HEAT BALANCE STUDY FOR COAL FIRED POWER PLANT

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HEAT BALANCE STUDY FOR COAL FIRED POWER PLANT

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CERTIFICATE

This is to certify that the work contained in this thesis titled "HEAT BALANCE STUDY FOR COAL FIRED POWER PLANT" has been carried out by Mr. Varinder Pal Singh under my/our supervision and has not been submitted elsewhere for a degree.

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ACRONYMS AND ABBREVIATIONS

HBD	Heat Balance Diagram
HP	High-Pressure
IP	Intermediate-Pressure
LP	Low-Pressure
SG	Steam Generator
DRTR	Deaerator
BFP	Boiler Feed Pump
CP	Condensate Pump
SH	Superheater
RH	Reheater
GCV	Gross Calorific Value or Higher Heating Value
Q	Heat
GWh	Gigawatt-hour
KW	Kilowatt
LHV	Lower Heating Value
MW	Megawatt
MWh	Megawatt-hour
FC	Fixed Carbon
VM	Volatile Matter
PA	Primary Air
SA	Secondary Air

ABSTRACT

The electricity sector in India had an installed capacity of 214.630 GW as of February 2013, the world's fifth largest. In terms of fuel, coal-fired plants account for 67% of India's installed electricity capacity. Therefore a major portion of power is depending on Thermal power plants. This dissertation work is intended to provide an overview upon heat balancing model of Steam Turbine and coal pulverizer. Comparison of sub-critical and supercritical Heat balance diagrams has been done. Heat balance diagram provides the steam properties at different point across the steam cycle, helpful to design the whole system and supporting systems. Calculations show that the boiler heat duty and heat rate is decreases in case of supercritical cycle for the same power output. Although, the initial investment in case of supercritical plant is higher than subcritical, it is around 500 to 600 crores. But the life time cost benefits are more in supercritical technology. Coal requirement calculation and amount of Flue Gas generated is found out to be 423790 kg/hr. and 2298511 kg/hr. respectively, with the help of Boiler Heat Output. Another Calculation has been performed on the basis of heat content in flue gases which in turn going to pass their heat to the air (Primary + Secondary) inducted in air preheater This heated air then supplied to coal mills and furnace. Further Calculation shows that the temperature of mill inlet air is depending on the coal properties and desired mill outlet. The desired mill outlet temperature is 73°C. To get desired output temperature of air (73°C) at coal mill outlet, it is required to supply air of 216°C.The heat content available in secondary air inside air preheater will directly contributes to increase the combustion efficiency and hence boiler efficiency.

CHAPTER 1: INTRODUCTION

The use of electricity has been an essential part of India economy since the turn of the century. Coal power, an established electricity source that provides vast quantities of inexpensive, reliable power has become more important as supplies of oil and natural gas diminish. Today, Thermal plant produces about 67% of total Electricity and out of this, Coal power plant produces about 86% of the electricity generated in India. In addition, proven coal resources are expected to last for one century at current rates of usage. Coal power is a rather simple process. In most coal fired power plants, chunks of coal are crushed into fine powder and are fed into a combustion unit where it is burned. Heat from the burning coal is used to generate steam that is used to spin one or more turbines to generate electricity.

The purpose of this thesis is to:

1. Understand the Heat balance of components used in power plants with the help of turbine heat balance diagram.

2. Evaluate cost benefits for Supercritical technology.

3. Understand the effects of coal components on plant efficiency.

4. Understand the heat balancing of mill.

This thesis focuses on thermal power plants, specifically Heat balancing, coal characteristics, combustion calculation, Coal mill heat balance and secondary air temperature.

This thesis begins with an introduction to the coal fired power plant chapter 2 explaining the Heat Balance Diagram and its importance, including the comparison between Subcritical and Supercritical plant parameters. Chapter 3, explaining the coal characteristics with Proximate and Ultimate analysis, also the effect of coal components on Gross calorific and other important parameters. Chapter 4 explaining the coal mill heat balance with derivations. Chapter 5 evaluating the saving potentials in supercritical power plants and also the mill inlet temperature and secondary air outlet temperature. Chapter 6 ends with the key conclusions of the research

CHAPTER 2:

HEAT BALANCE DIAGRAM AND COMPARISON BETWEEN SUBCRITICAL & SUPERCRITICAL HEAT BALANCE

2.1.1 Heat Balance Diagram

Heat Balance Diagram or HBD for Thermal Power Station is the basically schematic representation of the whole steam cycle from Boiler to High Pressure (HP) Turbines Intermediate Pressure (IP) Turbines and Low Pressure (LP) Turbines to condenser to pumps to re-heaters and again to boiler.

This diagram also contains some information of steam properties like Pressure Temperature, enthalpy and mass of the steam at every junction of the line.

As mentioned above, Heat Balance Diagram or HBD has the heat equation at points before and after every component. Considering the first point after the boiler, knowing the steam properties, pressure and temperatures, other properties like enthalpy of the steam can also be determined.

Knowing the efficiencies and considerations like pressure drop across the control valves, these properties along the cycle can be determined, thus the heat rate of the system. With help of heat rate, the mass of steam required can be determined.

2.1.2 Importance of Heat Balance Diagram

Heat Balance Diagram is generally one of the first produced diagrams and part of Process Control Diagrams (PCDs), by an engineering wing or consultancy while working on the specifications of the project (power plant). HBD helps to engineer the plant by way of providing the steam properties at different point across the steam cycle, thus providing vital information, helpful to design the whole system and supporting systems. HBD, in fact also helps in estimating the cost of the plant as well as it provides the heat rate, operational cost can also be estimated. Knowing the both costs, it is easier to decide on refining the specifications of components (comparing initial investments as well as the operational costs). Usually there has been no ways for the project owner to comment on the consultant's decision about the specifications. Mostly it has to be dependent on individual discretion and experience and expertise. However, recently some software solutions have come to provide support to engineers, which can simulate the Heat Balance Diagram for engineers to understand the process in a better way and not only to comment over the design provided by consultants, but also provide an opportunity to increase the operating efficiencies, resulting into significant saving in operational costs.

2.1.3 Typical Heat Balance Diagram

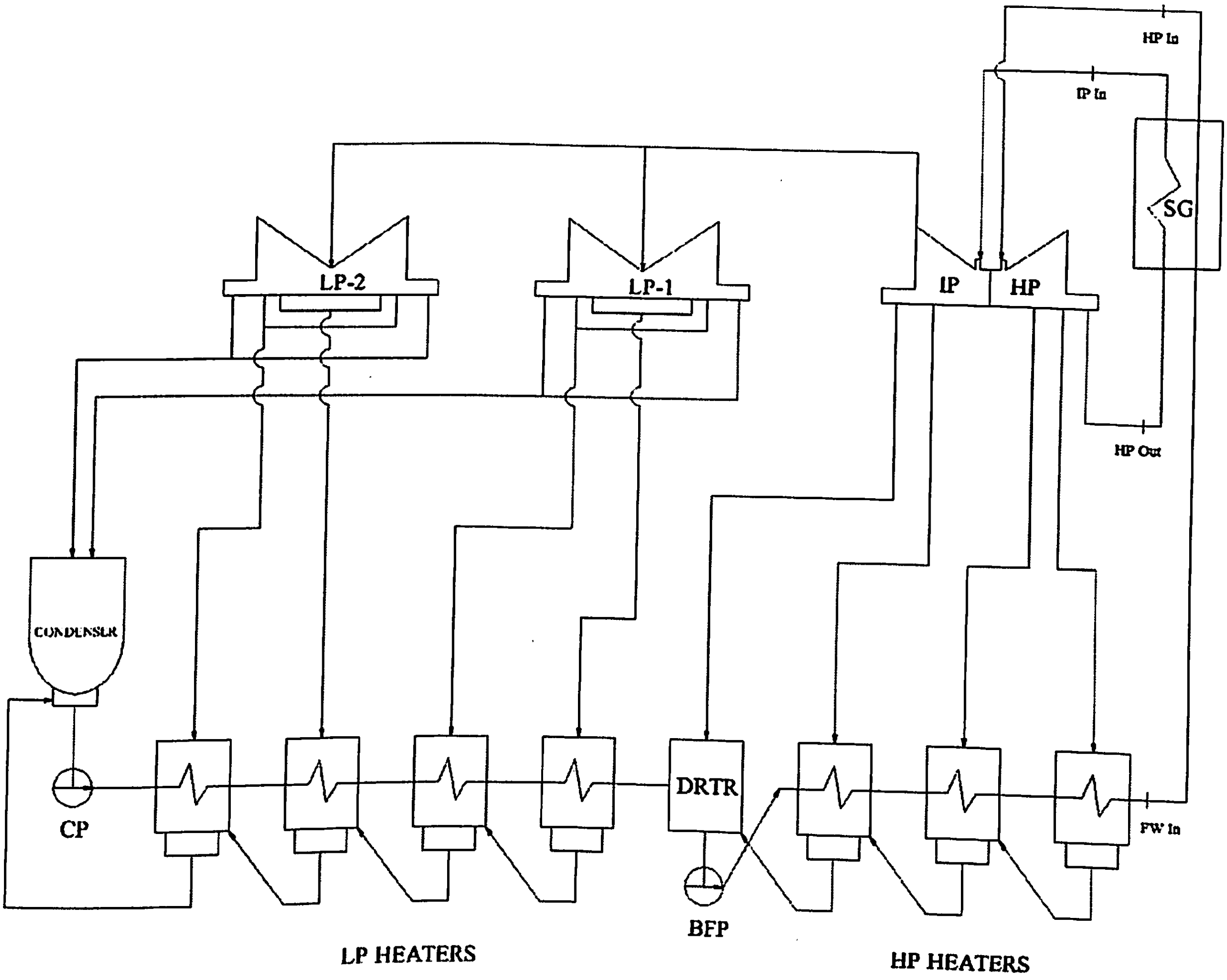


Figure 2.1: Typical Heat Balance Diagram for a Thermal power plant

The above diagram shows the heat balance for turbine with a particular generation capacity. In this, we can see the number of turbines and also the number of feed-water heaters required to achieve the maximum efficiency. There are various important parameters in it, like steam flow at superheater outlet, pressure at turbine inlet, pressure at superheater outlet, temperature at superheater outlet, steam flow to reheater, steam pressure at HP turbine exhaust , steam temperature at HP turbine exhaust and feed water temperature at economizer outlet. These parameters help in calculating the Boiler heat output. On the basis of boiler heat output the design of boilers can be done by knowing the coal requirement. With the amount of coal required, we can calculate the amount of air required for complete combustion of fuel, number of pulverizers, capacity of pulverizers, size of primary air fan, size of forced drafty fan and also the size of induced draft fan by calculating the mass of flue gas generated.

2.2 Comparison of Super-critical and Sub-critical HBD

Description		Unit	Supercritical 660MW	Subcritical 600MW
Main Steam Flow		kg/h	1918600	1802451
RH Steam Flow		kg/h	1612600	1597965
SH out	Pressure	MPa (g)	24.85	18.10
	Temperature	Deg C	568	540
HP-T in	Pressure	MPa (g)	24.12	17.12
	Temperature	Deg C	565	537
IP-T in	Pressure	MPa (g)	4.88	4.00
	Temperature	Deg C	593	537
Feed Water in	Temperature	Deg C	290	253.50
	Flow	kg/h	1918600	1802451
Boiler Heat Output		GJ/h	5090	4889
SH Heat Output		GJ/h	4067	4119
RH Heat Output		GJ/h	1023	770
Heat Rate		kJ/kWh	7713	8150

Table 2.1: Comparison between subcritical and supercritical plant

2.3 Derivations based on Heat Balance Diagram

Boiler heat output $= W_{SH} (h_{so} - h_{fw}) + W_{RH} (h_{ro} - h_{ri})$ GJ/hr.

SH heat output $= W_{SH} (h_{so} - h_{fw})$ GJ/hr.

RH heat output $= W_{RH} (h_{ro} - h_{ri})$ GJ/hr.

Boiler heat duty per MW $= \frac{\text{Boiler heat output}}{\text{Plant capacity}}$ GJ/MWh

SH heat duty per MW $= \frac{\text{SH heat output}}{\text{Plant capacity}}$ GJ/MWh

RH heat duty per MW $= \frac{\text{RH heat output}}{\text{Plant capacity}}$ GJ/MWh

Heat Rate $= \frac{\text{WSH (hso} - \text{hfw)} + \text{WRH (hro} - \text{hri)}}{\text{Plant capacity} * 1000}$ kJ/KWh

Where

W_{SH} = Steam flow at superheater outlet, kg/hr.

W_{RH} = Steam flow to reheater, kg/hr.

h_{so} = Enthalpy at superheater outlet, kJ/kg

h_{ri} = Enthalpy at RH inlet, kJ/kg

h_{ro} = Enthalpy at RH inlet, kJ/kg

h_{fw} = Feed water enthalpy, kJ/kg

CHAPTER 3:

INTRODUCTION TO COAL AND COMBUSTION CALCULATION

3.1 Coal

Coal is the most important & abundant fossil fuel in India. It accounts for 55% of the County energy need. The Countries Industrial heritage was would upon indigenous business coal. The increasing demand of India for energy for sustaining the economic growth will have to be met by a combination of renewable, nuclear and conventional sources of energy. Coal along with clean technologies forms an important role in India's increasing energy demand. To provide energy security to the country, guaranteed supply of coal with Better quality is a primary requirement. Coal is an input in the manufacturing process of steel, cement, fertilizer and other industries. Ministry of Coal has planned to increase the coal production by an average of 36 million tons per annum. It is anticipated that the demand for thermal coal and coking coal by power and steel sectors, respectively, will gain momentum in near future.

Coal is formed from plants by chemical and geological processes that occur over millions of years. Bacterial action, pressure and temperature act on the organic matter over time to form coal. The geochemical process that transforms plant debris to coal is called coalification. Various physical and chemical processes occur during coalification. The heat and pressure to which the organic material is exposed cause chemical and structural change. These changes include an increase in carbon content, loss of water, oxygen and hydrogen.

In a Thermal power station, Coal is delivered by highway by truck, rail, and ship or coal slurry pipeline. In some cases, the plants are even built near coal mines and coal is delivered by conveyors to reduce the transportation and handling cost. The properties of coal vary according to the conditions because the upper layer of coal has different chemical and structural properties and lower layer has different properties for the same mine. In that case, the equipments of thermal plant are designed according to those properties of coal. For Combustion calculations, the coal is divided into three categories like Design coal, Worst coal and Best coal. Design coal is that coal which is available in plant for most of the time and its carbon percentage and heating value is vary between the worst and best coal. Worst coal, as the name indicates is lowest quality of coal which has less carbon content, less Heating value but high ash content. Best coal is the coal with higher carbon content, higher heating value, less ash content and minimum moisture present in it.

3.2 Availability of coal

Coal is the most abundant fossil fuel resource in India, which is the world's 4th largest coal producer. The principal deposits of hard coal are in the eastern half of the country, ranging from Andhra Pradesh, bordering the Indian Ocean, to Arunachal Pradesh in the extreme northeast: the eastern States of Chhattisgarh, Jharkhand, Orissa and West Bengal together account for about 77% of reserves. The Ministry of Coal states that at 1 April 2012, India's geological resources of bituminous coal comprised 118 billion tonnes of 'proved resources', 142 billion tonnes of 'indicated resources' and 33 billion tonnes of 'inferred resources'. The resources quoted are the result of exploration down to a depth of 1,200 m.

Research in India has indicated that only about 21% of total geological resources can be regarded as recoverable. On the basis of expert advice from an Indian research institute, proved recoverable reserves of hard coal have been estimated as 21% of the total geological resources of 2,93,497 million tonnes as at 1 April 2012, giving a (slightly rounded) level of 61,634 million tonnes.

As on	Geological Resources of Coal (in Million Tonnes)			
	Proved	Indicated	Inferred	Total
1.4.2007	99060	120177	38144	257381
1.4.2008	101829	124216	38490	264535
1.4.2009	105820	123470	37920	267210
1.4.2010	109798	130654	36358	276810
1.4.2011	114992	137471	34390	285862
1.4.2012	118145	142169	33183	293497

Table 3.1: Status of Coal Resources in India during last years
Source: Ministry of Coal

Considerable uncertainty remains regarding India's coal reserves, particularly as to (i) whether they represent remaining tonnages or need to be reduced by the subtraction of past years' production, and (ii) whether it is appropriate to assess coal resources down to a depth of 1,200 meters, when current coal mines in India do not generally exceed 300 m. Although it is not possible to draw definitive conclusions from the information available, the downside implications of these considerations should be borne in mind.

Although India's coal reserves cover all ranks from lignite to bituminous, they tend to have high ash content and a low calorific value. The low quality of much of its coal prevents India from being anything but a small exporter of coal (traditionally to the neighbouring countries of Bangladesh, Nepal and Bhutan) and conversely, is responsible for sizeable imports (in 2007, 22 million tonnes of coking coal and 28 million tonnes of steam coal), mainly from Australia, China, Indonesia and South Africa.

3.3 Coal Classification

A coal classification system is needed because coal is a heterogeneous substance with a wide range of composition and properties. Coals are typically classified by rank. This indicates the progressive alteration in the coalification process from lignite to sub-bituminous, bituminous and anthracite coals. The rank indicates a coal's geological history and broad characteristics.

ASTM classification by rank

The system used for classifying coal by rank was established by the American Society for Testing and Materials (ASTM). ASTM classifications is a system that uses the volatile matter (VM) and fixed carbon (FC) results from the proximate analysis and the heating value of the coal as ranking criteria. This system aids in identifying commercial uses of coals and provides basic information regarding combustion characteristics. Proximate analysis is based on the laboratory procedure described in ASTM D 3172. In this procedure, moisture content, ash remaining after complete burning, amount of gases released when heated to a pre-scribed temperature, and fixed carbon remaining after volatilization are determined. For older or higher rank coals, FC and VM are used as the classifying criteria.

The following descriptions briefly summarize the characteristics of each coal rank.

a. Lignite

Lignite is the lowest rank coal. Lignite is relatively soft and brown to black in color. The deposits are geologically young and can contain recognizable remains of plant debris. The moisture content of lignite is as high as 50% (Typical Neyveli Lignite) but the volatile content is also high; consequently, they ignite easily. Lignite coal dries when exposed to air and spontaneous combustion during storage is a concern. Long distance shipment of these coals is usually not economical because of their high moisture and low heating content. The major deposits of Lignite reserves are located in the State of Tamil Nadu. Other states where lignite deposits have been located are Rajasthan, Gujarat, Kerala, Jammu & Kashmir and Union Territory of Pondicherry.

b. Sub-bituminous

Sub-bituminous coals are black, having little of the plant-like texture and none of the brown color associated with the lower rank lignite coal. Sub-bituminous coals are non-coking (undergo little swelling upon heating) and have a relatively high moisture content which averages from 15 to 30%. They also display a tendency toward spontaneous combustion when drying.

Although they are high in VM content and ignite easily, sub-bituminous coals generally have less ash and are cleaner burning than lignite coals. Sub-bituminous coals have reasonably high heating values and low sulfur content, switching to sub-bituminous coal has become an attractive option for many power plants to limit SO_2 emissions.

c. Bituminous

Bituminous coal is the rank most commonly burned in electric utility boilers. In general, it appears black with banded layers of glossy and dull black. Typical bituminous coals have high heating values and a fixed carbon content of 46 to 86%. The heating value is higher, but moisture and volatile content are lower than the subbituminous and lignite coals. Bituminous coals rarely experience spontaneous combustion in storage. Furthermore, the high heating value and fairly high volatile content enable bituminous coals to burn easily when pulverized to a fine powder. Some types of bituminous coal, when heated in the absence of air, soften and release volatiles to form the porous, hard, black product known as coke. Coke is used as fuel in blast furnaces to make iron.

d. Anthracite

Anthracite, the highest rank of coal, is shiny black, hard and brittle, with little appearance of layers. It has the highest content of fixed carbon, 86 to 98%. However, its low volatile content makes it a slow burning fuel. Most Anthracite have a very low moisture content of about 3%; heating values of 34,890 kJ/kg are slightly lower than the best quality bituminous coals. Anthracite is low in sulfur and volatiles and burns with a hot, clean flame. These qualities make it a premium fuel used mostly for domestic heating.

3.4 Coal Analysis

Coal analysis is needed because coal is a heterogeneous substance with a wide variety and composition and substance. Coals are typically classified by rank and rank indicates a coal's geological history and broad characteristics. The system used for classifying the coal is established by American Society for Testing and Materials. There are two methods for analyzing the coals.

3.4.1 Proximate analysis

It includes the determination of volatile matter, fixed carbon and ash. Volatile matter and fixed carbon, exclusive of the ash and moisture, are two indicators of coal rank. The amount of volatile matter in a coal indicates ease of ignition and whether supplemental flame stabilizing fuel is required. The ash content indicates the load under which the ash collection system must operate. It also permits assessing related shipping and handling costs.

$$\mathrm{FC} + \mathrm{VM} + \mathrm{M} + \mathrm{A} = 100\%\text{by mass}$$

3.4.2 Ultimate analysis

It includes measurements of carbon (C), hydrogen (H), nitrogen (N) and sulfur content (S), moisture (M) and the calculation of oxygen content (O). Used with the heating value of the coal, combustion calculations can be performed to determine coal feed rates, combustion air requirements, heat release rates, boiler performance, and sulfur emissions from the power plant.

$$\mathrm{C} + \mathrm{H} + \mathrm{O} + \mathrm{N} + \mathrm{S} + \mathrm{M} + \mathrm{A} = 100\% \text{ by mass}$$

Typical example of Coal Analysis Sheet

Coal characteristics

	Design	Worst	Best
Proximate Analysis			
Total moisture(%)	15	17	12
Ash(%)	40	44	34
Volatile matter(%)	19	18	22
Fixed carbon(%)	26	21	32
Ultimate Analysis			
Carbon(%)	30.87	26.53	39.38
Hydrogen(%)	3.4	2.8	3.5
Sulphur(%)	0.4	0.5	0.36
Oxygen(%)	8.25	7.26	8.73
Nitrogen(%)	1.5	1.45	1.78
Carbonates(%)	0.3	0.26	0.15
Phosphorus(%)	0.28	0.2	0.1
Total moisture(%)	15	17	12
Ash(%)	40	44	34
Hard Grove Index	55	50	60
GCV(Kcal/Kg)	3300	2800	4000

Table 3.2: Sample of Coal Characteristics sheet

3.5 Coal properties

a. Heating value, the gross calorific value of coal, determined using an adiabatic bomb calorimeter, is expressed in Btu/lb (kJ/ kg) on various bases (dry, moisture and ash free, etc.). This value determines the maximum theoretical fuel energy available for the production of steam. Consequently, it is used to determine the quantity of fuel which must be handled, pulverized and fired. Gross (higher) heating value (HHV) is defined as the heat released from combustion of a unit fuel quantity (mass), with the products in the form of ash, gaseous CO_2, SO_2, nitrogen and liquid water, exclusive of any water added as vapor. The net (lower) heating value (LHV) is calculated from the HHV. It is the heat produced by a unit quantity of fuel when all water in the products remains as vapor. In India, the gross calorific value is commonly used in heat balance calculations, while in Europe the net value is generally used.

$$\mathrm{HHV} = 33.83\,C + 144.45\left(H - \frac{O}{8}\right) + 9.38\,S \qquad \text{in MJ/kg}$$

b. Grindability Index

The Hardgrove Grindability Index is used to determine the relative difficulty of reducing various coals to a particle size required for efficient combustion in pulverized coal boiler furnaces. The higher the HGI value, the more readily a coal can be reduced to smaller particle sizes. “A ring ball mill, containing eight 1 inch balls, is driven under a Pressure of 64 lb. on the balls. The 50 g prepared coal sample, is Ground for exactly 60 revolutions of the upper ring. If w is the Weight of coal passing a 75 m aperture sieve, then

$$\text{Hardgrove Index} = 13 + 6.93\,w$$

c. Sulphur content

Sulphur content in coal is combustible and generates some energy by its oxidation to SO_2. Sulphur dioxide is a major source of atmospheric pollution. There is an environmental regulation on SO_2 emission. The operation cost of SO_2 removal equipment need be considered while selecting a coal with high Sulphur content.

d. Free swelling index

The free swelling index can be used to indicate caking characteristics. Some type of coal during and after release of volatile matter become softy and pasty and form agglomerates. These are called caking coal. In a fixed bed, such as a travelling grate stoker, the coal must not cake as it burns. Coal that does not cake is called free-burning coal. It breaks apart during combustion exposing large surface area to the air, thus enhancing the combustion process. A qualitative evaluation method, called the swelling index, has been devised to determine the extent of caking of coal. A free-burning coal has a high value of swelling index.

e. Ash softening temperatures

The ash softening temperature is the temperature at which the ash softens and becomes plastic. This is somewhat below the melting temperature point of ash. The design of steam generator greatly depends on the ash softening temperature of coal. If the furnace temperature is higher than the ash softening temperature , all the ash will melt and would come out of the furnace bottom continuously as molten slag.

3.6 Dulong formula for Higher Heating Value

The heating (calorific) value of coal is of great importance in the conversion of coal to other useful forms of fuel as well as in its direct use. . Dulong suggests the following approximate formula for higher heating value when the oxygen content is less than 10%. Dulong formula is used, if it is desired to calculate the calorific value from the ultimate analysis,

$$Q = 0.238*(339*C+1427*H+90.94*S-178.375*O) \quad (Gcal/kg)$$

Ultimate Analysis			
1	Carbon	% by wt.	30.87
2	Hydrogen	% by wt.	3.4
3	Sulphur	% by wt.	0.4
4	Oxygen	% by wt.	8.25

Table 3.3: Typical ultimate analysis of Coal with major components

By Dulong Formula,

$$Q = 0.238*(339*C+1427*H+90.94*S-178.375*O) \quad (Gcal/kg)$$

$$= 0.238*(339*30.87+1427*3.4+90.94*.4-178.375*8.25)$$

$$= 3304 \quad (Gcal/kg)$$

3.7 Effect of Coal Components on Calorific Value

Ultimate Analysis	Design	Worst	Best
Carbon (%)	30.87	26.53	39.38
Hydrogen (%)	3.4	2.8	3.5
Sulphur (%)	0.4	0.5	0.36
Oxygen (%)	8.25	7.26	8.73
GCV (Kcal/Kg)	3304	2794	4003

Table 3.4: Typical ultimate analysis of coal for different conditions

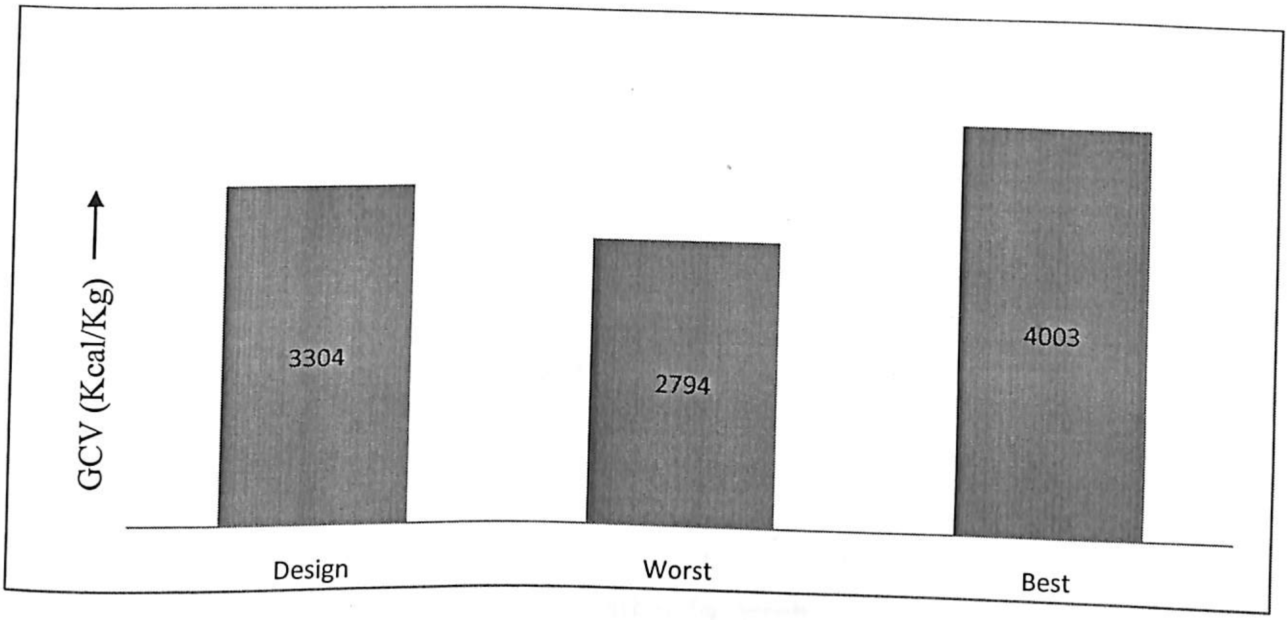


Figure 3.1: GCV of Different Coals

Fig 3.1 shows the change in heating values of coal with the change in coal components. Dulong formula, as explained earlier shows that the higher heating (Gross calorific) value is mainly depend on the percentage of carbon, hydrogen, Sulphur and oxygen. We can also see that, in the above table, the percentage of hydrogen, Sulphur, oxygen for design coal, worst coal and best coal is almost same; only the carbon's percentage varies. Due to that the higher heating value also varies.

3.7.1 Effect of Carbon on the Calorific Value

Carbon (%)	Hydrogen (%)	Sulphur (%)	Oxygen (%)	GCV (Kcal/Kg)
25	3.4	0.4	8.25	2830
30	3.4	0.4	8.25	3234
35	3.4	0.4	8.25	3637
40	3.4	0.4	8.25	4040
45	3.4	0.4	8.25	4444
50	3.4	0.4	8.25	4847

Table 3.5: Typical ultimate analysis with change in Carbon percentage only

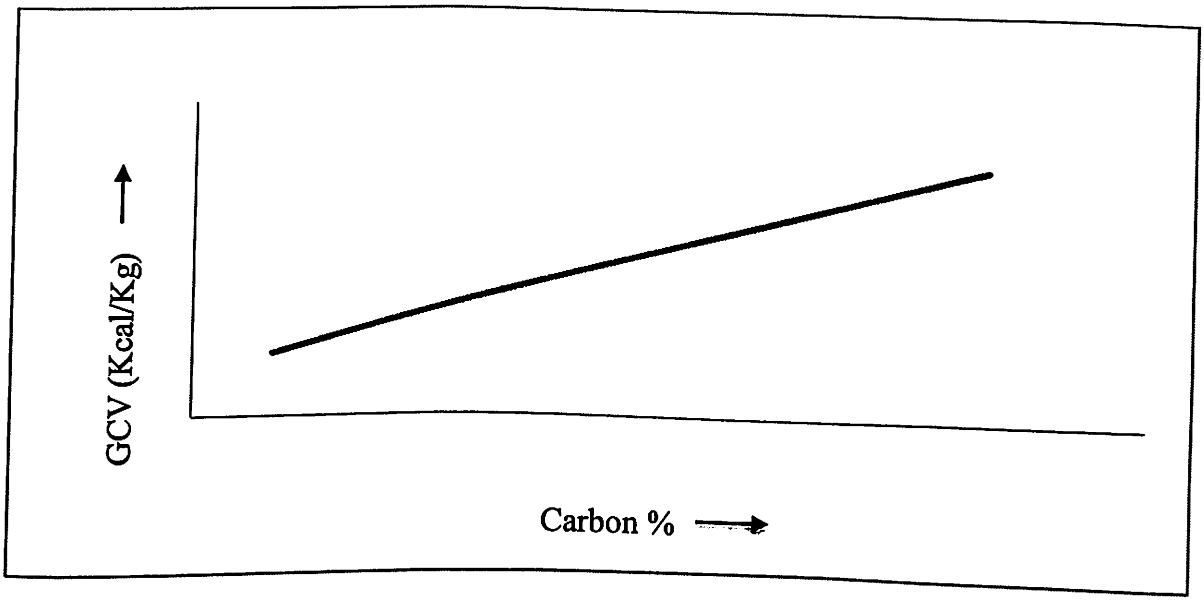


Figure 3.2: Effect of Carbon content on GCV

Fig 3.2 shows the effect of change in carbon percentage on higher heating value. According to Dulong formula, the carbon, hydrogen, Sulphur and oxygen percentage affects the higher heating value. In the table, the hydrogen, Sulphur and oxygen percentages are kept same for different conditions; only we are changing the percentage of carbon. The figure shows that heating value is very low in case of low carbon percentage and high in case of high carbon percent. From this we can conclude that the higher heating value is mostly depending on the percentage of carbon. With 25 percent of carbon, the higher heating value is 2830 kcal/kg and with 50 percent of carbon, the higher heating value is 4847 kcal/kg.

3.7.2 Effect of Hydrogen on the Calorific Value

Carbon (%)	Hydrogen (%)	Sulphur (%)	Oxygen (%)	GCV (Kcal/Kg)
30.87	2	0.4	8.25	2828
30.87	3	0.4	8.25	3168
30.87	4	0.4	8.25	3508
30.87	5	0.4	8.25	3847
30.87	6	0.4	8.25	4187
30.87	7	0.4	8.25	4526
30.87	8	0.4	8.25	4866

Table 3.6: Typical ultimate analysis with change in Hydrogen percentage only

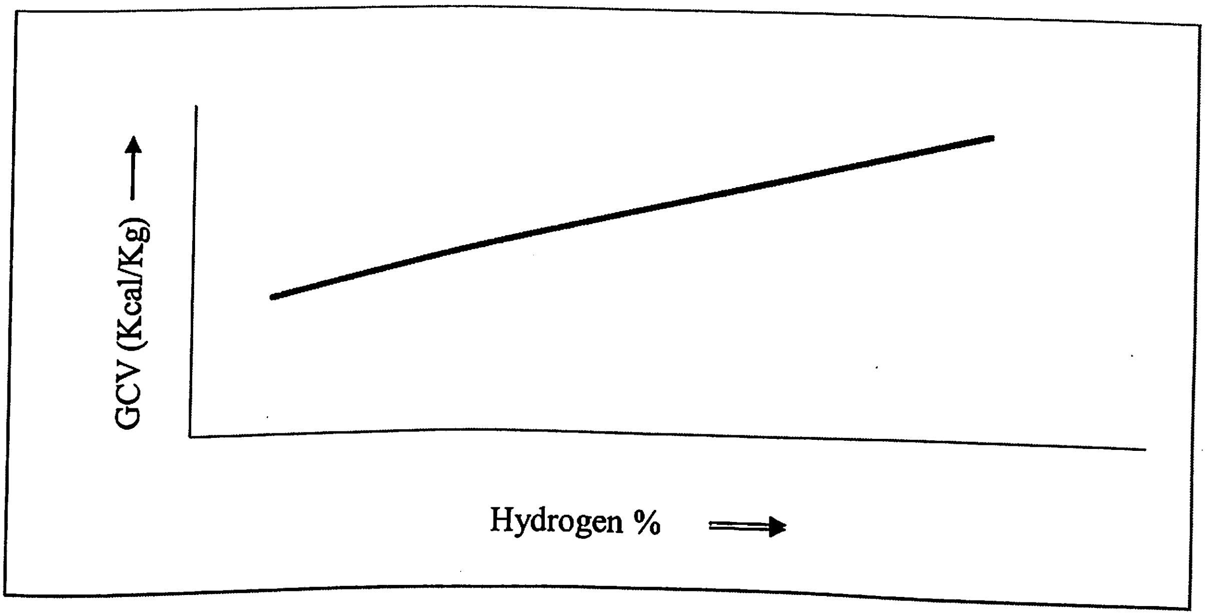


Figure 3.3: Effect of Hydrogen content on GCV

The fuel specification can also have a dramatic effect on efficiency. *Fig 3.3* shows the effect of change in hydrogen percentage on higher heating value. In the table, the carbon, Sulphur and oxygen percentages are kept same for different conditions; only we are changing the percentage of hydrogen. Figure shows that heating value is very low in case of low hydrogen percentage and high in case of high hydrogen percent. From this, we can conclude that hydrogen percentage is the next major contributor to the higher heating value after carbon. With 2 percent of hydrogen, the higher heating value is 2828 kcal/kg and with 8 percent of hydrogen, the higher heating value is 4866 kcal/kg. The higher the hydrogen content, the more water vapor is formed during combustion. This water vapor uses energy as it changes phase in the combustion process. Higher water vapor losses when firing the fuel result in lower efficiency.

3.7.3 Effect of Oxygen on the Calorific Value

Carbon (%)	Hydrogen (%)	Sulphur (%)	Oxygen (%)	GCV (Kcal/Kg)
30.87	3.4	0.4	2	3569
30.87	3.4	0.4	4	3484
30.87	3.4	0.4	6	3399
30.87	3.4	0.4	5	3442
30.87	3.4	0.4	8	3314
30.87	3.4	0.4	10	3230

Table 3.7: Typical ultimate analysis with change in Oxygen percentage only

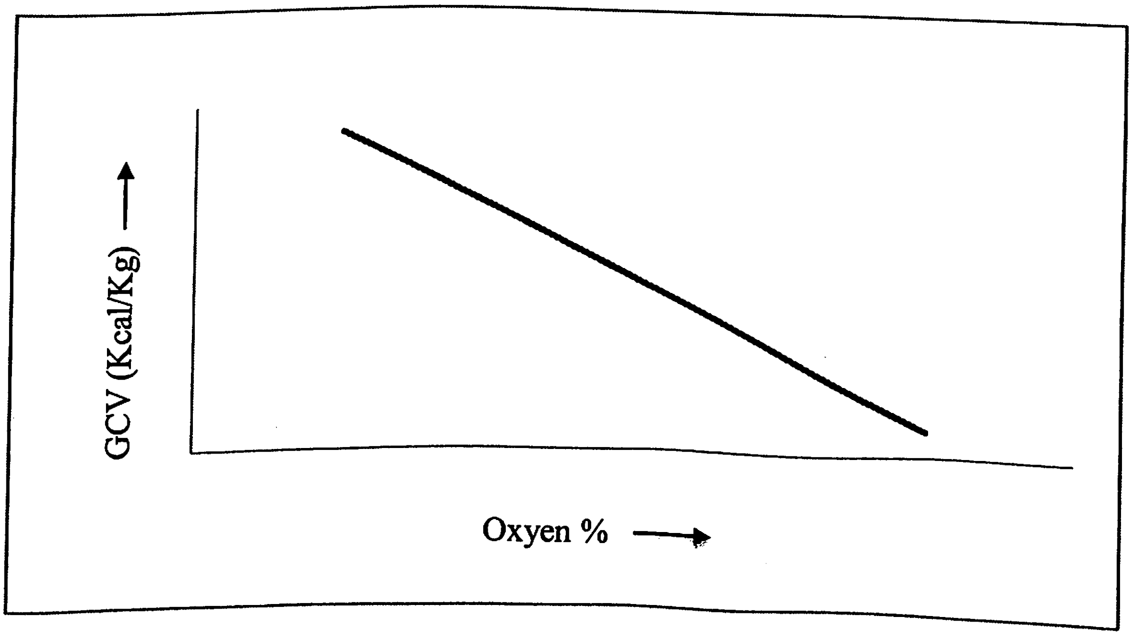


Figure 3.4: Effect of Oxygen content on GCV

Fig 3.4 shows the effect of change in Oxygen percentage on higher heating value. It shows that the heating value is very low in case of high oxygen content. With 2 percent of oxygen, the higher heating value is 3569 kcal/kg and with 10 percent of oxygen, the higher heating value is 3230 kcal/kg.

3.7.4 Effect of Sulphur on the Calorific Value

Carbon (%)	Hydrogen (%)	Sulphur (%)	Oxygen (%)	GCV (Kcal/Kg)
30.87	3.4	0.4	8.25	3304
30.87	3.4	0.6	8.25	3308
30.87	3.4	0.8	8.25	3312
30.87	3.4	1	8.25	3317
30.87	3.4	1.2	8.25	3321
30.87	3.4	1.4	8.25	3325

Table 3.8: Typical ultimate analysis with change in Sulphur percentage only

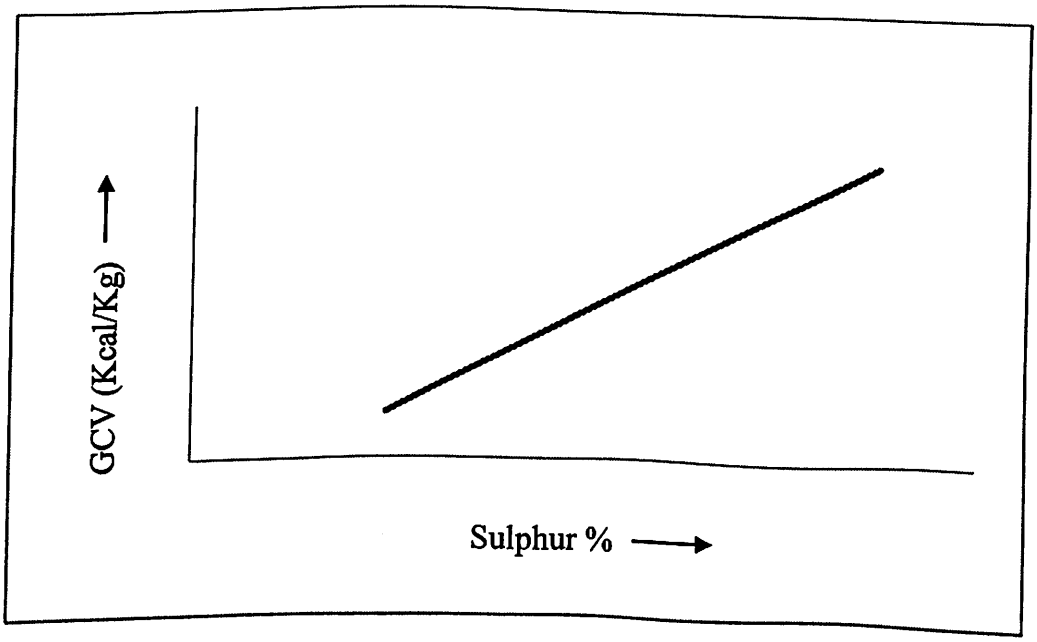


Figure 3.5: Effect of Sulphur content on GCV

Sulphur content in coal is combustible and generates some energy by its oxidation to SO_2. *Fig 3.5* shows the effect of change in Sulphur percentage on higher heating value. In the table, the carbon, hydrogen and oxygen percentages are kept same for different conditions; only we are changing the percentage of Sulphur. Figure shows that the change in Sulphur percentage in fuel will not affect the heating value too much. We can see the variation in GCV from the table.

But on the other hand, higher Sulphur content in fuel will increase the quantity of Sulphur dioxide and Sulphur dioxide is a major source of atmospheric pollution. As a result, the operation cost of SO_2 removal equipment will increase with high Sulphur content.

3.8 Effect of Calorific Value on Dry gaseous products

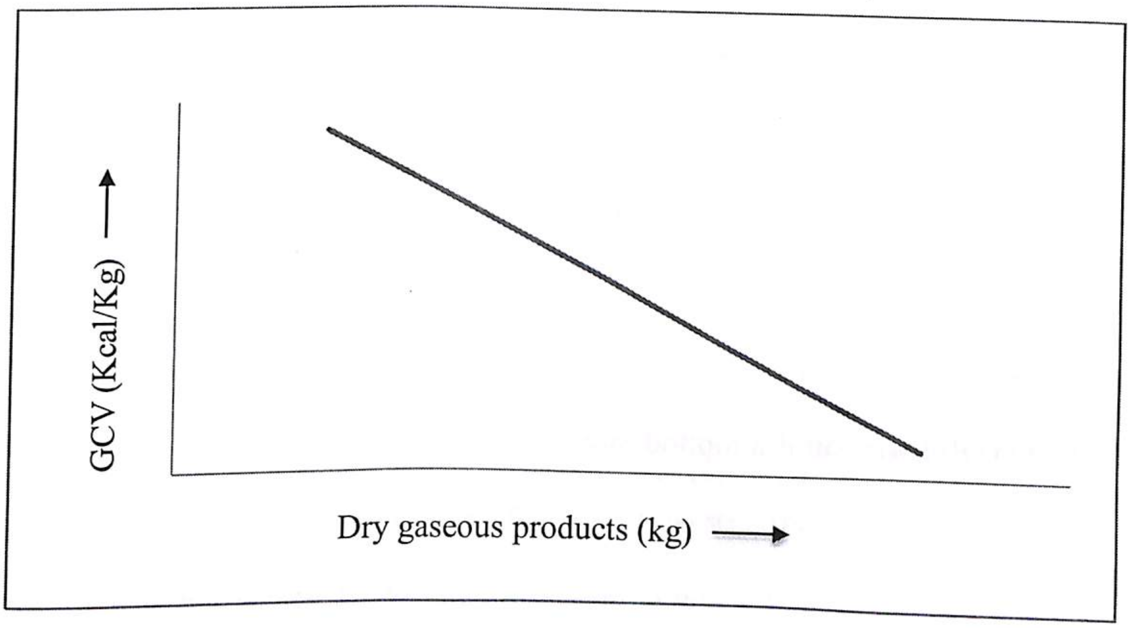


Figure 3.6: Effect of Higher heating value on dry gaseous products

Fig 3.6 shows that dry gaseous products are inversely proportional to the higher heating value. If the higher heating value is more, the generation of dry gaseous products will be less and the dry gaseous products increase with decrease in higher heating value of fuel. We also know that higher heating value is directly depending on the carbon percentage in fuel. Therefore, high carbon content in fuel will decrease the dry gaseous products, its operational cost and size of handling Equipments.

3.9 Effect of ash content

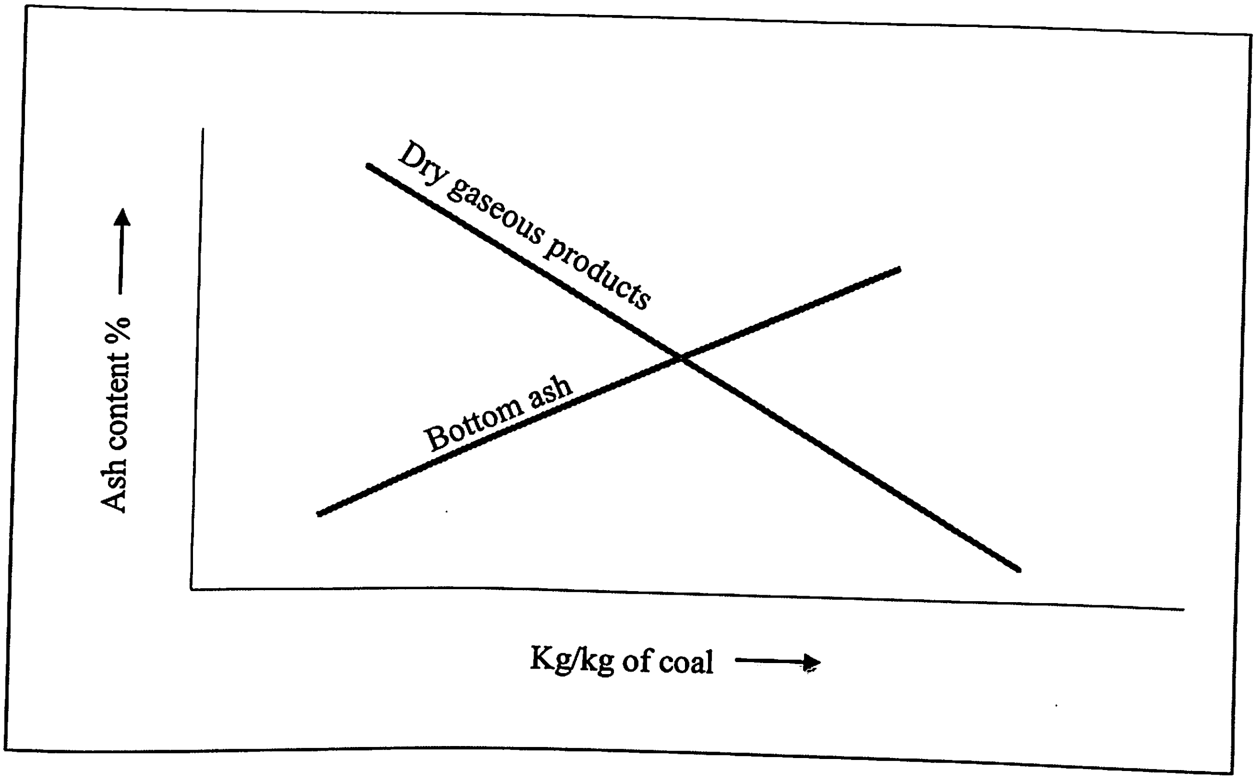


Figure 3.7: Effects of Ash content in fuel

Fig 3.7 shows the variation in amount of bottom ash and dry gaseous products with respect to ash content in coal. We can see that bottom ash in fuel is directly depending on the ash content. Higher ash content in fuel results in higher bottom ash because ash content does not play any role in combustion calculation .It is like a waste product. On the other hand, dry gaseous products are inversely depending on ash content. Higher the ash content in fuel means lower will be the carbon content i.e. low higher heating value, which results in higher dry gaseous products and its higher handling cost.

3.10 Coal Requirement

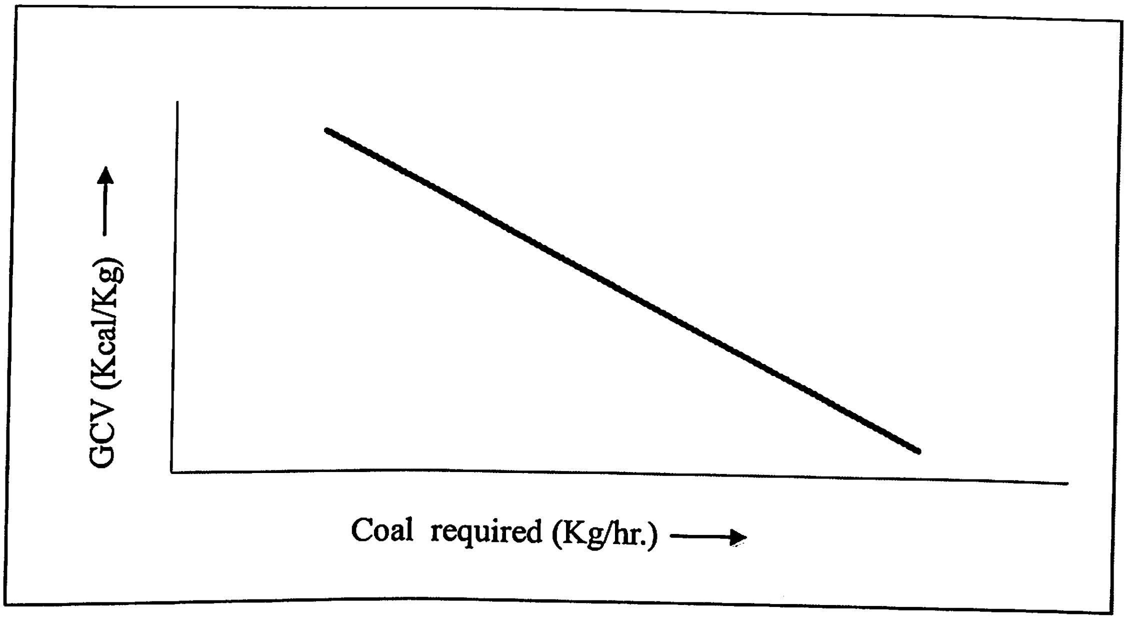


Figure 3.8: Coal requirement based on gross calorific value

The quantity of coal required for generating the desired power is mainly depend on the higher heating value. Coal requirement is inversely proportional to the higher heating value. If the carbon content in coal is more, then the higher heating value is more. With high heating value of fuel, the kg of coal required per KW of power output will be less. Similarly, low heating value the coal requirement will increase. The increase in coal quantity will also increase the transportation, storage and handling cost.

3.11 Ash vs. coal consumption

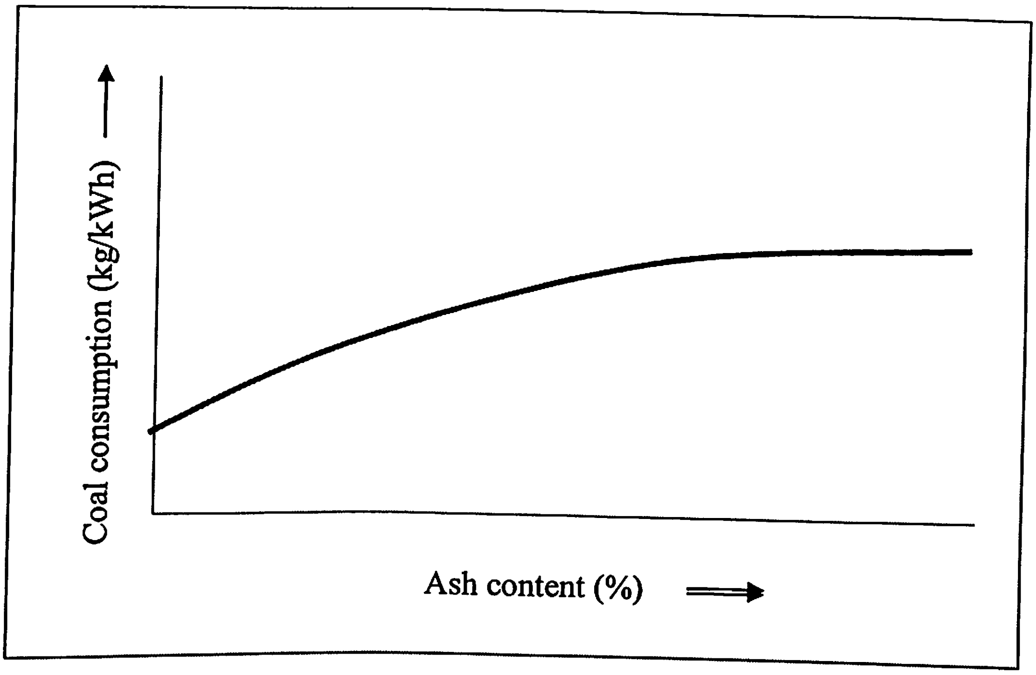


Figure 3.9: Profile of Coal Consumption with increase in ash content

Fig 3.9 shows the change in coal consumption with respect to ash content present in fuel. Coal consumption is directly depending on the ash content present in fuel. With higher ash content present in fuel, the higher heating value or GCV decreases. GCV becomes “zero” at very high ash content i.e. about 80 to 90%, av. being 88%. Decrease in GCV means the heat content present fuel in the form of carbon is very low. Due to this, the consumption of coal will increase.

3.12 Components of efficiency

Boiler efficiency, when calculated by the ASME heat balance method, includes stack losses and radiation and convection losses. The basic boiler design is the major factor. However, there is room for interpretation when calculating efficiency. The following are the key factors to understanding efficiency calculations.

a. Flue Gas Temperature

Flue gas temperature or "stack temperature" is the temperature of the combustion gases as they exit the boiler. The flue gas temperature must be a proven value for the efficiency calculation to be reflective of the true fuel usage of the boiler. A potential way to manipulate an efficiency value is to utilize a lower-than-actual flue gas temperature in the calculation. If a boiler is represented to be 85% efficient firing coal, follow the 85% on the left to the coal line and down to the flue gas temperature. The result is approximately 270 deg F. This shows the boiler would have to operate at a 270 deg. F. stack temperature to meet the 85% efficiency.

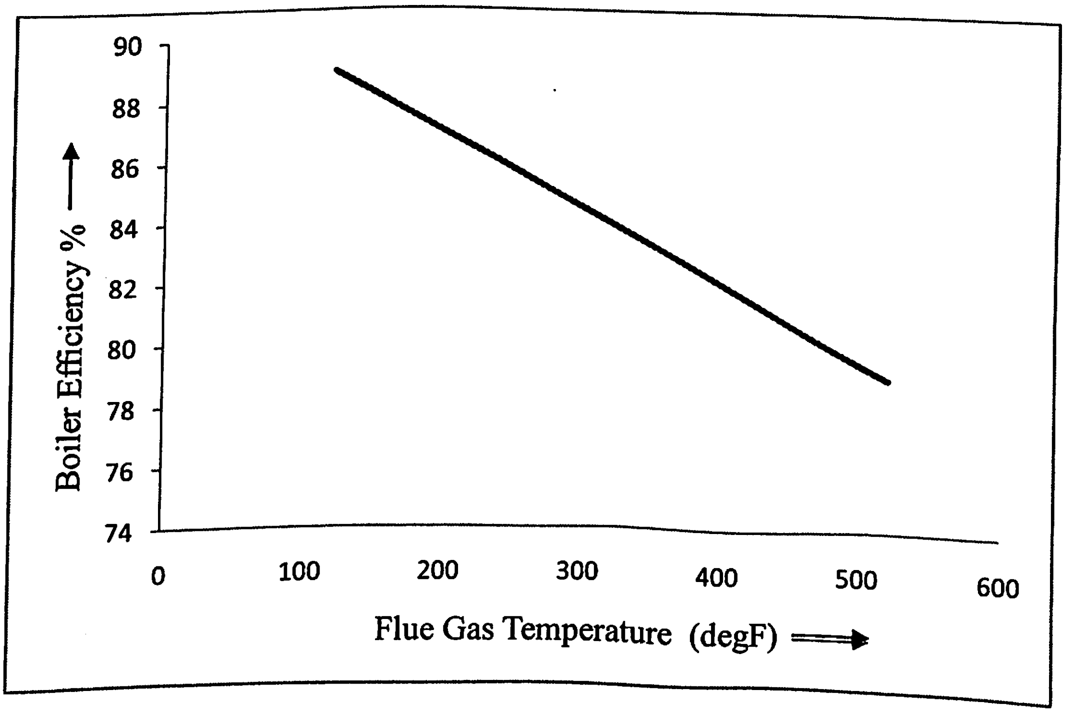


Figure 3.10: Fuel-To-Boiler Efficiency VS. Flue Gas Temperature

b. Fuel specification

The fuel specification can also have a dramatic effect on efficiency. In the case of coal, the higher the hydrogen content, the more water vapor is formed during combustion. This water vapor uses energy as it changes phase in the combustion process. Higher water vapor losses when firing the fuel result in lower efficiency. To get an accurate efficiency calculation, a fuel specification that represents the jobsite fuel to be fired must be used. When reviewing an efficiency guarantee or calculation, check the fuel specification.

c. Excess Air

Excess air is the extra air supplied to the burner beyond the required air for complete combustion of the fuel. Excess air is supplied to the burner because a boiler firing without sufficient air, or “fuel rich”, is operating in a potentially dangerous condition. Therefore, excess air is used to provide a safety factor above the theoretical air required for combustion. In ultra-low emission burners, excess air is also used to eliminate CO production and particulate, and reduce the formation of oxides of nitrogen (NOx) to very low levels by controlling the temperature of the flame. Because excess air is heated by the flame, it takes energy away from combustion, thus taking away potential energy for transfer to the water in the boiler. In this way, excess air reduces boiler efficiency. A quality design will allow firing at minimum excess air levels of 15% for a conventional burner and 25% for ultra-low emissions burner. Seasonal changes in temperature and barometric pressure can cause the excess air in a boiler to fluctuate 5% - 10%. Furthermore, firing at low excess air levels can result in high CO and boiler sooting.

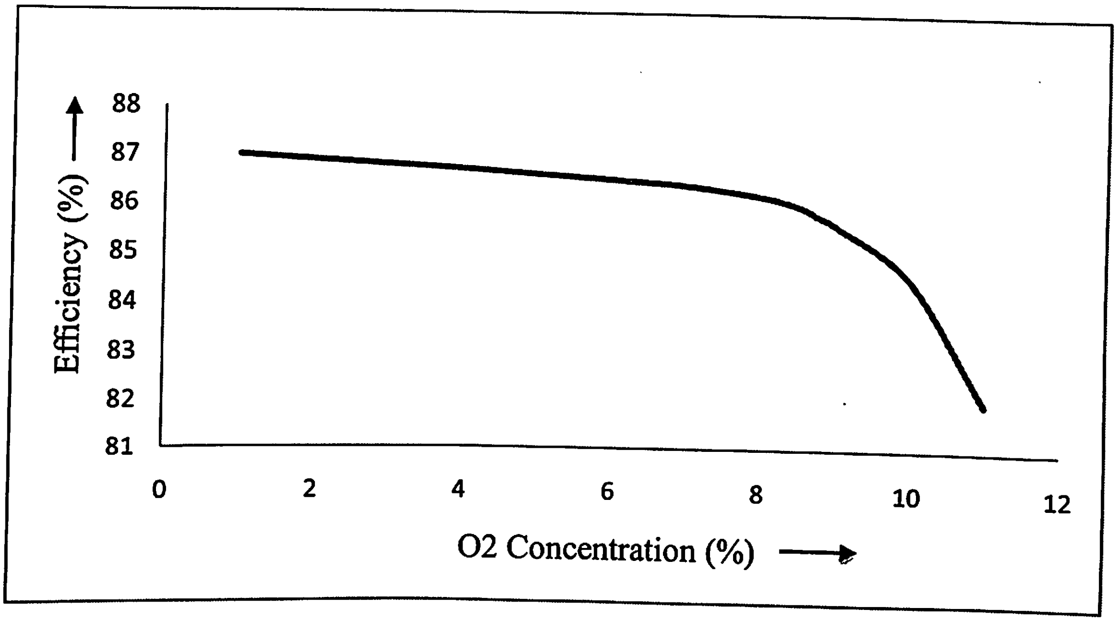


Figure 3.11: Effect of O_2 concentration on Boiler Efficiency

d. Air-Fuel Ratio

The efficiency of the boiler depends on the ability of the burner to provide the proper air to fuel mixture throughout the firing rate, day in and day out.

The density of air and gaseous fuels changes with temperature and pressure, a fact that must be taken into account in controlling the air-to-fuel ratio. For example, if pressure is fixed, the mass of air flowing in a duct will decrease when the temperature increases. The controls should therefore compensate for seasonal temperature variations and, optimally, for day and night variations too (especially during the spring and fall when daily temperature variations are substantial).

The figure below shows that the effect of air temperature on excess air in the flue gas can be dramatic.

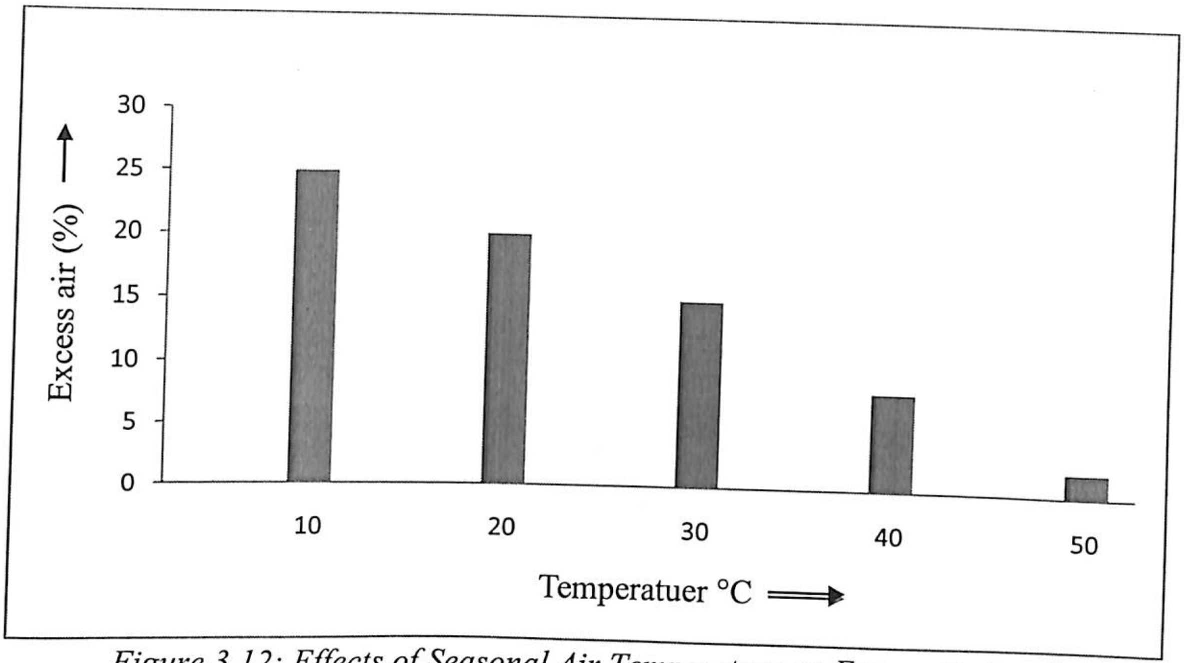


Figure 3.12: Effects of Seasonal Air Temperature on Excess Air Level

3.13 Combustion calculation

Combustion is defined as the rapid chemical combination of oxygen with the combustible elements of a fuel. A boiler requires a source of heat at a sufficient temperature to produce steam. Coal is generally burned directly in the boiler furnace to provide this heat. There are just three combustible elements of significance in most fossil fuels: carbon, hydrogen and sulfur. Sulfur, usually of minor significance as a heat source, can be a major contributor to corrosion and pollution problems. The objective of good combustion is to release all of the energy in the fuel while minimizing losses from combustion imperfections and excess air. The combination of the combustible fuel elements and compounds in the fuel with all the oxygen requires temperatures high enough to ignite the constituents, mixing or turbulence to provide intimate oxygen-fuel contact, and sufficient time to complete the process, sometimes referred to as the three T's of combustion.

a. Humidity in air

Humidity is defined as the mass of water vapors present in the same mass of dry air. Humidity is depending on the ambient temperature, relative humidity and saturated steam pressure at ambient temperature. Air normally contains some moisture. As standard practice, considers moisture content to be 0.013 lb water/lb dry air, which corresponds to approximately 60% relative humidity at 27°C. The moisture content in air is normally determined from wet and dry bulb temperatures or from relative humidity using a psychrometric chart. Air moisture may also be calculated from:

$$W = 0.622 * \frac{Pv}{Pb - Pv}$$

Where

W = moisture content in air, kg /kg

P_b = barometric pressure, kg/cm2

P_v = partial pressure of water vapor in air, kg/cm2

= 0.01 (RH) (P_{vd}), kg/cm2

P_{vd} = saturation pressure of water vapor at dry bulb temperature, kg/cm2

RH = relative humidity, %

b. Excess air

For commercial applications, more than theoretical air is needed to assure complete combustion. This excess air is needed because the air and fuel mixing is not perfect. Because the excess air that is not used for combustion leaves the unit at stack temperature, the amount of excess air should be minimized. The energy required to heat this air from ambient to stack temperature usually serves no purpose and is lost energy. Typical values of excess air required at the burning equipment are different for different fuels and methods of firing.

c. Unburned carbon loss

For design of a unit, this is normally estimated based on historical data and/or combustion models. For an efficiency test, this item is calculated from measured un-burned carbon in the residue.

d. Combustion air

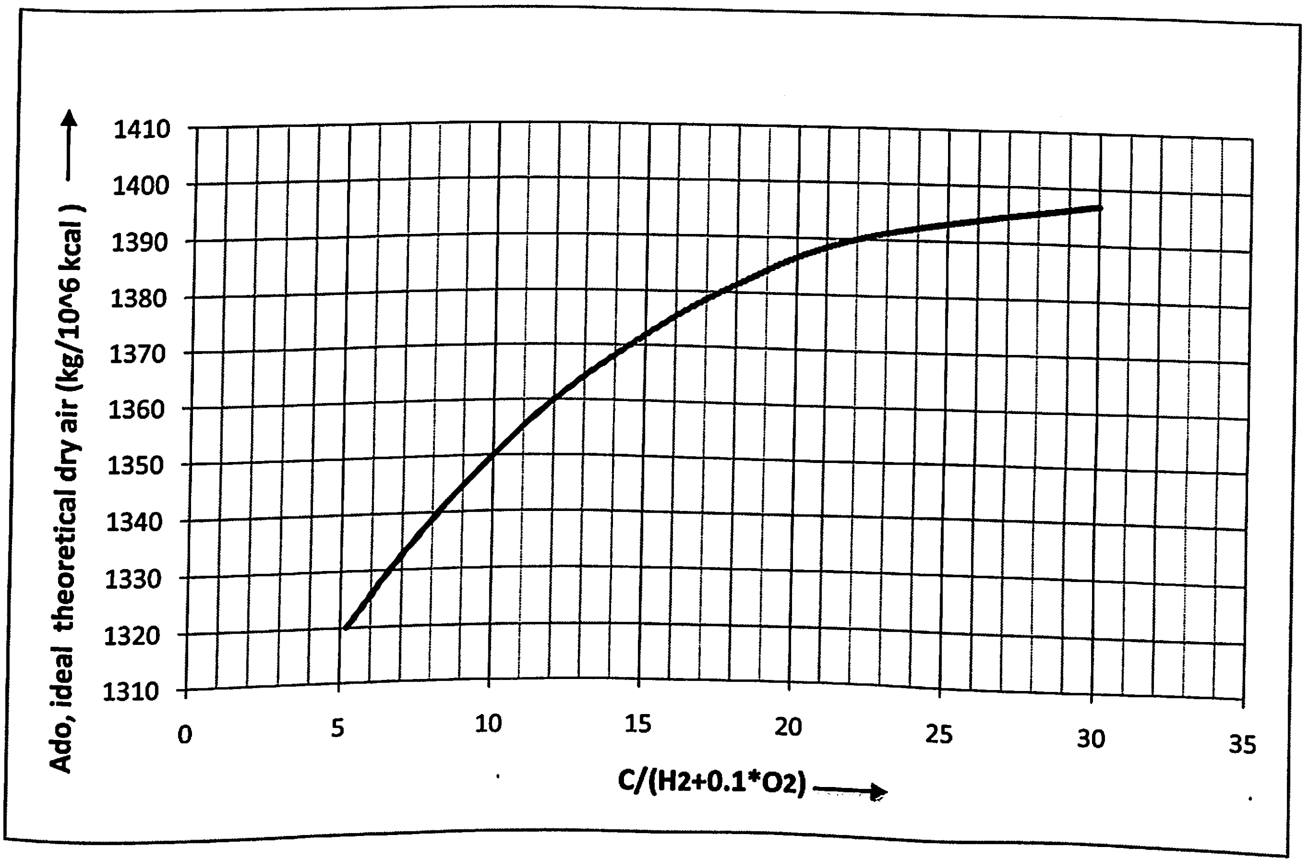


Figure 3.13: Estimation of Ideal Theoretical Air based for combustion calculation

The combustion air is the total air required for the burning equipment; it is the theoretical air plus the excess air. Theoretical air is the minimum air required for complete conversion of the carbon, hydrogen and sulfur in the fuel to standard products of combustion. For some fuels and/or combustion processes, all of the carbon is not converted. In addition, when limestone or other additives are used, some of the sulfur is not converted to sulfur dioxide. However, additional air is required for the conversion of sulfur dioxide to sulfur trioxide in the sulfation reaction ($CaO+SO_4+{}^1/_2O_2 \rightarrow CaSO_4$). Because the actual air required is the desired calculation result, the theoretical air is corrected for unburned carbon and sulfation reactions.

Theoretical air = 11.51*C + 34.29*H2 + 4.31*S - 4.32*O2 kg/Gcal

Actual air = Theoretical Air * (1+% EA/100)

kg/Gcal

Where

EA = Percent Excess air, %

C = Carbon in fuel, %

H_2 = Hydrogen in fuel, %

S = Sulphur in fuel, %

O_2 = Oxygen in fuel, %

Fuel constituents	% by wt.	Molecular weight	Combustion product	Theoretical air required
C	30.87	12.01	CO_2	2.57
H2	3.4	2.01	H2o	1.69
S	0.4	32.06	SO_2	0.012
O_2	8.25	31.99		0.26
N_2	1.5	28.01	N_2	0.00
H_2O	15	18.01	H_2O	0.00
Ash	40			
Total	100			4.54

Table 3.9: Calculation of Combustion Products and Theoretical Oxygen Requirement

e. Flue gas

The total gaseous products of combustion are referred to as wet flue gas. Solid products or residue are excluded. The wet flue gas flow rate is used for heat transfer calculations and design of auxiliary equipment. The total gaseous products excluding moisture are referred to as dry flue gas; this parameter is used in the efficiency calculations and determination of flue gas enthalpy. The wet flue gas is the sum of the wet gas from fuel (fuel less ash, unburned carbon and sulfur captured), combustion air, moisture in the combustion air, additional moisture such as atomizing steam and, if sorbent is used, carbon dioxide and moisture from sorbent. Dry flue gas is determined by subtracting the summation of the moisture terms from the wet flue gas. Wet gas from fuel is the mass of fuel less the ash in the fuel, less the percent unburned carbon and, when sorbent is used to reduce SO2 emissions, less the sulfur captured.

$$\text{Dry gaseous products} = GPC - MF - MCF - MA \qquad \text{kg/Gcal}$$

Where

GPC = Gaseous products of combustion (wet), kg/Gcal

MF = Moisture in fuel, kg/Gcal

MCF = Moisture from combustion of fuel, kg/Gcal

MA = Moisture in air, kg/Gcal

CHAPTER 4: COAL MILL HEAT BALANCE AND AIR PREHEATER

4.1 Coal mill

The coal is fed to the coal mill through the central inlet pipe. The coal is pulverized on the rotating grinding table by the rollers. The pulverized coal is then blown up and the moisture content is evaporated by the hot primary air. The primary air is mixed by cold outside air and heated outside air, which is heated by the furnace. The ratio of these air flows are used to control the temperature of the primary air flow.

4.2 Principles of operation

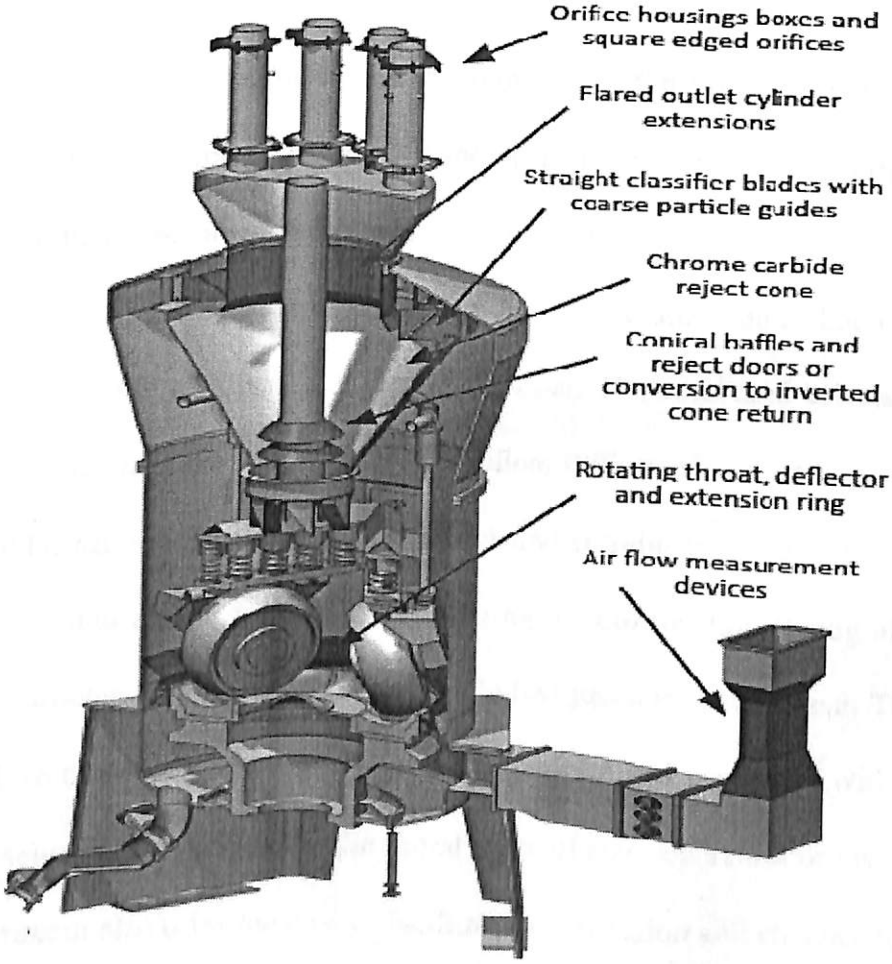


Figure 4.1: Typical Coal Pulverizer with components

The elements of a rolling action grinding mechanism are shown above. The roller passes over a layer of granular material, compressing it against a moving table. The movement of the roller causes motion between particles, while the roller pressure creates compressive loads between particles. Motion under applied pressure within the particle layer causes attrition (particle breakup by friction) which is the dominant size reduction mechanism. The compressed granular layer has a cushioning influence which reduces grinding effectiveness but also reduces the rate of roller wear dramatically. When working surfaces in a grinding zone are close together, near the dimensions of single product particles, wear is increased by three body contact (roller, particle and table). Wear rates can be as much as much as 100 times those found in normal pulverizer. Wear from the three body contact has also been observed in operating mills when significant amounts of quartz bearing rock are present in sizes equal to or greater than the grinding layer thickness.

As grinding proceeds, fine particles are removed from the process to prevent excessive grinding, power consumption and wear. As shown in figure, the table is turned from below and elements, in this case called roll wheels, rotate against the table. Raw coal is fed into the mill from above and passes between the rollers and the rotating table. Each passage of the particles under the rollers reduces the size of the coal. The combined effects of centrifugal force and displacement of the coal layer by the rollers spills partly ground coal off the outside edge of the table. An upward flow of air fluidizes and entrains this coal. The point where air is introduced is often called the throat, airport ring, or nozzle ring. Rising air flow, mixed with the coal particles, creates a fluidized particle bed just above the throat. The air velocity is low enough so that it entrains only the smaller particles and percolates with them through the bed. This selective entrainment is the initial stage of size separation or classification. The preheated air stream also dries the coal to facilitate pulverization and enhance the combustion process. Vertical pulverizers are effective drying devices. Coals with moisture content up to 40% have been successfully handled in vertical mills. Higher moisture coals could be pulverized, but the very high primary air temperature needed would require special structural materials and would increase the chance of pulverizer fires. A practical moisture limit is 40%, by weight, requiring mill inlet air temperatures up to 400°C. As the air-coal mixture flows upward, the flow area increases and velocity decreases, allowing gravity to return the larger particles to the grinding zone for the second stage of size separation. The final stage of size separation is provided by the classifier located at the top of the pulverizer. This device is a centrifugal separator.

4.3 Pulverizer systems

Pulverizers are part of larger systems, normally classified as either direct-fired or storage. In direct firing, coal leaving each mill goes directly to the combustion process. The air, evaporated moisture, and the thermal energy which entered the mill, along with the ground coal, all become part of the combustion process. Storage systems separate the ground coal from the air or gas, evaporated moisture and the thermal energy prior to the combustion process. Stored ground coal is then injected with new transport air or gas to the combustion process. Bin storage systems are seldom used in steam generation today, but are still used with special technologies such as coal gasification and blast furnace coal injection. Today, most of the pulverizers in service are used in direct-fired systems.

The essential elements of a direct-fired system are:

1. A raw coal feeder that regulates the coal flow from a silo or bunker to the pulverizer,
2. A heat source that preheats the primary air for coal drying,
3. A pulverizer (primary air) fan that is typically located ahead of the mill (pressurized mill).
4. A pulverizer, configured as either a pressurized or suction unit,
5. Piping that directs the coal and primary air from the pulverizer to the burners,

6. Burners which mix the coal and the balance of combustion air, and

7. Controls and regulating devices.

These components can be arranged in several ways based on project economics. With pressurized pulverizers, the choice must be made between hot primary air fans with a dedicated fan for each mill, or cold fans located ahead of a dedicated air heater and a hot air supply system with branches to the individual mills. Hot fan systems have a lower capital cost because a dedicated primary air heater is not required. Cold fan systems have lower operating costs which, on larger systems, may offset the higher initial cost. The terminology for air-swept pulverizers refers to the air introduced for drying and transport as primary air. Control of primary air is of vital importance to proper pulverizer system operation. Primary air must be controlled for flow rate and pulverizer outlet temperature. This control can be achieved by three inter-related dampers. Hot and cold air dampers regulate air temperature to the mill and these dampers are often linked so that as one opens, the other closes. The third damper independently controls air volume. On cold fan systems, modern controls allow flow and temperature control with just the hot and cold air dampers, eliminating the need for the independent flow control damper, thus reducing cost with no loss of controllability. Because direct-fired pulverizers are closely linked to the firing system, engineering must coordinate the design performance of the mills and burners.

For bituminous coals burned in water-cooled enclosures, a fineness of 70% passing through 200 mesh (74 microns) or better is traditionally required. This value is suitable for good combustion efficiency with conventional combustion systems. Coarse particles, those larger than 100 mesh (150 microns), are primary contributors to unburned carbon loss. With traditional stationary classifiers it may be necessary to maintain fineness above 70% passing 200 mesh for acceptable unburned carbon loss.

4.4 Pulverizer design requirements

Many different pulverizer designs have been applied to coal firing. Successful designs have met certain fundamental goals and requirements:

1. Optimum fineness for design coals over the entire pulverizer operating range.
2. Rapid response to load changes.
3. Stable and safe operation over the entire load range.
4. Ability to handle variations in coal properties.
5. Minimum building volume.

4.5 Outlet temperature for mill

Coal with low volatile content may require higher air-coal temperatures to assure stable combustion, especially at lower burner inputs or low furnace loads. The typical pulverizer exit temperature is 73°C. Higher temperatures, up to 99°C for coal, may be used if needed. Higher temperatures require care in the selection of internal lubricants and soft seal materials. In addition, high outlet temperatures require high inlet temperatures which increase the risk of pulverizer fires. Usually, 82°C is adequate to assure drying of coal having raw coal moisture up to 10%. For direct firing, the outlet temperature requirements are determined by volatile content and the need for stable combustion.

Fuel Type	**Volatile Content, %**	**Exit Temperature F (°C)**
High volatile bituminous	Above 31	40 to 175 (60 to 79)
Medium and low volatile bituminous	14 to 31	160 to 200 (71 to 93)
Anthracite	0 to 14	200 to 210 (93 to 99)

Table 4.1: lists mill outlet temperatures for various coal types.

4.6 Derivation for Mill Heat Balance

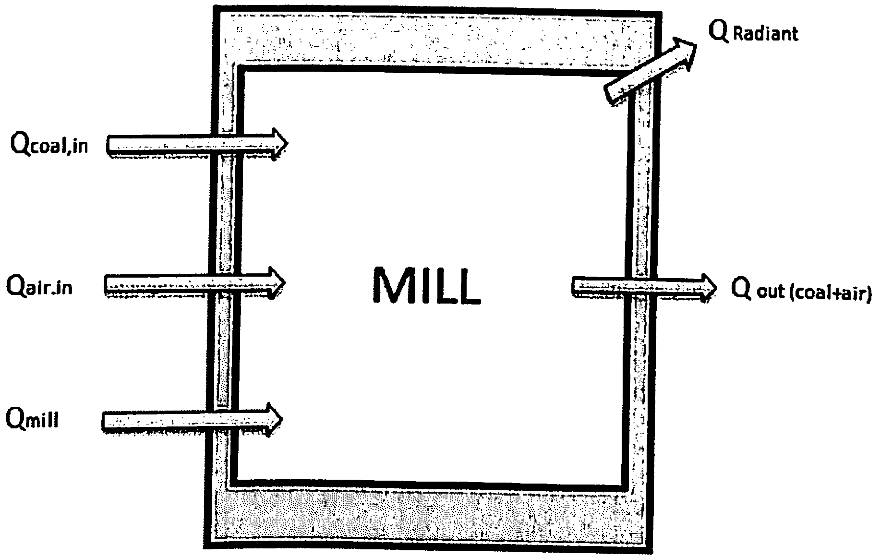


Figure 4.2: Heat balance model of coal mill

For heat balance of coal mill assume coal mill as one body. The above diagram shows the mill heat balance system. The heat exchange is between the coal mill body and coal. The coal body includes mainly the roller and rotating table, etc. A known mass of raw coal enters into the mill at ambient temperature and exit at required temperature. Coal with low volatile matter requires higher air-coal temperature to assure stable combustion, especially at low furnace loads. Mostly the pulverizer exit temperature is around 70°C to 75 °C.

Higher temperature up to 210F (99°C) for coal, may be used, if needed. Special care of lubricants and seal materials is required in case of higher temperature. Also, higher exit temperatures require higher inlet temperatures which increase the risk of mill fires.

In this model, it is assumed that the input coal flow is equal to the output coal flow. The heat balance is given by

$$Q_{air,\ in} + Q_{coal,\ in} + Q_{mill} + Q_{seal\ air} = Q_{pf,\ out} + Q_{air,\ out} + Q_{moisture} \qquad (1)$$

$$Q_{air,\ in} = Q_{pf,\ out} + Q_{air,\ out} + Q_{moisture} - Q_{seal\ air} - Q_{coal,\ in} - Q_{mill} \qquad (2)$$

The output heat carried by the pulverized coal at mill outlet can be expressed by

$$Q_{pf,\,out} = m_{pf} \cdot C_{pf} \cdot T_o \tag{3}$$

The output heat carried by the primary air at mill outlet can be expressed by

$$Q_{air,\,out} = W_a \cdot C_a \cdot T_o \tag{4}$$

The heat required to remove the required moisture from the raw coal can be expressed by

$$Q_{moisture} = W_{out} \cdot C_m \cdot (T_{out} - T_{in}) \tag{5}$$

The heat loss of the grinding motor in the mill can be represented as,

$$Q_{mill} = 6.86 \text{ kCal / kg of coal} \tag{6}$$

Here, we are assuming that the heat loss in mill per kg of coal is 6.86 for this type of mill.

The input heat is carried by the primary air flow $Q_{air,\,in}$, the coal flow $Q_{coal,\,in}$, $Q_{seal\ air,\,in}$, and the heat loss of grinding motor in the mill. They can be expressed as

$$Q_{seal\ air,\,in} = W_{sa} \cdot C_{sa} \cdot T_{in} \tag{7}$$

$$Q_{coal,\,in} = W_{rc} \cdot C_{rc} \cdot T_{in} \tag{8}$$

The heat radiant from the equivalent mass to mill body can be expressed by

$$Q_{radiant} = k_e \cdot (T_o - T_{mill}) \tag{9}$$

Where, T_{mill} denotes the temperature of coal mill body and k_e is a heat transfer constant [kW/°K]. In practice, the constant k_e depends on the inner surface area of the mill and its material.

Substituting equations (3) ~ (9) into (10) yields,

$$m_{pf}.C_{pf}.T_o = m_a.C_a.T_{in} + m_{rc}.C_{rc}.T_{in} + C_{mot}.I_{mot} - m_{evp}.C_m.\ (T_o - T_{m,\,in}) - k_e.\ (T_o - T_{mill}) \quad (10)$$

Mill inlet temperature, °C

Specific heat of air at T_i, kCal / kg °

Hot Primary air temperature

$$Q_{hot\ pa} + Q_{temp} = Q_{mill\ inlet}$$

$$W_{hpa}*C_{paph}*T_{hpa} + W_{temp}*C_{papc}*T_{temp} = W_i*C_{pai}*T_i$$

Heat input from APH

Air heaters are used in most steam generating plants to heat the combustion air and enhance the combustion process. Most frequently, the flue gas is the source of energy and the air heater serves as a heat trap to collect and use waste heat from the flue gas stream. This can increase the overall boiler efficiency by 5 to 10%. Air heaters can also use extraction steam or other sources of energy depending upon the particular application. These units are usually employed to control air and gas temperatures by preheating air entering the main gas-air heaters. Air heaters are typically located directly behind the boiler, where they receive hot flue gas from the economizer and cold combustion air from the forced draft fan(s). The hot air produced by air heaters enhances combustion of all fuels and is needed for drying and transporting the fuel in pulverized coal-fired units. In supercritical boilers, generally the temperature of hot flue gas received from the economizer is around 350°C and the outlet temperature from air preheaters is 125°C.

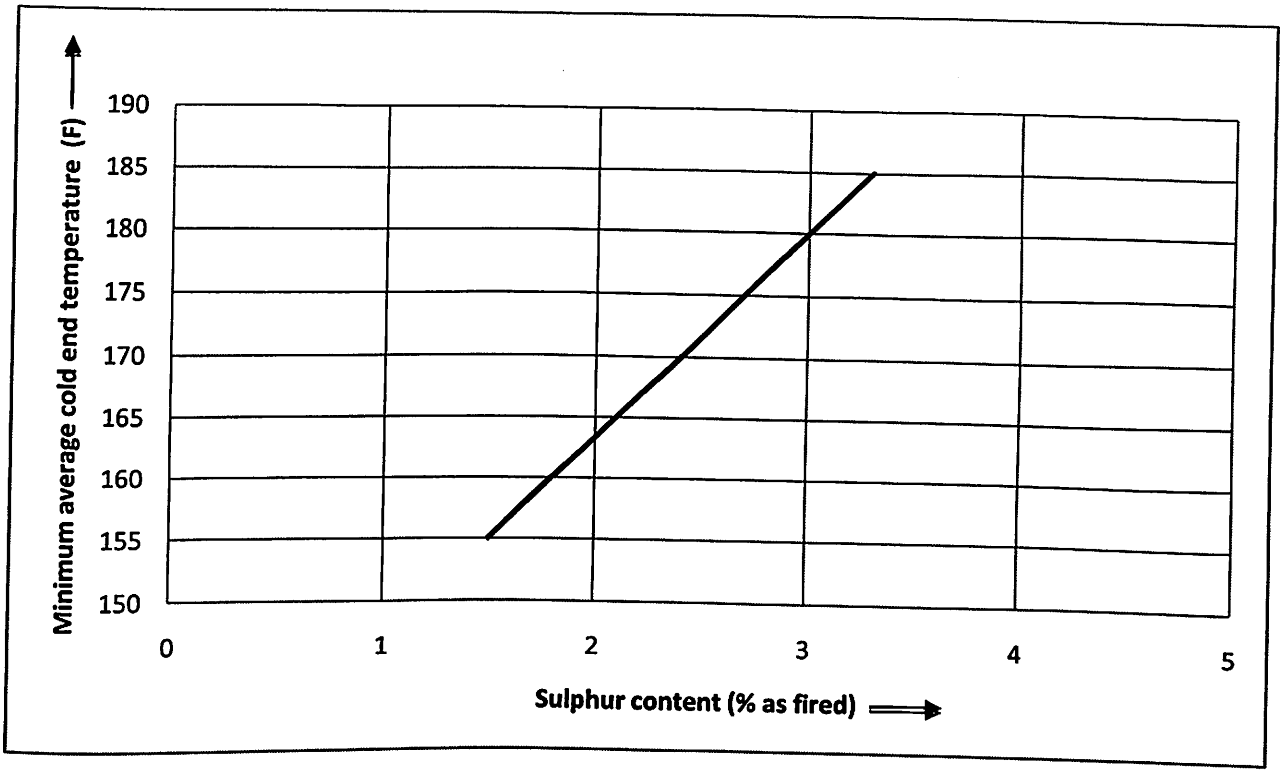


Figure 4.3: Recommended Minimum average cold end temperature (F)

Air heaters used on units firing sulfur bearing fuels are subject to cold end corrosion of heating elements and nearby structures. In a boiler, a portion of the sulfur dioxide (SO_2) produced is converted to sulfur trioxide (SO_3) which combines with moisture to form sulfuric acid vapor. This vapor condenses on surfaces at temperatures below its dew point of 125°C.The above graph shows the minimum average cold end temperature (F) against the Sulphur content present in fuel. Normal air heater cold end metal temperatures are frequently as low as 200F (93C), acid dew point corrosion potential exists. The obvious solution would be to operate at metal temperatures above the acid dew point but these results in un-acceptable overall boiler heat losses.

4.7 Mill Heat Balance Calculation

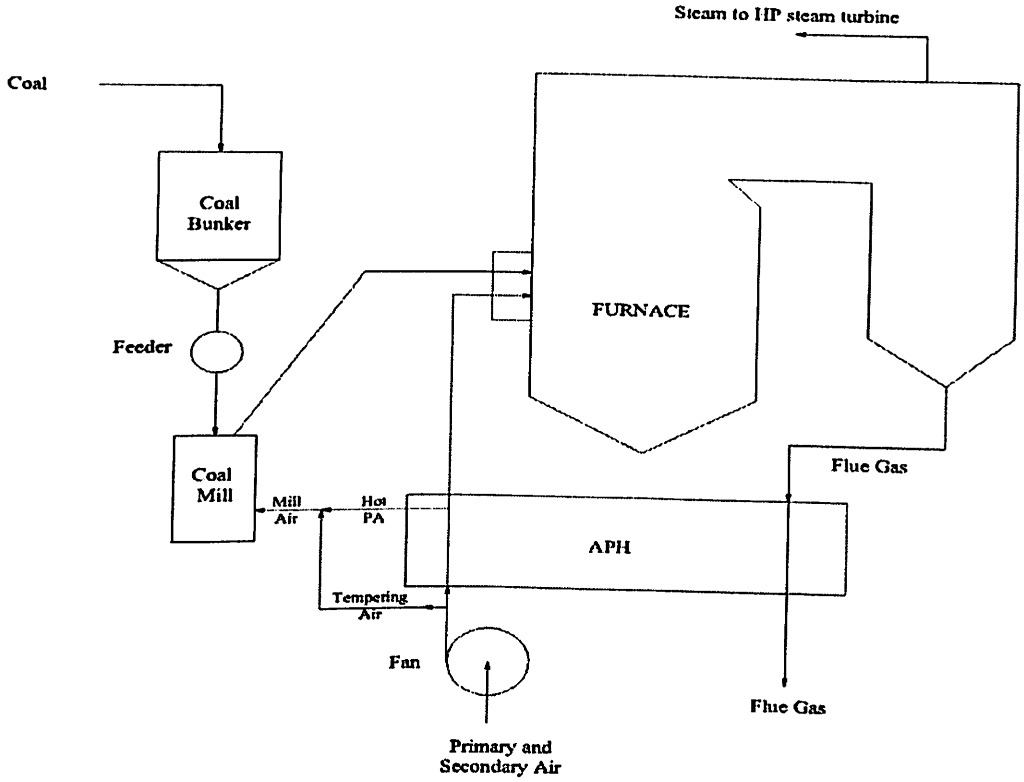


Figure 4.4: Air and Flue Gas path for Mill Heat Balance

$$Q_{air,\,in} + Q_{coal,\,in} + Q_{mill} + Q_{seal\,air} = Q_{pf,\,out} + Q_{air,\,out} + Q_{moisture} \qquad (1)$$

$$Q_{air,\,in} = Q_{pf,\,out} + Q_{air,\,out} + Q_{moisture} - Q_{seal\,air} - Q_{coal,\,in} - Q_{mill} \qquad (2)$$

Air flow rates

No. of operating mills = 6

Total Primary Air to mills, W_{tpa} = 674100 kg/hr. (Assume)

Primary air flow, W_{pa} = 112350 kg/hr./mill

Tempering air flow, W_t = 47187 kg/hr.

Hot 1ry air flow, W_h = 626913 kg/hr.

Seal air flow, W_{se} = 6500 kg/hr. (Used)

The heat carried by the pulverized coal at mill outlet can be expressed by

$Q_{pf,\ out}$ $= W_{pf}.\ C_{pf}.T_o$

$= 70632*0.30*73$

$= 1546840$ kCal/ hr. (3)

Where,

W_{pf} = mass of pulverized coal, 70632 kg/hr./mill

C_{pf} = Specific heat constant at outlet, 0.30 kCal / kg °C

T_o = Outlet temperature of mill, 73 °C

The heat carried by the primary air at mill outlet can be expressed by

$Q_{air,\ out}$ $= W_a.\ C_a.T_o$

$= 112350*0.2431*73$

$= 1993797$ kCal/ hr. (4)

Where,

W_a = mass of pulverized coal, 112350 kg/hr. (Assume)

C_a = Specific heat constant at outlet, 0.2431 kCal / kg °C

T_o = Outlet temperature of mill, 73°C

The heat required to remove the required moisture from the raw coal can be expressed by

$Q_{moisture}$ $= W_{out} \cdot C_m \cdot (T_{out} - T_{in})$

$= 2740 * 1 * (73-27)$

$= 126040$ kCal/hr. (5)

Where,

W_{out} = moisture at outlet, 0.0388 kg/ kg of coal = 2740 kg/hr.

C_m = Specific heat constant of moisture in coal at inlet, 1 kCal / kg °C

T_{out} = coal outlet temperature, 73°C

T_{in} = coal inlet temperature, 27°C

The heat loss of the grinding motor in the mill can be represented as,

Q_{mill} = 6.86 kCal / kg of coal

$= 6.86 * 70631$

$= 484542$ kCal/hr. (6)

Here, we are assuming that the heat loss in mill per kg of coal is 6.86 for this type of mill.

The input heat is carried by the primary air flow $Q_{air, in}$, the coal flow $Q_{coal, in}$, $Q_{seal air}$, in, and the heat loss of grinding motor in the mill. They can be expressed as

$Q_{seal air, in}$ $= W_{sa} \cdot C_{sa} \cdot T_{in}$

$= 6500 * 0.2429 * 37$

$= 58417$ kCal/hr. (7)

$Q_{coal, in}$ $= W_{rc} . C_{rc} . T_{in}$

$= 70632*0.30*27$

$= 572120$ kCal/ hr. (8)

Where,

W_{sa} = primary air flow, 6500 kg/hr.

C_{sa} = Specific heat constant of air at inlet, 0.2429 kCal / kg °C

T_{in} = seal air temperature, 37°C

W_{rc} = raw coal flow, 70632 kg/hr./mill

C_{rc} = Specific heat constant of coal at inlet, 0.30 (kCal / kg °C)

T_{in} = raw coal temperature, 27°C

The raw coal flow m_{rc} usually contains water and the coal specific heat constant C_{rc} varies with moisture content.

The heat radiant from the equivalent mass to mill body can be expressed by

$Q_{radiant}$ $= k_e . (T_o - T_{mill})$ (9)

Where, T_{mill} denotes the temperature of coal mill body and k_e is a heat transfer constant [kW/°K]. In practice, the constant k_e depends on the inner surface area of the mill and its material.

Substituting equations (3) ~ (9) into (2), we get

Mill inlet temperature, T_i = 217 °C

Specific heat of air at T_i = 0.2460 kCal / kg °C

Hot Primary air temperature

Tempering air temperature, t_{pc} = 37°C

Specific heat of air at t_{pc} = 0.2429kCal / kg °C

Tempering air flow, W_t = 47187 kg/hr.

Hot 1ry air flow, W_h = 626913kg/hr.

Total Mill inlet air flow, W_{tpa} = 674100kg/hr.

Specific heat of air at t_{ph} = 0.2455kCal / kg °C

$$Q_{hot\ pa} + Q_{temp} = Q_{mill\ inlet}$$

$$W_{hpa}*C_{paph}*T_{hpa} + W_{temp}*C_{papc}*T_{temp} = W_i*C_{pai}*T_i$$

$$T_{hpa} = \frac{(674100*0.2460*217) - (47187*0.2429*37)}{(0.2455*626913)}$$

Hot Primary air temperature, T_{hpa} = 231°C

Heat Gain from Flue gas in APH

Heat exchanged, $Q_{\text{flue gas}}$ $= W_g*((C_{pi}*T_{gi}) - (C_{po}*T_{go}))$

$= 2298511*(0.2659*350 - 0.2586*125)$

$= 140$Gcal/kg

Where,

AH flue gas flow, W_g = 2298511 kg/hr.

AH inlet gas temperature, T_{gi} = 350°C

Specific heat at inlet, C_{pi} = 0.2659 kCal / kg °C

AH outlet gas temperature, T_{go} = 125°C

Specific heat at outlet, C_{po} = 0.2586 kCal / kg °C

Secondary air outlet temperature from Heat balance of APH

$$Q_{\text{flue gas}} = Q_{\text{hot pa}} + Q_{\text{secondary air}}$$

$$W_g*(C_{pgo}*T_{go} - C_{pgi}*T_{gi}) = W_{hpa}*C_{paph}*T_{hpa} + W_{sa}*(C_{psao}*T_{sao} - C_{psao}*T_{sao})$$

$$140*10^6 - (626913*0.2455*231) = 1639830*(0.2460*T_{sao} - 0.2428*30)$$

Secondary air outlet temperature, T_{sao}= 288°C

CHAPTER 5: RESULTS / DISCUSSION

To size the components for power plant, calculations have been performed. The calculations results in the sizing of boiler and coal mill. Boiler heat output, Steam flow rates and reduction in Heat Rate along with the operating cost saving potentials have been determined for Subcritical and supercritical plant. Also the calculations for sizing of coal mill have been performed. This chapter outlines the results for both the plants and further emphasis is drawn upon the saving opportunities.

5.1For Heat balance diagram

Description		Unit	Supercritical 660MW	Subcritical 600MW
Main Steam Flow		kg/h	1918600	1802451
RH Steam Flow		kg/h	1612600	1597965
SH out	Pressure	MPa (g)	24.85	18.10
	Temperature	Deg C	568	540
HP-T in	Pressure	MPa (g)	24.12	17.12
	Temperature	Deg C	565	537
IP-T in	Pressure	MPa (g)	4.88	4.00
	Temperature	Deg C	593	537
Feed Water in	Temperature	Deg C	290	253.50
	Flow	kg/h	1918600	1802451

Subcritical

Boiler heat output $= W_{SH} (h_{so} - h_{fw}) + W_{RH} (h_{ro} - h_{ri})$

$= 1802451 (3388 - 1103) + 1597965 (3533 - 3051)$

$= 4889$ GJ/hr.

Heat Rate or Heat Duty $= \frac{WSH (hso - hfw) + WRH (hro - hri)}{\text{Plant capacity}}$

$= \frac{1802451 (3388 - 1103) + 1597965 (3533 - 3051)}{600}$

$= 8.148$ GJ/MWh

Supercritical

Boiler heat output $= W_{SH} (h_{so} - h_{fw}) + W_{RH} (h_{ro} - h_{ri})$

$= 1918600 (3398 - 1278) + 1612600 (3654 - 3020)$

$= 5090$ GJ/hr.

Heat Rate or Heat Duty $= \frac{WSH (hso - hfw) + WRH (hro - hri)}{\text{Plant capacity}}$

$= \frac{1918600 (3398 - 1278) + 1612600 (3654 - 3020)}{660}$

$= 7.713$ GJ/MWh

Saving potentials

Basis

Fuel : Indian coal with 40 % ash

Fuel GCV : 3300 kCal/kg (Design coal)

Description	Unit	Subcritical 600 MW	Supercritical 600MW	Reduction
Boiler heat duty	GJ / MWh	8.15	7.71	0.44
Heat rate	kCal / kWh	1947	1842	105 (5%)
Boiler efficiency	%	87	87	0
Coal consumption	MMT/Annum	3.90	3.71	0.19
CO_2	MMT/Annum	4.42	4.21	0.21
SO_2	MMT/Annum	0.0311	0.0296	0.0015

Cost Benefits

Fuel

Reduction in coal consumption : 0.19 MM T / Annum

Coal cost : Rs. 750 / T

Reduction in coal cost : Rs.14 crores (approx.) per annum

CO_2

Reduction in CO2 generation : 0.21 MM T /Annum

Carbon credit benefit : 6 Euro / MT of CO2 reduction

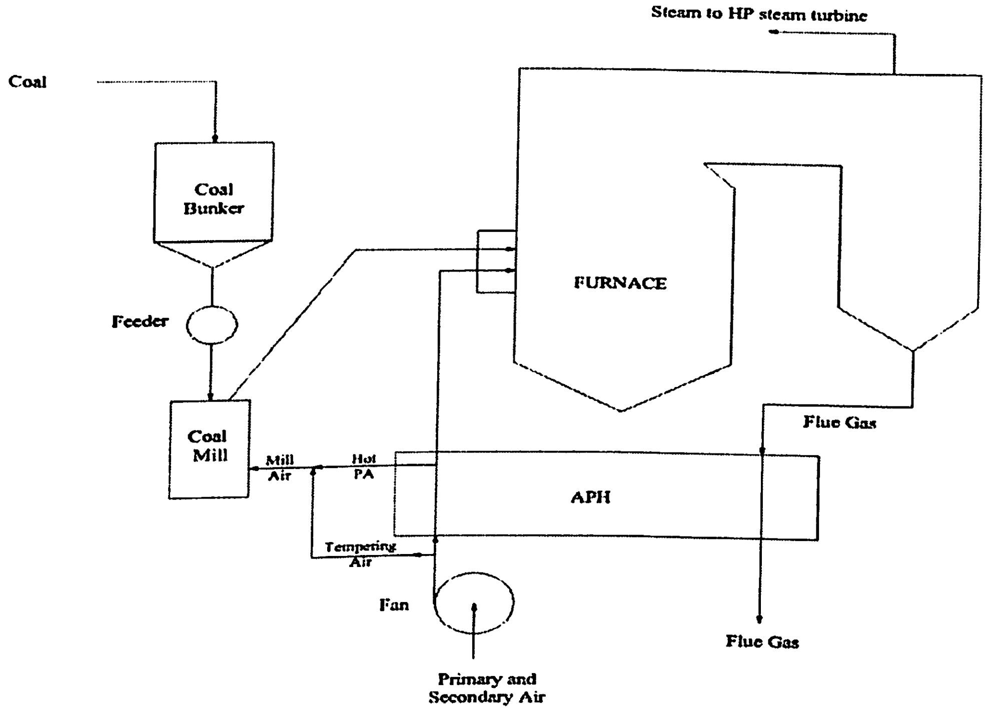
Total carbon credit benefits : Rs. 9 crores (approx.) per annum

Initial Investment

1. Subcritical plant : Rs.2900 – 3000 crores
2. Supercritical plant : Rs. 3400 – 3500 crores
3. Difference : (+) Rs. 500 crores
4. Plant life : 30 years
5. Saving : Rs. 190 crores

A considerably big saving is being observed in supercritical. Although the equipment size and cost is more in this case but it can save up to Rs. 190 crores. Today supercritical technology is preferable over Subcritical. This also results in faster payback, more power output and an efficient operating system.

5.2 For Coal mill



Total Primary Air to mills, W_{tpa} = 674100 kg/hr.

Primary air flow, W_{pa} = 112350 kg/hr./mill

Tempering air flow, W_t = 47187 kg/hr.

Hot 1ry air flow, W_h = 626913 kg/hr.

Mass of pulverized coal = 70632 kg/hr./mill

Outlet temperature of mill = 73 °C

Heat carried by the pulverized coal at mill outlet = 1546840 kCal/ hr.

Heat carried by the primary air at mill outlet = 1993797 kCal/ hr.

Heat required to remove the required moisture from the raw coal = 126040 kCal/hr.

Heat loss of the grinding motor in the mill = 484542 kCal/hr.

Heat in the primary air at mill inlet = 58417 kCal/hr.

Heat in the coal at mill inlet = 572120 kCal/ hr.

Mill inlet temperature, T_i = 217 °C

Specific heat of air at T_i = 0.2460 kCal / kg °C

Hot Primary air temperature

Tempering air temperature, t_{pc} = 37°C

Specific heat of air at t_{pc} = 0.2429kCal / kg °C

Tempering air flow, W_t = 47187 kg/hr.

Hot 1ry air flow, W_h = 626913kg/hr.

Total Mill inlet air flow, W_{tpa} = 674100kg/hr.

Specific heat of air at t_{ph} = 0.2455kCal / kg °C

$$\text{Hot Primary Air Temperature} = \frac{674100*0.2460*217 - 47187*0.2429*37}{0.2455*626913}$$

$$= 231°C$$

Heat Gain from Flue gas in APH

AH flue gas flow, W_g = 2298511 kg/hr.

AH inlet gas temperature, T_{gi} = 350°C

AH outlet gas temperature, T_{go} = 125°C

Heat exchanged, $Q_{\text{flue gas}}$ = 140Gcal/kg

Secondary air outlet temperature, T_{sa} = 288°C (To Furnace)

With the heat balance of coal mill and Air preheater, the Secondary Air temperature calculated is 288°C. The secondary air temperature directly affects the combustion efficiency and overall efficiency. Secondary air serves to shape the flames that shoot out from burners, to control flame temperature, and to mix fuel with combustion air.

CHAPTER: 6 CONCLUSION AND RECOMMENDATIONS

Components of the power plant are based upon the Heat balance. The optimum heat balancing of Steam turbine, Steam generator, Air preheater and coal mill leads to reduction in losses and investment cost. Supercritical technology improve the turbine cycle heat rate significantly over subcritical. The extents of improvement depend on the main steam and reheat steam temperature for the given supercritical pressure. By Comparing Heat balance diagrams of Subcritical and Supercritical thermal power plants result in saving outcome. Boiler heat duty reduces by 0.44 GJ/MWh, Heat Rate reduces by 5% and CO_2 reduce by 0.21 MMT/Annum. Economical saving can also be observed Rs. 19 Crores (approx.). Also the Recovery of heat content from flue gas with air pre heaters improves the overall thermal effectiveness of the boiler. The recovered heat thus can be exchanged with inlet primary and secondary air. This operation results in efficient combustion of coal and better flame stability inside furnace. The Operating costs will decrease due to improved boiler efficiency and lower fuel costs

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APPENDICES

HBD Comparison

OUTPUT			700MW	660MW	660MW	600MW
			100% TMCR 0% MU	100% TMCR 0% MU	With low FW Temp.	100% TMCR 0% MU
Main Steam Flow		kg/h	2146564	2010427	1918600	1802451
RH Steam Flow		kg/h	1758390	1634307	1612600	1597965
SH out	**PRESS**	MPa(g)	24.92	24.22	24.85	18.10
	TEMP	Deg C	568	568	568	540
	ENTHALPY	kJ/kg	3397.29	3404.71	3398.00	3388.39
HP-T in	**PRESS**	MPa(g)	24.12	24.12	24.12	17.12
	TEMP	Deg C	565	565	565	537
	ENTHALPY	kJ/kg	3396.54	3396.54	3396.54	3396.54
HP-T out	**PRESS**	MPa(g)	5.8	5.38	5.39	4.46
	TEMP	Deg C	349.8	339	336.7	339
	ENTHALPY	kJ/kg	3048.50	3029.33	3022.55	3053.86
RH in	**PRESS**	MPa(g)	5.7	5.26	5.27	4.36
	TEMP	Deg C	347.8	337	334.7	337
	ENTHALPY	kJ/kg	3045.49	3027.01	3020.26	3051.21
RH out	**PRESS**	MPa(g)	5.53	5.09	5.06	4.2
	TEMP	Deg C	595	595	595	539
	ENTHALPY	kJ/kg	3650.87	3654.48	3654.72	3533.09
IP-T in	**PRESS**	MPa(g)	5.33	4.93	4.88	4.00
	TEMP	Deg C	593	593	593	537
	ENTHALPY	kJ/kg	3647.85	3651.14	3651.56	3530.48
FEED WATER in	**TEMP**	Deg C	306.5	305.9	290	253.5
	FLOW	kg/h	2146564	2010427	1918600	1802451
	ENTHALPY	kJ/kg	1361.55	1358.60	1278.00	1102.80

Boiler Heat Output	GJ/h	5434.35	5139.03	5090.56	4889.69
Boiler Heat Output	Gcal/h	1298.84	1228.26	1216.67	1168.66
SH Heat Output	GJ/h	4369.85	4113.55	4067.43	4119.66
RH Heat Output	GJ/h	1064.49	1025.48	1023.13	770.03
SH Heat output	%	0.80	0.80	0.80	0.84
RH Heat output	%	0.20	0.20	0.20	0.16
Boiler Heat Duty per MW	GJ/MWh	7.76	7.79	7.71	8.15
SH Heat Duty per MW	GJ/MWh	6.24	6.23	6.16	6.87
RH Heat Duty per MW	GJ/MWh	1.52	1.55	1.55	1.28
Main Steam rate /MW	kg/MWh	3066.52	3046.10	2906.97	3004.09
RH Steam rate /MW	kg/MWh	2511.99	2476.22	2443.33	2663.28

Coal Characteristics

		Design Coal	Worst Coal	Best Coal
PROXIMATE ANALYSIS				
Total moisture(%)	% by wt	15	17	12
Ash(%)	% by wt	40	44	34
Volatile matter(%)	% by wt	19	18	22
Fixed carbon(%)	% by wt	26	21	32
Total		100 %	100 %	100 %
ULTIMATE ANALYSIS				
Carbon(%)	% by wt	30.87	26.53	39.38
Hydrogen(%)	% by wt	3.4	2.8	3.5
Sulphur(%)	% by wt	0.4	0.5	0.36
Nitrogen(%)	% by wt	1.5	1.45	1.78
Oxygen(%)	% by wt	8.25	7.26	8.73
Carbonates(%)	% by wt	0.3	0.26	0.15
Phosphorus(%)	% by wt	0.28	0.2	0.1
Total moisture(%)	% by wt	15	17	12
Ash(%)	% by wt	40	44	34
Total		100 %	100 %	100 %
GCV	(Kcal/Kg)	3300	2800	4000
Hard Grove Index	HGI	55	50	60
GCV (By Dulong's Formula)	**(Kcal/Kg)**	3303.80	2794.06	4003.12
For mill design:				
GCV	Kcal/kg	3300	2800	4000
Hard Grove Index	HGI	55	50	60
Moisture	% by wt.	15	17	12

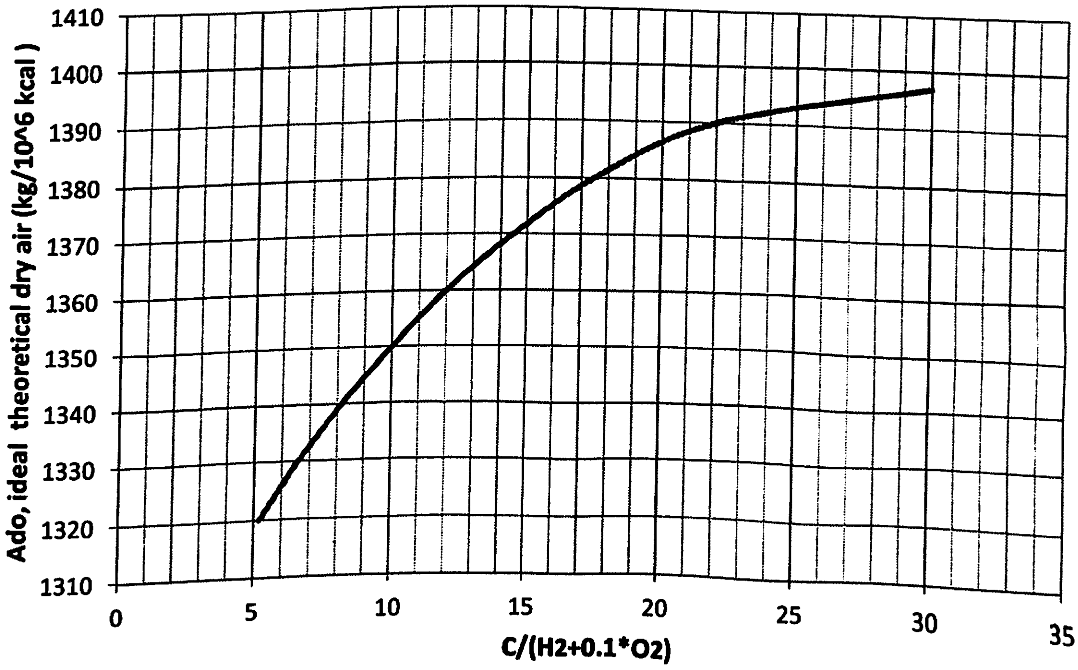
Combustion Calculations (Experimental Curve Method)

ULTIMATE ANALYSIS

Properties	Design	Worst	Best	
	kg/kg as fuel fired	kg/kg as fuel fired	kg/kg as fuel fired	
Carbon	0.3087	0.2653	0.3938	
Hydrogen	0.034	0.028	0.035	
Sulphur	0.004	0.005	0.0036	
Nitrogen	0.015	0.0145	0.0178	
Oxygen	0.0825	0.0726	0.0873	
Carbonates	0.003	0.0026	0.0015	
Phosphorus	0.0028	0.002	0.001	
Total moisture	0.15	0.17	0.12	
Ash	0.4	0.44	0.34	
GCV(Kcal/Kg)	3300	2800	4000	

1	**Humidity in Air**			
	Ambient air Temp.	(t_a)	Deg C	27
	Relative humidity	(ø)	%	60
	Saturated steam pressure at ambient tem	(Po)	kg/cm2	0.036
	Absolute humidity	(χ)	kg/kg dry air	0.0133
2	**Excess Air Calculation**			
	Excess air	EA	%	20
	Excess air Ratio	(μ)		1.2
3	**Unburned combustible**			
	Unburned carbon in fly ash	u	%	0.3
	Unburned carbon loss	Luc	Kcal /kg	0.2954
	Unburned carbon(solid combustible Wt. loss)	Sc	kg/kg as fuel fired	0.0012

	Burned Fuel (Combustible correction factor)			B	kg/kg as fuel fired	0.9988
	Burned combustible matter			F	kg/Gcal	181.4535
	Burned Carbon			Cb	kg/kg as fuel fired	0.3075
4	**Theoretical Dry Air**					
	2.Experimental Curve Method					
	$C/(H_2+0.1*O_2)$	**Ado**				
	-	1300				
	5.2	1320				
	5.9	1325				
	6.6	1330				
	8.2	1340				
	10	1350				
	12	1360				
	14.5	1370				
	17.5	1380				
	22	1390				
	30	1397				



	$C/(H_2+0.1*O_2)$			7.31
	a. Ideal theoretical dry air (complete combustion)	Ado	kg/Gcal	1333.00
	b. Net theoretical dry air (consider unburned carbon)	Ad	kg/Gcal	1331.40
		At	kg/Gcal	1029.71
5	**Actual Wet Air**			
	Theoretical Wet Air	*A w*	kg/Gcal	1350.70
	Actual Wet Air	A	kg/Gcal	**1620.84**
6	**Gaseous Product**			
a)	**Gaseous product in weight**			
	Gaseous products of combustion (wet)	G	kg/Gcal	1802.29
	Moisture in Fuel	Wm	kg/Gcal	45.45
	Moisture from combustion of fuel	Wh	kg/Gcal	92.07
	Moisture in air	Wa	kg/Gcal	21.22
	Dry gaseous products	Gd	**kg/Gcal**	**1643.56**
7	**Gas composition & Density Calculation**			
a)	**Production of Components**			
	Max. Produced CO2 per weigh fuel	Y_{co2}	Nm3/10^6 kg fuel	573210.30
	SO2 produced volume per weight fuel	Y_{so2}	Nm3/10^6 kg fuel	2730.79
	Theoretical dry gas volume per weight fu	Y_g	Nm3/10^6 kg fuel	3273073.05
	CO2 max.	X_{co2}	%	17.51
	Produced N_2 from Nitrogen in Fuel			
		M_{N2f}	kg/Gcal	4.55
		V_{N2f}	Nm3/Gcal	3.64
	Produced CO2			
		M_{co2}	kg/Gcal	344.60
		V_{co2}	Nm3/Gcal	174.32
	Produced SO2			
		M_{so2}	kg/Gcal	2.42
		V_{so2}	Nm3/Gcal	0.83

	Produced O2			
		M_{O2}	kg/Gcal	61.63
		V_{O2}	Nm3/Gcal	43.13
	Matter other than O_2,CO_2 in actual dry air			
		M_R	kg/Gcal	1227.03
		V_R	Nm3/Gcal	976.41
	Produced total H_2O			
		M_{H2O}	kg/Gcal	158.74
		V_{H2O}	Nm3/Gcal	197.50
8	**Gas Density**			
	Total Gas(for gas density & composition c			
	Wet	M_g	kg/Gcal	1798.96
		V_g	Nm3/Gcal	1395.82
	Dry	M_{gd}	kg/Gcal	1640.22
		V_{gd}	Nm3/Gcal	1198.32
	Density of Gas			
	Wet	ρ_g	kg/Nm3	1.29
	Dry	ρ_{gd}	kg/Nm3	1.37
6 b).	**Gaseous products in volume**			
	Gaseous products of combustible (wet),vo	Gv	Nm3/Gcal	**1398.41**
	Dry Gaseous products,volume	Gvd	Nm3/Gcal	**1200.76**
9	**Gas Composition**			
	Wet Weight %			
	CO2 : M_{MCO2}		wt%	19.16
	H2O : M_{MH2O}		wt%	8.82
	N2 : M_{MN2}		wt%	68.46
	O2 : M_{MO2}		wt%	3.43
	SO2 : M_{MSO2}		wt%	0.13
				100.00

	Wet Volume %			
	CO2 : MvCO2		vol%	12.49
	H2O : MvH2O		vol%	14.15
	N2 : MvN2		vol%	70.21
	O2 : MvO2		vol%	3.09
	SO2 : MvSO2		vol%	0.06
				100.00

Coal & Air Requirement

OUTPUT			700MW	660MW	660MW	600MW
			100% TMCR 0% MU	100% TMCR 0% MU	With low FW Temp.	100% TMCR 0% MU
Main Steam Flow		kg/h	2146564	2010427	1918600	1802451
RH Steam Flow		kg/h	1758390	1634307	1612600	1597965
Boiler Heat Output		GJ/h	5434.35	5139.03	5090.56	4889.69
Boiler Heat Output		Gcal/h	1298.84	1228.26	1216.67	1168.66
Boiler Efficiency		%	87	87	87	87
GCV or HHV	**Design**	Kcal/kg	3300	3300	3300	3300
	Worst	Kcal/kg	2800	2800	2800	2800
	Best	Kcal/kg	4000	4000	4000	4000
Coal Req. Or Fuel Burning Rate	**Design**	T/h	452.40	427.82	423.78	407.06
	Worst	T/h	533.19	504.21	499.46	479.75
	Best	T/h	373.23	352.95	349.62	335.82
Theoretical Air Req. with 20% EA	**Design**	kg/kg of coal	4.46	4.46	4.46	4.46
	Worst	kg/kg of coal	3.78	3.78	3.78	3.78
	Best	kg/kg of coal	5.40	5.40	5.40	5.40
Actual Air Req. with 20% EA	**Design**	kg/kg of coal	5.35	5.35	5.35	5.35
	Worst	kg/kg of coal	4.54	4.54	4.54	4.54
	Best	kg/kg of coal	6.48	6.48	6.48	6.48
Total Actual Air Req.	**Design**	T/h	2419.79	2288.29	2266.71	2177.26
	Worst	T/h	2419.79	2288.29	2266.71	2177.26
	Best	T/h	2419.79	2288.29	2266.71	2177.26

Mass of Flue Gas Generated With 20 % EA	**Design**	kg/kg of coal	5.42	5.42	5.42	5.42
	Worst	kg/kg of coal	4.60	4.60	4.60	4.60
	Best	kg/kg of coal	6.57	6.57	6.57	6.57
Total Mass of Flue Gas Generated	**Design**	T/h	2453.70	2320.36	2298.47	2207.77
	Worst	T/h	2453.70	2320.36	2298.47	2207.77
	Best	T/h	2453.70	2320.36	2298.47	2207.77

Mill & Air heater calculation (For 660 MW low FW)

MILL			
Mill outlet air temperature	t_{ao}	°C	73
Ambient air Temp.	Ta	°C	27
Temp. rise in PA Fan	Tri	°C	10
Seal air temperature(fan outlet)	Tai	°C	37
Tempering air temperature (fan outlet)	t_{pc}	°C	37
Mill inlet coal temperature	t_{fi}	°C	27
Specific heat of air at t_{ao}	C_{pao}	kcal/kg°C	0.2431
Specific heat of air at t_{pc}	C_{papc}	kcal/kg°C	0.2429
Specific heat of coal	C_{coal}	kcal/kg°C	0.3
Primary air flow		kg/hr/MILL	112350
Heat loss in mill			0.05
Primary Air/coal Ratio	R_{ac}	kg air/ kg coal	1.59
Seal air to coal ratio	S_a	kg air/ kg coal	0.05
Moisture in coal at mill inlet	m_i	kg/kg coal	0.15
Moisture in coal at mill outlet	m_o	kg/kg coal	0.0437
Partial pressure of steam in mill outlet air	P_s	ata	0.0966
Enthalpy of steam at P_s,t_{ao}	h_{so}	kcal/kg	629.62
Heat input by mill power		kcal/kg-coal	6.86
Specific heat of air at t_{ai}	**C_{pai}**	**kcal/kg°C**	**0.246**
Mill inlet air temperature	**t_{ai}**	**°C**	**216.87**
Air Flow Rates			
No. of operating mills			6
Primary air flow		kg/hr/MILL	112350
Total Primary Air to mills		kg/hr	674100
Tempering air flow	W_t	kg/h	47187
Hot 1ry air flow	W_h	kg/h	626913
Hot 1ry air flow and tempering air flow			
Tempering air temperature	t_{pc}	°C	37
Specific heat of air at t_{ph}	C_{paph}	°C	0.2435
Specific heat of air at t_{pc}	C_{papc}	°C	0.2429

Tempering air flow	W_t	kg/h	47187
Hot 1ry air flow	W_h	kg/h	626913
Mill inlet air flow	W_{mi}	kg/h	674100
Specific heat of air at t_{ph}	**C_{paph}**	**kcal/kg°C**	**0.2455**
Hot 1ry air temperature	**t_{ph}**	**°C**	**230.92**
Air Heater			
Heat Exchange,Q (Flue Gas)			
AH inlet gas temperature	Tgi	°C	350
Specific heat at inlet	Cpi	kcal/kg°C	0.2659
AH outlet gas temperature	Tgo	°C	125
Specific heat at outlet	Cpo	kcal/kg°C	0.2586
AH flue gas flow	Wg	kg/h	2298473.05
Heat exchanged	Q	kcal/kg	139609253.30
Mill inlet temp. Calculation			
Primary Air			
Ambient air Temp.	Ta	°C	27
Temp. rise in PA Fan	Tri	°C	10
Primary air temperature(fan outlet)	Tai	°C	37
Mill Outlet Air Temp. Required		°C	73
Specific heat at outlet	Cpo	kcal/kg°C	0
Primary air flow		kg/hr/MILL	112350
No. of operating mills			6
Total Primary air flow		kg/hr	674100
Total Actual Air Req.		kg/hr	2266705.99
Secondary air			
Ambient air Temp.		°C	27
Temp. rise in FD Fan		°C	3
Secondary air inlet temperature(fan outlet)		°C	30
Specific heat at inlet		kcal/kg°C	0.2428
Secondary air flow		kg/hr	1639792.993
Secondary air heat exchanged		kcal/kg	104069556.34
Specific heat at outlet		**kcal/kg°C**	**0.2460**
Secondary Air outlet temp.		**°C**	**287.60**