



ADDIS ABABA INSTITUTE OF TECHNOLOGY
CENTER FOR ETHIO-MINES DEVELOPMENT

Title: Proximate Analysis and Flotation Performance of Biyo Gurgur Coal, Somali Region, Ethiopia: Effects of Particle size and Collector Dosage on Grade and Recovery.

BY:

YAHYE AHMED HASSEN

A Master's Project Work Presented to the Center for Ethio-Mines Development, Addis Ababa University, in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Mineral Engineering.

Advisor

Dr. Mulugeta Sissay (PhD)

FEBRUARY, 2025

ADDIS ABABA, ETHIOPIA

Declaration

I declare that the project entitled "Proximate Analysis and Flotation Performance of Biyo Gurgur Coal, Somali Region, Ethiopia: Effects of Particle size and Collector Dosage on Grade and Recovery" is my original work. This project has not been submitted for any degree at any other university. The work is presented in partial fulfillment of the requirements for the Master of Engineering in Mineral Engineering degree, submitted to the Center for Ethio-Mines Development (CEMD), Addis Ababa University. This research work has been conducted under the supervision of Dr. Mulugeta Sissay (PhD). I further declare that all sources and materials used in this project have been acknowledged, and the content represents my independent work.

Name: _____

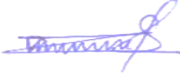

Signature: _____

Date: _____

Approval Sheet

This is to certify that the project work prepared by **Yahye Ahmed Hassen**, entitled “Proximate Analysis and Flotation Performance of Biyo Gurgur Coal, Somali Region, Ethiopia: Effects of Particle size and Collector Dosage on Grade and Recovery” and submitted to Addis Ababa University, AAiT in partial fulfillment for the award of the degree of Master of Engineering in Mineral Engineering. The project complies with the regulations of the University and meets the accepted standards concerning its originality, content, and quality.

Approved by:

External examiner: Dr. Zekarias	Signature: 	Date: _____
Internal examiner: Dr. Kebede	Signature: 	Date: _____
Director of Center: Dr. Abubaker	Signature: _____	Date: _____
Advisor: Dr. Mulugeta Sissay	Signature: _____	Date: _____

Acknowledgment

First and foremost, I would like to express my gratitude to ALLAH for His countless blessings, enabling grace, and perseverance to complete this stage of my academic career. Second, I would like to thank my advisor, Dr. Mulugeta Sissay, for his invaluable guidance, constructive comments, and suggestions which were instrumental in completing this project. I also appreciate his tireless support and encouragement throughout my research.

I want to express my gratitude to the Ministry of Mines and the Center for Ethio-Mines Development for their financial sponsorship of my project and their ongoing encouragement which has helped me complete my graduate studies. I am especially thankful to Dr. Abubaker Yimam director of the Center for Ethio-Mines Development for his excellent support and leadership I am also thanking Mr. Hinsa for his support during the laboratory work. I am profoundly grateful to my family for their unconditional support and love, which has sustained me throughout my academic career. I would also like to thank my friends and colleagues for their unwavering support, encouragement, and prayers during my studies. Last but not least, my deepest gratitude goes to Uncle Ahmed A/Salaam, for his continuous support throughout my academic journey. Your dedication and presence here today mean a great deal to me.

Abstract

This study investigates the proximate Analysis and flotation performance of coal from the Biyo Gurgur area in the Somali Region of Ethiopia to assess its quality and industrial potential. Despite Ethiopia's heavy reliance on imported energy, domestic coal resources such as those in Biyo Gurgur remain underutilized due to limited characterization and beneficiation data. This study's main objective was to evaluate the coal quality in the Biyo Gurgur region using flotation experiments, calorific value, and proximate analysis. ASTM standards determine important factors such as moisture, ash, volatile matter, fixed carbon, calorific value, and sulfur content. Proximate analysis showed that the coal is low-grade lignite with high ash content (19.3%-63.2%), moderate volatile matter (19.5%), and low fixed carbon (13.2%-50.6%), resulting in a calorific value of 1626.48cal/gm. With a sulfur content level of 0.16%, there was little risk of sulfur emission to the environment. Flotation experiments were carried out to evaluate the effects of particle size and collector dosage on grade and recovery. The findings showed that both parameters significantly influence efficiency. The highest recovery (11.84%) and grade (97.85%) were achieved at a particle size of -125+75 with a 10mL collector dosage, while coarser particles exhibited lower recovery rates. The flotation process effectively separated hydrophobic coal particles from hydrophilic ash-forming minerals, highlighting its potential as a beneficiation technique to improve coal quality. These results demonstrate the coal's limited energy potential and significant impurity levels, which restrict its industrial use in its unprocessed form. However, flotation and other beneficiation techniques can improve its quality for industrial and energy applications. The study concludes that although biyo gurgur coal has limited application in its raw state, beneficiation through flotation can significantly improve its quality for industrial and energy uses.

Keywords: Flotation Experiment, Particle size, Collector dosage, Proximate analysis.

Table of Contents

Declaration.....	i
Approval Sheet.....	ii
Acknowledgment.....	iii
Abstract.....	iv
Lists of Acronyms.....	vi
List of Abbreviations.....	vii
List of Figures.....	viii
List of Tables.....	ix
Chapter 1 Introduction.....	1
1.1 Background of the Study.....	1
1.2 Geological Description of the Study Area.....	2
1.3 Statement of the Problem.....	3
1.4 Objective of the Study.....	4
1.5 Scope of the Study.....	4
1.6 Significance of the Study.....	5
1.7 Project Outline.....	5
Chapter 2 Literature Review.....	6
2.1 Overview of Coal Science.....	6
2.2 Coal Formation and Classification.....	6
2.3 Composition of Coal.....	9
2.4 Characterization Techniques of Coal.....	11
Chapter 3 Materials and Methods.....	16
3.1 Materials.....	16
3.2 Methods.....	17
Chapter 4 Results and Discussions.....	21
4.1 Proximate Analysis Results.....	21
4.4 Flotation Test.....	25
Chapter 5 Conclusion and Recommendation.....	30
5.1 Conclusions.....	30
5.2 Recommendation.....	31
REFERENCES.....	32

Lists of Acronyms

Lists of Acronyms

(CEMD): center for ethio-mines development	i
AAiT: Addis Ababa Institute of Technology.....	24
ASTM: Americal Society for Testing and Material	iv
EIAs. Environmental Impact Assessment.....	29

List of Abbreviations

List of Abbreviations

FC: Fixed Carbon.....	11
IM: Inorganic Matter.....	10
OM: Organic Matter	11
ROM: Run-of-Mine	1
SEM: Scanning Electron Microscope.....	12
VM: Volatile Matter	11
XRD: X-ray Diffraction	12
XRF: X-ray Fluorescence	12

List of Figures

List of Figures

Figure 1. Location map of the study area	3
Figure 2. Klimpel, 1984 summary of variables in the flotation system.....	14
Figure 3 Field and Laboratory equipment used in coal sampling and preparation.....	16
Figure 4 Experimental procedure of coal flotation process	19
Figure 5. Overall component distribution.....	24
Figure 6. Effects of particle size on the grade and recovery of the coal flotation.	27
Figure 7. Effects of collector dosage on the grade and recovery of the coal flotation.	28

List of Tables

List of Tables

Table 1. Results of proximate analysis for moisture, ash, volatile, fixed carbon, calorific value, and sulfur content.	21
Table 2. Full factorial design of coal sample for flotation experiment.	25
Table 3. Results of the flotation experiment.	26

Chapter 1 Introduction

1.1 Background of the Study

Coal is made of carbon, oxygen, hydrogen, sulfur, nitrogen, and other components and comes from organic sedimentary rock. It is a fossil fuel that burns [1]. Plant matter is converted to peat, which is next followed by lignite and, lastly anthracite, the best kind of coal [2]. The ASTM-D388 standard categorizes coal into four types: lignite, sub-bituminous, bituminous, and anthracite [3]. To assist people, comprehend the various characteristics of each. Due to its significantly higher energy density than other fuels, coal is used as an energy source in numerous industries, particularly in the metallurgical and cement sectors [4]. Cement companies depend on coal to generate very high kiln temperatures of about 1450°C, and the metallurgical industry smelts iron at high temperatures using it [5]. The coal reserves in Ethiopia are estimated at nearly 300 million tons. They are mostly found in the northern Chedia basin and the country's southwest. However, based on ASTM-D388 criteria and its degree of metamorphism, Ethiopian coal has low carbon content and calorific values, as well as numerous impurities, indicating significant levels of ash and sulfur [3]. By eliminating the mineral components, coal beneficiation raises the fixed carbon content and raises the coal's calorific value. It includes limiting gas emissions and particle pollutants, decreasing slagging and fouling features, and improving combustion behavior [6].

Compared to other coal deposits in the Ethiopian basin, the Biyo Gurgur area's coal deposit sites lack a thorough composition characterization. But after a thorough analysis, it ought to help us comprehend the coal's quality better [5]. It might also be a useful input for processing plant optimization. Therefore, research on closeness, calorific value, and sulfur analysis is required to ascertain the coal's power capacity in the area. Run-of-mine (ROM) coal needs to be processed with a certain technique to provide the proper product quality in terms of particle size, ash, sulfur, and moisture content. To produce coal with the highest economic value, a variety of coal preparation processes must be used. The choice of coal preparation procedures for run-of-mine (ROM) coal is strongly influenced by its physical and chemical characteristics, particularly rank, (intrinsic ash and sulfur content) and particle size. According to ASTM standards and mineral processing literature, lower- rank coals with high ash or sulfur require more intensive beneficiation techniques, such as froth flotation or chemical leaching, while coarser, higher-rank coals may be effectively treated using gravity separation methods [7]. This project's goal was to characterize the composition of coal and how it affects the indication of coal quality. As described in ASTM D3172, proximate analysis is a common technique for assessing these attributes. For instance, a high ash concentration might increase emission during combustion and decrease the calorific value. The Biyo Gurgur region, which is part of Ethiopia's Somali Regional State's Siti Zone, is becoming a significant location for the exploitation of coal resources. According to historical accounts, geological investigations intended to evaluate Ethiopia's natural resources were the first to discover the area's potential for coal reserves. These investigations, which were mostly carried out by geological experts and the Ministry of Mines, revealed unique geological structures in the region that suggested the existence of sedimentary rock formations, such as coal beds and shale,

that are favorable for coal formation. The Biyo Gurgur coal resource is strategically significant since it can support Ethiopia's energy industry. Limited exploration and use of domestic coal resources have taken place, despite the nation's significant reliance on imported energy sources. The discovery of coal resources in Biyo Gurgur offered a chance to lessen dependency on imported fuels and diversify the country's energy mix. The majority of the coal in this area, according to later geological analyses, is lignite, a lower-grade coal that has industrial potential after beneficiation. To fully realize the potential of the Biyo Gurgur coal resources, more investigation and characterization work, like the one described in this study, are needed. These resources may open the door for industrial uses and sustainable energy solutions in the area and beyond if their composition and quality are better understood.

1.2 Geological Description of the Study Area

The study area features a variety of different rock types, including both sedimentary and igneous rocks present. The most common rock formation in the region includes rhyolite, basalt, and coal. In addition to the above-mentioned rock units, non-mappable rocks such as dolerite outcrops are also observed in the study area. The sedimentary units exposed in the study area are shale and coal beds. Basalt is the most dominant rock unit in this area; it has a fine-grained texture and a dark color, typical of its mafic composition. The basalt unit makes contact with both rhyolite and coal beds. Plagioclase and olivine phenocrysts buried in a fine-grained groundmass composed of pyroxene and plagioclase minerals make up this unit's mineral composition.

The study area is located in the Somali Regional State of Ethiopia, in the southern part of the Afar Depression. It spans an area of 10,358 square kilometers, located between 10°00' to 11°20' North latitude and from 42°00' to 43°20' East longitude [8].

* Ethiopia has a varied geological background consisting of three main geological terrains [9].

- The Basement Complex, composed of Precambrian metamorphic rocks and syn- to post-tectonic intrusions.
- The late-Paleozoic to Mesozoic marine and continental sediments.
- The Cenozoic sediments and volcanic deposits.

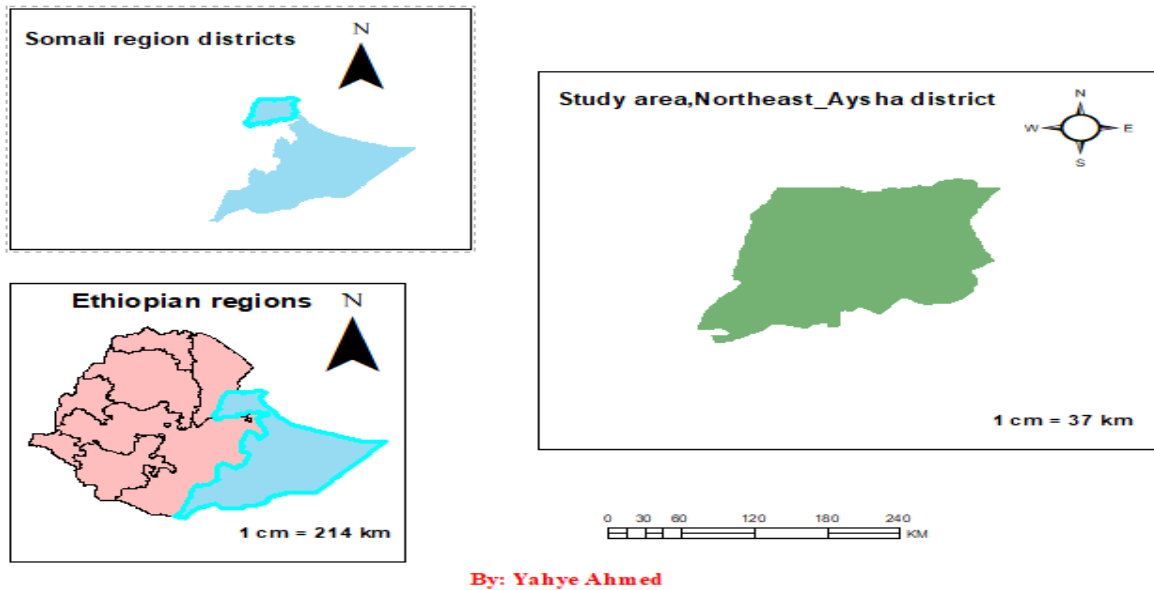


Figure 1. Location map of the study area

1.3 Statement of the Problem

Despite the considerable potential of coal as an alternative energy source in Ethiopia, particularly in the Biyo Gurgur area of the Somali Region, there remains a significant gap in knowledge regarding the specific composition, rank and quality of the coal deposits in this locality. This lack of detailed characterization limits the understanding of the coal's suitability for energy production and its potential role in reducing reliance on imported fuels. The absence of detailed geochemical and mineralogical characterization, especially with respect to key properties such as ash content, sulfur concentration, fixed carbon, moisture, and calorific value, hampers decision-making on the feasibility of coal exploitation in this region.

Furthermore, it has been challenging to determine whether this coal can be upgraded to meet industrial standards due to a lack of beneficiation studies, such as flotation testing. Without this kind of information, it is impossible to accurately assess the economic potential of Biyo Gurgur coal or its environmental implications, such as sulfur dioxide emissions and particulate matter during combustion. Therefore, by determining the quality and upgrading potential of Biyo Gurgur coal by proximate analysis and flotation experiments, this study aims to close the crucial information gap. Through the creation of baseline data and the assessment of processing effectiveness.

1.4 Objective of the Study

1.4.1 General Objective of the Study

- Using proximate analysis and flotation experiments, to evaluate the quality and beneficiation potential of coal from the Biyo Gurgur area, focusing on the impacts of collector dosage and particle size on grade and recovery.

1.4.2 Specific Objectives of the Study

1. To conduct a proximate analysis of Biyo Gurgur coal
2. To evaluate the coal sample's energy potential and environmental impact by calculating its calorific value and sulfur content.
3. To use various particle size fractions and collector doses to perform flotation tests on Biyo Gurgur coal.
4. To examine how particle size affects flotation performance, specially how it affects grade and recovery.
5. To evaluate how collector dose affects coal recovery and grade during flotation.
6. To determine provide recommendations for optimizing flotation parameters to enhance coal quality.

1.5 Scope of the Study

Coal samples from the Biyo Gurgur region were analyzed and characterized in this study in order to evaluate their quality and potential for beneficiation. In order to comprehend the physicochemical characteristics of the coal and how it reacts to processing methods, the study concentrated on both proximate characterization and flotation performance. To determine important factors related to coal quality and energy value, laboratory tests were carried out.

- Proximate analysis: To assess essential characteristics of the coal samples, the moisture content, volatile matter, ash content, and fixed carbon were measured.
- Calorific value testing: To evaluate the coal's potential as a fuel source, its energy content was determined using adiabatic calorie meter technique.
- Flotation response evaluation: Flotation experiments were conducted to determine how the grade and recovery of the coal were affected by the particle size distribution and collector dosage. These testes were intended to determine the best conditions for beneficiation and to evaluate the coal's washability.

The study's scope was restricted to laboratory-scale testing and analysis with the goal of producing baseline data for upcoming technical and industrial uses of the Biyo Gurgur coal resources.

1.6 Significance of the Study

The significance of this study lies in enhancing the understanding of coal quality: It provides detailed insights into the proximate, calorific value, and flotation technique of the coal, helping to determine its suitability for various applications.

This research is important as it addresses a critical knowledge gap in the understanding of coal characterization. The findings contributed to the optimization of mineral processing operations, leading to improved process efficiency, cost reduction, and enhanced resource recovery.

This study also focused on clean coal technology, which encompasses a range of methods designed to reduce the environmental impacts associated with coal energy production [10]. By finding coal with low sulfur concentration, lowering ash content through flotation, and assessing energy efficiency using calorific value analysis.

1.7 Project Outline

This research work contains five chapters. The first chapter addresses the general introduction, objectives, scope, and significance of the study. Chapter two briefly discusses the literature review relevant to the study. Chapter three presents the materials and methodologies used to complete the research. Chapter four introduces the results and discussions. The final chapter, Chapter Five, includes the conclusion and recommendation.

Chapter 2 Literature Review

2.1 Overview of Coal Science

Over millions of years, the remains of dead plants accumulated to a specific thickness before being covered by silt or water, becoming coal, an organic rock. In an appropriate geological setting, this process takes place under physical, chemical, and biological circumstances [1].

Coal is a highly flammable rock that consists of over 50 percent organic matter (carbon) by weight, with approximately 70 percent of its volume composed of carbon-rich material, which includes its natural moisture content. It was formed by the compaction and transformation of plant remains [11]. Coal is created over millions of years by the decomposition and conversion of plant matter into peat, which is subsequently transformed into coal under the pressure and heat of deep burial, in contrast to mineral rocks, which are made of inorganic material.

Along with natural gas and oil, coal is one of the most abundant non-renewable fossil fuels on the planet. It is anticipated to remain a significant contributor to the world's energy supply for the foreseeable future, particularly for electricity [12].

To determine coal's physical and chemical characteristics, proximate, ultimate, and calorific value. Analyses are employed [7].

Proximate analysis measures volatile matter, ash, moisture, and fixed carbon. Volatile matter refers to the gases and chemicals, such as hydrocarbons and other volatile substances (excluding from intrinsic moisture), that are emitted when coal is burned without air. Non-combustible materials like moisture and ash reduce the quantity of useable energy in coal, which lowers its calorific value. The primary components that contribute to a coal's heating value are volatile matter and fixed carbon. To determine the fundamental composition of coal, including carbon, hydrogen, nitrogen, oxygen, sulfur, and moisture, ultimate analysis is used in addition to proximate analysis. Additionally, trace elements like mercury and chlorine, as well as various types of sulfur (pyrite, marcasite, gypsum, and organically bonded sulfur), can be identified by specialized chemical testing. Usually, the bomb calorimeter method is used to calculate the calorific value.

2.2 Coal Formation and Classification

2.2.1 Coal Formation

Environments that support the collection and preservation of plant materials are often conducive to the creation of coal [13]. The following are the ideal circumstances for coal formation:

- Swampy wet terrain is an area where groundwater is close to us just above the topsoil, enabling vegetation to create organic matter more rapidly than it can break down.
- Inter delta wetlands, back-barrier swamps, and coastal marshes: these are places where coal is formed from peat, a spongy buildup of partially decomposed organic matter.

Peatification, in which bacterial activity produces peat, and coalification, in which rising temperatures and pressures from burial turn the peat into coal over millions of years, are the two primary stages of the coal creation process.

Coal is formed by the decomposition of plant matter without free access to air and under the influence of moisture, pressure, and temperature. Throughout the geologic process that forms coal, coalification, the chemical composition of the coal gradually changes to compounds of lower hydrogen content and higher carbon content in aromatic ring structures. With an increase in the degree of coalification, the percentage of volatile matter decreases, and the calorific value increases. Coal is formed from the buildup of plant material that has undergone various physical and chemical transformations over millions of years. This process involves the decay of vegetation, its deposition, and burial under sediment, followed by compaction and the conversion of the organic matter into rock. Coal is categorized into four ranks based on its carbon content, moisture level, and energy potential. These ranks reflect different phases in the coalification process, which is the natural evolution of buried plant matter into denser, drier, and more carbon-rich substances [14].

Coal formation is a natural process involving the accumulation of plant material, its transformation into peat, and subsequent geological changes that lead to various types of coal [7]. Understanding this process is essential for both energy production and environmental management. The four ranks, listed in ascending order of carbon content, are peat, lignite, bituminous, and anthracite [15]. Anthracite, the highest rank, is a type of hard, brittle, and lustrous coal: with high fixed carbon content and low volatile matter. It has the highest heat-producing capacity and is often used for heating and electricity generation. Peat and lignite exhibit lower carbon content and energy value. Bituminous coal is the most common type, has intermediate properties, and is widely used worldwide. Lignite, or brown coal, has low heating value and high moisture content, making it suitable for cement production and electricity generation with moderate heat.

Peat is a soil-like, partially decayed plant material that accumulates in wetlands (distinct ecosystems inundated by water) and is the precursor material from which coal is derived. Peat formation is influenced by at least three key factors: (1) the evolution of plant life; (2) climatic conditions that must be warm enough to encourage plant growth and sufficiently moist to enable partial decomposition of plant material, thereby preserving peat; and (3) the physical characteristics of the region, including (its geographic position about the sea or other water bodies, as well as rates of subsidence or uplift rates) [16].

The process of coalification involves chemical and physical alteration in both organic and inorganic substances. It continues until the highest heating during the Earth's history. Three important physical factors can influence the coalification process: duration, increasing temperature, and increasing pressure [17].

The loading of the sediments that cover it, temperature, pressure, and time all have an impact on the organic components of peat, resulting in a mix of biological, chemical, and physical processes known as the coalification stage [18]. Because of pressure, burying, and temperature, the coalification process turns peat, lignite, sub-bituminous, bituminous, and anthracite meta into anthracite. The rank of coal refers to the extent of coalification or transformation [18]. At this point, the proportion of carbon will rise while that of hydrogen and oxygen will fall [19].

Coalification is the process of increasing carbon content while reducing other impurities. This transformation occurs as overburdened material accumulates, raising pressure and temperature levels [19]. The process involves the gradual transformation of deceased plant material under minimal overlying pressure and maximum temperature, leading to the formation of anthracite. The coalification process, which affects the organic components in coal, consists of various sequential reactions from the base material to the plant life which forms the basis for coal. Highly reactive substances may experience low-grade oxidation or volatilization processes in heat and pressure. The characteristics are defined by its chemical and physical properties, which encompass moisture content, ash content, volatile matter, sulfur content, and calorific value. Proximate analysis is a common technique employed to assess these characteristics (ASTMD3172). For example, a high ash content can significantly diminish the calorific value and increase emissions during combustion.

2.2.2 Coal Classification

Coal is a diverse blend of altered organic plant material and inorganic substances. It is abundant in carbon and mineral content. Coalification describes the processes that convert this organic plant material into coal. The initial phase of this change involves the creation of peat from the breakdown and decay of dead vegetation via biological mechanisms. The ongoing accumulation of mineral sediments on the peat bed for an unlimited time due to heat and pressure aids in the conversion of peat into coal. Every step of the transforming process indicates the rank of the coal, which reflects its maturity level, or the extent of coalification. The more moisture coal is, the higher its rank.

Along with oil and gas, coal is one of the three fossil fuels that provide 40% of the world's electricity and around 25% of its primary energy. The World Coal Association states, that coal is the world's main source of electricity and that it will produce 22% of all electricity in 2024. The quantity of thermal energy that coal can produce and its carbon content have a direct impact on its quality[20]. In comparison to lower-quality coal, higher-quality coal contains more carbon, produces less smoke, burns for a longer period, and produces more energy. Consequently, anthracite, bituminous, sub-bituminous, lignite, and peat are the five main categories or ranks (from highest to lowest) into which coal is generally divided [21]. The following fragment provides an overview of the different grades of coal, ordered from the lowest to the highest quality.

Anthracite —→ **Bituminous** —→ **Sub-Bituminous** —→ **Lignite** —→ **Peat**

Peat

The first stage in the formation of coal is called peat. It is a dark brown, mushy, crumbly substance that formed over many years from partially decomposing and dead organic matter. To transform peat into coal, it must be sunk 4–10 km below the surface of the sediment [22]. Peat has the lowest energy density and the lowest carbon concentration (less than 60%).

Lignite

With a carbon content ranging from 65% to 70, lignite, which is commonly referred to as brown coal, is the lowest quality coal [22]. It contains the highest amounts of sulfur and mercury, among other components, compared to other coal [23]. The most recent fossil fuel is lignite, which was about 60 million years ago. At 18MJ/kg, its energy density is quite low. In contrast to other better-grade coals, lignite uses less carbon dioxide because of its higher moisture content and lower carbon concentration.

Subbituminous

Black lignite, also known as sub-bituminous coal, occurs in a variety of colors, from dark black to dark brown, and hardness levels, from hard to soft. It serves as a kind of coal in between high-quality bituminous coal and low-quality lignite. Sub-bituminous coal has between 70% and 76% carbon [24]. It is roughly 251 million years old and belongs to the younger coals. As a result, the energy density is increased by 18 and 23MJ/kg due to the longer burial duration compared to lignite. Sub-bituminous coal resources account for 305 of coal resources.

Bituminous

With a carbon concentration of 76-86%, bituminous coal is the second-best quality [24]. With an estimated age of 300 million years, it is the most prevalent kind of the longest-buried fossil fuel. Its energy density, which ranges from 23 to 33 MJ/kg, is therefore comparatively high. This kind of coal's high carbon and low moisture content makes it perfect for power generation, coke production, and the manufacture of steel and cement.

Anthracite

Anthracite is a high-quality coal that is dark black. It contains over 95% carbon, is extremely hard, and has low moisture content [24]. The oldest type of coal is often anthracite, which was formed from biomass that was buried 350 million years ago. With a 33 MJ/kg energy density [21]. Out of all varieties of coal, it has the highest calorific value. Space heating is accomplished with anthracite. It is appealing for use in home heating stoves since it burns longer than wood. In light of the global energy crisis, anthracite coal is both required and beneficial.

2.3 Composition of Coal

Coal has a very diverse composition, just like any other sedimentary rock. Peat that has been formed under varied wetland conditions is buried and compacted to create coal, which is primarily a macro-molecular organic rock [25]. Inorganic material is a minor component of coal, which is primarily made up of organic materials. The line separating coal from impure coal, often referred to as coaly middling (the intermediate between shale and coal), is thought to be reached when coal has 30% inorganic (mineral matter) content.

The composition of coal is determined by physical, physicochemical, and chemical analytical methods. These methods characterize the diversity and heterogeneities of coal at various coalification stages. Coal can be examined by macroscopic (physical), microscopic (physico-chemical), and chemical methods. Coal is primarily composed of carbon along with hydrogen, oxygen, sulfur, and nitrogen and is interspersed with small amounts of inorganic impurities and trace elements. A detailed examination of its constituents includes:

Proximate Analysis: it focuses on the physical and thermal properties of coal. The main components measured are:

- Moisture: The water content in coal, affects its heating value.
- Volatile matter: Organic compounds and gases released when coal is heated, such as hydrocarbons, carbon dioxide, and water vapor. High volatile matter indicates greater combustibility.
- Fixed carbon: The solid carbonaceous material that remains after the volatile matter is driven off. It represents the fuel portion of coal.
- Ash: The non-combustible mineral residue left after combustion. High ash content lowers the energy content of coal and requires disposal.

Ultimate Analysis: it determines the elemental composition of coal, including

- Carbon (C): The primary element in coal.
- Hydrogen (H): Contributes to the combustion process and heat generation.
- Nitrogen (N): Present in small quantities and contributes to Nox emissions during combustion.
- Oxygen (O): Affects coal reactivity and heating value.
- Sulfur (S): It exists as organic sulfur, pyritic sulfur, or sulfate sulfur. Due to SO₂ emissions, sulfur is a concern for environmental pollution.

Trace Elements: The trace elements and minerals found in coal may affect its use and effects on the environment.

Modern analyses of trace elements in coals were developed as a result of Goldschmidt's application of the quantitative chemical evaluation method by optical emission spectroscopy, which he developed and applied to coal ash. In these early works [26].

- Arsenic, mercury, selenium, and lead, are examples of trace elements that can pose environmental and health risks when released during combustion.
- Minerals: Common minerals in coal include quartz, clay minerals, pyrite, and carbonates. These affect the ash content and slagging behavior in furnaces.

2.4 Characterization Techniques of Coal

2.4.1 Proximate Analysis of Coal

As a practical and efficient way to ascertain the distribution of products produced by heating coal under a series of standard solutions, the proximate analysis of coal was developed. The most straightforward and widely used method of evaluating coal is proximate analysis, which is used to ascertain the fuel's structure, characteristics, and energy worth. It is based on ASTM and determines the amount of moisture, volatile matter, ash, and fixed carbon.

- Since all coal mines are damp, moisture is a crucial coal component. While the moisture retained in the coal itself is known as inherent moisture and is quantitatively examined, adventitious moisture, which includes groundwater and other external moisture, easily evaporates. Most coals, as they are dug from the ground, have some moisture. Coals often have a moisture content of 5% to almost 70%, which is an unwanted component since it lowers the heating value and increases the weight and cost of transportation. The fluid matter of coal comprises moisture, gas, and gas-liquid inclusions associated with both solid organic matter (OM) and inorganic matter (IM) [27]. The increased contents of this physically and chemically adsorbed water are characteristic of lower-rank coals, while the decreased values of this parameter are typical of higher-rank coals.

Analysis of the moisture content is the weight loss of coal in a crucible heated to roughly 105° C. A known quantity of finely ground coal sample is placed in a silica crucible, heated to 105-110° C for approximately an hour in an electrical hot air oven, cooled in a desiccator, and then weighed. Until the weight of the crucible holding anhydrous coal is consistent, this heating, chilling, and weighing procedure is repeated. Weight loss is expressed as the moisture content percentile.

- The components of coal, excluding moisture, that are released at high temperatures without the presence of air are referred to as volatile matter (VM). These components are typically a mixture of aromatic hydrocarbons, short and long-chain hydrocarbons, and certain sulfur compounds. When moisture and ash are present, the VMO concentration is measured and ranges from 2% to around 50%. Large concentrations of volatile stuff in coals make them easy to ignite, burn quickly, and frequently produce a lengthy, smoky flame in home stoves, furnaces, and small industrial units. Low-ran coals are more likely to have a greater VM content, whereas higher-ran coals are likely to have a lower value [7]. The weight loss of moisture-free coal at a specific temperature and time is known as volatile matter. A lidded silica crucible containing the moisture-free coal sample is placed in a muffle furnace that has been preheated at 900+/-20° C for seven minutes. After being removed and allowed to cool in the air and then inside desiccators, the crucible is weighted once again. The weight loss percentile is expressed as volatile matter.

- The ash content of coal is the non-combustible residue left after the coal is burnt representing the bulk mineral matter after carbon, oxygen, sulfur, and water are driven off during combustion indicating the quality of coal. These results reveal that the bulk ash yield is a poor informative characteristic of coal if the origin, composition, and abundance are not considered to resemble the correlation of ash yield as relatively contradictory [28]. The ash content in the lignite and coaly shale samples vary from 7.74 to 29.10 Wt% an arithmetic mean of 17.10 Wt%.

Determination of ash content: The weight of residue obtained after burning a known amount of dry coal in an open crucible. In a muffle furnace, the sample is heated to 700-750° C for 30 minutes. Until a consistent weight is achieved, heating, cooling, and weighting are repeated. The implication is that coal of higher quality has a lower ash concentration.

- The amount of carbon content that remains after volatile elements are removed is known as its fixed carbon content. Because some carbon is lost in hydrocarbons with the volatiles, this is different from the coal's final carbon concentration. The amount of coke that will be produced from a sample of coal is estimated using fixed carbon. The mass of volatiles identified by the volatility test above is subtracted from the initial mass of the coal sample to determine fixed carbon. When moisture and ash are excluded, coals have a constant carbon content that ranges from 50% to roughly 98%. The FC values are highly dependent on the values of C and OM in coals. It is well known that the FC content increases with coal rank advance.

Fixed carbon: After the determination of moisture, volatile matter, and ash content, the remaining material is the fixed carbon representing the quality of coal that can be burnt by a primary current of air drawn through the hotbed of a fuel. The fixed carbon analyses require the designing of the furnace and shape of the firebox as it burns in a solid state. The trend is that the higher the fixed carbon greater the calorific value hence the better quality of coal.

2.4.2 Ultimate Analysis of Coal

Ultimate analysis provides a detailed determination of the elemental composition of coal, including the proportions of carbon, hydrogen, oxygen, nitrogen, sulfur and sometimes trace elements. This analysis is more chemically precise than proximate analysis and is essential for understanding the combustion behavior of coal [7]. While proximate analysis assesses coal's suitability for burning or coking by estimating moisture, ash, volatile matter, and fixed carbon, ultimate analysis is used to quantify the actual chemical constituents.

2.4.3 Calorific Value (Heating Value)

The quantity of heat emitted when a unit mass of coal burns completely under normal circumstances is known as calorific value of coal. It regarded as one of the most crucial factors in assessing the quality of coal, especially given its use in industrial heating and thermal power generation [29]. Through burning a coal sample in excess oxygen inside a sealed calorimeter and measuring the heat released, oxygen bomb calorimetry is the most widely used technique for calculating calorific value [30]. Energy reserves and resources are also estimated using calorific value. One of the essential variables for coal type categorization in the ASTM system for ranking coal is the calorific value [29]. In addition to being crucial for determining the energy output of coal, calorific value is also used to estimate energy reserves and is a key components of ASTM's coal ranks classification system, which helps differentiate between lignite, sub-bituminous, bituminous, and anthracite coals.

2.4.4 Mineralogical Analysis of Coal

Mineralogical analysis of coal involves studying and identifying the mineral components present within the coal sample. These minerals can significantly affect coal's properties, usage, and processing. The mineral matter in coal is either calculated using X-ray fluorescence (XRF) or determined directly using X-ray diffraction (XRD) and a scanning electron microscope (SEM).

2.4.5 Froth Flotation Technique

Froth flotation is a widely technique for improving coal and other fine particulate matter because it can effectively separate hydrophobic particles from hydrophilic ones [31]. To improve the separation of useful particles, such as fine coal, from contaminants, like ash-forming minerals, this procedure uses chemical reagents. A vital aspect of coal beneficiation, especially for fine or ultrafine coal fractions where conventional gravity-based procedures are less successful, is froth flotation, despite its widespread use in concentrating sulfide ores and finely dispersed low-grade metallic ore complexes. The ability of precious mineral particles to rise to the surface more quickly than the gangue minerals is what makes the flotation process effective. However, flotation performance is significantly influenced by various parameters [32]. Klimpel (1984) has divided the major variables into three principal groups (see Figure 2)

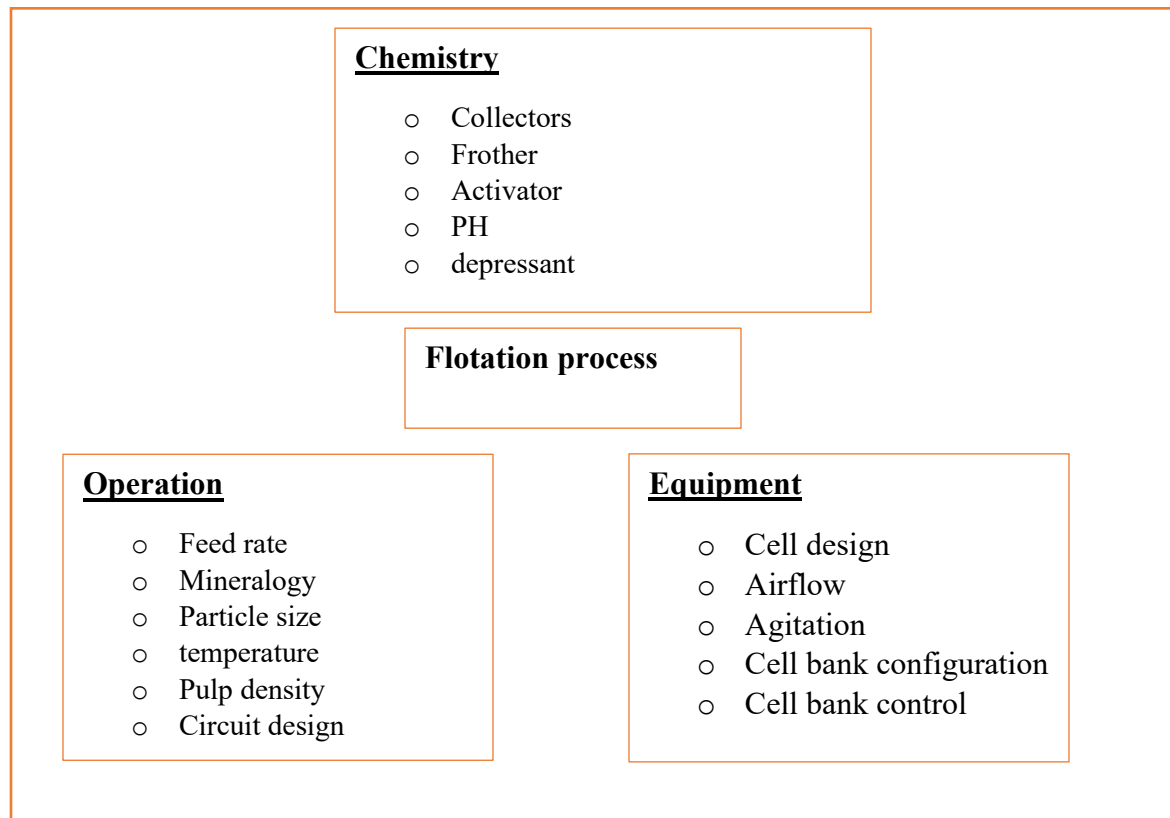


Figure 2. Klimpel, 1984 summary of variables in the flotation system.

Today, flotation is the most widely used technology in the minerals industry, with applications in various minerals processing [33].

2.4.6 Flotation Reagents

Flotation-related reactions flotation chemicals are introduced to the pulp to modify the surface chemistry of the minerals and facilitate the separation of precious minerals from gangue components by increasing the hydrophobicity difference between the minerals [31]. These substances are dispersed throughout the slurry using an impeller. To modify the surface features of particles, flotation uses a variety of chemical treatments. The most commonly used reagent types in the flotation procedure are collector, frother, and depressant; each has a specific purpose. The flotation process is made possible by the chemicals that are introduced into the water suspension of finely ground coal. Ash-forming minerals and other coal particles or impurities are selectively made to exhibit an affinity for air by these reagents. Selecting the right chemical combination to most economically and selectively separate the desired mineral phases with good recovery is the ultimate goal of the flotation reagents.

Collectors

In the coal flotation process, collectors are essential reagents. By creating a water-repellent (hydrophobic) encompassing on the coal particle's surface, they primarily serve to increase the affinity between coal particles and air bubbles [34]. By attaching to the surface of coal, these organic chemicals enhance its hydrophobic qualities. Because of this adsorption, the water barrier separating of the coal surface from air bubbles becomes less stable, which makes it easier for coal particles to attach to the bubbles during flotation. Samples having a mass of 100 grams or comparable standardized units are commonly used by researchers to assess the flotation potential of coal.

The surface of the target mineral particles can be made selectively hydrophobic by using collectors. Usually, a collector is made up of two parts: a nonpolar molecule that adheres to an air bubble and a polar component that interacts with the mineral surface. Collectors are concentrated at the mineral-water interface because the non-polar groups provide a hydrophobic surface when they come into contact with water. The behavior of the collector is influenced by both the alkyl chain and the functional group [35].

Frothers

Frother are surface-active substances with particular features that are essential to the flotation of coal [36]. Both polar and non-polar groups found in them help to maintain the froth layer and enhance bubble formation. By lowering the water's surface tension, frothers enhance the formation of stable froth during flotation. The literature has categorized frothers in a number of ways: Wills (2005), for example categorized them as neutral, basic or acidic. Pine oil, aliphatic alcohols, polypropylene glycols, polypropylene glycol alkyl ethers, and cresylic acids are often utilized foaming agents in coal flotation. By preserving a persistent foam that aids in lifting hydrophobic coal particles to the top, these chemicals improve the efficiency of flotation.

Regulators

In flotation, regulators also referred to as modifiers, are frequently employed to change the collector's operation by increasing or decreasing its water-repellent impact on the particle surface. With this modification, the collector's operation is more targeted at particular particles, such as coal or pollutants. Activators, pH modifiers, and depressants are the three types of regulators.

Chapter 3 Materials and Methods

3.1 Materials

The materials used in this study encompassed both field and laboratory tools necessary for coal sample collection, preparation, analysis, and flotation testing. Fieldwork materials included a GPS device, which was used to accurately record the sampling locations and Sample bags that can be seen in the figure 3 to ensure the safe storage and transportation of coal sample. A geological hammer was employed for the extraction of coal samples from outcrops, while proper labeling materials were used to maintain clear identification and traceability of each sample through the experimental process. For the proximate analysis, the study required standard materials and reagents for determining moisture content, ash content, volatile matter and fixed carbon. These parameters were analyzed following ASTM procedure, to assess the fundamental quality of the coal. In the flotation experiments, coal particles of various size fractions were prepared and tested. The flotation process involved the use of collector reagents (kerosene), frother reagents (pine oil), and 2.5 liters of distilled water to create the flotation slurry and facilitate separation in the flotation cell. Laboratory equipment used in the study included in the figure 3 shows a jaw crusher for primary size reduction of the coal samples and centrifugal or cutting mill to further grind the samples to particles smaller than 500 microns. A sieve shaker was utilized to classify and separate the samples into specific particle size ranges required for flotation test. A flotation cell was used to evaluate the separation efficiency and flotation response of coal samples under varying conditions. Additionally, a crucible was used for determining moisture, ash, and volatile matter, while a drying oven supported moisture analysis by maintaining required heating temperature. To measure the energy content of the coal, an adiabatic bomb calorimeter and gravimetric method were employed for calorific value determination in Ethiopian geological survey.



Figure 3 Field and Laboratory equipment used in coal sampling and preparation.

3.2 Methods

The following methods were employed to achieve the objectives of characterizing coal resources in Biyo Gurgur through proximate analysis and evaluating their quality for industrial applications.

3.2.1 Sample Collection and Examination

3.2.1.1 Sample Collection

Representative coal samples were collected from the Biyo Gurgur region. Proper sampling techniques ensured that the samples accurately reflected the characteristics of the entire coal deposits. This process includes:

- Collecting coal from surface outcrops and subsurface layers (where accessible).
- Labeling and storing samples in sealed bags to prevent contamination.
- Crushing the samples into smaller sizes to facilitate laboratory analysis.

The goal of collecting and preparing a coal sample is to obtain a test sample that accurately reflects the characteristics of the entire lot. This process is essential for ensuring that the analysis yields reliable results representative of the coal from which the sample originates. Proper sampling and preparation are vital for achieving accurate analytical outcomes [37].

3.2.1.3. Preparation of coal sample

The coal samples were collected from the Biyo Gurgur area and prepared according to the ASTM standards. This preparation process included crushing, milling, and sieving. Crushing is the first stage of reducing the coal to a smaller size. The bulk samples from the crusher were milled by centrifugal milling and separated according to their size by a sieve shaker (+500 μm , +250 μm , +125 μm , and +75 μm). The mass of the feeds for each particle size was measured before the beginning of the flotation experiments.

3.2.1.4. Sampling Techniques

- A GPS device was used to locate an accessible coal-bearing outcrops in the Biyo Gurgur area for sampling. Field observations helped to identify the exact location, and the coordinates were recorded on-site. A representative coal sample was taken from exposed outcrop based on visible coal presence. By selecting samples from geologically significant and observably rich coal zones, our judgmental approach improved the quality and applicability of the samples for flotation analysis and coal characterization.

3.2.2 proximate Analysis

In accordance with common ASTM standards, proximate analysis was performed for determining the coal sample's moisture content, volatile matter, ash content, and fixed carbon. For every test, about 1 gram of oven-dried coal was used. The following measures were taken to carry out the procedures.

1. Moisture Content: After the samples was weighted, it was heated up for an hour at 105°C in an oven. The proportion of moisture in the coal was determined by recording the weight loss of each coal particle size. A significant factor influencing coal's energy value and combustion efficiency is its moisture content. Moisture content has a major effect on coal's burning properties by affecting the energy needed for pyrolysis and the internal temperature history during combustion [38]. Added that one of the primary factors affecting coal quality is moisture content since a higher calorific value is implied by lower moisture content [39]. Coal quality and utilization physical qualities are significantly influenced by moisture. Coal's high water content affects its burning and vent gas capacity per energy unit, requires more time to heat, and has a lower calorific value [40]. Furthermore, excessive moisture content causes massive vent gas volumes, increases coal consumption, and requires massive equipment measurements.

2. Volatile Matter: Following the removal of moisture, the sample was heated for seven minutes at 950°C in a muffle furnace while enclosed in a covered crucible. The weight loss at this step was used to compare the volatile components driven off.

3. Ash Content: To ensure full combustion, the residue from the moisture test was burned for a further two hours at 750°C in an open crucible. The ash content was calculated by weighting the residual inflammable material or ash. This pattern suggests that the finer particles contain a higher concentration of mineral materials, maybe as a result of their finer surface area and stronger bond with clay-rich impurities [41]. Some fraction have a comparatively high ash content, which may indicate a decreased calorific value and have an adverse effect on combustion efficiency [38].

4. Fixed Carbon: The formula Fixed Carbon (%) = 100 – (Moisture + Volatile matter + Ash) was used to compute fixed carbon indirectly.

By determining these components, proximate analysis provides a snapshot of the coal's combustibility and efficiency, guiding its appropriate use in energy production and other applications.

3.2.3 Flotation Testing

Flotation experiments were conducted to assess the coal sample's washability and separation effectiveness; flotation tests were conducted. Particle size distribution, collector dose, and frother dosage were the main factors examined. Throughout the experiments, distilled water was utilized as the medium to ensure the flotation processes' quality and reduce the impact of contaminants. Coal samples of different particle sizes were prepared, certain amount of collector and frother were added, and flotation was used to separate the coal from impurities. To determine the ideal parameters for optimal coal beneficiation, the results were examined.

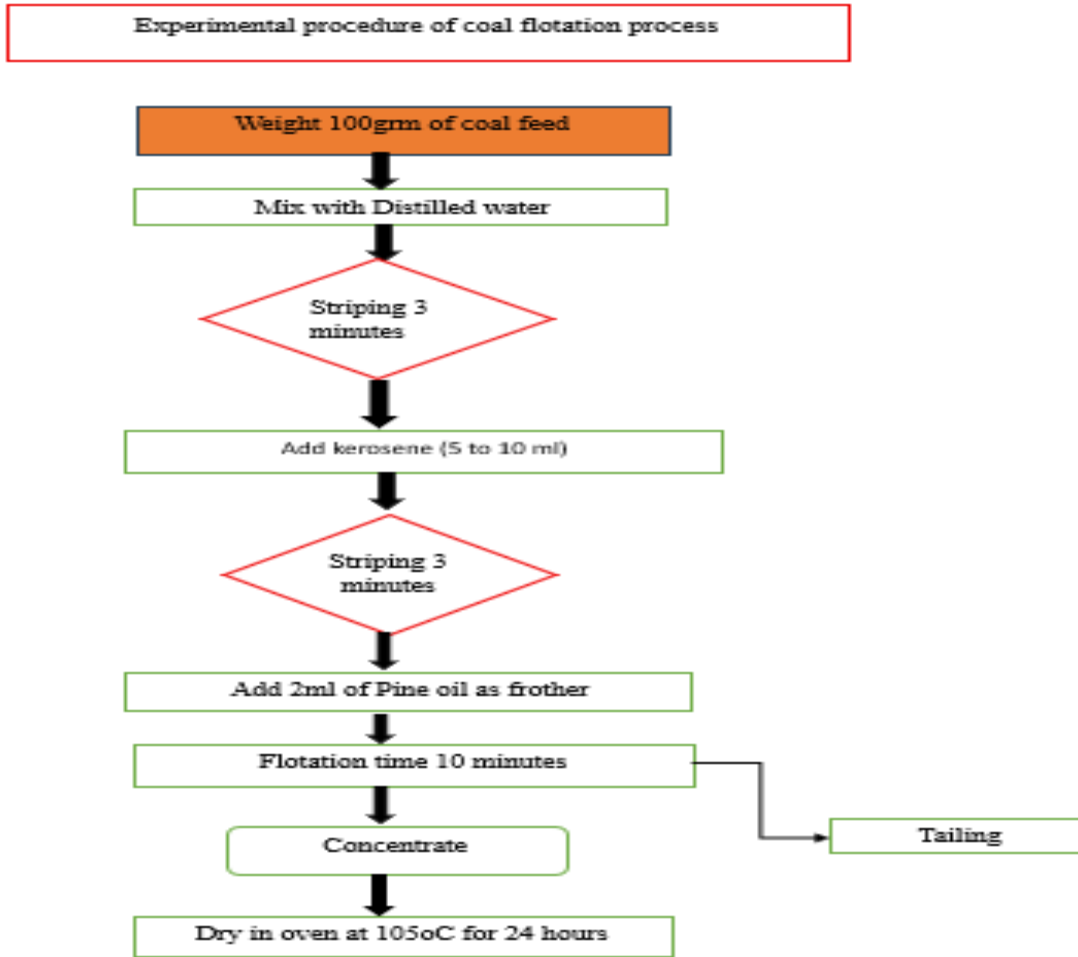


Figure 4 Experimental procedure of coal flotation process

3.2.4 Calculations and Data Analysis

Ash Analysis

In the proximate analysis, we calculated and analyzed the percentage of ash content and the mass of each sample after combustion as follows:

$$\text{Wt. of Ash} = (\text{Wt. of crucible with coal sample(g)} - \text{Wt. of crucible} + \text{sample after combustion(g)})$$

$$\% \text{ Ash} = \frac{\text{Wt. of Ash left}}{\text{Wt. of Coal Sample}} \times 100$$

$$\text{Mass of ash in the concentrate} = \% \text{ of Ash} \times \text{Mass of concentrate}$$

Recovery and Grade Analysis

- **Recovery:** describes the amount of mineral or metal of interest that is present in the concentrate about that present in the feed stream and it is usually expressed as a percentage and written as:

$$\text{Recovery} = \frac{\text{Mass of coal in the concentrate stream}}{\text{Mass of coal in the feed stream}} \times 100$$

- **Grade:** refers to the concentration of a mineral in a stream and is expressed as a percentage and written as:

$$\text{Grade} = \frac{\text{Mass of the coal in concentrate}}{\text{Total Mass of concentrate}} \times 100$$

Analysis Tools

Microsoft Excel was the main tool used for data entry, processing, and visualization in this study. Based on experimental mass and composition data, ash content, recovery, and grade were manually calculated using excel, and graphs and trendlines were created to show the relationship between flotation parameters (like particle size and collector dosage) and flotation responses (like grade and recover).

Chapter 4 Results and Discussions

This chapter presents the results and discussion of the flotation experiments, proximate analysis, and col sample preparation carried out to investigate how particle size and collector dosage affect flotation performance.

4.1 Proximate Analysis Results

Coal proximate analysis is a test for moisture, ash, volatile matter, and fixed carbon [42]. The results of the proximate analysis for fixed carbon, moisture, ash, volatile, calorific value and sulfur content in coal samples of varying particle sizes are summarized in Table 1.

Table 1. Results of proximate analysis for moisture, ash, volatile, fixed carbon, calorific value, and sulfur content.

Run	Particle size (μm)	Moisture %	Ash %	Volatile matter %	Fixed carbon %	Calorific value cal/gam	Sulfur%
1	+500 μm	10.59%	19.30%	19.50%	50.61%	1626.48	0.16
2	-500+250 μm	7.96%	40.62%	19.50%	31.92%	1626.48	0.16
3	-250+125 μm	5.02%	60.41%	19.50%	15.07%	1626.48	0.16
4	-125+75 μm	4.12%	63.22%	19.50%	13.16%	1626.48	0.16

The proximate analysis results for coal samples with varying particle sizes are summarized in Table 1. Important findings include:

- From 19.3% (coarse particles, +500 μm) to 63.2% (fine particles, -125+75 μm), the ash content varies. This pattern suggests that inorganic contaminants are substantially greater in finer particles, most likely as a result of mineral materials being released during grinding. An excessive amount of ash lowers the coal's potential energy and raises processing expenses.
- Fixed carbon has an inverse relationship with ash content, falling sharply from 50.6% (+500 μm) to 13.2%(-125+75 μm). This predominance of non-flammable minerals at these sizes is confirmed by lower fixed carbon in finer fractions.
- The coal is classified as poor-grade lignite due to its consistently low calorific value of 1626.48cal/gm across all particle sizes. This is consistent with ASTM guidelines, which state that lignite with a high ash content often has poor calorific values.
- Sulfur content: 0.16%, which is far less than the 1-3 percent global average for lignite. Although this reduces SO₂ emissions, it doesn't offset the coal's poor energy quality.

4.1.1 Determination of Moisture Content

The reduction in weight following an hour of heating coal samples to 105°C was used to calculate the moisture content in accordance with ASTM guidelines.

$$\% \text{ of Moisture} = \frac{\text{loss in weight}}{\text{weight of coal}} \times 100$$

According to the findings, the average moisture content was 6.9%, with a range of 4.12% to 10.59%. The moisture content was lowest in the finest fraction (-125+75 μm) and highest in the coarsest particle size (+500 μm). This implies that because of their increased surface area and pore spaces, coarser particles often retain more moisture. Low recovery efficiency and higher processing costs may result from handling, drying time, and flotation behavior being impacted by high moisture content in coarse particles. On the other hand, finer particles may support more effective flotation and combustion due to their reduced moisture content.

4.1.2 Determination of Ash Content

By burning known amounts of dry coal in an open crucible at 750°C for two hours and weighing the residue, the amount of ash was determined.

$$\% \text{ of Ash} = \frac{\text{Wt. of Ash left}}{\text{Wt. of coal sample}} \times 100$$

As particle size decreased the Biyo Gurgur coal samples' ash concentration increased, ranging from 19.30% to 63.22%. The finest fraction (-125+75 μm) had the highest ash percentage, suggesting a larger concentration of mineral contaminants. Due to increasing ash retention, this trend may result in poorer calorific value and decreased flotation efficiency in smaller particles. This suggests that because finer particles are more strongly associated with clay and other contaminants, they contain more mineral stuff. The low calorific value of the coal is partly due to the high ash content of the fine fractions, which may also account for their poor flotation recovery. This demonstrates that in order to lower ash and enhance fuel quality, beneficiation processes are required. Coal rank does not change by ash content, although a high ash percentage lowers fuel quality and combustion efficiency. Additionally, it may result in operational problems including fouling, slagging, and more residue handling. Effective ash management is important because the behavior of ash at high temperatures affects the designing and operational of combustion systems.

4.1.3 Determination of Volatile Matter

Volatile matter is released when coal is heated to high temperatures because it undergoes thermal breakdown [45]. These volatile substances include inflammable gases like carbon monoxide and hydrocarbons as well as flammable gases like steam and vapor.

The carbon, hydrogen, and oxygen components found in coal that evaporate when heated are referred to as volatile matter; these are typically a combination of short and long-chain

hydrocarbons. It has been demonstrated that volatile content affects the thermal behavior of solid fuels, although the structure and bonding of the fuel also have an impact [46]. The average moisture content of the coal from the Biyo Gurgur area that was examined was 6.9%. The average volatile matter percentage of the coal samples from the Biyo Gurgur area, according to the experimental results, was 19.50% for all particle sizes. Lower-rank lignite coals have a modest capacity to ignite and burn, which is suggested by this degree of volatile content. It also affects how the coal burns. It is important to note that the moisture content, which was 6.9% on average for all samples, can affect the total gas released after burning, which in turn can affect the assessment of volatile matter. Accurately determining volatile matter and maximizing combustion efficiency depends on proper moisture regulation.

Volatile matter represents the component of the coal that is released as gases or vapors when heated at high temperatures in the absence of air. This includes hydrocarbons, carbon monoxide, hydrogen, and incombustible gases like carbon dioxide and nitrogen. Volatile matter is determined by heating coal for 7 minutes at 950°C in a controlled environment and its percentage is calculated using the formula.

$$\% \text{Volatile matter} = \frac{\text{Weight loss due to VM}}{\text{Total weight of sample}} \times 100$$

Coal rank and volatile matter content are directly correlated; the more volatile matter, the lower the coal rank. Understanding and managing volatile matter is essential for optimizing coal combustion and assessing its suitability for energy applications.

4.1.4 Determination of Fixed Carbon

The main source of heat during burning is fixed carbon, which establishes the grade of coal. The higher the fixed carbon and heating values, the higher the coal rank [47]. The fixed carbon provides a rough estimate of the heating value of the coal. The fixed carbon content of the coal is the carbon found in the material which is left after volatile materials are driven off. Fixed carbon is used as an estimate of the amount of coke that will be yielded from a sample of coal. The fixed carbon content of coal particles ranges from 50.61% to 13.16% by weight with an arithmetic mean of 27.69% by weight.

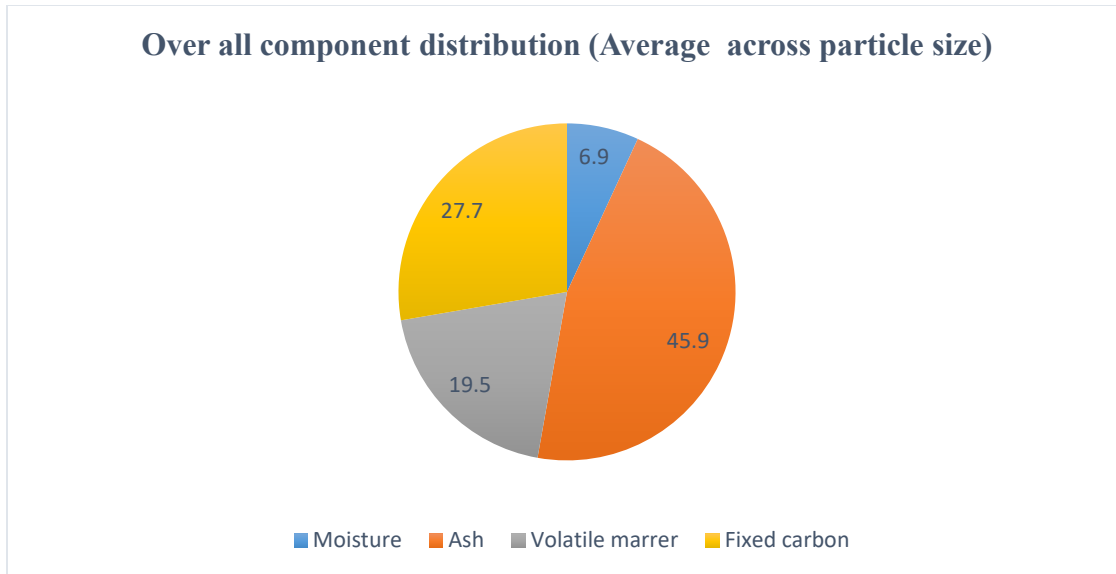


Figure 5. Overall component distribution.

Ash content (45.9%) dominates all particle fractions in the material's overall composition, as seen in the pie chart. This suggests that there is a substantial amount of non-combustible residue in the material which may affect its calorific value and total energy potential. In industrial applications like fuel generation or metallurgical processes, a high ash level can be problematic since it lowers efficiency and raises processing costs.

Only 6.9% of the entire composition is made up of moisture, indicating that the material is rather dry. For some applications, this is advantageous because less moisture means fewer pre-drying procedures are required, which increases handling efficiency. About 19.5% and 27.7%, respectively, come from fixed carbon and volatile matter.

4.2 Determination of Calorific value

The experimental calorific value is determined by using the adiabatic calorimeter at the Geological Institute of Ethiopia. The obtained result of calorific value is 1626.48 cal/gm, which means this coal sample is a low-grade fuel with limited applications. Its low energy content suggests that it contains significant impurities or non-combustible materials, making it unsuitable for high-energy demand markets but potentially useful in specialized or low-cost applications.

Low-grade coal has a calorific value of less than 5000 kcal/kg and a high moisture content (20% to 40%) when compared to global coal reserves. Because of its high moisture content, which lowers its energy potential, this kind of coal is deemed uneconomical for export [48]. This group includes the Biyo Gurgur coal sample, which has a calorific value of 1626.48 cal/gm, indicating its low energy viability in the absence of beneficiation. Its potential for use in energy applications could be increased by additional processing, such as ash reduction and moisture control.

4.3 Determination of Sulfur Content

The sulfur concentration of the Biyo Gurgur coal was determined to be 0.16%, which is quite low when compared to other lignite coals. For example, Breeze observed sulfur levels of 1-3% in lignite coal from various places [21]. The low sulfur concentration reduces SO₂ emissions during combustion, making the coal more environmentally friendly. This finding is consistent with Rani and Kalpana, who underlined the importance of low-sulfur coal in lowering air pollution and adhering to tight environmental rules [10]. However, the low sulfur level does not compensate for the limitations given by the coal's high ash content and poor calorific value, which limit its industrial application.

4.4 Flotation Test

The flotation test at the Addis Ababa Institute of Technology (AAiT) was conducted. Using a sieve shaker, the required particle size distribution (+500 μ m, +250 μ m, +125 μ m, and +75 μ m) was attained. The flotation experiment used flotation equipment. The cell was filled with 2.5 liters of water and a 100g sample of coal. 10 and 5 milliliters of kerosene were added to the slurry after it had been stirred for 3 minutes at 1500rpm. 2 milliliters of pine oil were also added to serve as a frother and encourage airflow into the cell, which helped to create froth. The suspension was agitated for ten minutes at 1500rpm after all reagents had been added, and the froth product was separated by flotation.

Table 2. Full factorial design of coal sample for flotation experiment.

Experimental Run	Particle size (μ m)	Collector (ml)	Frother (ml)
1	+500 μ m	10ml	2ml
2	-500+250 μ m	10ml	2ml
3	-250+125 μ m	10ml	2ml
4	-125+75 μ m	10ml	2ml
5	+500 μ m	5ml	2ml
6	-500+250 μ m	5ml	2ml
7	-250+125 μ m	5ml	2ml
8	-125+75 μ m	5ml	2ml

The study employed a full factorial design to assess all combinations of factors. Table 2 represents 8 experimental runs conducted with no replicates and manipulating two factors in this experiment to observe their effects on the flotation response. The manipulating factors are collector dosage and particle size distribution which are independent variables.

1. Particle size distribution: particles were categorized into four sizes

- +500 μ m
- -500+250 μ m
- -250+125 μ m
- -125+75 μ m

2. Collector dosage: I used two different collector dosages which are 10ml and 5ml of kerosene.

Table 3. Results of the flotation experiment.

Run	Particle size	Collector dosage	Ash %	Grade %	Recovery %
1	+500	10 ml	4.09%	95.91%	2.32%
2	-500+250	10 ml	11.73%	88.27%	0.80%
3	-250+125	10 ml	1.97%	98.03%	5.34%
4	-125+75	10 ml	2.15%	97.85%	11.84%
5	+500	5 ml	3.60%	96.40%	2.33%
6	-500+250	5 ml	13.19%	86.81%	0.88%
7	-250+125	5 ml	7.04%	92.96%	2.25%
8	-125+75	5 ml	2.72%	97.28%	11.57%

The findings are shown in Table 3: As particle size lowers, recovery increases. Recovery is highest at 11.84% (10ml collector) for -125+75 μ m compared to 2.33% for +500 μ m particles. This is because the surface area of finer particles is larger, which promotes bubble attachment. Effective ash rejection is indicated by the highest grade (97.85%) for -125+75 μ m particles (10ml collector). Coarser particles larger than 500 μ m maintain a high quality (95.91%) but recover poorly, most likely as a result of inadequate coal release from gangue.

The experiment looked into how coal flotation performance was affected by particle size and collector dosage. The findings showed that raising the collector dosage enhances the floated coal's recovery and grade. With a recovery of 11.84%, a grade of 97.85%, and an ash percentage of 2.15%, the coal product was obtained with a collector dosage of 10 ml and a particle size of -125 +75 μ m performed the most effectively. However, with a recovery of 0.88%, a grade of 86.81%, and an ash percentage of 13.19%, the coal product produced with a collector dose of 5 ml and a particle size of -500+250 μ m performs the lowest in quality. These findings demonstrate how important it is to maximize particle size and collector dosage to accomplish effective coal flotation. Particle size has a significant impact on flotation performance, as numerous earlier studies have documented.

4.4.1 Effects of Particle Size on Grade and Recovery

One of the key elements in coal flotation is particle size. Size fraction's impact on coal flotation has been analyzed [49]. The impact of particle sizes on the ability of froth flotation to clean coal has been extensively examined in several research papers. Large particle sizes, like +500 μ m, have more mass and inertia, making them harder to suspend and float. Poor attachment to air bubbles and possible settling result in reduced recovery.

During froth flotation, the grade (purity) and recovery (amount recovered) of coal are both significantly influenced by the particle size distribution. The grade of coal remains consistently high across all particle size ranges, with very slight fluctuations. This suggests that coal purity can be maintained by the flotation process regardless of particle size. Because they are less likely to be tainted by gangue material, larger particles continue to keep a high grade. Smaller gangue

particles find it more difficult to stick to them during flotation because of their size. Smaller particles improve recovery because they are more easily suspended and adhere to a bubble, but they may marginally lower grade because of the higher risk of contamination.

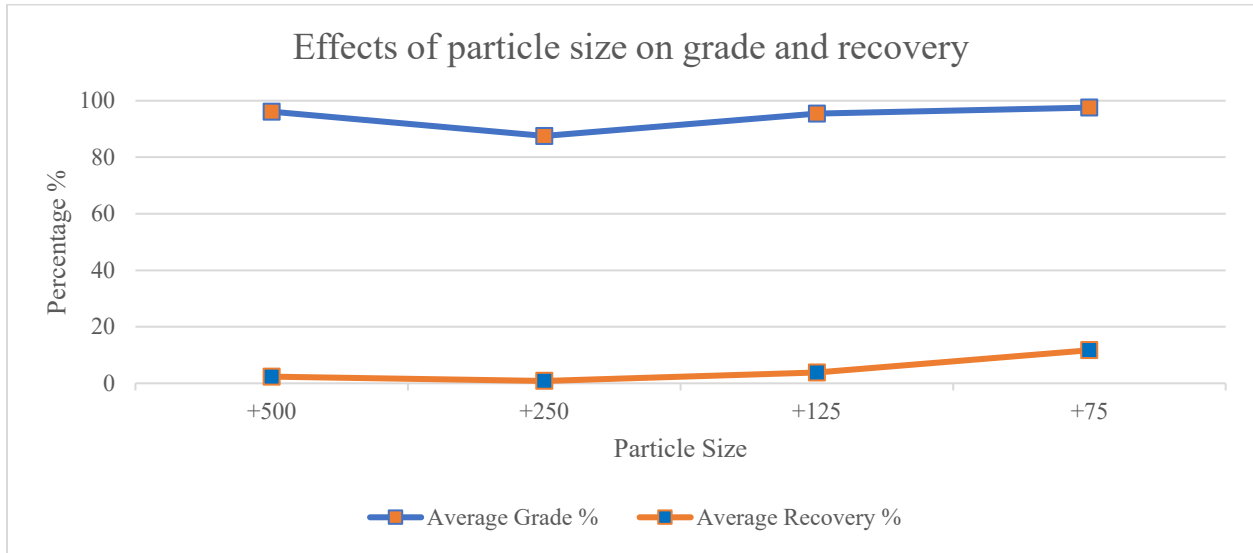


Figure 6. Effects of particle size on the grade and recovery of the coal flotation.

For all particle sizes, the grade typically remains high with only minor deviations. The lowest grade (88.27%) is found in the -500+250 μ m range, while the highest quality (98.03%) is found in the (-250+125 μ m) size. On the other hand, recovery shows a sharp increase when particle size decreases. Recovery is relatively low (2.3%) for the largest particles (+500 μ m), but it increases significantly (11.84) for the smallest particles (-125+75 μ m). Because they are better at releasing and attaching to bubbles during flotation smaller particle sizes enhance the recovery of valuable material. However, because they are less likely to be contaminated by gangue material larger particles typically maintain a high grade.

As shown in figure 5 indicates that recovery increases significantly as particle size decreases, with the -125+75 μ m fraction showing the maximum recovery. This pattern emphasizes how crucial it is to reduce particle size to improve flotation efficiency. With just minor variances, the grade is consistently high for all particle sizes. This implies that coal purity is preserved irrespective of particle size, and potential as a result of effective gangue mineral separation.

4.4.2 Effects of Collector Dosage on Grade and Recovery

Collectors are employed to adsorb onto surface particles selectively. The grade and recovery of coal during the flotation process are greatly influenced by the dosage of the collector. The coal surface becomes more hydrophobic when a collector is preferentially adsorbed at the water or solid interface.

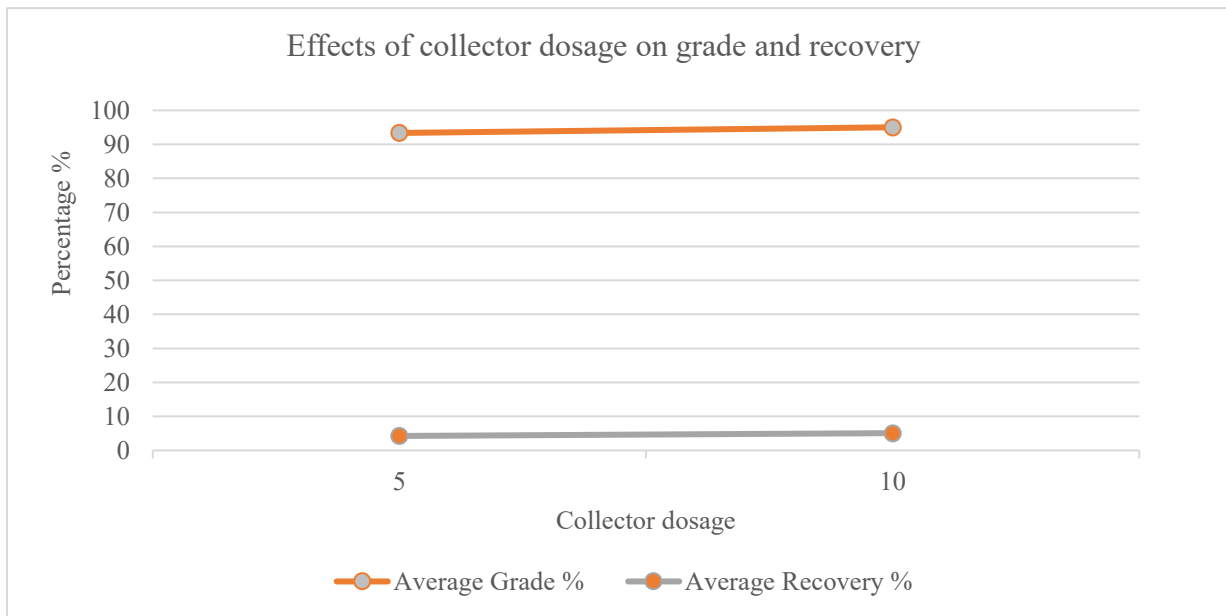


Figure 7. Effects of collector dosage on the grade and recovery of the coal flotation.

The grade is somewhat lower at 10 ml collector dosage (95.91%) than at 5 ml (96.40%). However, recovery is slightly greater at 5 ml (2.33%) than at 10 ml (2.32%).

Within this experiment range, recovery and grade are not significantly affected by variations in collector dosage. Although the 10 ml dosage may improve bubble formation, it may also saturate the flotation system, which would have a slight impact on grade and selectivity.

As shown in figure 6 shows that grade stays the same at both dosage levels, even though recovery somewhat increases with greater dosage. This suggests that while higher collector dosage improves bubble particle attachment, the quality of the floated coal product is not considerably impacted.

These results highlight the importance of optimizing both particle size and collector dosage to achieve effective coal flotation, with finer particles and higher collector dosage generally yielding better results.

Summary of the Discussion

1. Proximate Analysis Results:

- The coal from Biyo Gurgur is classified as low-grade lignite.
- High ash content (19.3%-63.2%) was observed, increasing with decreasing particle size.
- Fixed carbon content ranged from 13.2% to 50.6%, inversely related to ash content.
- The low calorific value of 1626.48 cal/gm was consistent across all particle sizes.
- Low sulfur content (0.16%) was noted, which is environmentally beneficial.

2. Flotation Test Results:

- Particle size significantly affected flotation performance. Smaller particles (-125+75 μm) showed highest recovery (11.84%) and grade (97.85%).
- Collector dosage also influenced performance, with 10 ml dosage generally yielding better results than 5 ml.

3. Industrial Implications:

- The high ash content and low calorific value limit the coal's industrial use in its raw form.
- Beneficiation processes like froth flotation could potentially enhance the coal's quality for industrial applications.

4. Environmental Considerations:

- The low sulfur content (0.16%) is advantageous, potentially reducing SO₂ emissions during combustion.

The study concludes that while the Biyo Gurgur coal has limitations due to its low quality, proper beneficiation techniques could improve its potential for energy and industrial uses.

Chapter 5 Conclusion and Recommendation

5.1 Conclusions

As a fossil fuel, coal has been essential to the growth of industry and the generation of energy worldwide. It is a complex and heterogeneous material that varies greatly in quality and composition, having formed over millions of years by the decomposition of plant material under pressure and heat. With an emphasis on assessing its quality and potential for industrial uses, this study sought to evaluate the coal composition in the Biyo Gurgur area, Siti, Zone, Somali, Region, Ethiopia. To evaluate the coal's qualities and appropriateness for energy production and other industrial applications, the study used flotation trials, proximate analysis, and calorific value estimation. Through proximate analysis, calorific value determination, and flotation experiments, this study thoroughly examined the coal composition in the Biyo Gurgur area and evaluated its industrial potential. It also offered important insight into the opportunities and challenges related to using this coal resource. The coal samples are primarily low-grade lignite with a high ash content and low calorific value, according to the results of the proximate analysis. The finer fractions (125+75 μ m) had the greatest ash levels, with the ash content ranging from 19.30% to 63.22%. This directly affects energy yield and combustion efficiency, underscoring the urgent need for beneficiation. Coarser particles retain more moisture, resulting in higher transportation and storage costs and lower net energy production after combustion. The moisture content ranged from 4.12% to 10.59%. However, the coal's very low sulfur level of 0.16% helps to reduce pollutants during combustion, which makes it less hazardous to the environment.

In addition to offering important new information about the Biyo Gurgur coal deposits, the study's conclusions support Ethiopia's larger initiatives to evaluate its energy resources. If correctly handled, domestic coal reserves have the potential to lessen the country's reliance on foreign energy sources, in contrast to imported energy. In contrast, the low sulfur concentration is a benefit to the environment that can support Ethiopia's objectives for pollution prevention and sustainable development.

The Biyo Gurgur area's coal consists mainly of poor-grade lignite, according to the proximate analysis, which can be determined by a high ash percentage (varying from 19.3% to 63.2%) and a low fixed carbon content (13.2% to 50.65). The coal's calorific value was found to be 1626.48 cal/gm, which is low by international standards and suggests that its energy potential is restricted. With a comparatively low sulfur concentration of 0.16%, the sulfur dioxide emissions during burning are likely to have little effect on the environment. However, coal's industrial use in its raw form is severely limited by its high ash content and low calorific value.

Particle size and collector dosage are important variables affecting coal recovery and grade, as the flotation tests showed. Greater recovery rates (11.84%) and lower ash content (2.15%) were seen for smaller particle sizes -125+75 μ m, whereas greater ash content 4.09% and lower recovery rate 2.32% were observed for larger particles +500 μ m. In comparison to smaller dosages, flotation performance was enhanced by using a larger collector dosage of 10 ml, which resulted in a higher grade of 97.85% and recovery of 11.84%. These results emphasize how crucial is to optimize flotation parameters to improve coal recovery and quality. It is encouraged that more investigation be done into advanced beneficiation methods targeted to the unique mineralogical properties of

Biyo Gugur coal. Methods like carbon capture or fluidized bed combustion can help to increase its combustion efficiency while reducing its negative effects on the environment. Furthermore, mineralogical research can help to identify the contaminants influencing coal quality, directing more focused beneficiation techniques. In conclusion, the high ash level and low calorific value of the coal from the Biyo Gurgur area indicate that it is of low quality. Although coal's low sulfur content is good for the environment, its high impurity levels and poor energy potential limit its industrial usage in its raw state. However, the coal's quality might be enhanced by the use of beneficiation processes like froth flotation, which would make it more appropriate for industrial uses and energy production.

5.2 Recommendation

The following suggestions are put out given the study's findings to improve knowledge and use of coal resources in the Biyo Gurgur region:

- ❖ The optimal balance between grade and recovery is provided by intermediate particle sizes (-250+125), whereas smaller particle sizes (-125+75) greatly increase recovery rates, according to the data. During flotation, it is advised to concentrate on grinding the coal to these ideal size ranges to optimize recovery and product quality to guarantee a uniform particle size distribution, which is essential for effective flotation, sophisticated screening and classification methods should also be used.
- ❖ For effective coal cleaning by froth flotation, the ideal range of particle sizes and reagent amounts to obtain more concentrates and fewer tailings should be carefully chosen depending on the balance between production cost and product quality.
- ❖ Perform Mineralogical Analysis: It is advised to carry out mineralogical analysis utilizing methods like X-ray diffraction (XRD) and X-ray fluorescence (XRF) to obtain a better knowledge of the coal's composition and impurities. To lower the ash content and enhance the quality of the coal, this study will assist in identifying the precise mineral impurities that are present in the coal and direct the creation of focused beneficiation techniques.
- ❖ Environmental and Economic Feasibility Studies: Environmental Impact Assessments (EIAs) and economic feasibility studies must be carried out before expanding coal processing. These studies will analyze the economic feasibility of applying beneficiation techniques as well as the environmental effects of coal mining and processing in the Biyo Gurgur area. This will guarantee that using coal is advantageous for the economy and the environment.
- ❖ The laboratory results of the proximate analysis showed a high ash content and a low amount of fixed carbon, which indicates it contains more impurities or inorganic matter. Therefore, it should be recommended that the beneficiaries of this coal use the technique of froth flotation.

REFERENCES

- [1] Wakuma. B, “Physicochemical characterization of coal and its alternative use as a source of energy,” IOSR-JESTFT, 2017, pp. 44–50.
- [2] Speight. J.G., “Handbook of Coal Analysis (Chemical Analysis),” Second ed., New York,: Wiley, 2015, pp. 1-28.
- [3] Suarez-Ruiz. I., “Coal. New Trends in Coal Conversion Combustion, Gasification, Emissions, and Coking.,” Elsevier, 2019, pp. 1–30.
- [4] Abraham. K., “Characterization and Evaluation of Mush Valley Coal for its Application as a Domestic Energy Source,” 2018.
- [5] Demoze. E.A., “Utilization of coal in metal industries,” 2007, pp. 2–35.
- [6] Meshram. P, “Demineralization of low-grade coal. Renew. Sustain. Energy,” 2015, pp. 41, 745–761.
- [7] Speight. JG, “The chemistry and technology of coal,” (Third edition)., 2013, p. 845.
- [8] Basalfew. Z. “Geology Geochemistry and Gravity survey of the Ayisha Area,” Ministry of Mines Geological Survey of Ethiopia Basic Geoscience Mapping Directorate, 2015, p. 1.
- [9] Worash. G and Solomon. T, “Textbook of economic geology,” 2015, pp. 271–285.
- [10] Rani. K and Kalpana. S, “Utilization in agricultural and related fields; a better alternative for ecofriendly maintenance of Coal Fly Ash,” vol. 2(5), Journal of Chemical and Pharmaceutical Research, 2010, pp. 365–372.
- [11] Blander. M, Sinha. S, Pelton. A, and Eriksson. G, “Calculations of the influence of additives on coal combustion deposits,” 1989, pp. 340–346.
- [12] Warwick. PD, “Coal geology and resources,” Encyclopedia of life systems, EOLSS, 2003.
- [13] Worash. G, “Coal formation.”
- [14] Anuradha. B and Rao. C.N, “Proximate and ultimate characterization of coal samples from Southwestern part of Ethiopia,” 2019.
- [15] Laskowski. JS, “coal flotation and fine coal utilization,” The University of British Columbia Vancouver. B.C., Canada: Elsevier, 2001.
- [16] Diessel. CFK, “The conditions of peat formation. In: Coal bearing depositional systems.,” Berlin: Springer, 1992, p. 5–39.
- [17] Straka. P and Sýkorová. I, “Coalification and coal alteration under mild thermal conditions,” 2018, pp. 58–173.
- [18] Mackowsky. MT and Stach. E, “Coal Petrology 3rd Revis. Ed.,” Berlin: Gebruder Borntraeger, 1982, pp. 71–153.
- [19] Cecil. CB, “The Coalification Phase of Coal Systems GSA Annual Meeting,” 2001, pp. 5–8.
- [20] Schweinfurth. SP, “An introduction to coal quality In: Chapter C of the national coal resource assessment overview,” US Geological Survey Professional Paper 1625–F, 2009.
- [21] Breeze. P, “Chapter 2 – Coal types and the production and trade in coal,” Academic press, cambridge, 2015.
- [22] Marshak. S, “Earth: Portrait of a planet,” (3rd edition)., WW Norton & Company, New York, 2015, p. 880.
- [23] Wolfson. R, “Energy, environment and climate,” (2nd edition)., WW Norton & Company, New York, 2012, pp. 95–96.
- [24] Kraushaar. J and Ristinen. R, “Energy and the environment,” (2nd edition)., Hoboken: John Wiley & Sons, 2015, p. 384.
- [25] Mukhopadhyay. PK. and Hatcher. PG., “Hydrocarbons from the coal,” Canada, 1993, pp. 79–118.

- [26] Goldschmidt. VM, "Rare elements in coal ashes," industrial and engineering chemistry, 1932, pp. 1100–1102.
- [27] Vassilev. S, Kitano. K, and Vassileva. C, "Some relationships between coal rank and chemical and mineral composition," 1996.
- [28] Vassilev. S, Kitano. K, and Vassileva. C, "Relations between ash yield and chemical and mineral composition of coals.," 1997.
- [29] Rees. O.W, "Chemistry, Uses, and Limitations of Coal Analyses," , Illinois State Geological Survey (ISGS), 2012.
- [30] ASTM D5865-19 Standard Test Method for Gross Calorific Value of Coal and Coke," ASTM international, 2019.
- [31] Wang. D, "flotation reagents (functional principale)," vol. 1, Springer, 2016.
- [32] Martinovic. J, Bradshaw. DJ, and Harris. PJ, "investigation of the surface properties of Gangue Minerals in Pgm Bearing Ores," vol. 105, South Africa: Southern African institute of mining and metallurgy, 2005, pp. 349–355.
- [33] Hassanzadeh. A, Safari. M, Hoang. D.H, Khoshdast. H, Albijanic. B, and Kowalczyk. P.B, "Technological assessments on recent developments in fine and coarse particle flotation systems. Miner. Eng.," 2022, p. 180.
- [34] Kawatra. SK and Eisele. TC, "Froth flotation-fundamental principles. Recovery pyrite coal float entrain or float," 1992, pp. 1–30.
- [35] King. RP, "Principle of flotation," johansburg: South Africa Institute of mining and metallurgy, 1982.
- [36] Napier-Munn. T and Wills. BA, "Wills' mineral processing technology," 2005.
- [37] Zhu. Q, "Coal sampling and analysis standards, IEA Clean Coal Centre," London, United Kingdom, 2014.
- [38] Yang. YB, Ryu. C, Khor. A, Yates. NE, Sharifi. VN, and Swithenbank. J, "Effect of fuel properties on biomass combustion. part ii. Modeling approach-identification of controlling factors, Fuel," vol. 84, 2005, pp. 2116–2130.
- [39] Aina. OM, Adetogun. AC, and Iyiola. KA, "Heat Energy from Ethiopia," vol. 2, Ethiopian Journal of Environmental Studies and Managemen, 2009, pp. 42–49.
- [40] Sarwar. A, Khan. MN, and Azhar. KF, "The physicochemical character-ization of a newly explored Thar coal resource. Energ Source," 2014, pp. 525–536.
- [41] Given. PH and Yarzab. RF, "In analytical methods for coal and coal products," vol. II, New York: Academic Press, Inc, 1978, p. chapter 20.
- [42] Speight. JG, "Handbook of coal analysis," 2nd edition., Hoboken, NewJersey: John Wiley & Sons, p. 344.
- [43] Kim. HJ, Lu. GQ, Naruse. I, Yuan. J, and Ohtake. K, "Modeling combustion characteristics of biocoal briquettes," vol. 123, Journal of Energy Resources Technology, 2001, pp. 27–31.
- [44] Míguez. JL, Porteiro. J, Behrendt. F, Blanco. D, Patiño. D, and Dieguez-Alonso. A, "Review of the use of additives to mitigate operational problems associated with the combustion of biomass with high content in ash-forming species.," Renewable and sustainable energy reviews, 2021, p. 141.
- [45] Zhang. D, "Thermal decomposition of coal. Coal, Oil Shale, Natural Bitumen, Heavy Oil, an Peat," 2009.
- [46] Chaney. J, "Combustion characteristics of biomass briquettes. Unpublished PhD studies. W.R.Hibbard, (1967), method of analyzing and testing coal and coke, U.S. Washington.," 2010.

- [47] Hong. BD and Slatick. ER, "Energy information administration .(DCQuarterly Coal Report, Washington, DC.)," Washington DC, 1994, pp. 1–8.
- [48] Belkin. HE, Tewalt. SJ, Hower. JC, Strucker. JD, and O'Keefe. JMK, "Geochemistry and petrology from selected coal samples from sumatra, kalimantan, sulawesi and papua," vol. 77, Indonesia. *International Journal of Coal Geology*, 2009, pp. 260-268.
- [49] Li. YF, Zhao. WD, Gui. XH, and Zhang. XB, "Flotation kinetics and separation selectivity of coal size fractions," *Physicochem. Probl. Miner. Process.*, 2013, pp. 387–395.