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The Utilization of Indigenous Coal as Energy Substitute in Cement Industry

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List of Acronyms

AACF	Addis Ababa Cement factory
AM	Alumina Modules
ASTM	American Society for Testing Materials
BSI	British Standard Institution
COFCOP	Coal-Phosphate Fertilizer Complex Project
EQS	Environmental Police Standard
EP	Electrostatic Precipitators
FF	Fabric Filter
ISO	International Organization for Standardization
IRZ	Internal Recircilauation Zone
LOI	Loss on Ignition
LSF	Lime Saturation Factor
MCE	Mugher Cement Enterprise
OPC	Ordinary Portland Cement
PCE	Purchased Cost of Equipments
PPM	Parts Per Million
PPC	Physical Plant Cost
PPC	Portland Pozzolana Cement
ROM	Run of Mine
SM	Silica Modules
St	Standard

Abstract

Ethiopia spends million of dollars to meet its energy requirement, it is estimated around 20-30 million dollars is spent for the purchase of furnace oil for cement sectors only. In order to change the country's economic situation and to come-out of poverty it is necessary to develop and utilize the country's energy potential.

For the reason of fuel economy cement plants all over the world are switching over from fuel oil or gas to coal for their kiln operation. Ethiopia has discovered large potential low grade coals at different areas. The development and the utilization of this indigenous coal as an energy source for all energy consuming sectors will be a major issue in this country in near future.

The study aims to determine the potential use of one of the indigenous coal as a substitute in place of furnace oil in cement industry.

Results from the analysis and comparisons of Yayu coal quality revealed the possibility of using Indigenous coal in place of furnace oil up to a certain percent. Based on the results the study attempts to select the equipments required if Yayu coal is replaced in place of fuel oil in Mugher Cement Enterprise.

Substantial investment for additional facilities and equipments are required, and as a consequent considerable saving in production cost in addition to the reduction of foreign currency can be achieved through the switch over to indigenous coal.

Additionally the study revealed air pollution, spontaneous coal fires and coal dust explosion are the major concerns of cement plant if this indigenous coal is used in place of furnace oil.

In view of this the study recommended cement plants to see this alternative source of energy and to identify their concerns as soon as possible.

1 INTRODUCTION

1.1 Background of the study

The world energy demand will keep growing at a sustained pace for a number of decades to come meeting the demand of energy shall remain the prerequisite for the economic development of any country.

Ethiopia spends millions of dollars annually to meet its primary energy requirement. The heavy furnace which was priced Birr 1.9432 per liter in July 2000 E.C, now in 2004 E.C costs Birr 2.4424 per liter [1]. As a consequence oil import bill of the country is expected to further increase due to the increase of price of crude oil. Currently Ethiopia imports around 2 million tons of oil costing around US $ 221 a year.

We can read from the above data that fuel oil takes the major share of the country's total import expenditure. The share is not only significant as compared to other materials, but also increasing at an increasing rate.

The Cement sector is one of the major energy intensive industries while playing an important role in the economy of a country. Presently there are 4 operating cement plants with a total installed capacity of about 1,366,000 million tons of ordinary Portland cement per annum in Ethiopia. Table1.2 presents the installed capacities and locations of the cement plants of Ethiopia.

Table 1.2: [2] Ethiopian cement plants

Regional state	Name of the cement Plant	Operating Unit	Year established (E.C)	Installed cement capacity (ton/year)
Dire Dawa City Council	Dire Dawa cement Plant	1	1936	36,000
Addis Ababa	Addis Ababa	1		70,000

	Cement Plant*		1964	
Oromia	Mugher Cement Enterprise	Line 1 Line 2	1977 1982	315,000 315,000
Tigray	Messobo Cement Factory	1	1992	600,000

*The kiln section of the Addis Ababa Cement Factory is shut down and the factory is under the Mugher Cement Enterprise.

The energy sources for all cement plants in Ethiopia are Fuel oil. The cement industry is energy-based which constitutes 45 per cent of the cost of production. The total average annual consumption of furnace oil by these factories based on their installed clinker capacity and average oil consumption is estimated to reach 120 million liter or around 30 million dollar in value. This approximates to ---% of the total imports of fuel in the country. Table 1.3 shows the consumption of heavy fuel oil by Mugher Cement Enterprise for the last 5 years.

Table1.3: [1] Furnace oil consumption by Mugher Cement plant in the last 5 years.

Year (E.C.)	Fuel consumed (liters)	Fuel (Birr)
1991	57,614,478	88,645,635
1992	57,673,490	97,095,467
1993	58,303,321	123,116,129
1994	59,934,343	129,527,180
1995	61,080,215	134,291,435

We can see from the above table that the consumption of heavy fuel by Mugher has increased by 6 % and 51% in the last five years in quantity and value respectively. It is also important to note that the rate at which the consumption increases in value is greater than the rate at which the quantity increases, indicating the continuous fuel price increase in the world market.

Generally, we can see how the above figures are significant compared to the country's scarce amount of foreign exchange. This situation coupled with the increasing trend of price of furnace oil call, therefore, for alternative domestic or any other sources of energy supply. Coal is one the possible alternative sources of energy.

Historically, coal has been used for a long period of time as a major source of energy. World wide large discoveries of oil and gas resulted in massive switchover from coal to furnace oil and gas. Once again, however, there is a worldwide shift back to the use of coal as a substantial source of energy. Coal is one of the cheapest fuels available in sufficient quantities in many countries. It is a non-renewable source of energy. Many factors, which underpin the key role of coal as primary energy source, are [3].

- Coal is a natural fuel
- Coal resources are well identified and do not require extensive investment for exploration.

- They are abundant and largely spread which minimize geopolitical risk for the supply chain.
- Coal production cost is low.
- Coal related industries are an important source of employment especially in developing countries.

The price of coal, interestingly enough, has remained static over the last period in contrast to other energy sources. In fact during the last 10 years, because of the economic crises in Japan and the Far East, the coal price has shown a downward trend. This resulted in a global shift during the last three decades from oil to coal; and as of today almost 90 per cent of cement plants in the world is using coal as fuel [3].

A switch over to coal, in addition to the production economy, would also reduce the import bill of a country, especially to a developing nation like Ethiopia. Therefore, the energy scenario leaves the local cement industry with no option but to fall in line with the cement industry of the world in substituting furnace oil with coal as expeditiously as possible.

Ethiopia has discovered a significant potential of higher-grade lignite resources at different places in the country. The most promising resource areas are found at Yayu, Delbi-Moye, Chilga and Debre birhan areas. The government has given grate importance to the study of coalmines and related products. One of such concern is reflected in the study made by the government ‘Coal-Phosphate Fertilizer Complex Project - (COFCOP)’. The development and utilization of this indigenous coal as an energy source for all energy consuming sectors should be a major issue in this country in the near future especially for the saving of the country’s scarce foreign currency. It was in line to this that the project has been established, among others, with a task of undertaking the necessary preparation for establishment of a coal-mine, fertilizer and thermal power plant complex. In accomplishing its responsibilities the COFCOP has undertaken project studies for coal mining around the Yayu area located in the Oromia region, Illubabor zone, 540 km west of the capital city Addis Ababa on the road to Metu. The purpose of this study is therefore to see the possible potential use of this indigenous coal to one of the major energy-consuming sector, the cement industry, based on the study made by the project.

1.2 Objective of the study

Generally, the objective of this study is to determine the potential of Ethiopian domestic coal as an energy substitute in the cement industry.

The Yayu coal is taken for our analysis as studied by the government 'Coal-Phosphate-Fertilizer Complex Project'. This paper therefore bases the technical analysis of the Yayu coal and would attempt to see the potential of utilizing it as source of energy in the Mugher Cement Enterprise.

The study examines the technical, economical and environmental issues, which encourage or discourage the utilization of this indigenous coal as a possible energy substitute in the cement industry. The following are the specific objectives of the study.

- To see the physical and chemical properties of the indigenous coal as against the requirements of the cement manufacturing process.
- To see the combustion behavior of this indigenous coal as source of energy in the cement manufacturing process.
- Selection of suitable machinery and equipment for storage, grinding, and firing of coal in the kiln.
- To evaluate the impacts of utilization of coal on the industry's economy.
- To highlight some of the major environmental impacts of utilization of coal.

1.3 Methodology

The following were the major methodologies adopted for the study

Literature survey: - a systematic review of available documents and studies related to the subject is made. The review covered documents related to coal preparation, coal conversion, studies and experiences on substitution of furnace oil by coal in European and Asian cement industries where coal utilization is believed to dominate. Moreover, journal reviews and internet sources are also used in addition to the above documents and books on coal utilization in the cement industry etc.

Consultation: - extensive consultation has been conducted with our engineers and cement technologists in the cement industry as well as the concerned expertise in the office of the Coal Phosphate Fertilizer Complex Project. Moreover consultations are also made with the major world cement web sites like ‘Cemnet’, ‘Cemforum’ etc.

Data collection: maximum information and data are collected from the following sources.

The data's on the quality of coal is taken from the study made by the office of the "Coal – Phosphate-Fertilizer-Complex Project" (COFCOP). The data on the chemical composition of raw materials and raw mixes are taken from the Mugher Cement laboratory reports.

The quality of the local coal was compared against the types of coal used in some five European and Asian cement manufacturing plants based on their coal quality standards in relation to their technologies.

Moreover the effect of the coal ash on the property of the raw material and on the cement clinker was analyzed by universally accepted proportioning formulas and methods.

An attempt is then made to select a proper firing system and equipments to the Mugher cement factory in utilizing the Yayu washed coal as an alternative source of energy based on the above analysis.

Finally an overview of the economical advantage and the environmental impact of this alternative source are assessed as against the existing system.

2 Coal and Coal Combustion

2.1 Origin, Formation and Properties of Coal

Coal is a firm brittle sedimentary combustible rock. It is a nonrenewable energy source because it takes millions of years to form. Geological studies have proved that coal originated from the decay of trees bushes, ferns, mosses, vines, and other forms of plants and conversion of this plant to coal occurs due to the prolonged action of bacteria, fungi, temperature and pressure. The energy we get from coal today came from the energy that plants absorbed from the sun millions of years ago. All living plants store energy from the sun, this energy is usually released as the plant decays. Overtime when the decay process halts due to the change of the earth climate this plant matters underwent chemical & physical change pushing out oxygen & leaving rich hydrocarbons. The two broad categories of coal [4] are:

I. Humie more common and originate from peat deposits consisting mostly organs debris deposited in situ (autochthonous).
II. Saprogenic Deland from redposited (allochthonous) resistant plant fragment such as spores or aquatic plant.

Peat is formed from the deposition of organic material with a restricted supply of oxygen the type of original plant input, the availability of nutrients, climate conditions, level of the water, the PH all help to determine the type of peat that is formed. For a coal to be developed, the peat has to be buried and persevered. The process that converts peat to coal is coiled coalification.

The transformation of plant material into coal takes place in two stages, biochemical degradation and physicochemical degradation.

The smallest microscopically recognizable in coal are called macerals. The chemical and physical properties of macerals vary with coal rank [5] and they are distinguished by;

- Their optical characteristics of colour.
- Relief of the polished surface.
- Morphology.
- Reflectance and fluorescence.

Macerals differ because they represent different parts of the original plant & microorganism that contributed to the peat. There are there macerals group's vitrinite, inertinite and liptinite [5].

Coal is composed of carbon hydrogen, nitrogen, oxygen, sulfur and inorganic impurities. The physical and chemical properties of coal is determined by proximate and the ultimate analysis.

The degree of physico-chemical coalification of a coal is indicated in proximate analysis. It is a simple test of the quality of coal it gives in percentage the amount of moisture, volatile matter, fixed carbon and ash content of coal.

Ultimate analysis of coal gives the amount of carbon hydrogen oxygen, nitrogen, sulfur and ash presenting in a sample of coal in terms of percentage by weight. Calorific values, Caking test, Ash Fusibility test, Agglutinating index and Grindability index are determined through other tests. The major properties, which are determined through this analysis, are [6] listed below

Moisture: - The total moisture content in coal consists of inherent and bed moisture.

Fixed carbon: - is the combustible residue left after the volatile matter is driven.

Ash: - is the non-combustible residue after complete coal combustion; it is the final form of the mineral matter present in coal.

Volatile matter: - that portion of the coal has driven off as gas or vapor when the coal is heated.

Sulfur: - is found in coal as Iron pyrites, sulfates and organic sulfur compounds. It is undesirable due to air pollution and corrosion effect.

Nitrogen: - is found in molecules; is also undesirable because the nitrogen oxides that are formed when coal burns contribute to air pollution.

Ash Fusion temperature: - a set of temperature that characterize the behavior of ash as it is heated.

Grindability index: - indicate the easy of pulverizing a coal in comparison to a reference coal.

Swelling index: - gives a measure of the extent of a coal and its tendency to agglomerate when heated rapidly.

Calorific value: - the amount of heat generated from 1 kg of fuel during combustion.

2.2 Classifications and application of coal

The diversity of source materials from which coal formed and the successive changes wrought by digenesis and metamorphism made coal so heterogeneous that statements about its property have little meaning unless they are related to scale. Most classification is based upon some property of coal, which varies with increasing maturity or rank of coal. The system of coal classification falls into two categories, scientific and commercial.

The ultimate and the proximate analysis are the basis for scientific and commercial classification respectively. Based on these analyses different classification systems were developed, the most commonly used classification systems are [4]

1 International organization for standardization (ISO)
2 American Society for Testing Materials (ASTM)
3 British Standard Institution (BSI)

Among these different classifications the most generally accepted and widely used classification is the ASTM, which distinguishes between four coal classes, each divided into several groups. The ASTM classification which is based on proximate analysis classifies coals according to rank and grades. The most recent version of the system is shown in Table 2.1.

Coal ranks [6]: - It is an indication how much transformation the original plant material has undergone. It relates the carbon content of the coal and other related parameters. All coals regardless of their origin, age or type can be arranged in ascending of carbon contents to form the coal rank as shown

Lignite → Subbituminous → → Bituminous
Anthracite

<u>Anthracite</u> -: The hardest coal type, (often referred to as "hard coal"), contains a high percentage of fixed carbon and a low percentage of volatile matter. Anthracite is the highest rank coal and it contains about 90% fixed carbon, more than any other form of coal. Anthracite has a semi-metallic luster and is capable of burning with little smoke (smokeless fuel). It is used in domestic and industrial applications, but is the least abundant of all the coals.

<u>Bituminous Coal</u>: It is soft, dense and black. Its moisture content usually is less than 20 percent. It is used for generating electricity, making coke, and space heating. Bituminous coal can be metallurgical (also known as coking coal) or thermal (also known as steam coal). Metallurgical/Coking coal is a coal that can be converted into coke and it gives a coke strong enough to resist pressure and breakage. The term coking coal covers a range of coals, the cokes from which serve different purposes depending primarily on the fixed carbon and volatile matter of the original coal. This coal is considered particularly suitable for boiler use, or power generation.

Sub bituminous Coal: Sub bituminous coal is dull black and generally contains 20 to 30 percent moisture. The heat content of sub-bituminous coal ranges from 16.88 to 25.32 MJ per kg and is used for generating electricity and space heating. Sub bituminous coal is the next highest coal in rank after lignite. It is softer than bituminous coal. Because it contains more moisture than bituminous coal, it is less economic to transport long distances.

Table 2.1 [4] ASTM Coal classification by rank

Class and Group	Fixed Carbon ^{A} (%)	Volatile matter ^{A} (%)	Heating value^B (MJ/kg)
Anthracite			
1. Meta anthracite	>98	<2	
2. Anthracite	92----98	2--------8	
3. Semi anthracite	86----92	8------14	
Bituminous			
1.Low volatile	78-----86	14-----22	
1. Medium volatile			
2. High volatile A	69----78	22-----31	>32.564
3. High volatile B	< 69	>31	30.238-----32.564
4. High volatile C			24.423-----26.749
I. Sub bituminous			
Sub bituminous A			24.423-----26.749
Sub bituminous B			22.097 -----24.423
Sub bituminous C			19.305-----30.238
II. Lignite			
Lignite A			14.653---19.305
Lignite B			< 14.653

(***A-Dry mineral matter free, B-Mineral matter free coal with bed moisture content***)

Lignite: - Lignite is a brownish-black coal of low rank with high inherent moisture and volatile matter (used almost exclusively for electric power generation). It is also referred to as brown coal. It is characterized by its high moisture content and low carbon and low energy content. Due to its high moisture content and relatively low calorific value, lignite is usually consumed at or close to where it is produced /mined.

Although rank can tell us much about the general characteristics of a given coal, it is important to recognize that coal properties vary widely between seams and within a given seam at different elevation and locations. Coal can vary greatly from mine to mine within the same seam.

Coal was initially obtained from the surface or near the surface where it was easily mined. Today where coal is found somewhat near the surface and the overlying layers of materials can be removed at a reasonable cost; it is mined using surface mining techniques. Where coal lies in deeper layers of the earth, it is reached through underground mining. There are different kinds of underground mines, such as drift, slope, and shaft. The type of mine depends on where the coal is located. All types of mines use either of these mining method's room-and-pillar, long wall, and board and pillar techniques

Application of coal

Coal has been recognized as a major source of energy, it was an important stimulus to industrialization in the world, and currently it contributes 28 % [3] of the world primary energy usage. 55 % of coal produced is used for power generation; the reminder is used for the production of steel, cement, certain chemicals and domestic purpose.

The use and rise of the coal in industries and other areas was linked to the industrial revolution in Europe, the earliest data on coal production and utilization date back to 1851.The second half of the nineteenth century was a period of rapid growth in coal utilization. At the end of this century coal fortune suffered further as firms switched to oil and gas because of availability and environmental consideration. The significant decline in the transmission of gas to the plant over the years and the ever-increasing prices of furnace oil were successfully countered through the use of coal by developing an in-house indigenous coal plant. The major uses of coal are discussed in short below [7].

Industrial energy use: - Coal is largely used as energy source in the major energy consuming industries like cement, paper, chemicals, petroleum , clay and glass, metals ,as an energy source, its use is limited to process steam (boilers),open fired application (kilns),and process heaters (pyrolysis units).

Coal for electricity generation: - Currently 55 % of the world's electricity is produced from coal. Although this figure is likely to remain fairly constant or perhaps even reduce slightly in future years, the actual consumption of power station coal worldwide is predicted to increase significantly. A number of systems are available for power generation from coal, including pulverized fuel and fluidized bed combustion.

Coal in process heaters: - Coal is largely used in process heaters like tube furnace used in petroleum and pyrolysis units that are used in chemical industries.

Coal in open fired systems: - open fired industrial energy usage encompass a broad range of processes including ovens, calciners, dryers, and kilns unlike boilers and heaters the product to be heated is usually in direct contact with the coal flame.

Coal for coke making: - The term coking refers to a process where a high rank coal is heated under a slight negative pressure to drive off the volatile mater (e.g. gases) to leave a substance with significantly higher carbon content.

Most steel production worldwide comes from iron made in blast furnaces using coal and coke as an energy source and a reducing agent in the production process. Additionally coke is used to produce ferroalloy, lead smelting, calcium carbide, Foundry coke, elemental phosphorous production and other industrial products.

Coal for chemical production: -The use of the by- products from coking industry become very important, this by-products are basically gases, oils, and tars and generally they include cokeoven gas, coke tar, crude light oil etc…

Coal gasification: - means complete transformation of its carbonaceous substances from solid to gaseous phase. High, Medium, Low heating value gases are produced from coal gasification.

Coal liquefaction: - means production of liquid fuels from coal. It is possible to transform coal into liquid hydrocarbons by direct and by indirect hydrogenation.

Coal for domestic use: - Coal has been used for hundreds of years for home heating and for cooking.

Coal in some products: - Coal is an essential ingredient in the production of special products like Activated carbon, Carbon fiber, and Silicon metal.

2.3 Coal preparations and processing

Mined coal is of variable quality and rarely meets the desired physical and chemical specifications of end-users; the end users can be power generating, steel-making, cement manufacture and in some countries industrial/commercial/domestic users. Coal preparation is thus necessary to meet quality standards and product consistency, and is an important element of clean coal technologies [3]. Generally the objective of coal preparation is to

- Increase recovery
- Enhance quality (to reduce ash, moisture, deleterious trace elements)
- Decrease variation in quality
- Increase capacities and lower costs
- For better handling and transport
- Reduce environmental impacts

The simplest of this preparation is removing foreign material and screening for size. Large pieces may be crushed, or the whole mass pulverized to a certain size. Coal can also be washed or cleaned to remove contaminants. Coal preparation involves a complex sequence of unit operations. The unit operation consists of washability assessment, breakage and liberation, slurry distribution, size classification, beneficiation processes, dewatering, instrumentation and process control.

Because of large density difference between the organic coal substance and the mineral matter associated with it cleaning is usually affected by gravity separation method. Determination of washability are made by float-and sink tests i.e. by measuring the weight percentage of the coal samples that will float on liquids of different specific gravities in the range of 1.2 -2.2. Different types of mechanical cleaning apparatus are used for cleaning of coals in different size ranges. Picking tables, Heavy media bath or drums Jigs, Diester table, Heavy media cyclones, Air tables, Froth flotation is the most commonly used [4].

As it leaves the mine, coal varies widely in size, ash content, moisture content, and sulfur content. These are the characteristics that can be controlled by preparation. Sizes range upward to that of foreign materials, such as a chunk of rock that has fallen from the mine roof or a metal tie; large pieces of coal from a very hard seam are sometimes included. Ash content ranges from three to sixty percent at different mines. Most of the ash is introduced for the roof or bottom of the mine or from partings (small seams of slate) in the coal seam. The remaining ash is inherent in the coal. The density of coal increases with the amount of ash present. The moisture content of the coal is also of two types. The surface moisture, which is introduced after the coal was broken loose from the seam, is the easier to remove. This moisture is introduced by exposure to air, wet mining conditions, rainfall (in stockpiles), and water sprays. The remaining moisture, called “bed”, “cellular”, or “inherent” moisture, is included during formation of the coal and only coking or combustion can remove it. Although inherent moisture cannot be changed, the surface moisture can be reduced to any level that is economically practicable. Sulfur in coal occurs as sulfates, organic sulfur, and pyrites (sulfides of iron). The sulfates usually are present in small quantities and are not considered a problem. Organic sulfur is bound molecularly into the coal and is not removable by typical coal preparation processes. Pyrites are generally present in the form of modules or may be more intimately mixed with the coal. Coal preparation plants remove only a portion of the pyritic sulphur; therefore the degree of sulfur reduction depends on the percentage of pyrites in the coal, the degree of mixing with the coal and the extent of coal preparation.

Coal preparation processes can improve the run of mine (ROM) coal to meet market demands, as limited by the inherent characteristics of a given coal. The top size of the ROM can be reduced to any size specified, depending on the amount of crushing required

The first operations performed on ROM coal are removal of tramp iron and reduction of size to permit mechanical processing. Various types of crushers are available for coal crushing. The crusher most commonly used for this purpose is a heavy-duty single roll with tramp iron protection. Double rolls are more difficult to maintain in this heavy service, are more expensive, and offer no particular advantage. Slow-speed hammer mills or impactors are more difficult to maintain, jaw crushers have not been required. The clean coal from various wet-cleaning processes is wet and requires drying to make it suitable for transportation and final consumption.

Thermal drying is employed to dry the wet coal. Drying in the thermal dryer is achieved by a direct contact between the wet coal and currents of hot combustion gases. The most common types of dryers, which are used in coal preparation plants, are the fluid-bed dryer, the multilouver dryer, and the cascade dryer.

2.4 Coal and cement industry

Cement is a construction material for buildings and other civil structures, which sets automatically as a consequence of chemical reaction with water and subsequently retains both its formed shape and strength. Cement basically consists of finely ground clinker and gypsum. It may, however, contain other constituents like granulated blast furnace slag, natural pozzolana; fly ash, burnt oil shale or limestone. Main constituents of the cement are lime, silica, alumina, iron, magnesia and some other trace ingredients. The raw materials, which used to obtain these constituents, are limestone, clay, iron ore Bauxite, and gypsum.

The cement manufacturing process begins with process of calcinations, which is decomposition of limestone (calcium carbonate, $CaCO_3$) at about 900 °C into calcium oxide (lime, CaO) and gaseous carbon dioxide (CO_2). This is followed by the clinkering process in which the calcium oxide reacts, at high temperature (typically 1400-1500 °C) with silica, alumina, and ferrous oxide to form the silicates, aluminates, and ferrites of calcium. Chemically clinker contains tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium alumino ferrite in different proportions. The clinker is then ground or milled together with gypsum and other additives to produce Portland cement. There are four alternate processes for the manufacture of cement: dry, semidry, semi-wet, wet process. All the cement manufacturing processes have the following operations and processes in common [8].

a) Quarrying and Transport of Raw Materials
b) Raw Materials Storage
c) Raw Materials Preparation

d) Fuel Transportation, Storage, Preparation and Charging
e) Clinker burning
f) Cement grinding and storage
g) Packing and dispatch

The cement industry is said to be an energy intensive industry together with steel, paper and petrol- chemical industry. The primary fuel used in cement Industries is fossil fuels i.e. oil, natural gas and coal. Figure 1 shows a simplified flow sheet presenting the cement manufacturing process.

The cement Industry in the early fifties was using coal as a fuel in wet processing and at that time environment was not a key issue. In the following two decades, however, with the advent of the dry process technology which required a uniform quality of raw material for satisfactory operation and with an increasing stress on environmental issue (pollution control), a transformation took place and gradually the cement Industry, switched over to furnace oil. The use of fluid fuels was economical & met the standard for clean air and also provided a clean, relatively simple firing system. Since 1973 oil embargo, the steep rise in the cost of oil has caused many plants to convert back to the use of pulverized coal as their primary fuel. During the last three decades, cement plants converted from oil to coal and as of today almost 90 per cent of cement plants in the world are using coal as fuel [3].

The fineness to which the coal should be ground for firing in cement will depend on its flammability and its combustion rate; these properties are governed by the content of the ash and the volatile constituents. Coal with a low volatile content will in general have to be ground finer than coal with high volatile content. Commonly applied fineness criteria are: 10-15 % by weight retained on 0.09 and 1-2% by weight on the 0.2 mm standard sieve [9].

In cement kiln, fuel react (interacts) with the raw material, apart from producing thermal energy, the chemical constituents of the fuel play a crucial role in the processing and chemistry of the cement clinker. Quantity and composition of coal ash influence to a great extent the quality of clinker. During burning process the ash is completely absorbed by the clinker therefore the chemistry of coal should be taken into consideration when calculating chemical composition of the raw mix. The volatile matter, sulfur, etc. are deleterious constituents and should not exceed permissible limits. Key characteristics of concern for the coal to be used for cement production are as follows [10]:

a. Heating Value: It is one of the principal parameters in selection of the coal. Heating value of coal (in terms of kilo calories per kg) shows the amount of heat energy that would be produced by combustion of unit weight of coal. The coals with higher heating values and lower unit costs per heat energy are more desirable.

b. Moisture Contents: Total moisture contents of coal (as received) including inherent and surface moisture, shall be as minimum as possible. Since coal is to be converted into pulverized form for use as kiln fuel, the moisture contents need to be removed from the coal. Presence of moisture, otherwise not required, unnecessarily adds to the coal transport, handling and processing costs.

c. Volatile Matter: Presence of volatile matter in coal indicates easy ignition and good combustion and therefore its contents shall not be too low. The required fineness of pulverized coal, for good combustion, is inversely related with the volatile matter contents. Coals with higher volatile matter, however, are more prone to spontaneous ignition and fire hazards, during their storage, due to their relative lower ignition temperatures.

d. Ash Contents: Ash is the non-combustible matter, left after the combustion of coal. A major part of these contents become part of the clinker. This needs to be allowed for in calculating the raw material proportion and so it is desirable to use fuel with a consistent, though not necessarily low ash content. Coals with higher ash contents result into lower flame temperatures and give rise to ring and ball formation in the kiln in addition to quality problems.

e. Sulfur: High fuel sulfur, in most cases, is considered undesirable both from production process and environmental point of views. The presence of sulfur also increases the propensity of spontaneous ignition and fire in stored coals.

High energy costs are forcing cement industries to use inferior quality coals it is, however, necessary to stress on the importance of the suitability of coal for use as fuel in cement plants. Price, availability, colorific value, moisture content, volatile matter, ash content are the main parameters in the choice of coal for cement industries.

2.5 Chemistry of coal combustion and combustion modes

Combustion occurs when fossil fuels such as natural gas, fuel oil, coal or gasoline react with oxygen in the air to produce heat. The combining of oxygen in the air and carbon in the fuel to form carbon dioxide and generate heat is a complex process requiring the right mixing turbulence, sufficient activation temperature and enough time for the reactants to come in to contact and combine.

Coal combustion is a very complex process and not all physical aspects are well understood. The principal steps of the reaction progress that have to be considered are the thermal decomposition of the raw coal (Pyrolysis) as well as the subsequent burnout of coke particles and the volatile matter. In coal combustion firstly the water vapor from the coal is released as its temperature is raised this process gets over about 100 ^{0}C, next the decomposition of its unstable compound starts. This coal now starts to emit volatile matter if the temperature is high then the volatile gases will burn like the fuel liquid droplets, the rate controlling factor being the diffusion mechanisms. The coal pieces remain dark during these processes, because of the burning of the volatile around the coal piece, its temperature is raised, and the coal particles are ignited and completely burn. Studies show that coal combustion begins with chemisorptions of oxygen at "active" sites on char surface and, that decomposition of the resultant surface oxides mainly generates CO which is oxidized to

CO_2 in a gaseous "boundary zone" around the char particles. Over all the combustion of char involves at least four carbon-oxygen interactions [7, 11]

$C + 1/2\ O_2 \rightarrow CO$

$C + 1/2\ O_2 \rightarrow CO_2$

$CO_2 + C \rightarrow 2CO$

$C + O_2 \rightarrow CO_2$

As well as Oxidation of non-carbon atoms

$S + O_2 \rightarrow SO_2$

$H_2 + ½\ O_2 \rightarrow H_2O$

This may be followed by

$2H_2O + C \rightarrow CO_2 + 2H_2$

$CO + H_2O \rightarrow CO_2 + H_2$

The rate of oxidation of carbon in coal depends up on the reaction rate between carbon and oxygen and up on the rate of the supply of oxygen to the coal surface these factors further depend up on the size and shape of the coal particle, velocity of the air supply, temperature of the coal surface and surrounding diffusion coefficient of oxygen and the products etc.

Coal combustion modes

The manner in which coal is burned and the devices in which it is burned is the major factors for combustion. There are basically two modes for burning of solid fuel [11].

I. Large particles in fuel beds.

II. Small particles in pulverized form.

Fuel bed combustion:-is accomplished with mechanical devices which are designed to achieve continuous or intermittent fuel feed, fuel ignition, proper distribution of the combustion air, free release of the gaseous combustion products and continuous or intermittent disposal of the unburned residue. In fixed bed combustion heating rate is slow and combustion time ranges from minutes to hours depending on particle size. There are different types of fuel bed combustion devices are available according to the techniques for feeding coal to the great and removing ash.

Fluidized bed combustion:-Combustion in fluidized beds involves the combustion of fuel in a bed of solid particles which is fluidized by the injection of air at the bottom of the bed, when coal is burned in this manner, the bed can consist of inert solids, coal ash or a sorbent such as limestone or dolomite .In this method heating rates can be estimated at 10^{3} to 10^{4} k/s, burning temperature are between 800 to 900 ^{0}C and burning times are in the order of seconds[12].

Suspension firing: - coal in pulverized form can be burned in a similar fashion as oil or gas, heating rates are high, temperature are more than 1500^{0}C and burning time are in the order of seconds. In pulverized coal burner more than 85 % of the coal particles should pass through a 240 mesh screen [11]. These finally ground particles are blown in to the combustion chamber by the air, this clouds of coal then burns inside the combustion chamber in a manner similar to that of droplets of liquid. The main advantage of pulverized coal burners are; high efficiency, greater flexibility in their control and operation, flexibility on the quality of to be used and easy design of burners but these advantage are off -set by the high cost of pulverizing the fuel and costly coal handling equipment.

2.6 Coal combustion in cement rotary kilns

The rotary kiln consists of a steel tube with a length to diameter ratio of between 10:1 and 38:1.The tube has an inclination of 2.5 to 4.5% and a drive rotates the kiln about its axis at 0.5 to 4.5 revolutions per minute. The upper end is the feed inlet. The combination of the tube slope and rotation causes material to be transported slowly towards the lower end, where clinker formation takes place at a temperature of about 1450 °C. In order to withstand the very high peak temperatures the entire rotary kiln is lined with heat resistant bricks. The raw meal is fed to the rotary kiln system, where it is dried, pre-heated, calcined and sintered to produce cement clinker. In the clinker burning process it is essential to maintain kiln charge temperatures of between 1400 to 1500 °C and gas temperatures of about 2000 °C. Also, the clinker needs to be burned under oxidizing conditions. Therefore an excess of air is required in the sintering zone of a cement clinker kiln. Hot air for combustion is taken from the clinker cooler, installed downstream of kiln. Fuel inside the kiln is burnt through specially designed burners, for fuel oil or coal, as the case may be. Some kilns are equipped with dual-fuel burners, to burn coal and furnace oil or natural gas, in any proportions. Long Rotary Kilns, Rotary Kilns with Preheater, Rotary Kilns with Preheater and Precalciner are widely used in cement industries .The clinker cooler is an integral part of the kiln system and has a significant influence on the thermal performance and economy of the plant. The cooler performs two tasks of recovering as much heat as possible from the hot (1450 °C) clinker so as to return it to the process and of reducing the clinker temperature to a level suitable for the downstream processing equipment [8,9].

In clinker cooler, air is used for cooling the clinkers discharged from the kiln. The cooling air close to the thermodynamic limit recovers the significant part of the clinker heat. Hot air from the cooler is used in the combustion of fuel in kiln and in precalciner. The air required for main and secondary fuel combustion determines the quantity of cooling air. Cooled clinker is released from the cooler, and then stored in clinker silo or open yards. Clinker is extracted from clinker silo and mixed with gypsum or other constituents, as required, before being finally pulverized in to cement. Clinker is ground to fine-sized cement in a mill.

The chemical reactions that occur in the kiln are more complex. The temperature is increased when going from the meal feed to the rotary kiln. The most important oxides that participate in the reactions are CaO, SiO_2, Al_2O_3 and Fe_2O_3. Up to about 700°C water is removed from the meal. In the preheating section (700-900°C), Calcination as well as an initial combination of alumina, ferric oxide and silica with lime takes place. Between 900°C and1200°C belite, C_2S ($2CaOSiO_2$), forms. Above 1250°C a liquid phase appears and this promotes the reaction between belite and free lime to form alite, C_3S (3CaOSiO2). During the cooling stage the molten phase forms C_3A, tricalcium aluminate, ($3CaOAl_2O_3$) and if the cooling is slow alite may dissolve back into the liquid phase and appear as secondary belite. Usually the production of clinker is done so that one type of clinker allows the plant to manufacture several well-defined types of cement that comply with the physical demands as specified by cement standards.

The burning process in a kiln is a direct-contact process; the material being processed is in a direct contact with the flame exposed and the dominant form of heat transfer being by radiation.Air preheat levels are high, typically in the range 500 to 1000°C, and consequently lead to very high flame temperatures resulting in the required effective radiative heat transfer. The matching of the combustion process, particularly the heat flux and aerodynamic flow profiles with the requirements of the material being processed is also critical. A mismatch can cause the production of unsaleable product or severe damage to the kiln lining.

The main strength giving compounds of clinker are alite and belite to obtain clinker with the optimum strength potential the maximum possible amount small imperfect alite crystals is required.To achieve this, the chemistry of the kiln feed material should be designed to give the optimum potential for alite formation and the physical state of the kiln feed should also be such as to foster the easy formation of this alite. There is no absorption of fuel ash by the clinker when natural gas or fuel oil is used. On the contrary, when using coal the matter of coal ash should be taken into account in to the chemistry of the feed. Coal ash is under saturated (low in lime with and typical analysis of 50% silica, 30% alumina, 10%ferric oxide and 5% lime). Depending on the kiln system, 75-100% 0f the coal ash is combined in the clinker, effectively lowering the LSF (and possibly the SM). 1 % of ash on raw mix lowers the LSF by about 4 %; hence the kiln feed must be modified to allow the effect of this ash [13]. The coal used in cement kilns should have as uniform ash content as possible to minimize the ash variation on the clinker chemistry. Additionally if the coal is finely ground there is a greater opportunity for the ash to be incorporated and absorbed in the feed before clinker nodules are formed: a lower clinkering temperature is required and quality will be higher.

2.6.1 Firing system

Coal is the most widely used fuel and a wide range of systems exist for the drying and milling of coal prior to firing into the cement kiln. There are three types of coal-firing systems used in cement plants

1. Direct firing system (Figure 2)

The simplest to operate, control and maintain. It has the lowest equipment cost and is the safest system in terms of dust explosion probability. Coal is pulverized in the mill and is fed with the primary air or hot drying gases directly into the kiln. The main source of air or hot drying gases is from clinker cooler, the kiln, or preheater exhaust.

The system has one major disadvantage in that all the air required to dry the coal is blown to the kiln, the primary air, which is usually high in moisture and low in temperature feeding directly into the kiln can adversely reduce the overall efficiency of the kiln and its ability to make good clinker. Another disadvantage is that the coal dust fines-air mixture flowing through the high speed fan blades can cause impurities or foreign objects to be lodged in the fan and ductwork. This may cause and serious frictional ignition problem that can lead to an explosion. The foreign objects or impurities can also cause fan blade wear resulting in a serious maintenance problem [9, 14].

2. Semi direct firing system (Figure 3)

It was developed to overcome some of the disadvantage inherent with the direct fired systems, in this system the pulverized coal and the transporting gases or air leaving the coal mill are separated by means of a cyclone. The cyclone collects the pulverized coal at its bottom but allows the air to pass freely out to the top. The air is re-circulated back to the mill as makeup air, after it is separated from the pulverized coal .Two advantages of this system are that the mill systems fan operates in a partially closed loop and that the coal feed is controlled by the rotary feeder and not by the primary air flowing through the coal pulverizer. The volume of air flowing through the coal mill and directly to the kiln burner can be reduced, increasing the thermodynamic efficiency of the system; however this system has a number of disadvantages. During the separation process in the cyclone some of the coal fines are inevitably carried out of the cyclone top with the re-circulating air. These coal fines are less damaging to the mill system fan blades than in the direct system but constitute and more serious fire and explosion hazard. Moisture from the coal in the re-circulating loop can accumulate and settle in the circuits leading to coal agglomeration, plugging, and other problems. One other major disadvantage is that the cyclone storage capacity is rather small, so and mill shutdown will soon cause a coal feed shutdown and result in kiln cooling and system shutdown unless some other fuel source is available for firing the system [9, 13, 14].

3. Indirect fired system (Figure 4)

In this system the hot air circulating loop, used for drying the coal and transporting the coal mill and into the cyclone, is completely separated from the system that transports the pulverized coal to its use point. The system provides for storage of large quantities of pulverized coal in a silo or bin (surge bin), usually with a three day maximum capacity, so that the coal firing can be maintained even during a mill shut down. An important feature of this system is that none of the drying and transporting air in the re-circulating loop, from the pulverizer to the cyclone to the bag house dust collector and back to the pulverizer, is used to transport the coal fines to the firing points. The drying and the transporting air vent the coal moisture directly to the atmosphere via an exhaust fan. There is a filter baghouse dust collector feeds its fines directly to the surge bin. Since the drying air circuit is completely separated from the coal firing circuit, clean and dried exhaust gas may be used as inert gas in the re-circulating loop instead of air. This allows the use of a much greater proportion of high-temperature secondary air to primary air in the kiln resulting in a more efficient regime.

The disadvantage of an indirect system include higher capital cost and greater danger of coal dust explosion than with direct or semidirect fired systems, as a result of the added handling and storage requirements of the pulverized fuel. The presence of the baghouse dust collector and surge bin would add to the coal dust explosion hazards.

The strategy behind the design of rotary kiln firing systems is to reduce energy consumption, ensure stable kiln operation, ensure consistent clinker quality is produced and ensure reducing conditions do not exist within the burning zone where the main clinkering reactions take place. It is also important to ensure refractory life is not compromised and for kilns fired with pulverized coal, to ensure that an optimum ash deposition pattern is achieved to encourage homogeneous incorporation of the ash within the clinker and prevent ash ring formation [9, 13, and 14].

2.6.2 Coal transport, storage, preparation and charging

Many coal mines are far from the user. Therefore it is necessary to have an extensive transportation and storage system to get the coal to the consumer. Coal is transported by truck, train, barge, or freighter. Trucks are used for local transportation and are the most expensive form of hauling. Trains are also used for short or long hauling and are considerably cheaper than trucking. The least expensive method of hauling is by water routes using barges on rivers and lakes and freighters on ocean routes.

There are two main types of coal storage systems in the cement industry [14].

Coal bin or silo: - bins are usually constructed of steel, but concrete is also used, bins are circular, square, or rectangular in cross section and generally designed for a three or four day capacity .The hopper should be designed for mass flow to eliminate static coal deposits .The bin outlet should be large enough to prevent arching or plugging, all bins should be self cleaning and internal surface should be kept free of stiffness, weld strips or flange surfaces.

Coal stockpiles can either be in the open or under and covered storage area. The storage site selected should be located away from any heat source, well drained, free from standing water and preferably on a dry, high ground area .The storage area should be clear of all foreign materials such as wood, rags, waste oil, or other materials having low ignition temperature. Coal should be spread in horizontal layers and piled so as to ensure effective ventilation to dissipate heat or packed firmly to ensure the minimization of communicating voids containing air.

Coal preparation: - in order to keep heat losses at minimum, cement kilns are operated at lowest reasonable excess oxygen levels. This requires highly uniform and reliable presentation of fuel in a form allowing easy and complete combustion. In order the meet these conditions, coal is processed, prior to its charging, in following steps:

Coal crushing: coals are fed into the crusher in required proportions. After crushing the mixed coal is stored in piles. From the piles the coal is moved to a conveyer belt system and is fed into a storage bunker.

Coal pulverization in coal mill: - from the storage bunker the coal is fed together with flue gases from the kiln outlet into a pulverization mill. Due to high temperature of the flue gases the coal is dried and its moisture content is decreased. In coal pulverizing mill the coal is pulverized to very fine powder form. The coarse particles, which are not grinded in the mill, are separated where as the fines is transferred to the pulverized coal silo. Coal pulverizing system is usually equipped with an explosion prevention system, to prevent explosions being triggered by smoldering fires and static electricity spark-over.

When drying coal it should be noted that completely dry coal is difficult to ignite, carbon doesn't directly react with atmospheric oxygen it first reacts with active OH radicals so as to promote the combustion, a moisture content of approximately 1-1.5% in the pulverized coal is required [13].

Coal grinding is performed either in tumbling mills or in tube mills. The fineness of the ground coal should be equivalent to a residue of 1.5 to 2 % on the 70 mesh sieve and approximately 15% residue on the 170 mesh sieve [13] but different coal meal fineness are recommended for the main types of coal according to their characteristics [9,13].

Pulverized coal firing: -from the coal feeder the coal is supported by hot air and it is transported pneumatically to the coal burner. The coal burners are specially designed for efficient burning. Burners used in cement kilns can be mono-channel design in which the primary air carries the coal particle to the kiln in the single channel or it can be a multi-channel design with further clean primary air entering the burner through a number of two annuli concentric with the coal channel, one of the channels is conventionally swirled to create an internal recirculation zone (IRZ) to aid flame stability. In both designs input conditions has to be optimized to secondary air and kiln aerodynamics. Some industries have burners of dual fuel type capable to fire simultaneously coal and fuel oil.

2.6.3 Coal Ignition, flame length and appearance

In coal firing the nature of the coal to ignition, flame stability and burn out are the key issue to be considered properly, Ignition temperature of coal is the surface temperature of coal at which the combustion reaction reaches a speed which ensures the uninterrupted burning of the coal .The influence of chemical and physical factors set limits of ignition or flame propagation in pulverized coal-air mixture. To reach the ignition temperature a certain period of time is required, this time is determined by the temperature gradient and by the heat transfer condition. The surface of the coal is the determining factor for the ignition and it depends on the particle size, i.e. on the fineness of the ground coal .The ignition temperature of pulverized coal is between 200 and 500^{o}C [12].

Coal combustion in cement rotary kilns produce propagating flame indefinitely away from the ignition source, the size and shape of this flame is governed by the different type of chemical reaction, heat transfer modes, and the flow pattern, amount of volatile matter. An inadequate flame can produce reduced clinker with poor workability, low C_3S , less water soluble alkali, increase SO_2 emission & increased preheated blockages high NOx emission, increase fuel , electricity consumption, decrease refractor life and lower production rate.

The coal flame structure is affected by the quantity of volatile matter in the coal, with increasing volatile content the center line re-circulation weakens allowing the coal air jet to penetrate where the point of ignition moves closer to the burner .A more stable flame arises from increased volatile content. The flame structure is not significantly affected by improved fineness, however fineness strongly influences the burn out that could be expected.

Additionally in cement rotary kilns the structure of pulverized coal flame is very sensitive to the coal feeding rate, primary airflow rate, secondary airflow rate etc. The effects of primary airflow rate can be attributed to the changes in availability of oxygen and residence time of coal particles in the flame region. As primary airflow rate is increased, the velocity in the axial direction increases and the residence period of coal particles decreases and thus leads to lengthening of visible flames. On the other hand, increased availability of oxygen increases the reaction rate and thus leads to shortening of the flames. The combined effects of these two factors are responsible for the peaking of the flame length vs. primary airflow rate curve. At low values of this flow rate, the insufficiency of available oxygen in the near-nozzle region also causes the occurrence of maximum axial temperature away from the burner nozzle.

When secondary airflow rate is increased, the mixing between primary air, coal jet and the secondary air is enhanced and increased entrainment of air occurs. This results in higher rates of oxidation reactions in both homogeneous and heterogeneous processes and leads to a reduction of flame length and increase in luminosity. The increased momentum of the flame jet also counteracts the effects of buoyancy and confines the flame to the axial region.

Combustion of Coal in the near-nozzle region is seen to be diffusion-controlled, whereas in the downstream region heterogeneous reaction processes are seen to dominate. An increase of coal feed rate increases flame length and shifts the location of peak flame temperatures downstream.

2.7 Coal dust explosion

One potential hazard of the coal, depending upon its characteristics and ambient conditions, is its propensity to spontaneous ignition and combustion at rather low temperatures, which may lead to outbreak of fire in stored coal.

Coal, as a primary fuel, must meet several requirements in order to be explosive. The following factors must be present to cause a coal dust explosion [10, 14].

1. The presence of coal dust in suspension in a concentration above its flammable limits.
2. Sufficient oxygen to enable combustion of fuel.
3. Source of energy to ignite the fuel.
4. Certain degree of confinement of the suspended coal dust mixed with oxygen.

The minimum explosive concentration is the minimum quantity of coal dust in suspension that will propagate an explosion if exposed to an ignition source of sufficient magnitude. For high volatile coals the minimum explosive concentration lies between 50 and 100 g/m^3. A coal pulverize under normal grinding conditions will in most cases, be loaded with a concentration of coal dust above this minimum concentration. The upper explosive limit is not well defined but is above 4000 g/m^3 [10].

The drying and conveying air in the pulverizer contains sufficient oxygen to support combustion of a coal dust cloud above its lower flammable limits. If coal containing a high percentage of moisture is being dried, the drying air will be diluted with water vapor, which will result in a reduction of the oxygen level in the air. This reduction may reduce the rate of pressure rise and maximum pressure generated, but will not prevent an ignition unless the overall oxygen concentration is reduced to about 13 % [10].

Many possible ignition sources may be present in a pulverized fuel system. Frictional sparks can be generated within the pulverizer itself by tramp iron or other foreign objects which may found their way into the system, and also hard inclusion in the coal such as pyrites or rock may be the source. Broken damper plates or fan blades from fans or ducting may also create frictional sparks which can ignite coal dust clouds or accumulation. The high temperature of the drying air often can provide enough heat to ignite coal accumulation in the mill under certain conditions.

Another important phenomenon which may lead to fire or explosion in pulverized coal system is that a spontaneous combustion, or self-heating. Spontaneous combustion occurs when a pile or accumulation of coal, over a period of time, begins to auto-oxidize and leads to a runaway exothermic reaction accompanied by the evolution of heat and/or flame. The principal factors that affect spontaneous combustion are as follows rank, air flow rate, particle size, moisture content of the air and coal, temperature, impurities in the coal and pile geometry.

Key measures for prevention and control of spontaneous coal fires include using high rank coals with low moisture contents, low volatile matter and low sulfur contents, segregation of coals with higher spontaneous ignition potential, minimizing storage times, following "first in, first out" rule of stock use, minimizing air circulation in coal piles, pile compaction in layers, minimizing windward exposure of pile, regular checking of pile for signs of self-heating, separation, cooling and replacing of hot coal, staff training and adequate fire protection equipment [10,14].

3 Indigenous coal

3.1 Source and characteristics of Ethiopian coals

Ethiopia has discovered a significant potential of higher grade lignite resource at different places in the country the most promising resource areas are found at Yayu, Debre birhan, Delbi Moya followed by Chilga, Mush Valley and Wuchali with low grades lignite potential respectively. This lignite deposits are found in various parts of the central high lands of Ethiopia but at present none of the deposits are mined. The qualities of coals found in Ethiopia are shown in Table 3.1.The location and qualities of these coals are as follows

Debre birhan: - a large deposit of lignite has been opened by erosion of mush river in an area 40 km north of Debre birhan and 5 km from Dessi road deposit is estimated to be over 1, 000,000 tons mining the lignite would present no difficulties as the amount of cover to the bed is very small the quality of the lignite is very poor having a calorific value of about 4000 kcal /kg and an ash content between 30-40 % [15].

Chiliga:-The lignite near Chiliga is very similar to that of Debre birhan and occurs in a river valley 44 km from Azeza on the chilga track which leaves the main Gonder to Bahir dar rod. The deposit is estimated to be over 2, 000,000 tons. The Lignite is inter bedded with shell and soft limestone and has a cover of 3 to 4 m alluvial deposit allowing for relatively easy mining. The quality of the lignite is fairly good having a calorific value of about 4,500 kcal /kg and ash content of approximately 6 % [15, 16].

Yayu coal:-Yayu is an area in the south western part of the country, the mine field which is called Achibo Sombo is located in the south part of Ethiopia; about 540 km west of the capital city of Addis Ababa on the road to Mutu via Jimma town .It can also be reached 488 km to the south via Nekemete, Bedle through an all weather road. The asphalt paved national high way passes through the area from east to west and there is good transportation service. The climate of this coal area belongs to tropic forest climate of continental high land. A year can be divided into rainy season from May to September and the dry season from November to next February .The climate from March, April and October lies in the two seasons [17, 18].

As indicated on the introduction part of this study, The Coal Phosphate Fertilizer Complex Project recently conducted a study on economically extractable coal in Yayu coal field in the Illubabor zone of the regional state of Oromia. The study investigate on the production of fertilizer from this indigenous coal and further concentrates on the coal beds that are most likely to be mined given such consideration as coal quality, coal thickness, etc.

The Yayu coal has ten coal seams with in the local bearing formation, among which 9 seams can be correlated and named as seam 1,2,3,4,5,6,7,8,and 9 from bottom to top. The mineable seam 4, 5, 6 are concentrated in the middle of the sedimentary lithologic units and the horizon of the 3 coal seam are very stable. The mineable coal seams in Yayu area have the following properties [18].

Seam 6

- It is located at the top
- The thickness of the coal seam including dirt band ranges from 0.15m to 2.16m and 1.5 on average. The thickness on the mineable scope ranges from 0.7 m to 1.91 m.
- The variable coefficient of coal thickness is 31%.
- The dirt band is mainly composed of carbonaceous mudstone.

Seam 5

- It is located in the middle of the three mineable coal seams.
- The thickness of the coal seams ranges from 0.55m to 2.2 m and 1.43 on average. The thickness on the mineable scope ranges from 0.7 to 1.25 m.
- The variable coefficient of coal thickness is 24%.

Seam 4

- It is located at lowest of the three mineable coal seams.
- The thickness of the coal seam ranges from 0.65 to 3.09 m thick and 2.03 on averages. The thickness on the mineable scope ranges from 0.7 to 2.15 m.

- The variable coefficient of coal thickness is 24%.
- The dirt band on this seam is composed of mainly of carboneous mudstone, silt sandstone and etc.

Table 3.1[15, 16, 18] Proximate values of Ethiopian coals (as received and air dried)

Resource	Moisture %	Volatile matter %	Ash %	Sulfur %	Calorific value kcal/kg	Geological potential (million tons)	Distance from Addis (km)
Delbi Coal	6.5	33.9	22.2	0.54	5024	41	500
Moye Coal	2.7	26.3	35.6	0.4	5040		
Yayu Coal	19.38	53.57	30.5	1.76	4419	229	540
Chilga Coal	N.A	N.A	6	N.A	4500	2	N.A
Debre birhan	N.A	N.A	30-40	N.A	4000	1	N.A

N.A not available

3.1.2 Coal quality and Rank

The rank of coal in the Yayu area is determined by using the "Chinese coal classification" scheme currently in effect and the area's N^{o} 6,4,5 coal seams all have no caking property, have not been strongly metamorphosed and belong to lignite rank further more the volatile matter of the three coal seams are larger than 50%, transmittance is in the range of 30 ~50, the high calorific value of the coal under moisture ash free basis is less than 24 MJ/Kg, thus the coals of the three coal seams belong to lignite N^{o}2 [18]. The average test results of the coal seams are shown in the table 3.2.

The Achobo-Sombo (Yayu) coal area deposit has moisture content between 18-21%; Volatile matter content between 53 and 55 % which belong to a high volatile content coal. The ash content of the coal is greater than 15% and it is a rich ash content coal. The average sulfur content of N^{o} 6 coal seam is less than 1.5%, which is low sulfur content where as the average sulfur content of coal seam 4 and 5 is larger than 1.5 %, but less than 2.5 % which is a medium sulfur content coal. Regarding the sulfur type, the total sulfur of coal seam N^{o} 6 and 5 is mainly organic sulfur while that of coal seam N^{o} 4 is mainly Pyritic. The net calorific value on dry basis of N^{o} 6 coal seam on raw coal ranges from 18.15 to 24.34 MJ/kg with an average medium calorific value 21.24 MJ/kg however the net calorific value on the dry basis of N^{o} 4 coal seam on raw coal ranges from 14.96 to 17.78 MJ/kg with average values of 16.67 MJ/kg, and the net calorific value on dry basis of N^{o}5 coal seam on raw coal ranges from 14.43 to 23.99 MJ/kg with average value of 17.66 MJ/kg. Both N^{o} 4 and 5 coal seams are coal categories with low calorific values [18].

Table 3.2: [17] average values of Yayu coal quality

Coal analysis (by weight)	Seam No.		
	4	5	6
Average ash content %	37.70	33.15	20.83
Average Volatile matter %	53.09	54.89	53.57
Average carbon content %	69.37	70.11	71.65
Average moisture content	18.27	18.86	21.03
Average calorific value (MJ/kg)	16.17	17.66	21.86

The quality of the coal from this area can be improved by coal preparation method (washing), by processing through water separation machines. The quality of raw and cleaned (washed) coal of the mineable coal seams are shown in Table 3.3. Washed coal has less ash and a higher calorific value to that of raw coal.

The carbon content of each coal seam is fairly stable with little variation, it decrease as the ash increase, the hydrogen contents of various coal seams of this area also very close all about 5.2% and this shows the hydrogen content has positive correlation with volatile matter, when the volatile matter is high the hydrogen content is also high too [18].

Table3.3: [18] approximate analysis table of mineable Yayu coal seams

Coal seam		M_{ad} (%) Min-Max Average	A_d (%) Min-Max Average	V_{daf} (%) Min-Max Average	$S_{t,d}$(%) Min-Max Average	Q_{net} (MJ/kg) Min-Max Average
6	Raw	14.42 - 28.16 21.03	13.66 - 30.55 20.83	49.73 - 55.45 53.57	1.06 - 1.76 1.37	18.15 - 24.34 21.86
	Clean	5.29 - 28.31 15.30	11.08-18.34 13.58	51.06-53.04 51.88	1.11-1.59 1.35	22.75-24.88 23.98
5	Raw	13.48 - 22.82 18.86	23.97-43.41 33.15	52.36-66.36 54.89	1.38-3.37 2.01	14.43-23.99 23.23
	Clean	8.09 - 23.04 14.16	8.05-17.98 14.32	48.76-54.1 50.63	1.65-3.46 2.15	19.17-23.99 23.23
4	Raw	13.81 - 22.07 18.27	31.27-42.07 37.43	50.49-54.72 53.09	1.48-3.11 2.06	14.96-17.78 16.17
	Clean	6.45 -17.18 12.73	11.19-5.61 18.07	48.94-54.07 50.7	1.21-2.42 1.78	19.82-24.26 21.91

ad - air dry ***d*** - dry ***daf*** - air dried and ash free

Table 3.4: [18] Elementary analysis of mineable coal seams

Coal seam	C_{daf} (%) Min-Max	H_{daf} (%) Min-Max	N_{daf} (%) Min-Max	C_{daf} (%) Min-Max
6	71.17-72.26 71.65	4.96-5.55 5.27	1.76-2.06 1.84	20.01-21.65 21.24
5	66.61-74.07 70.12	4.7-5.45 5.18	1.68-7.46 2.37	18.85-26.46 22.33
4	68.30-70.72 69.37	4.68-5.43 5.22	1.04-1.87 1.71	22.11-24.62 23.7

The nitrogen content of the various coal seams is also close, all about 2%. The oxygen and sulfur content of the various coal seams have positive correlation with ash content, which is the (O+S) increase along with ash content, thus decrease vertically from bottom to top. The elementary analyses of mineable coal Seams are shown in table 3.4.

Coal technological properties

Technological properties of coal from Yayu area are shown in the following tables

Table 3.5: [18] The coaking and caking properties of the Yayu area coal

Coal seam	Y(mm) Points	Curve form	Caking index (point)
6	2(3)	Smoothly Slopping Down	0 (2)
5	0(1)		0 (3)
4	0(1)		0 (5)

From the table the plastic layer thickness of the coal seams are all zero mm and all seams have no cohesiveness and coking property, and all seams have zero caking indices, hence the coal in this area has no caking property.

Table 3.6: [18] Ash fusibility of workable seams

Coal Seam No	T1(^oC) Min - Max Average	T2(^oC) Min - Max Average	T3(^oC) Min - Max Average
6	1180-1290 1218	1200-1330 1251	1260-1360 1310
5	1200-1410 1306	1300-1450 1388	1350-1450 1419
4	1200-1410 1295	1230-1450 1364	1300-1450 1392

Table 3.7: [18] Average values of ash viscosity characteristics of workable coal seams

Coal Seam No.	1700 ^oC	1650 ^oC	1600 ^oC	1550 ^oC	1500 ^oC	1450 ^oC	1400 ^oC	1350 ^oC
6	7.6	11.3	16.5	27.9	52.3	60.6	-	-
4	4.25	7.05	9.45	13.55	22.5	37.75	47.3	61.5
5	9.15	12.6	15.9	23.06	34.9	58.16	61.5	-

Table 3.8: [18] Sulfur content of workable coal seams

Coal Seam N^o		Total Sulfur, d (%)	Pyritic Sulfur, d (%)	Sulfate Sulfur, d (%)	Organic Sulfur, d (%)
6	Raw	1.37	0.41	0.11	0.89
	Washed	1.35	0.37	0.04	1.00
5	Raw	2.01	0.63	0.3	0.83
	Washed	2.15	0.75	0.1	1.12
4	Raw	2.06	1.1	0.28	0.77
	Washed	1.78	0.73	0.09	0.92

Table 3.9: [18] Average values of Pernicious elements contained in workable seams

Coal Seam No		P %	As(ppm)	Cl (%)	Pb (ppm)	Cd (%)
6	Raw	0.018	1.5	0.07	9	1
	Washed	0.033	1		1	1
5	Raw	0.014	2.27	0.09	12.18	1
	Washed	0.008	1.75		5.5	1
4	Raw	0.013	1.82	0.056	12.55	1.36
	Washed	0.067	1		-	1

Table 3.10: [18] Hardgrove Grindability indices of mineable coal seams

Coal Seam No.	Hardgrove Grindability Index Min - Max
6	43-110
	68.75
5	73-123
	92.5
4	60-135
	83

Table 3.11: [18] Yayu coal ash composition

Coal seam N^{o}	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	CaO %	MgO %	SO_3 %	K_2O %	Na_2O %	P_2O_5 %	MnO_2 %
6	62.02	16.65	5.65	1.48	5.83	1.91	3.23	0.53	0.65	0.33	0.04
5	65.58	17.81	6.65	1.07	3.1	1.07	1.9	0.43	0.54	0.12	0.02
4	67.23	17.87	6.03	1.6	2.34	0.93	1.26	0.42	0.45	0.1	0.01

Table 3.12: [18] Density of the mineable coal seams

Coal Seam	True density (tons/m^3)	Apparent density (tons/m^3)
6	1.5	1.3
5	1.75	1.41
4	1.7	1.41

3.1.3 Coal reserve

Assuming 0.7 m as the minimum thickness of mineable coal seams 32,573, 953 ton of the total geological reserve was worked out with in the target area in the geological exploration report generally taking 15 % for the mining losses, the mineable reserves of the mine is 22,750,917 ton which is shown in table 3.13.

Table 3.13: [17] Mineable reserves of the Yayu coal mine

Seam No	Designed reserve (tons)	Mining reserve (tons)	Mineable reserve (tons)
6	5,216,192	523,049	4,693,143
5	8,380,940	956,688	7,424,252
4	12,736,755	2,103,233	10,633,522
Sub Total	26,334,887	3,582,970	22,750,917

3.2 Potential use of Yayu-area coal in cement industry

3.2.1 Comparisons of Yayu coal quality.

Comparisons of the characteristics of Yayu coal with the requirements of cement industries and low rank coals which are presently used in cement plants are shown in table 3.14. It shows the local coals are similar in characteristics to the different type of coal qualities used in different cement plants. The quality of Yayu coals with the key characteristics of coals in cement industries are discussed below

Low heating Values:-The heating value of Yayu coal is low 4419 and 5485 kcal/kg for raw and washed coals respectively. This value is with in the range when it is compared with the lower limit for net heating value in cement plants which is 3800 kcal /kg for calciner and 4000 kcal/kg for kiln [19]. The comparison from the requirement and from other cement plants, shows the heating value of Yayu coal is acceptable, the disadvantage which arise from this low calorific value coal is the accessories required for handling, transportation and the high volume of coal required to give the required heat.

High Moisture content:-The moisture content of Yayu raw and washed coal is high 19.38 and 14.06 % for raw and washed coal respectively. The amount of energy required to dry the coal will be high, additionally the cost of transporting this high moisture coal from the mine to the point of use is another drawback.

High Volatile Matter: - The volatile matter of Yayu coal is between 53 and 55 % which belong to the a high volatile content, the presence of this volatile matter indicates easy ignition and good combustion, the required size of the coal for combustion is not as high as to the low volatile coals. But the main drawback of this type of coals is they are more prone to spontaneous ignition and fire hazards during their storage, grinding and handling, and due to this extra care and precautions are required.

High ash Content: -The average ash content of Yayu raw coal is 30.56 % which is high and brings serious effect on the quality of clinker and cement (the effect of the ash on the quality of the clinker is treated in the next section), additionally the high content of the ash has impact on the operation of the kiln, give rise to ring and ball formation, increase wear and erosion of refractory bricks, increase coating, increase the wear of grinding equipment, fans, pipes burner parts etc. The minimum requirement of ash according to DIN (German Standard) for cement industries is 15% [13] for easy operation; but considering other references high ash coals are blended with low ash coals and widely used in most cement industries. The ash content of Yayu coal is with in the requirement of cement industries when it is washed.

Low Sulfur content: -The sulfur content of Yayu coal is below 2 % and belongs to medium sulfur coal; it satisfies the requirement of cement industries, which is 1.5 % (max) [13].

Trace elements:-In addition to the major elements of the coal ash, impurities and metals can be introduced into the kiln and incorporated with the clinker and may lead to some problems on cement quality. From the coal ash analysis the impurities K_2O, NaO, MgO etc, which are found in small percentages, may not bring deleterious properties to the cement quality and to the operation of the kiln if they incorporated in the raw mix design. The average value of chloride which is found on the mineable coal seam is 0.07 % and it is high to the allowable content of chloride in raw mix and thus may lead to heavy coating and ring formation on the upper part of the kiln and preheater.

Other trace elements like P, As, Pb, and Cd since they are found in small percentages in the coal they may not bring any undesirable properties on the cement quality and on the operation of the kiln.

Table 3.14: Requirements, types of low rank coals used in cement industries

Source		Moisture Content %	Volatile Matter %	Fixed Carbon %	Ash Content %	Sulfur Content %	Calorific Value Kcal/kg
Cement Data Book [13]		-	18-22	-	12-15	2	5000
European Countries [13]		-	40-50	-	12-15	-	4800
Cement Manufacturing [20]		33.4	40.4	17.2	9.0	0.6	4167
Cement Plants in Russia [13]			25.3 18.2 23.7 30.2 42.2 -	-	19.8 22.4 22.6 15.4 41.4 63.7	-	6144 5875 5435 5420 3730 3025
Cements Plants in India [21]		33.20	27.9	25	7.6-14.7		3754-6107
Lignite coal [22]		34.8	28.2	30.8	6.2		3994
Local Coal in Pakistan [3]		5-27	15-45	18-54	15-40	2-7	4000-5500
Ethiopian Coals	Delbi Coal	6.5	33.9	-	22.2	0.54	5024
	Moye Coal	2.7	26.3	-	35.6	0.4	5040
	Yayu Raw Coal	19.38	53.85	-	30.56	1.81	4419
	Yayu Washed Coal	14.06	51.03	-	15.32	1.76	5485
	Chilga	-	-	-	6	-	4500
	Debre birhan	-	-	-	30-40	-	4000

3.2.2 The effects of coal ash on clinker and raw mix quality

For the production of cement it is necessary to have, or make raw material mixtures whose chemical composition is with in certain limits, the continuous product of high quality cement is possible only if the raw mix posses optimum composition and furthermore if variation in this composition remain with in the narrowest possible range.

For practical purposes the raw materials composition are (also the composition of the cement clinker) usually characterized by certain ratios, they are formulas into which the percentage of the various oxides are substituted. They ensure that the finished product meet the specification of the cement to be made and also show the burnability of the material in the kiln. The limiting values stated for the manufacture of Portland cement clinker is shown in table 3.15.

Table 3.15 [8] Chemical and Mineralogical composition of Portland Cement Clinker (Representative chemical compositions)

Components	[% by weight]	**Ratio**	
SiO_2	19.71-24.25	LSF	90.5-104.1
Al_2O_3	3.76-6.78	SR	1.6-4.1
TiO_2	0.21-0.52	AR	1.4-3.7
Fe_2O_3	1.29-4.64	**Clinker phase**	
MnO_3	0.03 - 0.68	C_3S	51.5-85.2
CaO	63.76-70.14	C_2S	0.2-27.1
MgO	0.00-4.51	C_3A	6.8-15.6
SO_3	0.2-2.07	C_4AF	4.0-16.2
K_2O	0.31-1.76		
Na_2O	0.03-0.33		
Na_2O-equivalent	0.31-1.34		
LOI	0.09-1.56		
CO_2	0.03-0.83		
H_2O	0.04-1.11		

In a coal fired plant the amount and composition of the ash from the composition of coal has to be considered in the preparation of the raw mix.

In this section using different formulas the effect of Yayu raw coal and washed coal on the quality of clinker and raw material preparation are worked and presented in a table with discussion. The formulas used for the analysis of raw meal and cement clinker are [20]

$$LSF = \ 100(CaO)/(2.8SiO_2 \times 1.1Al_2O_3 \times 0.7Fe_2O_3)$$

$$SM = SiO_2 / (Al_2O_3 + Fe_2O_3)$$

$$AM = Al_2O_3 / Fe_2O_3$$

$$C_3S = 4.071CaO - (7.602SiO_2 + 6.718Al_2O_3 + 1.43Fe_2O_3 + 2.852SO_3)$$

$$C_2S = 2.867SiO_2 - 0.7544C_3S$$

$$C_3A = 2.65Al_2O_3 - 1.692Fe_2O_3$$

$$C_4AF = 3.034Fe_2O_3$$

$$Burnability\ Index = C_3S / C_3S + C_4AF$$

$$Burnability\ Factor = LSF + SM - (3 \times (MgO + Na_2O + K_2O))$$

$$Percent\ Liquid = 1.13C_3A + 1.35C_4AF + MgO + Na_2O + K_2O$$

$$Theortical\ heat\ required = 4.11Al_2O_3 + 6.48MgO + 7.646CaO - 5.116SiO_2 - 0.59Fe_2O_3$$

The calculations are based on the composition of materials and data's, which is listed below and in the tables. Additionally the following parameters are considered for the analysis

Coal substitution from 40 to 100 %
Ash absorption by the clinker from 80 to 100 % (for dry process)
Heat required by the clinker 820 kcal / kg [23]

The calculation assumes that the coal seams are uniformly mixed for firing and additionally the ash is uniformly mixed with the raw mix to give a clinker. The average values of Yayu coal seams that is taken for the analysis are

Raw coal

Calorific value	4419 kcal/kg
Ash content	30.47 %

Washed coal

Calorific value	5485 kcal/kg
Ash content	15.323 %

Table 3.16:-presents the average composition of the Yayu coal, the ash has to be incorporated in the formation of the clinker and on the raw mix design.

Table 3.17:-presents raw materials composition which are used to prepare a raw mix for the production of cement clinker, this composition of raw materials are randomly taken from Mugher cement laboratory report for the possibility of preparing different raw mix design.

Table 3.18:- presents already prepared raw mixes from Mugher cement laboratory that help to show the effect of the ash on the clinker produced.

Table 3.16: [18] Chemical composition of Yayu coal ash (wt)

Seam	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	MnO_2	LOI	Balance	Total
6	62.02	16.65	5.65	5.83	1.91	3.23	0.65	0.53	1.48	0.33	0.04	0.00	1.68	100.00
5	65.58	17.81	6.65	3.10	1.07	1.90	0.54	0.43	1.07	0.12	0.02	0.00	1.71	100.00
4	67.23	17.87	6.03	2.34	0.93	1.26	0.45	0.42	1.60	0.10	0.01	0.00	1.76	100.00
AVERAGE	64.94	17.44	6.11	3.76	1.30	2.13	0.55	0.46	1.38	0.18	0.02	0.00	1.72	100.00

Table 3.17: [24] Chemical composition of raw materials used in the calculation

Raw materials Chemical components	Raw materials A			Raw materials B			Raw materials C		
	Lime stone	Clay	Sand	Lime stone	Clay	Sand	Lime Stone	Clay	Sand
SiO_2	8.56	35.08	86.27	8.16	40.18	85.71	10.22	40.06	87.18
Al_2O_3	1.9	20.36	1.75	1.55	22.63	6.28	1.81	25.5	5.09
Fe_2O_3	0.91	17.25	1.3	0.79	20.1	2.04	0.88	18.07	1.35
CaO	48.31	7.84	1.75	48.42	1.33	1.28	47.44	1.34	1
MgO	0.64	1.37	4.93	0.71	0.8	0.28	0.48	0.8	0.4
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Na_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MnO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LOI	38.57	14.08	2.5	39.36	11.39	2.86	38.18	11.22	2.5
S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balance	1.11	4.02	1.5	1.01	3.57	1.55	0.99	3.01	2.48
Total	100	100	100	100	100	100	100	100	100

Table 3.18: [24] Chemical composition of raw mixes used in the calculation

Chemical Components	raw mixes					
	A	B	C	D	E	F
SiO_2	13.38	12.8	12.86	13.08	12.96	11.98
Al_2O_3	4.08	3.92	3.64	3.77	3.67	4.28
Fe_2O_3	2.039	2.47	2.37	2.39	2.23	2.36
CaO	43.26	42.81	43.45	44.06	43.51	43.05
MgO	0.73	0.8	0.48	0.4	0.8	0.88
SO_3	0.0	0.0	0.0	0.0	0.0	0.0
Na_2O	0.0	0.0	0.0	0.0	0.0	0.0
K_2O	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.0	0.0	0.0	0.0	0.0	0.0
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0
MnO_2	0.0	0.0	0.0	0.0	0.0	0.0
LOI	34.32	35.77	35.82	35.63	35.88	35.93
S	0.0	0.0	0.0	0.0	0.0	0.0
Balance	2.19	1.43	1.38	0.67	0.95	1.52
Total	100	100	100	100	100	100

First the amount of ash absorbed by the clinker and the raw mix for different quantity of coal substituted has to be calculated that are the bases for the analysis of the quality, as an example one case is illustrated as follows

For 100 % raw coal substitution, assuming 100 % coal absorption and 10 % tolerance factor for moisture, dust and related losses. Using the average calorific value, the amount of coal required for the production of 1 kg of clinker is calculated as

$$= (820 \times 100\% / 4419.33) + (0 \cdot 1 \times 820 \times 100\% / 4419.33)$$

=0.204 kg of coal / kg of clinker

The Ash per 100 parts of clinker, using the average ash content on raw coal (30.47%) becomes

$$= 0.204 \text{ kg of coal/ kg of clinker} \times 0.3047 \text{ kg of ash/ kg of coal} \times 100\,\%$$

$$= 6.219\ \%$$

And the ash per 100 parts of raw mix, using 1.55 [24] ignition factor of the raw feed becomes

$$= 6.219 \times (100 \div (100 - 6.219)) \times (1 \div 1.55)$$

$$= 4.279\ \%$$

The above values show the amount of ash absorbed by the clinker and the raw mix when the raw Yayu coal is substituted in place of furnace oil as an example; similarly the calculated results for the different cases are presented in table 3.19.

Table 3.19: Amount of ash absorbed by the clinker and raw mix

Type of coal	Coal to be fired %	Coal rate (kg coal / kg clinker)	Ash absorbed by clinker %	Ash absorbed by raw mix %
Raw	100	0.204	6.219	4.279
	90	0.184	5.597	3.826
	80	0.163	4.975	3.378
	70	0.143	4.353	2.937
	60	0.122	3.731	2.501
	50	0.102	3.110	2.071
	40	0.082	2.488	1.646
Washed	100	0.164	2.520	1.668
	90	0.148	2.268	1.497
	80	0.132	2.016	1.328
	70	0.115	1.764	1.159
	60	0.099	1.512	0.991
	50	0.082	1.260	0.823
	40	0.066	1.008	0.657

Effect of coal ash on clinker quality

Using the formulas and the results from above tables, the possible effect of the ash on clinker quality is analyzed for different raw material mixes.

Table 3.20 up to Table 3.34 shows the influence of raw coal ash on the burnability and Quality of clinker for different raw mix design. The first results LSF, SM, AM, C_3S, C_2S, C_3A, C_3A_4 show the quality of the clinker, burnability index, and burnability factor. The percent liquid shows the burnability of the material and the influence of the mix on the operation. Comparison of the computed results with the chemical mineralogical composition of Portland cement clinker presented in (table 3.15) shows the computed results for raw coal are completely unacceptable in terms of burnability and clinker quality requirement.

Because of the high silica content of the coal ash, the LSF of the clinker is lowered by 6 - 16 % from 40 % up to 100 % coal substitution .Due to this effect the amount of C_3S which is an important constituent as it is responsible mainly for early strength development of mortar and concrete is very low and out of specification of clinker requirement.

The SM, AM are also increased as the amount of ash introduced into the kiln increases, the increase in SM shows it is difficult to burn the clinker, implies low liquid phase, more fuel is required, high heat loss by radiation and will lead to an increase in alite (C_2S) quantity as shown in the tables.

The AM shows the quantity and viscosity of liquid phase and the higher AM, more viscous liquid phase will be created at the sintering zone, which highly influences the quality of the coating and on the operation of the kiln.

The Percent liquid, semi -liquid state of clinker at 1450 ^{o}C is a very important control factor for a kiln operation. Most Portland cement clinker shows a liquid content of 25 – 27.5 %

and from the table's percent liquid increases as the amount of ash introduced increases and a higher liquid percent produces stickier burning zone clinker bed appearances, as this value increases the influence of the mix on the coating and on kiln operation will be more pronounced.

The burnability index, burnability factor are indicators and show the easy of burning for the given clinker. The higher these indexes the clinker is harder to burn. The theoretical heat required by a kilogram of clinker is for the given LSF and C_3S content is also computed and shown in the tables as the ash content increase the theoretical heat required by a kilogram of clinker is lowered.

Table 3.35 up to 3.50 shows the effect of the washed coal on the quality of clinker and from the computed results the quality of clinker and the burnability of the clinker is with in the specification of cement clinker. The LSF of the clinker is lowered by 2 - 4 % from 40 % up to 100 % coal substitutions. When the raw mix quality design is low in LSF, the quality of clinker falls out of the acceptable range, so even if the ash content of the coal is reduced the raw mix has to be designed properly considering the ash value and its variation.

Effect of Yayu coal ash on raw mix quality

Table 3.51 and 3.52 shows the effect of raw coal ash on the raw mix for a desired clinker composition. The quality of the raw mix in case of oil firing and for different coal substitution are shown at the top part of the table, the mix which has to be prepared for a given clinker quality (to produce quality clinker shown at the bottom part) is increasing from 94 %LSF as the coal rate increase, and have to be as high as 113 and 115 % in LSF (shown in table 3.51 and 3.52) when the coal is fired 100%. Such over limed mix is impossible to prepare and use for the production of clinker, leading to high fuel consumption, high burning zone temperature, damage of refractory bricks, and poor clinker quality with high free lime content and difficult operating conditions.

Table 3.53 and 3.54 presents the influence of washed coal ash on raw mix quality and the computed results show due to the reduced ash content, the increasing trend of LSF is not as high as to the raw coal and the quality of the raw mix required is with in the specification. From both tables at the top part the maximum LSF for the raw mix is around 100 % when 100 % washed coal is used

Effect of ash on limestone

Because of the introduction of coal ash proportioning should introduce more CaO (lime stone). It can be seen that the more the ash content, CaO rises gradually. For example looking at table 3.51 when fuel oil is used as a an energy source the lime stone requirement is 90 % but the requirement increase to 91.9 % as 50 % coal is replaced in place of fuel oil.

Effect of ash on clay

The basic component of coal ash are silica, alumina and Silica Modula of the Yayu coal ash is high compared to the silica ratio of clay used in Mugher cement ,due to this effect the amount clay consumed will be lowered as the amount of the ash increases. See the gradual decrease of clay requirement as the coal amount increase from 50 % to 100 % on tables 3.51 up to 3.54.

Effect of ash on sandstone

Due to the high silica content in the ash the sandstone which is used as a corrective for the silica can be reduced to a great extent. Interestingly the sand consumption decreases by a high percentage as the coal substitution increases .See the decrease of sand requirement as the coal amount increase from 50 % to 100 % on tables 3.51 up to 3.54.

The effect of raw Yayu coal

Table 3.20: Raw coal ash effect on clinker for raw materials A with LSF=106.

Type of Coal	Fuel substituted %	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn. factor	Liquid phase %	Theoretical heat required kcal/kg
Raw	100.00	50.00	30.47	95.41	2.24	1.57	60.27	15.74	9.12	11.28	96.41	2.95	113.97	26.83	422.28
	100.00	60.00	30.47	93.56	2.25	1.58	55.77	19.98	9.30	11.33	96.37	2.70	112.18	27.11	417.92
	100.00	70.00	30.47	91.74	2.26	1.60	51.23	24.25	9.48	11.38	96.34	2.46	110.42	27.39	413.52
	100.00	80.00	30.47	89.96	2.27	1.61	46.65	28.55	9.67	11.43	96.30	2.21	108.70	27.67	409.09
	100.00	90.00	30.47	88.20	2.28	1.62	42.03	32.90	9.85	11.48	96.26	1.97	107.01	27.95	404.62
	100.00	100.00	30.47	86.48	2.29	1.64	37.38	37.28	10.04	11.53	96.22	1.73	105.34	28.24	400.11

Lime stone = 89.31 % **Clay** = 8.35% **Sand** = 2.33 %
LSF = 106.00 **SM** = 2.2 **AM** = 1.49

Table 3.21: Raw coal ash effect on clinker for raw materials A with LSF=104

Type of Coal	Fuel substituted %	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn. factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	0.00	30.47	103.47	2.20	1.49	78.64	-1.55	8.30	11.19	96.58	4.03	121.66	25.76	439.94
	100.00	50.00	30.47	93.94	2.24	1.56	56.78	19.02	9.18	11.43	96.40	2.76	112.46	27.10	418.78
	100.00	60.00	30.47	92.14	2.25	1.57	52.30	23.23	9.36	11.48	96.36	2.51	110.72	27.38	414.44
	100.00	70.00	30.47	90.36	2.26	1.59	47.78	27.48	9.54	11.52	96.32	2.27	109.01	27.66	410.07
	100.00	80.00	30.47	88.62	2.27	1.60	43.22	31.77	9.72	11.57	96.28	2.03	107.33	27.94	405.66
	100.00	90.00	30.47	86.91	2.28	1.62	38.63	36.09	9.90	11.62	96.24	1.79	105.68	28.22	401.22

Lime stone = 88.4% **Clay** = 8.9 % **Sand** = 2.6 %
LSF = 104.00 **SM** = 2.6 **AM** = 1.49

Table 3.22: Raw coal ash effect on clinker for raw materials B with LSF=102, for different ash absorption by the clinker

Type of Coal	Fuel substituted %	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required kcal/kg
Raw	100.00	50.00	30.47	92.46	2.24	1.55	53.20	22.37	9.23	11.58	96.38	2.56	110.95	27.38	415.20
	100.00	60.00	30.47	90.71	2.25	1.57	48.74	26.56	9.41	11.63	96.34	2.32	109.26	27.66	410.89
	100.00	70.00	30.47	88.98	2.26	1.58	44.24	30.79	9.59	11.68	96.30	2.08	107.59	27.93	406.54
	100.00	80.00	30.47	87.28	2.27	1.60	39.71	35.05	9.77	11.72	96.26	1.85	105.96	28.21	402.16
	100.00	90.00	30.47	85.61	2.28	1.61	35.14	39.35	9.96	11.77	96.23	1.62	104.35	28.49	397.73
	100.00	100.00	30.47	83.97	2.28	1.62	30.54	43.69	10.14	11.82	96.19	1.39	102.76	28.77	393.28

Lime stone = 88.03% **Clay** = 9.131 % **Sand** = 2.83 %
LSF = 102.00 **SM** = 2.20 **AM** = 1.48

Table 3.23: Raw coal ash effect on clinker for raw materials A with LSF=94, proper mix for the given material

Type of Coal	Fuel substituted %	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required kcal/kg
Raw	100.00	80.00	30.47	78.96	2.28	1.54	16.50	57.24	10.00	12.80	96.53	0.72	98.25	29.75	378.40
	90.00	80.00	30.47	80.43	2.27	1.52	21.00	53.01	9.81	12.75	96.58	0.93	99.67	29.47	382.75
	80.00	80.00	30.47	81.93	2.26	1.51	25.47	48.81	9.63	12.71	96.62	1.14	101.12	29.20	387.07
	70.00	80.00	30.47	83.45	2.26	1.49	29.90	44.64	9.44	12.67	96.66	1.35	102.58	28.93	391.35
	60.00	80.00	30.47	84.99	2.25	1.48	34.30	40.51	9.26	12.63	96.70	1.57	104.07	28.66	395.59
	50.00	80.00	30.47	86.56	2.24	1.47	38.66	36.41	9.08	12.59	96.74	1.78	105.58	28.39	399.80

Lime stone = 87.18 % **Clay** = 9.29 % **Sand** = 4 %
LSF = 94.00 **SM** = 2.20 **AM** = 1.39

Table 3.24: Raw coal ash effect on clinker for raw materials B with LSF=100, 80 % ash absorbed by the clinker

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	80.00	30.47	85.99	2.27	1.52	36.84	38.13	9.40	12.26	96.62	1.70	105.17	28.33	398.40
	90.00	80.00	30.47	87.31	2.26	1.51	40.45	34.74	9.25	12.22	96.66	1.88	106.44	28.11	401.89
	80.00	80.00	30.47	88.64	2.25	1.50	44.04	31.37	9.10	12.19	96.69	2.07	107.73	27.89	405.35
	70.00	80.00	30.47	89.99	2.25	1.48	47.60	28.02	8.96	12.15	96.72	2.26	109.04	27.67	408.80
	60.00	80.00	30.47	91.36	2.24	1.47	51.14	24.69	8.81	12.12	96.75	2.44	110.36	27.45	412.22
	50.00	80.00	30.47	92.75	2.23	1.46	54.66	21.38	8.67	12.08	96.79	2.63	111.71	27.24	415.61

Lime stone = 88.24 %
Clay = 8.72 %
Sand = 3.02 %
LSF = 100.00
SM = 2.20
AM = 1.40

Table 3.25: Raw coal ash effect on clinker for raw materials B with LSF=100, 90 % ash absorbed by the clinker

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	87.87	2.12	1.65	39.92	34.44	10.74	12.17	97.26	1.74	106.78	29.34	405.43
	90.00	90.00	30.47	89.43	2.11	1.64	44.07	30.54	10.58	12.13	97.30	1.94	108.28	29.09	409.47
	80.00	90.00	30.47	91.01	2.11	1.63	48.18	26.66	10.42	12.09	97.35	2.14	109.80	28.85	413.47
	70.00	90.00	30.47	92.62	2.10	1.62	52.27	22.81	10.26	12.05	97.39	2.34	111.34	28.60	417.45
	60.00	90.00	30.47	94.26	2.09	1.60	56.33	18.99	10.10	12.01	97.43	2.55	112.92	28.36	421.40
	50.00	90.00	30.47	95.92	2.08	1.59	60.36	15.20	9.95	11.97	97.47	2.75	114.51	28.12	425.32

Lime stone = 88.43 %
Clay = 9 %
Sand = 3 %
LSF = 100.0
SM = 2.20
AM = 1.48

Table 3.26 **:** Raw coal ash effect on clinker for two materials mixes B with LSF 104

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	87.87	2.12	1.65	39.92	34.44	10.74	12.17	97.26	1.74	106.78	29.34	405.43
	90.00	90.00	30.47	89.43	2.11	1.64	44.07	30.54	10.58	12.13	97.30	1.94	108.28	29.09	409.47
	80.00	90.00	30.47	91.01	2.11	1.63	48.18	26.66	10.42	12.09	97.35	2.14	109.80	28.85	413.47
	70.00	90.00	30.47	92.62	2.10	1.62	52.27	22.81	10.26	12.05	97.39	2.34	111.34	28.60	417.45
	60.00	90.00	30.47	94.26	2.09	1.60	56.33	18.99	10.10	12.01	97.43	2.55	112.92	28.36	421.40
	50.00	90.00	30.47	95.92	2.08	1.59	60.36	15.20	9.95	11.97	97.47	2.75	114.51	28.12	425.32

Lime stone = 90.86 % **Clay** = 9.138 % **Sand** = 0 %
LSF = 104.00 **SM** = 2.20 **AM** = 1.53

Table 3.27: Raw coal ash effect on clinker for raw mix A

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	100.00	30.47	83.58	2.16	1.81	27.01	45.45	11.79	11.51	95.77	1.16	101.60	30.05	391.79
	100.00	90.00	30.47	85.03	2.15	1.80	31.08	41.62	11.64	11.46	95.80	1.35	102.99	29.81	395.74
	100.00	80.00	30.47	86.50	2.14	1.79	35.12	37.81	11.48	11.42	95.83	1.53	104.40	29.57	399.66
	100.00	70.00	30.47	88.00	2.13	1.78	39.12	34.03	11.33	11.38	95.86	1.72	105.83	29.33	403.55
	100.00	60.00	30.47	89.52	2.12	1.77	43.10	30.28	11.18	11.33	95.89	1.91	107.29	29.09	407.41
	100.00	50.00	30.47	91.07	2.11	1.76	47.04	26.56	11.03	11.29	95.92	2.11	108.76	28.85	411.24

LSF = 99.16 % **SM** = 2.06 **AM** = 1.70

Table 3.28: Raw coal ash effect on clinker for raw mix B

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	85.90	2.10	1.70	33.64	39.25	11.19	12.10	96.18	1.44	102.97	30.29	399.91
	90.00	90.00	30.47	87.42	2.09	1.69	37.75	35.38	11.03	12.06	96.22	1.63	104.41	30.05	403.90
	80.00	90.00	30.47	88.96	2.08	1.68	41.82	31.54	10.88	12.02	96.25	1.83	105.88	29.81	407.86
	70.00	90.00	30.47	90.52	2.07	1.67	45.86	27.72	10.72	11.98	96.28	2.02	107.37	29.58	411.80
	60.00	90.00	30.47	92.11	2.06	1.65	49.87	23.94	10.57	11.94	96.32	2.22	108.88	29.34	415.70
	50.00	90.00	30.47	93.73	2.05	1.64	53.86	20.18	10.41	11.90	96.35	2.41	110.42	29.11	419.58

LSF = 102.218 **SM** = 2.003 **AM** = 1.587

Table 3.29: Raw coal ash effect on clinker for raw mix C

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	87.56	2.22	1.66	40.11	35.13	10.43	11.75	97.41	1.81	107.25	28.49	405.18
	90.00	90.00	30.47	89.11	2.21	1.65	44.28	31.20	10.27	11.70	97.46	2.02	108.75	28.24	409.25
	80.00	90.00	30.47	90.69	2.21	1.63	48.43	27.31	10.10	11.66	97.50	2.23	110.28	27.99	413.29
	70.00	90.00	30.47	92.29	2.20	1.62	52.54	23.44	9.94	11.62	97.55	2.44	111.83	27.74	417.30
	60.00	90.00	30.47	93.92	2.19	1.61	56.63	19.61	9.78	11.57	97.59	2.65	113.40	27.49	421.28
	50.00	90.00	30.47	95.57	2.18	1.60	60.68	15.80	9.63	11.53	97.64	2.87	115.00	27.25	425.23

LSF = 104.26 **SM** = 2.14 **AM** = 1.53

Table 3.30: Raw coal ash effect on clinker for raw mix D

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	87.43	2.21	1.69	39.69	35.90	10.81	11.75	98.16	1.76	107.33	28.81	407.51
	90.00	90.00	30.47	88.95	2.20	1.68	43.83	32.01	10.65	11.71	98.21	1.96	108.81	28.56	411.56
	80.00	90.00	30.47	90.50	2.19	1.67	47.94	28.15	10.49	11.67	98.25	2.16	110.31	28.31	415.57
	70.00	90.00	30.47	92.08	2.18	1.66	52.02	24.32	10.34	11.62	98.30	2.37	111.83	28.07	419.55
	60.00	90.00	30.47	93.67	2.17	1.65	56.07	20.51	10.18	11.58	98.35	2.58	113.37	27.82	423.50
	50.00	90.00	30.47	95.30	2.17	1.64	60.09	16.74	10.02	11.54	98.39	2.79	114.94	27.58	427.43

LSF = 103.80 **SM** = 2.123 **AM** = 1.57

Table 3.31: Raw coal ash effect on clinker for raw mix E

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	87.32	2.27	1.76	39.14	35.87	10.83	11.05	96.88	1.79	106.12	28.46	405.98
	90.00	90.00	30.47	88.86	2.27	1.75	43.27	31.98	10.67	11.00	96.92	2.00	107.61	28.21	410.01
	80.00	90.00	30.47	90.42	2.26	1.74	47.38	28.12	10.51	10.95	96.96	2.21	109.11	27.96	414.01
	70.00	90.00	30.47	92.01	2.25	1.73	51.46	24.28	10.35	10.91	97.00	2.42	110.65	27.71	417.98
	60.00	90.00	30.47	93.62	2.24	1.72	55.50	20.48	10.20	10.86	97.04	2.64	112.20	27.47	421.92
	50.00	90.00	30.47	95.26	2.24	1.70	59.52	16.70	10.04	10.81	97.07	2.85	113.79	27.22	425.84

LSF = 103.877 **SM** = 2.197 **AM** = 1.646

Table 3.32: Raw coal ash effect on clinker for raw mix F

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.0	90.0	30.470	89.976	1.921	1.910	41.097	30.301	12.888	11.637	95.923	1.676	104.729	31.765	413.221
	90.0	90.0	30.470	91.629	1.910	1.900	45.246	26.376	12.741	11.593	95.956	1.859	106.284	31.534	417.298
	80.0	90.0	30.470	93.310	1.899	1.891	49.365	22.479	12.596	11.549	95.989	2.045	107.867	31.305	421.345
	70.0	90.0	30.470	95.021	1.887	1.881	53.453	18.611	12.451	11.506	96.021	2.231	109.478	31.077	425.363
	60.0	90.0	30.470	96.762	1.875	1.872	57.511	14.772	12.308	11.462	96.054	2.419	111.119	30.851	429.351
	50.0	90.0	30.470	98.533	1.864	1.862	61.540	10.960	12.166	11.419	96.086	2.609	112.789	30.627	433.309

LSF = 107.88 **SM** = 1.804 **AM** = 1.184

Table 3.33: Raw coal ash effect on clinker for raw materials C with LSF = 100

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	84.44	2.27	1.76	31.25	43.36	11.08	11.30	97.00	1.40	104.56	28.66	395.96
	90.00	90.00	30.47	85.89	2.27	1.75	35.34	39.52	10.92	11.26	97.04	1.59	105.96	28.41	399.93
	80.00	90.00	30.47	87.36	2.26	1.74	39.40	35.70	10.76	11.21	97.08	1.79	107.39	28.16	403.87
	70.00	90.00	30.47	88.86	2.25	1.73	43.43	31.92	10.61	11.16	97.12	1.99	108.85	27.91	407.78
	60.00	90.00	30.47	90.38	2.25	1.72	47.43	28.16	10.45	11.12	97.16	2.20	110.32	27.66	411.66
	50.00	90.00	30.47	91.92	2.23	1.70	51.39	24.42	10.30	11.07	97.19	2.40	111.81	27.42	415.51

LSF = 100.00 **SM** = 2.20 **AM** = 1.65

Table 3.34: Raw coal ash effect on clinker for Raw materials C with LSF = 98.26

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Raw	100.00	90.00	30.47	83.13	2.27	1.76	27.55	46.84	11.18	11.43	96.99	1.22	103.24	28.94	392.32
	90.00	90.00	30.47	84.54	2.27	1.75	31.61	43.01	11.02	11.39	97.03	1.41	104.62	28.69	396.26
	80.00	90.00	30.47	85.98	2.26	1.74	35.65	39.22	10.86	11.34	97.07	1.61	106.01	28.45	400.18
	70.00	90.00	30.47	87.44	2.25	1.73	39.65	35.46	10.71	11.30	97.11	1.80	107.42	28.20	404.07
	60.00	90.00	30.47	88.92	2.24	1.72	43.63	31.72	10.55	11.25	97.15	2.00	108.85	27.96	407.93
	50.00	90.00	30.47	90.41	2.24	1.71	47.57	28.00	10.40	11.20	97.19	2.20	110.30	27.72	411.75

LSF = 98.27 **SM** = 2.2 **AM** = 1.65

The effect of washed Yayu coal

Table 3.35: Washed coal ash effect on clinker for raw materials A with LSF =106

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	50.00	15.32	101.13	2.22	1.52	73.46	3.34	8.60	11.14	96.53	3.72	119.48	26.02	435.04
	100.00	60.00	15.32	100.33	2.22	1.53	71.68	5.01	8.67	11.16	96.52	3.62	118.71	26.13	433.32
	100.00	70.00	15.32	99.54	2.23	1.54	69.90	6.69	8.74	11.17	96.50	3.51	117.95	26.24	431.59
	100.00	80.00	15.32	98.75	2.23	1.54	68.11	8.37	8.81	11.19	96.49	3.40	117.19	26.35	429.86
	100.00	90.00	15.32	97.97	2.23	1.55	66.32	10.06	8.88	11.21	96.48	3.30	116.44	26.46	428.12
	100.00	100.00	15.32	97.20	2.24	1.55	64.52	11.75	8.95	11.23	96.46	3.20	115.69	26.57	426.38

Lime stone = 89.31% **Clay** =8.35 % **Sand** = 2.33 %
LSF = 106.00 % **SM** = 2.20 **AM** = 1.49

Table 3.36: Washed coal ash effect on clinker for raw materials A with LSF = 104.00

	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	50.00	30.47	99.50	2.22	1.52	69.89	6.68	8.65	11.29	96.51	3.51	117.83	26.30	431.47
	100.00	60.00	30.47	98.73	2.22	1.52	68.13	8.34	8.72	11.31	96.50	3.40	117.08	26.41	429.76
	100.00	70.00	30.47	97.96	2.22	1.53	66.35	10.01	8.79	11.33	96.49	3.30	116.34	26.52	428.05
	100.00	80.00	30.47	97.19	2.23	1.54	64.58	11.69	8.87	11.35	96.47	3.20	115.60	26.63	426.32
	100.00	90.00	30.47	96.43	2.23	1.54	62.79	13.37	8.94	11.37	96.46	3.09	114.87	26.74	424.59
	100.00	100.00	30.47	95.68	2.24	1.55	61.00	15.05	9.01	11.38	96.45	2.99	114.14	26.85	422.86

Lime stone = 88.4 % **Clay** =8.9 % **Sand** = 2.6 %
LSF = 104.00 % **SM** = 2.20 **AM** = 1.49

Table 3.37 : Washed coal ash effect on clinker for raw materials A with LSF = 102

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	50.00	15.32	97.88	2.22	1.51	66.24	10.10	8.71	11.44	96.50	3.29	116.17	26.59	427.65
	100.00	60.00	15.32	97.12	2.22	1.52	64.49	11.75	8.78	11.46	96.48	3.19	115.45	26.69	425.95
	100.00	70.00	15.32	96.37	2.22	1.52	62.72	13.41	8.85	11.48	96.47	3.08	114.72	26.80	424.24
	100.00	80.00	15.32	95.63	2.23	1.53	60.95	15.08	8.92	11.50	96.46	2.98	114.01	26.91	422.53
	100.00	90.00	15.32	94.89	2.23	1.54	59.18	16.75	8.99	11.52	96.44	2.88	113.29	27.02	420.81
	100.00	100.00	15.32	94.16	2.23	1.54	57.40	18.43	9.07	11.54	96.43	2.79	112.59	27.13	419.09

Lime stone = 88.03% **Clay** =9.13 % **Sand** = 2.83 %

LSF = 102 .00 **SM** = 2.20 **AM** = 1.49

Table 3.38: Washed coal ash effect on clinker for raw materials A with LSF = 94; proper mix for the given material

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.0	80.0	15.323	89.360	2.227	1.504	45.578	29.484	9.164	12.157	96.383	2.138	107.596	28.113	407.397
	90.0	80.0	15.323	89.891	2.224	1.500	46.962	28.181	9.108	12.143	96.394	2.210	108.107	28.029	408.731
	80.0	80.0	15.323	90.424	2.222	1.495	48.342	26.882	9.051	12.129	96.404	2.282	108.619	27.944	410.061
	70.0	80.0	15.323	90.960	2.219	1.491	49.719	25.586	8.995	12.116	96.415	2.355	109.135	27.860	411.388
	60.0	80.0	15.323	91.499	2.216	1.487	51.091	24.293	8.939	12.102	96.426	2.428	109.653	27.776	412.711
	50.0	80.0	15.323	92.041	2.214	1.482	52.461	23.004	8.883	12.089	96.436	2.501	110.174	27.692	414.031

Lime stone = 87.18 % **Clay** =9.29 % **Sand** = 3.52 %

LSF = 94.00 % **SM** = 2.2 **AM** = 1.40

Table 3.39: Washed coal ash effect on clinker for raw materials B with LSF = 100

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.0	80.0	15.323	94.067	2.228	1.523	57.246	18.554	8.981	11.659	96.439	2.774	112.408	27.201	419.053
	90.0	80.0	15.323	94.645	2.225	1.519	58.654	17.228	8.924	11.644	96.450	2.852	112.966	27.115	420.411
	80.0	80.0	15.323	95.227	2.222	1.514	60.058	15.906	8.867	11.629	96.460	2.930	113.526	27.029	421.765
	70.0	80.0	15.323	95.812	2.220	1.510	61.459	14.587	8.811	11.614	96.471	3.009	114.090	26.942	423.116
	60.0	80.0	15.323	96.400	2.217	1.505	62.856	13.272	8.754	11.600	96.482	3.088	114.657	26.857	424.463
	50.0	80.0	15.323	96.991	2.214	1.501	64.249	11.960	8.698	11.585	96.492	3.168	115.227	26.771	425.807

Lime stone = 88.24 % **Clay** =9.29 % **Sand** = 3.02 %
LSF = 100.00 % **SM** = 2.2 **AM** = 1.406

Table 3.40: Washed coal ash effect on clinker for raw materials B with LSF = 96

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	90.28	2.23	1.45	48.50	27.17	8.76	12.38	96.81	2.29	109.22	27.73	409.48
	90.00	90.00	15.32	90.88	2.23	1.45	50.08	25.69	8.70	12.36	96.82	2.38	109.80	27.64	411.00
	80.00	90.00	15.32	91.50	2.22	1.44	51.64	24.21	8.63	12.35	96.83	2.46	110.39	27.54	412.51
	70.00	90.00	15.32	92.11	2.22	1.44	53.21	22.74	8.57	12.33	96.85	2.55	110.99	27.44	414.01
	60.00	90.00	15.32	92.73	2.22	1.43	54.76	21.28	8.50	12.32	96.86	2.63	111.59	27.35	415.51
	50.00	90.00	15.32	93.35	2.22	1.43	56.32	19.81	8.44	12.30	96.87	2.72	112.19	27.25	417.01

Lime stone = 87.54 % **Clay** =9.09 % **Sand** = 3.35 %
LSF = 96.00 **SM** = 2.2 **AM** = 1.401

Table 3.41: Washed coal ash effect on clinker for raw materials B with LSF = 98

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	100.00	15.32	91.14	2.23	1.46	50.64	25.16	8.75	12.24	96.80	2.41	110.10	27.54	411.67
	90.00	100.00	15.32	91.83	2.23	1.45	52.40	23.50	8.68	12.22	96.81	2.51	110.76	27.44	413.37
	80.00	100.00	15.32	92.52	2.23	1.45	54.16	21.85	8.61	12.20	96.83	2.60	111.43	27.33	415.06
	70.00	100.00	15.32	93.22	2.22	1.44	55.91	20.20	8.54	12.19	96.84	2.70	112.11	27.22	416.75
	60.00	100.00	15.32	93.93	2.22	1.44	57.66	18.56	8.47	12.17	96.85	2.79	112.79	27.11	418.43
	50.00	100.00	15.32	94.64	2.22	1.43	59.40	16.92	8.39	12.15	96.87	2.89	113.48	27.00	420.10

Lime stone = 87.64 % **Clay** =9.08 % **Sand** = 3.34 %
LSF = 98.00 **SM** = 2.2 **AM** = 1.40

Table 3.42: Washed coal ash effect on clinker for raw materials B with LSF = 100

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	93.37	2.23	1.46	56.10	19.89	8.59	12.04	96.62	2.72	112.31	27.09	416.32
	90.00	90.00	15.32	94.02	2.23	1.45	57.68	18.40	8.52	12.03	96.63	2.81	112.93	26.99	417.86
	80.00	90.00	15.32	94.67	2.22	1.45	59.27	16.91	8.46	12.01	96.65	2.90	113.56	26.89	419.39
	70.00	90.00	15.32	95.32	2.22	1.44	60.85	15.42	8.39	12.00	96.66	2.98	114.19	26.80	420.92
	60.00	90.00	15.32	95.97	2.22	1.44	62.42	13.94	8.33	11.98	96.68	3.07	114.82	26.70	422.44
	50.00	90.00	15.32	96.63	2.22	1.43	63.99	12.47	8.26	11.97	96.69	3.16	115.46	26.61	423.96

Lime stone = 88.24 % **Clay** =8.72 % **Sand** = 3.02 %
LSF = 100 **SM** = 2.20 **AM** = 1.40

Table 3.43 **:** Washed coal ash effect on clinker for raw mix A

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	92.56	2.10	1.75	50.82	23.08	10.91	11.26	96.07	2.29	110.18	28.67	415.34
	90.00	90.00	15.32	93.20	2.10	1.75	52.40	21.59	10.85	11.24	96.08	2.37	110.80	28.57	416.88
	80.00	90.00	15.32	93.84	2.10	1.74	53.98	20.11	10.79	11.22	96.09	2.45	111.41	28.48	418.42
	70.00	90.00	15.32	94.49	2.09	1.74	55.55	18.62	10.73	11.21	96.11	2.53	112.04	28.39	419.95
	60.00	90.00	15.32	95.15	2.09	1.73	57.12	17.15	10.67	11.19	96.12	2.61	112.66	28.29	421.48
	50.00	90.00	15.32	95.81	2.09	1.73	58.68	15.67	10.61	11.17	96.14	2.69	113.29	28.20	423.00

LSF = 99.16 **SM** = 2.068 **AM** = 1.70

Table 3.44: Washed coal ash effect on clinker for raw mix B

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	95.29	2.04	1.63	57.55	16.63	10.26	11.85	96.29	2.60	111.91	28.86	422.84
	90.00	90.00	15.32	95.96	2.04	1.63	59.15	15.13	10.20	11.83	96.31	2.68	112.55	28.77	424.39
	80.00	90.00	15.32	96.64	2.04	1.62	60.73	13.63	10.14	11.82	96.32	2.77	113.20	28.68	425.94
	70.00	90.00	15.32	97.32	2.03	1.62	62.32	12.14	10.08	11.80	96.34	2.85	113.84	28.58	427.49
	60.00	90.00	15.32	98.00	2.03	1.61	63.90	10.65	10.02	11.79	96.35	2.93	114.50	28.49	429.03
	50.00	90.00	15.32	98.69	2.02	1.61	65.47	9.16	9.96	11.77	96.37	3.01	115.16	28.40	430.56

LSF = 102.21 **SM** = 2.2 **AM** = 1.54

Table 3.45: Washed coal ash effect on clinker for raw mix C

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	97.17	2.17	1.59	63.94	12.10	9.39	11.39	96.83	3.08	116.56	26.78	425.22
	90.00	90.00	15.32	97.86	2.17	1.58	65.55	10.59	9.33	11.38	96.84	3.17	117.23	26.68	426.78
	80.00	90.00	15.32	98.55	2.17	1.58	67.15	9.08	9.27	11.36	96.86	3.26	117.90	26.58	428.33
	70.00	90.00	15.32	99.25	2.16	1.57	68.75	7.58	9.21	11.34	96.87	3.35	118.57	26.49	429.88
	60.00	90.00	15.32	99.95	2.16	1.57	70.34	6.08	9.14	11.32	96.89	3.44	119.25	26.39	431.43
	50.00	90.00	15.32	100.66	2.16	1.56	71.93	4.58	9.08	11.31	96.90	3.53	119.94	26.29	432.97

LSF = 104.269 **SM** = 2.14 **AM** = 1.536

Table 3.46 : Washed coal ash effect on clinker for raw mix D

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	96.86	2.16	1.62	63.50	13.10	9.82	11.43	97.85	2.99	116.46	27.19	428.56
	90.00	90.00	15.32	97.53	2.15	1.62	65.10	11.60	9.76	11.41	97.87	3.07	117.12	27.09	430.12
	80.00	90.00	15.32	98.21	2.15	1.62	66.69	10.10	9.70	11.40	97.89	3.16	117.77	26.99	431.67
	70.00	90.00	15.32	98.90	2.15	1.61	68.28	8.61	9.63	11.38	97.90	3.25	118.43	26.90	433.22
	60.00	90.00	15.32	99.58	2.14	1.61	69.87	7.12	9.57	11.36	97.92	3.34	119.10	26.80	434.76
	50.00	90.00	15.32	100.28	2.14	1.60	71.45	5.63	9.51	11.35	97.94	3.43	119.77	26.71	436.30

LSF = 103.00 **SM** = 2.12 **AM** = 1.58

Table 3.47 **:** Washed coal ash effect on clinker for raw mix E

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	96.84	2.23	1.69	63.08	13.10	9.86	10.73	96.77	3.06	115.32	26.90	428.03
	90.00	90.00	15.32	97.53	2.23	1.69	64.68	11.59	9.80	10.71	96.79	3.15	115.98	26.80	429.59
	80.00	90.00	15.32	98.21	2.22	1.68	66.28	10.09	9.74	10.69	96.80	3.24	116.65	26.70	431.14
	70.00	90.00	15.32	98.90	2.22	1.68	67.87	8.59	9.68	10.67	96.82	3.34	117.31	26.61	432.70
	60.00	90.00	15.32	99.60	2.22	1.67	69.46	7.10	9.61	10.66	96.83	3.43	117.99	26.51	434.24
	50.00	90.00	15.32	100.30	2.21	1.67	71.04	5.61	9.55	10.64	96.84	3.52	118.66	26.41	435.79

LSF = 103.00 **SM** = 2.19 **AM** = 1.64

Table 3.48 **:** Washed coal ash effect on clinker for raw mix F

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	100.24	1.85	1.85	65.33	7.37	12.03	11.38	96.12	2.79	114.40	30.42	437.04
	90.00	90.00	15.32	100.98	1.85	1.85	66.95	5.85	11.98	11.36	96.13	2.87	115.10	30.33	438.62
	80.00	90.00	15.32	101.73	1.84	1.84	68.55	4.33	11.92	11.34	96.14	2.95	115.80	30.24	440.20
	70.00	90.00	15.32	102.48	1.84	1.84	70.16	2.81	11.86	11.33	96.15	3.03	116.51	30.15	441.78
	60.00	90.00	15.32	103.23	1.83	1.84	71.76	1.30	11.81	11.31	96.17	3.10	117.22	30.06	443.35
	50.00	90.00	15.32	103.99	1.83	1.83	73.35	-0.21	11.75	11.29	96.18	3.18	117.94	29.97	444.91

LSF = 107.00 **SM** = 1.84 **AM** = 1.81

Table 3.49 : Washed coal ash effect on clinker for raw materials C with LSF=100

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	93.41	2.23	1.70	55.13	20.91	10.16	11.03	97.23	2.60	113.25	27.19	419.14
	90.00	90.00	15.32	94.69	2.22	1.69	58.30	17.93	10.03	11.00	97.26	2.77	114.50	27.00	422.22
	80.00	90.00	15.32	95.34	2.22	1.68	59.88	16.45	9.97	10.98	97.28	2.86	115.13	26.90	423.75
	70.00	90.00	15.32	95.99	2.22	1.68	61.46	14.97	9.91	10.96	97.29	2.94	115.76	26.80	425.28
	60.00	90.00	15.32	96.65	2.22	1.67	63.03	13.49	9.85	10.94	97.31	3.03	116.40	26.71	426.80
	50.00	90.00	15.32	96.65	2.22	1.67	63.03	13.49	9.85	10.94	97.31	3.03	116.40	26.71	426.80

LSF = 100.00 % **SM** = 2.2 **AM** = 1.64

Table 3.50 : Washed coal ash effect on clinker for raw materials C with LSF= 98.26

Type of Coal	Fuel substituted%	Ash absorbed by the clinker %	Content of ash %	LSF	SM	AM	C_3S	C_2S	C_3A	C_4AF	Total	Burn. Index	Burn factor	Liquid phase %	Theoretical heat required Kcal/Kg
Washed	100.00	90.00	15.32	91.86	2.23	1.69	51.29	24.52	10.26	11.17	97.23	2.39	111.71	27.49	415.36
	90.00	90.00	15.32	92.48	2.23	1.69	52.87	23.03	10.20	11.15	97.24	2.48	112.31	27.39	416.90
	80.00	90.00	15.32	93.11	2.22	1.68	54.44	21.55	10.13	11.13	97.26	2.56	112.92	27.29	418.43
	70.00	90.00	15.32	93.74	2.22	1.68	56.01	20.07	10.07	11.11	97.27	2.64	113.53	27.20	419.95
	60.00	90.00	15.32	94.38	2.22	1.67	57.58	18.60	10.01	11.10	97.29	2.73	114.14	27.10	421.47
	50.00	90.00	15.32	95.01	2.22	1.67	59.14	17.13	9.95	11.08	97.30	2.81	114.76	27.01	422.99

LSF = 98.26 % **SM** = 2.2 **AM** = 1.64

4 Technology transfer

4.1 Overview of switch over

To see the technical and economical effect of Yayu washed when it is substituted in place of furnace oil coal, Mugher Cement Enterprise is selected.

The Mugher Cement Enterprise (MCE) is an autonomously managed public enterprise, located in the region of Oromia some 102 km north- west of Addis Ababa near to the village of Mugher. The MCE was established in 1984 with one production line with 300,000 tons of clinker or an initial capacity of 315,000 tons per annum of Ordinary Portland Cement (OPC).A second similar production line 300,000 ton clinker per annum was installed in 1990.This increases the total capacity to 630,000 tons per annum of OPC or 750,000 tons per annum of Portland Pozzolana Cement (PPC). Presently both kilns are operating at full capacity producing more than 600,000 tons of clinker.

Switching from fuel oil to coal, for combustion in the existing cement kilns system, requires substantial capital investments, for additional facilities and equipment and changes in some existing ones. In this section an attempt is made to select the major required equipments for the existing system of the kilns, considering 100 % Yayu washed coal is used in place of furnace oil.

4.2 Coal and air requirement

Coal requirements

Clinker specific energy requirement [23] = 820 ± 5% Kcal/kg
Clinker production for one line [23] =1000 ton /day
Heating valve of washed Yayu coal =5485 Kcal/kg
Working days [24] =300 days/year
Moisture content of coal at fired basis [13] =1.25 %

From the previous section 3.2.2, from table 3.19, for washed Yayu coal

Coal rate for 100 % substitution = 0.164 kg of coal /kg of clinker

So based on the above figure, the coal requirement for one kiln if 100 % coal is fired can be calculated as

= 0.164 kg of coal/ ton of clinker × 1000 ton of clinker /24 hours

= 6.8 ton of coal /hr

= 48960 ton /year

For two kilns, the annual washed coal requirements becomes

= 97920 ton /year

Air requirement

The exact amount of air required for combustion is calculated as follows. The chemical composition of the Yayu coal at different basis is calculated and shown in the table.

Table 4.1: [18] Chemical composition of Yayu coal

Element	Ash and moisture free %	Dry basis %	As fired %
C	70.00	59.27	58.53
H	5.22	4.42	4.37
S	-	1.76	1.738
N	1.97	0.166	0.163
O	22.42	17.22	17.00
Ash	-	15.32	15.12
Volatile matter	51.07	43.24	42.70
Moisture	-	-	1.25

The balanced complete chemical equation of combustion equation is represented by

$$H_2 + \frac{1}{2} O_2 \longrightarrow H_2O$$

$$C + O_2 \longrightarrow CO_2$$

$$S + O_2 \longrightarrow SO_2$$

The theoretical minimum amount of oxygen from combustion reaction stoichiometry analysis and ultimate analysis as fired basis [11]

$$O_{min} = [(0.0437 \div 4) + (0.5853 \div 4) + (0.01738 \div 12) - (0.17 \div 32)]$$

$$= 0.0549$$

The amount of oxygen available in the air by volume is 21 %, the theoretical air required is

$$= 0.0549 \div 0.21$$

$$= 0.2614 \text{ kmole of air /kg of coal}$$

The volume of air to be supplied at standard condition is

$$= 0.2614 \times 22.4 \text{ m}^3 \text{ or}$$

$$= 5.858 \text{ m}^3 \text{ dry air/kg coal}$$

In practice the theoretical air is not sufficient to accomplish complete combustion so considering excess air $\lambda = 1.12$ which is a combustion factor [24]. The air required becomes

$$= 0.2614 \times 1.12$$

$$= 6.56 \text{ St. m}^3 \text{ dry air/kg coal} \quad \text{or}$$

$$= 8.482 \text{ kg dry air/kg coal}$$

The moist are required can be calculated as, considering moisture content of the combustion air to be 0.02249 kg/kg [24]

$$V_{air} = (6.56 \text{ St. m}^3 \text{ of air/kg of coal} \times 6833 \text{ kg of coal /hr} \times (1 + 0.02249 \div 0.804))$$

$$= 46{,}078 \text{ St. m}^3 \text{of air/hr}$$

Primary air volume [24], which is 10% of the combustion air volume becomes

$$= 4607 \text{ st. m}^3 \text{of air/hr}$$

Secondary air volume

Secondary air = total combustion air - primary air

$$= 41{,}471 \text{ st. m}^3 \text{of air/hr}$$

Cooling air volume

Cooling air volume = Secondary air volume

= 41,471 st. m^3 /h

4.3 Equipment Selection

4.3.1 Firing system

The different types of coal firing systems are discussed in section 2.6.1, in order to select the suitable type of firing system for our purpose the advantage and disadvantage of the firing systems are discussed as follows[9, 13, 14, and 25].

1. Direct firing system

Advantages

- Simple in terms of layout and equipment
- Low capital expedition
- Low operational reliability
- No pulverized coal storage
- No any dust-laden exhaust gas to be dedusted

Disadvantages

- High rate of primary air that results a higher heat consumption of the kiln.
- Throughput of the mill has to be varied, according to the kiln requirements. So optimum setting of the mill is impossible.
- Malfunction of the mill results in shut down of the kiln.
- Any variations on the function affect the firing system and the operation of the kiln.

2. Semi direct firing system

- There are different types of semi direct firing system.

- It is more or less the same to that of the direct firing system except the pulverized coal as collected in the cyclone.

In general if direct firing is used for two or more consumer units, more particularly cement kilns it will be necessary to use two or more coal grinding mills to achieve suitable trouble free operation.

3. Indirect firing system (Central firing system)

Advantages

- Operational independences of coal grinding and kiln firing plant.
- Possibility of supplying several consumer plants (kilns).
- Possibility of optimum rate or primary air.
- Greater accuracy of feeding pulverized coal.
- Shorter control dead time.

Disadvantages

- More elaborate interims of mechanical installation.
- High control technology and safety arrangements.
- The need for a filter with high dust collecting efficiency.
- The need for high safety precaution.
- High capital cost of the equipment.

Based on their features the comparisons of the coal firing system for our purpose are presented in table 4.2.Due to the different advantages seen an indirect fired system (option III) is selected for our purpose. The indirect firing system is selected due to the following reason.

- There are two kilns in the existing cement plant and it is possible to operate both kilns by indirect firing system (a central grinding plant can fed both kilns).
- It is possible to use coal, furnace oil or a combination of these fuels with indirect firing system.

- Two independent mills are required and operation of kilns is not stable if direct or semi direct firing is selected.

Table 4.2: Comparisons of firing system operational parameters

Kiln operational parameter (Requirements)	Option I Direct firing	Option II Semi-direct	Option III Indirect firing
Flame modification	Poor	Poor	Good
Implementation cost	Very low	Low	Very high
No_x control	Poor	Poor	Good
Heat consumption	Low	Low	High
Clinker quality control	Poor	Poor	Good
Alterative fuel firing	Difficult	Difficult	Feasible
Flexibility of fuel feeding	Poor	Poor	Good

4.3.2 Burner

Fundamental requirement in any burner

- Carry or transport fuel to the burner tip & release with desired velocity.
- Provide adequate oxygen rich air at the tip to ensure complete burning of fuel.
- Atomize the fuel at the tip so the burning is fast resulting in quick heat release.
- Provide mechanism to adjust flame shape and type.
- Provide mechanism to adjust direction of burner so as to control the direction of the flame.
- Provide mechanism to either suspend the burner from overhead trolley or floor-mounted trolley.
- Mechanism to connect air supply line from primary air fan to the burner.
- Provide to insert light oil gun for initial firing (heat up kilns).

The different types of burner, which are used for coal firing in cement kilns, are [26, 27].

1. Traditional or conventional burner

- The coal dust will be transport to the kiln by the primary air.
- It is mostly used in direct firing systems.
- The primary air carries the fuel to the burner.
- Primary air requirement is high.

2. Multi channel burner

- The air and the fuel are fed independently.
- Coal, oil, gaseous or any combination of these fuels can be fired with this burner.
- Allows degree of variation in the mass and velocity flows of air and fuel.
- Allows degree of flame optimization.
- The central swirl air produce a recirculating vortex near the burner tip which entrains the fuel. The vortex reduces the shear and velocity in the region near the burner tip that greatly increase the stability of the flame.
- Lower primary air is used.

3. Pyro - Jet burner

- The axial air emerges at high velocity through several individual jets distributed around the circumference.
- Percentage of primary air can be significantly reduced.
- Primary air including transport air can be reduced to 6 - 8 percentages (even lower primary air up to 4 % can be achieved).
- The velocity of the air can be as high as 150 m/sec.

4. Three Channel burners

- The burner is designed featuring a central duct for gaseous & liquid fuel placed inside an annual coal duct which is surrounded by two concentrate ducts that form two primary air channels one for radial air and one for axial air.
- Pulverized coal or coke, oil, natural gas or any mixture of these fuels can be fired with this burner.

- Extra ducts for secondary fuel can be adjusted.

5. Precessing tip burner (Gyro - Therm)

- Consist of a chamber with a large sudden expansion at its inlet to generate naturally occurring flow instability.
- Reduced ignition distance
- High heat flux close to the burner.
- There is high mixing intensity in close proximity to the secondary air.

6. Low NO_X burner

- These burners stage combustion at the burner outlet to inhibit the formation of NO_X from the fuel bound nitrogen.
- The approach to NO_X reduction involves use of low NO_X burner couple with an over fire air system these burner operate under fuel rich conditions (fuel lean techniques via radial staging).
- The design is based on staging of airflow (air split) and staging of fuel.

The comparisons of different types of burners for our purpose are presented in table 4.3 and multi channel burners are selected due to following reasons

- Most of the required parameters are achieved through these burners.
- They are more suitable for firing low-grade coals.
- They are more suitable to fire both fuel and coal.
- They are mostly used in cement industries and there are different designs of multi-channel burner according to their mode of operation.
- The cost of these burners is low compared to the other burners.

Multi – channel burner, the selected burner have the following parameters

Pulverized coal Volatile matter ~51%
Fineness 15 % residue on 170 mesh screen [13]
Altitude 2540 m above sea level [23]
Air velocity in the burner 35 – 120 m/sec [22]
Pressure at the tip 120 – 130 mbar [22]

Table 4.3: [26, 27] Comparisons of coal burners

Requirements	Traditional burners	Multi channel burners	Precessing Jet – burner (Gyro - Therm)	Low NO_X burner	Pyro jet burner
Burner must be able to Fire coal and oil	Not possible	Possible	Possible	Possible	Possible
Burner must produce a short narrow strongly radiant flame. - higher momentum (Primary air percentage × velocity of air)	Good < 1000 %	Very good 1780%max	Very good 1560% max	Very good 1500%max	Very good 1500%max
Primary air quantity	High (>15%)	Small (<10%)	Small (10%)	Small	Small (<8%)
Suitability for Low grade coal (especially for high ash coals)	Good	Very good	Good	Very good	Good
Flame adjustment	Not easy	Very easy	Easy	Very easy	Easy
Power consumption	Low	High	High	High	High
Cost	Low	Moderate	High	High	High

The actual tip velocity of the tip can be calculated as follows, from section 4.2 the primary air volume which is 10 % of the total combustion air for multi channel burners

$=10\% \times 46{,}078$ St. m^3 /hr

= 4607 st. m^3 /hr, this gas volume has to be calculated in operational condition, i.e.

$V_2 = (V_1 \times P_1 \times T_2) / (P_2 \times T_1)$

Where V_2 is the volume at operating condition in m^3 /hr

V_1 is the volume at standard condition in m^3 /hr

P_1 is the pressure at standard condition in kPa

T_1 is the temperature at standard condition in K

P_2 is the pressure at altitude of 2540 m above sea level.

T_1 is the temperature at operating condition in K

$$= 4607 \times (101.34 \div 273) \times (333 \div 73.7)$$

$$= 7727 \text{ m}^3 \text{/hr}$$

Primary air temperature [23] Tp ~ 60^0C

Primary air pressure (selected) P ~ 120 mbar or 1224 mm H_2O

The density of the air at the operating temperature can be calculated [22].

$$\rho = (1.2929 \times (273 \div (273 + 60)) \times (760 - (0.0736 \times 1224)) \div 760)$$

$$\rho = 0.9343 \text{ kg/ m}^3$$

The volume of the primary air at the operating condition becomes.

$V = 166.13 \div 0.9343$ kg of air /min per kg of air/ m^3 of air

= $177.81 m^3$ of air /min.

The area of the primary air nozzle can be calculated by (which is very small)

$A = 3.1416r$ [22]

Assuming $r = 20mm$, $A = 0.0628 \text{ m}^2$

Velocity of air at the tip can be calculated

$v = V \div A$

$= 177.81$ m^3 of air/hr $\div 0.0628 \text{ m}^2$

$= 47\, m/\sec$ Very small

Iteration give

$r = 10mm$ $\qquad\qquad A = 0.0282 \ \mathrm{m}^2$

$v = 100m/\sec$

Effective burner tip opening $= 0.0157 \ \mathrm{m}^2$

Primary air momentum $= 10\% \times 100m/\sec$

$= 1000$ % m/s with in the required range for multi channel burners.

Using the above values a coal burner can be selected with the following parameters [27].

Coal – 7500 kg/hr and Oil – 4300 kg/hr

Primary air consumption and transport air ~ 10%

Diameter max – 330 mm, Length – 6000 mm

Radial blower is required to blow the air through the burner nozzle so the power requirement based on the burn parameter

Fan volume	V = 7727 m3/hr
Fan static pressure	P = 120 mbar
Fan efficiency	η= 80 %
Factor for loss in coupling	= 1.12

P = (P×V×1.12)/ (102× η)

$= (7727 \times 120 \times 10 \times 1.12) \div (102 \times 0.8 \times 3600)$

$= 35.35 \ \mathrm{kW}$

4.3.3 Dry Grinding

The mills used for coal grinding and drying are [9, 13, 28,].

1. Tumbling mills
2. Roller mills

<u>Tumbling mills:</u> - have the following features

- This mills include tube mills and balls mill and they are especially suitable for indirect firing system. They are suitable for closed or open circuit grinding.
- The mills can be operated economically at a constant optimum rate of through put.
- The ball mill is insensitive to foreign bodies in the feed material.

- Grinding media is cheap and the wear of the grinding media much can be compensated without any great effort or cost.
- The relatively long resident time of the coal in the mill has the effect of equalizing any short term variations in the quality of the mill feed.
- They are more suitable for abrasive materials and harder constituents such as quartz and pyrite are effectively realized.
- Drying compartment is required.
- Cost of installation is low, specific energy consumption is high.
- Suitable for an inert mixtures (for explosive material like coal).
- Different types of tumbling mills are available

  Example Air swept mill, Tandem hammer mill, Bucket elevators mill

<u>Roller mills</u>:-have the following features

- Grinding elements consist of rollers and balls.
- Highly suitable for direct coal firing systems.
- The power consumption of the mill derive depends on closely the rate of the material through put. They are more flexible, can be adjusted to varying through put. (40 - 100% of normal capacity
- Less Operational availability, less space requirement.
- Lower specific energy consumption ,high cost of installation.
- Moisture of feed can amount to 15- 18%.
- More air is required to convey the material.
- High rate of wear of the grinding media (needs frequent renewal) and they are not suitable for abrasive coal.
- Different types of roller mills are available

  Example Loesch mills, MPS mills, Polysius mills

The selection of the possible type of mill for our system

Type of material - lignite coal

Size of feed - The size prepared for the gasification (Coal Phosphate Fertilizer Complex Project plant is taken for our case 0-- 25 mm [18].

Considering relation of the volatile matter a with the finesse required [9], the fines of the product is for this type of coal are assumed to be

~ 15% residue on the 170 meters, 88 microns.

The reduction ratio is calculated to be -

$$n = D_{max} / d_{max} \quad = 25 \text{ mm} \div 0.088 \text{ mm} \quad > 100$$

Moisture content - 6 % max is selected as the maximum moisture content of the coal which has to be delivered to the plant due to the following reasons

-The amount of hot gas available in the existing condition which will be necessary for drying the coal is small.

- The moisture content of the coal has to be reduced to a certain percent to reduce the transportation cost.

Abrasiveness of Yayu coal is low

The required mill capacity can be estimated as follows

Number of Kilns – 2, kiln capacity - 1000 ton / day

Coal to clinker ratio from section 3.2.2 for 100 % washed coal = 0.164 kg of coal / kg of clinker

Bulk density of the coal - 1.35 ton / m^3

Mill running hour for new plant is usually estimated to be - 20 hours / day

Using the above parameters the amount of coal required per day for the two kilns is calculated to be

$= 2\times1000$ ton of clinker/ day $\times$ 0.164 kg coal / kg clinker

= 328 ton / day

The mill capacity is calculated as follows, considering the moisture content

Moisture factor in the washed Yayu Coal

$$m = (100 - 6)/100 \quad = 0.94$$

Mill capacity

$$= (328 \text{ ton / day}) / (20 \text{ hours/ day} \times 0.94)$$

$$= 17.44 \text{ ton / hr}$$

Hardgroove Index of Yayu coal = 90

The working index acc. to Bond can be calculated as follows:

$W_i \sim 7.98$ kWh / ton

Dry grinding factor 1.3

The work index becomes $1.3 \times 7.98 = 10.374$ kWh/ton

So using the above parameters and different properties of Yayu coal, the comparisons of coal mills are presented in table 4.4.

Table 4.4 Comparisons of tumbling mill Vs roller mill for the dry grinding of Yayu coal

Requirement	tumbling mill	roller mill
Ability to dry Yayu coal	Good	Very good
Ability to handle sticky coal	Good	Poor
Ability to handle low abrasive coal	Very good	Good
Feed size (for 25 mm)	Good (the max.feed size25mm)	Very Good (the max.feed size 80mm)
Specific power requirement (kW/ton)	Relatively high 25.24 (max.)	Relatively low 7.57 (max.)
Trough put (ton/hr)	Not flexible	Variable throughout
Investment	Low	High
Operating cost	High	Low
Ability to use Kiln gas	Good	Poor
Suitability for firing system	More suitable for Indirect coal firing system	More suitable for direct coal firing system

Due To the following reasons tumbling mill especially an air swept mill is selected for the coal dry -grinding plant

- Tumbling mills are more suitable to indirect coal firing plants.(indirect coal firing is selected for our propose)
- The amount of air required by the tumbling mill is small compared to roller mill & the hot gas available at the existing system is limited, since the raw materials are also dried from the same source.
- Advantageous to install a similar mill to the existing system for economic reasons in spare parts & in maintenance (4 ball mills are available to the existing Factory)
- Low investment is required for tumbling mills even if the specific energy requirement of these mills is high compared to roller mills.

Using the above values standard coal mill is selected with the following parameters [13]

Normal production	22.2 ton /hr
Diameter	3 m
Length	4.4m
Motor power	405 kW
Grinding media	31.8 ton

Gas required for the drying of coal in the mill.

The amount of hot gas required for drying the coal by the selected coal mill has to be calculated and compared to the available amount of hot gas in the existing system, considering one of the kilns as a source of hot gas for our purpose and through energy balance around the mill, we can estimate and compare the amount of hot gas required by the coal mill.

On the average the hot gas available has the following properties

Hot gas temperature [15]	T_h= 180 ^{0}C
Specific heat of hot gas [15]	C_h= 0.34 Kcal/^{0}c – st.m^3

The necessary parameters that are required for the above energy balance are listed as follows

Base temperature	T_b= 20 ^{0}C
Ambient temperature	T_{amb} = 22 ^{0}C
Specific heat of air [6]	C_a= 0.3 kcal /^{0}C.Nm^3
Altitude [23]	Alt = 2540m
Mill Capacity	M_c = 22.2 ton/hr
Moisture content of feed	M_f= 6 %
Moisture content of product	M_p= 1.25%
Specific heat of coal [6]	C_c= 0.315 kcal/kg. ^{0}c
False air percentage	F_a= 10%
Power	P= 405 kW
Volume of waste gas [9]	M_g = 22,200 st.m^3 /hr (for transport of material ball mill 1 st.m^3 /kg of coal is assumed)
Specific heat of waste gas [13]	C_g= 0.31 Kcal/ Nm^3.^{0}C
Waste gas temperature [9]	T_g= 80 ^{0}C
Radiation loss (assumed)	R_a= 5%

Using the energy balance, we have to calculate

V_{hg} = required hot-gas quantity

V_C = recirculating air

1. Heat out put:-the heat out put from the mill can be calculated as follows

1. Heat to washed coal

$H_1 = M_c \times C_c \times \Delta T$

$= 22200 \times 0.315\ Kcal/^{o}C\ kg \times (75-20)^{o}C$ (The temperature difference between the gas and the product is assumed to be around 5 ^{0}C)

$= 384{,}615\ kcal/hr$

2. Heat to dedusting gas

$H_2 = V_g.\ C_g.\ (T_g\text{-}T_b)$

$= 22{,}200\ st.m^3/hr \times 0.31\ kcal/st.m^{30}C \times (80\text{-}20)\ ^0C$

$= 412{,}920\ kcal/hr$

3. Heat loss to evaporate moisture

Moisture to be evaporated is calculated by

$M_m = M_c \times (M_f - Mp) / (100 - M_f)$

$= 22{,}200\ kg/hr \times (6-1.25) \div (100-6)$

$= 1121.8$ kg of water/hr

The latent heat required to evaporate water at 20 ^{0}C is assigned to be 540 kcal/kg [13]

$H_3 = (M_m \times L) + (M_m \times \Delta T)$

$= 1121.8 \times (540 + 80 - 22)$

$= 670{,}358$ kcal /hr

4. Heat loss to false air

$H_4 = (V_g \times F_a \times C_a \times (T_g - T_b))/100$

$= (22{,}200 \times 10 \times 0.3\ Kcal/^{o}C\ St.m^3 \times (80-22)) \div 100$

$= 38{,}628$ kcal/hr

5. Heat loss to radiation:-The heat loss to radiation is estimated to be 5 % of the total heat input so it can be calculated as follows

$= 5\ \% \times (H_1+H_2+H_3+H_4)$

= 75,326 kcal/hr

The total heat out put becomes

$$\text{Total} = H_1 + H_2 + H_3 + H_4 + H_5$$

= 1,581,847 kcal /hr

2. Heat Input:-the heat input to the mill is calculated as follows

1. Heat from fresh feed

$$H^1{}_1 = M_c \times C_c \times \Delta T$$

$$= 22{,}200 \text{ kg/hr} \times 0.315 \text{ kcal/ kg } ^{o}\text{C} \times (22-20)\, ^{o}\text{C}$$

= 13,986 kcal/hr

2. Heat flow the mill power

$$H_2{}^1 = 0.85.\ P$$

= 0.85 x 405 kW

= 295,071 kcal/hr

3. Heat from false air

$$H_3{}^1 = (M_g.\ F_a.C_A.\ (T_a\text{-}T_b))/100$$

$$= 22200 \times 10 \times 0.3 \times (22-20) \div 100$$

= 1332 kcal/hr

The total heat input to the mill becomes

$$H_{\text{Input}} = H^1{}_1 + H_2{}^1 + H_3{}^1$$

= 310,389 kcal/hr

The overall energy balance for the mill becomes

$$H_{\text{Hot gas}} + H_{\text{Input}} = H_{\text{output}}$$

$$H_{\text{Hot gas}} = H_{\text{output}} - H_{\text{Input}}$$

$$H_{\text{Hot gas}} = 1.271{,}458 \text{ kcal/hr}$$

So the hot gas required becomes,

$$V_{hg} = (1{,}271{,}458\, Kcal/hr) \div \left(0.34 kcal/St.m^3\ ^{o}C \times (280-20)^{o}C\right)$$

$$V_{hg} = 14{,}383 \text{ St.m}^3\text{/hr}$$

Checking: - If the dedusting gas quantity is less than the hot gas required then we have to increase the hot gas temperature, (in our case the temperature of the hot gas is fixed).or it is necessary to increase the dedusting gas amount and it is necessary to run the energy balance again.

$$Mg = 22{,}200 - 1.24\ (M_m) - F_n/100\ (25{,}000)$$
$$= 22{,}200 - 1391 - 2500\ Nm^3/hr$$
$$= 18{,}309\ st.m^3/hr \quad (< 14383)$$

Since $M_g > M_{hg}$ – The calculation is Ok, the assumption of the quantity of waste gas that is also ok.

The hot gas required by the coal firing system is less than 14,383 st.m^3/hr and the available hot gas from kiln amounts to be approximately 16,000 St.m^3/hr [23] so the amount of hot gas available from kiln is sufficient to be utilized for the coal drying plant. Based on the amount of hot gas the recirculating gases can be calculated

$$V_C = Mg - V_g$$
$$= 18{,}309 - 14{,}383\ st.m^3/hr$$
$$= 3{,}926\ st.m^3/hr$$

4.3.4 Storages and material handling equipment

Storage bin:-The types of storage required for coal preparation plant are [9, 14]

1. Open storage: - washed coal which is transported from the mine is stored in open storage usually the open storage which has a roof for one month. For our purpose a storage which has a capacity for a month has to be constructed.
2. Storage bin:-the types of bin are classified according to the material flow characteristics [6].

Mass flow bin: - represent the type of bins which means that are the material in the vessel moves whenever any is withdrawn. Funnel flow bin, only a portion of the material flows.

Mass flow bins feature the most sought after characteristic of a storage vessel, unassisted flow whenever the bottom gate is opened a funnel flow bin may or may not flow but probably can be made to flow by some means. For our purpose mass flow bins are selected due to the following reasons.

- Flow is uniform.
- Density of flow is constant.
- No dead zone.
- No segregation of particles.
- No flooding effect.

The following storages are necessary for the proposed coal firing plant

Storage bin 1:-for the storage of washed coal for mill feed

Mill capacity $Q = 22.2$ ton / hr

Chosen stock time $H_T = 3$ hrs.

Bulk density $\rho = 1.35$ ton / m^3.

Moisture content = 6 %

$F_m = (100-6)/100 = 0.94$

The storage capacity can be estimated as

$$= Q \times H_T / F_m \times \rho$$

$$= 22.2 \times 3 / 0.94 \times 1.35$$

$$= 52 \ m^3$$

A steel plate bin with an effective capacity of 60 m^3 is selected

Storage Bin 2 For the storage of Pulverized washed coal

Pulverized coal is extracted from this storage and fed to the burners

Coal requirement of the kilns are calculated to be 9 ton / hr for each kiln.

Chosen stock time H_T= 2 days (1 day for each kiln)

Bulk density $\rho = 0.8$ ton / m^3 [9]

Moisture content = 1.25%

$F_m = (100-1.25) / 100 = 0.9875$

The storage capacity can be estimated as

$$= Q \times H_T / F_m \times \rho$$

$$=18 \times 24 / 0.9875 \times 0.8$$

$$= 548 \text{ m}^3$$

As we can see from the figure the size of the silo is high due the hourly coal requirement that is high due to the grade of coal.

Material handling equipments

The coal handling equipments required for the firing plant are discussed as follows

1. from the open storage to the mill storage bin m:-material to be conveyed is washed coal and has the following properties.

Bulk density	1.35 ton / m^3
Through put	23 ton/hr
Design factor	15%
Length of travel	30 m (approximately)
Size	coarse material
Abrasiveness	Less

Inclination:-depends on the grinder plant height and it is estimated to be around 30^o.Using the above properties, the possible types of conveyors & their comparison are shown in table 4.5.

Table 4.5: [7, 9] Comparisons of conveyor's for washed coal handling

Factors to be considered	Apron conveyor	Screw conveyor	Belt conveyor	Continuous - flow conveyor
Nature of solid Size(25mm) Abrasiveness (low)	 Very good Good	 Good Good	 Good Good	 Good Good
Length of travel	30m	30m	30m	30m
Elevation	Max 45^0	Special units are available at very high cost	Max 30^0	Can move vertically & horizontally
Available throughput (ton/hr)	39.75	28.86	39.69	33.75
Annual cost (per ton handled)	Moderate	High	Low	Moderate
Power consumption (kW)	6.09	11.45	3.93	10.5

The best type of equipment to handle this washed coal is belt conveyor due to the following reason

- Reliable and economical
- Power consumption is low
- Investment cost is low

The selected belt conveyer has [9]

Belt width	B= 400mm
Belt troughing angle	$\lambda= 20^0$
Filling coefficient	Y= 0.7
Reduction factor	K= 0.56

Speed	$v = 1$ m/s
Power term 1	$P_1=0.5$ kW
Power term 2	$P_2= 0.0068$ kW
Power term	$P_5= 1$ kW
Volume	$V=75\ m^3/hr$
Frication factor	$f= 2$

The maximum capacity of the belt conveyor becomes

$$M= V \times \rho \times Y \times K$$

$$= 39.69 \text{ ton/hr}$$

Power requirement

$$= (f \times m \times L)/(3.6 \times 102)$$

$$= 2 \times 30 \times 23/3.6 \times 102$$

$$= 3.75 \text{ kW}$$

2. from the bin to the burners:-the material to be transported is pulverized coal with the following property.

Size 15 % on 170 mesh screen

Bulk density (estimated) [9] $\rho = 0.8$ ton/m3

Length of travel: - for kiln I and Kiln II assuming both the kilns can be fed with the same conveyor and the distance is approximately to be 30 m.

Inclination – the pulverized coal storage is below the height of existing conditions of the kilns so it is necessary to consider the conveyor is expected to travel a certain inclination which is approximated to be 20^0. The possible types of conveyors and their comparisons are shown in table 4.6.

Table 4.6: Comparisons of conveyor's for pulverized coal handling

Requirement	Screw conveyor	Continuous flow conveyors
Natural of the pulverized coal free – flowing abrasiveness	 Good Good	 Very good Good
Inclination 20^{0}	Special units are available at high cost	Can move vertically & horizontally ,no limitation to the angle
Length of travel (m)	30	30
Through put (ton/hr)	18	19.8
Power consumption (kW)	11.45	9
Annual Cost	High	Moderate

The best type of conveyors for our purpose is continuous flow conveyor with the following reason.

- Due to length of travel, through put & power consumption advantages.
- The possibility of feeding both kilns with of single continues flow conveyor.
- It can travel in several directions with only a single drive & it is advantageous to adapt with the existing system.
- It occupies little space and needs little support.

The selected continuous flow conveyors have the following parameters [9]

Type – single Strand

Trough width	=400 mm
Depth of the flight in the conveyor	=300 mm

Speed	$v=0.1$ m/sec
Friction factor	$f=3$
Volume -Max volume	$= 33.6\ m^3/hr$

Power requirement:-if both kilns are fed with the same continuous flow conveyor, the power requirement is calculated as

$$= (f \times m \times L)/(3.6 \times 102)$$

$$= 3 \times 18 \times 30 / 3.6 \times 102$$

$$= 4.4 \text{ kW (not including inclination)}$$

3. To transport the coarse coal from the static air separator back to the mill with the following properties

Bulk density	~0.9 ton/m^3
Length of travel	- 5m (estimated)
Inclination -	Horizontal

Throughput =20 ton/hr (usually recirculation a max. of 75% is assumed for the transport systems from the separator) [13] & with a design reserve of 15 %.

The possible type of conveyors for handling this type of material are screw conveyors and continuous flow conveyor, but continuous flow conveyors are not recommended for a short distance since they are not economical. So screw conveyor is selected for our purpose. Using the given capacity and required length of travel, the screw conveyor has the following parameters [9].

Screw diameter	$D= 350$mm
Handling Length	$L= 5$m
Screw ascent	$a = 263$mm
Filling coefficient	$F= 40$ %
Speed	$v= 55\ min^{-1}$
Friction Coefficient	= 3

Maximum Capacity can be calculated by

$$M = \pi/4 \times D^2 \times a \times F \times v \times \rho$$

$$M_{max} = (\pi/4) \times 0.35^2 \times 0.263 \times 0.4 \times 55 \times 60 \times 0.8$$

$$= 26.7\ \text{Ton/hr}$$

Power

$$= (f \times m \times L)/(3.6 \times 102)$$

$$= 3 \times 20 \times 5/3.6 \times 102$$

$$= 0.82\ \text{kW}$$

4. Feeder to the air swept Ball mill:-various types of feeders are used in industrial practice for feeding of coal to the grinding equipment, many of there feeders are capable of extracting material at uniform rate from a bin, bunker or hopper and provide a basis for at least a volumetrically controlled & measured flow, in automated industrial process, however more exacting requirements as to the accuracy of flow measurements are often applied, more particularly precise weighing of quantities are required. Due to this reasons weight belt feeder is selected for the feeding of washed coal to the mill .The selected weigh belt feeder has the following parameters

For full capacity

22.2 ton/hr × (100-6)/ 100 = 23.61 ton/hr

For lower grinding media change

0.5 x 22.2 ton/hr × (100)/ (100 –6) = 11.8 ton/hr

Based on the existing system weigh belt feeder with the control range of 3 to 30 ton/hr is selected [23].

4.3.5 Separator and Dust collector

For very fine size reduction using closed circuit operation, it is necessary to separate the particles fine enough to qualify as "finished product" from the coarser particle (oversize) in the product discharged from the grinding mill.

The Separator used in the cement Industry are broadly similar in principle, they differ in matters of design & range of application their difference mainly consist of in the method of introducing the material & the separating air [9,13].The main separators which are used in cement industry for coal firing plants are discussed in short below

Static air separator:-this separator has the following features [13]

The material to be classified is carried along in a stream of air from the mill and enters the separator from below as a result of increasing cross section the air velocity is reduced here and coarser particles are precipitated.

- No moving mechanical parts.
- Used in conjunction with air - swept grinding plants (operating with tube mills or roller mills).

Control possibilities for this separator

- By varying the air flow rate and the velocity of the air.
- By adjusting the deflector over the bottom.

Circulating air separator:-has the following features [9, 13]

- The material is feed mechanically to the separator by means of a suitable continuous conveyor.
- The air current required for the function of the separator is generated by a fan inside the separator casing or mounted outside.

E.g. Conventional air separator cyclone air separate

Bladed rotor separators:-has the following features [9, 13]

- The feature of this air separator is a rotor comprising a set of blades in a conically tapered arrangement & rotating on a vertical shaft in a casing of truncated conical shape. The material laden stream is introduced from below & distributed sideways by deflection.
- Used with air swept mills particularly with roller mills.
- Because of the effect on the performance of the grinding mill rotations of air flow rate is possible within limits

Control possibilities are

- By varying the rotor speed

In our case the whole system is dependent on the transport of material by means of the hot gas steam. The available fan is in responsible for the suction of ground material from the system; the best type of separator in conjunction with our system is static air separator.

The separating air volume for the static separator with the design reserve of 15 % is estimated to be 25,000 st.m^3 /hr. max with a capacity of 20 ton/hr (a maximum of 75% of the mill output and design reserve of 15 % is used to determine the capacity of the separator)

Dust collector

The combining phenomena of comminution, handling and processing of the coal leads to the generation of large volumes of dust laden gases. To prevent the dust from escaping into the environment various types of dust collectors are used in cement plants. The possible types of dust collector for our purpose is filter bags& electrostatic precipitators [9, 13].

a. Electrostatic Precipitators (EP): Electrostatic precipitators generate an electrostatic field across the path of particulate matter in the air stream. The particles become negatively charged and migrate towards positively charged collection plates. The collection plates are rapped or vibrated periodically, dislodging the material so that it falls into collection hoppers below. Generally EP has the following features

- Electrostatic precipitators collect very fine particles, < 2 μm at high efficiencies.
- Capital and operating costs are high.
- Selected where the gas are hot or corrosive.

b. Fabric Filters (FF): The basic principle of fabric filtration is to use a fabric membrane which is permeable to gas but which will retain the dust. Initially, dust is deposited both on the surface fibers and within the depth of the fabric, but as the surface layer builds up the dust itself becomes the dominating filter medium. Gas for treatment can flow either from the inside of the bag outwards or vice versa. As the dust cake thickens, the resistance to gas flow increases. Periodic cleaning of the filter medium is therefore necessary to control the gas pressure drop across the filter. FF has the following features

- Separate small particle down to around 1 μm.
- Extensively used in cement & coal firing plants.

- Woven or felted cloths of cloth & variables fibers are extensively used.

The possible types of dust collector and their comparisons for our purpose are shown in the table 6.7.

Table 6.7: Comparison of dust collector's [13]

Requirement	Electrostatic Precipitators	Bag filter
Collection efficiency	100 mg/Nm^3	50 mg/Nm^3
Pressure drop	0.06 - 0.3 kPa	0.5 - 2 kPa
Temperature of gas to be handled (~ 80 ^0C)	0 - 800 ^0C	0 - 250 ^0c
Power consumption	Low	High
Space requirement	Large	Small
Relative cost		
Capital	High	Low
Operating cost	High	Low

Bag filter is selected for our purpose due to the following reasons

- Small capital and operating cost
- The temperature of the gas to be handled is very small around 80 – 100 ^0C, it is economical to use filter bags rather than electrostatic precipitator that is mostly preferred for high temperatures.
- Less space requirement.

The bag house filter with the following requirement is selected

Medium to be filtered coal	dust laden gas
Kind of dust	coal dust
Air pressure (2450 above sea level)	73.7 kPa
Dust content of gas [13]	100 – 120 mg/ st. m^3

Volume of air is; including pulverized coal silo, false air the total air from the system is estimated to be ~ 25,000 m^3 /hr

The gas volume has to be calculated in operational condition, i.e.

$$V_2 = (V_1 \times P_1 \times T_2) / (P_2 \times T_1)$$

Where V_2 is the volume at operating condition in m^3 /hr

V_1 is the volume at standard condition in m^3 /hr

P_1 is the pressure at standard condition in kPa

T_1 is the temperature at standard condition in K

P_2 is the pressure at altitude of 2540 m above sea level.

T_1 is the temperature at operating condition in K

$V = 25000\ m^3/hr \times (101.34kpa/73.7kpa) \times (353\ ^oK / 273\ ^oK)$

$= 44{,}449\ m^3/hr$

The clean gas dust content (since bag filter is selected) [13] = 150 mg/st. m^3

The amount of dust (assuming bulk density of dust to be 1 ton/ m^3) which is filtered from the filter bags become

$= 110 - 0.15\ g/st.m^3$

$= 109.85\ g/st.m^3 \times 25{,}000\ st.\ m^3/hr$

$= 2.7$ ton/hr

The area rating for the pneumatic cleaning is [9] for coal dry grading plant is estimated to be ~ 130 m^3 / m^2. hr, so the filter surface can be calculated to be

$= 44{,}449\ m^3/hr / (130\ m^3 / m^2.\ hr)$

$= 341\ m^2$

$\sim\ 350\ m^2$

Discharge screw:-screw conveyors are the best conveyors to transport the collected dust from the FF to the pulverized coal bin. Throughput of dust collector with 15 % design reserve is calculated to be 3 ton/hr with a bulk density of 1 ton /hr.

The selected screw conveyor [9] has the following parameter

Screw diameter	D=250
Screw length	L=10
Filing degree	F=30 %
Friction coefficient	h=3
Screw ascent	a=0.15

Speed v=75 min^{-1}

The maximum capacity [9] is calculated to be

$$= \pi / 4 \times D^2 \times a \times f \times v \times \rho$$

$$= \pi/4 \times 0.25^2 \times 0.15 \times 0.3 \times 75 \times 60 \times 1$$

$$= 9.9 \text{ ton/hr}$$

The power requirement is calculated to be

$$= (f \times m \times L)/(3.6 \times 102)$$

$$= (3 \text{ x } 3\text{x}10)/(3.6 \text{ x } 102)$$

$$= 0.24 \text{ kW}$$

4.3.6 Process Flow Descriptions

The Process flow diagram of the coal firing plant which is selected for our purpose is shown in Figure 5.

Material flow circuit

Following the flow sheet we can see that the washed coal is discharge in to the hopper by a single belt conveyor mounted on top of the hopper. Magnetic separator is arranged on top of the preceding conveyor which helps in removing any Iron / magnetic material which may have found its way along with the material.

The hoppers are mounted on load less to monitor the quantity of material present in the hopper.

Coal from the hopper is weighed and conveyed by weigh belt feeders to the air swept mill through a rotary air lock system, in which the purpose of the air lock to prevent entrance of false air in to the mill system. The washed coal in the Air swept mill ground to a fine dust coal with simultaneous drying (principle of dry grinding).

The static air separator separates the fines from the coarse, the finer product is carried by hot air in to the cyclone dust collector in which the product is separated from hot air. The coarse particle from the air static separator is transported back to the mill by a screw conveyor. The fine coal from the pulverized silo will be transported by continuous flow convoys to the burners.

Airflow circuit

Air is required in the circuit to dry the washed coal in the coal mill and for carrying the milled coal in to the separator & further carry and transport the fine into the bag house dust collector.

Hot air for drying and transporting is sourced from the gas condition tower through pipe and the high advantage of using this inert gas is the amount of oxygen which is very low, as a result it reduces the risk of fires and explosion due to the low amount oxygen, which is usually recommended to be kept below 14 % [14].

Hot gas with a temperature of 150 - 300 ^{o}C from the conditioning tower inlet is passed (through circulating air fan) in to the mill where the materials is dried and ground, then pass through the separator. The humid gas carry the product from the separator through the duct to the cyclone dust collector where the product & the humid air is separated, a part of the gases is recirculated back to the mill to make up for the total quantity of air that is required by the mill. In the event of start up of the kiln where there is no available hot gas an air pre heater is operated to provide the required hot gasses.

The hot gas from the cyclone will be further cleaned in the bag house dust collector. The fines will be transported to the pulverized silo through screw conveyor where as the cleaned air will be vented to the atmosphere via exhaust fan.

5. Economical evaluation

5.1 Estimation of cost of major equipments and total investment

This chapter covers the overall economic analysis of the switch over, it estimates and provides major equipment and operating cost necessary if washed Yayu coal is used as a source of energy in place of furnace oil at Mugher Cement Enterprise.

Costs for major process equipments are found in charts and or other graphical methods, use of these available data frequently requires scaling from one size or another and from the past to the present or future.; then based on the total purchased equipments and related parameters for installation cost the total capital cost is determined.

When accurate data are not available, good results can be obtained by using the logarithmic relationship known as “sixth-tenth rule” [29]. This can be expressed as follows

$$C_{P,b,1} = C_{P,a,1}\ (b/a)^{X}$$

Where $C_{P,b,1}$ is the purchase price of equipment in question which has a size or capacity of b by in the year 1.

$C_{P,b,1}$ Is the purchase price of the same type of equipment in the same year but of capacity or size a.

X is a size or capacity exponent to relate the cost of one size to another.

The purchased equipment cost are normally estimated from old price data, thus because of inflation corrective indices or trending factors are needed to adjust older data to current of future status.

In this analysis, the cost of equipments when the second production line of Mugher cement is erected in 1986 [30] is used to estimate the cost of the major equipments selected for the coal firing plant. Additionally a corrective indices or a trending factor, which is obtained from the internet is used to estimate the cost of equipments in the present time. [32]

1. Air swept mill

The cost of a ball mill including drive and accessories for 90 ton /hr capacity at 1986 was $ 660,000. By "sixth-tenths rule" the cost of similar ball mill for 22.2 ton /hr in the same year is estimated to be

$$= \$\ 660{,}000(22.2/90)^{0.6}$$

$$= \$\ 284{,}977$$

Using the trending factor 2.63, the present value of a ball mill for the given capacity is estimated to be

$$= \$\ 284,\ 977 \times 2.63$$

$$= \$\ 749{,}489$$

2. Static air separator

The cost of separator including accessories for handling 38,500 st.m^3/hr of air was $ 64970 at 1986 so using the rule, the cost for handling 30,000 st.m^3 /hr in the same year is estimated to be

$$= \$64{,}970 \times (30{,}000/38{,}500)^{0.6}$$

$$= \$\ 55{,}938$$

Using the trending factor 2.63, the present value of a static separator for the given capacity is estimated to be

$$= \$\ 55938 \text{ x } 2.63$$

$$= \$\ 147{,}116$$

3. Cyclone separation unit

The price of a cyclone unit for almost the same type of capacity at 1986 was around $ 11,583. Using the trending factor 2.63, the present value of a cyclone separator is estimated to be around

= 11, 583 × 2.63

= \$ 30,463

4. Set of grinding media

A set of grinding media was purchased for the mill at the cost of \$ 30, 794 at 1986 for 90,570 kg, the price for 31,800 kg in the same year using the sixth rule is

$$= \$\ 30{,}794 \times (31800/90570)^{0.6}$$

$$= \$\ 16{,}433$$

Using the trending factor 2.63, the present value of a cyclone separator is estimated to be around

= \$ 16, 433 × 2.63

= \$ 43, 220

5. Weight belt feeder

The cost of a weight belt feeder for a capacity of 3 ---30 ton/hr at 1986 was \$ 13,286.For the same type of belt conveyor, using the trending factor 2.63 the present value is estimated to be

= \$13,286 ×2. 63

= \$ 34,942

6. Primary air fan

A radial fan with static pressure of 12,062 Pa was purchased at a cost of \$ 3760 at 1986, almost for the same blower, the present value is estimated to be

= 3760 × 2.63

= \$ 9888

7. Burner

Burner including firing carriage with accessories was purchased at a cost of \$24,679 at 1986.The present value is estimated to be

= 24,679 × 2.63

= $64,905

8. Belt conveyor

A belt conveyor for 11 m was purchased by a value of \$ 9795 in 1986, for 30 m using the sixth rule in the same year the cost is estimated to be

$$= \$ 9795 (30/11)^{0.6}$$

$$= \$ 17,883$$

Using the trending factor of 2.63 the present value is estimated to be

$$= \$ 17,883 \times 2.63$$

$$= \$ 47,032$$

9. Continuous flow conveyor

For Trough width of 400 mm and Length of 30m the cost of a continuous flow conveyor for the given dimension at 1986 was \$ 55,896, the present value of this conveyor is estimated to be

$$= \$ 55,896 \times 2.63$$

$$= \$ 147,006$$

10. Bag –house Filter

The cost of equipment for bag filter with automatic cleaning of filters by compressed and for filters surface area of 180m^2 with screw conveyor and 140 bags at 1986 was \$ 27,692. Using the sixth rule the cost A_2= 150 m^2 is

$$= 27,692 (150/180)^{0.7}$$

$$= \$ 24,374$$

Using the trending factor 2.63, the present value is the cost is estimated to be

$$= \$ 64,103$$

11. Radial fan

For handling of hot gas from the mill for a capacity of 130,000 st.m^3/hr air, the price at 1986 was $ 53,145, using the sixth rule for a capacity of 30,000 m^3/hr air at the same year is estimated to be

$$=\$53,145 \times (30,000/130,000)^{0.6}$$

$$=\$ 22,047$$

The present cost of potential with its accessories, using the trend factor 2.63 is estimated

$$= \$ 22047 \times 2.63$$

$$= \$ 57,986$$

12. Radial fan for the clean dust.

Radial fan for handling 105,000 st.m^3/hr clean gases after the bag house filter was $ 43,831 at 1986, using the sixth rule for a capacity of air at the same year for 30,000st.m^3/hr of air is estimated to be

$$= \$ 43,831 (30,000/105,000)^{0.6}$$

$$= \$ 20,670$$

Using the trending factor 2.63, the cost at present time is estimated to be

$$= 20,670 * 2.63$$

$$=\$ 54,362$$

13. Washed coal silo

Proportion bin of 15 m^3 with steel plate had a price $ 4215 by 1986 so the price in the same year for 52 m^3, for storages n=0.8[32]

$$= \$ 4215 (52 /15)^{0.8}$$

$$= \$ 11,395$$

The price in the present time, using the trending factor is estimated to be

$$= 11,395\times 2.63$$

$$= \$ 29,968$$

14 <u>Pulverized coal silo</u>

It is not recommended to use sixth rule methods when the capacity or size factor of equipments are too large, when it is more than tenth fold, the capacity for this silo is high therefore we use another method to estimate the cost of this pulverized silo [32]

Cost = $C\ S^{n}$

Where C = cost constant

S = the characterization size parameter

n = cost index

The cost for the year 1992 is calculated

$S = 548\ m^{3}$,n=0.55 ,

$C = 2900\ (548)^{0.55}$

Using the trending factor

= Cost at 1992 × cost index at 2004/cost index at 1992

= \$ 93,052 × (351/281)

= \$ 116,232

The total purchase cost of the major equipments are summarized as follows

Air swept mill	$ 749,489
Static air separator	$ 147,116
Cyclone	$ 30,463
Grinding media	$ 43,220
Weigh belt feeder	$ 34,942
Primary air fan (2 fans are required)	$ 19,776
Burners (2 burners are required)	$ 129,810
Belt conveyor	$ 47,032
Continuous flow conveyor	$ 294,012
Bag house filter	$ 64,103
Radial fan for circulating	$ 57,986
Radial fan for dedusting gas	$ 54,362
Washed coal silo	$ 29,968
Pulverized coal silo	$ 116,232
Total (PCE)	**$ 1,818,511**

Using this total cost of equipments we estimate the fixed capital investment cost can be estimated as follows [32],

Equipment erection	f1=0.5
Piping	f2=0.2
Instrumentation	f3=0.1
Electrical	f4=0.1
Building and process	f5=0.05
Utilities	f6=0.25
Storage	f7=0.25
Site development	f8=0.05
Ancillary building	f9=0.3
Total	**1.8**

Total physical plant cost is estimated as follows

$$PPC = PCE\,(1+f1+f2+f3+f4+f5+f6+f7+f8+f9)$$

= \$ 1,818,511(2.8)

= \$ 5,091,830

Design and Engineering f10 =0.2

Contractor fee f11 = 0.05

Contingency f12=0.1

The fixed capital investment becomes

= PPC (1+f10+f11+f12)

= \$ 5,091,830(1.35)

= \$ 6,873,970

The Working capital can be calculated which is 10 % of the fixed capital

Wc= 10 % (\$ 6,873,970)

= \$ 687,397

The total capital investment required for the firing system is

= Fixed capital + Working capital

= 6,873,970+687,397

= \$ 7,561,367

The total investment for the proposed coal firing plant is around \$ 7,561,367 or 64,271,634 birr.

5.2 Estimation of variable and fixed costs

1. Washed coal cost

The total coal requirement for both kilns considering 6% moisture content & a max- size of 25mm is 97920 ton.

The clean coal price at 2001 was estimated to be 46.16 USD/ ton [17], so using a trending factor [31] the present coal price is estimated to be

=Cost at 2001× (cost index at 2004/ cost index at 2001)

= 46.16 USD/ (351/305)

= \$53.12 per ton

So the total cost of raw coal is estimated to be

= $ 5, 201,510 per year

2. Additional cost of Electricity

The preparation of 1 ton of coal is connected with the following energy requirements [13]

Drying	2 kWh/ton
Grinding	25 kWh/ton
Dust collection	1.5 kWh/ton
Conveying	5 kWh/ton
Losses to substation	2.5 kWh/ton
Total	36 kWh/ton

The cost of power per kWh is 0.4736 Birr/kWh [1]. The cost of electric consumption can be estimated, the average exchange rate for a dollar is taken to be 8.50 birr

= 36 kWh/ton ×102,868 ton

= 3,703,248 kWh/ton ×0. 4736 Birr/kWh / (8.5 Birr /USD)

= $ 206,336 Birr/ year

3. Additional cost of labour

The manpower required for coal handling transport & processing can be estimated from the existing system. 20 personals are required 5 per shift & 5 for staff ,with this an average of annual salary and benefits of $ 4000 per person is taken for the coal firing plant, based on this figures labour cost can be estimated to be

The total cost of labour for 20 personals per head becomes

= $ 4000 × 20

=$ 80,000 per year

Adding 50% for the various allowance & overhead, the total cost of labour is estimated to be

=$ 120,000 per year

4. Additional cost of supplies, stores and maintenance

At first estimate the annual cost of maintenance can be taken as 10% of the fixed capital cost [32],

= 10% × \$ 6,873,970 per year

= \$ 687,397 per year.

5. Additional cost of Laboratory

As a rough estimate, the cost can be taken as 20 to 30% of the operating labor cost or 2 or 3% of the total production cost, based on the operating the cost becomes [32]

= 30 % × 120,000

= \$ 36,000 per year

6. Depreciation cost on account of additional capital investment

Additional annual deprecation cost, on account of the investment made for the fuel switch over, are estimated on the basis of 10 % per annum of the investment, assuming an average life of 10 years. The total average additional depreciation cost becomes [32]

= 10 % × \$ 7,561,367per year

= 756,136 per year

7. Insurance Cost

The additional insurance cost is estimated to be 1% of fixed capital [32].

= \$ 68,739 per year

8. Miscellaneous costs

A rough guide for the cost of miscellaneous materials can be taken as 10% of the total maintenance cost is estimated and it is estimated to be [32].

= 10% × \$ 687,397

= $ 68,739 per year

9. Washed coal transportation

The coal has to be transported for a total of 640 km to the point of use. From the known transport company, the cost of transportation for the given distance is estimated to be between 432 to 450 Birr /ton. So taking the maximum estimated cost that is 450 birr/ton, using the average exchange rate 8.50 Birr /USD. The cost of transportation for our purpose is estimated to be

= 450 Birr/ (8.50 USD/Birr) × (102, 868 ton/year)

= $ 5,445,952 per year

Summary of the fixed and variable costs

1, Raw Coal Cost	$ 5,201,510
2, Additional Cost of electricity	$ 206,356
3, Additional cost of labor	$ 120,000
4, Additional cost of Maintenance	$ 687,397
5, Additional cost of laboratory	$ 36,000
6, Depreciation cost	$ 756,136
7, Insurance cost	$ 68,739
8, Transportation cost	$ 5,445,952
9, Miscellaneous additional Cost	$ 68,739
Total	$ 12,590,829

The operational cost if washed Yayu coal is used as an energy source is estimated to be around 107,022,046 birr per annum.

5.3 Net savings from the switch over

a. Direct Savings on account of Fuel Change: Direct average savings on account of fuel switchover from oil to coal are estimated as follows:

Taking the average consumption of furnace oil consumption to be 98 liter/ton [1], to produce 600,000 ton of clinker per year 58,800.000 liter furnace oil is required. The cost of furnace all at Mugher at present is 2.44 [1].So the price of furnace oil for the production of 600.000 ton clinker per year is around 143,472,000 Birr.

If washed Yayu coal is used in place of furnace oil for the two lines, using the average dollar exchange rate of 8.5 Birr /USD the total cost is estimated to be around

= 8.50 Birr/USD× USD 12,590,829

= 109,256,156 Birr /year

The annual net saving from the switch over is

= 143,472,000-107,022,047

= 36,449,953 birr

b. Indirect saving on account of added ash content of coal

The other saving that is obtained in case of coal firing is the added ash content of the coal, for our case we take the average ash content to be 15 % and the average ash content coal consumption of the coal is calculated to be 160 kg of coal /ton of clinker is, the amount of ash that is incorporated in the clinker is

= 15%× 160 kg of ash/ ton of clinker

= 24 kg of ash / ton of clinker

=2.4 % (this much percentage of ash is encountered in 1 ton of clinker)

If the production cost of clinker is 300 Birr /ton of clinker [1], the saving on account added ash contents is about

= 2.4 % × 300 Birr/ton of clinker

= 7.2 Birr / ton of clinker

The total saving for 600,000 ton of clinker due to the added ash becomes,

= 4,320,000 Birr

The total saving if Yayu coal is used in place of furnace oil is summarized as follows

Cost	Birr/year
Total cost if fuel is used	143,472,000
Total cost if Yayu washed coal is used	109,256,156
Saving from the added ash	4,320,000
Net saving from the switch over	38,535,844

The above analysis shows the net saving of 38,535,844 birr per year or, around 64 birr per ton of clinker can be obtained, based on present cement production a saving of 46 birr per ton of cement can be obtained. Range of net savings is expected to fall, in most of the cases, in the range of 50-60 Birr per ton of cement [10] for cement plants due to coal switch over. Actual saving would vary from time to time and on variations in all effecting factors, mentioned above.

6. Environmental Issues and Impacts

6.1 Air Pollution: Source, Impacts, and Standards

Regardless of how it is used, coal like other hydrocarbon fuels, always generate some process waste that ,if fully discharged or carelessly disposed of ,would cause serious air pollution and attendant ecological damage and ,in some instances ,even pose major health hazards ,the nature of coal pollutants determine the impact on the environment .Table 6.1 shows the emission standard for cement plants irrespective of the fuel type used.

Air pollution is the main environmental issue with possible significant differential impacts, consequent to switching over from fuel oil to coal for cement production. Other issues of concern are potential hazards of spontaneous coal fires and coal dust explosions, potential contamination of soil and ground water from coal storage facilities and noise from coal processing facilities. Following are the sources and operations, which can result into differential emissions of pollutants, consequent to switch over from fuel oil to coal for cement production.

a. Kiln system
b. Coal pulverization mill
c. Fugitive emissions from coal storage and handling facilities
d. Fugitive emissions from transport of coal

The different types of pollutants due to switchover from oil to coal are as follows

1. Particulate Matter

Traditionally the emission of particulate matter, particularly from kiln stacks, has been the main environmental concern in relation to cement manufacture. Other major point sources of particulate matter are raw materials crusher, raw mills, clinker cooler, gypsum crusher, cement mill and coal pulverization mills

The common sources and operations responsible for fugitive emissions of particulate matter, related to the cement production, irrespective of the type of fuel used, are as follows:

a. Raw materials quarrying and mining operations
b. Transport of raw materials and finished product
c. Raw materials storage and handling facilities

The main sources and operations, which can result into differential fugitive emissions of particulate matter, consequent to switch over from fuel oil to coal for cement production are

a. Transportation of Coal: Mostly the trucks are used to transport coal from quarry to the cement plant. As material is mostly uncovered during transportation, Particulate Matter emissions to atmosphere take place due to vibration and wind.
b. Coal Storage and Handling with in the Plant: Mostly the coal is being stored in open area, in forms of dumps. The emissions from storage area depend on the wind speed and the moisture content of the coal. Dust emissions can also take place during dumping of coal.
c. Coal Feeding and Conveying: Sources and operations of fugitive Particulate Matter emissions to the plant atmosphere are:
    i. Feeding of coal to the crushers by loaders.
    ii. Transportation of coal for further processing through conveyor belts, mostly uncovered.

The amount of particulate matter is expected to increase to a certain number, issue of additional Particulate matter emissions, mainly arising from the above source, shall not be underrated and ignored, because these emissions, if not controlled properly, may cause a lot of public health hazard and nuisance, to the communities located in the vicinity of the plant, particularly since these emissions get released at the ground level, with less chances of diffusion. In this regard necessary prevention methods must be followed to reduce the emission of this particulate matter from the additional facilities.

Table 6.1[8]Emission standard for cement production plants (in mg/st.m^3)

Parameter	EQS	World Bank Guidelines	European Countries Standards
Particulate Matter (> 10 micron)		50	
Cement Kilns	300		50-150
Grinding. Crushing. Clinker coolers	500		50-400
Oxides of Sulfur (SO_x):- Other plants except power plants operated on oil and coal	1700	400	> 200
Oxides of Nitrogen (NO_x) Other plants except power plants operated on oil and coal		600	500-1800
Oil Fired	600		
Coal Fired	1200		
Carbon monoxide (CO)	800	-	-
Hydrogen Chloride (HCl)	400	-	30-250
Hydrogen Fluoride (HF)	150	-	5-50
Lead (Pb)	50		
Mercury (Ng)	10	-	-
Cadmium (Cd)	20	-	-
Arsenic (As)	20	-	-
Copper (Cu)	50	-	-
Antimony (Sb)	20	-	-
Zinc (Zn)	200	-	-

The Environmental Quality Standards (EQS), all emission figures for cement kilns are referred to 0 °C. 101.3 kPa, dry gas and 10% O^o[8].

2. Oxides of Sulfur (SOX)

SO_2 is the main (99%) sulfur compound released from the cement kilns, although some SO_3 is produced and, under reducing conditions, H_2S can be generated. SO_X emissions from cement kilns primarily depend upon the content of the volatile sulfur in the raw materials, fuel sulfur, kiln type and extent of kiln gases diverted to the mill for drying purposes. The SO_2 emission concentrations increase with increased levels of volatile sulfur in the used raw materials and fuels. The volatile sulfur compounds are readily oxidized under high temperature conditions and presence of oxygen. The amount of sulfur in fuel and coal is

Type of oil	Sulfur (%) wt.
Fuel oil used in Mugher Cement	2 - 3.5 %
Yayu raw coal	1.81 %
Yayu washed coal	1.76 %

Coal essentially contains more sulfur than the fuel oil. The above data shows that range of sulfur contents of available Yayu coals is significantly lower than that of fuel oils. Even sulfur contents of some good quality local coals are within the same range as that of the fuel oils. However, since consumption of coal is about 1.8 times more than that of the fuel oil for clinker production, the sulfur contents in coal shall be less by the same factor as compared to fuel oil, if the same order of sulfur input is to be maintained in the system. The coal sulfur contents shall be 0.8-2.0%.

As the data indicates, the Yayu coal, which is a low sulfur coal, has the same SO_X emission levels, or the same range of sulfur input is maintained and a desirable balance is kept between the total sulfur (fuel + raw meal) input regardless of the switchover.

3. Oxides of Nitrogen (NO_X)

NO (Nitric Oxide) and NO_2 (Nitrogen dioxide) are the dominant oxides of nitrogen, in cement kiln exhaust gases, with NO being more than 90%.There are two main processes for production of NO_X as follows:

a. Thermal NO_X: Thermal NO_X forms at temperatures above 1200 ^{O}C and involves the reaction of nitrogen and oxygen molecules in the combustion air. Thermal NO_X is produced mainly in the kiln burning zone where it is hot enough to achieve this reaction. The amount of thermal NO_X produced in the burning zone is related to both burning zone temperature and oxygen content (air excess factor). The rate of reaction for thermal NO_X increases with temperature, therefore, hard-to-burn mixes which require hotter burning zones will tend to generate more thermal NO_X than kilns with easier-burning mixes [10, 21].

Besides temperature and oxygen content (air excess factor), NO_X formation can be influenced by flame shape and temperature, combustion chamber geometry, the reactivity and nitrogen content of the fuel, the presence of moisture, the available reaction time and burner design.

b. Fuel NO_X: Fuel NO_X is generated by the combustion of the nitrogen present in the fuel. Nitrogen in the fuel either combines with other nitrogen atoms to form N_2 gas or reacts with oxygen to form fuel NO_X.

It is anticipated that no substantial difference in NO_X emissions would occur, consequent to shift in kiln fuel from oil to coal. In case of pre-heater or pre-heater/pre-calciner type of kilns, the NO_X emissions shall remain within the standard limits, for both oil as well as coal based kilns without any end-of-pipe control. This aspect, however, requires further investigations and studies.

4. Carbon monoxide (CO)

One of the serious impacts of the use of solid fuels including coals for kiln operation is the potential increase in frequencies of short-term excessive carbon monoxide (CO) releases, consequent to unsteady state operation of the combustion system, resulting from surges of solid fuel feeding, owing to poor fuel feeding controls. Control of CO levels is critical in cement kilns when electrostatic precipitators (ESP) are used for particulate abatement, to ensure that the concentrations are kept well below the lower explosive limit (typically to 0.5% by volume)[10]. If the level of CO in the ESP rises above this limit, then the electrical system is automatically switched off to eliminate the risk of explosion. This leads to unabated particulate releases from the kiln

The emission of CO is related to the content of organic matter in the raw material, but may also result from poor combustion, when control of the fuel feed is sub-optimal.

It is anticipated that no substantial difference in overall CO pollution loads would occur, consequent to shift in kiln fuel from oil to coal, provided the plants can maintain stabilized and steady fuel feed control. CO concentrations, however, would continue to exceed the standard values, irrespective of the fuel type, in cases, where desirable combustion efficiencies are not achieved in the kiln operations, by proper operational control.

5. Volatile Organic Compounds (VOC)

In combustion processes, in general, the occurrence of volatile organic compounds (and carbon monoxide) is often associated with incomplete combustion. In cement kilns, the emission will be low under normal steady-state conditions, due to the large residence time of the gases in the kiln, the high temperature and the excess oxygen conditions. Concentrations may increase during startup or upset conditions. There is no significant difference on the emission of volatiles organic compounds due to the switchover to coal.

6. Polychlorinated Dibenzodioxins (PCDD) and Polychlorinated Dibenzofurans (PCDF)

Polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) are extremely toxic chemical compounds. Any chlorine input in the presence of organic material may potentially cause the formation of PCDD and PCDF in combustion processes.

The chlorine contents of coals (mostly as chlorides) are generally higher than those of fuel oils. Introduction of coal, therefore, in place of fuel oil would in most cases increase chlorine input in the kiln system. The use of high ash coal with high chlorine contents causes serious problems of coating and ring formation in cement kilns, and their use therefore is not desirable even from the process point of view. The chlorine contents of coals show a large variation of 0.01-0.4% [10].

The chlorine content of Yayu raw coal has an average value of 0.07 % which is high, where as the chlorine content of the washed coal is not available in the study, therefore, further investigation to see the above pollutants and the effect on the operation has to be conducted.

7. Metals and their compounds

Raw materials and fuels always contain trace amounts of toxic metals. The concentrations of these metals vary widely from source to source. Metals and their compounds can be categorized into three classes, based on their volatilities, as follows:

1. Non-volatile or Refractory:-Arsenic (As),Copper (Cu)
2. Semi-volatile:- Lead (Pb), Cadmium (Cd), Antimony (Sb), Zinc (Zn)
3. Volatile:-Mercury (Hg)

The behavior of these metals in the burning process is dependent on their volatility. Non-volatile metal compounds remain within the process and exit the kiln as part of the cement clinker composition. Semi-volatile metal compounds are partly taken into the gas phase at sintering temperatures to condense on the raw material in cooler parts of the kiln system. This leads to a cyclic effect within the kiln system (internal cycles), which builds up to the point, where equilibrium is established and maintained between input and output through the cement clinker.

Volatile metal compounds condense on raw material particles at lower temperatures and potentially form internal or external cycles, if not emitted with the flue gas of the kiln. Mercury and their compounds are particularly easily volatilized and to a lesser extent so are cadmium, lead, and their compounds. An internal cycle of easily volatile metal compounds is formed, when they react with the calcination feedstock or when they precipitate on the feedstock in cool areas of the calcination chamber, in the preheater

The dusts from the production of cement contain small amounts of compounds of volatile and semi-volatile metals. The main source of metal-laden dusts is the kiln system, including preheaters, precalciners, rotary kilns and clinker coolers. The metal concentration depends on the feedstock and recirculation in the kiln system.

Use of Yayu coal may increase the input of metals into the process, and consequently an increase in their emissions. A detailed investigation shall be required to establish the toxic metal contents concentrations of metals in the kiln emissions. In this regard, special emphasis shall be placed on the volatile toxic metals like mercury.

8. Stack emissions from coal pulverization mill

Coal pulverization mill is an important component of a coal based cement plant. Generally, hot flue gases from the kiln are introduced into the pulverization plant to dry the coal. The flue gas thus introduced, after carrying additional pollution loads from coal processing, leaves from the pulverization mill stack. The air flow used to dry the coal can not be reintroduced into the kiln due to the relatively high moisture and sulfur contents.

It implies that in case of coal as kiln fuel, the emissions originating from kiln are divided into two parallel streams, one emitting from the kiln stack and the other from the coal pulverization mill stack. Continued use of electrostatic precipitators or fabric filters on kiln systems as well as coal pulverization mills, shall be necessary to control Particulate Matter emissions and it is necessary to keep them well within Environmental Quality Standard.

For our case from a coal pulverization mill equipped with fabric filter, the emission of stuck from the firing system when coal is used as a fuel is expected to be with in the standard.

6.2 Spontaneous dust fires and coal dust explosion

One potential hazard of the coal, depending upon its characteristics and ambient conditions, is its propensity to spontaneous ignition and combustion at rather low temperatures, which leads to outbreak of fire in stored coal. This spontaneous combustion may occur naturally or the combustion process may be triggered by other causes, like lightening, electric or mechanical sparks.

Three necessary elements of fire triangle, which must occur simultaneously to cause a fire, are Fuel, Heat and Oxygen. Removing any one of these requirements would prevent fire. Coal reacts with atmospheric oxygen even at ambient temperatures and this reaction is exothermic. If the heat liberated during the process is allowed to accumulate, the rate of the above reaction increases exponentially and there is a further rise in temperature. When this temperature reaches the ignition temperature of coal, the coal starts to burn.

For conditions favoring spontaneous combustion the air supply needs to be high enough to support the oxidation, but too small for a sufficient cooling. The temperature, at which the coal oxidation reaction becomes self - sustaining and at which spontaneous combustion occurs, varies depending on the type (nature and rank) of coal and surrounding conditions of heat dissipation. In poor quality coal and where the heat retention is high the coal and carbonaceous material may start burning at temperatures as low as 30-40 ^{0}C.

Besides burning away the important nonrenewable energy resource and causing financial losses, these fires pose danger to man and machine; raise the temperature of the area; and may cause damage to the adjacent buildings and structures. Excessive levels of air pollution of the occupational and surrounding atmosphere would result from such fires, for as long as the fire continues.

Under all circumstances, coal dust would continuously be present in the occupational atmosphere of the plant. Its entry and accumulation in the electrical panels, equipment and machinery, not duly protected, and on power cables, laid in open or in trenches, may damage them otherwise or as a result of the spontaneous ignition, due to self heating or else triggered by some electric spark. Such ignitions may lead to the outbreak of fire and cause more damage.

Due to the high moisture and high content of volatile matter, the tendency and propensity of Yayu coals to spontaneous ignition and combustion is high, and thus accordingly the required level of precautions in their storage, for prevention of spontaneous fires shall be high.

Pulverized coal is potentially explosive and can be set off by spontaneous ignition or by proximity of hot elements, static charges or flames. Pulverized coal is present in the coal pulverization mill and in the elements the coal feeding and firing system. Like fire triangle, there is explosion pentagon of five necessary elements of Fuel, Heat, Oxygen, Suspension and Confinement, which must occur simultaneously, to cause and propagate an explosion. Like the fire triangle, removing any one of these requirements would prevent an explosion from propagating. For example, if fuel, heat, oxygen, and confinement occurred together in proper quantities, an explosion would still not be possible without the suspension of the fuel. However, in this case, a fire could occur. If the burning fuel were then placed in suspension by a sudden blast of air, all five sides of the explosion pentagon would be satisfied and an explosion would be imminent.

The principal impact of any coal dust explosion is consequent potential loss of the human life and limb. Other major impacts include loss of fuel, destruction of the machinery, equipment and surrounding structures and loss of production due to possible closure of plant for some time. Socio-psychological impacts of such an explosion, if it ever occurs unfortunately, on the surrounding communities and the plant staff itself, owing to their persistent fears in future, and their reaction to such an incidence, may turn out to be more disastrous, than the incidence itself. The general measures for prevention and control of pulverized coal explosions should be exercised.

6.3 Other related impacts

Open storage of coal on unpaved soil surface, with no proper drainage system, may lead to contamination of soil and groundwater, particularly, consequent to rainfall. The rainwater passing through stacks of coal may leach certain dissolved organic constituents like phenols and carry them to soil and ground water.

Coal crushers and pulverization mill are two main additional sources of noise pollution, resulting from fuel switchover from oil to coal.

Conclusion and Recommendation

The results of the study revealed the possibility of using the indigenous coal as an energy source in cement industries up to a certain percent using alternative mechanism.

The Yayu Raw coal, is not suitable to use it 100 % in cement kilns because of its high ash content and non-uniform quality. The use of 100% Yayu raw coal is not possible due to the effect of coal ash on the clinker quality and on the operation of kiln. However, there is a large possibility of utilizing this coal in a calciner kilns to a high percentage because the ash is intimately mixed in to the raw mill as a consequence of turbulence and high material retention time, utilizing this raw coal in cement kilns is also possible by blending with low ash imported coals to a certain percent.

The potential use of Yayu coal in cement kilns is also significant by improving the quality of the coal by preparations methods that is by reducing the ash content of the coal into an acceptable percent. Washed Yayu coal in which the ash content is reduced into 15 % is with in the requirement of cement industries and the effect on the quality of clinker is acceptable and with in the specification.

The effect of the washed coal ash on the raw materials and on the raw mix proportioning can be adjusted on the basis of the desired clinker.

When Yayu washed coal is used in place of furnace oil, the raw materials requirement will be affected due to the high amount of ash found in the coal, accordingly the limestone requirement will rise to balance the silica in the ash, the clay requirement will be reduced and due the high silica nature of the Yayu coal, and interestingly sand stone which is used as a corrective material can be reduced significantly.

The sulfur content is significantly lower than to that of fuel oils, used by the cement plants, so the total in put of sulfur to the kiln in case of Yayu washed coal utilization is in the same range to that of fuel oil.

In order to minimize the system disturbances and need for process control adjustments, to maintain the desirable product quality, the process requirement of reasonable uniformity and consistency in coal characteristics is the determining factor for utilization of Yayu coal in cement plants.

Anticipated annual coal requirement of Mugher Cement Enterprise for the existing system if Yayu washed coal is substituted in place of furnace oil is estimated to be around 100,000-105,000 tons per annum, which is around 0.5 % of the present mineable reserve of the area.

The introduction of Yayu washed coal in place of furnace oil for the existing system require substantial capital investment, for additional facilities and equipments. The main additional equipments include coal pulverization, conveyor belts, coal feeder, coal burner, continuous flow conveyor, coal storages etc. Additionally an increased process control and adjustments are required to counter act the variation in the coal characteristics.

Labour, maintenance and electricity requirements will increase on account of additional coal handling and preparation plants.

The total investment cost required to switch from furnace oil is estimated to be around 65-75 million Ethiopian birr.

The main consequence of the switch over from fuel oil to Yayu washed coal are potential reduction in the production cost and the country's import bill, it is estimated that for the existing kilns Net Savings on the production costs of 60-65 Birr per ton of clinker or 45-50 Birr per ton of cement can be obtained.

One potential hazard of Yayu coal is since it is a low rank coal; high volatile and high moisture its propensity to spontaneous ignition and combustion at rather low temperature which may lead to outbreak of fire in the case of storage and transportation. Necessary prevention and control measures shall be exercised to avoid incidences of spontaneous coal fires and coal dust explosions, and thus accordingly the required level of precautions in their storage and transportation, the cost associated with the prevention methods shall increase.

In order to arrive at more accurate and reliable estimates of incremental pollution loads, resulting from fuel switchover, a detailed investigative study, based on independent monitoring of emissions and other associated parameters shall be required.

Recommendation

It is suggested that cement industries to see this alternative source of energy as soon as possible, and accordingly studies has to be carried to identify the internal and external concerns of the industry about the substitution of furnace oil by indigenous coal to a certain percent.

Cement plants all over the world are already using high ash coals and advantage can be taken of the experience of others.

The blending of coals from different sources will be necessary for smooth operation of the plant. To compensate for deficiencies in indigenous coal, it will be necessary to use some imported coal as well. In the first few years the Indigenous coal would be blended with imported coal, with progressive increase, till it completely replaces the imported coal.

The quality of coal shall have to be monitored so that cement quality is not affected and pyroprocessing system remains stable.

Special measures shall have to be adapted to ensure timely delivery of coal to the plant.

Necessary infrastructure shall have to be developed for economic transportation of coal to be used by cement plants.

In view of the foregoing it is recommended that coal as fuel should be handled with - care and necessary prevention and control measures need be exercised to prevent and to avoid coal fires and coal dust explosions.

Large scale mining should be developed to ensure economical mining operations, modern mining technology and supply of suitable quality of coal.

Import terminal conditions and facilities have to be assessed and improved for their potential handling large coal cargo potential if coal blending is necessary.

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