balanced draft). Oxygen level decreases percentage of flue gases. Above this level heat losses are increases & below this carbon mono-oxide is formed. Steam power plant is using fuel to generate electrical power. The used of the fuel must be efficient so the boiler can generate for the maximum electrical power. By the time the steam cycle in the boiler, it also had heat losses through some parts and it effect on the efficiency of the boiler. This project will analyze about the parts of losses and boiler efficiency. to find excess air which effect heat losses in boiler. By using the 27 MW coal fired thermal power plant of ***Birla Corporation Limited, Satna (M.P.)*** *the data is collect by using types of Combustion & heat flow in boiler. Result of the analysis show that the efficiency of boiler depends on mass of coal burnt & type of combustion .This study is fulfilling the objective of analysis to find the boiler efficiency and heat losses in boiler for 27 MW thermal power plant of Birla Corporation Limited, Satna (M.P.)*

Keywords*: Rankine Cycle, AFBC Boiler, Ash Handling System, Coal Fired Thermal Power Plant*

I. INTRODUCTION

Thermal power plants convert heat (via mechanical energy) into electrical energy. The most important types are coal, gas and nuclear power stations. Thermal power plants are the backbone of our electricity system. Their efficiency is typically between 30 and 50%. Based on this, it is often concluded that thermal power stations are inadequate, waste energy, and need to be replaced by 'better' facilities. To evaluate this conclusion, one needs to look at the physical properties of heat energy, as well as at the fine-print in efficiency calculations, defined by man.

Rapid growth of electrical energy demand, not only in developing countries, discussions on fossil fuel reserves and the impact of thermal power generation on global warming, have increased the focus on alternative primary energy sources and the efficiency improvement techniques for the conversion of the fossil fuels into electricity. Development efforts are ongoing to reduce, capture and/or store CO2 emitted from burning fossil fuels. The following is a quote from the McKinsey report of May 2007 "Curbing the energy demand growth".

QUOTE Reducing current losses from electricity generation and distribution is another substantial opportunity. Power generation used 155 QBTUs (Quad =1015) – representing a hefty 37% of global energy use – to generate 57 QBTUs of deliverable electricity in 2003. In short, close to two-thirds of the energy put to the process is lost before it reaches the final end user.

UNQUOTE In this essay, we will look at some of the auxiliary load in fossil-fueled power stations and see what can be done to reduce this part of the losses. Thermal power stations use 3% to 10 % of their gross generation capacity for auxiliary processes. A conventional coal-fired thermal power plant uses slightly more (5 – 10%) of the electricity it produces for the auxiliary load. For a combined-cycle power plant, the auxiliary consumption can be less than 3.5 %. Auxiliary processes are required to keep the generator running; they are, for instance, conveying fuel coal to coal mills and maintaining the cooling water flowing through the condenser. Most of the auxiliary power demand, up to 80%, is used by large electric motors that are typically connected to the medium voltage switchboard, supplied through auxiliary transformers. The increasing demand for "clean coal" and CO2 emission capture and storage technologies will increase the auxiliary electricity consumption of electric power generation. Power stations, especially base-load ones, are running at full load all the time. It is easy to imagine that not much change or control is needed for the auxiliary processes in such cases. The fact is however, that very few power stations run at their maximum capacity throughout the year; instead the capacity is being adjusted all the time to match demand and various operation conditions and parameters. See Figure 1 illustrating a one year capacity utilization curve and Figure 2 for the corresponding operating hours of a 27 MW steam generator

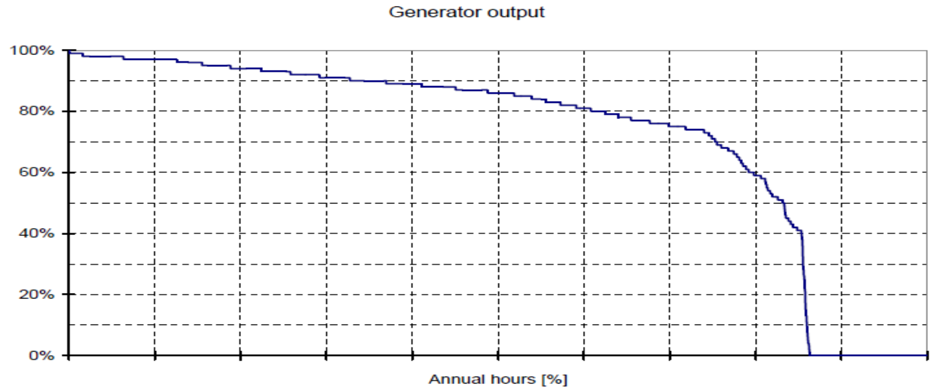


Fig 1: CAPACITY UTILIZATION CURVE OF A 27 MW STEAM GENERATOR.

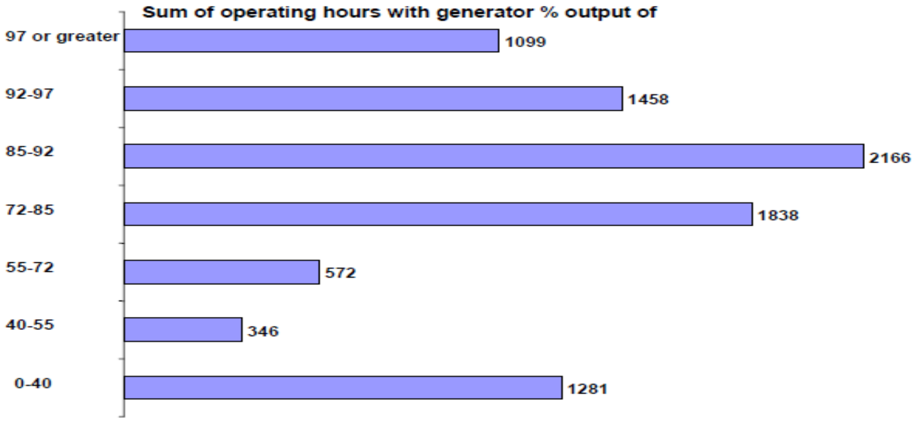


Fig 2: OPERATING HOURS AT VARIOUS LOAD RANGES OF A 27 MW STEAM GENERATOR.

1.1 EFFICIENCY:

The efficiency of a power station is indicated with the Greek character n, and is defined as follows:

$$\eta = \frac{output\ \ of\ station}{input\ \ of\ station} \text{X100}$$

This definition applies to any power plant. It seems to be straight forward, but in practice, a few problems arise with it. First, power plants themselves use electricity for their operation (lighting, pumps, etc.). Using the total amount of electricity generated yields the 'gross Efficiency', while subtracting the power plants own use gives 'net efficiency'. Comparisons are only meaningful based on net efficiency.

The energy efficiency of a conventional thermal power station, considered as salable energy as a percent of the heating value of the fuel consumed, is typically 33% to 48%. This efficiency is limited as all heat engines are governed by the laws of thermodynamics. The rest of the energy must leave the plant in the form of heat. This waste heat can go through a condenser and be disposed of with cooling water or incooling towers. If the waste heat is instead utilized for district heating, it is called co-generation. An important class of thermal power station are associated with desalination facilities; these are typically found in desert countries with large supplies of natural gas and in these plants, freshwater production and electricity are equally important coproducts. The outstanding efficiency of variable speed fans has been discussed in this paper. The fan input power varies as the cube of the speed and while satisfying the system requirements at maximum continuous rating or at lower loads, power savings are maximized as compared to any other method of flow control. Sometimes it is difficult to match all three parameters (flow, pressure and speed) at the maximum efficiency point. To select a fan at maximum efficiency, sometimes the fan needs to be selected at a speed other than synchronous speed, which becomes possible with a variable speed drive. Also, a fan has higher efficiency when inlet vanes or inlet dampers are totally eliminated. Through the energy efficiency of variable speed fan, investment in electric variable speed drives can typically prove to be the most economical choice in all cases with longer than few years operating period. This is especially the situation in cases where investment must be split over several years and the alternative is to install and operate a heavily throttled fixed speed fan dimensioned to future demand.

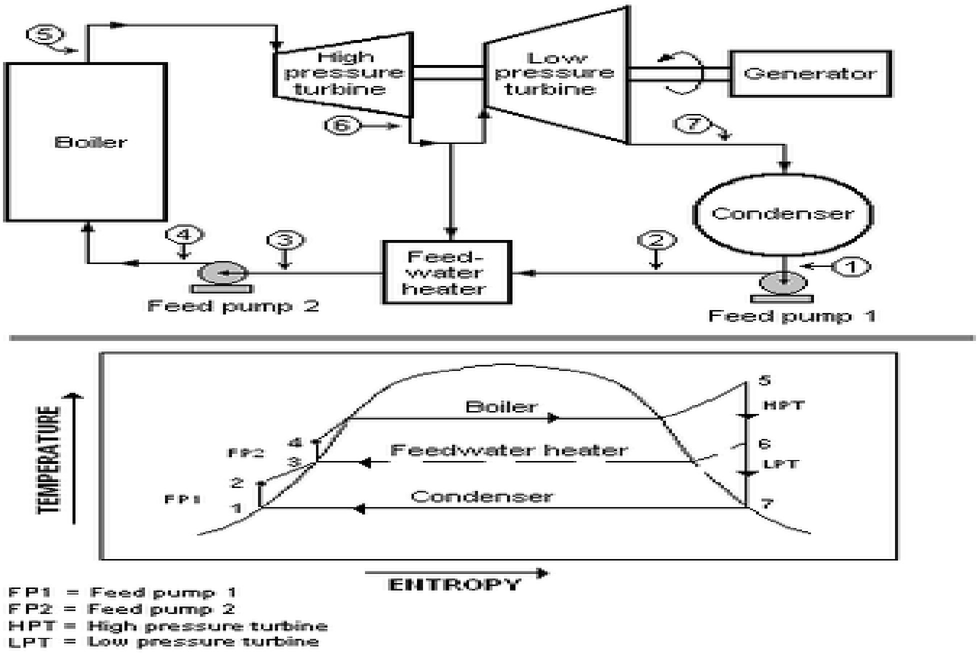


Fig 3 : A Rankine Cycle With A Two-Stage Steam Turbine And A Single Feed Water Heater.

Above the critical point for water of 374 °C and 22.06 MPa there is no phase transition from water to steam, but only a gradual decrease in density. Boiling does not occur and it is not possible to remove impurities via steam separation. In this case a super critical steam plant is required to utilize the increased thermodynamic efficiency by operating at higher temperatures. These plants, also called *once-through* plants because boiler water does not circulate multiple times, require additional water purification steps to ensure that any impurities picked up during the cycle will be removed. This purification takes the form of high pressure ion exchange units called condensate polishers between the steam condenser and the feed water heaters. Sub-critical fossil fuel power plants can achieve 36–40% efficiency. Super critical designs have efficiencies in the low to mid 40% range, with new "ultra critical" designs using pressures of 30.3 MPa and dual stage reheat reaching about 48% efficiency.

Current nuclear power plants operate below the temperatures and pressures that coal-fired plants do. This limits their thermodynamic efficiency to 30–32%. Some advanced reactor designs being studied, such as the Very high temperature reactor, Advanced gas-cooled reactor and Super critical water reactor, would operate at temperatures and pressures similar to current coal plants, producing comparable thermodynamic efficiency.

1.2 ELECTRICITY COST:

The direct cost of electric energy produced by a thermal power station is the result of

(1) Cost of fuel,
(2) Capital cost for the plant,
(3) Operator labour,
(4) Maintenance,
(5) Ash handling and disposal.

Indirect, social or environmental costs such as the economic value of environmental impacts, or environmental and health effects of the complete fuel cycle and plant decommissioning, are not usually assigned to generation costs for thermal stations in utility practice, but may form part of an environmental impact assessment.

1.3 WHY POWER PLANT EFFICIENCY IS IMPORTANT:

Increased efficiency implies :

- Same MW / Electricity from less quantity of coal
- 1%efficiency improvement implies:
- ~3%reduction in coal consumption and
- ~3% reduction CO_2/GHG & particulate emission

Generation efficiency : percentage energy content of the fuel being converted into electrical energy. Focus needed on technology options to improve generation efficiency of existing & new power stations.

- Efficiency of modern coal power plant = 34-36%
- Efficiency of old power plant = 20-30%

II. LITERATURE REVIEW

2.1 INTRODUCTION:

In this chapter, all the important information related of this project is stated. Besides that, the literature review can give a brief explanation about the steam power plant and its operation also the effect of the excess air & unburnt carbon loss. Some of the points in this chapter can give extra information which is useful while doing this project.

2.2 THE USE OF THE STEAM:

Steam is a critical recourse in today's industrial world. It is essential for cooling and heating of large buildings, driving equipment such as pump and compressors and for powering ships. However, its most importance priority remains as source of power for the production of electricity. Steam is extremely valuable because it can be produced anywhere in this world by using the heat that comes from the fuels that are available in this area. Steam also has unique properties that are very important in producing energy. Steam is basically recycled, from a steam to water and then back to steam again, all in manner that is nontoxic in nature. The steam plant of today are a combination of complex engineered system that work to produce steam in the most efficient manner that is economically feasible. Whether the end product of this steam is electricity, heat or a steam process required to develop a needed product such as paper, the goal is to have that product produced at the lowest cost possible. The heat required to produce the steam is a significant operating cost that affects the ultimate cost of the end product. (Everett,
2005)

2.3 STEAM IS EFFICIENT AND ECONOMIC TO GENERATE:

Water is plentiful and inexpensive. It is non-hazardous to health and environmentally, sound. In its gaseous form, it is a safe and efficient energy carrier. Steam can hold five or six times as much potential 'energy as an equivalent mass of water. When water is heated in a boiler, it begins to absorb energy. Depending on the pressure in the boiler, the water will evaporate at a certain temperature to form steam. The steam contains a large quantity of stored energy which will eventually be transferred to the process or the space to be heated. It can be generated at high pressures to give high steam temperatures. The higher the pressure, the higher the temperature. More heat energy is contained within high temperature steam so its potential to do work is greater.

- Modern shell boilers are compact and efficient in their design, using multiple passes and efficient burner technology to transfer a very high proportion of the energy contained in the fuel to the water, with minimum emissions.
- The boiler fuel may be chosen from a variety of options, including combustible waste, which makes the steam boiler an environmentally sound option amongst the choices available for providing heat. Centralized boiler plant can take advantage of low interruptible gas tariffs, because any suitable standby fuel can be stored for use when the gas supply is interrupted.
- Highly effective heat recovery systems can virtually eliminate blow down costs, return valuable condensate to the boiler house and add to the overall efficiency of the steam and condensate loop.

The increasing popularity of Combined Heat and Power (CHIP) systems demonstrates the high regard for steam systems in today's environment and energy conscious industries. (Everett, 2005)

2.4 ENERGY IS EASILY TRANSFERRED TO THE PROCESS:

Steam provides excellent heat transfer. When the steam reaches the plant, the condensation process efficiently transfers the heat to the product being heated. Steam can surround or be injected into the product being heated. It can fill any space at a uniform temperature and will supply heat by condensing at a constant temperature; this eliminates temperature gradients which may be found along any heat transfer surface - a problem which is so often a feature of high temperature oils or hot water heating, and may result in quality problems, such as distortion of materials being dried. Because the heat transfer properties of steam are so high, the required heat transfer area is relatively small. This enables the use of more compact plant, which is easier to install and takes up less space in the plant. A modern packaged unit for steam heated hot water rated to 1200 kW and incorporating a steam plate heat exchanger and all the controls, requires only 0.7 rn2 floor spaces. In comparison, a packaged unit incorporating a shell and tube heat exchanger would typically cover an area of two to three times that size.

2.5 THE STEAM PLANT CYCLE:

The simplest steam cycle of practical value is called the Rankine cycle, which originated around the performance of the steam engine. The steam cycle is important because it connects processes that allow heat to be converted to work on a Continuous basis. This simple cycle was based on dry saturated steam being supplied by a boiler to a power unit such as a turbine that drives an electric generator. Dry saturated steam is at the temperature that corresponds to the boiler pressure, is not superheated, and does not contain moisture. The steam from the turbine exhausts to a condenser, from which the condensed steam is pumped back into the boiler. It is also called a condensing cycle, and a simple schematic of the system is shown in Fig. 4.

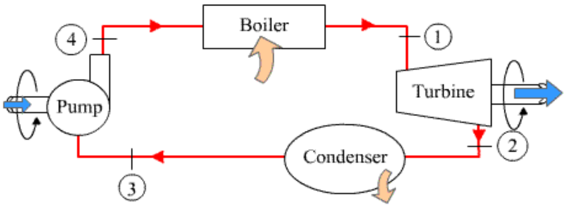
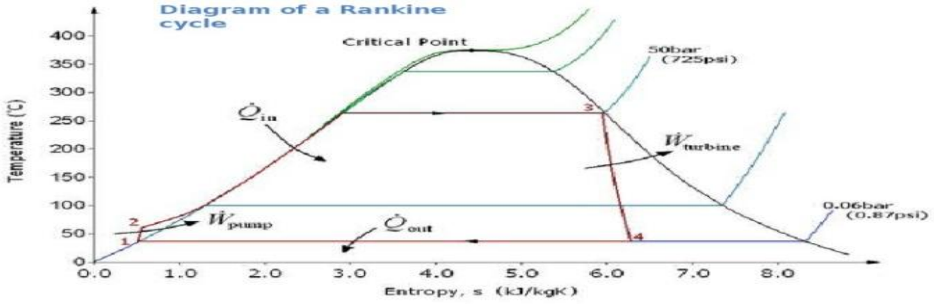


Fig 4 : Steam Plant Cycle



Rankine thermal efficiency = h3-h4h3-h1

Fig 5: Rankine Thermal Cycle

This schematic also shows heat (Qin) being supplied to the boiler and a generator connected to the turbine for the production of electricity. Heat (Qout) is removed by the condenser, and the pump supplies energy (Wp) to the feed water in the form of a pressure increase to allow it to flow through the boiler. A higher plant efficiency is obtained if the steam is initially superheated, and this means that less steam and less fuel are required for a specific output. (Superheated steam has a temperature that is above that of dry saturated steam at the same pressure and thus contains more heat content, called enthalpy, Btu/1b.) If the steam is reheated and passed through a second turbine, cycle efficiency also improves, and moisture in the steam is reduced as it passes through the turbine. This moisture reduction minimizes erosion on the turbine blades. When saturated steam is used in a turbine, the work required rotating the turbine results in the steam losing energy, and a portion of the steam condenses as the steam pressure drops. The amount of work that can be done by the turbine is limited by the amount of moisture that it can accept without excessive turbine blade erosion. This steam moisture content generally is between 10 and 15 percent. Therefore, the moisture content of the steam is a limiting factor in turbine design. With the addition of superheat, the turbine transforms this additional energy into work without forming moisture, and this energy is basically all recoverable in the turbine. A reheater often is used in a large utility. (Kenneth, 2005).

2.6 FEEDWATER:

The feed water system requires accessories to supply the correct amount of water in the proper condition to the boiler. A feed water accessory is equipment that is not directly attached to the boiler that controls the quantity, pressure, and/or tore of water supplied to the boiler. Maintaining the correct level of water in the boiler is critical for safety and efficiency. If the water level in the boiler is too high, water can be carried over into steam lines, which can lead to water hammer and line rupture. If the water level in the boiler is too low, heat from the furnace cannot be properly transferred to the water. This can cause overheating and damage to boiler tubes and heating surfaces. Significant damage from over heating can lead to a boiler explosion. Feedwater is treated and regulated automatically to meet the demand for steam. Valves are installed in feedwater lines to permit access for maintenance and repair. The feedwater system must be capable of supplying water to the boiler in all circumstances and includes feedwater accessories required for the specific boiler application, In a steam heating system.) Heat necessary for providing comfort in the building starts at the boiler. Water in the boiler is heated and turns to steam. Steam leaves the boiler through the main steam line (boiler outlet) where it enters the main steam header-. From the main steam header, main branch lines direct the steam up a riser to the heating unit (heat exchanger). Heat is released to the building space as steam travels through the heating unit, Steam in the heating unit coals and turns into condense. The condensate is separated from the steam by a steam trap that allows condensate, but not steam to pass. The condensate is directed through the condenser return line to the condensate return tank. The feed water pump pumps the condensate and/or water back to the boiler through check valves and stop valves on the feed water line. Feed water enters the boiler and is turned to steam to repeat the process. (Kenneth, 2005)

2.7 BOILER EFFICIENCY:

Boiler Efficiency may be indicated by

1. Combustion Efficiency indicates the burners ability to burn fuel measured by unburned fuel and excess air in the exhaust
2. Thermal Efficiency - indicates the heat exchangers effectiveness to transfer heat from the combustion process to the water or steam in the boiler, exclusive radiation and convection losses
3. Fuel to Fluid Efficiency - indicates the overall efficiency of the boiler inclusive thermal efficiency of the heat exchanger, radiation and convection losses - output divided by input. Boiler Efficiency is in general indicated by either Thermal Efficiency or Fuel to Fluid Efficiency depending the context. (Chattopadhyay, 2005)

2.8 BOILER LOSSES:

1. Dry flue gas loss.
2. Moisture in combustion air loss
3. Unburnt carbon loss – carbon in ash loss.
4. Unburnt gas loss, due to incomplete combustion of carbon,
5. Wet flue gas loss loss due to moisture in fuel & due to moisture formed by combustion of H_2 in fuel
6. Radiation & Unaccounted losses. (Dr. V.K. Sethi,2011)

III. MAJOR ENERGY SAVING POTENTIAL AREAS IN THERMAL POWER PLANT

Thermal power plant is designated sector as per EC act 2001. Most thermal power plant uses 30-40% of energy value of primary fuels. The remaining 60-70% is lost during generation, transmission and distribution of which major loss is in the form of heat. Thermal power consist of various sub cycles / systems like air & flue gas cycle, main steam, feed water & condensate cycle , fuel & ash cycle, Equipment cooling water (ECW), auxiliary cooling water (ACW) system, Compressed air system, Electrical auxiliary power & lighting system, HVAC system etc.. There is tremendous scope of energy saving potential in each system/cycle which is given below.

3.1 AIR & FLUE GAS CYCLE:

(i) Optimizing excess air ratio: - It reduces FD fan & ID fan loading.

(ii) Replacement of oversize FD and PA fan: - Many thermal power plants have oversize fan causing huge difference between design & operating point leads to lower efficiency. Hence fan efficiency can be improved by replacing correct size of fan. If replacement is not possible, Use of HT VFD for PA & ID fan can be the solution.

(iii) Attending the air & flue gas leakages: - Leakages in air & flue gas path increases fan loading. Use of Thermo vision monitoring can be adopted to identify leakages in flue gas path.

(iv) Air preheater performance is one crucial factor in leakage contribution. If APH leakage exceeds design value then it requires corrective action.

3.2 STEAM FEEDWATER &CONDENSATE CYCLE:

(i) BFP scoop operation in three element mode instead of DP mode: - In three element mode throttling losses across FRS valve reduces leads to reduction in BFP power.

(ii) Optimization of level set point in LP & HP heater: - Heater drip level affects TTD & DCA of heater which finally affect feed water O/L temp. Hence it requires setting of drip level set point correctly.

(iii) Charging of APRDS from CRH line instead of MS line: - APRDS charging from cold reheat (CRH) is always more beneficial than from MS line charging.

(iv) Isolation of steam line which is not in use: - It is not advisable to keep steam line unnecessary charge if steam is not utilized since there energy loss occurred due to radiation. For example deareator extraction can be charged from turbine Extraction/CRH or from APRDS. In normal running APRDS Extraction is not used so same can be kept isolated.

(v) Replacement of BFP cartridge: - BFP draws more current If Cartridge is wore out, causing short circuit of feed water Flow inside the pump. It affects pump performance. Hence cartridge replacement is necessary.

(vi) Attending passing recirculation valve of BFP: - BFP Power consumption Increases due to passing of R/C valve. It requires corrective action.

(vii) Installation of HT VFD for CEP: - CEP capacity is underutilized and also there is pressure loss occurs across Deareator level control valve. There is large scope of energy saving which can be accomplished by use of HT VFD for CEP or impeller trimming.

3.3 FUEL & ASH CYCLE:

(i) Optimized ball loading in Ball tube mill :- Excessive ball loading increases mill power. Hence ball loading is to be Optimized depending upon coal fineness report.

(ii) Use of Wash Coal or Blending with A- grade coal : - F-grade coal has high ash content. Overall performance can be improved by using Wash coal or blending of F-grade coal with A- grade coal instead of only using F- grade coal.

(iii) Avoiding idle running of conveyors & crusher in CHP

(iv) Use of Dry ash Evacuation instead of WET deashing System: - Dry deashing system consumes less power & also minimizes waste reduction.

(v) Optimize mill maintenance:- Mill corrective/preventive maintenance is to be optimized depending parameter like- running hrs, mill fineness, bottom ash unburnt particle, degree of reject pipe chocking etc.

3.4 ELECTRICAL & LIGHTING SYSTEM:

(i) Optimizing Voltage level of distribution transformer: - It is found that Operating voltage level is on higher side than required causing more losses. It is required to reduce the voltage level by tap changing.

(ii) Use of Auto star/delta/star converter for under loaded motor Lighting: - Use of electronic chock instead of conventional use copper Chock, Use of CFL, Replacement of mercury vapor lamp by metal Halide lamp. Use of timer for area lighting is the methods can be used. Lighting has tremendous potential of saving.

3.5 ECW & ACW SYSTEM:

(i) **Isolating ECW supply of standby auxiliaries: -** Many times standby coolers are kept charged from ECW side. Also Standby equipment’s auxiliaries like Lube oil system kept running for reliability. We can isolate Standby cooler from ECW system & switching of standby auxiliaries, doing trade off between return & reliability.

(ii) **Improving condenser performance by condenser tube cleaning & use of highly efficient debris filter:** Tube cleaning by bullet shot method increases condenser performance, condenser tube cleaning is necessary which is to be carried out in overhaul. Also highly advanced debris filter contribute condenser performance.

(iii) **Application of special coating on CW pump impeller: -** It improves pump impeller profile condition, increasing pump performance.

3.6 COMPRESSED AIR SYSTEM:-

(i) **Optimizing discharge air pressure by tuning loading/unloading cycle: -** It helpful to reduce sp. Power consumption.

(ii) **Use of heat of compression air dryer instead of electrically heated air dryer: -** Heat of compression air dryer use heat generated in compression cycle, thus reduces sp. Power consumption.

(iii) **Use of screw compressor instead reciprocating compressor: -** Sp. Power consumption of screw compressor is less than reciprocating air compressor leads to reduce aux. power consumption.

3.7 HVAC SYSTEM:

(i) Cooling tower performance improvement

(ii) Installing absorption refrigeration system instead of vapor compression system Use of wind turbo ventilators instead of conventional motor driven exhauster

IV. OBJECTIVES OF THE STUDY

- To increase the thermal efficiency of 27 MW coal fired power plant.
- To identify and bring forth the operation and working of a typical thermal power plant with special reference to Birla **Corporation Limited, Satna (M.P.).**
- To explore the various avenues and areas, where the waste related to energy consumption can be minimized.
- To identify and study the key factors for improving the energy efficiency of a thermal power.

- To study the various environmental issues in relation to the working efficiency of the thermal power plants.

V. DESCRIPTION OF COAL FIRED POWER PLANT

(1) Pulverized coal
(2) Fluidized Bed Combustion
(3) Atmospheric Fluidized Bed Combustion Boiler
(4) Ash Handling System
(5) Super heater
(6) Economizer

5.1 PULVERIZED COAL:

A pulverized coal-fired boiler is an industrial or utility boiler that generates thermal energy by burning pulverized coal (also known as powdered coal or coal dust since it is as fine as face powder in cosmetic makeup) that is blown into the firebox.

The basic idea of a firing system using pulverized fuel is to use the whole volume of the furnace for the combustion of solid fuels. Coal is ground to the size of a fine grain, mixed with air and burned in the flue gas flow. Biomass and other materials can also be added to the mixture. Coal contains mineral matter which is converted to ash during combustion. The ash is removed as bottom ash and fly ash. The bottom ash is removed at the furnace bottom. This type of boiler dominates the electric power industry, providing steam to drive large turbines. Pulverized coal provides the thermal energy which produces about 50% of the world's electric supply.

Pulverized coal power plants account for about 97% of the world's coal-fired capacity. The conventional types of this technology have an efficiency of around 35%. For a higher efficiency of the technology supercritical and ultra-supercritical coal-fired technologies have been developed. These technologies can combust pulverized coal and produce steam at higher temperatures and under a higher pressure, so that an efficiency level of 45% can be reached (ultra-supercritical plants). Supercritical power plants have become the system of choice in most industrialized countries, while ultra-supercritical plant technology is still in the process of demonstration. Supercritical and ultra-supercritical plants are more expensive (because of the higher requirements to the steel needed to stand the higher pressure and temperature) but the higher efficiency results in cost savings during the technical lifetime of the plants.

In a pulverized coal-fired boiler of a large power plant, an oxygen analyzer is essential for combustion ontrol. A pulverized coal-fired boiler is an industrial or utility boiler that generates thermal energy by burning pulverized coal (also known as powdered coal or coal dust). This type of boiler dominates the electric power industry, providing steam to drive large turbines. Pulverized coal provides the thermal energy which roduces about 50% of the world's electric supply. Exhaust gases from the pulverized coal boiler contain a large quantity of dust and flow very fast. Oxygen analyzers that employ a sampling method may be subject to wear or clogging, resulting in increased maintenance workload and cost. A solution to this problem is the ZR22/ZR402 Direct In-Situ Zirconia Oxygen Analyzer that has no sampling system and utilizes a long-life sensor. A probe protector is attached to protection it against wear.

5.1.1: PROCESS: Coal is inexpensive and readily available. coal produces a large quantity of ashes when it is burned; necessitating pulverized coal-fired boilers to be equipped with an ash removal system such as a cyclone. Exhaust gases from these boilers contain a large quantity of dust (10 to 30 g/Nm3) and flow very fast as the result of the large volume of air being blown into the boiler. For oxygen measurement in large ducts, a probe with a long insertion length is used.

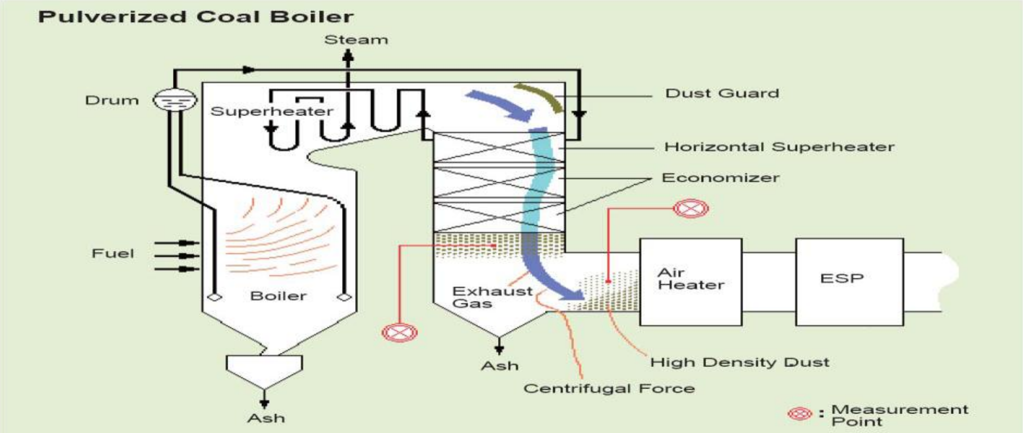


Fig 7: Pulverized Coal Boiler

5.1.2: COMBUSTION EFFICIENCY

Operating your boiler with an optimum amount of excess air will minimize heat loss up the stack and improve combustion efficiency. Combustion efficiency is a measure of how effectively the heat content of a fuel is transferred into usable heat. The stack temperature and flue gas oxygen (or carbon dioxide) concentrations are primary indicators of combustion efficiency.

Given complete mixing, a precise or stoichiometric amount of air is required to completely react with a given quantity of fuel. In practice, combustion conditions are never ideal, and additional or "excess" air must be supplied to completely burn the fuel.

The correct amount of excess air is determined from analyzing flue gas oxygen or carbon dioxide concentrations. Inadequate excess air results in unburned combustibles (fuel, soot, smoke, and carbon monoxide), while too much results in heat lost due to the increased flue gas flow—thus lowering the overall boiler fuel-to-steam efficiency. The table relates stack readings to boiler performance

5.1.3: FLUE GAS ANALYZER:

The percentage of oxygen in the flue gas can be measured by inexpensive gas-absorbing test kits. More expensive (ranging in cost from $500 to $1,000) hand-held, computer-based analyzers display percent oxygen, stack gas temperature, and boiler efficiency. They are a recommended investment for any boiler system with annual fuel costs exceeding $50,000.

5.1.4: OXYGEN TRIM SYSTEM:

When fuel composition is highly variable (such as refinery gas, hog fuel, or multi-fuel boilers), or where steam flows are highly variable, an online oxygen analyzer should be considered. The oxygen "trim" system provides feedback to the burner controls to automatically minimize excess combustion air and optimize the air-to-fuel ratio.

To ensure complete combustion of the fuel used, combustion chambers are supplied with excess air. Excess air increase the amount of oxygen and the probability of combustion of all fuel.

- when fuel and oxygen in the air are in perfectly balance - the combustion is said to be **stoichiometric**

The combustion efficiency will increase with increased excess air, until the heat loss in the excess air is larger than the heat provided by more efficient combustion.

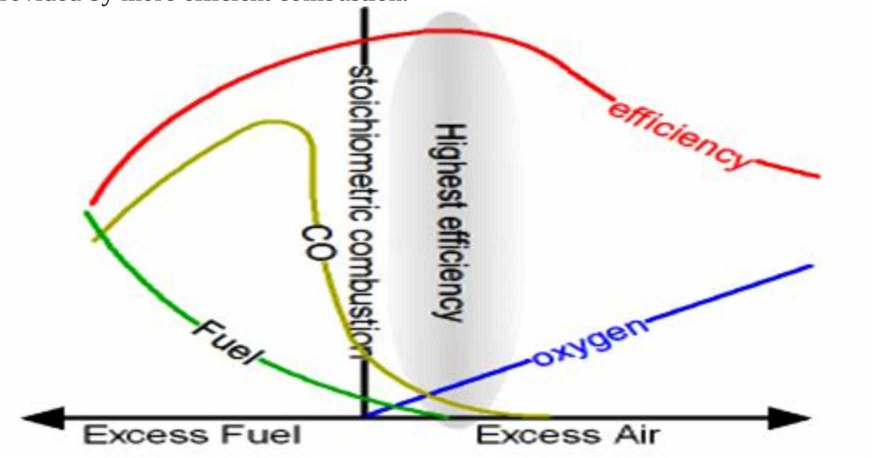


Fig 8 : COBUSTION EFFICIENCY

Typical excess air to achieve highest efficiency for different fuels are *15 - 60%* for coal

Carbon dioxide - CO_2 - is a product of the combustion and the content in the flue gas is an important indication of the combustion efficiency.

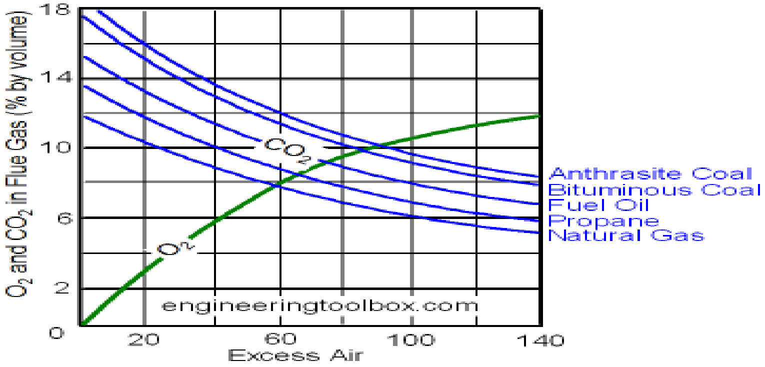


Fig 9: EXCESS AIR VS O2&CO2 IN FLUE GAS (% BY VOLUME)

An optimal content of carbon dioxide - CO_2 - after combustion is approximately *10%* for natural gas and approximately *13%* for lighter oils.

5.2 FLUIDIZED BED COMBUSTION:

The major portion of the coal available in India is of low quality, high ash content and low calorific value. The traditional grate fuel firing systems have got limitations and are techno-economically unviable to meet the challenges of future. Fluidized bed combustion has emerged as a viable alternative and has significant advantages over conventional firing system and offers multiple benefits – compact boiler design, fuel flexibility, higher combustion efficiency and reduced emission of noxious pollutants such as SOx and NOx. The fuels burnt in these boilers include coal, washery rejects, rice husk, bagasse & other agricultural wastes. The fluidized bed boilers have a wide capacity range- 0.5 T/hr to over 100 T/hr.

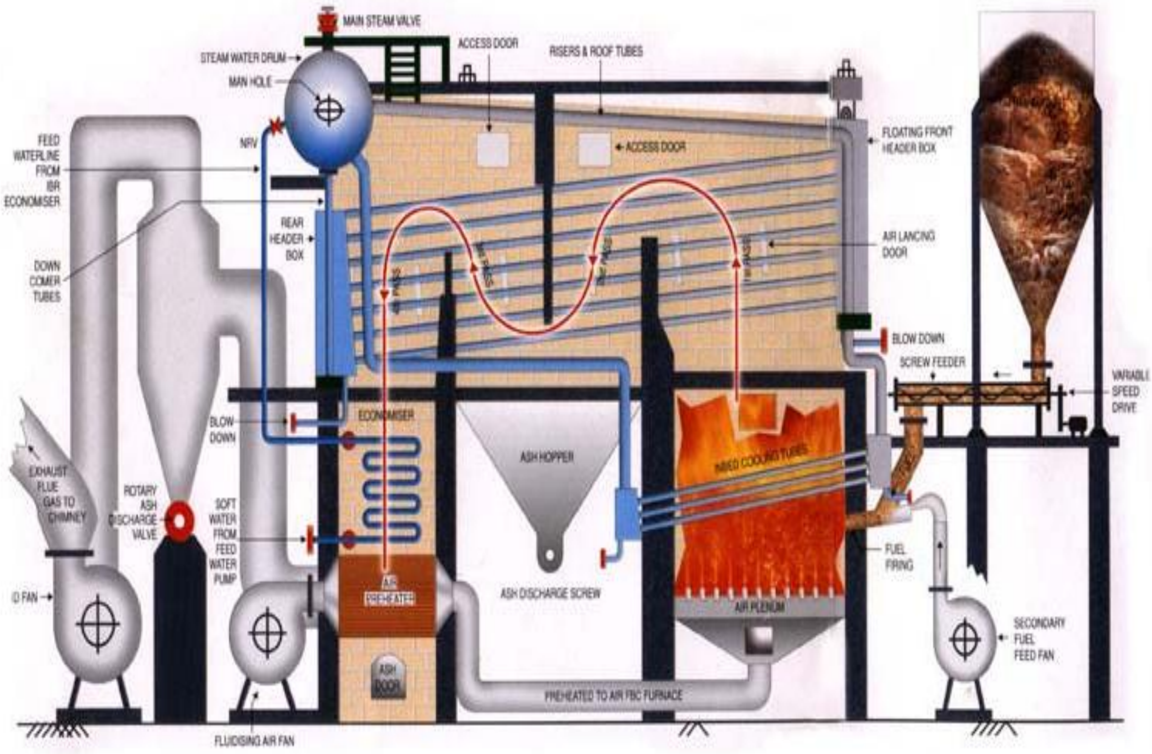


FIG 10 : MECHANISM OF FLUIDISED BED COMBUSTION

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream – the bed is called "fluidized". With further increase in air velocity, there is bubble formation, vigorous turbulence, rapid mixing and formation of dense defined bed surface. The bed of solid particles exhibits the properties of a boiling liquid and assumes the appearance of a fluid – "bubbling fluidized bed".

At higher velocities, bubbles disappear, and particles are blown out of the bed. Therefore, some amounts of particles have to be recirculated to maintain a stable system – "circulating fluidized bed". This principle of fluidization is illustrated in Figure1.

Fluidization depends largely on the particle size and the air velocity. The mean solids velocity increases at a slower rate than does the gas velocity, as illustrated in Figure 6.2. The difference between the mean solid velocity and mean gas velocity is called as slip velocity. Maximum slip velocity between the solids and the gas is desirable for good heat transfer and intimate contact. If sand particles in a fluidized state is heated to the ignition temperatures of coal, and coal is injected continuously into the bed, the coal will burn rapidly and bed attains a uniform temperature. The fluidized bed combustion (FBC) takes place at about 840^{O}C to 950^{O}C. Since this temperature is much below the ash fusion temperature, melting of ash and associated problems are avoided.

The lower combustion temperature is achieved because of high coefficient of heat transfer due to rapid mixing in the fluidized bed and effective extraction of heat from the bed through in-bed heat transfer tubes and walls of the bed. The gas velocity is maintained between minimum fluidization velocity and particle entrainment velocity. This ensures stable operation of the bed and avoids particle entrainment in the gas stream.

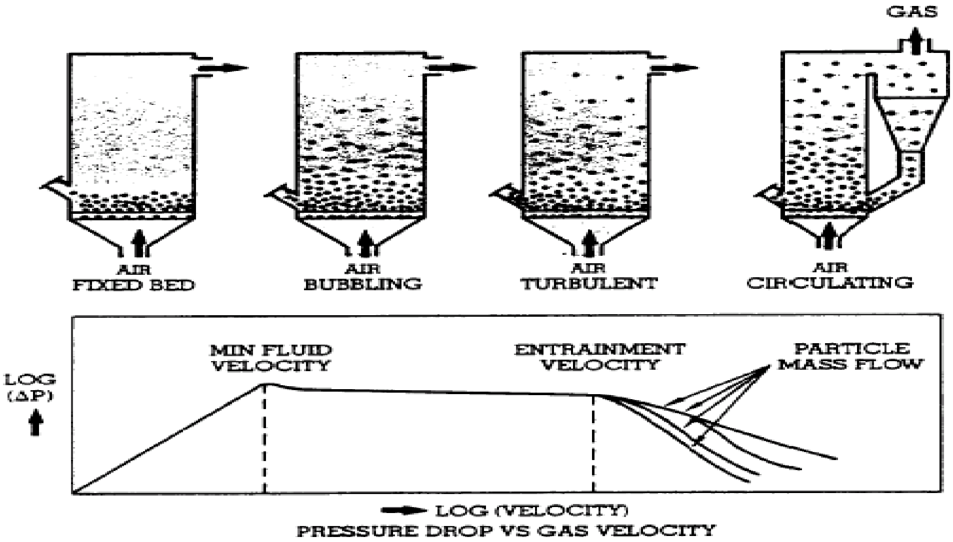


Fig 11: Relation Between Gas Velocity And Solid Velocity

Combustion process requires the three “T”s that is Time, Temperature and Turbulence. In FBC, turbulence is promoted by fluidisation. Improved mixing generates evenly distributed heat at lower temperature. Residence time is many times greater than conventional grate firing. Thus an FBC system releases heat more efficiently at lower temperatures.

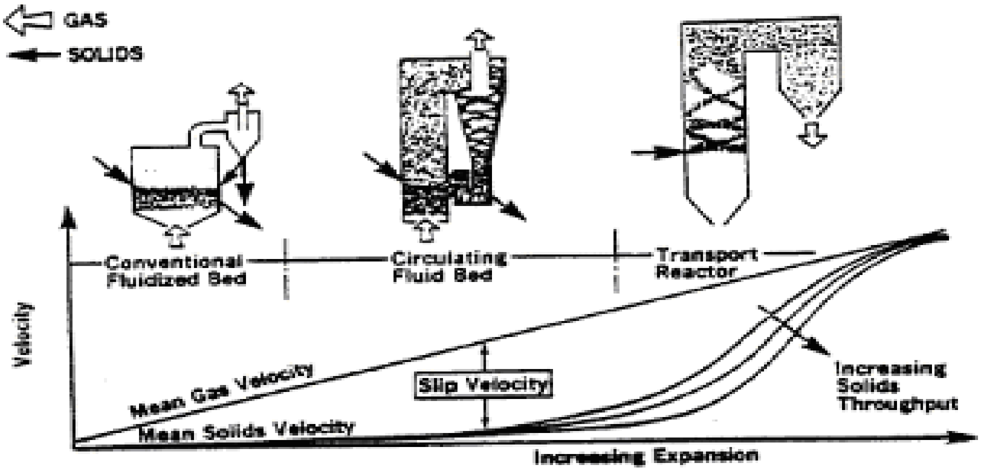


Fig 12: Velocity Vs Increasing Expansion

Firing. Thus an FBC system releases heat more efficiently at lower temperatures.
Since limestone is used as particle bed, control of sulfur dioxide and nitrogen oxide emissions in the combustion chamber is achieved without any additional control equipment. This is one of the major advantages over conventional boilers.

5.3 ATMOSPHERIC FLUIDIZED BED COMBUSTION:

In AFBC, coal is crushed to a size of 1 – 10 mm depending on the rank of coal, type of fuel feed and fed into the combustion chamber. The atmospheric air, which acts as both the fluidization air and combustion air, is delivered at a pressure and flows through the bed after being preheated by the exhaust flue gases. The velocity of fluidising air is in the range of 1.2 to 3.7 m /sec. The rate at which air is blown through the bed determines the amount of fuel that can be reacted. Almost all AFBC/ bubbling bed boilers use in-bed evaporator tubes in the bed of limestone, sand and fuel for extracting the heat from the bed to maintain the bed temperature. The bed depth is usually 0.9 m to 1.5 m deep and the pressure drop averages about 1 inch of water per inch of bed depth. Very little material leaves the bubbling bed – only about 2 to 4 kg of solids are recycled per ton of fuel burned. Typical fluidized bed combustors of this type are shown in Figures 9.1 and 9.2

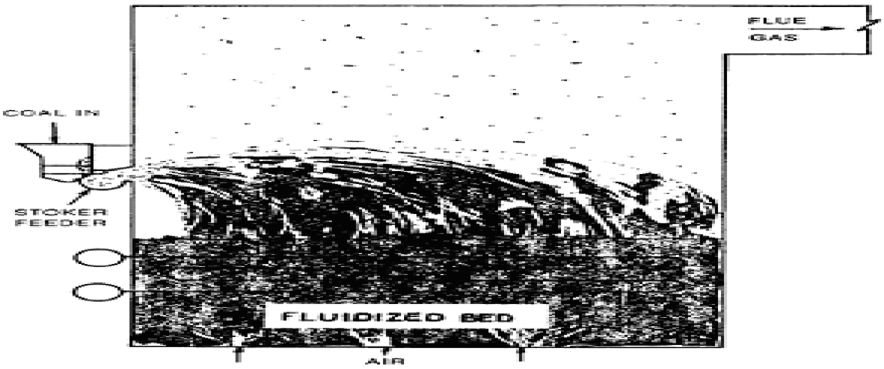


Fig 13: Bubbling Bed Boiler

The combustion gases pass over the super heater sections of the boiler, flow past the economizer, the dust collectors and the air preheaters before being exhausted to atmosphere.

The main special feature of atmospheric fluidized bed combustion is the constraint imposed by the relatively narrow temperature range within which the bed must be operated. With coal, there is risk of clinker formation in the bed if the temperature exceeds 950°C and loss of combustion efficiency if the temperature falls below 800°C. For efficient sulphur retention, the temperature should be in the range of 800°C to 850°C.

5.3.1 GENERAL ARRANGEMENTS OF AFBC BOILER

AFBC boilers comprise of following systems:

i) Fuel feeding system
ii) Air Distributor
iii) Bed & In-bed heat transfer surface
iv) Ash handling system

5.3.2 MANY OF THESE ARE COMMON TO ALL TYPES OF FBC BOILERS :

1. FUEL FEEDING SYSTEM

For feeding fuel, sorbents like limestone or dolomite, usually two methods are followed: under bed pneumatic feeding over-bed feeding.

5.2.4.1 UNDER BED PNEUMATIC FEEDING :

If the fuel is coal, it is crushed to 1-6 mm size and pneumatically transported from feed hopper to the combustor through a feed pipe piercing the distributor. Based on the capacity of the boiler, the number of feed points is increased, as it is necessary to distribute the fuel into the bed uniformly.

5.4.4.2 OVER-BED FEEDING :

The crushed coal, 6-10 mm size is conveyed from coal bunker to a spreader by a screw conveyor. The spreader distributes the coal over the surface of the bed uniformly. This type of fuel feeding system accepts over size fuel also and eliminates transport lines, when compared to under-bed feeding system.

5.4.3 AIR DISTRIBUTOR :

The purpose of the distributor is to introduce the fluidizing air evenly through the bed cross section thereby keeping the solid particles in constant motion, and preventing the formation of defluidization zones within the bed. The distributor, which forms the furnace floor, is normally constructed from metal plate with a number of perforations in a definite geometric pattern. The perforations may be located in simple nozzles or nozzles with bubble caps, which serve to prevent solid particles from flowing back into the space below the distributor.

The distributor plate is protected from high temperature of the furnace by:

i) Refractory Lining
ii) A Static Layer of the Bed Material or
iii) Water Cooled Tubes.

5.3.3 BED & IN-BED HEAT TRANSFER SURFACE:

5.3.3.1 *BED*

The bed material can be sand, ash, crushed refractory or limestone, with an average size of about 1 mm. Depending on the bed height these are of two types: shallow bed and deep bed.

At the same fluidizing velocity, the two ends fluidise differently, thus affecting the heat transfer to an immersed heat transfer surfaces. A shallow bed offers a lower bed resistance and hence a lower pressure drop and lower fan power consumption. In the case of deep bed, the pressure drop is more and this increases the effective gas velocity and also the fan power.

5.3.3.2 *IN-BED HEAT TRANSFER SURFACE :*

In a fluidized in-bed heat transfer process, it is necessary to transfer heat between the bed material and an immersed surface, which could be that of a tube bundle, or a coil. The heat exchanger orientation can be horizontal, vertical or inclined. From a pressure drop point of view, a horizontal bundle in a shallow bed is more attractive than a vertical bundle in a deep bed. Also, the heat transfer in the bed depends on number of parameters like (i) bed pressure (ii) bed temperature (iii) superficial gas velocity (iv) particle size (v) Heat exchanger design and (vi) gas distributor plate design.

5.3.4ADVANTAGES OF FLUIDIZED BED COMBUSTION BOILERS

1. HIGH EFFICIENCY

FBC boilers can burn fuel with a combustion efficiency of over 95% irrespective of ash content. FBC boilers can operate with overall efficiency of 84% (plus or minus 2%).

2. REDUCTION IN BOILER SIZE

High heat transfer rate over a small heat transfer area immersed in the bed result in overall size reduction of the boiler.

3. FUEL FLEXIBILITY

FBC boilers can be operated efficiently with a variety of fuels. Even fuels like flotation slimes, washer rejects, agro waste can be burnt efficiently. These can be fed either independently or in combination with coal into the same furnace.

4. ABILITY TO BURN LOW GRADE FUEL

FBC boilers would give the rated output even with inferior quality fuel. The boilers can fire coals with ash content as high as 62% and having calorific value as low as 2,500 kcal/kg. Even carbon content of only 1% by weight can sustain the fluidised bed combustion.

5. ABILITY TO BURN FINES

Coal containing fines below 6 mm can be burnt efficiently in FBC boiler, which is very difficult to achieve in conventional firing system.

6. POLLUTION CONTROL

SO_2 formation can be greatly minimised by addition of limestone or dolomite for high sulphur coals. 3% limestone is required for every 1% sulphur in the coal feed. Low combustion temperature eliminates NO_x formation.

7. LOW CORROSION AND EROSION

The corrosion and erosion effects are less due to lower combustion temperature, softness of ash and low particle velocity (of the order of 1 m/sec).

8. EASIER ASH REMOVAL – NO CLINKER FORMATION

Since the temperature of the furnace is in the range of 750 – 900 ^{o}C in FBC boilers, even coal of low ash fusion temperature can be burnt without clinker formation. Ash removal is easier as the ash flows like liquid from the combustion chamber. Hence less manpower is required for ash handling.

9. LESS EXCESS AIR – HIGHER CO_2 IN FLUE GAS

The CO_2 in the flue gases will be of the order of 14 – 15% at full load. Hence, the FBC boiler can operate at low excess air - only 20 – 25%.

10. SIMPLE OPERATION, QUICK START-UP

High turbulence of the bed facilitates quick start up and shut down. Full automation of start up and operation using reliable equipment is possible.

11. FAST RESPONSE TO LOAD FLUCTUATIONS

Inherent high thermal storage characteristics can easily absorb fluctuation in fuel feed rates. Response to changing load is comparable to that of oil fired boilers.

12. NO SLAGGING IN THE FURNACE-NO SOOT BLOWING

In FBC boilers, volatilisation of alkali components in ash does not take place and the ash is non sticky. This means that there is no slagging or soot blowing.

13 PROVISIONS OF AUTOMATIC COAL AND ASH HANDLING SYSTEM

Automatic systems for coal and ash handling can be incorporated, making the plant easy to operate comparable to oil or gas fired installation.

14 PROVISION OF AUTOMATIC IGNITION SYSTEM

Control systems using micro-processors and automatic ignition equipment give excellent control with minimum manual supervision.

15 HIGH RELIABILITY

The absence of moving parts in the combustion zone results in a high degree of reliability and low maintenance costs.

16 REDUCED MAINTENANCE

Routine overhauls are infrequent and high efficiency is maintained for long periods.

17 QUICK RESPONSES TO CHANGING DEMAND

A fluidized bed combustor can respond to changing heat demands more easily than stoker fired systems. This makes it very suitable for applications such as thermal fluid heaters, which require rapid responses.

18 HIGH EFFICIENCY OF POWER GENERATION

By operating the fluidized bed at elevated pressure, it can be used to generate hot pressurized gases to power a gas turbine**.** This can be combined with a conventional steam turbine to improve the efficiency of electricity generation and give a potential fuel savings of at least 4%.

5.4. ASH HANDLING SYSTEM:

5.4.1: BOTTOM ASH REMOVAL:

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

5.4.2 FLY ASH REMOVAL:

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

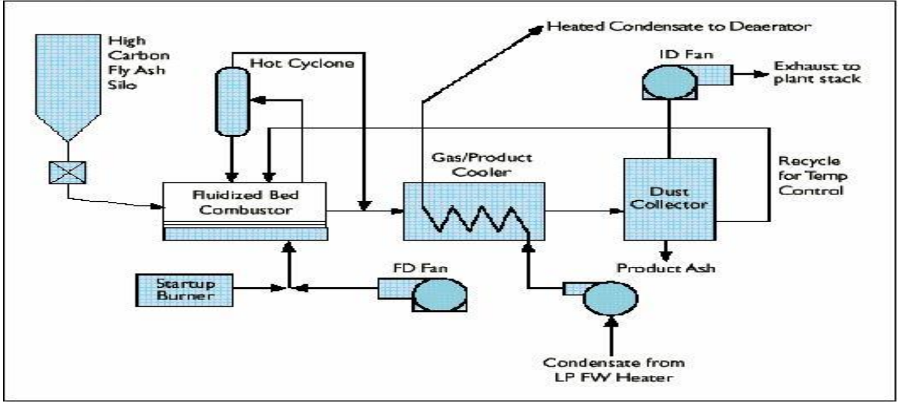


Fig 15: Fly Ash Removal

5.5 SUPERHEATER:

Steam superheaters are widely used in steam generators and heat-recovery steam generators (HRSGs). Their purpose is to raise steam temperature from saturation conditions to the desired final temperature, which can be as high as 550^{0}C in some cases. When used in steam turbines, superheated steam decreases steam heat rate of the turbine and thus improves the turbine and overall plant power output and efficiency. Also, steam conditions at the steam turbine exit will have little or no moisture, depending on the pressure ratio; moisture in the last few stages of a steam turbine can damage the turbine blades. This article outlines some of the design considerations and performance aspects of super heater. A superheater is a device used to convert saturated steam or wet steam into dry steam used for power generation or processes. There are three types of superheaters namely: radiant, convection, and separately fired. A superheater can vary in size from a few tens of feet to several hundred feet.

- A radiant superheater is placed directly in the combustion chamber.
- A convection superheater is located in the path of the hot gases.
- A separately fired superheater, as its name implies, is totally separated from the boiler.

A superheater is a device in a steam engine, when considering locomotives, that heats the steam generated by the boiler again, increasing its thermal energy and decreasing the likelihood that it will condense inside the engine. Superheaters increase the efficiency of the steam engine, and were widely adopted. Steam which has been superheated is logically known as superheated steam; non-superheated steam is called saturated steam or wet steam. Superheaters were applied to steam locomotives in quantity from the early 20th century, to most steam vehicles, and to stationary steam engines. This equipment is still an integral part of power generating stations throughout the world.

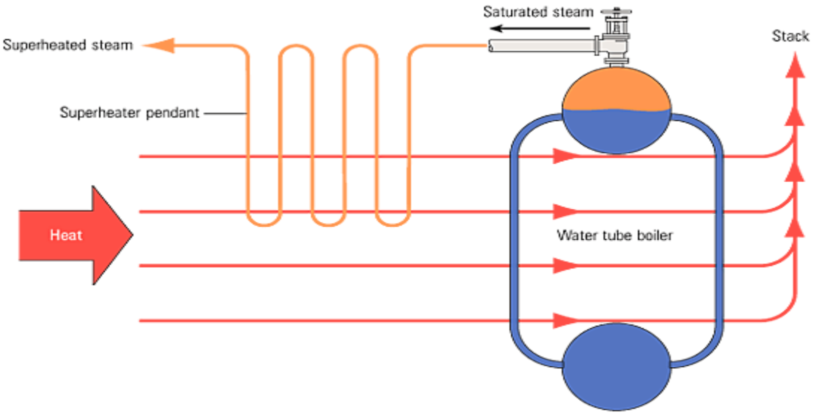


Fig 16: A Water Tube Boiler With A Superheater

5.5.1 ADVANTAGE & DISADVANTAGES:

The main advantages of using a superheater are reduced fuel and water consumption but there is a price to pay in increased maintenance costs. In most cases the benefits outweighed the costs and superheaters were widely used. An exception was shunting locomotives (switchers). British shunting locomotives were rarely fitted with superheaters. In locomotives used for mineral traffic the advantages seem to have been marginal. For example, the North Eastern Railway fitted superheaters to some of its NER Class P mineral locomotives but later began to remove them.

Without careful maintenance superheaters are prone to a particular type of hazardous failure in the tube bursting at the U-shaped turns in the superheater tube. This is difficult to both manufacture, and test when installed, and a rupture will cause the superheated high-pressure steam to escape immediately into the large flues, then back to the fire and into the cab, to the extreme danger of the locomotive crew.

5.6 ECONOMIZER:

In boilers, economizers are heat exchange devices that heat fluids, usually water, up to but not normally beyond the boiling point of that fluid. Economizers are so named because they can make use of the enthalpy in fluid streams that are hot, but not hot enough to be used in a boiler, thereby recovering more useful enthalpy and improving the boiler's efficiency. They are a device fitted to a boiler which saves energy by using the exhaust gases from the boiler to preheat the cold water used to fill it.

A feedwater economizer reduces steam boiler fuel requirements by transferring heat from the flue gas to incoming feedwater. Boiler flue gases are often rejected to the stack at temperatures more than 100°F to 150°F higher than the temperature of the generated steam. Generally, boiler efficiency can be increased by 1% for every 40°F reduction in flue gas temperature. By recovering waste heat, an economizer can often reduce fuel requirements by 5% to 10% and pay for itself in less than 2 years. The table provides examples of the potential for heat recovery.Economizers or economisers are mechanical devices intended to reduce energy consumption, or to perform another useful function like preheating a fluid. The term economizer is used for other purposes as well. Boiler, powerplant, and heating, ventilating, and air-conditioning (HVAC). In boilers, economizers are heat exchange devices that heat fluids, usually water, up to but not normally beyond the boiling point of that fluid. Economizers are so named because they can make use of the enthalpy in fluid streams that are hot, but not hot enough to be used in a boiler, thereby recovering more useful enthalpy and improving the boiler's efficiency. They are a device fitted to a boiler which saves energy by using the exhaust gases from the boiler to preheat the cold water used to fill it (the feed water).

METHODOLOGY:

(1) I adopted for the conduct of my Project study was basically Survey and Observation.

(2) it was relatively easy for me to understand the working and operations of the plant, but still there were many areas

(3) I was quite unacquainted with and hence had to take help and assistance from text books, journals , magazines and reference material provided by Birla Corporation Llimited, Birla vikas cement.27MW thermal power plant.

(4) I studied the operations of the power plant 1x27, and was able to explore and identify the various avenues and areas related to energy conservation and waste reduction.

(5) My focus of study was to enhance the Thermal efficiency of Boiler at different stages of working cycle by unburnt carbon .
(6) I went on to studying the various aspects of the working of a Thermal Power Plant. Keeping in mind the need of today that is the methods and measures adopted by Organizations and Government initiatives.
(7) I thought why not study the factors responsible for achieving and improving thermal efficiency in 27MW coal fired power plants.

A NOTE ON THERMAL ENERGY CONSUMPTION

- **SATNA CEMENT WORKS :**

Specific fuel consumption depend on various factors like Coal quality with respect to

(1) Calorific value,
(2) Ash content and
(3) Moisture content.

Specific Fuel consumption in terms of Kcal/kg Clinker was more during the year 2008-2009, while percentage consumption of coal was lowest.This is due to more UHV and low coal ash content in coal during this year, as compared to other two years. In 2009-2010, fuel consumption was more than 2008-2009, due to low UHV of coal than previous and manufacturing Low Alkali sulphate resistant Cement for Export.To Produce Low Alkali Clinker, Fuel consumption increases due to running of Alkali By-pass System to extract Alkali dust from Kiln inlet at 1000 ^{0}C. A Comaprative table below confirms above statement.

	Unit	2009-2010	2010-2011	2011-2012
Specific Heat Consumption	Kcal/kg Clkr	754	760	746
Coal Consumption	Kg/hr	20209	20152	20082
Specific Heat of Coal (UHV)	Kcal/kg coal	4089	4223	4145
Ash Content	%	31.97	30.97	31.22
Moisture Content	%	2.89	2.92	3.24
Coal Consumption	Tons/day	14459245	14459152	14459040

CASE STUDY:

- **ECONOMIZER:**

Specification Box Econ. Rev.1, 04.04.2012

Boiler Economizer Specification – Rectangular Design

This specification defines the minimum requirements that must be met for the design and fabrication of vertical gas flow, horizontal tube economizers. No deviation from this specification is permissible without documented approval.

I. Description of Operation

The purpose of the equipment is to recover waste heat using the established principle of a gas to liquid heat exchanger. The economizer should be a bare, welded, or extruded finned tube coil assembly installed either inside or parallel to the boiler exhaust stack or duct. Feedwater under pressure will circulate in the tubes of the coil and heat will be transferred from the flue gases to the water.

II. The Heat Exchanger

- Furnish economizer, as described below, to recover waste heat from the boiler exhaust stack.
- The economizer shall be a rectangular box type, completely packaged unit, utilizing bare tube or extended surface.
- The economizer shall be counterblow type arranged to allow the boiler exhaust gas to travel vertically upward, while the feed water travels vertically downward (or vice versa).
- Structural steel, inlet and outlet transitions, when required, shall be provided with the economizer. The structural steel shall be designed to support the economizer, inlet and outlet transition, and stack.

III. Construction Features

- All pressure parts shall conform to the applicable provisions of the current ASME Power Boiler Code. The economizer shall be properly name plated and code stamped. The design pressure shall meet or exceed the design pressure of the boiler.
- Tubes shall of the welded type, 2” O.D. with a minimum wall thickness of .120”.

- Return bends shall be cold bent or manufactured by a forging process. Cold bends shall be assumed to have a 30% thin out or less for code calculation purposes; hot forged bends shall have no thin out of wall thickness. Headers shall be SA 106 B material, Sch. 80 minimum. Vent, drain, and safety relief valve connections shall be a minimum of ¾" npt and shall include a plug.
- The method of tube-to-header attachment shall be welded. Compression fittings, as they are not an accepted Section I joint, shall not be used.
- All coils shall be completely drainable by gravity.
- Method of tube supports shall allow for free flow of hot gases around the welds, return bends and manifolds. The outlet feedwater temperatures shall be at least 30°F below the saturation temperature. The tubes shall be arranged for tube internal acid cleaning, and tube external soot blowing (for fuels other than natural gas).
- For fuels other than natural gas, the economizer shall be provided with a soot blower lane, soot blower wall box (es), and distal bearings. Soot blowers shall be installed transverse to the tubes.
- A gas tight inner seal welded 10 Ga. steel shall be insulated and covered with 30 Ga. thick corrugated, galvanized, carbon steel metal lagging.
- **Finned tubes:**

1. The tube pitch shall be square to ensure ease in cleaning for fuels other than natural gas or the equivalent in which case triangular (staggered) tube pitch is allowable.
2. Fin pitch shall be: 6 fins/inch for natural gas, 4 fins/inch for #2 ,fuel oil, and 3 fins/inch for #6 fuel oil. For solid fuels such as coal or wood, a maximum of 2 fins/inch shall be used.
3. The fin attachment shall be by high frequency weld process. Tension wrapped, embedded, or brazed finned tubes are not acceptable.
4. The fin material shall be carbon steel.

- All exterior surfaces not galvanized shall be painted with high temperature black paint.
- Economizer shall be protected to prevent damage during shipping.
- Maximum allowable pressure drops will be 15 PSIG for the feedwater and 1.5" W. C. for the flue gas.
- Insulation shall be 8 lb density mineral wool and of sufficient thickness to yield a skin temperature no greater than 140°F.
- As a minimum, 10% of the tube to tube welds will be radiographed.
- The economizer's performance, while in a commercially clean condition, shall be guaranteed by the manufacturer.
- Three sets of operating and instruction manuals shall be furnished at time of shipment to include: ASME Code Report; material test reports; nameplate facsimile; economizer assembly drawings; other as required by customer or engineering specifications.
- Economizer shall be designed to operate at 100 percent load without bypassing any flue gas or feedwater.

TECHNICAL DATA

OBSERVATION

27MW Coal Fired Tharmal Power Plant

(1) Capacity of boiler = 65 TPH X 2 = 130 TPH
(2) Type of Boiler = Coal Fired, Semi door, Natural draught, Balanced draft, Single drum, Water Tube
(3) Type of Combustion = Atmospheric Fluidized Bed Combustion
(4) Pressure of superheated steam = 86.4 Bar
(5) Temperature of superheated steam = 505^0 C
(6) Temperature of feed water = 188^0 C
(7) G.C.V. of Coal = 16568.64 KJ /Kg (3960Kcal/kg)
(8) N.C.V. of Coal = 15878.28 KJ/Kg
(9) Gas plenum Pressure At furnace = - 1.8 mm WC
(10) Oxygen level = 4.8%
(11) Ash content in coal = 45-52%
(12) Temperature of Flue Gases leaving in chimney = 138 ^{0}C
(13) Temperature of Boiler house = 32^0C
(14) Total steam generated (m_s)=103416 Kg/Hr
(15) Total coal consumption (m_f)= 20082 Kg/Hr
(16) Output of station = 24.33 MW

(17) FOR ECONOMIZER
a. Inlet temperature of feed water = 188^{0}C
b. Outlet temperature of feed water = 293^{0}C
c. Inlet temperature of Flue gases = 550^{0}C
d. Outlet temperature of Flue gases = 243^{0}C
e. Inlet draught = -4 mmWC
f. Outlet draft = - 34.8 mmWC

(18) FOR SUPERHEATER
a. Inlet temperature of flue gases = 575^{0}C
b. outlet temperature of flue gases = 550^{0}C
c. primary heat transfer = pendent convective type
d. secondary heat transfer = radiant type

(19) FOR REHEATER
a. inlet temperature of steam = 423^{0}C
b. outlet temperature of superheated steam = 502^{0}C
c. pressure of superheated steam = 84.4 kg/cm^2

(20) FOR STEAM CONDENSER
a. inlet pressure of steam = -0.88 mmWC
b. outlet pressure of steam = -0.88 mmWC
c. inlet temperature of steam = 48.26 kg/cm^2
d. outlet temperature of steam = 49^{0}C

(21) FOR STEAM TURBINE
a. inlet pressure of superheated steam = 82.88 kg/cm^2
b. exit pressure of steam = 0.43 kg/cm^2
c. inlet temperature of superheated steam = 500^{0}C
d. inlet temperature of superheated steam = 48^{0}C
e. steam turbine heat rate = 2631 kcal/kwh
f. speed of steam turbine = 7059 rpm (rated)
(22) speed of generator = 1500 rpm (rated)

(23) FOR BOILER NO. 1
a) Mass of steam (m_s)= 1343 T/day=55958 Kg/Hr
b) Mass of Coal consumption (m_f)= 260.8 T/day= 10866 Kg/Hr
c) Mass of Gases formed = 76392 Kg/Hr
d) Mass of Unburnt Coal = 472 Kg/ Hr
e) Excess air for combustion = 61 T/hr to 56 T/Hr

(24) FOR BOILER NO 2
a) Mass of steam (m_s)= 1139 T/day=47458 Kg/Hr
b) Mass of Coal consumption (m_f)= 221.2 t/day= 9216Kg/Hr
c) Mass of Gases formed = 70534 Kg/Hr
d) Mass of Unburnt Coal = 390 Kg/ Hr
e) Excess air for combustion = 60 T/hr to 55 T/Hr

CALCULATION:

- **FOR BOILER NO 1**

We know that
1. Pressure of superheated steam (P) = 86.4 kg/cm^2
2. Temperature of superheated steam (T) = 505^{0}C
3. Mass of steam (m_s) =55958 Kg/Hr
4. Mass of coal (m_f) = 10866 Kg/hr
5. C.V. of Coal = 16568.64 KJ/Kg

To calculate
1. Equivalent evaporation (E)= ?
2. Boiler Efficiency = ?
3. Heat Balance Sheet=?

We know that:

Equivalent evaporation (E)=$\frac{me\ (hsup - hf1)}{2257}$ kg /kg of coal

Boiler efficiency (η_{boiler}) = $\frac{ms\ (hsup - hf1)}{mf\ X\ CV\ of\ coal}$ X100

From steam table

For superheated steam at P= 86.4 bar , Temperature =505^{0}C

Enthalpy of steam (h_{sup}) = 3390.5 KJ/Kg

Enthalpy of feed water at 188^{0}C

$h_{f1=}$ 1x 4.184 (188-0)

$h_{f1\,=}$ 786.59 KJ/Kg

Equivalent mass (m_e)

$m_e = \frac{mass\ of\ steam}{mass\ of\ coal}$ kg/kg of coal

$m_e = \frac{55958}{10866}$

$$\boxed{m_e = 5.149 \text{ kg/kg of coal}}$$

(1) EQUIVALENT EVAPORATION (E)

Equivalent evaporation (E)=$\frac{me\ (hsup - hf1)}{2257}$ kg /kg of coal

E $=\frac{5.149\ (3390.5-786.59)}{2257}$

E= $\frac{5.149 X 2603.91}{2257}$

$$\boxed{E = 5.94 \text{ Kg/Kg of coal}}$$

BOILER (1)EFFICIENCY (□$_{\text{boiler}}$)

Boiler efficiency (η_{boiler}) = $\frac{ms\ (hsup - hf1)}{mf\ X\ CV\ of\ coal}$ X100

$\eta_{\text{boiler}} = \frac{55958\ (3390.5-786.59)}{10866\ X\ 16568.64}$ X100

$\eta_{\text{boiler}} = \frac{55958\ X 2603.91}{180034842.24}$ X100

$\eta_{\text{boiler}} = \frac{145709595.78}{180034842.24}$ X100

$$\boxed{\eta_{\text{boiler}} = 80.93\ \%}$$

(2) HEAT BALANCE SHEET :

HEAT SUPPLIED	KJ	HEAT UTILISATION	KJ	% **UTILISATION**
Heat supplied by coal (Kg / hr)	$Q_S = m_f$ X CV of coal Q_s = 180034842.24	(1)heat utilized to generate superheated steam	$Q_1 = m_s (h_{sup} - h_{f1})$ = 145709595.78	80.93%
		(2)heat carried by dry flue gases	Q_2 = 8907074	4.94%
		(3)heat lost due to unburnt coal	Q_3 = 7820398	4.34%
		(4)heat lost due to convection & radiation	Q_4 = 17597774.14	9.77%

(1) Heat supplied :

$Q_s = m_f$ X CV of coal

Q_s = 10866 X 16568.64

$$\boxed{Q_s = 180034842.24 \text{ KJ}}$$

(2) Heat utilized to generate superheated steam

$Q_1 = m_s (h_{sup} - h_{f1})$

Q_1 = 55958 (3390.5 – 786.59)

$$\boxed{Q_1 = 145709595.78 \text{ KJ}}$$

(3) Heat carried by dry flue gases

$Q_2 = m_g$ X $C_{pg} (T_g - T_a)$

= 76390 X 1.1 (138-32)

$$\boxed{Q_2 = 8907074 \text{ KJ}}$$

(4) Heat lost due to unburnt coal

$Q_3 = m_{uf}$ X CV of coal
= 472 X 16568.64

$\boxed{Q_3 = 7820398 \text{ KJ}}$

(5) Heat lost due to convection & radiation

$Q_4 = Q_s - (Q_1 + Q_2 + Q_3)$

$\boxed{\mathbf{Q_4 = 17597774.14\ KJ}}$

FOR BOILER NO 2

We know that:

1. Pressure of superheated steam (P) = 86.4 bar
2. Temperature of superheated steam (T) = 505^0 C
3. Mass of superheated steam (m_s) = 47458 Kg/hr
4. Mass of coal consumption (m_f) = 9216 Kg/hr
5. Temperature of feed water (t ^{0}C) = 188^0 C
6. C.V. of coal = 16568.64 KJ/Kg

CALCULATION:

(1) Equivalent evaporation (E)=?
(2) Boiler efficiency (η_{boiler}) =?
(3) Heat balance sheet = ?

From steam table for superheated steam

At P=86.4 bar , T=505^{0}C
Enthalpy of superheated steam (h_{sup}) = 3390.5 kJ/Kg
At feed water temperature =188^0 C

Enthalpy of feed water (h_{f1}) = 1 x 4.184 (188-0)
h_{f1}= 786.59 KJ/Kg

$$m_e = \frac{ms}{mf} = \frac{mass\ of\ steam}{mass\ of\ coal}$$

$$m_e = \frac{47458}{9216}$$

m_e = 5.149 Kg/kg of coal
h_{sup} = 3390.5 kJ/Kg
h_{f1}= 786.59 KJ/Kg

(1) EQUIVALENT EVAPORATION (E)

$$\mathbf{E} = \frac{\boldsymbol{me\ (hsup - hf1)}}{\mathbf{2257}}$$

$$E = \frac{5.149(3390.5 - 786.59)}{2257}$$

$\boxed{E = 5.94 \text{ kg/kg of coal}}$

(2) BOILER(2) EFFICIENCY (□$_{\mathbf{boiler}}$)

$$\eta_{boiler} = \frac{ms\ (hsup - hf1)}{mf\ x\ CV\ of\ coal} \text{ X } 100$$

$$\eta_{boiler} = \frac{47458\ (3390.5 - 786.59)}{9216\ x\ 16568.64} \text{ X } 100$$

$$\eta_{boiler} = \frac{47458\ x\ 2603.91}{152696586.24} \text{ X } 100$$

$$\eta_{boiler} = \frac{123576360.78}{152696586.24} \text{ X } 100$$

$\boxed{\mathbf{n_{boiler} = 80.93\%}}$

(3) **HEAT BALANCE SHEET :**

Heat Supplied	KJ	Heat utilized	KJ	% Utilised
Heat supplied by coal (Kg per hour)	$Q_s = m_f$ x CV of coal =152696586.24	1.Heat utilized to generate superheated steam	=123576360.78	80.93%
		2.Heat carried by dry flue gases	$Q_2 =$ m_g x $C_{pg}(T_g - T_a)$ =8224264.4	5.38%
		3.Heat lost due to unburnt coal	$Q_3 = m_{uf}$ x CV of coal =6461769.60	4.235%
		4.Heat lost due to convection & radiation	$Q_4 = Q_s - (Q1+Q_2+Q_3)$ =14434191.46	9.46%

Heat supplied by coal

$Q_s = m_f$ x CV of coal

$Q_s = 9216 \times 16568.64$

$\boxed{\mathbf{Q_s = 152696586.24\ KJ}}$

(1) Heat utilized to generate superheated steam

$Q_1 = m_s (h_{sup}=h_{f1})$

$Q_1 = 47458 \text{ X } (3390.5-786.59)$

$Q_1 = 47458 \text{ X } 2603.61$

$\boxed{\mathbf{Q_1=123576360.78KJ}}$

(2) Heat carried by dry flue gases

$Q_2 = m_g \text{ X } C_{pg}(T_g - T_a)$

$Q_2 = 70534 \text{ X } 1.1 (138-32)$

$\boxed{\mathbf{Q_2 = 8224264.4KJ}}$

(3) Heat lost due to unburnt coal

$Q_3 = m_{uf}$x CV of coal

$Q_3 = 390 \text{ X } 16568.64$

$\boxed{\mathbf{Q_3 = 6461769.60\ KJ}}$

(4) Heat lost due to convection & radiation

$Q_4 = Q_s-(Q1+Q_2+Q_3)$

$Q_4 = 152696586.24 + 123576360.78 + 8224264.4 + 6461769.60$

$\boxed{Q_4=14434191.46\ KJ}$

- **COAL SAMPLE GAVES BY WEIGHT PER KG OF COAL (PER KG OF COAL/HR) :**

PERCENTAGE VOLUMETRIC ANALYSIS OF SAMPLE OF FLUE GASES OF 27 MW COAL FIRED POWER PLANT OF BCL,SATNA

CO2 = 12%
CO = 0.7%
O2 = 7.8%
N2 = 79.5% (by difference)

& GRAVEMETRIC % ANALYSIS OF COAL PER HR

C= 55%
H2 = 3.5%
O2 = 4.7%
Incombustible = 36.8% (by difference)

CALCULATION :

(1) Weight of dry flue gases per kg of coal per hr
(2) Weight of excess air per kg of coal per hr

- **WEIGHT OF EXCESS AIR PER KG OF COAL PER HR**

ELEMENT ,WT (kg)	O2 used	DRY PRODUCT
C= 0.55	0.55 x 8/3 = 1.47	0.55 x 11/3 = 2.017(CO_2)
H_2 = 0.035	0.035 x8 =0.28	
O_2 = 0.047	----------------------	

Total O_2 = 1.75 kg

(i) Minimum weight of air needed for combustion =

= 1.75 x 100/23

Min. air = 7.61 Kg

Excess air supplied is about 10%

= 7.61 x 0.10

= 0.761 kg

Total air supplied for combustion = Min. air + Excess air

= 7.61 + 0.761

= 8.371 Kg

Weight of N_2 in flue gases

= 8.371 x 77/100

= 6.44 kg

Minimum weight of air needed = (1.75-0.047) x 100/23

= 7.404 Kg

- **WEIGHT OF DRY FLUE GASES PER KG OF COAL PER HR:**

Name of gas	Volume per m^3 of DFG (x)	Molecular wt (y)	Relative volume Z= xy	Wt. per kg of DFG Z=Z/ ∑Z
CO_2	0.12	44	5.28	0.1746
CO	0.007	28	0.196	0.00648
N_2	0.795	28	22.26	0.7364
O_2	0.078	32	2.496	0.08257

∑Z = 30.23

Amount of carbon present per kg of gases=

Amount of carbon in 0.1746 kg of CO_2 + Amount of carbon in 0.00648 kg of CO

= 3/11 x 0.1746 + 3/7 x 0.00648

= 0.04762 + 0.00278

= 0.0504 kg

Also,

Carbon in coal = 0.55 kg

Weight of DFG per kg of coal/hr

= [wt of C in 1 kg of coal] / [wt of C in 1 kg of flue gas]

= 0.55 / 0.0504

= 10.91 kg

Weight of excess oxygen per kg of DFG

= 0.09524 - 4/7 x 0.00648

= 0.09524 – 0.0037

= 0.9154 kg [allowing for unburnt carbon monoxide]

Weight of excess oxygen = 10.91 x 0.09154

= 0.9987 ≈1 kg

Weight of excess air = 1 x 100/23

Weight of excess air= 4.35 kg

- **OVERALL PLANT EFFICIENCY :**

At full load on turbine =24330 kW ,& total coal burnt = 20082 kg/hr

Total mass of coal = 47458 +9216 =20082 Kg/hr

$$\eta_{overall} = \frac{output\ \ of\ station\ \ x\ 860}{coal\ \ burnt\ \ X\ cv\ of\ coal}\ X100$$

$$\eta_{\text{overall}} = \frac{24330\ X860}{20082\ X\ 3960}\ \text{X100}$$

$$\boxed{\eta_{\text{overall}} = \mathbf{26.31\ \%}}$$

Where 860 is the conversion factor which makes both numerator & denominator in same unit

But in the Birla Corporation Limited 27MW Thermal power Plant

Power generation is 24330 KW

Total coal burnt = 20082 – (472+390)

= 20082 - 862

$$\boxed{\mathbf{m_f = 19220\ kg/hr}}$$

$$\eta_{\text{overall}} = \frac{output\ \ of\ station\ \ x\ 860}{coal\ burnt\ \ X\ cv\ of\ coal}\ \text{X100}$$

$$\eta_{\text{overall}} = \frac{24330\ X\ 860}{20082\ X3960}\ \text{X100}$$

$$\eta_{\text{overall l}} = \frac{20923800}{79409880}\ \text{X100}$$

$$\boxed{\eta_{\text{overall}} = \mathbf{26.34\%}}$$

<u>MODIFICATION:</u>

For Boiler No. 1

Total combustion of coal = 10866 - (unburnt coal X 0.01)

m_f = 10866 – (472 x 0.01)

m_f = 10866 – 47.2

$$\boxed{\mathbf{m_f = 10861.287\ kg/hr}}$$

Increases in boiler efficiency

$$\eta_{\text{boiler}} = \frac{ms\ (hsup - hf1)}{mf\ X\ CV\ of\ coal}\ \text{X100}$$

$$\eta_{\text{boiler}} = \frac{55958\ (3390.5 - 786.59)}{10861.287 X\ 16568.64}\ \text{X100}$$

$$\eta_{\text{boiler}} = \frac{145709595.78}{179956638.3}\ \text{X100}$$

$$\boxed{\square_{\text{boiler}} = \mathbf{80.96\ \%}}$$

- **Increase s in boiler (1) efficiency**

Increase s in boiler efficiency= 80.96 - 80.93

Increases in boiler (1) efficiency=0.03% to 0.06%

Incresease in efficiency upto 0.03 % to 0.06%

- **In Boiler No. 2**

Total combustion of coal = 9216 - (unburnt coal X 0.01)

m_f = 9216 – (390 x 0.01)

m_f = 9216 – 3.9

$$\boxed{\mathbf{m_f = 9212.1\ kg/hr}}$$

Increases in boiler efficiency

$$\eta_{\text{boiler}} = \frac{ms\ (hsup - hf1)}{mf\ X\ CV\ of\ coal}\ \text{X 100}$$

$$\eta_{\text{boiler}} = \frac{47458\ (3390.5 - 786.59)}{9212.1\ X\ 16568.64}\ \text{X 100}$$

$$\eta_{\text{boiler}} = \frac{123576360.8}{152631968.5}\ \text{X 100}$$

$$\boxed{\square_{\text{boiler}} = \mathbf{80.96\ \%}}$$

- **Increase s in boiler (2) efficiency:**

Increase s in boiler efficiency= 80.96 - 80.93

Increases in boiler (2) efficiency=0.03% to 0.06%

- **<u>INCREASES IN OVERALL PLANT EFFICINCY</u>**

$$\eta_{\text{overall}} = \frac{output\ \ of\ \ station\ \ (KW) x\ 860}{coal\ \ burnt\ \ x\ CV\ of\ coal} \text{ X100}$$

$$\eta_{\text{overall}} = \frac{24330\ x\ 860}{20073.38\ X\ 3960} \text{ X 100}$$

$$\eta_{\text{overall}} = \frac{20923800}{79490584.8} \text{ X 100}$$

$$\boxed{\boldsymbol{\eta}_{\textbf{overall}} \textbf{ = 26.32\%}}$$

Increase in Overall plant Efficiency in %

increase in overall efficiency= 26.32 – 26.31

increase in overall plant efficiency= 0.01% to 0.02%

RESULT & DISCUSSION

- **RESULT:**

(1) Efficiency of boiler (1) = 80.93%
(2) Efficiency of boiler (2) = 80.93 %
(3) Overall plant efficiency = 26.31 %

After modification

(1) Efficiency of boiler (1) = 80.93% to 80.99%
(2) Efficiency of boiler (2) = 80.93 % to 80.99%
(3) Overall plant efficiency = 26.31 % to 26.32%

Increase in boiler efficiency is from 0.03 to 0.06%

➢ Increases in overall plant efficiency is 0.01 % to 0.02%

- **DISCUSSION** :

If the excesses air supplied is very large amount then the ignition temperature required for combustion of coal is decrease which effect the combustion efficiency of coal is reduced and due to this losses in boiler is maximized & formation of carbon monoxide is increase. So quantity of excess air is to maintained. And furnace draft pressure is also effect the combustion of coal. The furnace draft pressure is maintained about the balanced draft.

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