Addis Ababa University

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School of Multidisciplinary

Center of Renewable Energy

Experimental analysis of coal upgrading: The case of Dawuro, southern, Ethiopia

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A Thesis Submitted to The School of Graduate Studies of Addis Ababa University, Addis Ababa Institute of Technology in Partial Fulfilment of Requirements for The Degree of Masters of Science in Renewable Energy Technology

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Date: September 2021

Addis Ababa, Ethiopia

EXPERIMENTAL ANALYSIS OF COAL UPGRADING: THE CASE OF DAWURO, SOUTHERN, ETHIOPIA

BY

MULUKEN FILMON

A THESIS SUBMITED TO

CENTER OF RENEWABLE ENERGY ENGINEERING

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MULTIDISCIPLINARY

ADDIS ABABA UNIVERSITY

IN PARTIAL FUIFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN RENEWABLE ENERGY TECHNOLOGY ENGINEERING

ADVISORS:

DR-ING WONDOSON BOGALE (ASSOCIATE PROFESSOR)

September 2021

ADDIS ABABA

DECLARATION

I, Muluken Filmon Tera, I declare that this thesis is the result of my own work and that all source and material used for this thesis have been duly acknowledged. This thesis is submitted in partial fulfillment of the requirement for master's degree in energy technology at Addis Ababa university and to be made available at the at the university's library under the role of the library. I confidently declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

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ACKNOWLEDGEMENT

First and foremost, praises and thanks to the Almighty God, for His showers of blessings throughout my research work to complete the research successfully. None of the activity is done without the will of God. Then I would like to express my deepest gratitude, great respect, appreciation and heartfelt thanks to my advisor Dr-Ing Wondoson Bogale (Associate Professor) for his support, guidance and suggestions during this thesis work. Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Solomon T/Mariam (Chairman of Renewable Energy Center), Dr. Ebrahim Tilahun and Dr. Kamil Dino Adem. I would also want to acknowledge FDRE minister of mines and petroleum and Ethiopian Geological survey staffs, for their support by giving coal sample and allowing their laboratory to conduct this experiment.

My sincere thanks also go to Gujii highland coffe plantation and mineral exporters. Specially for Chala Wodessa and Ato Wodessa for their finical support.

I am extremely grateful to my parents for their love, prayers, caring and sacrifices for educating and preparing me for my future. I am very much thankful to my elder brother Fekadu Filmon, and Tigabu Filmon. My Special thanks goes to my friend and brothers in Christ, Temesegen W/yohannis, Meron Desta, Mitiku Yano, Zemenu Yohannis, Amanuel Alemayewu and Tarekegn Yohanis for their love, understanding, prayers and continuing support to complete this research work. for their support and valuable prayers.

ABSTRACT

Coal has been major energy source for cement, steel and chemical industry in Ethiopia and also the country has high coal deposit. However, Ethiopian Coal is low in quality and calorific value and high sulfur, ash, and volatile content. Due to this, almost all local and international industries do not like to use Ethiopian coal. Hence, this study experiment on the ways of upgrading or enhancing the low quality of Ethiopian coal to high quality. Fluidized bed or dry cleaning is used to separate impurities from raw coal based on density difference, and chemical cleaning method is used to remove sulfur content by leaching with hot alkaline solution. The experimental result shows that Fluidized bed and washing machine have a capacity to upgrade its calorific value from 3000kcal/kg to 6,600kcal/kg, reduce moisture content from 37% to 5%, ash content, 27% to 4%, volatile matter 8% to 3.43%, reduce Sulfur content from 1.5% to 0.45%. Chemical cleaning effectively removes almost all sulfur up to 99% but high cost. Physical cleaning is effective in cost rather than chemical cleaning. This shows that it's possible to use low graded coal by upgrading its qualities.

Key word: Coal, Coal Cleaning, Calorific Value, Leaching and Fluidized bed.

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LIST OF ABBREVIATION AND ACRONYMS

LRC	Low rank coal
CCT	Clean coal technology
CP	Specific heat capacity
CA	Calorie
KCA	Kilocalorie
BTU	British thermal unit
KJ	Kilo joules
ISO	International standard organization
IS	Indian standard
VM	Volatile matter
CV	Calorific value
AS	Ash content
EACM	East Africa coal mining
Q	Heat

1. INTRODUCTION

1.1 Background

Coal is nonrenewable energy resource that exist natural in earth as sedimentary rock, it is a fossil fuel that formed by decay of animal and plant before millions of years ago [1]. Coal is the major source of energy in world used for power generation, steel making, cement production and many other purposes [1,2]. Each year, billion tonnes of coal are traded in local and international markets [3]. However, when burned, coal can emit significant amounts of pollutants which create environmental problems and also using low rank coal hinder the operation of power plants because the high moisture content reduces the power plant's efficiency and increases flue gas emissions. It can damage the equipment and not meet their heating value demand. In addition, burning raw coal pollutes the environment and also, there are some disadvantages to using low rank coal such as costly transportation, potential safety hazards during transportation and storage, and operational problems [4]. If raw coals upgraded, those problems can be solved. This thesis is intended (aimed) to solve this problem by up grading this low-quality coal in to high quality grade coal.

Cleaning of coal refers to the removal of non-coal material from raw coal to produce a relatively clean coal product. Raw coal is composed of high purity coal material and non-coal material. Non-coal material includes Ash, pyrite, clay, and aluminosilicates materials [3]. The presence of large amounts of these ash materials can create problems during combustion, such as slagging and fouling. Sulfur is present in raw coal in two forms, organic sulfur and inorganic sulfur [6]. Organic sulfur is chemically bound as part of the coal matrix. Inorganic sulfur is all sulfur not chemically bound in the coal matrix. Pyrite sulfur is the predominate form of inorganic sulfur. Physical cleaning effectively removes only inorganic sulfur and however chemical cleaning remove also organic sulfur [3-5]. Hence, an appropriate cleaning process is necessary to develop an energy-efficient calorific value upgrading with lower environmental impacts. Among the other cleaning systems, the fluidized bed and leaching method was studied in this thesis.

1.1.1 Coal Energy potential of Ethiopia

Deposits of coal and natural gas are also known to exist in Ethiopia [1]. Several geological investigations had been also conducted for coal by the Geological Survey of Ethiopia and approved coal occurrences at Gojeb, Chinda, Kindo, Halul and Koyisha, Dawuro, Wolayita and

Wake in the Southern People, Nation, Nationalities, and Wuchale in the Amhara, and Arjo, Nejo and Mendi in the Oromia National Regional States are worth mentioning [2]

According to the study made by Changshi China based company, the Yayo Woreda alone endowed with over 179 million tons of coal potential [1-3] . Provided that it is possible to produce 100,000 tons of coal per day, the nation can derive a lot from its coal potential for over 40 years. The ministry of mines Ethiopia claims that there are more than 430 million potentials of coal in the country [3].

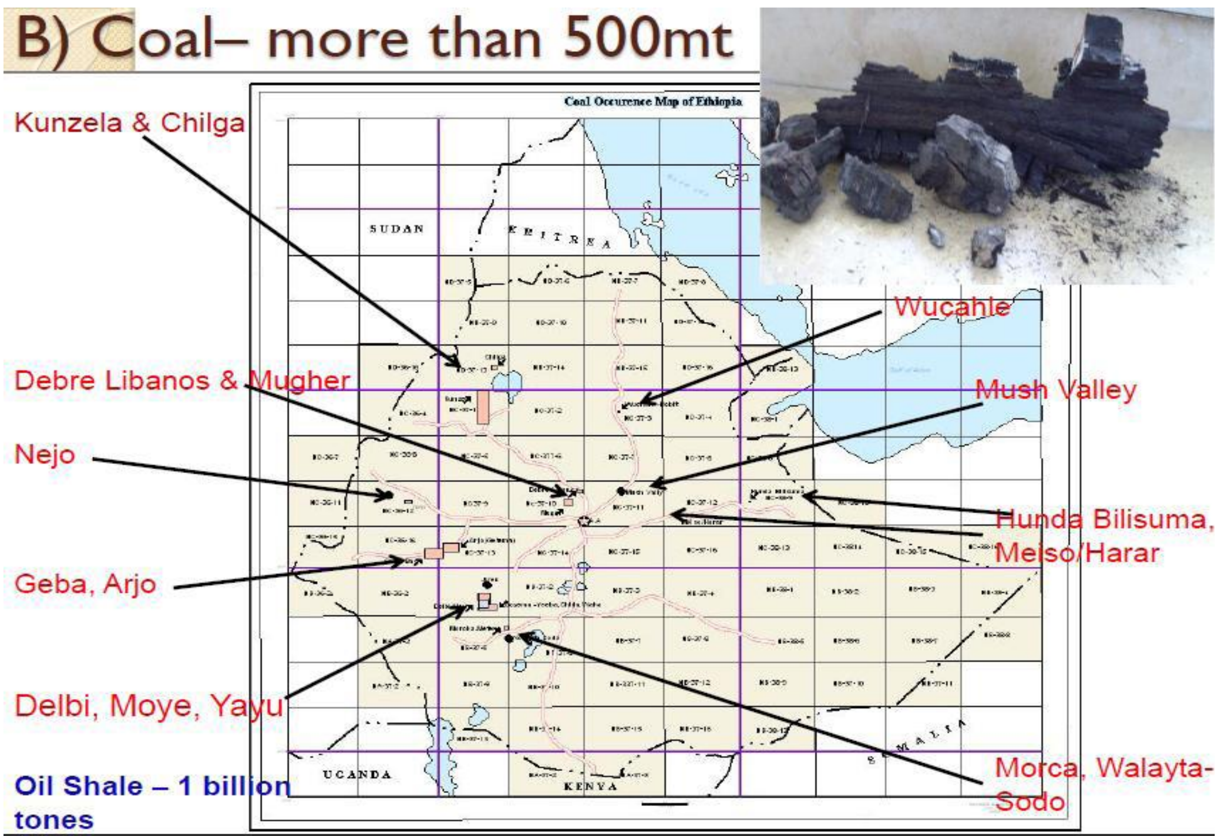


Figure 1: Coal distribution in Ethiopia [2]

1.2 Statement of Problem

Ethiopia is one of the countries depend on imported coal, having huge coal energy consuming industry, The industrial growth and construction development is increasing in Ethiopia from time to time this implies that future demand of coal energy in the country is high. Nearly 300 million tons of coal is imported annually from South Africa in Ethiopia in 2017 [2]. but the country has more 500 million tons capacities to export annually. However, Ethiopia coal is low in quality, Low calorific value, high sulfur content, high ash content and high volatile matter, due to this almost all local and international industry did not like to use Ethiopian coal, because using low rank coal hinder the operation of plants because the high moisture content reduces the plant's efficiency and increases flue gas emissions. It can also damage the equipment [5-9]. In addition, burning raw coal pollutes the environment therefore the country is sacrificing a lot in foreign currency due to locally available coal won't meet standard quality parameters [10-11]. If these coals are upgraded, those problems can be solved. This thesis is intended to solve this problem by up grading this low-quality coal in to high quality grade coal.

1.3 Objectives

1.3.1 General objective

The general objective of this study is to up grading the quality of coal from low grade to high grade which is obtained from, Dawuro, Southern part of Ethiopia.

1.3.2 Specific objectives

- Characterize the proximate analysis of raw coal before treatment and after treatment
- Conduct experimental analysis of coal using physical method.
- Conduct experimental analysis of coal using chemical leaching method.
- Determine optimum working conditions (Treatment time, Temperature, Particle Size and Air velocity, Feed rate).

1.4 Research Question/Hypothesis

- 1. How to use our country coal by processing?
- 2. How to increase the carbon percept of locally available Ethiopia low-grade coal toupgrade for industrial consumption? And how to reduce the sulfur content of coal to be relatively clean coal and decrease environmental pollution.

1.5 Significance of the Research

Energy is one of the basic inputs for economic development and human survival. Energy is needed as an input in industry, agriculture, mining, construction, transportation and service-giving organization. The availability of energy at a reasonable cost has always become a condition of industrial growth, economic and social progress. Ethiopia is one of the countries that depend upon imported petroleum products. The yearly import of petroleum products is absorbing more than one third of Ethiopia's annual exporting products [1]. The need of domestic fuel in the country is the major factor for deforestation and soil degradation. To overcome this problem, geological studies were carried to find out a valuable amount of oil shale, coal, oil and gas deposits in country therefore chemical engineers have amendatory to upgrade local available coal to high grade class to replace the import by country resource. Coal, oil shale, oil and gas deposits could possibly play an important role in the future energy budgets of Ethiopia.

This project has benefit to growth the country. The project benefits both the people of Ethiopia and the stakeholders if this project is implemented accordingly. Increase the price of coal which lead to more profitable and create more competitive global market for mining investors. Reduce sulfur emission to the environment. If this research is implemented accordingly, it benefits mainly Scientific community, Policy maker(government) and information to investors those who are interested to invest

The research focus is upgrading the coal with low processing cost as compared as imported coal from foreign countries of the same energy content or calorific value.

Economic benefits of Coal up-grading

Coal up-grading strengthens the economy, saves foreign, it makes profitable investors those who are working in this area, it satisfies the industry those use coal as energy source, it increases job opportunities, the family and community income. It helps to diversify and therefore stabilize the local economy. It increases the investments and therefore creates business opportunities both within and outside the industry. It provides the opportunity for innovation and creativity. It strengthens and supports the existing businesses and services (like coal demanding industries).

Social benefits of Coal up-grading

The social benefit of coal upgrading are it creates a pride of place and a sense of place, It makes stronger the infrastructure projects for the community, It brings different people together providing therefore opportunities for cultural exchange, through the development of cultural and entertainment activities brings people of the community closer and creates a team spirit.

Environmental benefits of Coal up-grading

The process of coal up grading reduces carbon dioxide, sulfur dioxide and other gases which affect the environment turns them into a rich supply of domestic energy.

Domestic benefit

Utilize natural resources and energy security and independence.

2. LITERATURE REVIEW

2.1 Formation of Coal

The word "coal" is taken from Old English word "col" which means glowing ember. Coal is a black sedimentary rock [1]. Coal is a solid combustible sedimentary rock which is brownish-black or more commonly dark black in colour found within the rock strata of the Earth forming layers of coal energy that are called coal beds [5]. Coal comprises of carbon, hydrogen, oxygen, sulphur, etc. When dead plants and animals decay and convert into peat which in turn is converted into lignite, then sub-bituminous coal, after that bituminous coal, and lastly anthracite [6-13]. Hence, coal is a fossil fuel. It takes places due to geological process and takes millions of years to form. Coal is extracted by mining [14-19]

Coal is a fossil fuel formed in ecosystems where plant remains were preserved by wood and mud from oxidation and biodegradation. The heat and pressure from the top layers helped the plant remains turn into what we call today coal [20-21]. Coal is a readily combustible black or brownish-black sedimentary rock composed mostly of carbon and hydrocarbons, with small quantities of other elements [22].

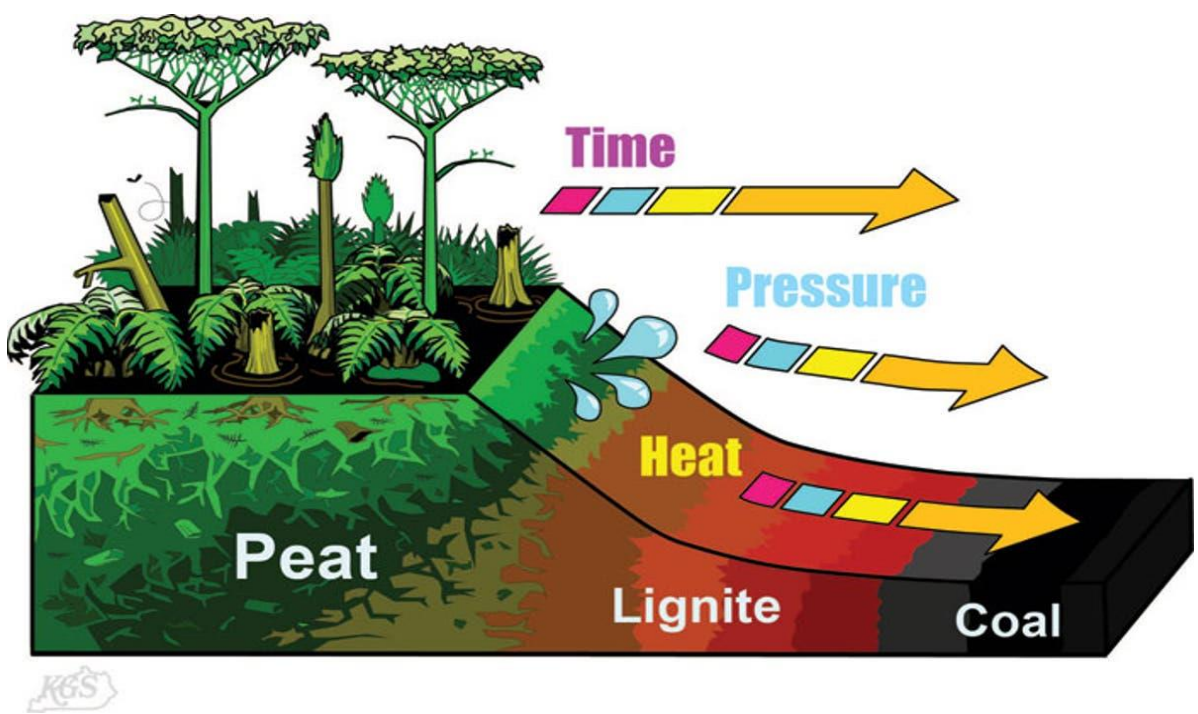


Figure.2: Coal formation [23]

Coal is used for power generation, steel making, cement production and many other purposes. Every year, billion tonnes of coal are traded in local and international markets. Its properties include calorific value, volatile matter, moisture, sulphur, chlorine and ash (elemental composition) content of coal. Coal cleaning removes the impurity that can lower the quality of coal, and upgrade the grade of coal; this led to high percent carbon and environmentally friend coal [23].

It takes millions of years for coal to form. millions of years ago, there were places on the earth with dense forests in wetlands, due to natural calamities such as flooding, tsunami, landslide, etc these forests got buried under the soil. Over the years, more and more soil compiled over these forests. Oxidation protected these trees from biodegradation, usually by mud or acidic water. This traps the carbon that was buried in the sediments. Carbonization takes place; carbonization is a process where vegetation turns into carbon. It is a slow process [24].

2.2 Uses of coal

Coal is used for power generation, steel making, cement production and many other purposes. Each year, billions of tonnes of coal are traded in local and international markets Coal has various purposes; the following are the basic uses of coal; Thermal coal is used to produce electricity. Coking coal is used in the production of steel. Coal is used to produce semi-conductor (Solar cell) and fibers to Wind Turbine. Coal is also used to make silicon metal which is used to produce silicones and silanes which are in turn used to make lubricants, water repellents, resins, cosmetics, hair shampoos, and toothpaste. Activated charcoal is used to make face packs and cosmetics. Carbon fiber is made from coal. Carbon fiber is an extremely strong but lightweight reinforcement material used in construction, mountain bikes, and tennis rackets. Activated carbon is used in filters for water and air purification and in kidney dialysis machines. Coal is used to make activated carbon. Paper manufacturers use coal to make paper. Coal helps to create alumina refineries. Thousands of different products have coal or coal by-products as components: soap, aspirins, solvents, dyes, plastics, and fibres, such as rayon and nylon.

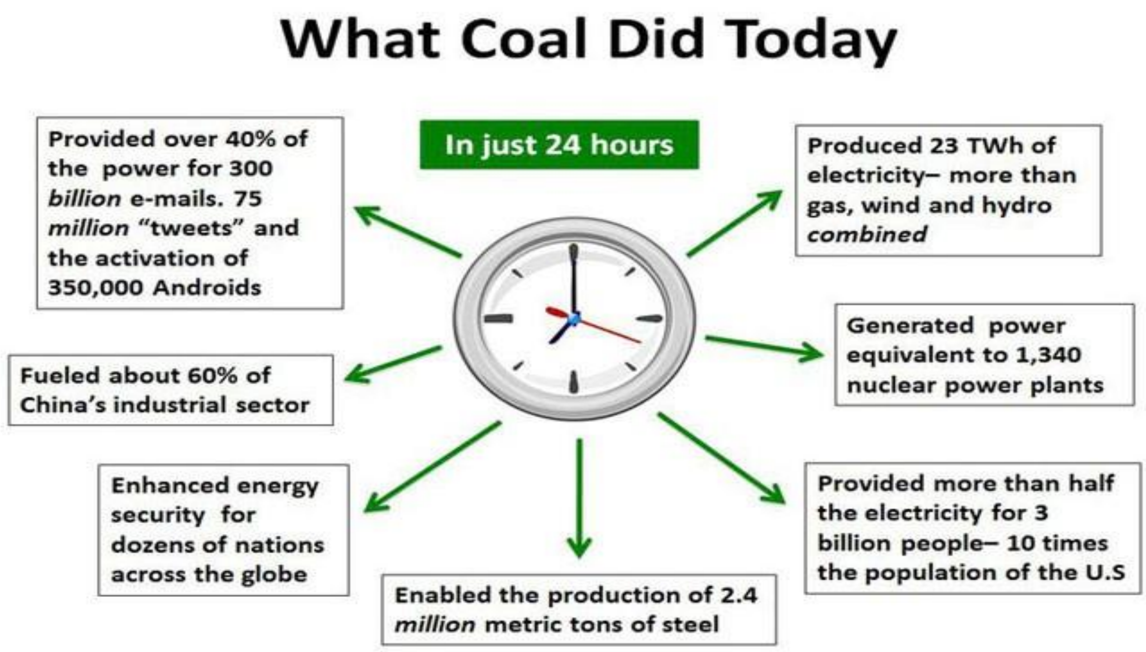


Figure 3: uses of coal [25]

2.3 Ethiopian coal consumption and annual coal import

Ethiopia imports more than 500 million tons of coal. For different industries like, cement industry, chemical industry and steel manufacturing

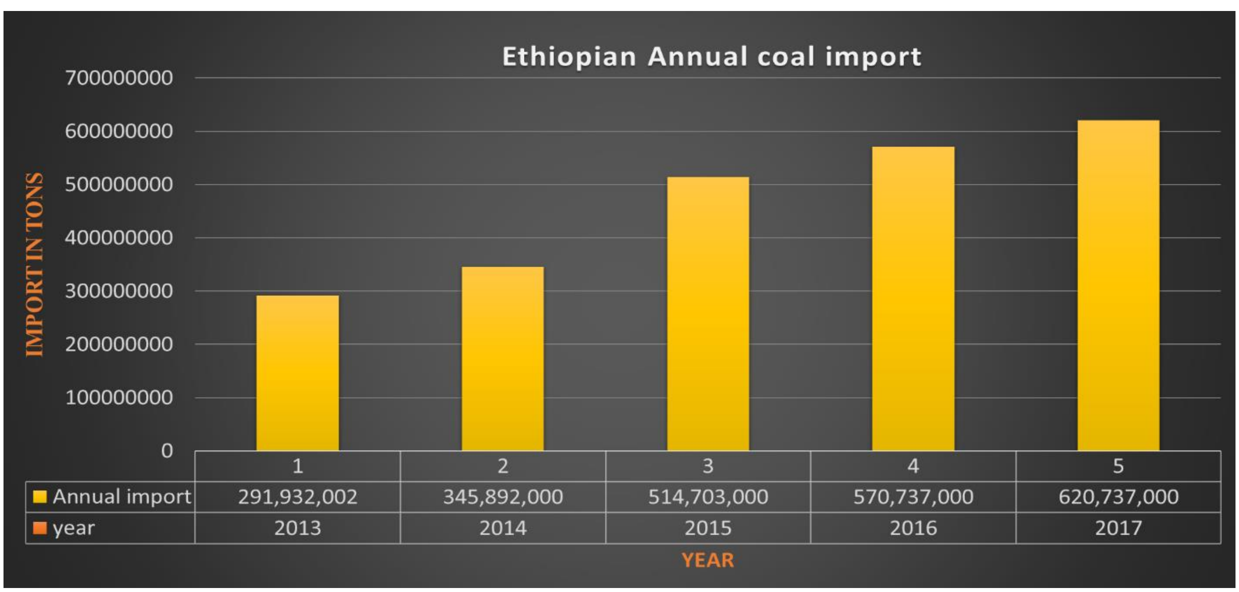


Figure 4: Ethiopian coal consumption and annual import coal report [2]

2.3 Types of Coal

All coal begins the same as peat, but not all fossil fuel coal energy reserves are the same. Coal as a fossil fuel is classified into different ranks based on its amount of carbon and moisture content, its calorific value, or the amount of heat energy that is released when the coal is burned, plus its hardness and mineral ash content left over after the combustion process. Coals that are older tend to have a higher-ranking value because they have been buried much deeper and for a longer period in time than much younger coals [15].

The main three factors that determine the quality of coal and therefore the amount of coal energy released are: the time in the ground, the compression pressure, and its exposure to underground heat. As a result of these three factors, the four main types of coal are [17]:

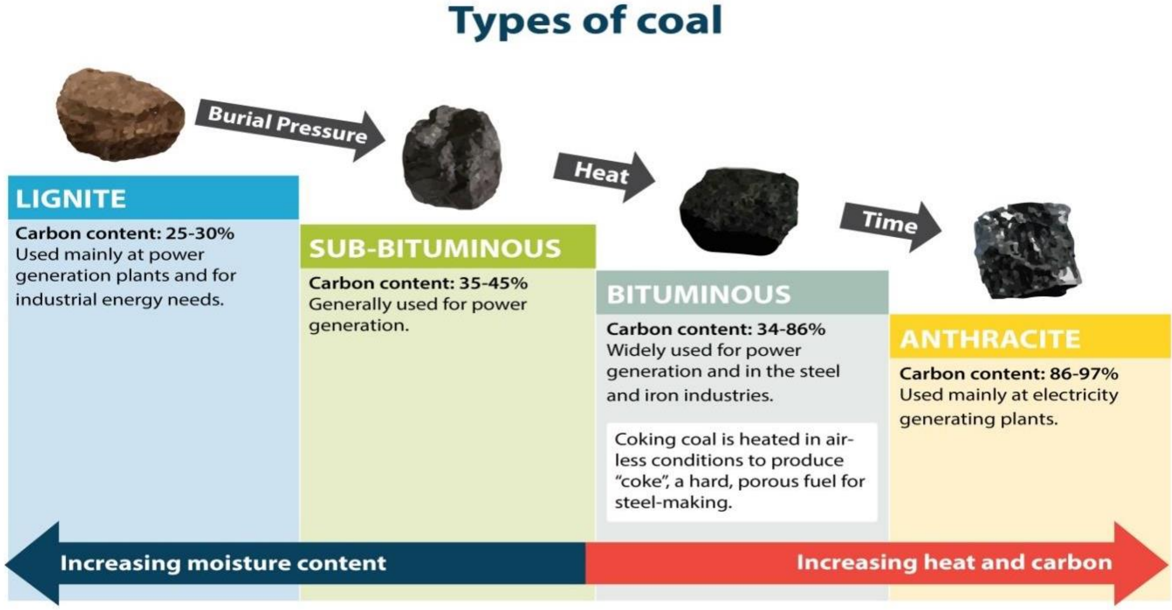


Figure 5: Types of coal in different age [11]

Lignite Coal: – This is the lowest ranked type of coal and the largest portion of the world's coal reserves are made up of lignite coal. This soft brownish-black coal has the lowest energy content and the highest moisture content as being a relatively young formation of coal it has had less exposure to heat and pressure. Lignite has a carbon content of about 25-to-35 percent and is therefore used in large quantities to produce electricity in power plants [24].

Sub-Bituminous coal: – Sub-bituminous coal is generally a dark brown to dull black in colour coal that gives off a little more heat energy than Lignite when burnt as it contains about 35-to-45 percent carbon. Sub-bituminous coals, known as brown coal, are used for generating electricity as some sub-bituminous coals have lower sulphur content than other types giving them an environmental advantage when combusted [24].

Bituminous coal: – Bituminous coal, also called soft coal, is the most abundant form of coal containing approximately 45-to-86 percent carbon. Because of its relatively high heat value and low moisture content, its ease of transportation and storage, bituminous coal has the broadest range of commercial uses among the coals. The heating value of bituminous coal is about two to three times greater than Lignite [24].

Anthracite Coal: – Anthracite ranks the highest in terms of its hardness and calorific value. Its heating value is slightly less than that of Bituminous Coal but has the highest carbon content of 86–to-98 percent. This high rank coal is mainly used for industrial and home heating applications because it burns nearly smokeless, generally has less than 10% volatile matter and ash-free. The disadvantage of Anthracite coal is its low global supply [24].

2.4 Clean Coal Technologies

2.4.1 Clean Coal Technologies in South Africa

Electricity demand in South Africa is increasing at a rate of 1000 MW per year. Whilst there is increasing pressure to adopt non-fossil fuel electricity generating technologies, the abundant reserves and low cost of coal make it the preferred energy source to meet increasing electricity demand for the foreseeable future [6]. The challenge in the future is to enhance both the efficiency and environmental acceptability of coal use by adopting clean coal technologies (CCTs). Integrated gasification combined cycle (IGCC) is a potential CCT that could be applied in South Africa to increase efficiency and reduce carbon dioxide emissions. IGCC also holds the advantage of reduced water consumption and the potential for co-production of liquid and gaseous fuels and chemicals. Fine coal gasification is a key enabling technology for the implementation of IGCC plants [26-27]. Fluidized bed gasification is being evaluated by the CSIR as a potential fine coal gasification process for incorporation into future IGCC plants. A suite of four South African coals has been identified as being possible fuels for power stations which would operate for three or four decades, towards the middle of this century [28-30].

2.4.2 Clean Coal Technologies in China

Coal is the dominant primary energy source in China, accounting for about 64% of the total primary energy consumption in 2015. It is the major source and material for power generation, energy-intensive industries (steel, cement, etc.), and residential and commercial heating [6]. In addition, it is a major source of greenhouse gases (GHGs) and air pollutants in China. In 2013, about 9.0231×10^9 t of carbon dioxide (CO_2) was emitted from fuel combustion in China, with more than 83% coming from the combustion of coal. In 2012, about 79% of sulfur dioxide (SO_2), 57% of nitrogen oxides (NOx), and 44% of particulate matter (PM) came from the direct combustion of coal, and about 93% of SO_2, 70% of NOx, and 67% of PM emissions came from all kinds of coal utilization (including direct combustion emission and emission from cok stoves and other industrial furnaces [33]. Although a great number of policy measures have been launched to control the consumption of coal in order to address climate change and alleviate air pollution, it is projected that coal will still play a dominant role in China's energy consumption portfolio—over 50% by 2030 and around 30% by 2050—even considering the high penetration of renewable energy Therefore, it is necessary to develop more efficient and clean technology options to enable China to continue to benefit from using its abundant and affordable coal resources. Clean coal technologies (CCTs) are technologies that facilitate the use of coal in an environmentally satisfactory and economically viable way. China has made remarkable progress in recent years in CCTs development. By the end of 2014, the installation capacity of ultra-supercritical coal-fired plants exceeded 100 GW. A 250 MW integrated gasification combined cycle (IGCC) demonstration power plant was put into operation. Localized water slurry gasification and dry feed pressurized gasification technology with a capacity of more than 2000 has been realized [33]. The world's first coal direct liquefaction plant, with a capacity of more than 1 Mt (oil), was completed in 2008. The commercial demonstration plants of coal-to-olefin have also been built. Indirect coal liquefaction plants with capacities of 160–180 kt have been built. Ultra-low-emission coal-fired power generation technology has been successfully demonstrated. Successful operation of 100 kt CO2 capture industrial equipment in a power plant has occurred. An enhanced oil recovery (EOR) demonstration project with a capacity of 150 kt and a CO_2 geological storage demonstration project with a capacity of 100 kt have been completed [4].

Innovation and adoption of these technologies has played and will continue to play an important role in the green low-carbon transformation of China. CCTs cover a wide range of coal production and utilizationrelated technologies, including green mining, coal purification, high-efficiency power generation, advanced coal conversion, pollution control, and carbon capture, utilization, and storage [6].

2.4.3 Clean Coal Technologies in America

Coal represents at present about 70% of world's proven fossil fuel resources. Moreover, coal is also a more delocalized resource and it has lower cost among the different fossil fuels. Thus, coal is likely to remain one of the main sources of primary energy for a long time, playing a strategic role in the medium–long-term energy production systems. Electric power from coal has been predominantly generated in pulverized-coal-fired power plants. Due to thermodynamic (the use of water) and metallurgic constraints, the efficiency of such plants is rather low. Modern pulverized-coal-fired power plants achieve efficiency of about 38–40% (based on the lower heating value of the fuel) operating at 250–300 bar and at the maximum temperature of 550–570 ^{o}C. But they are characterized by quite high pollutant emissions, especially carbon dioxide (about 800 g for each kWh of electric energy produced [31]

The growing energy demands of developing countries together with the need of a significant reduction in greenhouse gas (GHG) emissions are the challenging tasks of future energy policies. The perspectives of coal as energy source are based on success in the energy market of ''clean coal technologies'' (CCT), where good thermodynamic performances of power plant are joined with a control of pollutant emissions (mainly CO_2 emissions) [32-35]. The most promising are the ultra-supercritical (USC), the integrated gasification combined cycle (IGCC), and the externally fired combined cycle (EFCC) power plants. The development of CCT is an objective not easy to be performed for different reasons. On the one hand coal is not a uniform source due to its extremely variable composition; this makes it difficult to reach a standardization of advanced technologies, which can be very sensitive to the fuel used. On the other hand, coal combustion produces structurally more pollutants than other fossil fuels since it contains mainly carbon (producing CO_x) and sulfur (SO_x is the resulting product) as reactive components but very little hydrogen turning into H_2O [33].

2.4.4 Clean coal Technology in India

Coal is the most abundant fuel resource in India, considering the limited reserves of petroleum and natural gas, and safety issues of nuclear power. India is the world's third largest coal producing country and the fourth largest coal importer. State owned Coal India Limited (CIL) is the largest company in the world in terms of coal production and contributes ~ 80% of coal production in India. Generally, Indian coals have low calorific value and high levels of inorganic impurities. Also, coal ash is difficult to remove beyond a certain level due to non-homogenously mix nature(Kinjavdekar, 2015). The typical characteristics of Indian coal being used for power are Ash Content 25 – 55 %, Moisture content 4 – 7 % (18 % during monsoon), Sulfur content 0.2 – 1%, Gross Calorific value 3100 – 5100 kcal/ kg and Volatile matter content 20 – 30 % [35-40].

Lots of research work is going on globally since long time to minimize the environmental impacts of various processes related to coal. CCT (Clean Coal Technology) is an umbrella term, encompassing a wide array of technologies and innovations that can help reduce various emissions – fly ash, particles and gasses such as carbon dioxide (CO_2), carbon moxide (CO) and nitrous oxides (NO_X) etc from the coal industry and minimize above mentioned concerns. There are still concerns regarding the economic viability and overall feasibility of these technologies and the timeframe of delivery [36]. There are numerous CCTs aimed at minimization of environmental impacts during various processes in coal life cycle. The typical CCT alternatives for three major processes in coal life cycle namely coal preparation, coal burning and carbon capture and storage (CCS).

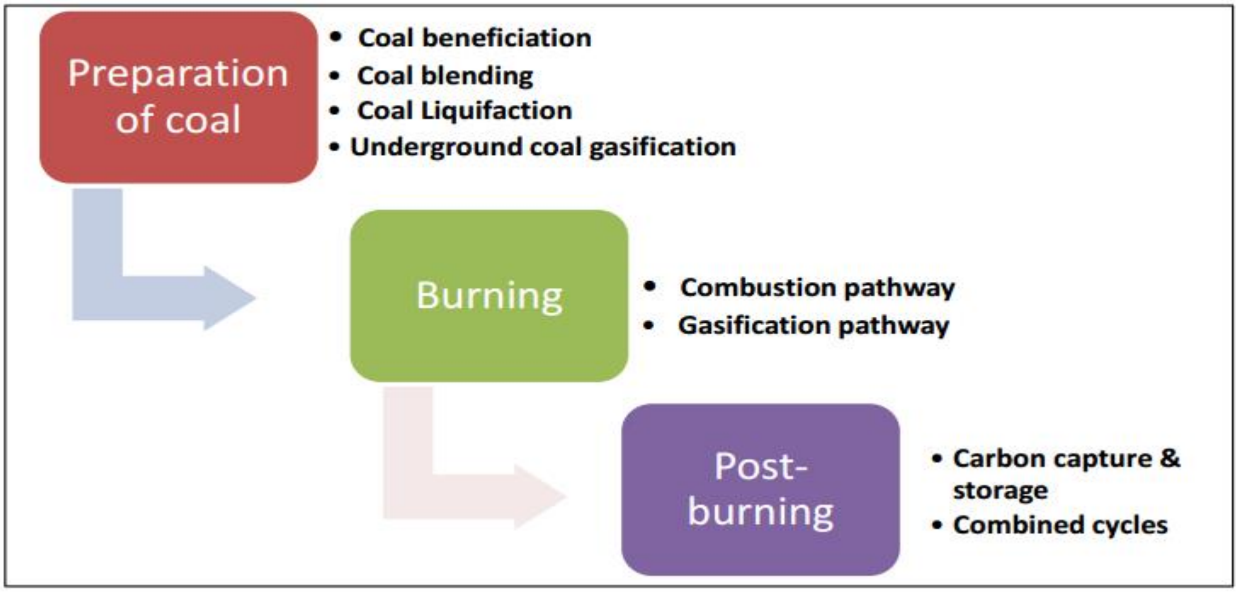


Figure 6 Green growth and clean coal technologies in India [27]

2.5 Research gap

Currently, the cleaning of the majority of run-of-mine coal is conducted by heavy medium separation, jigs and chemical Flo flotation, wet processes. these techniques use water as a separation medium. use of wet separation techniques is accompanied with the generation of large amounts of coal slurry, which is used as a replacement fuel for oil-fifi red boilers and other furnace systems [13]. however, dry gravity processing opens better possibilities for down scaling, being less restrictive for small capacities allowing on-site separation with less transportation cost. Further, mobile operations are easier to operate without a water circuit, also temporary operations and underground operations can be conducted at lower cost [14].

In many countries the supply of water is not abundant, and the disposal of the spent water is not always easy. Dry processing allows for mobile installations to operate at reduced cost [25].

German research at the time of World War II, uses of hot aqueous caustic solutions for the demineralization of coal dates back to in which the objective was to produce a low-ash product suitable for conversion to electrode carbon [27]. Subsequent work at the U. S. Bureau of Mines demonstrated that treatment of coal with 10% NaOH solutions at 225°C shadowed by washing with dilute HC1, could decrease the ash content to 0.7% from an original level of 9.8% [12].

Since that time, several workers have addressed the chemical extraction of coal using aqueous caustic under various circumstances. Some treated the coal with caustic at 300°C, followed by extracting with hot H_2SO_4 and then HNO_3 [23].

Others used a mixture containing 10% NaOH and 2-3% Ca $(OH)_2$ at 250-300 ^{O}C and high pressure for their treatment [34]. Recent work in Australia a and in India also employed leaching with aqueous NaOH and washing with acid to achieve low levels of ash in the final product.

Wheelock, T. D reviewed the use of liquified oxygen in hot aqueous solutions of sodium carbonate to desulfurize coal [27]. Since then, our efforts were redirected towards cleaning of coal "By using aqueous alkaline solutions, under non-oxidizing conditions, with subsequent acid treatment to remove the ash-forming mineral matter from coal [31]. The extraction of most of the mineral matter from coal was accomplished recently by treating fine size coal with a hot alkaline solution to dissolve quartz and to convert clay minerals and iron pyrite into acid-soluble compounds which were extracted with dilute acid in a second step [36]. Although various alkalis and acids may be utilized, Na_2CO_3 and H_2SO_4 are advantageous because of low cost and ready availability. Preliminary work has shown that hot Na_2CO_3 solutions readily convert kaolinite into sodium hydroaluninosiiicates which are acid-soluble [29]. That work has also shown that hot sodium carbonate solutions will dissolve quartz and convert iron pyrite into hematite, but not as readily as sodium hydroxide solutions. In this work, the characteristics of the two-step process was studied in greater detail using twenty different bituminous coals under a variety of conditions, with particular attention being given to the first step [23]. The relative effectiveness of various alkalis was studied as well as the effects of alkali concentration, alkaline treatment time, and temperature. The alkali-treated coals were subsequently leached with hot HNO_3 to remove mineral matter. Nitric acid was employed because it dissolves iron pyrite and is used for that purpose in ASTM Method D2492 for determining various forms of sulfur in coal. Since only organically bound sulfur should remain in coal which has been leached with HN03, it was possible to obtain an indication of how much organic sulfur was removed by the two-step treatment [10].

2.6 Literature summary

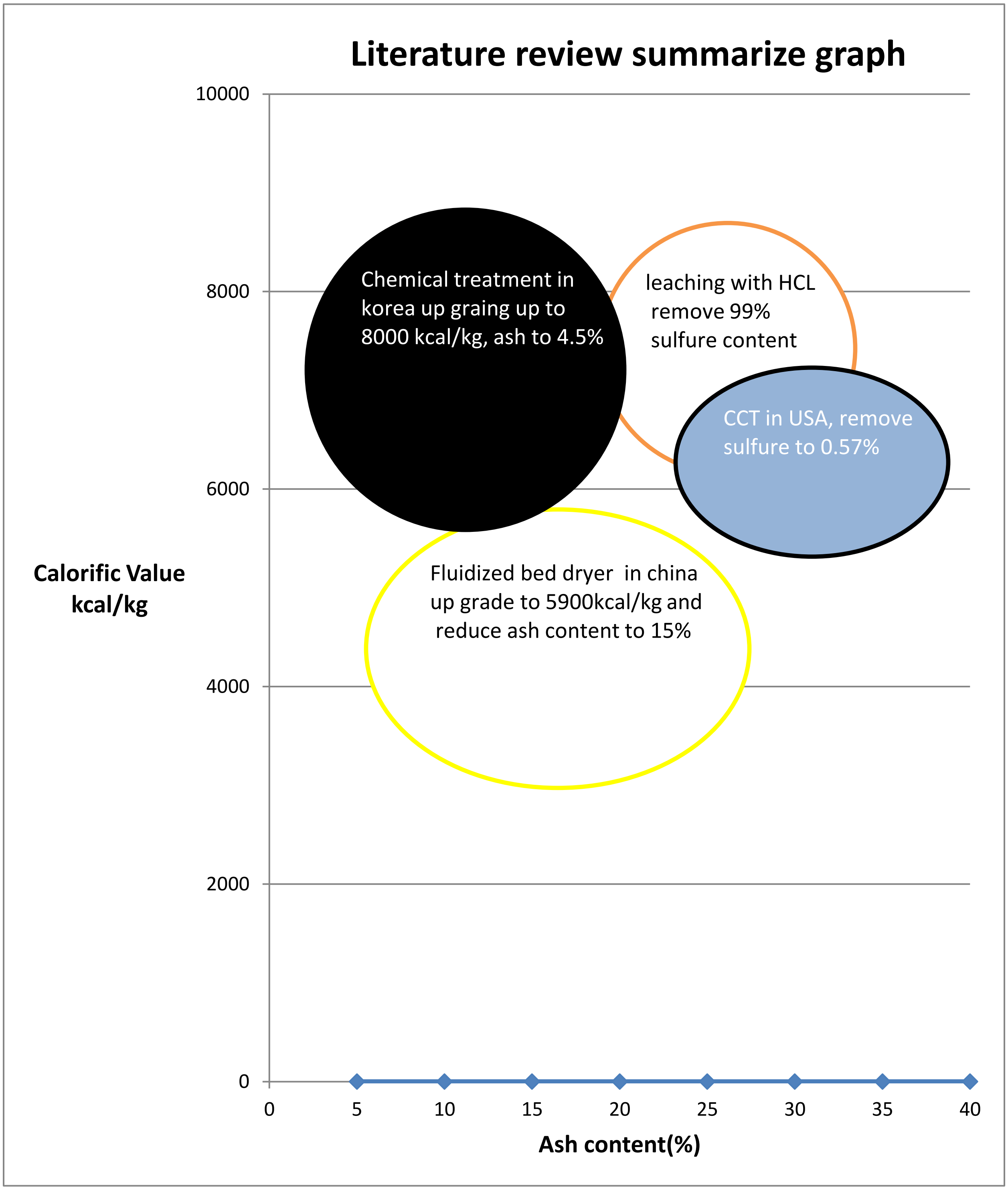


Figure 7 literature review summarize graph

The researcher N. Berkowitz, gives an introduction to coal technology, by using this technology CCT, reduce the sulfur after combustion by using absorption reactor to separate sulfate from the flue gas [8]. CCT can reduce sulfur up 0.54% in USA. Similar research in India reported like this green growth and clean coal technologies in India by Kinjavdekar, C. 2015 from The Energy and Resources Institute. [32]. Chemical leaching reported from south Korea that calrofic value (heating value) of coal is up graded up to 8000 kcal/kg and ash content is reduced up to 4.5 %.

The researcher Demir, I. and Khan, L. reported in 1999, Advances in coal cleaning. Preprints of American Chemical Society, Division of Fuel Chemistry, that sulfur reduction is possible up to 50% [7]. This result is half for that achieved by chemical leaching and coal cleaning in Germany by Richard Markuszewski and C.Y. Chi reported that removal of sulfur by hot alkaline is decrease up to 0.03 (98%) which double reduction than physical cleaning [33]. Norton, G. A., Araghi, H. G., & Markuszewski, reported in 1985 Removal of Trace Elements During Chemical Cleaning of Coal they achieve in sulfure reduction up 80 % [33].

Table 1: Summary of literature review

No	Title	Method	Finding	Refences
1	The preparation of ultra-clean coal in Germany	hot aqueous caustic solutions for the demineralization of coal were to produce a low-ash and product suitable for conversion to electrode carbon	Decrease sulfur by 95% from original value of 1.5 % content	[12]
2	Preparation of ash-free, pyrite-free coal by mild chemical treatment,"	treatment of coal with 10% NaOH solutions at 225°C followed by washing with dilute HC1, could	decrease the ash content to 0.7% from an original level of 9.8%.	[11
4	Hydrothermal coal process," in Coal Desulfurization: chemical and Physical methods	used a mixture containing 10% NaOH and 2-3% $Ca(OH)_2$ at 250-300°C and high pressure for their treatment	Desulfurize by 70%	[17]
5	Removal of mineral matter from bituminous coals by aqueous	leaching with aqueous NaOH and washing with acid to achieve low levels of ash in the final product.	Volatile matter reduction by 37%	[33]

	chemical leaching,			
6	Removal of sulphur from Indian coals by sodium hydroxide leaching	leaching with aqueous NaOH and washing with acid to achieve low levels of ash in the final product.	Reduce ash content by 45%	[34]
7	Dry Cleaning of Coal	Density separation, by using sand	Up grade heating by 45%	[17]
8	Dry beneficiation of fine coal	fluidized dense medium bed	Calorific value to 6000 cal/gm	[7]
9	Coal dry beneficiation technology in China	Dry cleaning	This mothed increase calorfic value from 3500kcal/kg to 5450 kcal/kg	[7]
10	Oxydesulfurization of coal in alkaline solutions	use of dissolved oxygen in hot aqueous solutions of sodium carbonate to desulfurize coal	Desulfurize sulfur	[34]
11	Process for producing low-ash, low-sulfur coal	cleaning of coal "By using aqueous alkaline solutions, under non-oxidizing conditions, with subsequent acid treatment to remove the ash-forming mineral matter from coal. to dissolve quartz and to convert clay minerals and iron pyrite into acid-soluble compounds which were extracted with dilute acid in a second step	decrease the ash content to 0.3% from an original level of 10.8%. And decrease sulfur by 98%	[32]
12	Behavior of mineral matter during alkaline leaching of coal,	Use hot Na_2CO_3 solutions readily convert kaolinite into sodium hydroaluninosiiicates which are acid-soluble	Remove sulfur and ash content	[27]
13	Evaluation of the removal of organic sulfur from coal, in New Approaches in Coal Chemistry	Hot alkaline leaching and Na_2CO_3	Remove sulfur From 2.7 to 0.06%	[38]

3. MATERIALS AND EXPERMENTAL METHODOLOGY

3.1 Data Collection

For the purpose of this study, and in order to achieve the objectives, both primary and secondary data collected. Primary data collected in two ways. Firstly, a questionnaire survey conducted with industries which use coal as a source of energy such as cement plant and deduce conclusions about the development and the design of the pilot plant. Secondly, interviews also carried out with stakeholders and members of the local authority.

Data collection procedure

1. FDRE Minster of mines and petroleum.
2. Ethiopian geological survey
3. Chemical and construction industry input development.
4. Deriban cement factory
5. From the site in Dawuro, SNNPR, Ethiopia.

3.1.1 Geographical location of coal site

The selected coal site for this study is Dawuro, exist in SNNPR, Ethiopia. 500km south west of Addis Ababa. Geological survey includes; coal site geological survey,

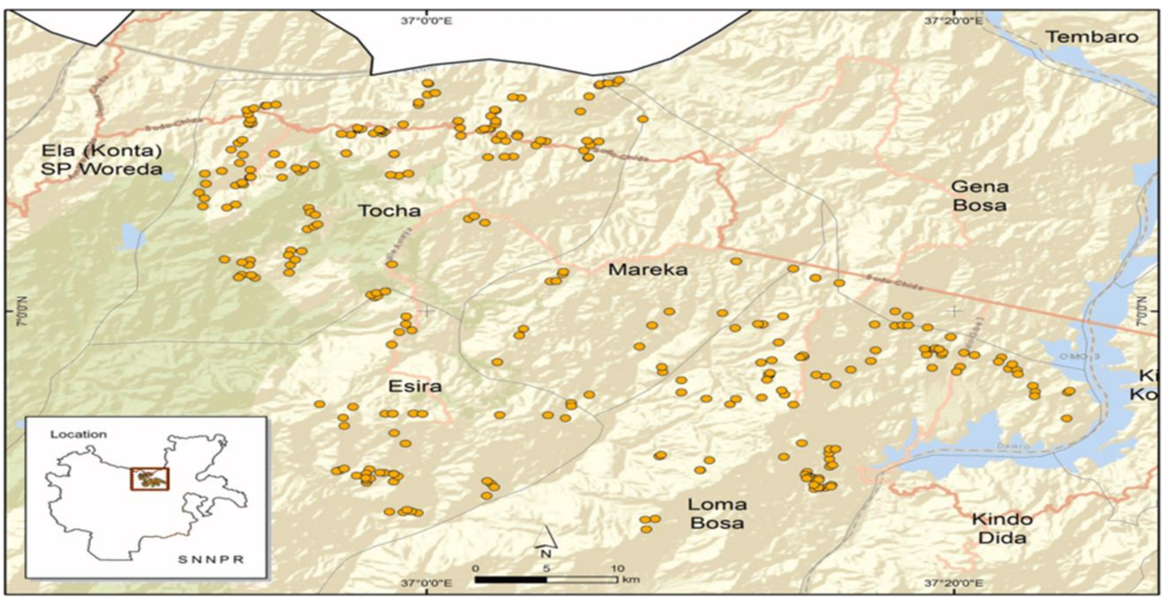


Figure 8: Geographical location of Dawuro (coal site)

3.1.2 Coal sampling survey

The sample is representative of bulk material, to ensure a representative sample is collected, correct sampling procedures should be followed and certain rules adhered to [11]. Which mean all part of the final sample have equal probability and sample does not undergo any chemical or physical change after completion of sampling procedure. Proper sampling and sample preparation are critical for accurate analysis [15]. The purpose of collecting and preparing a sample is to provide a test when analyzed.


Figure 9: Coal site in Bonsa Woreda

3.2. Materials

In this study the materials used for experimental analysis are listed below in table 1.

Table 2: The main raw materials

Materials	Functions
Local available Koyisha and Dawuro coal	It is a source of sample test
Bituminous coal	For comparison test
Lignite coal	To conduct experiment
Water	Water removes water sink minerals by density separation

3.3 Chemicals

Table 3: Table of chemical and their function

Chemical name	Function
Sulfuric Acid	Used used as solved to leaching process
Sodium hydroxide (NaOH)	Used as solvent to make ash forming material to be dissolved acid
Sodium carbonate (Na_2CO_3)	To convert kaolinite to magnetite
Hydrochloric acid (HCL)	Leaching solvent

3.4. Equipment needed

Table 4: Table of equipment's and their functions

Equipment	Function
Crusher	To Crush the coal in to small size.
Air Heater(oven)	To remove surface moisture and to measure moisture content.
Burner	To combust the coal
Washer	Used to remove weak black impurities
Oven dryer	To remove surface moisture from clean or de watering and to determine the moisture content
Fluidized bed	Froth flotation and for density separation for physical cleaning
Furnace	To measure ash content, to determine the volatile matter
Silica dishes	Used to put our sample inside the high temperature furnace up to 925C furnaces, and oven.

Various equipment's and instrument were used to analyze the physio chemical properties of coal and to conduct proximate analysis. Instruments like plastic bag, mixing blender, muslin cloth, chopping board, measuring cylinders, beakers, glass stirring rod, pipette, crucibles, desiccator, funnel, scissor and ruler which available at AAU were used. In addition to this instrument cutting mill, weighing balance (OHAUS CORP-ARA520), drying oven (DHG-9055A), hot air oven (OV/125/SS/F/DIG/A), temperature adjustable electric hot plate (STUARTUC125), Muffle furnace (CSF12/13-Astone lane, Hope Sheffield, S30 2RR, England) and Kjeldhal analyzer (Kjeltec ™ 2300 analyzer, wagtech, sweden) were used.

3.5 Sample preparation

Coal sample used in this study were prepared in critical manner because sample preparation has great influence in accurate analysis. More than 20 sample were prepared from different types of coal, at different site with different spatial variation, with different particle size (30mesh,60mesh, 120mesh) alkaline and acid solution is also prepared with, 10% concentration and 1M. The sample code that was given for each sample is as shown below in Table 4.

Table 5: Coal sample used in Experiment.

No	Sample Code	Specification Name
1	AAiT/B01	Sample before treatment HNO_3
2	AAiT/B02	Sample before treatment dry cleanings
3	AAiT/B03	Sample before treatment by fluidized bed
4	AAiT/B04	Sample before treatment by two step leaching (hot alkaline followed dilute acid concentration)
5	AAiT/B05	Sample before treatment by HCl
6	AAiT/A01	Sample after treatment by HNO_3
7	AAiT/A02	Sample after treatment by dry cleanings
8	AAiT/A03	Sample after treatment by fluidized bed.
9	AAiT/A04	Sample after treatment by two step leaching, (hot alkaline followed dilute acid

		concentration)
10	AAiT/A05	Sample after treatment by HCl
11	AAiT/A06	Sample after treatment by HNO_3 at variance temperature.
12	AAiT/A07	Sample after treatment by two step leaching, (hot alkaline followed dilute acid concentration) at variance temperature.
13	AAiT/A08	Sample after treatment by HCl at variance temperature.
14	AAiT/09	Sample after treatment by HNO_3 at variance time
15	AAiT/10	Sample after treatment by two step leaching, (hot alkaline followed dilute acid concentration) at variance time.
16	SS/01	Site 01, dawuro, bonsa wereda
17	SS/02	Site 02, koyisha
18	SS/03	Site 03, konta
19	SS/04	Site 04, kindo didaye
20	SS/05	Site 05, wuchale, 19 kebele
21	SS/06	Site 06, coal with spatial variation from surface coal.
22	SS/07	Site 07, coal with spatial variation from underground 5mm
23	SS/08	Site 08, coal with spatial variation from underground 10mm

3.6 Characterization of Coal

Characterization of coal parameter is mainly including proximate analysis and ultimate or elemental analysis

3.6.1 Proximate analysis of Coal

The proximate analysis of coal includes the determination of moisture, volatile matter, ash, fixed carbon and calorific value. The first three are determined in laboratory and the fixed carbon is found out by difference the calorific value is calculated with the help of the Proximate analysis data using Goutal's formula, The proximate analysis is carried out by adopting the procedures as recommended in Indian Standard-Methods of Test for Coal.

3.6.1.1 Determination of Moisture Content

Moisture in coal may be present as adsorbed water on external surface of coal or in the capillary of pores present in the coal and this is termed as free or accidental moisture. It is also present as combined water, as water of hydration of inorganic constituents, as dissolved water resulting from decomposition of organic compound and this is distinguished as inherent or hygroscopic moisture. The free moisture can be removed by air-drying but the inherent moisture can only be removed completely by drying in an oven at 100+5°C for about an hour. The added amount of free and inherent moisture is called total moisture. A moisture capsule consisting of two shallow glass dishes is cleaned and dried. The weight of the capsule is taken and one gram of coal is weighed in the capsule (W_1). Coal is spread with a brush in one dish. Then it is heated in an electric oven out of contact with air (To avoid oxidation) at 100+5°C temperature for 24 hour. After heating, the capsule is transferred to a desiccator and rapidly cooled and reweighed (W_2). The difference in weight (i.e., $W_1 – W_2$) will give the amount of moisture. Moisture content is expressed in percent of coal [26].

3.6.1.2 Determination of Ash Content

The residue left after burning of coal is known as ash. It is generally composed of inorganic substances. 1 gm. of coal is weighed in a silica basin (W_1). Coal is spread with a brush. Then the basin is kept inside a muffle furnace and the temperature is gradually raised up to 800°C. At 800°C the temperature is kept constant and the incineration of coal is completed by heating the coal for an hour at that temperature. After incineration, the basin is allowed to cool and transferred to a desiccator. After sometime the basin is re-weighed (W_2). Deduction of weight (weight of the basin) from W_2 (weight of the basin + ash) gives the amount of ash in the coal. Ash content is expressed in per cent of coal.

3.6.1.3 Determination of Volatile Matter

The volatile matter, sometimes called volatiles consists mainly of the gases and water and tarry vapours evolved from coal when it is heated at high temperature. To determine it, 1 gm of coal is taken in a silica crucible with a porous silica cover. The weight of the silica crucible and coal is wi. The cover is used to avoid oxidation. The coal is then heated for 7 minutes at a constant temperature of 925°C inside a furnace. After heating the crucible is cooled and transferred to a desiccator. After few minutes the silica crucible is re-weighed (W_2). The difference between wt and w_2 gives the amount of apparent volatile matter in the coal. The actual volatile matter is obtained after deducting the moisture content of the sample. Volatile matter content is expressed in per cent of coal.

3.6.1.4 Calculation of Fixed Carbon

The fixed carbon represents the carbon content in a coal that has not combined with any other element (in a free state). The amount of fixed carbon increases with the rank of coal and is highest in Anthracite coal. The amount of fixed carbon is computed by subtracting the sum of the percentage of moisture, volatile matter and ash from hundred [24, 36].

Fixed carbon = 100 - (moisture% + ash% + volatile matter%) …… eq (1)

3.6.1.5 Calculation of Mineral Matter (M.M.)

The mineral matter in coal represents the inorganic mineral present in it. It is left as residue or ash after complete combustion of coal or coke. The residue is made up of non-combustible mineral matter consisting of silicates of calcium, magnesium, iron and titanium, oxides of iron and silicon, carbonates of iron, calcium and magnesium, sulphate of calcium and some phosphates. The actual amount of mineral matter in coal is calculated using the following formula [17, 36].

Mineral matter = 1.08 x ash + 0.55 x pyritic sulfur ……………..…eq (2)

3.7 Experimental procedure

The raw coal used in this study was obtained from Bonsa weredda, Dawuro, SNNPR source with different spatial variation (table 4). These different coals were ground in to 60 meshes. A sample of each prepared 100gm and 200gm coal was treated by physical and chemical cleaning.

3.7.1 Physical Cleaning of Coal

An experimental analysis on coal upgrading by dry technologies (physical cleaning) was carried out in this study. The crushed raw coal entered to fluidized bed which exposed to air, it converts the fine solid coal in to fluid nature at that time high density coal which contains impurities sinks down wards and pure coal (law density coal) moves down ward. Physical cleaning of coal refers to the removal of non-coal material from raw coal to produce a relatively clean coal product. Those impurities exist in raw coal has density above 2.2 gm/cm^3. Raw coal is composed of high purity coal material and non-coal material. Non-coal material in coal, commonly referred to as ash, normally includes pyrite, clays, and other aluminosilicate materials. Processes for cleaning coal are carried out by fluidized bed [25].

For physical coal cleaning, two main separating principles pre-dominate:

(i) Separation based on differences in relative density (RD) between coal and associated mineral matter; pure coal has RD of ~1.3 and associated mineral matter commonly has an RD of >2.2

(ii) Separation based on differences in surface properties between coal and associated mineral matter; coal is hydrophobic, whilst associated mineral matter is generally hydrophilic.

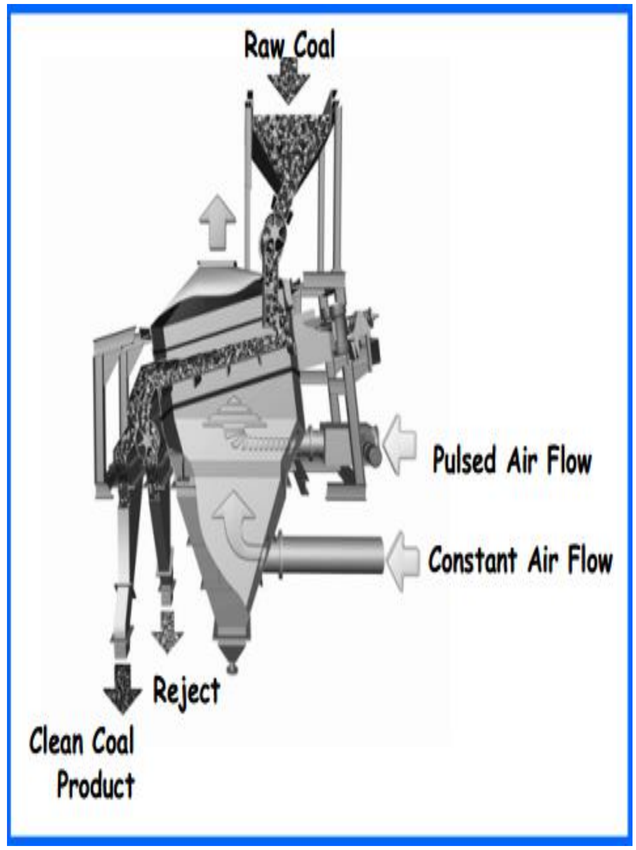


Figure 10, Fluidized dry cleaning

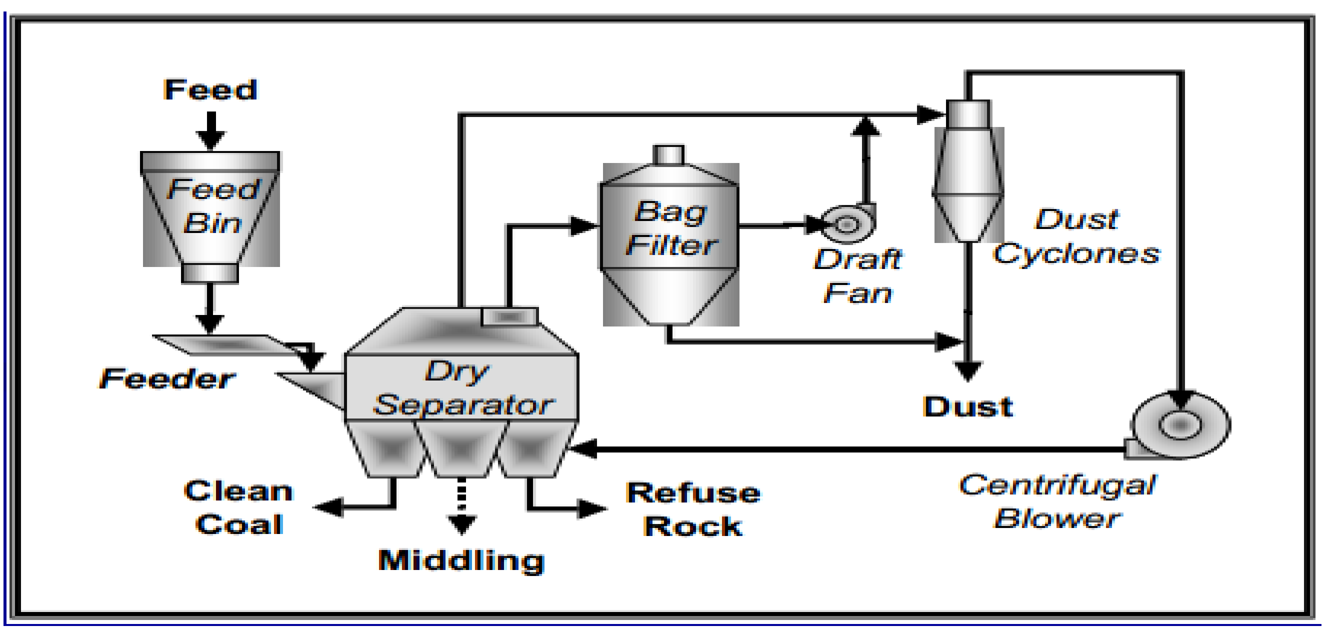


Figure 11: Schematic diagram of dry-cleaning process

Coal preparation includes blending and homogenization, size reduction, grinding, screening and handling. The most important step is coal beneficiation or cleaning. The schematic diagram of the procedure is depicted as shown in Figure 12.

Figure 12: Flow diagram of dry cleaning

The presence of non-combustible material or ash in run-off-mine coal increases in net heat content but it reduces the dust, ash content, and transportation and shipping costs. Ash content also increases wear in coal grinding equipment and boilers. Therefore, coal can be subjected to different levels of cleaning, depending upon its type, its utilization with consideration of the cost of cleaning [27]. Very dirty coals containing large amount of extraneous mineral material, could only match the market specification after substantial cleaning. The final selling price of these coal is determined by the cost of the cleaning steps [33]

Dry fluidized bed separators

Fluidized bed provides an environment having a density between the densities of the materials to be separated, so that the less dense particles float on the top of the bed and the heavier one was sink through it [17]. Separator consisting of an inclined vibrating trough with a porous base filled with dry sand. Mixtures are added to the sand. Excess sand with floating particles overflows the separator at the weir side end. sinking particles are transported from the bottom to the other end of the incline by vibration, the optimum air flow rate 7m/s.

3.8 Chemical treatment

The raw coals used in this study were obtained from Dawuro, is sub-bituminous. The chemical leaching uses 10% dilute aqueous chemical solution (NaOH solution, HNO_3 Solution), Various bituminous coals were demineralized by an experimental two-step leaching process in which the ball milled coals were first treated with a hot alkaline solution and then with a dilute mineral acid, finally washed by water [37]. The schematic diagram of the procedure is depicted as shown in Figure 13. First, dilute NaOH has been used to convert kalonite to hematite. Then two step leaching extraction followed after that, pyrite has been removed. Finally, the treated coal has been dewatered.

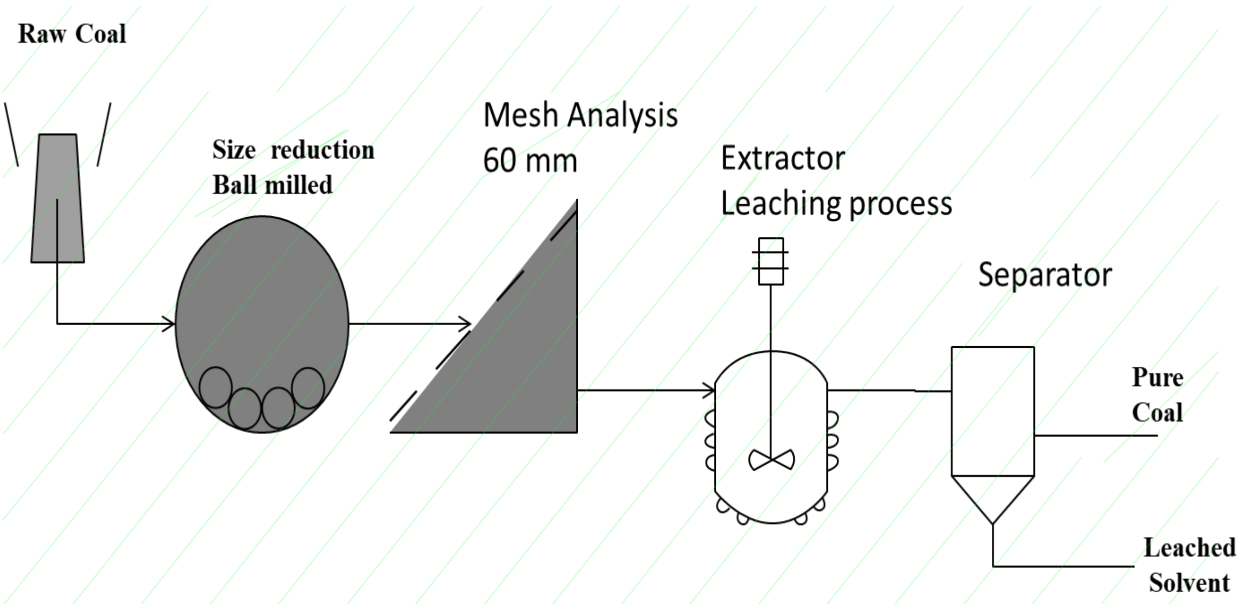


Figure 13: Flow diagram of coal upgrading by leaching

The major unit operation

Pre treatment

The raw coal dinged from the soil have surface impurities so removing these impurities such as rock, mud or soil, removing surface moisture is called pretreatment

Size reduction

The raw coal crushed in to different particle size (coarse and fine particles) when particle size decreases the mineral matter exposed to be easily washed this is because contact area increases as particle size decrease. Ball mill crusher is used to reduce the size.

Coal sizing and classification

In this study 60 meshes is used for leaching purpose. The processes employed in coal cleaning are determined, to a large extent, by the variability in size of the coal feed and the size range desired in the final products.

Extraction or chemical Leaching process

The extraction of the mineral matter from coal was accomplished by treating fine size- coal (60mesh) was done with dilute nitric acid, dilute hydrochloric acid and two step leaching(hot alkakine solution followed by dilute acid to dissolve quartz , sulphide, iron pyrite and clay minerals to convert and to acid-soluble compound which were extracted with dilute acid in a second step [33].

$$\text{Pyrite} + \text{NaOH} \longrightarrow \text{Hematite} \text{ .... eq (3)}$$

The chemistry

$$2FeS_2 + 15Cl_2 + 16\ H_2O \longrightarrow 2FeCl_3 + 4H_2SO_4 + 24HCl \text{ ....eq (4)}$$

$$RSR' + 4Cl_2 + 4\ H_2O \longrightarrow R'Cl + RCl + H_2SO_4 \text{ .... eq (5)}$$

A two-step process for extracting mineral matter and sulfur from coal will be demonstrated with three different coals under variety of treatment conditions. Sulfur is banded with carbon we use hot alkaline solution to break this bond [23] . sulfur exists in two form those are organic and inorganic sulfur; physical cleaning only removes the organic sulfur but in order to remove the inorganic we have to break its bondage with carbon at temperature of 210 ^{o} C with hot alkaline solution. The raw coal was determined by extraction method. The impurities were extracted from 100g and 200g sample per each experiment of the ball milled coal and the selected mesh size is 60mm. It is preferred and the extraction temperature was carried out at 210℃ is optimum. The coal in the solvent mixture was washed by water after extraction at local temperature for 10 minutes. Then the coal was collected and weighted. Based on our experiment there was twenty experiments.

Leaching with HNO_3

The ratio of extraction is 1:1, in order to leach 100gm of fine coal. It requires 100ml of nitric acid. 10% concentration of nitric acid was used. The prepared concentration of dilute nitric acid is added in to exctractor tank then 100gm of prepared raw coal sampled mixed with it. The experiment was conducted at different temperature starting from room temprature up 430^{o}C in 30 ^{o}C increanment, with different treatment time start from 0 mintute up to 80 minute in 10 increanment [33].

Two step leaching

In this experimental procedure raw coal dimeniralized by two steps first hot alkaline solution, followed by dilute acidThe experimental work has shown that hot NaOH solutions readily convert kaolinitein to sodium hydroaluninosiiicates which are acid solubl**e.** work has also shown that hot sodium carbonate solutions will dissolve quartz and convert iron pyrite in to hematite wich is easily dissolve in acid and finally washed by water from the coal as impurties. the experiment conducted at temprature starting from room temprature up 430^{o}C in 30 ^{o}C increanment, and treatment time start from 0 mintute up to 80 minute in 10 increanment.

3.9 Analyses of the coal

The coal samples were analyzed by the Ethiopian geological survey laboratory **(**EGSL, Geochemical and Hydrocarbon Laboratory Directorate Division) according to the ISO standards as noted in Table 5. EGSL lab is an accredited laboratory and all of the analyses discussed in this thesis can be considered credible according to industry standards. Table 5 contains the analyses standards followed by EGSL.

Table 5: ISO standard of coal analysis.

Test	**Unit**	**Standard**
Total moisture	%	ISO 11722:1995
Ash	%	ISO 1171:1997
Volatile matter	%	ISO 562:2010
Fixed carbon	%	By difference
Calorific value	%	ISO 1928: 2009
Washability analyses	-	ISO 7936: 1992

4. RESULT AND DISCUSSIONS

4.1. Characterization of raw coal

The carbon content of raw coal in Ethiopia was found in the range of 27% to 35% in this study. This result is similar value with that reported by Yirga, T.; Zewdeneh, [20]. This result shows that the coal type that exist is lignite and sub bituminous. The result of raw coal from Dawuro Zone was shown in the Table 6.

Table 6: The value with spatial variation in, raw coal

Sample site	**Calorific value(kcal/kg)**	**Sulfur content (%)**	**Ash content (%)**	**Volatile matter (%)**	**Fixed carbon (%)**	**Moisture content (%)**
SS1	5553.81	0.54	16	28.59	34.53	9.21
SS2	4353.81	0.64	17	29.59	24.35	8.87
SS3	4052.59	1.37	14	26.37	31.34	8.46
SS4	1900.34	0.97	23	29.32	27.45	7.45
SS5	2345.54	2.67	17	18.67	31.34	9.45
SS6	3546.67	2.57	16	18.56	35.34	9.98
SS7	3876.92	1.29	15	24.34	34.54	8.35
SS8	3458.74	1.13	11	22.5	29.45	12.4

As seen in Table 6, the quality of coal varies from place to place, and its calorific values was different with spatial variation. The value of sample cite SS1 was highest caloric value than others this was due to the geochemistry of the study area (Bonsa woreda, Dawuro, SNNPR). The basic reason for the value in SS1 was higher than other is due to geological appears, that it mined from deep underground below 10m, this shows that the quality of coal varies from place to place and coal exist in Dawuro is bituminous and the rest area are lignite coal. The study of Fantaw, D. in 2019 reported the resource potential of Coal in Ethiopia area, is line with this result [1].

4.2 Proximate value of coal before and after treatment

Table 7: The result before and after treatment of Bonsa, woreda coal

Sample site	Calorific value (Kcal/kg)	Sulfur content (%)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)	Moisture content (%)
AAiT/B01	4353.81	0.54	16	28.59	34.53	9.21
AAiT/B02	4052.59	1.37	19	26.37	31.34	8.46
AAiT/B03	5632.12	2.98	12.91	37.79	42.41	6.81
AAiT/A01	6578.43	0.97	6.01	38.36	45.41	10.22
AAiT/A02	6655.7	0.15	4.18	27.8	47.63	7.72
AAiT/A03	6490.45	0.35	9.93	35.84	53.11	1.11
AAiT/A04	4371.25	0.06	16.22	31.74	32.89	19.15

When the result from Table 7 was compared, sample site AAiT/A02 had higher calorific value than others due to, leaching with HNO_3 was efficient by removing non-coal materials like clay, pyrite, this increases fixed carbon content in coal. However, sample code AAiT/A04 least sulfure content (0.06%) this was due to leaching with hot alkaline solution pyrite is dissolve in NaOH and converted into hematite which was easily removed by H_2SO_4. Therefore, leaching with hot alkaline solution followed by dilute acid was more effective for sulfur removal. This result was line with the previous work reported that removal of sulfur by hot alkaline decrease up to 0.06. This result show 2% increment from the work of Markuszewski, R.; Miller, 2007 reported that the removal of organic sulfur from coal, new approaches in coal chemistry was achieved up 96.5%. [33].

Table 8: Comparison of value before and after physical treatment for sample site AAiT/B01

No	Coal parameters	Unit	Before (AAiT/B01)	After (AAiT/A01)
1	Calorific Value	Kcal/Kg	4353.81	6578.43
2	Sulfur content	%	0.54	0.97
3	Ash content	%	16	6.01

4	Moisture content	%	28.59	10.22
5	Volatile matter	%	9.21	7.72
6	Fixed carbon	%	34.53	45.41

The experimental result of dry cleaning or fluidized bed was shown in table 6. raw coal was passed through the upgrading system by density separation, its increase calorific value from 4353.81 kcal/kg to 6578.43 kcal/kg, reduce sulfur content from 0.54% to 0.15%, ash content from 16% to 4.18 %, Moisture content from 28.59% to 40.41%, fixed carbon from 29.21% to 47.67%, volatile matter from 34.53% to 7.72%.

$$\% \, Sulfur\ reduction = \frac{Wf - Wi}{Wi} \, X \, 100 \ldots\ldots\ldots\ldots \text{ eq (6)}$$

$$= \frac{0.54 - 0.21}{0.54} \, X \, 100 = 61\%$$

Total sulfur reduction by fluidized bed is 61%, physical cleaning removes only the organic sulfur, those exist inside high-density course coal with mineral matter, however the rest of 39% of sulfur exist in the form of inorganic form. Physical cleaning cannot remove inorganic form of sulfur from coal.

$$\% \text{ Calorific value increment } = \frac{Wf - Wi}{Wi} \, X \, 100 \ldots\ldots\ldots\ldots\ldots\ldots \text{eq (7)}$$

$$= \frac{6578.43 \, KCa/Kg - 4353.81 \, KCa/Kg}{4353.81 \, KCa/Kg}$$

= 51.1%

This increment in calorific value is due to the impurities exist in the coal, like clay, iron pyrite, aluminum silicate removed, therefore pure fixed carbon percentage increase this leads to high heating (calorific) value in coal. This result confirms that coal cleaning by physical method (fluidized bed separator) was able to upgrade caloric value by 51%. Which agree with previously reported result for Dry beneficiation of fine coal by Terblanche. AN. In 2014.

4.3 proximate value of leaching

Table 9: Comparison of value before and after chemical treatment (leaching with HNO_3)

No	Coal parameters	Unit	Before (AAiT/B03)	After (AAiT/A02)
1	Calorific Value	Kcal/Kg	5632..98	6655.7
2	Sulfure content	%	2.98	0.15
3	Ash content	%	12 91	4.18
4	Moisture content	%	6.81	7.72
5	Volatile matter	%	37.79	27.8
6	Fixed carbon	%	42.41	47.63

The experimental result of leaching by HNO_3 is shown in Table 9, The result show that nitric acid alone removes less sulfur when compared to two step leaching, however its increase fixed carbon higher than all other method, because extract more other impurities those lower the calorific value.

Table 10: Comparison of value before and after chemical treatment (two step leaching)

No	Coal parameters	Unit	Before (AAiT/B02)	After AAiT/A04
1	Calorific Value	Kcal/Kg	4052.59	4371.25
2	Sulfur content	%	1.37	0.06%
3	Ash content	%	19	16.22
4	Moisture content	%	26.37	19.15
5	Volatile matter	%	31.34	31.74
6	Fixed carbon	%	8.46	32.89

The experimental result of extraction by two step is shown in Table 10. A two-step leaching process (hot alkaline solution followed by dilute acid) for extracting mineral matter and sulfur from coal was demonstrated with different coals under a variety of treatment conditions. 10 %, 1M, dilute hot alkaline solution (NaOH solution) was first removing some impurities from raw coal and convert the rest to acid soluble which finally dissolve in the second step. Two step leaching best regarding to remove sulfur.

The first step involves treatment with a hot alkaline solution which extracts part of the sulfur and generally converts much of the mineral matter to an acid-soluble form. The second step involves leaching with a dilute acid to extract the converted mineral matter. Although H_2S0_4 would likely be used in the second step of a commercial process, HCl, was chosen for the present study in order to remove both inorganic and organic sulfur. The experimental result show that sulfur reduced from 1.37% to 0.06% and at optimum temperature (210 ^oC) it reduces from 2.9% to 0.06%

$$\% \text{ Sulfur reduction} = \frac{Wf-Wi}{Wi} X\, 100 \ldots\ldots\ldots \text{ eq (8)}$$

$$= \frac{1.37-0.06}{1.37} X\, 100 = 95.62\%$$

% Sulfur reduction at optimum temperature 210^{o}C =

$$= \frac{Wf-Wi}{Wi} X\, 100$$

$$= \frac{2.9-0.03}{2.9} X\, 100 = 99\%$$

The best way to reduce sulfur content is two step leaching, it reduces 99% sulfur content, this due to both organic and in organic sulfur dissolve in two step leaching. This result shows double increment from the report of Cleaning of Coal Density separation, by using sand [7].

4.4 Factors that affect operating conditions

4.4.1 The effect of temperature

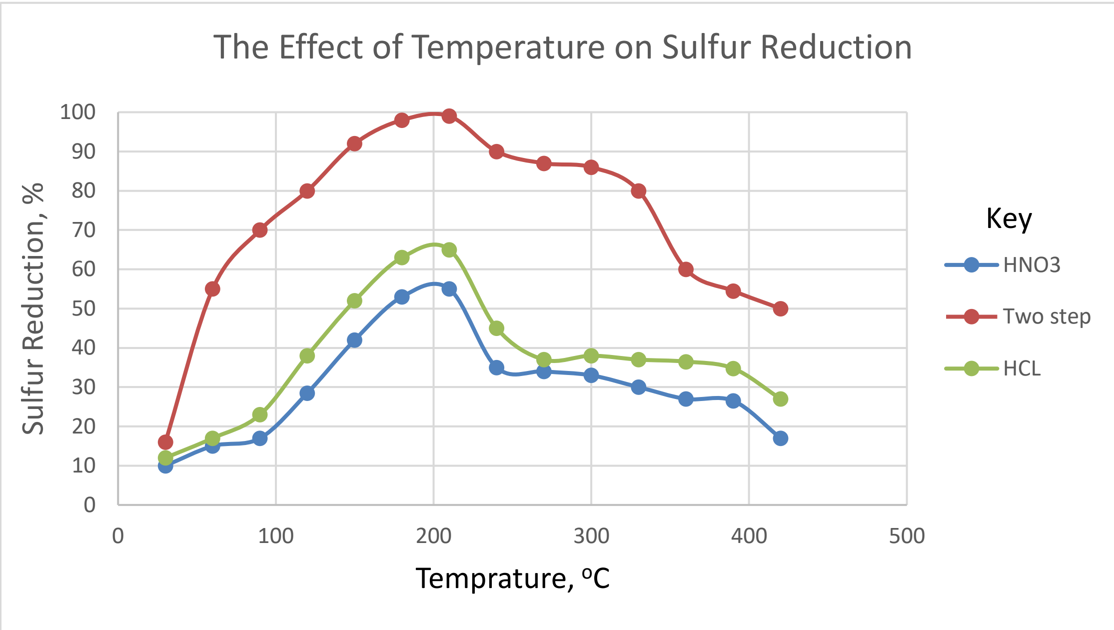


Figure 14: The effect of temperature on sulfur reduction

Effect of temperature demonstrated in Figure 14. Alkali-treatment time and temperature affected the results greatly. Sulfur removal increased in the first step with rising temperature, and above 210^{O}C decreased excessively. Removal of mineral matter in the second step was affected by the temperature of the first step. With both the dawuro and kontta coals, the overall reduction in ash content for both steps increased with temperature up to 300 ^{O}C and then leveled off. But with dawuro coal, 210^{O}C seemed to be the optimum temperature for reducing the ash content. Increasing the alkaline treatment time resulted in increasing sulfur removal in the first step, but beyond this point less sulfur was removed. Sulfur removal declined as the alkaline treatment time was extended, and the rate of decline accelerated after prolonged treatment. The optimum extraction time is 60 minutes, as the result in Figure 21 shown, the graph is peak at 60 minute and 210^{o} C.

4.4.2 The effect of Treatment Time on sulfur reduction

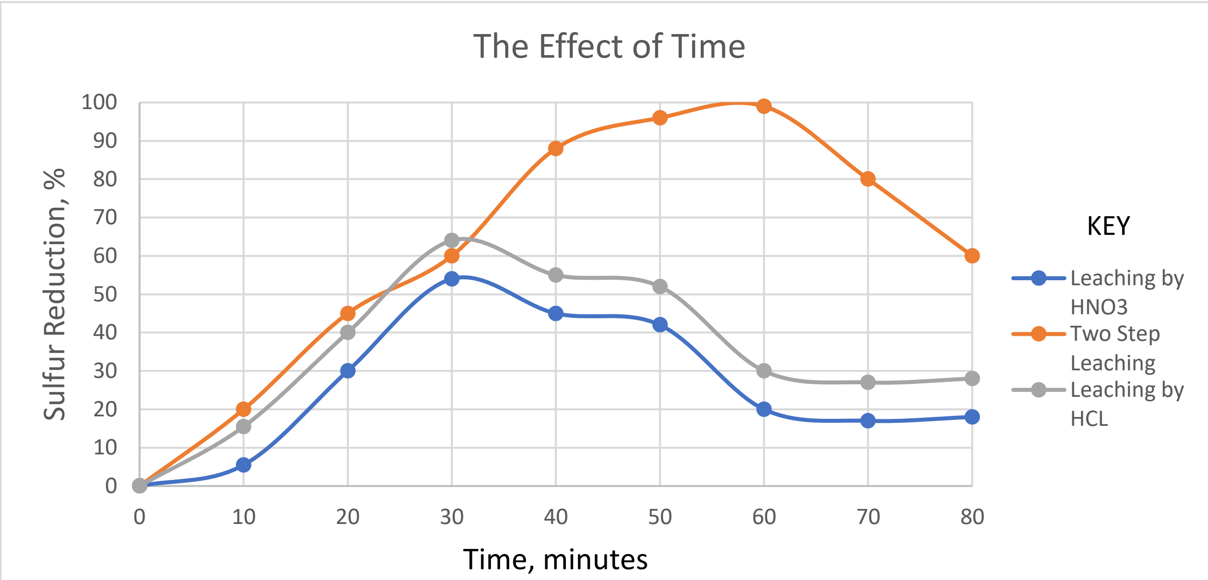


Figure 15: The effect of treatment time in leaching

From experimental result and conditions, nitric acid dissolved iron pyrite but not the hematite which was formed during the alkaline treatment step. More rigorous alkaline treatment conditions were more effective than less rigorous conditions for converting the iron pyrite into hematite which could not be easily removed by the nitric acid. Consequently, when rigorous alkaline treatment conditions were applied to lower raw coal, the residual hematite more than made up for the other minerals which were extracted so that the overall reduction in ash content for the two-step process was no better than for HNO_3 leaching alone.

A major concern of the present study was to find the optimum operating condition and to know the effect of various parameters involved in the alkaline treatment step and dry cleaning to upgrade the quality coal. Early in the investigation it was observed that Na_2CO_3, and NaOH were equally effective for removing sulfur in the first step while HNO_3 and HCl were less effective. On the other hand, coal recovery suffered greatly when NaOH was used. For the combined two-step treatment, the lowest sulfur and ash contents were achieved with Na_2CO_3 but higher sulfur reduction when NaOH, followed by H_2SO_4 and Na_2CO_3.

The effects of alkali concentration appeared relatively minor in most instances. However, for Lower raw coal an alkali concentration of 1.0 M appeared optimum for removing sulfur in the first step whereas a smaller concentration (0.2 M) resulted in a lower ash content overall for the two-step process.

Alkali-treatment time and temperature affected the results greatly. Sulfur removal increased and coal recovery decreased in the first step with rising temperature, and above 210 ^{O}C coal recovery decreased disproportionately. Removal of mineral matter in the second step was affected by the temperature of the first step. With both lignate and bituminous coals, the overall reduction in ash content for both steps increased with temperature up to 300 ^{o} C and then leveled off. But with Lower Kittanning coal, 250 ^{o} C seemed to be the optimum temperature for reducing the ash content. Increasing the alkaline treatment time up to a point resulted in increasing sulfur removal in the first step up to 30 minutes it leaching with HNO_3 and HCl achieve it maximum and drop down and however two step leaching is increasing up to 60 minutes since initial two step leaching exothermic reaction, but beyond this point less sulfur was removed. Coal recovery declined as the alkaline treatment time was extended, and the rate of decline accelerated after prolonged treatment.

The apparent removal of organic sulfur by the two-step treatment observed with all three coals was of considerable interest. Since the total sulfur content of the treated coal was lower than that achieved by leaching with HNO_3 alone, it appeared that the alkaline leaching step either removed a significant quantity of organic sulfur or converted some of the organic sulfur into a form which was extractable with HNO_3. In several instances, the total sulfur content of Dawuro coal treated by the alkaline leaching step alone was below the apparent organic sulfur content of the raw coal, indicating organic sulfur removal as well as inorganic sulfur removal.

5. ECONOMIC ANALYSIS

5.1 Economic analysis of dry cleaning

Assume that the mining industry produce 10-million-ton raw coal per year before treatment or upgrading. If the industry uses the upgrading technology 36.4% is rejected as a wastage that contains impurities

$$Yield\ to\ Reject\ =\ 36.4\%$$

$Reject\ Amount\ =\ 10\ x\ 0.364 =\ 3.64\ \ million\ ton\ per\ annually$……………eq(9)

Transportation Savings

Transportation Cost

= 0.4ETB/ton*KM………………eq(10)

Mine to Plant Distance = 700 KM

Transportation Cost/ton = 700KM x 0.40ETB/ton*KM = 280 ETB /ton

Reduction in Tons Hauled

= 3.64 million tons/yr

Annual Transportation Savings = 3.64 million x 280 ETB = 1.0192 billion ETB = $25.48M

Lost Coal Cost

Total Reject = 3.64 tons/year, % 1.60 Float in Reject = 0.78%

Total Coal Loss

= 3.64 million ton/year x 0.0078 = 28392 ton/year

Sales Price = $70/ton

Lost Coal Cost

= 28392 x 70 = $1,987,440/yr. = 79, 497,600 ETB/yr.

Summary Economic Benefit

Dry cleaning Operating Cost

= $0.50/ton

Annual Operating Cost

= $0.50 x 10Mton

= $5M/yr. = 200METB/year.

Summary:

Transportation Savings = $25.48M

Coal Loss Cost = $1.92M

Operating Cost = $5M

Net Profit Gain = $18.56M

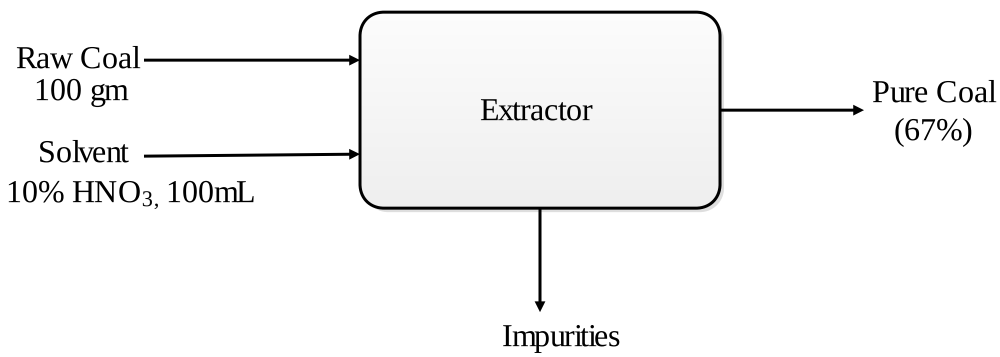
Capitol Cost = $3200/tph

1666 tph unit = $5.33 M

Dry cleaning is economical feasible

5.2 Economic analyses for chemical leaching

Material balance



From theory of conservation of mass, it's known that "stated that mass is neither created nor destroyed"

Mass input = mass output

100gm raw coal + 100gm HNO_3 = 0.67 X MT + m of impurities

The amount of HNO_3 added to the extractor is = 10 % x 100gm

Mass of HNO_3 = 10gm = 10ml (assume 1gm = 1ml)

Therefore, to leach 1tone it requires 100 litters of strong nitric acid

One litter HNO_3 costs = $5/litter

100 litter =?

Therefore, to leach one tonne coal its costs $500/litter. Which is too expensive and its production cost is above the sell revenue.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this study a detailed experimental analysis to upgrade raw coal was performed in order to increase its quality and remove unwanted components from the raw coal. The experimental result shows that physical cleaning increase calorific value from 4356kcal/kg to 6545kcal/kg, reduces the sulfur content from 2.5% to 0.45%, reduces ash content from 25% to 4% which above the import standard therefore upgrading the quality of coal using physical cleaning (dry cleaning and washing) is more feasible. Chemical leaching removes sulfur content by 99%. Based on the experimental result, it can be concluded that chemical purification process would be considered as the best way to reduce sulfur content from the result recorded Chemical cleaning effectively remove sulfur content by 99%, but it’s costly, where as physical cleaning is less cost than chemical cleaning. Therefore, dry cleaning to upgrade coal is highly recommended to upgrade low grade coal for commercial purpose.

Upgrading the quality of raw coal was affected by operating parameters. The optimum operating condition for fluidized bed separator was 7m/s velocity of air. Chemical leaching was affected by coal size, acid concentration, temperature and leaching time. The experimental results for leaching showed that the type of solvent used during leaching significantly influenced the coal quality after treatment. Nitric acid extracts more impurities, the residual hematite more than made up for the other minerals which were extracted so that the overall reduction in ash content for the two-step process was less than HN03 leaching alone. the optimum temperature for treatment for leaching is 210 ^oC, 60 mesh particle size and 10% concentration.

The researcher conclusion was solid regarding to geological site and spatial variation, the raw coal from Dawuro, in SNNPR was best regarding calorific value, in aspect of spatial variation the Bonsa woreda, which is located 10 KM away from Tarcha city was more preferable and near to import standard. By using coal upgraded technology we can improve the economy of the country by substitute the import coal by local available coal, this also reduce foreign currency problem, increase industrialization in country specially construction sector highly developed

6.2 Recommendations

Our country Ethiopia, gifted by high coal deposit with the distinct advantage of long-term availability. Unfortunately, it is also a resource with high sulfur and mineral matter content. In Ethiopia the organization like KH coal mining and others those close their production due to the less quality or grade of coal (ash, moisture, calorific values) and environmental issue, now this study has a solution, with minimum cost with high profit by using physical treatment.

As our country case it's recommend to use physical cleaning, because of its versatility, high efficiency and ease of operation, and low-cost. Chemical cleaning is not recommended for small scale plant but for highly developed plant it's recommend to use chemical cleaning depending on the function of coal where and why they use it

It's recommended that low grade coal must be treated before they burn and used as energy source because of environmental pollutant gas it emits to the atmosphere and because of its high ash content that hinder the operation of plant and damage the equipment.

Future works can be performed by using different coal types, by different upgrading technologies to better select the right technologies that are efficient, economic and environmentally friendly and the effect of temperature, particle size, treatment time on coal cleaning must be studied in detail. In addition to this full plant design and detail economic analysis must or can be recommended for future work.

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APPENDIX

Appendix A: Annual coal import data (FDRE Minster of trade and industry)

Table A1: FDRE Minster of trade and industry **2013** import data

Item	**Country**	**Quantity (Gross Wt. (Kg))**	**CIF Value (ETB)**	**CIF Value (USD)**
Coal	South Africa	49,594,000.00	131,301,121.46	6,984,065.06
Coal	South Africa	48,617,000.00	128,999,879.90	6,861,659.24
Coal	South Africa	2.00	1,134.82	60.36
Coal	South Africa	48710000	125734100.1	6687948.476
Coal	South Africa	47,045,000.00	124,452,343.68	6,619,770.30
Coal	South Africa	48427000	129882075.6	6908584.296
Coal	South Africa	49,539,000.00	132,682,694.38	7,057,552.59
Total		291,932,002.00	773,053,350.00	41,119,640.32

Table A2: FDRE Minster of trade and industry **2014** import data

Item	**Country**	**Quantity (Gross Wt. (Kg))**	**CIF Value (ETB)**	**CIF Value (USD)**
Coal	South Africa	48,126,000.00	141,107,182.65	7,005,062.78
Coal	South Africa	49,541,000.00	134,240,787.43	6,664,190.48
Coal	South Africa	49,466,000.00	135,114,834.80	6,707,581.31
Coal	South Africa	48280000	133803081.8	6642461.219
Coal	South Africa	10,942,000.00	31,543,855.74	1,565,949.27
Coal	South Africa	48537000	131844310.8	6545220.854

Coal	South Africa	49,000,000.00	127,393,670.21	6,324,275.21
Coal	South Africa	42,000,000.00	104,449,369.91	5,185,238.48
Total		345,892,000.00	939,497,093.35	46,639,979.61

Table A3: FDRE Minster of trade and industry **2015** import data

Item	**Country**	**Quantity (Gross Wt. Kg)**	**CIF Value (ETB)**	**CIF Value (USD)**
Coal	South Africa	96,718,000.00	172,235,754.25	8,287,737.19
Coal	South Africa	10,327,000.00	35,380,785.93	1,702,472.62
Coal	South Africa	48,562,000.00	84,317,033.24	4,057,214.57
Coal	South Africa	48324000	86740509.92	4173828.79
Coal	South Africa	92,300,000.00	172,398,667.23	8,295,576.33
Coal	South Africa	8236000	16235016.93	781205.7035
Coal	South Africa	50,205,000.00	89,446,475.23	4,304,035.96
Coal	South Africa	49,888,000.00	85,524,626.36	4,115,322.22
Coal	South Africa	60,000,000.00	106,443,697.02	5,121,917.86
Coal	South Africa	50,143,000.00	83,803,047.36	4,032,482.31
Total		514,703,000.00	932,525,613.47	44,871,793.55

Table A4: FDRE Minster of trade and industry **2016** import data

Item	**Country**	**Quantity (Gross Wt. (Kg))**	**CIF Value (ETB)**	**CIF Value (USD)**
Coal	South Africa	50,017,000.00	80,740,997.88	3,679,545.28
Coal	South Africa	49,690,000.00	83,303,977.78	3,796,345.92
Coal	South Africa	110,997,000.00	179,995,986.89	8,202,813.94
Coal	South Africa	31000	7433.69	338.7696416
Coal	South Africa	49,898,000.00	92,354,702.29	4,208,807.39
Coal	South Africa	50078000	106636118.8	4859643.024
Coal	South Africa	50,005,000.00	106,752,179.64	4,864,932.17
Coal	South Africa	50,571,000.00	107,009,915.13	4,876,677.75
Coal	South Africa	81,622,000.00	229,422,969.33	10,455,310.50
Coal	South Africa	77,828,000.00	217,505,203.78	9,912,191.65
Total		570,737,000	1,203,729,485.22	54,856,606.38

Appendix B. Hydrocarbon Laboratory Analysis Report.

	GEOLOGICAL SURVEY OF ETHIOPIA	**Doc.Number: GSE/F 5.10-2**	**Version No: 1**
	GEOCHEMICAL LABORATORY DIRECTORATE		**Page 1 of 1**
Document Title:	**Hydrocarbon Laboratory Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: - 17/06/2021

Customer Name:- Muluken Filmon

Request No: - GLD/RN/1119/21

Report No: - GLD/TR/565/21

Sample type: - Coal

Sample Preparation : - 60 Mesh

Date Submitted: -14/06/2021

Number of Sample: -One (01)

Elements to be determined:- (Moisture, Volatile matter, Fixed carbon and Ash) & Calorie

Method of analysis:- Proximate Analysis, Adiabatic & Calorie Metter

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.
AAiT/A02	7.72	40.41	47.68	4.18	6655.70

Note: - This result represent only for the sample submitted to the laboratory.

Analysts

Haimanot Bayeh

Shashe Haile

Approved By

Alemnesh Abate

Quality Control

Gosa Haile

Geological Survey of Ethiopia Central Geological Laboratory

	GEOLOGICAL SURVEY OF ETHIOPIA	**Doc.Number: GSE/F 5.10-2**	**Version No: 1**
	GEOCHEMICAL LABORATORY DIRECTORATE		**Page 1 of 1**
Document Title:	**Hydrocarbon Laboratory Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: - 28/04/2021

Customer Name: -Muluken Filmon

Request No: - GLD/RN/924/21

Report No: - GLD/TR/399/21

Sample type: - Coal

Sample Preparation : - 60 Mesh

Date Submitted: -19/04/2021

Number of Sample: -One (01)

Elements to be determined:- (Moisture, Volatile matter, Fixed carbon and Ash), Calorie & Su

Method of analysis:- Proximate Analysis, Adiabatic Calorie Metter and Gravimetric method

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.	Sulfur%
AAiT-01	10.22	38.36	45.41	6.01	6578.43	0.97

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
Haimanot Bayeh
Shashe Haile

Approved By
Alemnesh Abate

Quality Control
Gosa Haile

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GSE/F 5.10-2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	**Hydrocarbon Laboratory Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: - 17/06/2021

Customer Name:- Muluken Filmon

Request No: - GLD/RN/1118/21

Report No: - GLD/TR/564/21

Sample type: - Coal

Sample Preparation : - 60 Mesh

Date Submitted: -14/06/2021

Number of Sample: -One (01)

Elements to be determined:- (Moisture, Volatile matter, Fixed carbon and Ash) & Calorie

Method of analysis:- Proximate Analysis, Adiabatic & Calorie Metter

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.
AAiT/A03	1.11	35.84	53.11	9.93	6490.45

Note: - This result represent only for the sample submitted to the laboratory.

Analysts

Haimanot Bayeh

Shashe Haile

Approved By

Alemnesh Abate

Quality Control

Gosa Haile

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GSE/F 5.10-2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	**Hydrocarbon Laboratory Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: - 17/06/2021

Customer Name:- Muluken Filmon

Request No: - GLD/RN/1120/21

Report No: - GLD/TR/563/21

Sample type: - Coal

Sample Preparation : - 60 Mesh

Date Submitted: -14/06/2021

Number of Sample: -One (01)

Elements to be determined:- (Moisture, Volatile matter, Fixed carbon and Ash), Calorie & Sulfer

Method of analysis:- Proximate Analysis, Adiabatic Calorie Metter and Gravimetric method

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.	Sulfur%
AAiT/A04	19.15	31.74	32.89	16.22	4371.25	0.06

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
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Shashe Haile

Approved By
Alemnesh Abate

Quality Control
Gosa Haile

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GSE/F 5.10-2	Version No:
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Hydrocarbon Laboratory Analysis Report	Effective date:	May, 2017

Issue Date: - 20/05/2021

Customer Name:-Muluken Filmon Tera

Request No: - GLD/RN/956/21

Report No: - GLD/TR/458/21

Sample type: - Coal

Sample Preparation : - 60 Mesh

Date Submitted: -27/04/2021

Number of Sample: -One (01)

Elements to be determined:- (Moisture, Volatile matter, Fixed carbon and Ash), Calorie & Su

Method of analysis:- Proximate Analysis, Adiabatic Calorie Metter and Gravimetric method

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.	Sulfur%
Aait/B01	9.53	28.59	34.21	27.67	4353.81	0.54

Note: - This result represent only for the sample submitted to the laboratory.

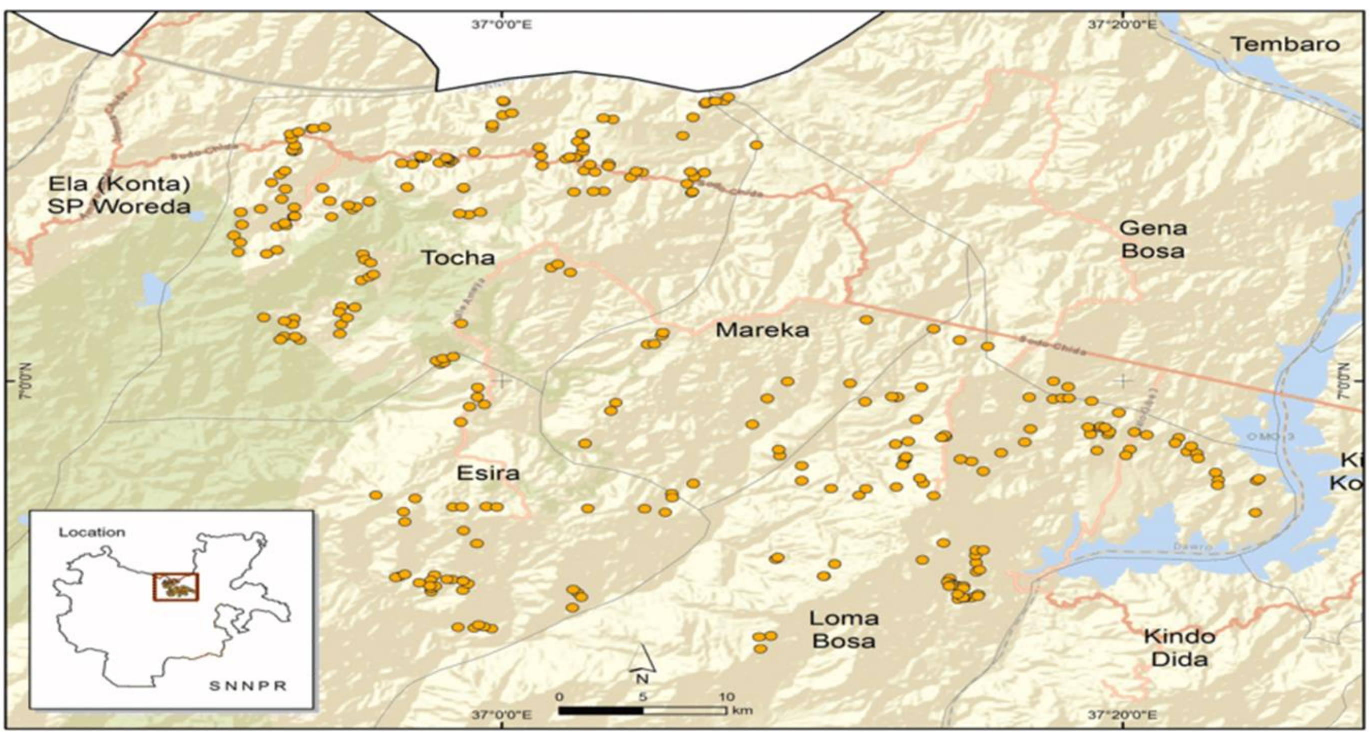
Analysts
Haimanot Bayeh
Shashe Haile

Approved By
Alemnesh Abate

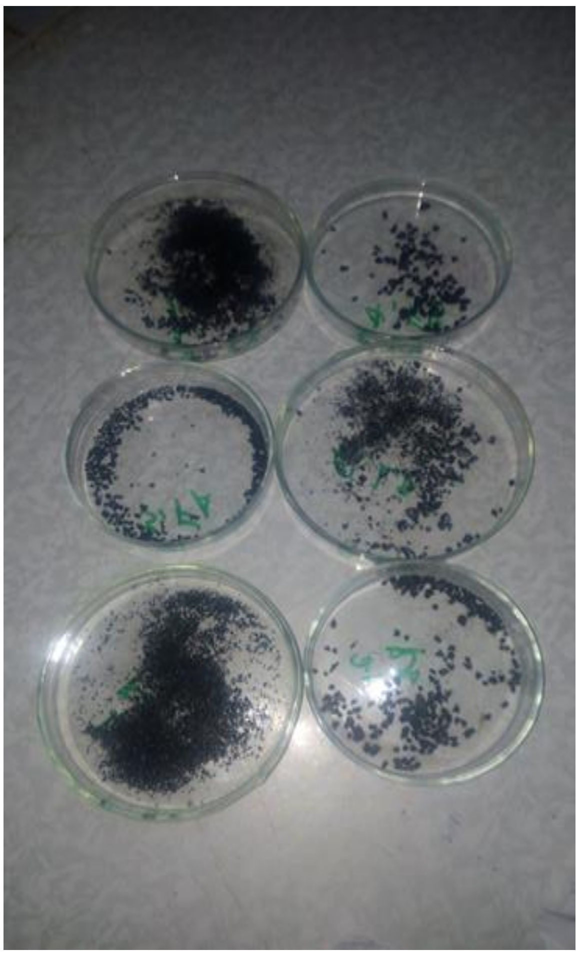
Quality Control
Gosa Haile

Geological Survey of Ethiopia Central Geological Laboratory

Appendix C: Coal site Map (Dawuro, SNNPR, Ethiopia)



Appendix D: Laboratory work



Appendix E: Photo on Laboratory